CORRECTION FACTOR TECHNIQUES FOR IMPROVING AERODYNAMIC PREDICTION METHODS

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CORRECTION FACTOR TECHNIQUES FOR IMPROVING AERODYNAMIC PREDICTION METHODS*

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SUMMARY

This report describes a method for correcting lifting surface theory so that it reflects known experimental data. Specifically the theoretical pressure distribution is modified such that imposed constraints are satisfied (e.g., lift, moment, etc.) while minimizing the change to the theoretical pressure distribution. It is assumed that a finite element or discretized lifting surface method is used, such as either the Doublet or Vortex Lattice Methods.

There are several ways in which the theoretical pressures are modified. One is a direct application of a set of correction factors to the pressures. This is accomplished by premultiplying the pressures with a diagonal matrix of correction factors. A second approach to correcting the theory is to modify the downwash. This modification can be accomplished by either multiplying the downwash by a diagonal matrix of correction factors or by adding an incremental downwash (which is proportioned to the pressure) to the theoretical downwash. In any case the correction factors are adjusted so that the imposed experimental constraints are satisfied by the corrected pressure distribution while the changes in the pressure distribution are minimized.

There are several features that have been built into the basic method and these include: (1) the ability to consider together experimental data

* The authors wish to acknowledge Dr. Edward Albano for interesting discussions of alternate formats (non-diagonal) of correction matrices and their potential derivations.

** Consulting Engineer

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from more than one mode (e.g., control surface rotation, pitch, camber, etc.), (2) the ability to limit the excursions of the correction factors (i.e., establish minimum and maximum values for them) and (3) the ability to use correction factor mode shapes (i.e., construct correction factors from known distributions or functions).

The methods developed have been implemented on the computer and many correlations and calculations made. Specifically cases involving all three Mach Number ranges are considered. For instance in the subsonic speed range a swept wing with an oscillating partial span flap and a swept wing with a leading edge droop are discussed. In the transonic speed range a two-dimensional symmetric airfoil with an oscillating flap is treated in detail. An arrow wing with and without camber is used in the supersonic analysis.

The computer program used to generate the correction factors for these cases is also fully described in this report and test cases are provided.

Finally, a new, simple method for accounting for transonic effects in the lifting surface theory is described and correlated for the two-dimensional case. Basically, a transformed distance between the sending element and receiving point is employed. The transformation depends on the time delay encountered by a signal traveling from the sending point to the receiving point.
INTRODUCTION

Wind tunnel data have provided the basis for semi-empirical methods of aeroelastic analysis for many years, whether in the estimation of stability and control characteristics, the calculation of structural loads, or in flutter analysis by modified strip methods. These semi-empirical methods have been tailored to aerodynamic lifting-line theory or to strip theory and not to the more general (and more accurate) lifting-surface methods. The use of a diagonal correction matrix to be applied as a premultiplying factor to matrices of aerodynamic influence coefficients obtained from lifting surface theory has been considered by a number of authors. A premultiplier may be regarded as a correction to the pressure distribution; as an alternative, a postmultiplier would be regarded as a correction to the downwash to account for thickness effects and for camber induced by boundary-layer displacement effects. Rodden and Revell (refs. 1 - 4) considered a real correction matrix derived from static wind tunnel measurements and theoretical load predictions. Bergh and Zwaan (refs. 5 and 6) investigated a complex correction matrix derived from oscillatory wind-tunnel pressure measurements and theoretical predictions. These authors assumed measurements were available only for a single mode, a steady angle of attack or an oscillatory pitching (or yawing) mode.

Current interest in using actively controlled aerodynamic surfaces to minimize aeroelastic response requires an improvement in accuracy in predicting unsteady aerodynamic characteristics of lifting surfaces equipped with control surfaces. The correction matrix provides one means of improving the accuracy but it requires experimental data on control surface characteristics in addition to the angle of attack characteristics of the surface. Hence, an extension of references 1 - 4 is necessary to obtain the correction matrix for more than one aerodynamic mode. Furthermore, the discrepancies between theory and experiment in predicting trailing-edge control surface loads are most likely caused by boundary-layer displacement effects on the effective downwash. Hence, another extension is necessary to obtain a postmultiplying correction matrix. These two extensions are considered in the present
development. The diagonal format has been retained* and complex pre- and postmultiplying correction matrices have been derived which satisfy the constraints of matching experimental data from multiple aerodynamic downwash modes.

The use of correction matrices is in the time-honored engineering tradition of empirical correction factors. It retains the generality of the theory while approaching the limiting values of the test results. Such a posteriori adjustment obviously cannot be regarded as addressing any of the fundamental causes of the discrepancies. Other possibilities exist whereby empirical corrections can be introduced directly into the theoretical solution. Ashley (ref. 7) has discussed two such "irrational correction methods". The first of these is of interest here and concerns the calculation of the downwash boundary condition and the pressure distribution by "local linearization" in terms of the local velocity $V_L$ rather than the free stream velocity $U_\infty$. The dimensionless downwash then becomes

$$\frac{W}{U_\infty}(x,y,0,t) = \frac{1}{U_\infty} \left[ \frac{\partial h}{\partial t} + V_L(x,y)\frac{\partial h}{\partial x} \right]$$

where $h(x,y,t)$ is the deflection of the mean surface. Applications of this "local linearization" to the downwash boundary condition (but not to the kernel function nor pressure coefficient) have been made for control surfaces by Ashley and Rowe (ref. 8) and by Rowe, Winther, and Redman (ref. 9), and improved correlations have been obtained. Tijdeman and Zwaan (ref. 10) have also employed the local linearization of the downwash boundary condition but have suggested another modification for use in the Doublet-Lattice Method for high subsonic flows, viz., that the free stream Mach number be replaced by a mean Mach number $M_{jl}$ for each panel (lifting element or box). The downwash induced at box i by the lifting pressure on box j then becomes

* The format of a full matrix was briefly investigated but it was found to destroy the distributional character of the theoretical aerodynamic influence coefficients, and was not considered further.
where $D_{ij}(M_{j1}, k_r)$ is the downwash influence coefficient between the jth lifting element and the ith downwash collocation point and its functional dependence on $M_{j1}$ and the reduced frequency $k_r$ is indicated. Tijdeman and Zwaan denote the freestream Mach number by $M_\infty$ and the local Mach number at the surface of box i by $M_{i2}$, so that the locally linearized downwash for harmonic motion becomes

$$\frac{w_i}{U_\infty} = D_{ij}(M_{j1}, k_r) \Delta C_{pj}$$

$$\frac{w_i}{U_\infty} = M_{i2} \frac{\partial h_i}{\partial x} + i \frac{\omega}{U_\infty} h_i$$

The values of $M_1$ and $M_2$ for a certain box are not equal, in general, because $M_1$ has to reflect the influence of the Mach number distribution normal to the surface ranging from $M_2$ at the surface to the freestream Mach number far away from the wing. Preliminary results from NLR calculations have shown that $M_1$ can be chosen simply to be the average value of $M_2$ and $M_\infty$. 


**LIST OF SYMBOLS**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>A</td>
<td>Matrix that gives pressures in terms of downwash. Inverse of D</td>
</tr>
<tr>
<td>$a_\infty$</td>
<td>Speed of sound in the free stream</td>
</tr>
<tr>
<td>$\hat{a}$</td>
<td>Constraining power of a constraint. If $\hat{a} = 1$ constraint is 100% effective. If $\hat{a} = 0$ constraint has no effect at all</td>
</tr>
<tr>
<td>B</td>
<td>Wing bending moment (about x-axis)</td>
</tr>
<tr>
<td>$b/2$</td>
<td>Semi span of wing</td>
</tr>
<tr>
<td>C</td>
<td>Aerodynamic coefficient (e.g. lift or moment coefficient). $C_e$ is used as an experimental constraint</td>
</tr>
<tr>
<td>$C_L$</td>
<td>Lift coefficient</td>
</tr>
<tr>
<td>$C_M$</td>
<td>Moment coefficient</td>
</tr>
<tr>
<td>$C_B$</td>
<td>Wing root bending moment coefficient</td>
</tr>
<tr>
<td>$\bar{c}$</td>
<td>Reference chord length</td>
</tr>
<tr>
<td>$c_\alpha$</td>
<td>Section lift coefficient</td>
</tr>
<tr>
<td>$c_m$</td>
<td>Section moment coefficient</td>
</tr>
<tr>
<td>$c_h$</td>
<td>Section hinge moment coefficient</td>
</tr>
<tr>
<td>D</td>
<td>Matrix that gives downwash (normalwash) in terms of pressures</td>
</tr>
<tr>
<td>h</td>
<td>Deflection normal to lifting surface</td>
</tr>
<tr>
<td>$i_a$</td>
<td>Unit vector in direction of axis</td>
</tr>
<tr>
<td>$k_r$</td>
<td>Reduced frequency $\frac{\omega c}{2U_\infty}$</td>
</tr>
<tr>
<td>$M_1$</td>
<td>An average Mach Number between $M_2$ and $M_\infty$</td>
</tr>
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Local Mach Number at wing surface

Free stream Mach Number

Average Mach Number between sending and receiving point

Compressible radius (see Eqn. 73)

Matrix that integrates pressures into aerodynamic parameters (e.g., $C_L$, $C_M$, $C_d$, etc.)

$[S] [\Delta C_p] \text{ see Equation (9)}$

$[S] [A][w] \text{ see Equation (30)}$

See Equation (45)

$[S] \left[ E_{0,1}^{+10} \right] \text{ see Equation (54)}$

See Equation (67)

Weights given to the correction factors $\varepsilon$ for the minimization process, $\sum T \varepsilon^2 = \min$

Time

Free stream velocity

Local surface speed

Correction factor $= 1 + \varepsilon \text{ (Called CF in computer program)}$

Downwash (or normalwash) (Called W in computer program)

Weights in the minimization process for estimates

Cartesian coordinates right handed system

x aft, y lateral (starboard), z vertical

Angle-of-attack, also direction cosine for force or moment axis

$\sqrt{1 - M_{\infty}^2}$

Direction cosine for force or moment axis
\( \gamma \)  
Dihedral of lifting surface

\( \Delta C_p \)  
Lower surface minus upper surface pressure coefficient

\( \Delta A \)  
Box area

\( \epsilon \)  
Incremental correction factors = \( W - 1 \)

\( \varepsilon \)  
Generalized incremental correction factors
\( \varepsilon = \phi \varepsilon \)

\( \wedge \varepsilon \)  
\( \varepsilon \sqrt{T} \)

\( \phi \)  
Correction factor mode shapes

\( \phi_d \)  
Doublet potential function

\( \omega \)  
Circular Frequency

**Subscripts and Superscripts**

\( a \)  
Stands for either p or w

\( d \)  
Designated or known correction factors

\( e \)  
Experimental

\( q \)  
Identifies estimates as opposed to constraints

\( H \)  
Hermetian transpose

\( \text{mod.} \)  
Modified values

\( p \)  
Identifies pressure modifying terms in the correction factor procedure

\( t \)  
Theoretical values

\( u \)  
Undesignated or unknown correction factors

\( w \)  
Identifies downwash modifying terms

\( l \)  
Deflection mode 1

\( 2 \)  
Deflection mode 2

\( 3/4 \)  
Three quarter chord point

\( 1/4 \)  
One quarter chord point
Matrix Notation

\{ \}  Column Matrix
\[ \]  Rectangular
\[ \]  Diagonal
THEORETICAL DEVELOPMENT

Basic Method

Premultiplying Correction Factor Matrix. - A derivation of a real pre-
multiplying correction matrix constrained to match aerodynamic data from a
single downwash mode is presented in references 1 - 4. The use of Lagrange
multipliers considerably simplifies the derivation so we present this alter-
native derivation here. As an introduction we will rederive the same case
first, i.e., the premultiplier for a single mode; then we will consider multi-
ple modes and the postmultiplier. Whether the correction matrix is real or
complex depends only on the experimental data: static data lead to a real
matrix and oscillatory data lead to a complex matrix.

Assume that we have a matrix \([A]\) of theoretical aerodynamic influence
coefficients (AIC's) that relates the theoretical pressures \(\{C_{pt}\}\) on a set
of aerodynamic finite-elements to the dimensionless downwashes \(\{w\}\) at the
same aerodynamic elements by

\[
\{\Delta C_{pt}\} = [A]\{w\}
\]

(1)

The AIC's correspond to the reduced frequency of the experimental data and,
hence, are real for static data and complex for oscillatory data. The pre-
multiplying correction matrix \([W_p]\) is used to obtain an estimate of the
experimental pressure distribution \(\{\Delta C_{pe}\}\) from the theoretical distribution
from

\[
\{\Delta C_{pe}\} = [W_p]\{\Delta C_{pt}\}
\]

(2)

The subscript p refers to modification of the pressure distribution. The
experimental force distribution is usually not known from the test data but
only the integrated force and moment coefficients \(\{C_e\}\) are measured. An
integration matrix \([S]\) relates the experimental force distribution to the
measured force coefficients through;
\[ \{C_e\} = [S] \{\Delta C_p\} \quad (3) \]

Combining equations (1) - (3) yields

\[ \{C_e\} = [S][W_p][A]\{w\} \quad (4) \]

which is the equation to be solved for the correction matrix \([W_p]\) given all the remaining terms in the equation. The remaining terms are all known: \(\{C_e\}\) and \(\{w\}\) are obtained from the test data, and \([S]\) and \([A]\) are known from the mathematical model and the theoretical aerodynamic analysis of the configuration. In general, equation (4) is underdetermined, i.e., there are many more unknowns than equations. The method of least squares provides a solution. We require that changes in the theoretical load distribution shall be as uniform as possible or, in least-squares terminology, the weighted sum of the squares of the deviations shall be a minimum, where the deviation \(\{\epsilon_p\}\) is defined as the difference between the correction factors and unity.

\[ \{\epsilon_p\} = \{W_p - I\} \quad (5) \]

We denote the weighting function by \(T_p\); it will be discussed below. The weighted least-squares condition then becomes

\[ \sum T_p \epsilon_p^2 = \{\epsilon_p\}^H \{T_p\} \{\epsilon_p\} \]

\[ = \text{a minimum} \quad (6) \]

where \(H\) denotes a Hermitian (complex conjugate) transpose. The Lagrange multipliers may be introduced by defining the error functional

\[ f_p = (1/2) \{\epsilon_p\}^H \{T_p\} \{\epsilon_p\} \quad (7) \]

and rewriting the measured generalized force coefficients (the constraints) as
\[
\{C_e\} = [S] \left[ 1 + \epsilon_p \right] \{\Delta C_{p_t}\} \\
= [S] \{\Delta C_{p_t}\} + [S] \left[ \Delta C_{p_t} \right] \{\epsilon_p\}
\]

The term \([S] \{\Delta C_{p_t}\}\) is just the theoretical integrated pressures which are the theoretical coefficients, \(\{C_t\}\). Thus

\[
\{C_t\} = [S] \{\Delta C_{p_t}\} \quad (8)
\]

Introducing also the following

\[
[S_p] = [S] [\Delta C_{p_t}] \quad (9)
\]

\[
\{\Delta C_e\} = \{C_e\} - \{C_t\}
\]

gives finally

\[
\{\Delta C_e\} = [S_p] \{\epsilon_p\} \quad (10)
\]

The variation of the error functional \(f_p\) is

\[
\delta f_p = \{\epsilon_p\}^H [T_p] \{\delta \epsilon_p\} \quad (11)
\]

and the variations of the incremental constraints, \(\Delta C_e\), given by equation (10) are

\[
\{\delta \Delta C_e\} = [S_p] \{\delta \epsilon_p\} \quad (12)
\]

\[
= 0
\]

The condition for the minimum subject to the constraints is then a linear combination of equations (11) and (12) set to zero in which the linear factors
are the Lagrange multipliers $\lambda_p$,

$$\delta f_p + \{\lambda_p\}^H \{\delta \Delta e\} = 0 \quad (13)$$

Substituting equations (11) and (12) into equation (13) yields

$$\{\varepsilon_p\}^H [T_p] + \{\lambda_p\}^H \{S_p\} \{\delta \varepsilon_p\} = 0$$

Since the variation $\{\delta \varepsilon_p\}$ is arbitrary,

$$\{\varepsilon_p\}^H [T_p] + \{\lambda_p\}^H \{S_p\} = 0$$

or, after Hermitian transposition.

$$[T_p] \{\varepsilon_p\} + [S_p]^H \{\lambda_p\} = 0 \quad (14)$$

The simultaneous solution of equations (5), (10) and (14) yields the desired solution. The simultaneous solution leads first to the Lagrange multipliers and then to $\varepsilon_p$ as follows:

$$\{\lambda_p\} = -([S_p] [T_p]^{-1} [S_p]^H)^{-1} \{\Delta e\} \quad (15)$$

$$\{\varepsilon_p\} = -[T_p]^{-1} [S_p]^H \{\lambda_p\} \quad (16)$$

and the correction factors are then

$$\{W_p\} = \{I\} + \{\varepsilon_p\} \quad (17)$$

The premultiplying correction factors are written in a diagonal format for use in subsequent aeroelastic analyses as in equation (2).

The above results can be restated in summary form as follows:

$$\text{Solution of } \{\Delta e\} = \{S_p\} \{\varepsilon_p\} \quad (18)$$
subject to \[ \sum \varepsilon_p^2 T_p = \min. \] (19)

\[ \rightarrow \{ \varepsilon \} = [\tilde{S}_p]^H \left( [\tilde{S}_p][\tilde{S}_p]^H \right)^{-1} \{ \Delta C_e \} \] (20)

where \[ [\tilde{S}_p] = [S_p] \sqrt{T_p} \] (21)

and \[ \{ \varepsilon_p \} = \{ \tilde{\varepsilon} \} / \sqrt{T_p} \] (22)

The weighting function \( T_p \) is arbitrary; the only requirement on it is that it should be positive. However, engineering judgment provides some guidance: if only a single constraint, e.g., the lift curve slope, is available, one would prefer all the correction factors to be simply the ratio of its experimental value to its theoretical estimate. Accordingly, the recommended choice for the weighting function for the premultiplier is

\[ \{ T_p \} = |A| \{ I \} \] (23)

However, other choices may be deserving of further investigation.

**Multiple Modes.** - We next consider multiple experimental downwash modes. The derivation will be presented using two modes \( \{ w_1 \} \) and \( \{ w_2 \} \). For these two modes, the theoretical pressure distributions are

\[ \{ \Delta C_{p1} \} = [A] \{ w_1 \} \]

\[ \{ \Delta C_{p2} \} = [A] \{ w_2 \} \]

so the incremental experimental force coefficients \( \Delta C_{e1} \) and \( \Delta C_{e2} \) become

\[ \{ \Delta C_{e1} \} = \{ C_e \} - [S] \{ \Delta C_{p1} \} \{ W_p \} \]

\[ = \{ C_e \} - [S_p] \{ W_p \} \] (24)
These two equations may be combined into one set as follows:

$$\{\Delta C_{e2}\} = \{C_e\} - [S] \{\Delta C_{pt2}\} \{W_p\}$$

$$= \{C_e\} - [S_{p2}] \{W_p\}$$  \hspace{1cm} \text{(Continued)(24)}

where

$$\{\Delta C_e\} = \{\Delta C_{e1}\} \{\Delta C_{e2}\}$$

and

$$[S_p] = [S_{p1}, S_{p2}]$$  \hspace{1cm} \text{(26)}

If again we impose the minimization condition

$$\sum \varepsilon_p^2 T_p = \min$$  \hspace{1cm} \text{(27)}

then the solution is identical to equation (20) since equations (25) and (27) are identical to (18) and (19).

Postmultiplying Correction Factor Matrix. - Now we consider the postmultiplying correction matrix. It is only necessary to consider a single downwash mode; the multiple mode case can be generalized by reference to equations (25) and (26). Since the postmultiplier modifies the downwash mode it defines an effective experimental downwash given by

$$\{w_e\} = [W_w] \{w\}$$

in which the subscript w refers to modification of the downwash. Our new estimate of the experimental pressure distribution becomes:
\{\Delta C_e\} = [A] \{w_e\}

= [A] [W_w] \{w\} \quad (28)

The experimental generalized forces or force coefficients are again given by equation (3) which with equation (28) becomes

\{C_e\} = [S] [A] [1+\epsilon_w] \{w\}

= [S] \{\Delta C_{p_t}\} + [S] [A] [W] \{\epsilon_w\} \quad (29)

And again noting that [S] \{\Delta C_{p_t}\} = \{C_t\} and introducing

\[S_w] = [S] [A] [W] \quad (30)

gives

\{C_e\} - \{C_t\} = [S_w] \{\epsilon_w\}

or since

\{C_e\} - \{C_t\} = \{\Delta C_e\}

\{\Delta C_e\} = [S_w] \{\epsilon_w\} \quad (31)

Again the minimization condition is imposed,

\[\sum \epsilon_w^2 T_w = \text{min.}\] \quad (32)

The solution for \epsilon_w is then identical to equation (20) since equations (31) and (32) are identical to equations (18) and (19). Again the correction factors are calculated from \epsilon_w as follows:

\{W_w\} = \{1\} + \{\epsilon_w\} \quad (33)
The weighting function $T_w$ is also arbitrary. However, the considerations that led to the recommendation of equation (23), in the premultiplying case, also lead to

$$\{T_w\} = |\{I\}^T [A]|$$

(34)

which is to say that the weighting function is the lift coefficient induced by a unit downwash at each lifting element. Equation (34) is the recommended choice for the weighting function in the postmultiplying case, although other choices may still warrant further investigation.

For multiple modes, say two, equations (31) and (32) provide the following:

$$\{\Delta C_{e_1}\} = [S_{w_1}] \{\epsilon_w\}$$

(35)

$$\{\Delta C_{e_2}\} = [S_{w_2}] \{\epsilon_w\}$$

(36)

$$\sum_{w}^2 \epsilon_w T_w = \min$$

(37)

Again equations (35) and (36) can be combined into one as follows:

$$\{\Delta C_e\} = [S_w] \{\epsilon_w\}$$

(38)

where

$$\{\Delta C_e\} = \begin{bmatrix} \Delta C_{e_1} \\ \Delta C_{e_2} \end{bmatrix}$$

and where

$$[S_w] = [S_{w_1} \quad S_{w_2}]$$

(39)

Equations (38) and (37) are now identical to equations (18) and (19) respectively and thus the solution is the same as before, i.e., equation (20).
Modifications to the Basic Method

In some instances correction factors become unrealistic. In order to correct this situation when it occurs or to minimize the probability of its occurrence initially, various modifications can be introduced. Three such modifications are discussed here, i.e., estimates, correction factor modes and limits. Estimates are like constraints except that the "constraining power" can be varied. Correction factor modes constrain the distribution of correction factors such that the final distribution is a superposition of a limited set of well behaved, user input mode shapes. The "limit" feature constrains the correction factors (or any subset of them) to be above a given minimum and below a given maximum.

Estimates. - In some instances data will be available in the form of estimates. These estimates can be based on past data, data from related configurations, two-dimensional data, empirical methods, or just past experience. In any case they do not have equal weight with the experimental data considered so far. Consider the case where some experimental data are available, leading to \( \Delta C_e \), then the usual equation applies to these data:

\[
\Delta C_e = [S_a] \{e_a\}
\]

where the subscript "a" stands for either p or w. If estimates exist, leading to \( \Delta C_g \), then it is desirable to minimize the difference between these estimates and the modified theoretical values. Let this difference be termed \( \{e_g\} \), then:

\[
\Delta C_g = [S_g] \{e_a\} + \{e_g\}
\]

where \( \Delta C_g = \{C_g - C_e\} \) and \( S_g \) is analogous to \( S_a \) with the exception that it refers to the estimates \( C_g \) and not the constraints \( C_e \). Thus we wish to minimize both \( \{e_a\} \) and \( \{e_g\} \) together and this is done as follows:
This equation can then be solved in the usual manner producing the following result:

\[ \sum T \varepsilon_a^2 + \sum \varepsilon_g^2 = \min \]

If it is desired to give the \( \varepsilon_g \) values more or less weight in the minimization scheme, then the \( \varepsilon_g \) values must be weighted.

\[ \sum T \varepsilon_a^2 + \sum (w_T \varepsilon_g)^2 = \min. \quad (40) \]

The equations for the constraints then become

\[
\begin{bmatrix}
\Delta C_e \\
\Delta C_g
\end{bmatrix}
= 
\begin{bmatrix}
S_a & 0 \\
S_g & I
\end{bmatrix}
\begin{bmatrix}
\varepsilon_a \\
\varepsilon_g
\end{bmatrix}
\]

(41)

where

\[ \{\varepsilon_{WT}\} = [w_T] \{\varepsilon_g\} \quad (42) \]

and where the values \( w_T \) are the weights assigned to the errors \( \varepsilon_g \). If the estimates are of high quality then the weights will be large. In the limit as \( w_T \to \infty \), \( \Delta C_g \) becomes a constraint instead of an estimate and equation (41) reduces to the form of equation (18). Equation (41) can also be cast into the same form as equation (18) for the general case, i.e., \( w_T \) finite, as follows:

\[ \{\Delta C_e\} = [S] \{\varepsilon\} \quad (43) \]

with
\{\Delta C_e\} = \begin{pmatrix} \Delta C_e \\ \Delta C_g \end{pmatrix} \tag{44}

\begin{bmatrix} \bar{S} \end{bmatrix} = \begin{bmatrix} S_a & 1 \\ -a & - \\ S_g & \frac{1}{WT} \end{bmatrix} \tag{45}

\{\varepsilon\} = \begin{pmatrix} \varepsilon_a \\ \varepsilon_{WT} \end{pmatrix} \tag{46}

Equation (40) can be written in terms of \(\varepsilon\) as:

\[ \sum T^* \varepsilon^2 = \min \]

where

\[ T^* = \begin{cases} T \text{ for constraints} \\ \frac{1}{(WT)^2} \text{ for estimates} \end{cases} \]

Thus equation (43) and (47) are formally identical to equation (18) and (19) and thus have the same solution, i.e., equation (20).

Currently the term \(\frac{1}{WT}\) is obtained from a term \(\tilde{a}\) where

\[ \frac{1}{WT} = \frac{1-\tilde{a}}{\tilde{a}} \tag{48} \]

\[ 10^{-4} \leq \tilde{a} \leq 1.0 \]

where \(\tilde{a}\) is called the constraining power of the estimate \(C_g\).
Correction Factor Modes. - The correction factors can be expressed in terms of a set of modes $\phi$ as follows:

\[ \{\epsilon\} = [\phi] \{\tilde{\epsilon}\} \quad (49) \]

Placing equation (49) into (43) gives

\[ \{\Delta C_e\} = [\tilde{S}] [\phi] \{\tilde{\epsilon}\} \]

\[ = [\tilde{S}] \{\tilde{\epsilon}\} \quad (50) \]

where

\[ [\tilde{S}] = [\tilde{S}] [\phi] \quad (51) \]

If the minimization process is applied to $\tilde{\epsilon}$ as usual

\[ \sum \epsilon^2 = \min \quad (52) \]

Here the weight $T$ is missing since it is usually not used with modes. Equations (50) and (52) are then identical to equations (18) and (19) and thus have the same solution, i.e., equation (20). A similar expression exists for the postmultiplying correction factors. This approach allows a bias based on experience and past tests and physical reasoning, to be built into the correction factors. When estimates are considered equation (50) must be altered since the $\epsilon_{WT}$ are not fitted with correction factor modes. Thus

\[ \{\epsilon\} = \begin{pmatrix} \epsilon_a^- \\ \epsilon_{-a}^- \\ \epsilon_{WT}^- \end{pmatrix} = \begin{bmatrix} \phi & 0 \\ 0 & I \end{bmatrix} \begin{pmatrix} \epsilon_a^- \\ \epsilon_{-a}^- \end{pmatrix} \quad (53) \]

and thus

\[ [\tilde{S}] = [\tilde{S}] \begin{bmatrix} \phi & 0 \\ 0 & I \end{bmatrix} \quad (54) \]
and then the solution proceeds as before.

**Limits.** - If certain basic properties of the weight factors are known, they could be limited to fall within a given set of bounds. If for instance the sign of an incremental weight factor is known to be positive, then it could be constrained to be positive. Also, for practical reasons, the maximum value of the weight factors should be limited and thus the incremental weight factors are constrained to lie below this maximum. In general, the weight factors can be constrained to lie between a maximum and a minimum.

\[
\tilde{\varepsilon}_{\text{min}} \leq \tilde{\varepsilon} \leq \tilde{\varepsilon}_{\text{max}}
\]

Notice that the generalized incremental correction factors, \(\tilde{\varepsilon}\), are the ones limited in the solution and not the actual ones, \(\varepsilon\). The values of \(\tilde{\varepsilon}\) are the coefficients of the correction factor modes, \(\phi\), and not the incremental correction factors themselves.

The basic procedure would be to set any generalized incremental weight factor to its maximum or minimum value if it exceeded these limits. This would require a multistep operation: (1) solving for the factors, (2) checking and setting those that exceeded the limits to the limit values, and (3) resolving. Before this can be done a capability must exist for assigning weight factors special values. This is easily accomplished as follows:

\[
\begin{align*}
\{\Delta C_\varepsilon\} &= [S_u | S_d] \begin{bmatrix}
\tilde{\varepsilon}_u \\ \tilde{\varepsilon}_d
\end{bmatrix} \\
\begin{bmatrix}
\tilde{\varepsilon}_u \\ \tilde{\varepsilon}_d
\end{bmatrix} &= [S_u | S_d]^{-1} \{\varepsilon_u\}
\end{align*}
\]  

(56)

where \(S\) is defined in equation (51). The subscript \(u\) indicates those factors that are undesignated and \(d\) indicates those that are designated. This equation can be solved for \(\{\varepsilon_u\}\) in terms of the known quantities:

\[
\{\Delta C_\varepsilon\} - [S_d] \{\varepsilon_d\} = [S_u] \{\varepsilon_u\}
\]

(57)

Equation (57) effectively eliminates the designated factors from the minimi-
zation process. This equation can then be solved in the usual manner for $\{\bar{\epsilon}_u\}$ since $\{\bar{\epsilon}_d\}$ is given. Specifically

$$\{\Delta C_{e_{\text{mod}}\epsilon}\} = [S_u] \{\bar{\epsilon}_u\}$$

(58)

where

$$\{\Delta C_{e_{\text{mod}}}\} = \{\Delta C_e\} - [S_d] \{\bar{\epsilon}_d\}$$

(59)

The minimization scheme is then

$$\sum T^* \bar{\epsilon}_{u\epsilon}^2 = \min$$

(60)

Equations (58) and (60) are now formally identical to equations (18) and (19) and thus the solution is identical to equation (20). In the computer program the final $\bar{\epsilon}$ array that are modified or have reached their limits is called $\bar{\bar{\epsilon}}$. 
A New Postmultiplying Correction Factor Matrix

The postmultiplying correction factor matrix developed in a previous section has been applied successfully to wings operating in pitch. Problems arise however when control surface modes are used. The discussion to be presented in the "Correlation Studies" section describes some of these problems. As a result of these, a new postmultiplying correction factor matrix was developed and it is derived here.

Viscous effects on airfoils can be thought of in terms of a displacement thickness added to the airfoil. The difference between the upper and lower surface displacement thicknesses produces a "decambering" of the airfoil or a change in the downwash $w$.

$$w_e = w + \delta w$$  \hspace{1cm} (61)

The changes in downwash, $\delta w$, exist over the entire airfoil or wing and not just in the region where $w$ is non zero. These changes are a function of the pressure distribution on the airfoil. Usually the displacement thickness at a point is an integral function of the pressure distribution upstream of that point. If the general case of correction factor mode shapes is assumed then the downwash correction $\delta w$ can be expressed as:

$$\{\delta w\} = [\phi] \{\delta \epsilon\}$$  \hspace{1cm} (62)

where $\{\delta \epsilon\}$ is proportional to the integrated pressures, $[\epsilon]$.

$$\{\delta \epsilon\} = [\epsilon] \{\epsilon\}$$  \hspace{1cm} (63)

where $[\epsilon]$ is given in terms of an integration matrix $[N]$ and the pressures $\{\Delta C_p\}$.

$$[\epsilon] = [N] \{\Delta C_p\}$$  \hspace{1cm} (64)
Combining equations (63) with (62) and using the result to obtain the corrected pressures leads to

\[
\{\Delta C_{pe}\} = [A] \{w_e\}
\]

\[
= [A] \{w + [\phi] [L] \{\xi\}\} \tag{65}
\]

The constraints \(\{C_e\}\) are obtained by integrating \(\{\Delta C_{pe}\}\) as follows:

\[
\{C_e\} = [S] \{\Delta C_{pe}\},
\]

\[
= [S] \{\Delta C_{pt}\} + [S_p^*] \{w\} \tag{66}
\]

where

\[
[S_p^*] = [S] [A] [\phi] [L] \tag{67}
\]

Noting that \(\{\Delta C_e\} = \{C_e\} - \{C_t\}\) equation (65) can be written as:

\[
\{\Delta C_e\} = [S_p^*] \{w\} \tag{68}
\]

Equation (68) has a form identical to that of equation (18) except \([S_p^*]\) is replaced by \([S_p^*]\) and thus has the same solution, i.e., equation (20). Once found, \(\{w\}\) can be placed into the expression for \(\{\Delta C_{pe}\}\), in equation (65), and the desired modified pressure found.

Currently in the computer program the matrix \([N]\) is simply either the identity matrix or the matrix \([\phi]^T\). The identity matrix implies that the correction to the downwash is proportional to the local lifting pressure. In addition the above derivation is good for only one mode and thus the multiple mode option can not be used with the new postmultiplier. The new postmultiplier can be extended to multiple modes by simply replacing

\[
\{\Delta C_e\} \quad \text{with} \quad \begin{bmatrix} \Delta C_{e_1} \\ \Delta C_{e_2} \end{bmatrix} \tag{69}
\]
and

\[ [s_p^*] \text{ with } \begin{bmatrix} s_{p1}^* \\ s_{p2}^* \end{bmatrix} \]  

(70)

but this has not yet been tried.
Empirical modification of theory is most meaningful if the theory qualitatively matches experimental data. If the theory misses an important feature of the data the modified theory will also usually miss it. Transonic effects fall in this category. The classic lifting surface theory makes no provision for transonic effects and it is the purpose of this section to investigate some simple modifications to help remedy this situation.

Direct Application of Local Mach Number. - Several methods based on the steady local Mach Number distribution have been tried and the results are discussed in later sections.

One of these methods, discussed in the Introduction, consists of making a simple substitution of a local Mach Number distribution in place of its free stream value both in the kernel function and in the boundary conditions and pressure equation (see refs. 7 and 10). The local Mach Number distribution is taken from steady flow results. For the kernel function, application of a Mach Number distribution that lies somewhere in between the surface values and the free stream value was used. Tijdeman and Zwaan (ref. 10) suggest a local Mach Number distribution that lies half way in between the actual local and the free stream values. The reason for this is that acoustic signals propagate to the surface along various paths out in the fluid and thus propagate at some average between the surface value and free stream value. For the kernel, the local receiving point value of Mach Number and the free stream values were averaged and used in place of the free stream value.

For the normalwash boundary condition and pressure evaluation the local Mach Number on the surface was used. Specifically, if $M_2(x)$ is the local surface steady Mach Number distribution then the normalwash boundary condition $w$ is (see ref. 10):

$$\frac{w}{U_\infty} = \frac{M_2(x)}{M_\infty} \frac{\partial h}{\partial x} + i \frac{\omega}{U_\infty} h$$

(71)
The second order Bernoulli Equation for steady flow is (see ref. 7):

$$\Delta C_{p_{SO}} = \Delta C_p \left[ 1 + \beta^2 \left( \frac{M_2(x)}{M_\infty} - 1 \right) \right]$$

(72)

where $\Delta C_p$ and $\Delta C_{p_{SO}}$ are the first and second order pressures respectively. This method did not prove to be all that was hoped for and thus a second method was investigated.

**A New Transonic Effects Method.** In this section a derivation of the newly developed Douglas transonic effects method is presented. The basic method was conceived under the McDonnell-Douglas IRAD program however its implementation in two-dimensions and its application to the airfoil-control surface problem was done under the current contract.

The lifting surface method is based on the following expression for the potential of a doublet, $\phi_d$:

$$\phi_d = \frac{3}{2n} \left\{ e^{i\omega t} e^{i\lambda[M_\infty(x-\xi)-R]} \right\}$$

(73)

where

$$\lambda = \frac{\omega M_\infty}{\beta^2 U_\infty} \quad , \quad R = \sqrt{(x-\xi)^2 + \beta^2 r^2}$$

and $n$ is the direction normal to the lifting surface. This expression can be rewritten as:

$$\phi_d = \frac{3}{2n} \left\{ e^{i\omega(t-\tau)} \right\}$$

(74)

where

$$\tau = \frac{M_\infty}{\beta^2 U_\infty} \left[ R - M_\infty(x-\xi) \right]$$

(75)
It can be shown that $\tau$ has a physical significance. The term $\tau$ is the acoustic time delay between the sending and receiving points. That is, $\tau$ is the time it takes an acoustic signal, originating at the point $\xi, \eta, \zeta$ to reach the point $x, y, z$ as the acoustic pulse washes downstream.

This statement can be illustrated by the example of figure 1.

A signal is emitted at $(\xi, \eta, \zeta)$ at time $\tau = 0$. At time $\tau$ the wave front, traveling at the speed of sound, $a_\infty$, has reached the receiving point at $(x, y, z)$. During this time the wave center has travelled a distance $U_\infty \tau$. Using the right triangle relations gives:

$$r^2 + (\xi - x + U_\infty \tau)^2 = a_\infty^2 \tau^2$$  \hspace{1cm} (76)

Solving for $\tau$ using the solution for a quadratic equation gives:

$$\tau = \frac{M_\infty}{U_\infty \theta^2} \left( M_\infty (\xi - x) + R \right)$$

which is exactly what is given in equation 75.
Thus \( \tau \) in the expression for \( \zeta_d \) has physical significance and it is the acoustic time delay between the sending and receiving points in a fluid moving with uniform velocity. This physical insight can form the basis of a correction factor for the theory. For instance if the wave is in a flow field whose velocity varies in the longitudinal direction then the distance \( d \) travelled by the wave center is not \( U_\infty \tau \) but is:

\[
d = \int_0^\tau U(t) \, dt
\]  

(77)

If we consider \( U(t) \) to be made up of \( U_\infty + \delta U(t) \) then \( d \) also can be so split.

\[
d = U_\infty \tau + \delta d
\]  

(78)

\[
\delta d = \int_0^\tau \delta U(t) \, dt
\]  

(79)

The wave center velocity \( U \) is being discussed, however this is not the velocity of the fluid particle located at the wave center as is the case for a uniform flow. The velocity \( U \) actually reflects the wave front speed and location and is the speed of an imagined wave center for the wave that strikes the receiving point. The wave front speed varies around the circumference of the wave, but the most important part of the wave is that part that strikes the receiving point. Thus the velocity \( U(t) \) is the time history of the wave center corresponding to that part of the wave that strikes the receiving point \( (x, y, z) \). As an approximation to the location of this part of the wave, it is assumed that it lies along a line connecting the receiving and sending points (shown dotted in figure 2). Thus \( \delta U \) is the difference between the local velocity and the free stream velocity along the dotted line. If a
coordinate $\tilde{R}$ is defined lying along this line then the integral in time of equation (79) can be converted into a space integral in $\tilde{R}$ as follows:

$$\delta d = \int_0^R \delta U(R) \, \frac{dt}{d\tilde{R}} \, d\tilde{R}$$

where $\tilde{R}$ is defined below equation (73) and where $\frac{d\tilde{R}}{dt}$ is the speed with which the wave front moves along the radial coordinate.

$$\frac{d\tilde{R}}{dt} = (a_\infty \, \hat{i}_a + U(\tilde{R}) \, \hat{i}) \cdot \hat{i}_R$$

The unit vectors $\hat{i}_a$, $\hat{i}$ and $\hat{i}_R$ are defined in figure 2.

For example, in the two-dimensional analysis for coplanar surfaces:
Thus
\[ \delta d = \int_\xi^\xi \Delta U \frac{dt}{dx} \, dx. \]

\[ \frac{dx}{dt} = a - U(x) \quad (80) \]

Thus
\[ \delta d = \int_{\xi}^{x} \frac{M(x) - U_\infty/a}{1 - M(x)} \, dx \quad (81) \]

where \( M(x) \) is the local Mach Number distribution. As an approximation set 
\( U_\infty/a = U_\infty/a_\infty = M_\infty. \)

The time \( \tau \) can now be calculated using the right-triangle relations and the quadratic formula solution.

\[ [U_\infty \tau + \delta d + \xi - x]_2^2 + r^2 = a_\infty^2 \tau^2 \]

Solving for \( \tau \) gives:

\[ \tau = \frac{M_\infty}{U_\infty B^2} \left( M_\infty (\xi - \tilde{x}) + \tilde{R} \right) \quad (82) \]

where

\[ \tilde{R}^2 = (\zeta - \tilde{x})^2 + b^2 \tau^2 \quad (83) \]

\[ \tau = x - \delta d \quad (84) \]

It is immediately evident that \( \tau \) has exactly the same form as \( \tau \) (see equation (75)) except that \( x \) is replaced, in the expression for \( \tau \), by \( x - \delta d \) in the expression for \( \tau \). In essence then the receiving and sending points
have increased their separation (in the x-direction) as far as the acoustic time delay \( \tau \) is concerned. Is there any reason to carry this increase in distance to other parts of the potential function, specifically, to the radius term in the denominator? It seems so. First, this radial distance is already modified in the expression for \( \tau \), see equation (82). Second it is known that transonic effects exist in steady flow \((\omega = 0)\) where \( \tau \) has no effect; i.e., \( \frac{\partial \phi}{\partial n} = \frac{2}{n} (1/R) \). Thus it seems appropriate to add \(-\delta d\) to all \( x - \xi \) terms. Thus

\[
\tilde{\phi}_d(x - \xi, y - n, z - \xi, \omega, M_\infty) = \phi_d(x - \xi - \delta d, y - n, z - \xi, \omega, M_\infty) \tag{85}
\]

where \( \tilde{\phi}_d \) is the potential modified for transonic effects.

This method has been implemented for the two-dimensional case and the results are discussed subsequently.

One variation of this method that is possible is to use an average Mach Number between sending and receiving points and define \( \delta U \) as the difference between the local value of velocity and this average. Thus the term \( M_\infty \) is replaced with \( \bar{M}_\infty \) where

\[
\bar{M}_\infty = \frac{1}{(x-\xi)} \int_\xi^x M(x)dx \tag{86}
\]

This method has also been tried and results using this variation are also discussed subsequently.

A final consideration is the determination of the local Mach Number distribution, \( M(\bar{x}) \). Tijdeman and Zwaan (ref. 10) note that the local surface Mach Number distribution should not be used but that some average between it and the free stream Mach Number should be used. This is because the signal arriving at a point has traveled both in the vicinity of the airfoil and out in the flow field. The recommendation of Tijdeman and Zwaan has been adopted in the present method.
Other work by Tijdeman and Bergh (ref. 11) can also be brought to bear on this work. Specifically a fully two-dimensional acoustic solution of a source pulse located at the control surface hinge was calculated for the case of a nonuniform flow field. This solution produced the exact time lag \( \tau \) from the hinge line to all other points on the airfoil. The equivalent distance \( \tilde{x} \), and also \( \tilde{R} \), from the hinge line to the receiving point can then be calculated using this information and the equation relating \( \tau \) to \( \tilde{x} \). Thus

\[
\xi - \tilde{x} = \sqrt{\frac{\tau^3}{\tilde{R} \cdot U_\infty}} \cdot U_\infty \cdot C - \tau^2
\]

If acoustic solutions were obtained for all other sending points then all the necessary \( \tilde{x} \) for this theory would be available. This method would be accurate, however it would require many expensive acoustic solutions. It appears that each of these solutions requires a computing effort comparable to a direct solution, by finite difference, of the original problem. This conclusion however, remains to be seen and further study is required.
CORRELATION STUDIES

Local Mach Number Studies

Several methods of accounting for local steady Mach Number variations in the oscillatory lifting surface theory have been studied for the two-dimensional case. A mathematical description of these methods has been presented in the Theoretical Development section. The cases considered here are for a two-dimensional symmetric airfoil (NACA 65A006) with an oscillating 25% chord flap. The local Mach Number variations over the airfoil at zero angle of attack are given in reference 11.

The first and simplest of the methods studied involves simply making a direct substitution of the steady local Mach Number in place of its free stream value. In general, this approach does not produce substantial changes in the pressures from their classical values.

In figure 3 the symbols marked by triangles indicate the pressures calculated using the local Mach Number in the downwash boundary condition. The pressures are reduced from their classical values (indicated by dots and a dashed line) as expected, but not by very much.

The circles indicate the pressures calculated using the local Mach Number in the downwash as well as in the kernel function. In the kernel function the average between the local receiving point Mach Number and the free stream value is used. The pressures again are generally reduced but not by any substantial amount.

The use of local Mach Number in the second order Bernoulli equation (Ashley, ref. 7) also produces very little change. In figure 5 this change is observed as the difference between the circles and triangles. This change is about the same order of magnitude as the other changes except it is generally in the opposite direction.

The second method studied is new and is described in the Theoretical
The basic idea of this method is to transform the longitudinal distance between sending and receiving points depending on the time it takes an acoustic signal to travel that distance. A variation of this method is simply to replace the free stream Mach Number, $M_\infty$, by $\bar{M}_\infty$, an integrated average of the Mach Number distribution between sending element and receiving point defined in equation (86).

On the face of it the new method gives the best correlation when $M_\infty$ and not $\bar{M}_\infty$ is used. Figure 4 presents a comparison between the two methods at a Mach Number of 0.875. Near the leading edge the basic method designated "Present Method ($M_\infty$)" and indicated by triangles produces the best agreement between experiment and calculation. Near the position of the steady shock wave however the peak pressure is better predicted by the variation of the basic method designated "Present Method ($\bar{M}_\infty$)" and indicated by circles. The location of the calculated peak is slightly forward of the experimentally observed peak. Either method, however, is better than the classic theory (indicated by dots) for predicting pressures as comparisons with experimental data shown.

Two features of the experimental pressure distribution illustrate transonic effects. One of these is the reduced leading edge pressure levels, and a second is the bump or peak in pressure near the location of the steady shock wave location. The new method qualitatively reproduces these features. However there is reason to suspect that the basic version of the new method (triangle) under-predicts the leading edge pressure. The reason for this lies in the fact that, even though the calculated and experimental pressures agree near the leading edge, viscous effects have not yet been accounted for and these effects reduce the calculated loads even further. A drop in the leading edge loading caused by application of viscous effects to the ($\bar{M}_\infty$) variation of the basic method (circles), renders this method more acceptable than before. However these effects are not large enough to bring the calculated pressures in line with the experimental values (see fig. 38). Further study is required in this area to decide which method is best or to discover other more accurate variations of the basic method.
The application of the new transonic method to a lower Mach Number, (0.85), is shown in figure 5. The agreement is good near the leading edge but only a slight indication of the shock bump is given by the theory. Also shown in this figure is the effect of local Mach Number on the Bernoulli equation (see equation (72)). The difference between the circles and triangles indicates this effect.

All applications thus far have been for the steady case. Figure 6 presents a comparison of the Present Method (new transonic theory) for the case of the control surface oscillating at a reduced frequency \( k_r = \frac{\omega C}{2U} = 0.059 \). Also shown in this figure is a calculation done using the Traci et al method (ref. 12) and a calculation done using the classic theory. The finite element theory of Traci et al predicts the bump at the shock wave fairly accurately however is not as good as the Present Method elsewhere. One part of the pressure distribution that does not seem to be predicted by any of the theories is the depth of the dip in pressure behind the shock.

Figure 7 presents a comparison similar to that in Figure 6 but at a lower Mach Number (0.85). Also instead of in phase (Real) and out of phase (Imaginary) parts given, amplitude \( \Delta C_p = \sqrt{(\text{Re} \Delta C_p)^2 + (\text{Im} \Delta C_p)^2} \) and phase angle \( \tan^{-1} (\text{Im} \Delta C_p/\text{Re} \Delta C_p) \) are presented. Again, as in the steady case the bump at the shock is barely noticeable in the Present Method and of course absent altogether in the classic theory.

Figure 8 presents a comparison of the Present Method, classic theory and experimental data for a case similar to that presented in figure 7 except that the Mach Number is 0.875 and the reduced frequency, \( k_r = 0.176 \). Again pressure amplitude and phase angle are shown. The two variations of the Present Method are in better agreement with the experimentally obtained pressure amplitudes than is the classic theory. However the same can not be said of the phase angles. The Present Method follows the experimental phase angle curve from about the 40% chord on to the trailing edge. However none of the theories follows the curve forward of that point. Tijdeman and Bergh (ref. 11) present a modified phase angle curve based on a full two-dimensional
acoustic solution of a pulse located at the control surface leading edge (see section on New Transonic Effects Method). This approach gives very good agreement with the experimental phase angle data (see figure 31 of reference 11). The correction was applied only to the phase angles and not the pressure amplitudes. The calculated phase angle was simply corrected using the additional time lag over and above that experienced in uniform flow. This additional phase lag was not used internal to the theory but applied after the theoretical calculation was completed. The section of this report entitled "A New Transonic Effects Method" describes how this acoustic type of information can be used internally with the theory so that the pressure amplitudes are also effected. This approach has not yet been tried.

A possible explanation of the phase angle differences between theory and experiment might be due to the fact that signal fronts, which emanated from the control surface, do not exactly travel normal to the flow as assumed in the Present Method. Tijdeman and Bergh have shown that the wave fronts are actually inclined to the flow to a considerable degree, within the supersonic zone. This being the case the wave fronts impinge on the forward part of the airfoil (forward of the shock wave) with very little longitudinal time delay. This would explain the flattening of the phase angle curve in front of the shock.

Thus far detailed pressure distributions have been discussed. Attention is now focused on the forces and moments these pressures produce. Figures 9 through 12 present comparisons of the present method with the classic theory and experimental data. In figure 9 the Traci, Farr, Albano theory is also plotted. This figure shows that the Present Method ($M_\infty$) is in better agreement with the data than is the classic method. As expected the Present Method and classic theory tend to coalesce at low Mach Numbers, out of the transonic region. The transonic peak lift, predicted by the Present Method, occurs earlier, as Mach Number is increased, than does the experimental data. Also the dip occurring after this peak is not nearly as deep as shown by the experimental data.

Both theories show values of lift coefficient that are higher than the
experimental values. This is due to reduced flap effectivity caused by the viscous boundary layers.

Figure 10 presents a comparison similar to the previous figure except that pitching and hinge moment coefficients are considered. Of particular note is the over prediction of hinge moment by both theories. Again this is due to viscous effects on the flap.

The last two figures have dealt with force and moment coefficients in steady flow for an airfoil with a deflected flap. Figures 11 and 12 present the same data for the oscillatory case. (The reduced frequency varies from 0.098 at $M_\infty = 0.5$ to 0.057 at $M_\infty = 0.901$ in these figures.) Generally speaking the same trends and conclusions hold for these figures as for the previous two figures.
Subsonic Cases

Oscillating Wing with Control Surface. - Extensive low speed wind tunnel measurements of static and oscillatory pressure data have been made by Hertrich (refs. 14 and 15) on straight and swept wings with a full span control surface. The wings had no taper and the control surface had a 30% chord; two aspect ratios, 2.5 and 3.1, were tested by changing the exposed span in the tunnel. The swept wings had a sweep angle of 25°. A later oscillatory test of the swept wing was made by Forshing, Triebstein, and Wagener (ref. 16) in which the full span control surface was split approximately in half (the inboard flap had 46.59% of the span) and the aspect ratio was set at 2.94.

The pressure data from the first tests (refs. 14 and 15) were integrated by Hertrich to obtain lift and moment coefficients and the static values for the swept wing with aspect ratio 3.1 have been used here as constraints to determine correction factors. The static values corrected for wind-tunnel wall interference are: lift curve slope $C_L = L/qs = 3.13$ per radian, pitching moment curve slope $C_m = M/qSc = 0.148$ per radian, flap lift effectiveness $C_L = L/qSc = 1.95$ per radian, flap pitching moment effectiveness $C_m = M/qSc = -0.432$ per radian, and the flap hinge moment coefficient $C_h = H/qSc = -0.0350 \cos 25° = -0.03172$ per radian where the sweep correction is added to give the moment about the hinge axis; the reference area is $S = 0.564 \text{ m}^2$, the reference chord is $c = 0.6 \text{ m}$, and the pitch axis is located at 61.5% of the root chord.

Rolling moment coefficients were not derived from the pressure data and neither was the hinge moment due to angle of attack $C_{h\alpha}$. The available data permitted a maximum of five constraints, and two sets of constraints were investigated; the first set used two constraints from the angle of attack data, $C_L$ and $C_m$, and the second set used all five constraints. The use of the flap rotation data alone without the angle of attack data was not considered.
The theoretical basis for the correction factors is the Doublet-Lattice Method (DLM) of reference 17. The idealization of the lifting surface consists of 110 boxes resulting from 11 strips and 10 equal chordwise divisions. The chordwise division on each strip results in 7 boxes on the primary surface and 3 boxes on the control surface. The strip widths $\Delta y_i$ are chosen so that the strip centerlines fall along the lines of pressure taps. The span of 0.940 m is divided into the following strip widths from root to tip: $\Delta y_1 = 0.110$ m, $\Delta y_2 = 0.080$ m, $\Delta y_3 = 0.075$ m, $\Delta y_4 = \Delta y_5 = \Delta y_6 = \Delta y_7 = \Delta y_9 = \Delta y_{10} = 0.090$ m, and $\Delta y_{11} = 0.045$ m. The pressure stations correspond to the strips as follows: pressure station VII is on Strip 1, VI on Strip 4, V on 6, IV on 8, III on 9, and finally station II is on Strip 10. Pressure station I is too close to the tip to permit a meaningful calculation.

The theoretical pressure distributions are compared to the experimental measurements in figures 13 through 24. The theoretical estimates of the five constraint parameters are: $C_{L\alpha} = 3.207462$, $C_{m\alpha} = 0.179494$, $C_{L\delta} = 2.131577$, $C_{m\delta} = -0.463554$, and $C_{h\delta} = -0.057784$. Three additional parameters are also of interest. These are the locations of the spanwise aerodynamic centers for angle of attack, $\bar{y}_{\alpha}/s$, and for flap deflection, $\bar{y}_{\delta}/s$, and the hinge moment coefficient for angle of attack, $C_{h\alpha}$. Their theoretical estimates are $\bar{y}_{\alpha}/s = 0.452071$, $\bar{y}_{\delta}/s = 0.464614$ and $C_{h\alpha} = -0.021034$.

A typical set of correction factors is shown in table I; it is for a premultiplying matrix and is based on five constraints. The factors are listed in order from leading edge to trailing edge on each strip beginning at the root; factors 1 to 10 are on Strip 1, and factors 101 to 110 are on Strip 11. The first seven factors on each strip apply to the primary surface and the last three apply to the control surface. The general trends seen in table I are a spanwise increase in factors from root to tip and a chordwise increase toward the hinge line. The minimum correction factor in table I is 0.255873 for Box No. 10 and the maximum factor is 2.00893 for Box No. 108.
## Table I

<table>
<thead>
<tr>
<th>Correction Factors</th>
<th>PREMULTIPLIER</th>
<th>CASE</th>
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<td>Pre-</td>
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<tr>
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<table>
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<th>Type of Number</th>
<th>Correction of Matrix</th>
<th>Matrix Constraints</th>
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## Table II

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<th>Type of Correction Matrix</th>
<th>Number of Constraints</th>
<th>( \bar{y}_\alpha / s )</th>
<th>( \bar{y}_\delta / s )</th>
<th>( C_{h\alpha} )</th>
<th>( C_{h\delta} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0</td>
<td>0.452071</td>
<td>0.464614</td>
<td>-0.021034</td>
<td>-0.057784</td>
</tr>
<tr>
<td>Pre-</td>
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<td>0.456751</td>
<td>0.469814</td>
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<tr>
<td>Pre-</td>
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<td>0.484939</td>
<td>0.522318</td>
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<td>-0.031721</td>
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<tr>
<td>Post-</td>
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<td>0.491720</td>
<td>+0.013014</td>
<td>-0.031721</td>
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</table>
The modified static pressure distributions for angle of attack are shown in figures 13 and 14, and for flap deflection are in figures 15 and 16. Perusal of these figures indicates the following results. For the angle of attack loading, both the premultiplying and postmultiplying corrections move the theoretical results slightly away from the experimental data, the postmultiplier causing a little greater change. The effect of five constraints is greater than that of two. For the flap loading, both the pre- and postmultipliers based on two constraints have small effect. The corrections based on five constraints improve the correlations on the control surface but increase the discrepancies on the wing. The postmultiplier causes a much larger change and, although the data show a pressure reversal near the trailing edge, the postmultiplier exaggerates this reversal to the extent that the sign of the hinge moment is reversed. Table II shows the effects of the four correction matrices on the aerodynamic centers and hinge moments. All of the correction matrices resulted in an outboard shift of the aerodynamic centers, the largest shift coming from the 5-constraint premultiplier.

Two constraints did not improve the hinge moment prediction; and the 5-constraint postmultiplier lead to an unreasonable prediction of $C_{n\alpha}$. The effect of additional constraints based on estimates is a topic deserving further investigation.

We can anticipate similar discrepancies when the correction factors derived from static data are applied to the oscillatory cases, and, indeed, they are shown in figures 17 through 20 for the angle of attack oscillating at $k_r = 0.622$, and in figures 21 through 24 for the flap oscillating at $k_r = 0.752$. The theoretical loading for the oscillating angle of attack is not changed significantly by either the premultiplier or the postmultiplier based on two constraints and both the real and imaginary parts are affected about the same. In some regions the theory is shifted toward the data and in others the theory is moved away from the data. The effects of five constraints are more extreme. The 5-constraint premultiplier improves the correlation for the real part but only improves the agreement for the imaginary part on the control surface while diverging on the wing. The 5-constraint postmultiplier
is substantially worse in correcting the real part but is no worse than the premultiplier in modifying the imaginary part. Again, the theoretical load distribution from the oscillating control surface is not changed significantly by either the 2-constraint pre- or postmultipliers. However, some improvement is noted with the 5-constraint corrections although it is only slight. As in the static case, an outboard shift in loading occurs with all correction matrices and for both modes of motion.

The above applications of correction matrices have achieved very limited, if any, success. The lack of improvement in the most elementary case, however, is rather puzzling. This was the case of the static loading at angle of attack for which the correction factors were derived using the two constraints of lift and pitching moment. The pitching moment constraint was expected to shift the theoretical chordwise center of pressure in such a manner that the predicted pressure distribution would be closer to the experimental data. Two explanations for the lack of improvement appear possible. The first is that the theoretical loading in the leading edge region differs so much from the data that it dominates the correction factor calculation and results in a distorted loading. The second possibility is that the limited number of pressure taps near the leading edge prevented an accurate evaluation of the leading edge contribution to the pitching moment. A strain gage measurement of pitching moment would have shed some light on this possible difference.

A number of options were not pursued with these data which may have shown better correlation. First, only one configuration was studied here, the swept wing with aspect ratio 3.1; as noted above, straight wings with two aspect ratios and a swept wing with another aspect ratio were also tested. Next, only the reported integrated loads were used as constraints: the two angle of attack coefficients and the three additional control surface coefficients. The three control surface coefficients were not used as constraints by themselves, nor were additional constraints used based on estimates of rolling or bending moments. The new postmultiplying matrix was also not investigated. Finally, it would have been interesting to apply complex correction factors derived from the oscillatory angle of attack data at
$k_r = 0.622$ to the oscillatory control surface data at $k_r = 0.752$; however, this would have required integration of the published oscillatory pressure data to obtain the complex constraint coefficients.

**Wing With and Without Leading Edge Droop.** - Trailing edge control surfaces are studied in several other sections of this report. In this section, an attempt is made to study leading edge control surfaces. Usable data for such devices is very scarce. Several references have been investigated; however, only reference 18 proved in any way useful. The leading edge device described in this reference is a wing droop of $6^\circ$. The droop was applied to the first 19% of the wing chord along its entire span (see fig. 25). The idealization shown in this figure is for the Doublet Lattice Method (DLM). The fuselage was simplified as simply a wing extension to the centerline.

A steady case at $M = 0.80$ is considered and the uncorrected calculated results using the DLM for $\alpha = 4^\circ$, (no droop) agree very well with the experimental data (see fig. 25). Only a lateral shift in the center of pressure seems evident. Correction factors were developed for this case to correct this slight deviation in the theory. The constraints used are lift, pitching moment and bending moment coefficients. These coefficients were summed on strips outboard of the station $y/(b/2) = 0.11$ and are defined as:

\[
C_L = \frac{L}{qA}, \quad \frac{A}{c^2_{\text{root}}} = 1.28
\]

\[
C_M = \frac{M}{qA C}, \quad \frac{c}{c_{\text{root}}} = 0.815 \text{ (moment taken about } x/c_{\text{root}} = 1.0)\]

\[
C_B = \frac{B}{qA b/2}, \quad \frac{b/2}{c_{\text{root}}} = 1.6 \text{ (moment taken about } x\text{-axis)}
\]

For the various modes the coefficients are:
A premultiplier and a postmultiplier (new type) were tried with equally good results on the span loading. Figure 26 illustrates the effect of the correction factors on the spanwise distribution of aerodynamic center. The correction factors increased the accuracy of the aerodynamic center inboard, but decreased it outboard.

The single mode application of both pre- and postmultipliers, also produces good results for leading edge droop span loadings (fig. 27). Notice that the unmodified results are approximately half of the experimental values. The experimental data were difficult to read on the plots (open squares). Thus, the pressure distributions were integrated to produce the darkened squares. The pressure distributions themselves were difficult to integrate accurately since there were down loads at the nose and uploads near the bend in the chord, such that the total loads were small. If the correction factors possessed only a slight variation in the chordwise direction, the balance of integrated load could shift drastically as a percent of the total.

The flow field near the wing changes at approximately $\alpha = 8^0$. Here the flow is to a large extent separated from the upper outboard surface. A comparison of uncorrected theory and experimental data, for the case of $\alpha = 10^0$, no wing droop, in figure 28, shows a loss of lift outboard of the 40% semi-span. Application of both pre- and postmultipliers (New), using $C_L$, $C_M$ and $C_B$ (bending moment at the centerline), show a much improved prediction of span loading. Also, shown in this figure is the application of the premultiplier correction factors, obtained at $\alpha = 4^0$ to the $\alpha = 10^0$ case (diamond symbols). The span loads are improved which shows that data obtained at one angle of attack can be profitably applied to other angles of attack. The corrections generated at $\alpha = 4^0$ are not as large as those generated at

<table>
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<tr>
<th>Pitch $\alpha$ = 4°</th>
<th>$\alpha$ = 10°</th>
<th>6° Droop</th>
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<tbody>
<tr>
<td>$C_L$</td>
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<td>.5356</td>
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<tr>
<td>$C_M$</td>
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<td>-.065</td>
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<tr>
<td>$C_B$</td>
<td>.0563</td>
<td>0.128</td>
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</tbody>
</table>
α = 10° because flow separation exist in the latter case. However, both corrections are in the same direction. Therefore, application of correction factors for α = 4° improves the results for the 10° case. In general, the reverse may not hold; i.e., the correction factors obtained at α = 10° (or larger angles) may be too large and an excessive correction may result leaving the corrected data further from the experimental data than there were originally. It does seem safe, however, to apply correction factors obtained at one angle of attack to other nearby angles if the flow is qualitatively similar (e.g., no great changes in flow pattern).
Transonic Cases

In this section applications of the correction factor technique are made to the same cases considered in the "Local Mach Number Studies" section. Specifically a two-dimensional symmetric airfoil (NACA 65A006) with an oscillating 25% chord flap is used.

Figure 29 illustrates the difference in results obtained when the classic theory (subsonic compressible) and the new transonic theory (Present Method \((M_\infty)\)) are corrected. A premultiplying set of correction factors were obtained using three constraints; lift, moment \((1/4\) chord) and control surface hinge-moment \((3/4\) chord). Each theory was corrected to the proper experimental constraints, i.e.,

\[
\begin{align*}
  c_a &= 4.93 \\
  m_{1/4} &= -1.57 \\
  h_{3/4} &= -0.053
\end{align*}
\]

\(M_\infty = 0.875\)

\(k_r = 0.0\)

where the characteristic length is the chord and the downwash over the control surface is unity. The classic theory does not have the bulge in pressure, near the compression (or shock) region for the steady flow as does the experimental data and applying correction factors will not make it appear. Thus correction factors can not make a qualitative feature appear where none existed before. The corrected classic theory does not compare well with the experimental data and the correction factors themselves, \((1 + \epsilon)\), show fairly large deviations from unity especially near the leading and trailing edges.

The Present Method \((M_\infty)\) however possesses a qualitative similarity with the experimental data and thus it is a better candidate for correction. Figure 29 shows such a correction. The bulge in pressure as calculated by the present method is amplified as it should be. The loading on the flap however is reduced, again as it should be, however the shape of the flap load is distorted. The correction factors themselves are better behaved for the
Present Method, \((M_\infty)\), showing large deviations from unity only on the flap surface.

Figure 30 presents the results of applying the premultiplying correction factors, obtained for the steady case, to an unsteady case. That is, the correction factors shown at the bottom of figure 29 are applied to the oscillatory results of the Present Method \((M_\infty)\) and the classic theory \((k_r = \omega c/2U_\infty = 0.059)\). Since the correction factors are real they do not effect the phase angles of the pressures but only the amplitudes, \(|\Delta C_p|\). Also shown in the figure is a pressure distribution corrected using factors based on the complex lift moment \((1/4\, \text{chord})\) and hinge moment obtained for the unsteady case. Specifically

\[
\begin{align*}
  c_\ell &= 3.5 - i \,1.18 \quad \text{and} \quad M_\infty = 0.875 \\
  c_{ml/4} &= -1.66 + i \,0.07 \quad \text{and} \quad k_r = 0.059 \\
  c_{h3/4} &= -0.057 - i \,0.016
\end{align*}
\]

The correction factors obtained in this manner produce pressures that are close to those obtained using the steady correction factors (except near the flap) even though the constraints in lift are considerably different in the two cases. There is one slight anomaly in the phase angle for the complex constraint case \((k_r = 0.059)\) and it exists on the last two pressure points on the flap. The phase angle there is quite large however these angles do not have a large effect since the amplitude of pressures is very small there.

The question arises; to what extent can static correction factors be applied with accuracy to the oscillatory case? Figures 31 and 32 illustrate the effect of static correction factors on lift, moment and hinge moment coefficient versus reduced frequency for a Mach Number of 0.85. Considering first the lift coefficient it is noticed that the accuracy of the imaginary part is increased up to \(k_r = 0.2\). Beyond this point application of correction factors decreases the accuracy of the theory. For the real part of the lift the corrected theory is more accurate only below a reduced frequency of 0.06. For the pitching moment and hinge moment the cross over point is roughly
$k_r = 0.1$. On the average then the static correction factors are useful up to about a reduced frequency of 0.1. Beyond this point it is better to use the original theory.

It is probably true that the accuracy of extrapolating correction factors versus reduced frequency depends on Mach Number. Figure 33 gives an indication that as Mach Number is reduced the accuracy increases. Specifically, static correction factors have been applied to the oscillatory case ($k_r = 0.098$) with very good results. Both amplitude and phase angle are improved.

The theory used in figures 31, 32 and 33 is a variation of the new transonic method presented previously. Specifically the variation utilizes an average local Mach Number ($\bar{M}_a$) in place of the free stream Mach Number, $M_{\infty}$. Figures 31 and 32 show the application of two separate types of correction factors; a premultiplier type, the type used in figures 29 and 30, and a postmultiplier type. The postmultiplier is actually an additive viscous type of correction. It can be seen that this correction does not extrapolate to higher frequencies as well as the premultiplier type (as far as the lift coefficient is concerned). As the frequency is increased the experimental data approach the unmodified theory. One interpretation of this fact is that as the frequency is increased viscous effects are reduced.

The postmultiplying correction factor (designated as "New Post") used in figures 31 and 32 is the new postmultiplying correction factor discussed in the Theoretical Development section. The reason a new type of postmultiplier was needed is because the original one seemed to fail when control surfaces are considered. Postmultipliers correct the downwash matrix. When all downwash values are non zero, e.g., wing pitch, the method seems to work. However, when this is not the case, e.g., control surface deflections, the method fails entirely. The corrected downwash values are either large and erratic themselves or they cause large and erratic pressures due to the modified downwash.

It was hoped that the introduction of correction factor mode shapes would smooth out the corrected downwash and produce accurate results. This did not
happen. Even though smooth, well behaved functions were used the results were unrealistic. Although not tried, it seems that limiting the maximum and minimum values of the correction factors probably would not help very much either.

This failure of the postmultiplying correction factors led to an interesting investigation and subsequent development of the "New Postmultiplier". The investigation consisted in finding out what downwash in the theory would produce the experimental pressure distribution. Specifically the theoretical influence coefficient matrix was multiplied by the vector of experimental pressures to produce a vector of downwash values.

Figure 34 shows the results of this type of analysis (designated as Experimental) for a steady subsonic case \( M_\infty = 0.5 \). Also shown is the theoretical downwash, i.e., unity over the flap. One thing is noticed immediately, there is a change in downwash ahead of the flap even though it is theoretically zero there. This downwash change is like a negative pitch of the entire airfoil. Figure 35 shows the camber (designated \( M_\infty = 0.5 \)) associated with the downwash given in figure 34 and indeed it is like a negative or nose down pitch. This fact suggests that an additive type of correction factor, whereby all downwash values are changed, is necessary. This resulted in the development of the "New Postmultiplier" as described in the Theoretical Development section. This name is somewhat of a misnomer since the correction factor is additive and not multiplicative although the correction factors are proportional to the theoretical pressures.

The results of applying the new postmultiplying correction factors are also shown in figure 34. Again lift, moment \((c/4)\) and hinge moment \((c3/4)\) coefficient were used as the constraints

\[
\begin{align*}
  c_l & = 3.2 \\
  c_{m1/4} & = -.70 \\
  c_{h3/4} & = -.0528
\end{align*}
\]

The corrected values of downwash (circular symbols) agree well with the experimentally deduced downwash. The disagreements at the leading edge of the air-
foil and ahead of the flap are due to the fact that downwash is a sensitive function of pressure and slight variations cause large variations in downwash. With this in mind the agreement is very good especially over the flap itself.

Applying this corrected downwash to the theory produces the results given in figure 36 for the pressure distribution. The results of the New Postmultiplier agree very well with the experimental pressures. For reference, corrections by a premultiplier are also shown and these are also very good. The uncorrected theory is also presented for reference.

At the low Mach Numbers used in the last few figures ($M_\infty = 0.5$) transonic effects are not present and any differences between theory and experiment are, in all probability, due to viscous effects. Figure 35 has shown that viscous effects modify not only the downwash over the flap but also over the forward part of the airfoil as well. This comes about due to the fact that the deflected flap causes an induced upwash over the forward portion of the airfoil which in turn generates a difference in boundary layer displacement thickness on the upper and lower surfaces. This difference in displacement thicknesses causes an effective nose down pitch.

It stands to reason that the correction factors generated at $M_\infty = 0.5$ could be used to increase the accuracy of the theory at all Mach Numbers since viscous effects are present at all Mach Numbers. Figure 35 shows the effective cambers at $M_\infty = 0.5$ and $M_\infty = 0.875$ using the ($M_\infty$) variation of the new transonic theory. Notice that the transonic camber can be thought of as composed of two pieces; one viscous piece very similar to that found at $M_\infty = 0.5$ and one transonic piece with the shape of a bump. This indicates that the accuracy of the corrected camber (or downwash) at transonic Mach Numbers can be increased if the subsonic ($M_\infty = 0.5$) results are known and used since it represents one part of the correction.

Figures 37, 38, 39 and 40 give examples of applying correction factors obtained at $M_\infty = 0.5$ to other Mach Numbers for both pressures and aerodynamic coefficients. Specifically figures 37 and 38 present the results for Mach Numbers of 0.85 and 0.875 respectively. Up to three separate corrected
pressure distributions are shown in each figure. One is the result of applying a premultiplying correction factor matrix to the \((M_\infty)\) variation of the new transonic method. A second is the result of applying a new postmultiplier to the same theory; and third is the result of applying a new postmultiplier to the \((\tilde{M}_\infty)\) variation of the new transonic method. The last pressure distribution is seen to be the most accurate and a definite improvement over the unmodified \((M_\infty)\) theory (see fig. 4).

Figures 39 and 40 give a clear picture of the effect of applying corrections obtained at \(M_\infty = 0.5\) to other Mach Numbers. Figure 39 presents the lift coefficients associated with corrected and uncorrected pressure distributions. Two types of corrections are used; both pre- and postmultiplier (New). The theory used is the \((M_\infty)\) variation of the new transonic method. Figure 40 presents similar results for the pitching moment and hinge moment coefficients. The corrections developed at \(M_\infty = 0.5\) greatly improve the theory as far as the lift coefficient is concerned. The pitching moment is not changed much because it was very close to the data to begin with. The hinge moment also is not changed much.

Figures 39 and 40 show that corrections obtained at low Mach Numbers can be applied to the theories to improve accuracy at higher Mach Numbers.

Figure 41 presents the results of correcting the theory with both a postmultiplier (New) and a premultiplier. First the theory is corrected using a new postmultiplier obtained at \(M_\infty = 0.5\). This represents a viscous type of correction. A premultiplier is then applied to the previously corrected results to account for transonic effects. This process produces a pressure distribution that approaches the data more closely than any of the others when it is combined with the \((\tilde{M}_\infty)\) variation of the new transonic method.

Figure 42 presents typical correction factors for the steady two-dimensional cases considered in this section. The theory used is the Present Method \((M_\infty)\). There is a greater change in premultiplying correction factors between \(M_\infty = 0.85\) and 0.875 than there is between \(M_\infty = 0.5\) and 0.85.
Supersonic Case

The arrow wing, shown in figure 43, has been chosen to illustrate the application of the correction factor technique to the supersonic case. The Douglas Supersonic Doublet Method (SDM) (ref. 20) has been used to determine the theoretical loads. The box idealization used is also shown in the figure. Notice that the tip of the wing has been clipped to reduce the number of boxes. Two modes are considered; (1) pitch ($\alpha = 4^\circ$) and (2) camber. The wing is operating at a Mach Number of 2.05 and a reduced frequency of zero.

Figure 43 presents a comparison of uncorrected theory (dotted line), corrected theory and experimental data. The experimental values lie below the theoretical (uncorrected) values over the entire span.

Four different methods of correcting the theory were tried. A pre- and postmultiplier (New) were applied using the pitch mode only and the results are very encouraging. The only real difference between the theory, corrected in this manner, and the experimental data appears at the wing tip. A multiple mode case was tried using the pitch and camber modes and the results are good but not as good as the previous two corrections. The fourth method is the application, to the pitch case, of a premultiplier correction factor matrix that was derived for the camber case. Thus a correction factor derived for one mode (camber) is applied to another mode (pitch). The results are not very accurate on the inboard part of the wing but agree as well as the other methods on the outboard part. The constraints used are summarized as follows:

\[
\begin{align*}
\text{Pitch } \alpha &= 4^\circ \\
C_L &= 0.1213 \\
C_M &= -0.035 \\
C_B &= 0.025 \\
\frac{C_L}{qA} &= \frac{C_m}{qA_c} = 0.02196 \\
\frac{A}{c_{\text{root}}} &= 0.28 \\
\frac{\bar{c}}{c_{\text{root}}} &= 0.665 \\
\text{Moment about } x/c_{\text{root}} &= 0.68
\end{align*}
\]
\[
C_B = \frac{B}{qAb/2} \quad (b/2)/c_{\text{root}} = 0.564 \\
B = \text{Moment about x-axis}
\]

A similar set of corrections were applied to the camber case and the results are shown in figure 44. Specifically pre- and postmultiplying correction factors were obtained using the camber mode. In addition a multiple mode (pitch, camber) premultiplying correction factor matrix was derived using six constraints; i.e., \(C_L, C_M, C_B\) for both modes. All three of these corrections give approximately the same good results except right at the wing tip.

Two other types of correction factors are applied to the theory and these refer to applying the correction factors derived for pitch to the camber mode. On the inboard portion of the wing these correction factors over-correct the theory, but are accurate on the outboard portion of the wing. On the inboard portions of the wing the correction factors move the corrected theory further from the data than it was originally in its uncorrected state.

Figure 45 illustrates how correction factors modify the pressure distribution over the wing (in pitch) using a premultiplier. It seems that the reduction in lift due to the correction factors is taken out at the trailing edge rather than the leading edge as the experimental pressures would indicate. This fact might be explained if the experimental pitching moment were inaccurate.

The postmultiplier does not directly modify the pressures but modifies the downwash. Modified downwash can be expressed in terms of modified camber. It is of interest to know how the postmultiplier (New) modifies the wing camber and figure 46 presents such a modification. The camber is reduced, by the correction factors, over most of the wing just as expected, since the boundary layer and separation regions act to reduce the effective wing camber. The postmultiplier, then, acts in a way that is consistent with physical processes.
RECOMMENDATIONS FOR DATA ACQUISITION

Most of the data utilized in this study were pressure data, and the correction factors were derived using constraints that were obtained in some instances from integrations of the pressures. Certain errors are associated with integrations of pressures to obtain generalized forces, arising primarily from the limited number of pressure pickup points on a practical model. The forces and moments should be measured directly in addition to the pressures. Control surface hinge moments should be measured and so should rolling moments, i.e., root bending moments, because of the importance of the spanwise aerodynamic center location. For swept surfaces it would be desirable to measure not only pitching and rolling moments in the streamwise coordinate system but also root bending moment and torque about some swept coordinate system, e.g., the 25% or 50% chord lines.

Two significant deficiencies were observed in available experimental data besides the absence of combined pressure and force data. One was a lack of any systematic variation in reduced frequency in covering the range from steady flow to high frequency, i.e., $k_f$ of order unity. The correction factors are frequency dependent, and it is not reliable to use factors derived from low frequency data to predict pressure distributions at high frequencies. The second deficient area is the effect of Reynolds number. An important source of discrepancy between theory and test is the neglect of viscosity in the theory. When extensions of oscillatory lifting surface theory are made to account for viscous effects, data will be needed to verify the accuracy of the improved theory. However, these data are also needed to determine the accuracy with which correction factors derived from data at one Reynolds number can be used to predict pressures at another Reynolds number. This is particularly important for trailing edge control surfaces.

A number of suggestions can be made for future wind tunnel tests in addition to those indicated above. Leading edge control surfaces should be tested; spoilers might also be considered. Very little data are available for these configurations. Models should be designed so that components can be
tested in their principal modes of motion. Complete models usually have moveable control surfaces but a moveable fin, horizontal tail, and engine pylon should also be considered to distinguish between component loads and interference loads. More oscillatory transonic data are needed. In two-dimensions, pitch data should be measured in addition to control surface data; in three-dimensions, data on both straight and swept wings are required.
CONCLUDING REMARKS

CONCLUSIONS

The basic conclusions arrived at as a result of the calculations and correlations presented are outlined as follows:

1. **One Set of Correction Factors Is Not Good For All Modes**

   Application of correction factors, determined from one mode, to other modes has not met with much success. Specifically, correction factors obtained using a pitch mode can not be applied to pressures due to control surface deflections. The converse is also true. In addition, application of correction factors, obtained using a pitch mode, to pressures due to a camber mode (and vice versa) have not proved to be very accurate either. Bergh and Zwaan, reference 6, on the other hand have concluded that correction factors calculated using a pitch mode can be applied to a roll mode. These two modes, however, are similar. One of them has a constant angle-of-attack along the span while the other has a linearly varying angle-of-attack along the span.

   Further study is required to find out what types of correction factors are required for the various modes encountered in flutter and other dynamic aeroelastic analyses. The practical method of implementing such a correction procedure also requires further study.

   The fact that one set of correction factors can not be applied to all modes has certain implications for testing procedures. It may be that more rigid body types of modes will be required (e.g., pylon yaw, wing alone pitch, tail alone pitch, outer wing pitch, inner wing pitch, fuselage alone pitch, etc.) than are now considered.

   A second approach to the problem of obtaining one set of correction factors for both a pitch and a control surface mode was attempted using the "multiple mode" capability of the program. This capability allows the theory to be constrained to produce the correct lift and moment coefficient, etc., for each of several modes. The resulting span loading and/or pressures were not improved for either the pitch or control surface modes.
Even within a single mode problems can occur for different amplitudes. For instance high angle-of-attack flow fields can be basically different (separated) from those at low angles-of-attack. However correction factors obtained at low angles-of-attack can result in improved predictions for all angles-of-attack. The basic reason being that the viscous corrections, although smaller for the unseparated case, are still in the same direction as that for the separated case.

(2) A Bending Moment Constraint Is Needed For Swept Wings

Lift and pitching moment constraints are not enough for the swept wing case. A bending moment constraint is also required so that the loading is not shifted outboard to accommodate an aft shift in aerodynamic center of pressure. Without the constraint on the bending moment the correction factors will cause the wing loading to be moved toward the wing tip instead of moving the load aft along the chordline.

(3) Correction Factors Can Be Extrapolated More Accurately To Other Mach Numbers Than To Other Frequencies

When correction factors are determined at low Mach Numbers they are caused primarily by viscous effects. Since viscous effects exist at all Mach Numbers an increase in accuracy will result if the low Mach Number correction factors are applied to the high Mach Number cases.

Extrapolation in frequency has not been as successful as extrapolation in Mach Number. For the two dimensional case studied it seems that extrapolation further than \( \Delta k_r = 0.1 \) (based on the half chord and a Mach Number of 0.85) will lead to a decrease in accuracy as \( k_r \) is increased. It is believed that extrapolation in reduced frequency is more accurate at lower Mach Numbers.

It appears that as the frequency is increased the viscous effects are reduced. This is an important fact and if steady wind tunnel results are to be used for correcting data then a good estimate of the reduction in the viscous effect must be known. One way to accomplish this without testing every configuration is to test a representative sample of configurations over
a range of frequencies and construct general trends to be used in conjunction with steady data to estimate the frequency effect on correction factors.

(4) **Qualitative Features Missing From The Theory Can Not Be Generated By Correction Factors**

Correction factors tend to produce quantitative changes to the theory and not qualitative ones. For instance, in transonic flow, the bulge in pressure at the shock location cannot be induced with correction factors if one did not exist in the basic theory.

(5) **Downwash Correction Factors Must Be Additive, Not Multiplicative**

It was found that postmultiplying correction factors did not work for control surface modes (they did work for pitch modes however). That is, scaling the downwash to reproduce the imposed experimental constraints ($C_L$, $C_M$, etc.) led to unusable results. Smoothing of the results was obtained by introducing correction factor modes; however, the levels of correction were still unrealistic. An analysis was performed to see what downwash was required to produce the experimental pressures and it became evident that the downwash had to be corrected everywhere and not just on the control surface. This suggested an additive downwash correction. A new method was developed and executed successfully.

Downwash correction factors essentially reflect the physical fact that viscous effects tend to change the effective airfoil camber (and thus the downwash). The camber is changed over the entire airfoil.

(6) **Premultiplying And (New) Postmultiplying Correction Factors Are Equally Accurate**

In the cases studied the accuracy of the corrected theory is improved equally well (approximately) by either type of correction factor matrix. The downwash correcting factors (New Postmultipliers) are physically more meaningful if interpreted as viscous corrections while premultipliers are more meaningfully interpreted as compressbility corrections.
Since transonic experimental data reflect both viscous and compressibility effects a very accurate way to obtain correction factors, if data permit, is to combine pre- and postmultipliers together. First a postmultiplier (New) is developed at low Mach Number where viscous effects dominate. This correction is then applied to the transonic case. The modified theory is then corrected further for transonic effects using a premultiplier. Correction factors produced in this way are more accurate than most.

(7) **New Transonic Method Useful But Requires Further Investigation**

Various methods of applying local Mach Number were tried. Simple procedures based on the substitution of the local steady Mach Number (or some average between surface and free stream) for the freestream value in the boundary conditions, kernel, and pressure equations have been tried. The results have only shown minor changes and have not even given qualitatively good results.

A new method was developed at Douglas (under the McDonnell Douglas IRAD program) and is based on a transformation of the distance between sending and receiving points based on acoustic travel time between the two points. This method was implemented for the two-dimensional case and correlated in the present study. The results are encouraging since the predicted pressures are qualitatively similar to the experimental data. That is, the new method predicts a bump in the pressure which is centered at the shock wave location and predicts a lowering of the pressure forward of the shock wave. This bump, however, is forward of the experimentally observed bump, and is usually smaller in amplitude.

The theoretically determined phase angles of the pressures are not in good agreement with the experimental data forward of the 40 percent point (for the case of a control surface rotation). One possible reason for this is the fact that the wave fronts emanating from points on the flap tend to move up and over the shock wave and arrive at the forward portions of the airfoil in nearly a horizontal configuration. On the other hand, in the theory, the paths of the wave fronts are assumed to be normal to the free stream flow with the wave fronts vertical, and this difference causes the phase angles to be greater for the theory than for the data. Further investigation of this
discrepancy and its solution is required. It may be possible to use a more exact phase lag time computation in the theory, such as the one used by Tijdeman and Bergh in reference 11.

When trying to decide which theory is best it is important to account for viscous effects. Without such a correction the new transonic method, designated as \((M_\infty)\), seems best. However, when viscous effects are accounted for, the variation designated \((M_\infty)\) is best.

With the current method of computation the new transonic method is probably not reliable past \(M_\infty = 0.90\). This may not be too restrictive since most wings are swept which reduces the normal Mach Numbers to values lower than 0.90.

(8) Overview of Conclusions

The concept of correcting theoretical pressure or load distributions so that they reflect associated experimental data works well with the correction factor technique, especially if the proper experimental data are available (e.g. bending moments.) It was hoped however that a set of correction factors, once developed, would be applicable to a wide variety of other cases. The range of applicability however has not been as wide as hoped for. Success in extrapolating correction factors was obtained for Mach Number and to a limited extent for frequency. Attempts to apply correction factors to dissimilar mode shapes however has not met with much success. Therefore more than one set of correction factors is required. The use of several sets of correction factors to correct oscillatory aerodynamic generalized forces for use in dynamic aeroelastic analyses requires further investigation.

Also concluded from the present analysis is that correction factors can not change the character of the load distribution. If a fundamental feature is missing from the theoretical loading then the correction factors will not make it appear. Thus theoretical methods must possess at least qualitative accuracy.
Recommendations for Further Studies

Further studies may be profitably pursued in several areas. The successes and failures of the correction factor technique, presented here, furnish a guide to such studies.

First, it seems advisable to exercise more of the various options in the present method and include more types of force data (integrated from pressure data) for some of the cases treated in this report. For instance such a case would be the Hertrich wing (refs. 14, 15). It would also be desirable to obtain new data similar to that obtained by Hertrich, in which both force and pressure data are available. It would be interesting to compare force data with integrated pressure data.

Second, it is now clear that one set of correction factors is not sufficient for all deflection modes. Thus a method for including multiple sets of correction factors into the determination of generalized oscillatory aerodynamic forces for various modes is required. This method may require special testing procedures whereby each major component or subcomponent is systematically given a rigid body rotation.

Third, the studies on viscous effects initiated in this report should be continued. Specifically the technique of determining theoretical camber lines that reproduce experimental pressure distributions seems valuable and could lead to a semiempirical method for viscous effects when combined with boundary layer theory.

Fourth, the new transonic method illustrated in this report should be refined and extended. Initially the two-dimensional capability should be refined in the areas of: 1) pressure phase angle and, 2) unsteady shock wave motion. Subsequent to this a three-dimensional method should be developed.

In addition, an investigation should be undertaken to explore the possibility of developing a semiempirical transonic method. The local steady Mach Number can be used as an adjustable parameter so as to produce the pressure distribution changes necessary to satisfy experimental constraints (lift moment etc.).
CORRECTION FACTOR COMPUTER PROGRAM

Introduction

As described in the Theoretical Development Section this method generates a set of correction factors that can be applied to a set of data (e.g., theoretical pressure) such that the data satisfies certain imposed (e.g., experimental) constraints.

For convenience this data will be referred to as pressure data since this is the most common application. However the correction factor procedure is not restricted to pressures and can be applied to other data sets (e.g., span loads, etc.).

For this procedure it is assumed that one or more theoretical pressure distributions, \( \Delta C_{p_j} \), \( (j = 1, \text{number of pressure modes}) \) are input. Associated with these pressures are: an area distribution, \( \Delta A \), a set of coordinates, \( (x, y, z) \), and a dihedral angle distribution \( \theta \) which are input via cards, tape or both. As an option the aerodynamic influence coefficient matrix, \([A] = [D]^{-1}\), along with one or more normalwash distributions, \( w_j \), can be input in place of \( \Delta C_{p_j} \); and as a matter of fact these must be input for postmultiplier correction matrices (i.e., correction factor matrices for the normalwash).

Constraint data (experimental data) are input as force or moment coefficients. If a force coefficient, \( C_e \), is considered it is defined as

\[
C_e = \frac{1}{\hat{c}} \sum_a \Delta A \Delta C_{p} \vec{n} \cdot \vec{i}_a \quad \text{(force coef.)} \tag{87}
\]

where \( \hat{c} \) is a constant used to convert the dimensional sum into a coefficient form. For example if \( C_e = C_L \) then \( \hat{c} \) is equal to the reference area. The limits of the sum are also input to the program. The unit vector \( \vec{i}_a \) is in the direction of an input axis. A set of axes are input for use in the constraining and monitoring features of the program. Each axis can be input in one of two
ways; (1) a point and a direction or (2) by two points. The unit vector \( \hat{t}_a \) is calculated as follows:

\[
\hat{t}_a = \cos \alpha \hat{i} + \cos \beta \hat{j} + \cos \gamma \hat{k}
\]  

(88)

The unit vector \( \hat{n} \) is in the direction of the lifting pressure which is given in terms of the dihedral angle of the lifting surface.

\[
\hat{n} = \sin \gamma \hat{j} + \cos \gamma \hat{k}
\]  

(89)

where \( \hat{j} \) and \( \hat{k} \) are unit vectors in the y and z directions respectively and where a right handed system is employed where \( z \) is up, \( y \) is out the starboard wing and \( x \) is aft.

If a moment coefficient, \( C_e \), is considered then it is defined as follows:

\[
C_e = \frac{1}{\tilde{c}} \sum_a b A C_p (r \times \hat{n}) \cdot \hat{t}_a \quad \text{(moment coef.)}
\]  

(90)

where

\[
r = (x - \xi^{(1)})i + (y - \eta^{(1)})j + (z - \zeta^{(1)})k
\]  

(91)

and where \( \xi^{(1)}, \eta^{(1)}, \zeta^{(1)} \) are the coordinates of the first end point of the axis considered and where \( \hat{t}_a \) is its direction. The constant \( \tilde{c} \) for the case of \( C_M \) has the dimensions of volume.

The program has various other capabilities and one of these is its ability to monitor the corrected or uncorrected pressures. The integrations performed in equations (87) and (90) can be performed using data without reference to constraints. Thus if span loads are desired for data that has been corrected (or uncorrected) then the proper summations are activated in the program in a manner similar to that for constraining the data.

The program also has the capability to use correction factor modes. That
is, the actual correction factors \( \{ \varepsilon \} \) are related to a set of modal coordinates \( \{ \tilde{\varepsilon} \} \) as follows:

\[
\{ \varepsilon \} = [\phi] \{ \tilde{\varepsilon} \}
\]

(92)

The modal matrix, \( \phi \), is either input directly by cards or certain built in modes can be activated.

The program has the capability to limit the excursion of any or all correction factors. The upper and lower bounds are simply input for the correction factors that are to be limited. If correction factor modes are used then the limits are placed on the modal coordinates, \( \tilde{\varepsilon} \), and not on the correction factors themselves.

In addition to limits, a factor \( \hat{a} \) is input for each constraint to indicate its "constraining power". The term \( \hat{a} \) ranges from 0 to 1.0. If \( \hat{a} \) is 1.0 the constraint has full power and is 100 percent effective as a constraint. If \( \hat{a} \) is 0 then the constraining power is zero and the "constraint" has no effect. For values of \( \hat{a} \) anywhere in between the constraint is said to be an estimate.

Finally, the program can be used to apply previously obtained correction factors to input pressure distributions. The program can also be used simply to monitor existing data without any constraints.

One nomenclature problem which might cause confusion is the fact that the normalwash \( w \) is called \( W \) in the program, while the correction factors \( W \) are called CF.
Program Input

The following table provides an overview of the card input data grouped according to their functions in the program. The layout of the input sheets and a detailed description of each input item are also given following the table.

Overview of Input Data

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>CARD NO.</th>
<th>WHEN NEEDED</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTROL DATA</td>
<td>1, 2, 3, 4</td>
<td>Always</td>
<td>Header card, control dimensions and control flags.</td>
</tr>
<tr>
<td>GEOMETRY AND PRESSURES</td>
<td>5, 6</td>
<td>If FLAGP=3</td>
<td>Geometry data is input on one card per i, i=1, NP (NP=number of pressures). Pressures are input either 6 real numbers per card (when FLAGI=1), or 3 complex numbers per card (when FLAGI=0). Repeat pressure input per pressure mode, symmetric modes first, antisymmetric modes (if any) last.</td>
</tr>
<tr>
<td>AXIS DATA</td>
<td>7, 8</td>
<td>Always</td>
<td>Axis data, 2 cards per i, i=1, NAXIS (NAXIS=number of input axes)</td>
</tr>
<tr>
<td>CONSTRAINT DATA</td>
<td>9, 10, 11, 12</td>
<td>If NC ≠ 0</td>
<td>Constraint data is input in a minimum of four cards per i, i=1, NC (NC=number of constraints)</td>
</tr>
<tr>
<td>MONITOR DATA</td>
<td>13, 14, 15, 16</td>
<td>If NMØN ≠ 0</td>
<td>Monitor data is input in a minimum of four cards per i, i=1, NMØN (NMØN= the number of monitored aerodynamic parameters)</td>
</tr>
<tr>
<td>LIMITS DATA</td>
<td>17</td>
<td>If NELIMS≠0</td>
<td>Minimum and maximum limit values on ε; repeat per i, i=1, NELIMS (NELIMS=number of min. and max. limiting value pairs)</td>
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67
<table>
<thead>
<tr>
<th>ITEMS</th>
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<th>COMMENTS</th>
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<td>CORRECTION FACTOR MODES</td>
<td>18, 19</td>
<td>If NEM ≠ 0</td>
<td>Correction factor modes may be input according to two options depending on the flag TYPE (see detail description of data) either in cards 18, 19 and 21, or in cards 18, 20 and 21. Repeat per i, i = 1, NEM (NEM=number of correction factor modes)</td>
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<td></td>
<td>20, 21</td>
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<tr>
<td>DOWNWASH DATA</td>
<td>22, 23</td>
<td>If FLAGW=1</td>
<td>Downwash data is input in a minimum of two cards per mode (see detail description of data). Input symmetric modes first, antisymmetric modes (if any) last.</td>
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Computer program requires less than 200K OCTAL storage.
### TABLE CONTENTS

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**Phone**: [Blank]

**Date**: [Blank]

**Punch in All Cards**

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<td>65-66-67-68</td>
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**SEQ. NO.**

| 77-78-79-80 |

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<th>FLAGW</th>
<th>ELAGT</th>
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<th>Y_i</th>
<th>Z_i</th>
<th>Y_j</th>
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<th>ZETA1</th>
<th>X12/cosα</th>
<th>ETA2/cosβ</th>
<th>ZETA2/cosγ</th>
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<th>CIT</th>
<th>Re CIE</th>
<th>Im CIE</th>
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- No underpunches in sign fields.
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<th>60</th>
<th>PROGRAM NO.</th>
<th>F</th>
<th>I</th>
<th>G</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIM1</td>
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<td>LIMN1</td>
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<td>ITYPE</td>
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</tr>
</tbody>
</table>

**DIRECTIONS FOR KEYPUNCH**

- DO NOT PUNCH BLANK COLUMNS
- NO UNDERPUNCHES IN SIGN FIELDS.
Description of Input Data

Control Data

These data items are required for all cases. They consist of a header, control numbers, flags, and tape (or scratch unit) numbers.

<table>
<thead>
<tr>
<th>CARD</th>
<th>ITEM</th>
<th>MNEMONIC</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Header</td>
<td>HEADER</td>
<td>Alpha-numeric description of case in card columns 1 through 60</td>
</tr>
<tr>
<td>2</td>
<td>NP</td>
<td>NP</td>
<td>Number of $\Delta C_p$ elements, where $\Delta C_p$ may represent any type of quantity ($NP \leq 350$)</td>
</tr>
<tr>
<td>2</td>
<td>NC</td>
<td>NC</td>
<td>Number of constraints to be applied to the $\Delta C_p$ values ($NC \leq 35$)</td>
</tr>
<tr>
<td>2</td>
<td>NEMODES</td>
<td>NEM</td>
<td>Number of correction factor modes if any ($NEM \leq 100$)</td>
</tr>
<tr>
<td>2</td>
<td>NELIMS</td>
<td>NELIMS</td>
<td>Number of input cards giving the minimum and maximum values of $\varepsilon$ ($NELIMS \leq 100$)</td>
</tr>
<tr>
<td>2</td>
<td>NMONITOR</td>
<td>NMON</td>
<td>Number of sets of monitoring data used to integrate $\Delta C_p$ into aerodynamic parameters ($NMON \leq 35$)</td>
</tr>
<tr>
<td>2</td>
<td>NAXIS</td>
<td>NAXIS</td>
<td>Number of axes input for use in integrating the $\Delta C_p$ data into forces and moments for constraint and monitoring purposes ($NAXIS \leq 25$)</td>
</tr>
</tbody>
</table>
| 3    | FLAGB | FLAGB, IFB | FLAGB=0, correction matrix calculation  
FLAGB=1, monitor data only  
FLAGB=2, apply input correction factor matrices to input pressure distribution |
| 3    | FLAGP | FLAGP, IFP | FLAGP=0, geometry data and $\Delta C_p$ are input from tapes; calculate premultiplying correction factors. (See Tape Description section for format)  
FLAGP=1, geometry data and $D^{-1}$ (inverse aero matrix) are input from tapes, $W$ (normalwash) input either from tape or on cards (see FLAGW below), calculate post-multiplying correction factors |
<table>
<thead>
<tr>
<th>CARD</th>
<th>ITEM</th>
<th>MNEMONIC</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FLAGT</td>
<td>FLAGP=2, input as for FLAGP=1; but calculate pre-multiplying correction factors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FLAGP=3, geometry data and $\Delta C_p$ input on cards; calculate pre-multiplying correction factors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FLAGP=4, geometry data and $D^{-1}$ input from tapes, W input either from tape or on cards; calculate modified post-multiplying correction factors</td>
</tr>
<tr>
<td>3</td>
<td>FLAGT</td>
<td>FLAGT</td>
<td>FLAGT=0, weights for minimization process are absolute values of forces for unit deflections</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FLAGT=1, weights are unity</td>
</tr>
<tr>
<td>3</td>
<td>FLAGW</td>
<td>FLAGW</td>
<td>FLAGW=0, normalwash matrix, $W^*$, is input from tape, if needed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FLAGW=1, normalwash matrix, W, is input on cards</td>
</tr>
<tr>
<td>3</td>
<td>FLAGI</td>
<td>FLAGI</td>
<td>FLAGI=0, $\Delta C_p$ values are input as complex numbers (either from tape or on cards)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FLAGI=1, $\Delta C_p$ values are input as real numbers (i.e. not complex)</td>
</tr>
<tr>
<td>3</td>
<td>IPRINT</td>
<td>IPRINT</td>
<td>Detail print flag; IPRINT = 1, print rows of the SAI matrix, and rows of the SAN matrix (if any)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IPRINT = 0, bypass printing of same</td>
</tr>
</tbody>
</table>

* Cap. W is normalwash in the computer program where correction factors are called CF.
<table>
<thead>
<tr>
<th>CARD</th>
<th>ITEM</th>
<th>MNEMONICS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>TS</td>
<td>NMSYM</td>
<td>Number of symmetric pressure modes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(NMSYM, NMASYM ≤ 10)</td>
</tr>
<tr>
<td>4</td>
<td>TA</td>
<td>NMASYM</td>
<td>Number of antisymmetric pressure modes</td>
</tr>
</tbody>
</table>

Note that all data items in cards 2 through 4 are input as integers, right-justified* in their respective fields of ten card columns each (format I10) as shown on the input sheets.

* Right justified means input ending in the last (or right-most) card column of the field.
**Geometry and Pressure Data**

Data items defining the geometry of a case are usually available on tape; similarly, pressure data (if needed; see item FLAGP under Control Data) are usually input from tape. However, if this is not the case, these data items may be input from cards by specifying FLAGP=3, as shown below.

<table>
<thead>
<tr>
<th>CARD</th>
<th>ITEM</th>
<th>MNEMONICS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>$x_i$</td>
<td>X</td>
<td>The following two cards are input only if FLAGP=3.</td>
</tr>
<tr>
<td>5</td>
<td>$y_i$</td>
<td>Y</td>
<td>$x, y, z$ coordinates of pressure point $i$.</td>
</tr>
<tr>
<td>5</td>
<td>$z_i$</td>
<td>Z</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$\gamma_i$</td>
<td>GMA</td>
<td>Dihedral angle of pressure point $i$.</td>
</tr>
<tr>
<td>5</td>
<td>$\Delta A_i$</td>
<td>DELA</td>
<td>Area of box over which the pressure acts. Repeat card 5 for all points, $i=1, NP$</td>
</tr>
<tr>
<td>6</td>
<td>$\Delta C_p$</td>
<td>DCP</td>
<td>Array of the $\Delta C_p$ values (lifting pressures) either 3 complex numbers per card (when FLAGI=0), or 6 real numbers per card (when FLAGI=1; see Control Data)</td>
</tr>
</tbody>
</table>

The format used for cards 5 and 6 is 6F10.0.
Axis Data

The following data items are required for all cases. These input data are used to describe an axis in space. Axes can be described by either two endpoints or by one endpoint and a set of direction cosines. These axes are used in the integration of the pressures into force or moment coefficients. Forces are resolved in the direction of the axis, while moments are taken about the axis.

<table>
<thead>
<tr>
<th>CARD</th>
<th>ITEM</th>
<th>MNEMONIC</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Axis number</td>
<td>IAX</td>
<td>Axis number</td>
</tr>
</tbody>
</table>
| 7    | Axis type   | IFA      | IFA=0, axis endpoints are input  
IFIA=1, a point and direction cosines are input |
| 8    | ξ1          | XI1      | Axis endpoint coordinates |
| 8    | η1          | ETA1     | Axis endpoint coordinates |
| 8    | ζ1          | ZETA1    | Axis endpoint coordinates |
| 8    | ξ2/cosα     | XI2      | Second axis endpoint coordinates if IFA=0;  
direction cosines if IFA=1 |
| 8    | η2/cosβ     | ETA2     | Second axis endpoint coordinates if IFA=0;  
direction cosines if IFA=1 |
| 8    | ξ2/cosγ     | ZETA2    | Second axis endpoint coordinates if IFA=0;  
direction cosines if IFA=1 |

Card 7 format is 6I10;  
card 8 format is 6F10.0
**Constraint Data**

The correction factors modify the theoretical values of $\Delta C_p$ by a minimum amount so that specified forces and moments are reproduced. For example, if the total lift is known experimentally, then several data items must be input specifying the actual value of the lift coefficient and describing the way the $\Delta C_p$ values are to be integrated to obtain this coefficient. The lift coefficient is then called a constraint on the theoretical data.

<table>
<thead>
<tr>
<th>CARD</th>
<th>ITEM</th>
<th>MNEMONIC</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Axis number</td>
<td>JAX</td>
<td>Number of the axis to be used for calculating the constraint force or moment</td>
</tr>
<tr>
<td></td>
<td>F-M Flag</td>
<td>IFF</td>
<td>IFF=0, the constraint, $C_e$, is a force in the direction of the axis; IFF=1, the constraint, $C_e$, is a moment about the axis (right-hand-rule).</td>
</tr>
<tr>
<td>10</td>
<td>$\delta$</td>
<td>NDI</td>
<td>$\delta=1$, symmetric pressure mode to be used; $\delta=-1$, antisymmetric pressure mode to be used</td>
</tr>
<tr>
<td>10</td>
<td>Press. mode</td>
<td>MI</td>
<td>Pressure mode number to be used with constraint $C_e$</td>
</tr>
<tr>
<td>10</td>
<td>$\hat{\alpha}$</td>
<td>AIT</td>
<td>Constraining effectiveness of $C_e$; $0 \leq \hat{\alpha} \leq 1$. If $\hat{\alpha} = 1$, $C_e$ is a constraint; if $\hat{\alpha} &lt; 1$, $C_e$ is only an estimate, and the resulting weighted (corrected) theory will only approximately reproduce $C_e$. If $\hat{\alpha}=0$, then $C_e$ will not affect data.</td>
</tr>
<tr>
<td>10</td>
<td>$\hat{C}$</td>
<td>CIT</td>
<td>Constant used to nondimensionalize integrated data. If $C_e$ is a force, $\hat{C} = \text{Area}$; if $C_e$ is a moment, $\hat{C} = \text{Area} \times \text{length}$.</td>
</tr>
<tr>
<td>CARD</td>
<td>ITEM</td>
<td>MNEMONIC</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>----------</td>
<td>-------------</td>
</tr>
<tr>
<td>10</td>
<td>$C_e$</td>
<td>CIE</td>
<td>Experimental (or any other) constraint on the data. Card format is 2I10, 4F10.0.</td>
</tr>
<tr>
<td>11</td>
<td>LIMI1, LIMI2</td>
<td>LIMI(1), LIMI(2)</td>
<td>Identification of a range of $\Delta C_p$ values (or boxes) from LIMI1 to LIMI2 defining the limits of integration for the pressures. There may be as many sets of ranges input as needed. Card format is 6I10.</td>
</tr>
<tr>
<td>12</td>
<td>-1</td>
<td>-1</td>
<td>The number -1; end indicator for the sets of data LIMI1, LIMI2</td>
</tr>
</tbody>
</table>

Cards 9 through 12 are repeated for all constraints, i.e. NC times.
Monitor Data

The following data are input only if the control data item NM0NITOR has a value different from zero. These data are used for the integration of the $\Delta C_p$ values into some meaningful parameters as a check on the effect of the correction factors on theory, whenever FLAGB = 0. Since often it is desirable to monitor the unmodified data as well, the setting FLAGB = 1 is designed to integrate the $\Delta C_p$ values into parameters without calculating the correction factors. Another monitoring option can be activated by the setting FLAGB = 2; in this case the correction factors are input from tape (FT16) saved in a previous run and the weighted $\Delta C_p$ values are integrated into parameters as specified by the monitor data.

<table>
<thead>
<tr>
<th>CARD</th>
<th>ITEM</th>
<th>MNEMONIC</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>Axis number</td>
<td>NAX</td>
<td>Axis number used in the integration of the $\Delta C_p$ values into forces and moments</td>
</tr>
<tr>
<td>13</td>
<td>F-M flag</td>
<td>IFN</td>
<td>IFN=0, parameter to be determined is a force</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IFN=1, parameter to be determined is a moment. Card format is 6I10.</td>
</tr>
<tr>
<td>14</td>
<td>$\delta$</td>
<td>NDN</td>
<td>$\delta$=1, symmetric pressure mode used</td>
</tr>
<tr>
<td></td>
<td>Press. mode</td>
<td>MN</td>
<td>$\delta$=-1, antisymmetric pressure mode used</td>
</tr>
<tr>
<td>14</td>
<td>$\hat{a}$</td>
<td>ANT</td>
<td>Pressure mode number</td>
</tr>
<tr>
<td>14</td>
<td>$\hat{c}$</td>
<td>CNT</td>
<td>Not used</td>
</tr>
<tr>
<td>14</td>
<td>LABEL</td>
<td>LABEL</td>
<td>Constant used to nondimensionalize integrated data</td>
</tr>
</tbody>
</table>

Alphameric identifier of the integrated parameter (ten characters long) Card format is 2I10, 2F10.0, 10A1
<table>
<thead>
<tr>
<th>CARD</th>
<th>ITEM</th>
<th>MNEMONIC</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>LIMN1,</td>
<td>LIMN(1)</td>
<td>Identification of a range of $\Delta C_p$ values defining the limits of integration for the pressures. There may be as many sets of ranges input as needed. Card format is 6I10.</td>
</tr>
<tr>
<td></td>
<td>LIMN2</td>
<td>LIMN(2)</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>-1</td>
<td>-1</td>
<td>The number -1; end indicator for the sets of data LIMN1, LIMN2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cards 13 through 16 are repeated for all parameters, i.e., NM\textsc{onitor} times
Limits Data

It is sometimes desirable to place a restriction on the range of values of $\varepsilon$ by specifying a minimum and a maximum bound on $\varepsilon$. In this case the control data item NELIMS is input as the number of $\varepsilon$ limit pairs to be supplied, which are input as shown below. Note that this input (card 17) is omitted when NELIMS = 0.

<table>
<thead>
<tr>
<th>CARD</th>
<th>ITEM</th>
<th>MNEMONIC</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>LIME1</td>
<td>LIMK(1)</td>
<td>A range of boxes, or $\Delta C_p$ elements, over which a limit is placed on $\varepsilon$</td>
</tr>
<tr>
<td></td>
<td>LIME2</td>
<td>LIMK(2)</td>
<td>The minimum value allowed for $\varepsilon$</td>
</tr>
<tr>
<td>17</td>
<td>EBMIN</td>
<td></td>
<td>The maximum value allowed for $\varepsilon$</td>
</tr>
<tr>
<td></td>
<td>EBMAX</td>
<td></td>
<td>Card format is 2I10, 4F10.0</td>
</tr>
</tbody>
</table>

Card 17 is repeated for all sets of ranges, i.e., NELIMS times.
Correction Factor Modes Data

In many instances it is desirable to restrict the incremental correction factors \( \{c\} \) to a linear combination of a set of modes, \( \{c\} = [\phi] \{\varepsilon_g\} \). The mode shapes \([\phi]\) can be input directly per box, and per mode, or the mode shapes may be selected from a set of functions. This set of data is input only if the control data item NEM is different from zero.

<table>
<thead>
<tr>
<th>CARD</th>
<th>ITEM</th>
<th>MNEMONIC</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>( \varepsilon ) MODE NUMBER</td>
<td>M\text{DEN0}</td>
<td>Weight factor mode number</td>
</tr>
<tr>
<td>18</td>
<td>TYPE</td>
<td>ITYPE</td>
<td>( \begin{aligned} \text{TYPE}=1, \text{use} \ (x-a)^n \ \text{TYPE}=2, \text{use} \ (y-a)^n \ \text{TYPE}=3, \text{use} \ (z-a)^n \ \text{TYPE}=4, \text{use} \ \exp[b(x-a)^n] \ \text{TYPE}=5, \text{use} \ \exp[b(y-a)^n] \ \text{TYPE}=6, \text{use} \ \exp[b(z-a)^n] \end{aligned} ) as mode equation</td>
</tr>
<tr>
<td>18</td>
<td>( n )</td>
<td>NL</td>
<td>Constants used in the mode equation</td>
</tr>
<tr>
<td>18</td>
<td>( a )</td>
<td>AL</td>
<td>Card format is 2I10, 4F10.0</td>
</tr>
<tr>
<td>18</td>
<td>( b )</td>
<td>BL</td>
<td></td>
</tr>
</tbody>
</table>

Card 19 is input only if TYPE = 0. Box (or element) number for which the \( \phi(J) \) applies

<table>
<thead>
<tr>
<th>CARD</th>
<th>ITEM</th>
<th>MNEMONIC</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>( J )</td>
<td>J</td>
<td>Card 19 is input only if TYPE = 0. Box (or element) number for which the ( \phi(J) ) applies</td>
</tr>
<tr>
<td>19</td>
<td>( \phi(J) )</td>
<td>PHI(J)</td>
<td>The modal value of the ( J )-th value of ( \varepsilon )</td>
</tr>
<tr>
<td>19</td>
<td>( J + 1 )</td>
<td>J + 1</td>
<td>Another set of ( \phi )-data</td>
</tr>
<tr>
<td>19</td>
<td>( \phi(J+1) )</td>
<td>PHI(J+1)</td>
<td>Card format is 2I10, 2F10.0. Repeat as needed, 2 sets of data per card. Note that only the non-zero elements need be input.</td>
</tr>
<tr>
<td>CARD</td>
<td>ITEM</td>
<td>MNEMONIC</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>----------</td>
<td>-------------</td>
</tr>
<tr>
<td>20</td>
<td>LIML1</td>
<td>LIML(1)</td>
<td>Omit card 20 if TYPE = 0.</td>
</tr>
<tr>
<td></td>
<td>LIML2</td>
<td>LIML(2)</td>
<td>Range of boxes or $\varepsilon$'s over which the current $\varepsilon$-mode applies. There may be as many sets of ranges input as needed. Card format is 6110.</td>
</tr>
<tr>
<td>21</td>
<td>-1</td>
<td>-1</td>
<td>The number -1; end indicator of data set for the current $\varepsilon$-mode (MODEN0)</td>
</tr>
</tbody>
</table>

Repeat cards 18 through 21 for all $\varepsilon$ modes, i.e., NEM times.
**Normalwash Data**

If the normalwash matrix \([W]\) is needed (see control data FLAGP), and it is not available on tape, the control flag FLAGW must be input as 1, and then the normalwash values are card input as shown below.

<table>
<thead>
<tr>
<th>CARD</th>
<th>ITEM</th>
<th>MNEMONIC</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>M(\text{DE})</td>
<td>M(\text{DE}(j))</td>
<td>Mode number for the current set of (W) values</td>
</tr>
<tr>
<td>22</td>
<td>(\delta)</td>
<td>IDELW</td>
<td>Symmetry flag to aid in identifying the mode; note that (\delta=1) type values are expected to precede the (\delta=-1) type values</td>
</tr>
<tr>
<td>22</td>
<td>LIMW1</td>
<td>LIMW(1)</td>
<td>A range of boxes over which the (W) value applies</td>
</tr>
<tr>
<td>22</td>
<td>LIMW2</td>
<td>LIMW(2)</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>(W)</td>
<td>WIN</td>
<td>Normalwash, (W), for the above range of boxes. Card format is 4I10, 2F10.0.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Repeat card 22 as needed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Note that only the non zero (W) values need be input.</td>
</tr>
<tr>
<td>23</td>
<td>-1</td>
<td>-1</td>
<td>The number -1; end indicator for the normalwash input data</td>
</tr>
</tbody>
</table>
Tape Description

Program ELGC uses a minimum of four, and a maximum of twelve tapes and/or utility (scratch) units depending on the type of the case considered. In addition NPIT = 5 and NPOT = 6 are used throughout the program as the system input/output units respectively. These, as well as all tapes and utility units are defined in subroutine WEYT by means of a DATA statement specification under their respective names. The following table gives a summary of tape names and their use; the formats of those tapes that may be specified as input/output units are described in subsequent tables.
### Summary of Tape Units

<table>
<thead>
<tr>
<th>NAME</th>
<th>UNIT</th>
<th>WHEN NEEDED</th>
<th>USER SUBROUTINES</th>
<th>DESCRIPTION OF CONTENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUTL1</td>
<td>1</td>
<td>Always</td>
<td>WEYT, WSWA, SDBL, EPSJ</td>
<td>Miscellaneous intermediate solutions</td>
</tr>
<tr>
<td>NUTL2</td>
<td>2</td>
<td>Always</td>
<td>WEYT, SDBL, DCPT, CEMN</td>
<td>SAI matrix rows</td>
</tr>
<tr>
<td>NTSAIJ</td>
<td>3</td>
<td>If NC≠0</td>
<td>WEYT, SAIJ, DELC, SDBL</td>
<td>SAN matrix rows</td>
</tr>
<tr>
<td>NTSANJ</td>
<td>4</td>
<td>If NM≠N≠0</td>
<td>WEYT, SAIJ, CEMN</td>
<td>S matrix columns</td>
</tr>
<tr>
<td>NTPHIJ</td>
<td>8</td>
<td>If NEM≠0</td>
<td>WEYT, PHIJ, SDBL, EPSJ</td>
<td>Geometry arrays; input tape</td>
</tr>
<tr>
<td>MASTSB</td>
<td>9</td>
<td>Always</td>
<td>WEYT, SDBL, GINV</td>
<td>The modified S matrix rows</td>
</tr>
<tr>
<td>NEWTSB</td>
<td>10</td>
<td>If NELIMS ≠ 0</td>
<td>WEYT, MØDF, GINV</td>
<td>W (normalwash) columns; input tape if NTAPW = 0, scratch unit otherwise</td>
</tr>
<tr>
<td>NTGEØM</td>
<td>11</td>
<td>If FLAGP≠3</td>
<td>WEYT</td>
<td>ΔC_p matrix columns; either input tape or scratch unit depending on FLAGP</td>
</tr>
<tr>
<td>NTDCP</td>
<td>12</td>
<td>Always</td>
<td>WEYT, DCPB</td>
<td>W (normalwash) columns; input tape if NTAPW = 0, scratch unit otherwise</td>
</tr>
<tr>
<td>NTAPW</td>
<td>13</td>
<td>If FLAGP ≠ 0, 3</td>
<td>WEYT, WSWA</td>
<td>Inverse downwash factor matrix [D]^{-1}</td>
</tr>
<tr>
<td>NTAPDI</td>
<td>14</td>
<td>If FLAGP ≠ 0, 3</td>
<td>WEYT, DCPB, SDBL, DCPT</td>
<td>Complex ΔC_p columns, when ΔC_p is input as a real matrix</td>
</tr>
<tr>
<td>NEWDCP</td>
<td>15</td>
<td>If FLAGI=1 and FLAGP = 0</td>
<td>WEYT, DCPB</td>
<td>CF, the correction factor matrix; NTAPCF is output tape (or scratch unit) for FLAGB = 0 cases; NTAPCF is an input tape for FLAGB = 2 cases</td>
</tr>
<tr>
<td>NTAPCF</td>
<td>16</td>
<td>If FLAGB≠1</td>
<td>WEYT, DCPT</td>
<td></td>
</tr>
</tbody>
</table>

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### Input Tape NTGEOM

<table>
<thead>
<tr>
<th>RECORD</th>
<th>WORD</th>
<th>ITEM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>LENGTH</td>
<td>Length of arrays in records 2 through 6 (LENGTH = NP)</td>
</tr>
<tr>
<td>2</td>
<td>1 - NP</td>
<td>X</td>
<td>x-coordinate array</td>
</tr>
<tr>
<td>3</td>
<td>1 - NP</td>
<td>Y</td>
<td>y-coordinate array</td>
</tr>
<tr>
<td>4</td>
<td>1 - NP</td>
<td>Z</td>
<td>z-coordinate array</td>
</tr>
<tr>
<td>5</td>
<td>1 - NP</td>
<td>GMA</td>
<td>Dihedral angle (( \gamma )) array</td>
</tr>
<tr>
<td>6</td>
<td>1 - NP</td>
<td>DELA</td>
<td>Array of box areas</td>
</tr>
</tbody>
</table>

### Input Tape (or Scratch Unit) NTDCP

<table>
<thead>
<tr>
<th>RECORD</th>
<th>WORD</th>
<th>ITEM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>NP</td>
<td>Row dimension of the ( \Delta C_p ) matrix (column length)</td>
</tr>
<tr>
<td>2</td>
<td>NSYM</td>
<td>( \Delta C_p ) columns for symmetric modes</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>NASYM</td>
<td>( \Delta C_p ) columns for antisymmetric modes</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1 - NP</td>
<td>DCP</td>
<td>( \Delta C_p ) column for first symmetric mode</td>
</tr>
<tr>
<td>2+NSYM +NASYM</td>
<td>1 - NP</td>
<td>DCP</td>
<td>( \Delta C_p ) column for last antisymmetric mode*</td>
</tr>
</tbody>
</table>

* Note that if NASYM = 0, the last \( \Delta C_p \) column refers to last symmetric mode.
### Input Tape (or Scratch Unit) NTAPW

<table>
<thead>
<tr>
<th>RECORD</th>
<th>WORD</th>
<th>ITEM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>NP</td>
<td>Row dimension of the W (normalwash) matrix</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>NSYM</td>
<td>Numbers of W columns for symmetric modes</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>NASYM</td>
<td>Number of W columns for antisymmetric modes</td>
</tr>
<tr>
<td>2</td>
<td>1 - NP</td>
<td>W</td>
<td>W column for first symmetric mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 + NSYM +NASDAQ</td>
<td>1 - NP</td>
<td>W</td>
<td>W column for last antisymmetric mode (if any)</td>
</tr>
</tbody>
</table>
## Input Tape NTAPDI

<table>
<thead>
<tr>
<th>RECORD</th>
<th>WORD</th>
<th>ITEM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>NP</td>
<td>Row dimension of matrix DI</td>
</tr>
<tr>
<td>2</td>
<td>NP</td>
<td></td>
<td>Column dimension of matrix DI</td>
</tr>
<tr>
<td>3</td>
<td>NCOL2</td>
<td></td>
<td>NCOL2 = NP if both symmetric and antisymmetric DI matrices are on tape; NCOL2 = 0 otherwise</td>
</tr>
<tr>
<td>2</td>
<td>1 - NP</td>
<td>DI</td>
<td>First row of DI, the inverse downwash factor matrix, ([D^{-1}]) for symmetry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 + NP</td>
<td>1 - NP</td>
<td>DI</td>
<td>Last DI-row for symmetry</td>
</tr>
<tr>
<td>2 + NP</td>
<td>1 - NP</td>
<td>DI</td>
<td>The following records may be omitted when antisymmetric modes are not desired. First DI-row for antisymmetry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 + 2NP</td>
<td>1 - NP</td>
<td>DI</td>
<td>Last DI-row for antisymmetry</td>
</tr>
</tbody>
</table>
## Input/Output Tape NTAPCF

<table>
<thead>
<tr>
<th>RECORD</th>
<th>WORD</th>
<th>ITEM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>CODE</td>
<td>Alphameric identifier of tape, 4 characters in length, left justified; CODE = PRE, for pre-multiplier cases, CODE = POST for post-multipier cases</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LENGTH</td>
<td>Length of array CF. LENGTH should be equal to NP.</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>LENGTH</td>
<td>Length of array CF. LENGTH should be equal to NP.</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>NMSYM</td>
<td>Number of symmetric modes for case</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>NMASYM</td>
<td>Number of antisymmetric modes for case</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Note that the last two items are not used when tape NTAPCF is an input tape</td>
</tr>
<tr>
<td>3</td>
<td>1 - NP</td>
<td>CF</td>
<td>Array of the complex correction factors</td>
</tr>
</tbody>
</table>
Test Cases. - The use of the program will be illustrated by two test cases. The first will be a premultiplier and will exercise most features of the program so that their use can be illustrated. The second test case will illustrate the use of the new postmultiplier, tape input, and downwash input on cards.

The theoretical pressures are taken from a two-dimensional analysis of an airfoil with a 25% chord flap. The new transonic procedure discussed previously will be used for the airfoil operating at a Mach Number of 0.875 and a reduced frequency of 0.0. Figure 47 illustrates the geometry, pressures and axes data for the airfoil for control surface rotation (Mode 1) and pitch (Mode 2). Also shown on the figure are the theoretical and experimental values of $c_x$, $c_{m1/4}$ and $c_{h1/4}$ for mode 1 and $c_x$ for mode 2. The experimental values are used as the constraints. An experimental value for $c_x$ for mode 2 is not available thus an estimate is given in its place in the figure.

Test Case I. - Table III presents the input cards for the first test case. The number of pressures, $NP$, is 19; the number of constraints, $NC$, is 4. For this case 19 correction factor modes, $\phi$, will be used, thus $NEM = 19$. In addition limits will be placed on the values of $\overline{\varepsilon}$. These limits will be described by one card thus $NELIMS = 1$. The number of axes, $NAXIS$, is 3. The program is able to monitor the corrected data, and in this test case the number of coefficients to be monitored, $NMON$, is 4 and they are $c_x$, $c_{m1/4}$ and $c_{h3/4}$ for mode 1 and $c_x$ for mode 2. Thus the monitored coefficients should reproduce the input constraints. This, in fact, is the case as the output shows in Table IV.

Since correction factors are to be calculated rather than data monitored only, $FLAGB = 0$. Also since the geometrical data and pressure data are to be card input and a premultiplier is to be calculated $FLAGP = 3$. The usual weight factor $T$, (the absolute value of the force on an element) is not used, thus $FLAGT = 1$. Normalwash values are not input thus $FLAGW = 0$. Only real values of pressure are used thus $FLAGI = 1$; the detail print flag is input as $IPRINT = 1$. In this example there are two modes (call them symmetric) thus
NMSYM = 2 and NMASYM = 0. This marks the end of the control data.

The geometry data are taken from figure 47 and are given on cards designated as type 5. The 1/4-chord point of each box is input along with its area, \( \Delta A = \Delta X \). The pressures at each 1/4-chord point of each box and for each mode are taken from figure 47 and are given on cards designated as type 6.

The axis data are encountered next. IAX identifies the axis number and IFA identifies how it is input (whether by two points or a point and a direction). In this case a point \((\xi(1), \eta(1), \zeta(1))\) and direction \((\cos \alpha, \cos \beta, \cos \gamma)\) are input thus IFA = 1. These points and directions are taken from figure 47 and are input on card designated as type 8.

The constraint data is next. Input are four constraints \(c_x\), \(c_{m1/4}\) and \(c_{h3/4}\) for mode 1 and \(c_x\) for mode 2 taken from the experimental values of these parameters given on figure 47. Each constraint has a 9 and 10 type card. JAX identifies the axis to be used with the constraint (axis 1 for \(c_x\), axis 2 for \(c_{m1/4}\) and axis 3 for \(c_{h3/4}\)). The flag IFA identifies the coefficient type to be calculated whether the force type (IFA = 0) or moment type (IFA = 1). The terms MI and NDI denote the mode to be used. In this case modes 1 and 2 are symmetric. The constraining power AIT is taken as 1.0 for the constraints of mode 1 to ensure a full constraint. However AIT for \(c_x\) of mode 2 is taken as .95 since this is an estimate. The nondimensionalizing constant CIT is the chord for the \(c_x\) constraint and the chord squared for \(c_{m1/4}\) and \(c_{h3/4}\). The limits of integration LIM1, LIM2 span the entire surface for \(c_x\) and \(c_{m1/4}\) (from box 1 to box 19) but only range over the control surface (box 13 to box 19) for \(c_{h3/4}\).

The monitor data found on card types 13, 14, 15, 16 are almost identical to that of the constraint data because in this case \(c_x\), \(c_{m1/4}\) and \(c_{h3/4}\) are the parameters to be monitored. Of course they could be any quantity or for that matter no quantities if monitoring is not desired. The only real difference between monitor data and constraint data is that an alpha-numeric identifier is input in place of the constraints for the monitor data.
As an example of the use of limiting values on $\varepsilon$, card type 17 is input for this test case. Specifically it is required that

$$-0.7 \leq \varepsilon \leq 1.5$$

hold for all values of $\varepsilon$, 1 through 19 (LIMK1 = 1, LIMK2 = 19).

As a simple example of the use of correction factor mode shapes, $\phi$, an identity matrix will be used;

$$[\phi] = [I] \quad (ITYPE = 0)$$

Card types 19 and 21 are used to input these modes.

The program output for this case is given in Table IV. The printed output, which fits on 8 1/2 x 11 sheets, contains most of the input. Integration matrices are then printed along with other intermediate steps in the process of solution. At the end of the printout a summary of the geometry data, incremental correction factors, $\varepsilon$, and modified pressures are printed. Next are the correction factors $\varepsilon + 1$ and finally the aerodynamic parameters, calculated using the modified pressures, that have been monitored by the program.

Test Case 2. - Table V presents the input sheets for the second test case. This test case is the same as the test case 1 with the following exceptions: (1) the geometry and $[D]^{-1}$ are input from tape; (2) a new postmultiplier is developed; (3) one mode is used with three constraints; (4) correction factor modes are not used and (5) limits on incremental correction factors, $\varepsilon$, are not imposed.

For this case changes from test case 1 occur in the control data (cards 1 through 4). First, no correction factor modes (NEM = 0) are to be used. Second, the card giving limits on $\varepsilon$ is omitted, thus NELIMS = 0. Third, $[D]^{-1}$ and the geometry are to be read in on tapes and the new postmultiplying
correction factor is desired, thus FLAGP = 4. In this case normalwash values are to be card read and so FLAGW = 1. Also only one mode is to be used (control surface rotation), thus NMSYM = 1. The geometry data remains the same as in test case 1.

Finally the normalwash is input on card type 22. The mode is a control surface rotation, thus \( W^* = 1.0 \) over boxes 13 through 19, i.e., \( \text{LIMW1} = 13 \), \( \text{LIMW2} = 19 \). The program output is given in Table VI.

* Remember \( W \) is downwash in this computer program
<table>
<thead>
<tr>
<th>TEST CASE</th>
<th>PRE-MULT.</th>
<th>CARD INPUT, M=0.375, K=0</th>
<th>CONTROL DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>-0.99358</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>-0.94291</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>-0.34502</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1.70657</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>-0.537</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>-0.5479</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>-0.132</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.03701</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.020657</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0459</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.49358</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.50627</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.55459</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.64193</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.75</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.8585</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.94459</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1.01</td>
<td>2.42</td>
<td>1.61</td>
<td>1.28</td>
</tr>
<tr>
<td>2.424</td>
<td>9.69</td>
<td>8.94</td>
<td>10.24</td>
</tr>
<tr>
<td>17.88</td>
<td>12.5</td>
<td>8.42</td>
<td>5.6</td>
</tr>
<tr>
<td>4.5014</td>
<td>71.7327</td>
<td>24.5187</td>
<td>15.4279</td>
</tr>
<tr>
<td>7.00346</td>
<td>6.31302</td>
<td>5.50703</td>
<td>4.08903</td>
</tr>
<tr>
<td>4.37345</td>
<td>1</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>0.0</td>
<td>2</td>
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TEST CASE NO. 1  PRE-MULT.,  CARD INPUT,  $M=0.875$, $K=0$

CONTROL FLAGS  ---

FLAGR = 0  CORRECTION FACTORS CALCULATED
FLAGT = 3  PREMULTIPLIER - PRESSURE AND GEOMETRY TAKEN FROM CARDS
FLAGW = 1  WEIGHTS = 1.0
FLAGW = 0  NORMALWASH TAKEN FROM TAPE (IF NEEDED)
PRINT = 1  (DETAIL PRINT FLAG)

CONTROL DIMENSIONS  ---

NP = 19  
NC = 4  
NEM = 19  
NELMS = 1  
NMON = 4  
NAXIS = 3

LIST OF INPUT/OUTPUT TAPES  ---

GEOMETRY TAPE = 11
DELTA-GP TAPE = 12
W TAPE = 13
D-INVERSE TAPE = 14
CORR. FACTORS = 16
### The 3 Sets of Input Data for All Axes

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The 4 sets of input data for all constraints

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7. \(0.209480E+00\) 0.0 8. \(0.876945E+00\) 0.0 9. \(0.692850E+00\) 0.0
10. \(0.609280E+00\) 0.0 11. \(0.474375E+00\) 0.0 12. \(0.217300E+00\) 0.0
13. \(0.221712E+00\) 0.0 14. 0.0 0.0 15. 0.0 0.0
16. \(0.310800E+00\) 0.0 17. \(0.170500E+00\) 0.0 18. \(0.621130E-01\) 0.0
19. \(0.696136E-02\) 0.0 20. 0.0 0.0 21. 0.0 0.0
22. 0.0 0.0 23. 0.0 0.0

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7. \(0.419129E-01\) 0.0 8. \(0.235464E+00\) 0.0 9. \(0.244773E+00\) 0.0
10. \(0.257424E+00\) 0.0 11. \(0.223646E+00\) 0.0 12. \(0.108101E+00\) 0.0
13. \(0.115511E+00\) 0.0 14. 0.0 0.0 15. 0.0 0.0
16. \(0.194235E+00\) 0.0 17. \(0.15812E+00\) 0.0 18. \(0.448922E-01\) 0.0
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10. 0.0 0.0 11. 0.0 0.0 12. 0.0 0.0
13. \(0.695065E-01\) 0.0 14. 0.0 0.0 15. 0.0 0.0
16. \(0.388901E-01\) 0.0 17. \(0.305621E-01\) 0.0 18. \(0.138357E-01\) 0.0
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22. 0.0 0.0 23. 0.0 0.0

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19. \(0.607283E-02\) 0.0 20. 0.0 0.0 21. 0.0 0.0
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TEST CASE NO. 2  NEW POST-MULT., TAPE INPUT, M=.875, K=0

CONTROL FLAGS

FLAGB = 0  CORRECTION FACTORS CALCULATED
FLAGP = 4  NEW POSTMULTIPLIER - DT INVERSE AND GEOMETRY TAKEN FROM TAPE
FLAGT = 1  WEIGHTS = 1.0
FLAGW = 1  NORMAL WASH TAKEN FROM CARDS (IF NEEDED)
IPRINT = 1 (DETAIL PRINT FLAG)

CONTROL DIMENSIONS

NP = 19
NC = 3
NEM = 0
NELIMS = 0
NHON = 3
NAXIS = 3

LIST OF INPUT/OUTPUT TAPE

GEOMETRY TAPE = 11
DELTA-CP TAPE = 12
W- TAPE = 13
D-INVERSE TAPE = 14
CORR. FACTORS = 16
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THE 3 SETS OF INPUT DATA FOR ALL CONSTRAINTS

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<th>LIM2</th>
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The 3 Sets of Input Data for Monitoring

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-W-- IS CARD INPUT

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The 1 columns of the delta-CP-RAP matrix.

**Column 1**

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FLAGP = 4  -- Tape contains the Epsilon-bar (er) values

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Subroutine Description

The computer program for generating correction factors (EIGC) consists of twenty subroutines. The MAIN of this program reads and writes the header card and reads the control dimensions for a case; the latter are used for dimensioning most of the complex arrays that are passed into Subroutine WEYT via the argument list. Subroutine WEYT is the actual working main of the program, which calls all the major subroutines, supplying these with the necessary information via their argument lists. The following is a detailed description of all subroutines of program EIGC including their flow charts, where applicable, given in alphabetical order. The computer program is written in the FORTRAN IV programming language.
SUBROUTINE CEMN(NPOT, IG0, MODE, NTAPSA, NP, NMON, LABEL, NUTL, SAI, DCPTIL, CE)

Functional Description

This subroutine integrates the corrected pressures, $\Delta C_{pe}$, into coefficients, $C_e$, which are used to monitor the results (See Eq. (3)). The integration procedure is identical to that required for obtaining the imposed constraints.

$$\{C_e\} = [S] \{\Delta C_{pe}\}$$

The coefficients $C_e$ are part of the printed output.
**Description of Argument List**

<table>
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<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPØT</td>
<td>Data set number of the system output data set</td>
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</table>
| IG0      | 1 for symmetric modes  
           | 2 for antisymmetric modes |
| MØDE     | Mode number |
| NTAFSA   | Data set (tape) number of tape containing the 
           | integration matrix [S] |
| NP       | Number of rows in the $\Delta C_p$ matrix |
| NMØN     | Number of integration rows used for monitoring |
| LABEL    | Alphanumeric label describing the aerodynamic 
           | parameters |
| NUTL     | Data set (tape) number of tape containing columns 
           | of the weighted pressures, $\Delta C_p$ |
| SAI      | A row of the integration matrix $[S]$ |
| DCPTIL   | A column of the weighted pressures $\{\Delta C_p\}$ |
| CE       | A column of the aerodynamic parameters $\{C_e\}$ |

**Calling Subroutine**  
WEYT
Flow Chart

Initialize

Begin loop on NMODE

Read DCPTIL from tape NUTL

Begin loop on NMN

Read SAN row from tape NTAPSA

Compute CE = SAN * DCPTIL

Print N, LABEL, CE

End loop on NMN

End loop on NMODE

END
SUBROUTINE DCPB(NTDCP, NTAPW, NTAPDI, IGØ, IFP, IFW, NRØW, NCØL,
   NMAX, DCP, CØL, WØRK)

Functional Description

This subroutine computes the theoretical pressure distribution if
it is not input. Specifically

\[ \{ \Delta C_{p, t} \} = [D]^{-1} \{ W \} \]

where \( W \) is the normalwash and \([D]^{-1}\) is the inverse of the aerodynamic
influence coefficient matrix. This corresponds to Equation (1) where \([D]^{-1}\)
= \([A]\). \( \Delta C_{p, t} \) is called DELCPB in this subroutine.
### Description of Argument List

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<th>Argument</th>
<th>Description</th>
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<tr>
<td>NTAPW</td>
<td>Tape number containing the normalwash matrix, ([W]), in column order</td>
</tr>
<tr>
<td>NTAPDI</td>
<td>Tape number containing the inverse-D matrix, ([A]^{-T}), in row order</td>
</tr>
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<td>1 for symmetric modes, 2 for antisymmetric modes</td>
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<tr>
<td>IFP</td>
<td>Control flag (see input flag FLAGP). IFP = 0, 2, 3 means premultiplying correction factors, IFP = 1, 4 means post-multiplying correction factors</td>
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<td>IFW</td>
<td>Normalwash flag. IFW = 0 means normalwash is tape input (if any), IFW = 1 means normalwash is card input</td>
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<td>One column of the (\Delta C_p) matrix (complex)</td>
</tr>
<tr>
<td>CØL</td>
<td>Temporary work array (complex)</td>
</tr>
<tr>
<td>WØRK</td>
<td>The NROW x NMAX complex array containing the (\Delta C_p) matrix</td>
</tr>
</tbody>
</table>

### Calling Subroutine

WEYT
Flow Chart

Initialize; define NTAPE

FLAGP = 1, 2, 4

YES

Read W from NTAPE into WORK

Call MATM compute DELCPB = DI x W

Print DELCPB columns

END

NO

Read DELCPB from NTAPE into WORK
SUBROUTINE DCPT(NPT, FLAGB, IG0, MDE, NP, NSCRCH, NUTL, NTAPDI,
    NTAPW, NTAPCF, X, Y, Z, GMA, DELA, NMAX, NEM, W,
    DI, EPS, DCPBAR, DCPTIL, WORK, EB)

Functional Description

This subroutine modifies the theory with the calculated correction factors. If a premultiplier is used the theoretical pressure, $\Delta C_p$, is modified to produce the modified pressures $\Delta C_p$ (see eqs.(2) and (5)).

$$\begin{align*}
\{\Delta C_p\} &= [1+\epsilon] \{\Delta C_{p_t}\}
\end{align*}$$

If a postmultiplier is used then the downwash, W, is modified to produce the corrected pressures $\Delta C_p$ (see eqs. (5) and (28)).

$$\begin{align*}
\{\Delta C_p\} &= [D]^{-1} [1+\epsilon] \{W\}
\end{align*}$$

If the new postmultiplier is used then

$$\begin{align*}
\{\Delta C_p\} &= [D]^{-1} \{W + [\phi] \{\bar{c}\}\}
\end{align*}$$

$$\begin{align*}
[\bar{\phi}] &= [\phi] [\lambda]
\end{align*}$$

$$\begin{align*}
[\lambda] &= [\phi]^T \{\Delta C_p\}
\end{align*}$$

(See eq. 65)

Also the correction factors, $CF$, are written on tape where

$$CF = 1 + \epsilon$$
Description of Arguments

NPØT        Data set number of the system output data set
FLAGB       Option flag for correction matrix calculation and/or
            monitoring of data
IGØ          1 for symmetric modes
            2 for antisymmetric modes
MØDE         Mode number
NP           Number of row elements in the $\Delta C_p$ matrix
NSCRCH       Data set (tape) number containing the $\Phi$ matrix in
            row order (for FLAGP=4 cases only)
NUTL         Data set (tape) number on which the $\Delta C_{pe}$
            columns are saved
NTAPDI       Data set (tape) number containing the $D^{-1}$ matrix rows
            (if needed) ($D^{-1} = A$)
NTAPW        Data set (tape) number containing the $W$ matrix columns
            (if needed)
NTAPCF       Data set (tape) number on which the matrix of correction
            factors, CF, is saved in column order
X            $x$ coordinates
Y            $y$ coordinates
Z            $z$ coordinates
GMA          Dihedral angle array of the boxes over which the
            pressures act
DELA         Array of box areas
NMAX         Column dimension of the two-dimensional complex
            array WORK
NEM          Number of correction factor modes
150
$W$ A column of the $W$ matrix (complex)

$DI$ A row of the $D^{-1}$ matrix (complex), ($[E_A]$ matrix)

$EPS$ $\varepsilon$ array

$DCPBAR$ A column of the $\Delta C_{pt}$ matrix (complex)

$DCPTIL$ A column of the $\Delta C_{pe}$ matrix (complex)

$W\text{ORK}$ Two dimensional complex array containing the $\Delta C_{pt}$ matrix

$EB$ $\varepsilon$ array ($\varepsilon = \phi\bar{\varepsilon}$)

Calling Subroutine WEYT
Initialize

\[ \text{FLAGB} = 2 \]

YES

Read and write code from tape NTAPCF

Read CF from tape NTAPCF

Compute \( \text{EPS} = \text{CF} - 1.0 \)

Begin loop on MDES

FLAGB = 1

YES

3A1

NØ

1B1

Begin loop on NEM

Read W from tape NTAPW

Read \( \phi \) column from tape NSCRCH

Compute \( \varphi[l] \)

CØL = \[ \varphi[l] \]

End loop on NEM

2A1
Flow Chart

Begin loop on NP

2A1

Compute
\( CF = 1 + \varepsilon \)

FLAGP = 4

YES

NO

NEM = 0

YES

Compute
\( C_{OL} = \varepsilon \)

FLAGP = 0, 2, 3

YES

2B3

2B2

Compute
\( \Delta C_{pe} = [D]^{-1}(1+\varepsilon W) \)

2B4

2B1

Compute
\( \Delta C_{pe} = [D]^{-1} * (W + C_{OL}) \)

2B4

2B3

Compute
\( \Delta C_{pe} = CF * \Delta C_{pe} \)

2B4

Print geometry
\( \varepsilon, \Delta C_{pe} \)

End loop on NP

3A2
Flow Chart

3A1

Begin

3B1

FlagB=1, 2

YES

NO

Write CF on tape NTAPCF

End loop on MTextures

Print CF

3A2

Write \( \Delta C_p \), column on tape NUTL

End loop on NP

End loop on NP

3A1

CF = 1.0

\( \Delta C_p = \Delta C_p \)

Print geometry, \( \bar{e} \), \( \Delta C_p \)

End
SUBROUTINE DELC(NTAPE, NPOT, NC, NP, NMODE, NMAX, CIE, DCI, SAI, WORK)

Functional Description

This subroutine forms the difference between the theoretical, \( C_t \), and the experimental (constrained) \( C_e \) coefficients (see Equations (9) and (10)).

\[
\{ \Delta C_e \} = \{ C_e \} - [S] \{ \Delta C_{pt} \}
\]

It also prints out \( C_t ( = [S] \{ \Delta C_{pt} \} ) \) and \( \Delta C \).
Description of Argument List

NTAPE  Tape containing rows of the integration matrix, [S]
NPØT  Data set number of the system output data set
NC  Number of constraints applied to $\Delta C_p$ values
NP  Number of row elements in the $\Delta C_p$ matrix
NMODE  Number of modes
NMAX  Maximum number of columns in the two-dimensional WORK array
CIE  Array containing the input values $C_e$ (experimental constraints)
DCI  The $[\Delta C_e]$ matrix
SAI  A row of the integration matrix [S]
WORK  The NP by NMAX complex array containing the $\Delta C_p$ matrix

Calling Subroutine

WEYT
Flow Chart

1. Initialize

   Begin

2. Loop on NC

3. Read SAI row from tape NTSAIJ

4. Compute
   CI = SAI * DELCPB,
   DCI = CIE - CI

   End

5. Loop on NC

6. Print DCI values

7. Print CI values

END
SUBROUTINE EDBL(NPOT, NELIMS, NP, NS, LIMK, JARR, NSMAD, EBMN, 
EBMX, EB, ELIM)

Functional Description

This subroutine compares the correction factors, $\tilde{e}$, with the input limits $\tilde{e}_{\text{min}}$, $\tilde{e}_{\text{max}}$. If any $\tilde{e}$ falls outside of the limits it replaces $\tilde{e}$ with the closest limit. (The values of $\tilde{e}$ are correction factors if correction factor modes do not exist). This subroutine forms the final correction factor array $\tilde{e}$ (see paragraph below Eq. (60)).
Description of Argument List

NPØT: Data set number of the system output data set
NELIMS: Number of input cards for EBMIN and EBMAX - see below
NP: Number of row elements in the ΔCₚ matrix
NS: NS = NP + NC when NEM ≤ NP
    NS = NEM + NC when NEM > NP
LIMK: A two-dimensional array containing the first- and last box numbers that define a range of boxes (or ΔCₚ) over which a limit is to be placed on ε
JARR: Array of the box numbers for which the ε values are modified
NSMØD: The number of ε values which are modified due to the limits placed on these
EBMIN: The minimum- and maximum value allowed for the values of ε for boxes (or ΔCₚ) in the range defined by LIMK
EBMAX: Array of the calculated ε values
ELIM: Array of the ε values that were modified due to the εₘᵢₙ', εₘᵢ₇ restrictions

Calling Subroutine: WEYT
Flow Chart

Initialize; \( K = 1 \)

Begin loop on \( J = 1, NS \)

\[ J > NP \]

YES \( \Rightarrow 1B3 \)

NO \( \Rightarrow 1A1 \)

\[ \text{LIM1}(K) < J < \text{LIM2}(K) \]

YES \( \Rightarrow 1B1 \)

NO \( \Rightarrow 2B1 \)

\[ \varepsilon \text{ min} \leq \varepsilon \leq \varepsilon \text{ max} \]

YES \( \Rightarrow 1B3 \)

NO \( \Rightarrow 1B2 \)

\[ J = \text{JCM} = \text{JCM} + 1 \]

\( \varepsilon > \varepsilon \text{ max} \)

NO \( \Rightarrow 1B1 \)

YES \( \Rightarrow 1B2 \)

End loop on \( NS \)

\[ \text{JCM} = \text{JCM} + 1 \]

\[ \text{NSM0D} = \text{JCM} \]

\[ \text{ETEMP} = \varepsilon \text{ max} \]

\[ \text{ETEMP} = \varepsilon \text{ min} \]

\[ \text{JARR}(J) = J \]

\[ \text{ELIM}(J) = \text{ETEMP} \]

2A1
Flow Chart

2A1

NSMØD = 0

YES

NO

Print $\bar{e}$, ELIM

END

2B1

K = NELIMS

YES

NO

K = K + 1

1A1

K = 1

1B3
SUBROUTINE EPSJ(NTPHIJ, NP, NEM, NS, EB, EPS, PHI)

Functional Description

This subroutine relates $e$ to $\bar{e}$, as in Equation (53).

$\{\epsilon\} = [\phi] \{\bar{\epsilon}\}$

where $[\phi]$ are correction factor modes and where

$\epsilon = \begin{cases} 
\epsilon_p & \text{for premultiplying correction factors} \\
\epsilon_w & \text{for postmultiplying correction factors}
\end{cases}$
Description of Argument List

NTPHIJ       Tape number containing the $\phi$ matrix
NP           Number of row elements in the $\phi$ matrix
NEM          Number of correction factor modes
NS           NS = the greater of (NP+NC) and (NEM+NC)
EB           Array of the $\varepsilon$ values
EPS          The final $\varepsilon$ array
PHI          A column of the matrix of weight factor mode shapes, $\phi$

Calling Subroutine       WEYT
Flow Chart

1. Initialize

2. If NEM = 0, then 
   - Set \( \varepsilon = \bar{\varepsilon} \)
   - Go to 1A1

3. Otherwise, go to loop on NEM

4. Read \( \phi \)-row from tape

5. Compute \( \{ \varepsilon \} = [\phi] \{ \bar{\varepsilon} \} \)

6. Loop on NEM

7. Go to 1A1

8. END
SUBROUTINE GINV(NPOT, NTAPSB, NC, NS, NX, DC, EB, B, S, SBB)

Functional Description

This subroutine provides a general inverse of the following set of equations:

\[ \text{NC} \{ \Delta C_e \} = [S] \{ \tilde{\varepsilon} \} \text{NS} \]

When \( \text{NC} = \text{NS} \) (Direct Solution)

\[ \{ \tilde{\varepsilon} \} = [S]^{-1} \{ \Delta C_e \} \]

When \( \text{NC} < \text{NS} \) (Minimization Solution, \( \sum_{\varepsilon}^2 = \min \) (see Eq. (20))

\[ \{ \tilde{\varepsilon} \} = [S]^H \{ \lambda \} \]

\[ \{ \lambda \} = [\{S\} [\{S\}]^H]^{-1} \{ \Delta C_e \} \]

When \( \text{NC} > \text{NS} \) (Least Squares Solution, \( \sum_\varepsilon^2 = \min. \))

\[ \{ \tilde{\varepsilon} \} + [\{S\} [\{S\}]^H]^{-1} \{ \Delta C_e \} \]

\[ \{ \lambda \} = [S]^H \{ \Delta C_e \} \]

In the above;

\[ [\tilde{S}] = [S] [\sqrt{T_p}]^{-1} \]

where \([\tilde{S}]\) given in Eq. (51). The term \( \tilde{\varepsilon} \) is given in Eq. (22). The superscript \( H \) indicates the Hermitian transpose.
### Description of Argument List

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPOT</td>
<td>Data set number of the system output data set</td>
</tr>
<tr>
<td>NTAPSB</td>
<td>Tape number containing the ( {\hat{S}} ) matrix</td>
</tr>
<tr>
<td>NC</td>
<td>Number of constraints; number of rows in the ( {\hat{S}} ) matrix (SBB)</td>
</tr>
<tr>
<td>NS</td>
<td>( NS = \text{the.greater.of.(NP+NC) and (NEM+NC);} ) number of columns in the ( {\hat{S}} ) matrix</td>
</tr>
<tr>
<td>NX</td>
<td>( NX=NS \text{ if NEM}=0, \ NX=NEM+NC \text{ otherwise} )</td>
</tr>
<tr>
<td>DC</td>
<td>The complex ( \Delta C_e ) array</td>
</tr>
<tr>
<td>EB</td>
<td>The complex array ( {\hat{c}} ), output of subroutine GINV</td>
</tr>
<tr>
<td>B</td>
<td>An array of intermediate solutions (complex)</td>
</tr>
<tr>
<td>S</td>
<td>A complex two-dimensional work array of dimension NC by NC</td>
</tr>
<tr>
<td>SBB</td>
<td>The complex NC by NS matrix, ( {\hat{S}}_B )</td>
</tr>
</tbody>
</table>

### Calling Subroutine

| WEYT |

### Called Subroutine

| MIS2, the standard IBM system subroutine for solving complex matrix equations |
Flow Chart

Read SBB from tape

NX - NC
= 0
> 0
< 0

Solve
DC = SBB*EB

Compute
B = [SBB*]T
* DC

Compute
S = SBB
* [SBB*]T

Compute
S = [SBB*]T
* DC

Solve
DC = S * B for B

Solve
B = S * EB for EB

Compute
EB = [SBB*]T
* B

Print solutions EB

END
SUBROUTINE MATM(NT, IGØ, NR, NC, NMAX, A, C, B)

Functional Description

Subroutine MATM is essentially a matrix multiplication routine. It obtains the DI matrix ([A]) rows from tape NT and the W matrix from the two-dimensional array B. The results of the matrix multiplication, ΔCₚₜ, are saved in array B which is returned to the calling routine, DCPB, via the argument list.

Description of Argument List

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT</td>
<td>Tape number containing the inverse-D matrix</td>
</tr>
<tr>
<td>IGØ</td>
<td>1 for symmetric modes&lt;br&gt;2 for antisymmetric modes</td>
</tr>
<tr>
<td>NR</td>
<td>Number of rows in the ΔCₚₜ matrix</td>
</tr>
<tr>
<td>NC</td>
<td>Number of columns in the ΔCₚₜ matrix</td>
</tr>
<tr>
<td>NMAX</td>
<td>Maximum number of columns in the ΔCₚₜ matrix</td>
</tr>
<tr>
<td>A</td>
<td>A row of the inverse-D matrix, [A]</td>
</tr>
<tr>
<td>C</td>
<td>Complex work array</td>
</tr>
<tr>
<td>B</td>
<td>Two-dimensional complex array in which the ΔCₚₜ matrix is stored</td>
</tr>
</tbody>
</table>

Calling Subroutine

DCPB
SUBROUTINE MODF(NC, NS, MASTSB, NEWTSB, JARR, SQRTT, ELIM, SBB, DCI, DCMOD)

Functional Description

When some of the values of $\bar{e}$ have exceeded their limits and have been replaced by the limit values, these new values of $\bar{e}$ (called $e_d$ in Equation (56)) are then considered fixed and known. However the constraints are now not satisfied and a change in the constraint $\Delta C_e$, i.e., $\Delta C_{\text{mod}}$, is calculated (see Equation (59)).

$$\Delta C_{\text{mod}} = \Delta C_e - [S_d] \{e_d\}$$

Since the new values of $\bar{e}$, i.e., $e_d$, can not influence solution further the $S$ matrix must be changed to delete the influence of $e_d$. Thus the elements of $S$ that give the influence of $e_d$, i.e., $S_d$, must be eliminated resulting in $\bar{S}_u$. This subroutine forms $\bar{S}_u$, or in the notation of the computer program $[\bar{S}_{\text{mod}}]$. 

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Description of Argument List

NC  Number of constraints - dimension of the complex arrays DCI and DCMOD
NS  Dimension of the complex array SBB
MASTSB  Tape number containing SBB arrays (i.e., rows of the \( \overline{S} \) matrix)
NEWTSB  Tape number containing the modified SBB arrays (i.e. rows of the \( \overline{S}_{\mathrm{mod}} \) matrix) \( \overline{S}_{\mathrm{mod}} = \overline{S}_u \)
JARR  Array of the element numbers for which the \( \overline{S} \)-values are replaced by zeroes
SQRTT  \( \sqrt{t_j} \) - see Equations (23) and (34)
ELIM  \( \overline{\varepsilon}_{\mathrm{limj}} \), array of the modified \( \varepsilon \) values
SBB  Complex array containing rows of the \( \overline{S} \) matrix
DCI  Complex array containing \( \Delta C_e \)
DCM\( \overline{O} \)D  Complex array containing \( \Delta C_{\mathrm{mod}} \)

Calling Subroutine  WEYT
Initialize

Begin loop on NC

Read SBB row from tape MASTSB

Begin loop on J=1,NS

J=JARR(J)

YES

Compute SUM=[SBB]*ELIM*SQR RT

SBB mod (J) = 0.0

End loop on NS

End loop on NC

Compute

ΔC mod = ΔC - SUM

Write SBB mod row on tape NEWTSB

Print SBB mod row

Print ΔC mod

END
SUBROUTINE PHIJ(NPIT, NPÔT, NTPHIJ, NEM, NP, KÔDE, MÔDES, X, Y, Z, PHI)

Functional Description

This subroutine forms the correction factor modes. If \( \phi \) is input element by element (TYPE = 0) then this subroutine simply arranges the data into arrays. If TYPE = 0 then modes are calculated as follows:

\[
\begin{align*}
(x_j - a}_\lambda)^{n_\ell} & \quad \text{TYPE = 1} \\
(y_j - a}_\lambda)^{n_\ell} & \quad 2 \\
(z_j - a}_\lambda)^{n_\ell} & \quad 3 \\
\exp[b(x_j - a}_\lambda)^{n_\ell}] & \quad 4 \\
\exp[b(y_j - a}_\lambda)^{n_\ell}] & \quad 5 \\
\exp[b(z_j - a}_\lambda)^{n_\ell}] & \quad 6
\end{align*}
\]

where \( a, b, n \) are input per mode and where \( \phi_{j\ell} = 0 \) over boxes are not considered.
Description of Argument List

NPIT  Data set number of the system input data set
NPØT  Data set number of the system output data set
NTPHIJ  Tape number containing columns of the NP by NEM
        \phi matrix
NEM  Row dimension of the \phi matrix
NP  Column dimension of the \phi matrix
KØDE -1 (end indicator of card input sets)
MØDES not used
X  \{ x \}  coordinates of the pressure points or
Y  \{ y \}  of the \Delta C_p's
Z  \{ z \}  
PHI  Complex array containing one column of the \phi matrix

Calling Subroutine  WEYT
Flow Chart

Begin loop on NEM

Read control data for \( \phi \)

TYPE = 0

YES

NØ

Read LIML1, LIML2 as needed

Read \( j, \phi_j \) as needed

Print control data

Compute one \( \phi \)-column as specified by TYPE

Write \( \phi \)-column on tape NTPHIJ

End loop on NEM

Print \( \phi \) matrix in column order

END

1B1
SUBROUTINE PØSN(NT, IGØ)

Functional Description

This subroutine positions tapes of a certain uniform format for reading; see Tape Description for NTDCP, NTAPW and NTAPDI.

Description of Argument List

NT                 Tape number to be positioned for reading
IGØ               1 for symmetric modes, 2 for antisymmetric modes

Calling Subroutines       DCPB, DCPT, MATM, SBAR
SUBROUTINE RECD(NTAPE, A, N)

Functional Description

This subroutine reads arrays of real numbers A of length N from tape NTAPE one record at a time. It is used for the reading of the geometry arrays when these are input from tape NTGEOM.

Description of Argument List

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTAPE</td>
<td>Tape number</td>
</tr>
<tr>
<td>A</td>
<td>Array to be read from tape</td>
</tr>
<tr>
<td>N</td>
<td>Length of array A</td>
</tr>
</tbody>
</table>

Calling Subroutine

WEYT
SUBROUTINE SAIJ(NPIT, NPOT, NTSAIJ, NTSANJ, NC, NP, NM0N, NAXIS,
       AIT, CIE, X, Y, Z, CG, SG, DELA, FLAGA, FLAGF,
       K0DE, IPRINT, LABEL, SAI)

Functional Description

This subroutine sets up proper argument lists for SROW so that integration matrices, \([S]\), can be calculated for both constraining and monitoring purposes.
Description of Argument List

NPIT  Data set number of the system input data set
NPOT  Data set number of the system output data set
NTSAIJ Tape number containing the integration matrix rows, \( SA_{ij} \), for constraints
NTSANJ Tape number containing the integration matrix rows, \( SA_{nj} \), for monitoring
NC    Number of constraints
NP    Number of \( \Delta C_p \) elements
NM0N  Number of sets of the monitoring data
NAXIS Number of axes
AIT   Constraining effectiveness of the experimental data, \( \hat{a}_i \)
CIE   Experimental (or any other) constraint on the data, \( C_e \)
X, Y, Z Coordinates of the pressure points (boxes)
CG, SG Cosine-, sine of box dihedral angles
DELA  Box areas
FLAGA Axis flag
\= 0, axis endpoints are input
\= 1, direction cosines are input
FLAGF Force/moment flag
\= 0, \( C_e \) is a force in the direction of axis
\= 1, \( C_e \) is a moment about axis
KØDE = -1

IPRINT
Detail print flag
IPRINT = 1, print $SA_{ij}$ and $SA_{nj}$ rows
IPRINT = 0, bypass print

LABEL
Alphameric identifier of the integrated parameters

SAI
Complex array containing a row of either one of the integration matrices $SA_{ij}$ or $SA_{nj}$

Calling Subroutine
WEYT

Called Subroutine
SRØW
Flow Chart

Begin loop on NC

Read and print axis data

NC=0

YES → 1A1

NO

Begin loop on NC

Read and print constraint data

Call SROW computes SAI row

Write SAI row on tape NTSAIJ

End loop on NC

NMØN=0

YES → 1B2

NO

1B1

1B1

Begin loop on NMØN

Read and print monitor data

Call SROW computes SAN row

Write SAN row on tape NTSANJ

End loop on NMØN

Print SAI rows (if any)

Print SAN rows (if any)

END
SUBROUTINE SBAR(NTSBIJ, NTAPDI, NC, NP, NS, FLAGP, FLAGT, FLAGW, I, IG0, SQRTT, AIW, SAI, DI, W, DELCPB, SBI)

Functional Description

This subroutine solves for the matrix SBI where

\[
SBI = [S]^{-1} \sqrt{T^*} \]

The matrix [S] contains all the capability of the program except modes and limits. This capability is outlined in Eqs. (45), (26) and (9) for pre-multipliers and (45), (39) and (30) for postmultipliers. The weights \( T^* \) are defined below Equation (47).

\[
SBI = \begin{cases} 
S_{\overline{A}}_{ij} & \text{when } j = 1, 2 \cdots NP, i = 1, 2 \cdots NC \\
WT_i & \text{when } j = NP + i \\
0 & \text{otherwise}
\end{cases}
\]

where NP = number of pressure values and NC = number of constraints.

\[
S_{\overline{A}}_{ij} = \begin{cases} 
SA_{ij} \frac{\Delta C_{P_j}}{\sqrt{T_j}} & \text{when } \Delta C_{P_j} \text{ available} \\
\sum SA_{i_k} DI_{k,j} W_j \frac{1}{\sqrt{T_j}} & \text{when } \Delta C_{P_j} \text{ not available} \\
(1 - \overline{a}_i) / \overline{a}_i & \overline{a}_i > 0.0001 \\
10^4 & \overline{a}_i \leq 0.0001 \\
\end{cases}
\]

\[
WT_i = \begin{cases} 
|\Delta C_{P_t}| \Delta A & \text{FLAGP} = 1 \\
or \\
|W| & \text{FLAGP} = 1 \\
1.0 & \text{FLAGT} = 1
\end{cases}
\]

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**Description of Argument List**

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTSBIJ</td>
<td>Tape number containing rows of the integration matrix without weight factor modes, $\tilde{S}$</td>
</tr>
<tr>
<td>NTAPDI</td>
<td>Tape number containing rows of the inverse-D matrix</td>
</tr>
<tr>
<td>NC</td>
<td>Number of constraints</td>
</tr>
<tr>
<td>NP</td>
<td>Number of $\Delta C_p$ elements</td>
</tr>
<tr>
<td>NS</td>
<td>Length of the SBI matrix rows</td>
</tr>
<tr>
<td>FLAGP</td>
<td>Option flag for $\Delta C_p$ and/or pre- or post-multiplying correction factors</td>
</tr>
<tr>
<td>FLAGT</td>
<td>Option flag for weights</td>
</tr>
<tr>
<td>FLAGW</td>
<td>Option flag for normalwash input</td>
</tr>
<tr>
<td>I</td>
<td>An intermediate index</td>
</tr>
<tr>
<td>IGØ</td>
<td>1 for symmetric modes</td>
</tr>
<tr>
<td></td>
<td>2 for antisymmetric modes</td>
</tr>
<tr>
<td>SQRRT</td>
<td>$= \sqrt{T}$; see equations</td>
</tr>
<tr>
<td>AIW</td>
<td>Constraining effectiveness $\hat{a}_i$</td>
</tr>
<tr>
<td>SAI</td>
<td>A row of the integration matrix $S_{ij}$</td>
</tr>
<tr>
<td>DI</td>
<td>A row of the inverse-D matrix</td>
</tr>
<tr>
<td>W</td>
<td>A column of the normalwash matrix</td>
</tr>
<tr>
<td>DELCPB</td>
<td>A column of the $\Delta C_p$ matrix (lifting pressure coefficients, either input, $\Delta C_p$, or computed as $[D]^{-1} (W)$)</td>
</tr>
</tbody>
</table>
| SBI        | A row of the integration matrix without weight factor modes, $[\tilde{S}] f\sqrt{T^*} J^{-1}$, $T^*$ =  \[
\begin{cases}
  T \hat{\alpha} & \text{for constraints} \\
  \frac{1-\alpha}{\hat{\alpha}} & \text{for estimates}
\end{cases}
\] |

**Calling Subroutine**

SDBL
Flow Chart

1. **Initialize**
   - FLAGP=0
   - YES → 1B1
   - NO → 1B2

2. **Flag on NP**
   - Loop on NP

3. **Read DI row from tape NTAPDI**

4. **Compute SBI = SAI*DI**

5. **Flag on NP**
   - Loop on NP

6. **Compute SBI = SBI+W/SQRTT**

7. **Judge AIW < EPSLØN**
   - YES → Remaining SBI element SBI=AIFIX
   - NO → Compute remaining SBI element SBI=(1-AIW)/AIW

8. **Write SBI row on tape NTSBIJ**

9. **Print SBI row**

10. **END**
SUBROUTINE SDBL(NSCRCH, NUTL, MASTSB, NTPHIJ, NTAPW, NTSAIJ,
NTAPDI, IGØ, FLAGW, FLAGP, FLAGT, NC, NP, NS,
NEM, SQRRTT, AIT, DELA, SBB, SBI, SAI, DI, W, PHI, DELCP)

Functional Description

This subroutine calculates \([\tilde{S}]\) described in Equation (54). The quantity calculated in this routine includes estimates and thus

\[
\tilde{S} = \begin{bmatrix}
\phi & 0 \\
-1 & -1 \\
0 & 1
\end{bmatrix}
\]
Description of Argument List

NSCRCH  Tape number containing columns of the $\phi$ matrix 
         (if any)
NUTL    Utility (scratch) tape number
MASTSB  Tape number containing the $S$ matrix rows
NTPHIJ  Tape number containing the $\phi$ matrix columns
NTAPW   Tape number containing columns of the normalwash matrix
NTSAIJ  Tape number containing rows of the integration matrix, $SA_{ij}$
NTAPDI  Tape number containing rows of the inverse-D matrix
IGØ     1 for symmetric modes
         2 for antisymmetric modes
FLAGW   Option flag for normalwash input
FLAGP   Option flag for $\Delta C_p$ input and/or pre- or post-multiplying 
         corrections
FLAGT   Option flag for weights
NC      Number of constraints
NP      Number of $\Delta C_p$ elements
NS      $= \max (NP+NC, NEM+NC)$
NEM     Number of correction factor modes
SQRRTT  $\sqrt{T_j}$, see equations
AIT     Constraining effectiveness $\tilde{a}_i$
DELA    Box areas
SBB     A row of the $\tilde{S}$ matrix (integration matrix with weight 
         factor modes)
SBI     A row of the $[S] \sqrt{T*J^{-1}}$ matrix
SAI     A row of the $S_{ij}$ elements
DI   A row of the inverse-D matrix
W    A column of the normalwash matrix
PHI  A column of the $\phi$ matrix (weight factor mode shapes)
DELCPB  A column of the $\Delta C_{p_t}$ matrix

Calling Subroutine
 WEYT

Called Subroutine
 SBAR
Flow Chart

Initialize; define NTSBIJ

Compute \( \sqrt{T} \) per FLAGP setting

Begin loop on NC

Read \( S_{ij} \) row from tape NTSAIJ

Call SBAR computes rows of SBI

End loop on NC

NEM=0

YES \( \rightarrow 2B2 \)

NO \( \rightarrow 1B1 \)

1B1

Begin loop on NC

Initialize SBB row

Read SBI row from tape NTSBIJ

Begin loop on NEM

Read \( \phi \)-column from tape NTPHIJ

FLAGP = 4

YES \( \rightarrow 2A1 \)

NO \( \rightarrow 1B2 \)

1B2

YES \( \rightarrow 2B1 \)

End loop on NEM

2B1
Flow Chart

2A1

Compute \( \phi \) columns

Write \( \phi \) columns on tape NSCRCH

Compute SBB elements using \( \phi \)

1B2

2B1

Compute remaining SBB elements

Write SBB row on tape MASTSB

End loop on NC

2B2

END
SUBROUTINE SR_W(FLAGA, FLAGF, XI1, ETA1, ZETA1, CG, SG, CTIL, X, Y, Z, DELA, LIMI, IIMAX, I, NP, IR, XI2, ETA2, ZETA2, SAI)

Functional Description

This subroutine constructs the integration matrix \([S]\) described in Equation (3) a row at a time.

\[
S_{ij} = SAIJ = \begin{cases} 
A_{ij} \Delta A_j & \text{for force calc.} \\
B_{ij} \Delta A_j & \text{for moment calc.}
\end{cases}
\]

\[
A_{ij} = \frac{-\cos \beta_i \sin \gamma_j + \cos \gamma_i \cos \gamma_j}{c_i}
\]

\[
B_{ij} = \{ \cos \alpha_i \left[ (y_i-n_i(1))(\cos \gamma_j) + (z_i-\xi_i(1))\sin \gamma_j \right] - \cos \beta_i (x_i-\xi_i(1))\cos \gamma_j \}
\]

\[
-\cos \gamma_i (x_i-\xi_i(1))\sin \gamma_j \}
\]

where \(\cos \alpha_i, \cos \beta_i, \cos \gamma_i\) are the direction cosines of the input axis and where \(x_i, y_i, z_i, \gamma_j\) are the coordinates and dihedral of the aerodynamic box and \(\xi_i(1), n_i(1), \xi_i(1)\) are the coordinates of the one edge of the input axis. \(SAIJ\) is of course zero on boxes that are not to be integrated.
Description of Argument List

FLAGA  Axis input option flag
        = 0, axis endpoints are input
        = 1, direction cosines are input

FLAGF  Force/moment flag
        = 0, \( C_i(e) \) is a force in direction of axis
        = 1, \( C_i(e) \) is a moment about axis

XI1, ETA1, ZETA1  Axis endpoint coordinates, \( \xi(1), \eta(1), \zeta(1) \)

CG, SG  Cosine-, sine of box dihedral angles

CTIL  Constant used to nondimensionalize integrated data (c)

X, Y, Z  Coordinates of the pressure points (boxes)

DELA  Box areas

LIMI  First-, last box numbers for the integration of the \( \Delta C_p \) values

IIMAX  Number of LIMI sets input for one constraint

I  Intermediate index

NP  Number of \( \Delta C_p \) values

IR  Row index of the \( S_{ij} \) matrix

XI2, ETA2, ZETA2  Second axis endpoint coordinates when FLAGF = 0,
                 direction cosines when FLAGF = 1

SAI  A row of the integration matrix \( S \)

Calling Subroutine  SAIJ
Flow Chart

Initialize

FLAGA 1

Compute direction cosines

II = 1

Begin loop, J=1, NP

ABIJ = 0.0

Define LIM1, LIM2

1B1

1B2

1A2

LIM1 ≤ J ≤ LIM2

YES

Compute ABIJ for forces

SAI = ABIJ*DELA

Compute ABIJ for moments

II = II + 1

II = IIMAX

YES

NO

NO

II = II + 1

End loop on NP

END
SUBROUTINE WEYT(NP, NC, NEM, NELIMS, NMØN, NAXIS, NMIN, NMAX, NS,
NPIT, NPØT, W, DI, DCP, EPS, PHI, SAI, DCPTIL,
DELCPB, CØL, CIE, DCMØD, EBMIN, EBMAX, EB, ELIM,
SBB, SBI, S, SBMAT, DCI, WØRK)

Functional Description

This subroutine is the core of the correction factor method. All logic for the method is established here. This subroutine uses input to decide what is to be done and sets up the argument lists for and executes the calls to all required subroutines. The following flow charts document the logic flow of this subroutine. This subroutine sets up the logic for various forms of input data and various types of calculations. The input data ranges over geometry, pressures, downwashes, aerodynamic influence matrices, previously generated correction factors, integration matrix data, etc. This data can enter the program by cards, tapes or both.

There are three basic computational branches; (1) correction factor calculation, (2) monitoring of data (integration of pressures into aerodynamic parameters) and (3) application of previously generated correction factors to pressure distributions. Within branch (1) there exists a choice of what type of correction factors to generate, premultiplier, postmultiplier and new postmultiplier. Also a choice as to the type of weighting to be used (i.e. the T) is available. The program also tests to see if limits are placed on the correction factors and if modes are used. The constraining power å is always input since a constraint is simply å = 1.0.
**Description of Argument List**

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP</td>
<td>Number of $\Delta C_p$ elements</td>
</tr>
<tr>
<td>NC</td>
<td>Number of constraints</td>
</tr>
<tr>
<td>NEM</td>
<td>Number of correction factor modes</td>
</tr>
<tr>
<td>NELIMS</td>
<td>Number of input cards for the EBMIN, EBMAX pairs</td>
</tr>
<tr>
<td>NMØN</td>
<td>Number of sets of monitoring data</td>
</tr>
<tr>
<td>NAXIS</td>
<td>Number of axes for use in the integration of the $\Delta C_p$ values</td>
</tr>
<tr>
<td>NMIN</td>
<td>$\max(1, NELIMS)$</td>
</tr>
<tr>
<td>NMAX</td>
<td>$\max(NC, NMIN, 10)$</td>
</tr>
<tr>
<td>NS</td>
<td>$\max(NP+NC, NEM+NC)$</td>
</tr>
<tr>
<td>NPIT</td>
<td>Data set number of the system input data set</td>
</tr>
<tr>
<td>NPØT</td>
<td>Data set number of the system output data set</td>
</tr>
<tr>
<td>W</td>
<td>A column of the normalwash matrix</td>
</tr>
<tr>
<td>DI</td>
<td>A row of the inverse-D matrix, ${A}$ matrix</td>
</tr>
<tr>
<td>DCP</td>
<td>A column of the theoretical $\Delta C_p$ matrix</td>
</tr>
<tr>
<td>EPS</td>
<td>Incremental weight factors array, $\epsilon$</td>
</tr>
<tr>
<td>PHI</td>
<td>A column of the weight factor mode shape matrix, $\phi$</td>
</tr>
<tr>
<td>SAI</td>
<td>Integration matrix row array, $[S]$. SAN = $[S]$ for monitoring</td>
</tr>
<tr>
<td>DCPTIL</td>
<td>A column of pressures modified by weight matrix, $\tilde{\Delta} C_p$</td>
</tr>
<tr>
<td>DELCPB</td>
<td>A column of the unmodified lifting pressure coefficients, $\Delta C_p$ (either input, $\Delta C_p$, or computed as $[D]^{-1} {W}$)</td>
</tr>
</tbody>
</table>
CØL Complex array for intermediate use
CIE Array of the experimental constraints, $C_{ei}$
DCMØD Array of the modified $\Delta C_e$ values
EBMIN, EBMAX Minimum-, maximum values allowed for the $\varepsilon$ array to take
$\varepsilon$ array (incremental weight factors) ($\varepsilon = \phi \bar{c}$)
EB Array of the modified $\varepsilon$ values
ELIM $\phi$ array (incremental weight factors) ($\varepsilon = \phi \bar{c}$)
SBB A row of the $\hat{S}$ matrix
SBI A row of the $[\hat{S}] [\sqrt{T^*}]^{-1}$ matrix
S A two-dimensional complex work array of dimension NC by NC
SBMAT $\hat{S}$ matrix of maximum dimension NC by NS
DCI Array of the $\Delta C_e$ values
WØRK A two-dimensional complex array of dimension NP by $P_t$

Calling Subroutine MAIN
Called Subroutines CEMN, DCPB, DCPT, DELC, EDBL, EPSJ,
GINV, MØDF, PHIJ, RECD, SAIJ, SDBL,
WSWA
Flow Charts (Read in geometry and pressures)

Read control flags and print

FLAGP=3

YES → IB1

NØ

Read geometry from tape

FLAGP=0

NØ

YES

FLAGI=0

YES → 2A1

Read real \( \Delta C_p \) from tape

NTDCP

Move \( \Delta C_p \) into complex array

Write complex \( \Delta C_p \) on tape

NTDCP = NEWDCP

IB1

Read geometry from cards and print

FLAGI=0

YES

NØ

Read real \( \Delta C_p \) from cards

Move \( \Delta C_p \) into complex array

Write complex \( \Delta C_p \)

Save complex \( \Delta C_p \) on tape

NTDCP

2A1
Flow Charts (Calculation of $S, \phi, W$)

2A1

Save arrays
$CG = \cos \gamma_i$
$SG = \sin \gamma_i$

NC = 0 and
NMØN = 0

YES

NO

Rewind
NTSAIJ, NTSANJ

NO

Call SAIJ
computes
SAI, SAN matrices

NELIMS=0

YES

NO

Read $\epsilon$-limits from cards

NEM=0

YES

NO

2B2

2B1

Call PHIJ
computes
$\phi$ matrix

FLAGP=0 or
FLAGP=3

NO

YES

CALL WSWA
reads W
from cards
saves on
tape

IGØ = 1
NMØDE=NMSYM

NO

YES

3A1

3A2

Rewind
NTAPCF
Flow Charts (Basic method)

3A1

FLAGP=0 or
FLAGP=3

YES

Write the word "PRE" on tape NTAPCF
Write the word "POST" on tape NTAPCF

3A2

Call DCPB computes DCPBAR
DCPB

FLAGB=0

NO

YES

Call DELC computes DCI, CI

Initialize ELIM array

3B1

Call SDBL computes SBB

Call GINV computes generalized inverse

3B2

Compute EB=EB/SQRRT

NELMS=0

NO

YES 4A3

NSMID=0

NO

YES 4A2

4A1

197
Flow Charts (Accounting for limits)

4A1
Call MDF computes $\Delta C_{mod}$

4B1
Call EPSJ computes $\epsilon_j$

Call GINV computes generalized inverse

4B2
Call DCPT computes DCPTIL

3B2

4A2
Compute $EB = EB + ELIM$

4A3
NTAPE = NTPHIJ

4A1

NTAPE = NUTL3

4B1

YES

FLAGP = 4

NO

END

NO

IG0 = 2 or NMASYM = 0

YES

IG0 = 2

NM0DE = NMASYM

NO

3A2

YES

NO

NM0N = 0

YES

NO
SUBROUTINE WSWA(NPIT, NPØT, NUTL1, NTAPW, KØDE, NP, NCØL,
               NMAX, NMSYM, NMASYM, W)

Functional Description

Subroutine WSWA is called from WEYT only if the input flag FLAGW = 1. It reads and prints the mode number and symmetry flag identifying the mode, the range of boxes over which the input W value applies, and the normalwash, W for this range of boxes. This card input is repeated for all ranges as needed, but only the non-zero W values are required as input. The complete W matrix is assembled from the input and is saved on tape NTAPW in column order.
Description of Argument List

NPIT               Data set number of the system input data set
NPØT               Data set number of the system output data set
NUTLI              Utility (scratch) tape number
NTAPW              Tape number containing columns of the W matrix
KØDE               = -1
NP                 Number of row elements in the W matrix
NCØL               Number of columns in the W matrix
NMAX               Maximum number of columns in the W matrix
NMSYM              Number of symmetric modes
NMASYM             Number of antisymmetric modes
W                  Two-dimensional complex array containing the W matrix

Calling Subroutine    WEYT
Flow Chart

1. Read card input and print
2. Initialize; accumulate modes NSYM, NASYM
3. Write W columns on scratch tape
4. Write NP, NSYM, NASYM on tape NTAPW
5. Copy W cols from scratch tape onto NTAPW
6. Print W columns
7. END
SUBROUTINE ZEROUT(WORK, LENGTH, LOOP, ITAPE)

Functional Description

This subroutine initializes a complex array WORK of length LENGTH to zeroes. In addition to this, when the argument ITAPE ≠ 0, the complex zeroes stored in WORK are written on tape ITAPE as many times as specified by the argument LOOP.

Description of Argument List

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>WORK</td>
<td>Complex array to be initialized to zeroes</td>
</tr>
<tr>
<td>LENGTH</td>
<td>Length of the complex array WORK</td>
</tr>
<tr>
<td>LOOP</td>
<td>Number of times the array WORK is to be written on tape ITAPE (only if ITAPE ≠ 0)</td>
</tr>
<tr>
<td>ITAPE</td>
<td>Tape number on which the array WORK is saved LOOP-times (if any)</td>
</tr>
</tbody>
</table>

Calling Subroutines

EPSJ, MAIN, MATM, SDBL
SUBROUTINE CEMN(NPOT, IGO, NMODE, NTAPSA, NP, NMON, LABEL, NUTL)

NPOT DATA SET NUMBER OF THE SYSTEM OUTPUT DATA SET
IGO 1 FOR SYMMETRIC MODES, 2 FOR ANTISYMMETRIC MODES
NMODE NUMBER OF MODES
NTAPSA TAPE NUMBER CONTAINING THE INTEGRATION MATRIX SA
NP NUMBER OF ROWS IN THE DELTA-CP MATRIX
NMON NUMBER OF INTEGRATION ROWS USED FOR MONITORING
LABEL LABEL DESCRIBING THE AERODYNAMIC PARAMETERS
NUTL TAPE NUMBER CONTAINING THE WEIGHTED PRESSURE COLUMN
SAI INTEGRATION MATRIX ROW
DCPTIL ARRAY OF THE WEIGHTED PRESSURES
CE AERODYNAMIC PARAMETERS

DIMENSION LABEL(10,35)
COMPLEX SAI(NP), DCPTIL(NP), CE

10 FORMAT (1H1/)//40H SYMMETRIC CE-N
      MODE, I3)
20 FORMAT (1H1/)//40H ANTISYMMETRIC CE-N
      MODE, I3)
30 FORMAT (/40H N LABEL CE(N)

40 FORMAT (14, 8X, 10A1, 2E16.6)

REWIND NUTL
DO 120 MODE = 1, NMODE
   READ (NUTL) IGO, MD, DCPTIL
   GO TO (50,60), IGO
GO TO 70
50 WRITE (NPOT,10) MODE
   GO TO 70
60 WRITE (NPOT,20) MODE
70 WRITE (NPOT,30)
   REWIND NTAPSA
   DD 110 N = 1, NMON
   READ (NTAPSA) NON, MN, SAI
   CE(N) = (0.0, 0.0)
   DD 100 I = 1, NP
   CE(N) = CE(N) + SAI(I) * DCPTIL(I)
   CONTINUE
WRITE (NPOT,40) N, (LABEL(M, N), M = 1, 10), CE(N)

RETURN
END

SUBROUTINE DCPB(NTDCP, NTAPW, NTAPDI, IGO, IFP, IFW, NROW,
   1 NCOL, NMAX, DCP, COL, WORK)

NTDCP TAPE NUMBER CONTAINING THE PRESSURE COEFFICIENTS
NTAPW TAPE NUMBER CONTAINING THE NORMALWASH MATRIX
NTAPDI TAPE NUMBER CONTAINING THE INVERSE -D- MATRIX
IGO 1 FOR SYMMETRIC MODES, 2 FOR ANTISYMMETRIC MODES
IFP DELTA-CP-OPTION FLAG (0, 1, 2, 3 OR 4)
CORRECTION FACTORS (E1GC) 02/03/76

IFW = OPTION FLAG (0 OR 1)  DCPB0120
NROW = NUMBER OF ROWS IN THE DELTA-CP MATRIX  DCPB0130
NCOL = NUMBER OF COLUMNS IN THE DELTA-CP MATRIX  DCPB0140
DCP = ONE COLUMN OF THE DELTA-CP-MATRIX (COMPLEX)  DCPB0150
COL = TEMPORARY WORK ARRAY (COMPLEX)  DCPB0160
NMAX = MAXIMUM NUMBER OF COLUMNS IN THE DELTA-CP MATRIX  DCPB0170
WORK = THE 2-D DELTA-CP-BAR MATRIX (COMPLEX)  DCPB0180
COMPLEX DCP(NROW), COL(NROW), WORK(NROW, NMAX)

NTAPE = NTDCP
IF (IFP.EQ.1.OR. IFP.EQ.2. OR. IFP.EQ.4) NTAPE = NTAPW
CALL POSN( NTAPE, IGO )
DO 10 J = 1, NCOL
READ (NTAPE) (WORK(I, J), I = 1, NROW)
10 CONTINUE
IF (IFP.EQ.0. OR. IFP.EQ.3) GO TO 30
CALL MATMINTAPDI, IGO, NROW, NCOL, NMAX, DCP, COL, WORK )
30 CONTINUE
WORK NOW CONTAINS THE ENTIRE DELTA-CP-BAR MATRIX
WRITE (6,50) NCOL
WRITE (6,60) J, (I, WORK(I, J), I = 1, NROW)
IF (J .NE. NCOL) WRITE (6, 70)
40 CONTINUE
50 FORMAT ( 1H1 /// 6H THE , I4, 55H COLUMNS OF THE DELTA-CP-BAR)
60 FORMAT ( // 9H COLUMN , I4 // (3(16,2E14.6)) )
70 FORMAT ( 1H1 // )
RETURN
END

SUBROUTINE DCP(TNPET, LINES, IGO, FLAGB, FLAGP, MODES, NP, NSCRCH, DCP0040
1 NUTL, NTAPDI, NTAPW, NAPCF, X, Y, Z, GMA, DELA, NMAX, DCP0050
2 NEM, W, DI, EPS, DCPBAR, DCPTIL, WORK, EB ) DCP0060

NPOT = DATA SET NUMBER OF THE SYSTEM OUTPUT DATA SET  DCP0070
FLAGB = OPTION FLAG FOR DATA MONITORING  DCP0080
IGO = 1 FOR SYMMETRIC MODES, 2 FOR ANTISYMMETRIC MODES  DCP0090
MODES = NUMBER OF MODES  DCP0100
NP = LENGTH OF THE DCPBAR ARRAY  DCP0110
NSCRCH = TAPE NUMBER CONTAINING THE PHI-BAR MATRIX (IF ANY) DCP0120
NUTL = TAPE NUMBER ON WHICH THE DELTA-CP-TILDA MATRIX DCP0130
NTAPDI = TAPE NUMBER CONTAINING THE INVERSE-D MATRIX ROWS DCP0140
NTAPW = TAPE NUMBER CONTAINING THE W MATRIX COLUMNS DCP0150

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CORRECTION FACTORS (E1GC) 02/03/76

NTA PCF
TAPE NUMBER ON WHICH THE CORRECTION FACTOR MATRIX

IS SAVED

X, Y, Z
COORDINATES OF THE PRESSURE POINTS

GMA
DIHEDRAL ANGLE ARRAY OF THE BOXES OVER WHICH THE

PRESSURES ARE ACTING

DELA
ARRAY OF BOX AREAS

NMAX
COLUMN DIMENSION OF THE TWO-DIMENSIONAL ARRAY WORK

NEM
NUMBER OF CORRECTION FACTOR MODES

W
A COLUMN OF THE W MATRIX

DI
A ROW OF THE INVERSE-D MATRIX

EPS
EPSILON ARRAY

DCPBAR
A COLUMN OF THE DELTA-CP-BAR MATRIX

DEPTIL
A COLUMN OF THE DELTA-CP-TILDA MATRIX

WORK
TWO-DIMENSIONAL COMPLEX ARRAY CONTAINING THE

DELTA-CP-BAR MATRIX

EB
EPSILON-BAR ARRAY (INCREMENTAL WEIGHT FACTORS)

INTEGER
FLAGB, FLAGP

DIMENSION
X(NP), Y(NP), Z(NP), GMA(NP), DELA(NP)

COMPLEX
ONE, EPS(NP), DCPBAR(NP), DEPTIL(NP), CF(350),

1
W(NP), DI(NP), WORK(NP, NMAX), EB(1)

COMPLEX
COL(350), PHILBAR(350)

DATA
COL / 350*0.0 /

DATA
WORD / 4H /

10 FORMAT (1H1///39H SYMMETRIC DELTA-CP-TILDA, MODE, 13 /)
20 FORMAT (1H1///39H ANTISYMMETRIC DELTA-CP-TILDA, MODE, 13 /)
30 FORMAT (97H J XI(J) YIJ) Z(J) GAMMA(J) DELTA-AP(J) DCP-TILDA(J) / 58X

2 42HREAL
IMAG. REAL. IMAG. /

40 FORMAT (14, 4F9.4, F12.4, 4F12.6)

50 FORMAT (1H1 /// 39H FLAGB = 1, MONITOR-STEP ONLY /)

60 FORMAT (1H1 /// 50H CORRECTION FACTORS ** PREMULTIPLIER 1CASE /

70 FORMAT (1H1 /// 50H CORRECTION FACTORS ** POSTMULTIPLIER 1CASE /

80 FORMAT (1H1 /// 32H FLAGB = 2 -- MONITOR DATA //

1 43H CORRECTION FACTOR (TAPE INPUT) CODE IS +1A4 /)

82 FORMAT (1H1 /// 67H FLAGP = 4 -- TAPE CONTAINS THE EPSILON-1BAR (EB) VALUES /)

90 FORMAT (1H1 /// 3(16, 2E14.6))

IF (FLAGB .EQ. 1) WRITE (NPOT, 50)

IF (FLAGP .EQ. 4) REWIND NSCRCH

ONE = (1.0, 0.0)

REWIND NUTL

IF (FLAGB .NE. 2) GO TO 110

REWIND NTAPCF

READ (NTAPCF) WORD

WRITE (NPOT, 80) WORD

READ (NTAPCF) WORD

READ (NTAPCF) (CF(I), I = 1, NP)

IF (FLAGP .EQ. 4) WRITE (NPOT, 82)
CORRECTION FACTORS (E1GC) 02/03/76

WRITE (NPOT, 90) (I, CF(I), I = 1, NP)
IF (FLAGP.EQ. 4) GO TO 102
DO 100 I = 1, NP
EPS(I) = CF(I) - ONE
100 CONTINUE
GO TO 110
102 CONTINUE
DO 104 I = 1, NP
104 EPS(I) = CF(I)
110 CONTINUE
DO 310 MODE = 1, MODES
IF (IGQ.EQ. 2) GO TO 120
WRITE (NPOT, 10) MODE
GO TO 130
120 WRITE (NPOT, 20) MODE
130 WRITE (NPOT, 30)
C
L IF (FLAGB.EQ. 1) GO TO 280
GO TO (180, 140, 180, 180, 140)
140 CONTINUE
CALL POSN( NTAPW, IGQ )
CALL POSN( NTAPDI, IGQ )
DO 150 M = 1, MODE
150 READ (NTAPW) W
IF (FLAGP.EQ. 1 .OR. NEM.EQ. 0) GO TO 180
IF (MODE.GT. 1) GO TO 180
REWIND NSCRCH
DO 170 K = 1, NEM
READ (NSCRCH) KK, (PHIBAR(M), M = 1, NP)
COL(M) = COL(M) + PHIBAR(M) * EB(K)
160 CONTINUE
170 CONTINUE
C
180 CONTINUE
DO 270 I = 1, NP
DCPTIL(I) = (0.0, 0.0)
IF (FLAGB.NE. 2) CF(I) = ONE + EPS(I)
GO TO (250, 220, 250, 250, 190)
190 IF (NEM.NE. 0) GO TO 210
DO 200 N = 1, NP
200 COL(N) = EB(N)
210 CONTINUE
IF (FLAGB.NE. 2 .OR. MODE.GT. 1) GO TO 220
DO 212 M = 1, NP
212 EPS(M) = COL(M)
220 CONTINUE
READ (NTAPDI) DI
DO 240 J = 1, NP
IF (FLAGP.EQ. 1) GO TO 230
C
CORRECTION FACTORS (E1GC) 02/03/76

DCPTIL(I) = DCPTIL(I) + DI(J) * \( (W(J) + COL(J)) \)

GO TO 240

CONTINUE

DCPTIL(I) = DCPTIL(I) + DI(J) * (ONE + EPS(J)) * W(J)

GO TO 260

CONTINUE

DCPTIL(I) = CF(I) * WORK(I, MODE)

GO TO 260

CONTINUE

WRITE (NPOT, 40) I, X(I), Y(I), Z(I), GMA(I), DELA(I)

IF (L / LINES) LT 1 GO TO 270

L = L + 1

IF (IG) .EQ. 1 WRITE (NPOT, 10) MODE

IF (IG) .EQ. 2 WRITE (NPOT, 20) MODE

WRITE (NPOT, 30)

CONTINUE

GO TO 300

CONTINUE

DO 290 I = 1, NP

DCPTIL(I) = WORK(I, MODE)

CF(I) = ONE + EPS(I)

WRITE (NPOT, 40) I, X(I), Y(I), Z(I), GMA(I), DELA(I)

CONTINUE

WRITE (NUTL) IGO, MODE, DCPTIL

CONTINUE

IF (FLAGB .EQ. 2 .AND. FLAGP .EQ. 4) RETURN

IFP

CONTINUE

WRITE (NPOT, 70)

GO TO 340

CONTINUE

WRITE (NPOT, 60)

CONTINUE

WRITE (NPOT, 90) (I, CF(I)), I = 1, NP

IF (FLAGP .EQ. 4) GO TO 350

IF (FLAGB .EQ. 4) WRITE (NTAPCF) (CF(I)), I = 1, NP

REWRITE NUTL

RETURN

WRITE (NTAPCF) (EB(I)), I = 1, NP

WRITE (NPOT, 82) (I, EB(I)), I = 1, NP

REWRITE NUTL
CORRECTION FACTORS (E1GC) 02/03/76

RETURN
END

SUBROUTINE DELCINTAPE, NPOT, NC, NP, NMODE, NMAX, CIE, DCI, SAI, WORK

NTAPE TAPE NUMBER CONTAINING THE INTEGRATION MATRIX SA
NPOT DATA SET NUMBER OF THE SYSTEM OUTPUT DATA SET
NC NUMBER OF CONSTRAINTS
NP LENGTH OF THE DELTA-CP COLUMNS
NMODE NUMBER OF MODES
NMAX MAXIMUM NUMBER OF COLUMNS IN THE DELTA-CP MATRIX
CIE ARRAY OF THE INPUT VALUES C-I(I)
DCI THE DELTA-C ARRAY
SAI A ROW OF THE INTEGRATION MATRIX SA
WORK THE NP-BY-NMAX COMPLEX ARRAY CONTAINING THE
DELTA-CP-BAR MATRIX

COMPLEX CIE(NC), DCI(NC), WORK(NP, NMAX), SAI(NP), CI(35)

WRITE (NPOT,40)
REWRITE NTAPE
DO 20 I = 1, NC
DCI(I) = (0.0, 0.0)
READ (NTAPE) NOI, MI, SAI
DO 10 J = 1, NP
DCI(I) = DCI(I) + SAI(J)*WORK(J, MI)
CONTINUE
10 CONTINUE = DCI(I)
DCI(I) = CIE(I) - DCI(I)
CONTINUE
20 CONTINUE

WRITE (NPOT,50) (DCI(I), I = 1, NC)
WRITE (NPOT,60)
WRITE (NPOT,50) (CI(I), I = 1, NC)

CONTINUE
C
FORMAT (1H12H DELTA-C / )
50 FORMAT (8F13.6)
60 FORMAT (12H THEORETICAL C-VALUES / )

RETURN
END

SUBROUTINE EDBL(NPOT, NELIMS, NP, NS, LIMK, JARR, NSMOD, EBMIN, EMAX, EBACK, ELIM

NPOT DATA SET NUMBER OF THE SYSTEM OUTPUT DATA SET
NELIMS NUMBER OF INPUT CARDS FOR THE EBMIN, EMAX PAIRS
NP LENGTH OF THE DELTA-CP COLUMNS
NS = MAX (NP+NC NEM*NC)
LIMK FIRST AND LAST BOX NUMBERS FOR THE EBMIN, EMAX
JARR ARRAY OF BOX NUMBERS FOR WHICH THE EPSILON VALUES WERE MODIFIED
NSMOD NUMBER OF MODIFIED EPSILON VALUES
EBMIN MINIMUM VALUE ALLOWED FOR EPSILON
CORRECTION FACTORS (J1GC) 02/03/76

MAXIMUM VALUE ALLOWED FOR EPSILON

ARRAY OF THE CALCULATED EPSILON-BAR VALUES

ARRAY OF THE MODIFIED EPSILON VALUES (LIMITS)

DIMENSION LIMK(2, 100), JARR(350)

COMPLEX EBMIN(NELMS), EBMAX(NELMS), EB(NS)

ELIM(NS), ETMP

10 FORMAT (1H1//8H , 7X, 11HEPSILON-BAR ,17X, )

1 14HEPSILON-LIMIT, 14X, 12HEPSILON-LAST

20 FORMAT (18, 6F14.6)

J Cum = 0

NSMOD = 0

J = 1

30 K = 1

40 CONTINUE

LIM1 = LIMK(1, K)

LIM2 = LIMK(2, K)

IF (J.GT. NP) GO TO 80

IF (J.LT. LIM1 .OR. J.GT. LIM2) GO TO 70

THE INDEX J IS BETWEEN THE TWO PRESCRIBED LIMITS

EB1 = REAL(EBMIN(K))

EB2 = REAL(EBMAX(K))

ABSEB = REAL(EB(J))

IF (ABSEB .GE. EB1 .AND. ABSEB .LE. EB2) GO TO 80

JCum = JCUM + 1

IF (ABSEB .GT. EB2) GO TO 50

ETMP = EBMIN(K)

GO TO 60

50 CONTINUE

ETMP = EBMAX(K)

60 CONTINUE

JARR(J) = J

ELIM(J) = ETMP

GO TO 90

70 CONTINUE

IF (K.EQ. NELMS) GO TO 80

K = K + 1

GO TO 40

80 CONTINUE

90 CONTINUE

IF (J.EQ. NS) GO TO 100

J = J + 1

GO TO 30

100 CONTINUE
CORRECTION FACTORS (E1GC) 02/03/76

NSMOD = JCUM
IF (NSMOD .EQ. 0) RETURN
WRITE (NPOT,10)

C DO 110 J = 1, NS
ETEMP = EB(J)
IF (J .EQ. JARR(J)) ET EMP = ELIM(J)
WRITE (NPOT,20) J, EB(J), ELIM(J), ETEMP
C 110 CONTINUE
C RETURN
C END

SUBROUTINE EPSJ(NTPHIJ, NP, NEM, NMIN, EB, EPS, PHI)

NTPHIJ TAPE NUMBER CONTAINING THE PHI MATRIX COLUMNS
NP NUMBER OF ROW ELEMENTS IN THE PHI MATRIX
NEM NUMBER OF COLUMNS IN THE PHI MATRIX
NS = MAX (NP+NC, NEM+NC)
EB ARRAY OF THE EPSILON-BAR VALUES
EPS THE FINAL EPSILON ARRAY
PHI A COLUMN OF THE PHI MATRIX (WEIGHT FACTOR MODE SHAPES)

COMPLEX EPS(NP), EB(1), PHI(NP)
CALL ZEROUT(EPS, NP, 0, 0)
IF (NEM .EQ. 0) GO TO 30
RE WIND NTPHIJ
DO 20 J = 1, NEM
READ (NTPHIJ) MODENO, PHI
C DO 10 I = 1, NP
EPS(I) = EPS(I) + PHI(I) * EB(J)
C 10 CONTINUE
C 20 CONTINUE
C RETURN
C 30 CONTINUE
C DO 40 I = 1, NP
EPS(I) = EB(I)
C 40 CONTINUE
C RETURN
C END

SUBROUTINE GINV(NPOT, NTAPSBN, NC, NS, NX, DC, EB, B, S, SBB)

NPOT DATA SET NUMBER OF THE SYSTEM OUTPUT DATA SET
NTAPSBN TAPE NUMBER CONTAINING THE S-DOUBLE-BAR MATRIX ROWS
NC NUMBER OF CONSTRAINTS
NS = MAX (NP+NC, NEM+NC)
NX = NS IF NEM=0, NX= NEM+NC OTHERWISE
DC THE COMPLEX DELTA-C ARRAY
CORRECTION FACTORS (E1GC) 02/03/76

THE COMPLEX EPSILON-BAR ARRAY, OUTPUT OF GINV

ARRAY OF INTERMEDIATE SOLUTIONS

2-D COMPLEX WORK ARRAY, NC-BY-NC

THE COMPLEX NC-BY-NS S-DOUBLE-BAR MATRIX

COMPLEX DC(NC), EB(NS), B(NC), S(NC, NC), SBB(NC, NS), SCALER

COMPLEX SBBCT

DATA NERR, M, SCALER, 0, 1, (1.0, 0.0, 0.0)

NOTE THAT -EB- STANDS FOR EPSILON-TILDA

NSMNC = NX - NC
DO 10 I = 1, NC
READ (NTAPS8) (SBB(I, J), J = 1, NS)
IF (NSMNC .LT. 0) GO TO 10
EB(I) = DC(I)
10 CONTINUE

IF (NSMNC) 90, 20, 30
20 CONTINUE

NS = NC BRANCH --- SOLVE THE EQUATION DC = SBB * EB
FOR EB USING MIS2

CALL MIS2( SBB, NS, NC, EB, M, NERR, SCALER )

GO TO 140

30 CONTINUE

NS-GREATERTHAN-NC BRANCH ---
COMPUTE S = SBB * (SBB-CONJUGATE-TRANSPOSE) AND
SOLVE THE EQUATION DC = S * B FOR B USING MIS2

DO 60 I = 1, NC
BII(I) = DC(I)
DO 50 K = 1, NC
SII(K) = (0.0, 0.0)
DO 40 J = 1, NS
SBBCT = CONJG( SBB(I, J) )
SII(K) = SII(K) + SBB(I, J) * SBBCT
40 CONTINUE
50 CONTINUE
60 CONTINUE

WRITE (NPOT, 180)
WRITE (NPOT, 200) S
WRITE (NPOT, 170) DC

CALL MIS2( S, NC, NC, B, M, NERR, SCALER )

WRITE (6, 190)
CORRECTION FACTORS (E1GC)  02/03/76

WRITE (6,200) B
    COMPUTE EB = (SBB-CONJUGATE-TRANSPOSE) * B

DO 80  J = 1, NX
    EB(J) = (0.0, 0.0)
DO 70  I = 1, NC
    SBBCT = CONJG(SBB(I, J))
    EB(J) = EB(J) + SBBCT * B(I)
70  CONTINUE
80  CONTINUE
GO TO 140
90  CONTINUE

NS-LESS-THAN-NC BRANCH --- THE LEAST SQUARES CASE ---

    COMPUTE B = (SBB-CONJUGATE-TRANSPOSE) * (DELTA-C)
    COMPUTE S = (SBB-CONJUGATE-TRANSPOSE) * SBB , AND
    SOLVE THE EQUATION B = S * EB FOR EB USING MIS2

DO 130  J = 1, NX
    EB(J) = (0.0, 0.0)
DO 100  L = 1, NC
    SBBCT = CONJG(SBB(L, J))
    EB(J) = EB(J) + SBBCT * DC(L)
100  CONTINUE
DO 120  K = 1, NX
DO 110  I = 1, NC
    SBBCT = CONJG(SBB(I, J))
    S(J, K) = S(J, K) + SBBCT * SBB(I, K)
110  CONTINUE
120  CONTINUE

CALL MIS2( S, NC, NS, EB, M, NERR, SCALER )

140  CONTINUE

WRITE (NPOT,150)
WRITE (NPOT,160) (EB(I), I = 1, NX)
150  FORMAT ( // 40H OUTPUT OF GEN. INVERSE (EPS-TILDA) / ) INVO030
160  FORMAT ( 8F13.6 ) INVO040
170  FORMAT ( // 16H -DC- COLUMN / ) INVO050
180  FORMAT ( 1H1 // 16H -S- MATRIX / ) INVO060
190  FORMAT ( // 28H SOLUTION OF MATRIX EQ. / ) INVO070
200  FORMAT ( 6E16.6 ) INVO080

RETURN
END

PROGRAM E1GC(INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT, TAPE1=512, MAIN00002
CORRECTION FACTORS (E1GC) 02/03/76

1      TAPE2=512, TAPE3=512, TAPE4=512, TAPE8=512, TAPE9=512, TAPE10=512,
      TAPE11=512, TAPE12=512, TAPE13=512, TAPE14=512,

2      MAIN0004
5      MAIN0006
3      MAIN0008
6      MAIN0010
4      MAIN0020
7      MAIN0030

*** WEIGHT FACTORS FOR FINITE ELEMENT LIFTING SURFACE THEORY***

PROGRAM E1GC CREATES PRE- OR POST-MULTIPLYING MATRICES THAT MODIFY THEORETICAL DATA TO REFLECT EXPERIMENTALLY KNOWN DATA. THIS PROGRAM CAN ALSO BE USED TO MONITOR THEORETICAL PRESSURE DATA. INPUT TO PROGRAM IS THEORETICAL PRESSURES, DATA NEEDED FOR THE INTEGRATION MATRICES AND EXPERIMENTAL CONSTRAINTS. OUTPUT TO PROGRAM IS WEIGHT MATRICES, MODIFIED PRESSURES AND MONITORED DATA.

COMPLEX WORK(10000)
DIMENSION HEADER(20)
DATA  END, 4, HEND, LOC, LENGTH / 1, 10000 /
DATA  NPIT, NPOT / 5, 6, NMIN, NMAX, NRHS / 1, 2*10 /
C
10 FORMAT (15A4)
20 FORMAT (1H1///, 10X, 15A4) /)
30 FORMAT (8110) --WORK ARRAY DOES NOT FIT INTO CORE-- STOP
40 FORMAT (///, 46H) *** CORE REQUIRED (NWORK) = 16
42 FORMAT (///, 33H) *** CORE AVAILABLE = 16
1
50 CONTINUE
C
READ HEADER CARD
READ (NPIT,10) (HEADER(I), I = 1, 15)
IF (HEADER(1), EQ, END) STOP
WRITE (NPOT,20) (HEADER(I), I = 1, 15)

READ CONTROL DIMENSIONS
READ (NPIT,30) NP, NC, NEM, NELIMS, NMON, NAXIS
NS = NP + NC
IF (NEM .GE. NP) NS = NEM + NC
NMATR1 = NC * NC
NMATR2 = NC * NS
IF (NELIMS .NE. 0) NMIN = NELIMS

CALCULATE SIZE OF WORK ARRAY

NMAX = MAX0(NC, NMIN, NRHS)
NMATR3 = NC
NMATR4 = NP * NMAX
NMATRIX = NMATR1 + NMATR2 + NMATR3 + NMATR4
NWORK = 9*NP + 2*(NC*NMIN) + 4*NS + NMATRIX

WRITE (NPOT,42) NWORK, LENGTH
IF (LENGTH .GE. NWORK) GO TO 60
WRITE (NPOT,40)
STOP 16
CORRECTION FACTORS  (EIGC)  02/03/76

C  60 CONTINUE
C
C CALL ZEROUT( WORK(LOC), NWORK, 1, 0 )
C
L1   LOC
L2   L1 + NP
L3   L2 + NP
L4   L3 + NP
L5   L4 + NP
L6   L5 + NP
L7   L6 + NP
L8   L7 + NP
L9   L8 + NP
L10  L9 + NP
L11  L10 + NC
L12  L11 + NC
L13  L12 + NMIN
L14  L13 + NMIN
L15  L14 + NS
L16  L15 + NS
L17  L16 + NS
L18  L17 + NS
L19  L18 + NMAT1
L20  L19 + NMAT2
L21  L20 + NMAT3

C CALL WEXT( NP, NC, NEM, NELMS, NMON, NAXIS, NMIN, NMAX, NS, NPIT, NPUT, WORK( L1), WORK( L2), WORK( L3), WORK( L4), WORK( L5), WORK( L6), WORK( L7), WORK( L8), WORK( L9), WORK(L10), WORK(L11), WORK(L12), WORK(L13), WORK(L14), WORK(L15), WORK(L16), WORK(L17), WORK(L18), WORK(L19), WORK(L20), WORK(L21) )

C GO TO 50
END

SUBROUTINE MATM( NT, IGO, NR, NC, NMAX, A, C, B )

C NT TAPE NUMBER CONTAINING THE INVERSE-D MATRIX ROWS
C IGO 1 FOR SYMMETRIC MODES, 2 FOR ANTISYMMETRIC MODES
C NR NUMBER OF ROW ELEMENTS IN THE DELTA-CP-BAR MATRIX
C NC NUMBER OF COLUMNS IN THE DELTA-CP-BAR MATRIX
C NMAX MAXIMUM NUMBER OF COLUMNS IN ARRAY B
C A A ROW OF THE INVERSE-D MATRIX
C C COMPLEX WORK ARRAY
C B 2-D COMPLEX ARRAY IN WHICH THE DELTA-CP-BAR MATRIX IS STORED

C COMPLEX A(NR), C(NR), B(NR, NMAX)
DO 40 K = 1, NC
CALL POSNI( NT, IGO )
CALL ZEROUT( C, NR, 1, 0 )
DO 20 I = 1, NR
CORRECTION FACTORS (E1GC) 02/03/76

READ (NT) A
DO 10 J = 1, NR
   C(J) = C(J) + A(J) * B(J, K)
10 CONTINUE
20 CONTINUE

C
DO 30 I = 1, NR
   B(I, K) = C(I)
30 CONTINUE
RETURN
END

SUBROUTINE MODF( NC, NS, MASTSB, NEWTSB, JARR, SQRIT, ELIM, SBB, DCI, DCMOD )

C
NC NUMBER OF CONSTRAINTS, LENGTH OF ARRAYS DCI, DCMOD
NS LENGTH OF THE SBB ARRAY
MASTSB TAPE NUMBER CONTAINING ROWS OF THE S.DOUBLE-BAR MATRIX (SBB)
NEWTSB TAPE NUMBER CONTAINING ROWS OF THE MODIFIED S.DOUBLE-BAR MATRIX
JARR ARRAY OF BOX NUMBERS (ELEMENTS) FOR WHICH THE SBB VALUES ARE REPLACED BY ZEREOES
SQRIT SQRIT -- SEE EQUATIONS
ELIM ARRAY OF THE MODIFIED EPSILON VALUES
SBB A ROW OF THE S.DOUBLE-BAR MATRIX (INTEGRATION MATRIX WITH WEIGHT FACTOR MODES)
DCI ARRAY OF DELTA-C VALUES
DCMOD ARRAY OF THE MODIFIED DELTA-C VALUES

DIMENSION JARR(350), SQRIT(350)
COMPLEX ELIM(350), SBB(NS), DCI(NC), DCMOD(NC), SUM

C
REWRITE MASTSB
REWRITE NEWTSB
C
WRITE (6,30) NC, NS
DO 20 I = 1, NC
   SUM = (O.O, 0.0)
20 READ (MASTSB), SBB
C
DO 10 J = 1, NS
   IF (J .NE. JARR(J)) GO TO 10
   SUM = SUM + SBB(J) * ELIM(J) * SQRIT(J)
   SBB(J) = (0.0, 0.0)
10 CONTINUE
DCMOD(I) = DCI(I) - SUM
WRITE (NEWTSB), SBB
WRITE (6,32) I, (K, SBB(K), K = 1, NS)
C
20 CONTINUE
C
REWRITE NEWTSB
CORRECTION FACTORS  (E1GC)  02/03/76

LL = LL + 1
GO TO 90

C 100 CONTINUE
LLMAX = LL - 1
WRITE (NPOT,40) MODENO, ITYPE, NL, AL, BL
1   , ( (LIML(J, LL), J = 1, 2), LL = 1, LLMAX)
DO 220 J = 1, NP
PHI(J) = (0.0, 0.0)
110 CONTINUE
LIM1 = LIML(1, LL)
LIM2 = LIML(2, LL)
IF (J .GE. LIM1 .AND. J .LE. LIM2) GO TO 120
IF (LL .EQ. LLMAX) GO TO 220
LL = LL + 1
GO TO 110
120 CONTINUE
PHI(J) = (1.0, 0.0)
IF (NL .EQ. 0.0) GO TO 210
GO TO (130, 140, 150, 160, 170, 180), ITYPE
130 PHR = (ABS(X(J) - AL))** NL
GO TO 200
140 PHR = (ABS(Y(J) - AL))** NL
GO TO 200
150 PHR = (ABS(Z(J) - AL))** NL
GO TO 200
160 EARG = BL * (ABS(X(J) - AL))** NL
GO TO 190
170 EARG = BL * (ABS(Y(J) - AL))** NL
GO TO 190
180 EARG = BL * (ABS(Z(J) - AL))** NL
190 CONTINUE
PHI(J) = CMPLX( EXP(EARG), 0.0)
GO TO 210
200 CONTINUE
PHI(J) = CMPLX(PHR, 0.0)
210 CONTINUE
220 CONTINUE
230 WRITE (NPOT,260) MODENO, (PHI(J), J = 1, NP)
IF (L .EQ. NEM) GO TO 240
L = L + 1
GO TO 60
240 CONTINUE

C C
C PHI MATRIX COMPLETE  (DIMENSION NP-BY-NEM)
C SAVED ON TAPE NTPHIJ IN COLUMN ORDER
C C
C REWIND NTPHIJ
WRITE (NPOT,260)
DO 250 I = 1, NEM
READ (NTPHIJ, MODENO, PHI
WRITE (NPOT,270) MODENO

PHI0450
PHI0460
PHI0470
PHI0480
PHI0490
PHI0492
PHI0494
PHI0500
PHI0510
PHI0520
PHI0530
PHI0540
PHI0550
PHI0560
PHI0570
PHI0580
PHI0590
PHI0600
PHI0610
PHI0620
PHI0630
PHI0640
PHI0650
PHI0660
PHI0670
PHI0680
PHI0690
PHI0700
PHI0710
PHI0720
PHI0730
PHI0740
PHI0750
PHI0760
PHI0770
PHI0780
PHI0790
PHI0800
PHI0810
PHI0820
PHI0830
PHI0840
PHI0850
PHI0860
PHI0870
PHI0880
PHI0890
PHI0900
PHI0910
PHI0920
PHI0930
PHI0940
PHI0950
CORRECTION FACTORS (E1GC) 02/03/76

30 FORMAT (1H1 // 6H THE, I4, 4H BY, I4, 22H S-DU=BLE-BAR MATRM 
   MODF0410
   11X / )
32 FORMAT ( //8H ROW, I4 //13 ( I6, 2E14.6 )))
40 FORMAT ( // 4H MODF0420
   MODF0420
50 FORMAT ( // 20H DELTA-C-MOD / )
WRITE (6,50) (DCMOD(I), I = 1, NC)
WRITE (6,40) (DCMOD(I), I = 1, NC)
C
RETURN
END
SUBROUTINE PHIJ(NPIT, NPOT, NTPHIJ, NEM, NP, KODE, MODES, 
1    X, Y, Z, PHI
X, Y, Z COORDINATES OF THE PRESSURE POINTS
PHI COMPLEX ARRAY CONTAINING ONE COLUMN OF THE 
NP-BY-NEM PHI MATRIX
C
D I M E N S I O N L I M L (2, 25), X(NP), Y(NP), Z(NP)
C O M P L E X PHI(NP), PHI1, PHI2
R E A L NL
10 FORMAT (8I10)
20 FORMAT (2I10, 5F10.0)
30 FORMAT (2(110, 2F10.0))
40 FORMAT (2I10, F12.4, 2F13.5, 2I10 /6(58X, 2I8))/
50 FORMAT ( // 79H MODENO(L), TYPE(L), N(L), LIM1, LIM2 /)
C
C
RE W I N D N T P H I J
L = 1
C
60 READ (NPIT, 20) MODENO, ITYPE, NL, AL, BL
C IF (ITYPE NE. 0) GO TO 80
C
CALL Z E R O U T ( PHI, NP, 1, 0)
70 READ (NPIT, 30) J, PHII, JP1, PHI2
IF (J LE. KODE) GO TO 230
IF (PHII = PH1) IF (JP1 NE. 0) PHI(JP1) = PHI2
GO TO 70
C
80 CONTINUE
IF (L .EQ. 1) WRITE (NPOT, 50)
L = 1
90 READ (NPIT, 10) (LIML(J, LL), J = 1, 2)
IF (LIML(1, LL) .LE. KODE) GO TO 100
C
PHI0050
PHI0060
PHI0070
PHI0080
PHI0090
PHI0100
PHI0110
PHI0120
PHI0130
PHI0140
PHI0150
PHI0160
PHI0170
PHI0180
PHI0190
PHI0200
PHI0210
PHI0220
PHI0230
PHI0240
PHI0250
PHI0260
PHI0270
PHI0280
PHI0290
PHI0300
PHI0310
PHI0320
PHI0330
PHI0340
PHI0350
PHI0360
PHI0370
PHI0380
PHI0390
PHI0400
PHI0410
PHI0420
PHI0430
PHI0440
CORRECTION FACTORS (E1GC) 02/03/76

WRITE (NPOT, 280) PHI
250 CONTINUE
260 FORMAT ( 1H1 /// 16H -PHI- MATRIX / )
270 FORMAT ( / 9H COLUMN, I3 / )
280 FORMAT ( 8F13.6 )

C
RETURN
END
SUBROUTINE POSNI( NT, IGO )
C
NT  TAPE NUMBER TO BE POSITIONED FOR READING
IGO 1 FOR SYMMETRIC MODES, 2 FOR ANTISYMMETRIC MODES
C
READ (NT) NROW, NCOL1, NCOL2
IF (IGO .EQ. 1 OR NCOL1 .EQ. 0) RETURN
DO 10 J = 1, NCOL1
READ (NT)
10 CONTINUE
C
RETURN
END
SUBROUTINE RECOI( NTAPE, A, N )
C
NTAPE  TAPE NUMBER
A  ARRAY TO BE READ FROM TAPE
N  LENGTH OF ARRAY A
C
DIMENSION A( N )
READ (NTAPE) A
RETURN
END
SUBROUTINE SAIJ(NPIT, NPOT, NTSAIJ, NTSANJ, NC, NP, NMON, NAXIS, 
1 AIT, CIE, X, Y, Z, CG, SG, DELA, FLAGA, FLAGF, KODE, IPRINT, 
2 LABEL, SAI)
C
NPIT DATA SET NUMBER OF THE SYSTEM INPUT DATA SET
NPOT DATA SET NUMBER OF THE SYSTEM OUTPUT DATA SET
NTSAIJ TAPE NUMBER CONTAINING THE MATRIX ROWS SAI
NTSANJ TAPE NUMBER CONTAINING THE MATRIX ROWS SAN
NC NUMBER OF CONSTRAINTS
NP NUMBER OF DELTA-CP ELEMENTS
NMON NUMBER OF SETS OF THE MONITORING DATA
NAXIS NUMBER OF AXES
AIT CONSTRAINTING EFFECTIVENESS OF EXPERIMENTAL DATA
CIE EXPERIMENTAL (OR ANY OTHER) CONSTRAINT ON THE DATA
X, Y, Z COORDINATES OF THE PRESSURE POINTS (BOXES)
CG, SG COSINE-, SINE OF BOX DIHEDRAL ANGLES
DELA BOX AREAS
FLAGA 0, AXIS ENDPOINTS ARE INPUT
1, DIRECTION COSINES ARE INPUT
FLAGF 0, CIE IS A FORCE IN DIRECTION OF AXIS
1, CIE IS A MOMENT ABOUT AXIS
KODE = -1
IPRINT DETAIL PRINT FLAG
IPRINT = 1, PRINT SAI AND SAN ROWS
CORRECTION FACTORS (E1GC) 02/03/76

IPRINT = 0, NO PRINT

LABEL SAI

INTEGER FLAGA, FLAGF

DIMENSION X(NP), Y(NP), Z(NP), CG(NP), SG(NP), DELA(NP)

1 DIMENSION IAX(35), IFF(35), DELI(35), EMI(35), AIT(35), CIT(35)

1 DIMENSION LIMI(2,35), LIMN(2,35), X1(25), ETA(25), ZETA(25)

1 DIMENSION NAXI(35), IFNI(35), LABEL(10, 35)

COMPLEX CIE(35), SAI(NP)

C

10 FORMAT (8I10)
12 FORMAT (34X, 217)
20 FORMAT (8F10.0)
22 FORMAT (1H1, /)
30 FORMAT (2I10, 4F10.0, 10A1)
40 FORMAT (1H1, /, 3H, THE, 14, 32H SETS OF INPUT DATA FOR ALL AXES)
1//102H AXISON(R) FLAGA(R) X1(R) ETA(R) ZETA(R) / 66X,
37H(COSA(R)) (COSB(R)) / (COSG(R)) /
60 FORMAT (2I10, 3F14.6, 1E14.6, 2F14.6)
70 FORMAT (2I10, 217, 10X, 1F14.6, 1E14.6, 2F14.6)
80 FORMAT (2I10, 217, 10X, 1F14.6, 1E14.6, 6X, 10A1)
90 FORMAT (1I10, 44H SETS OF INPUT DATA FOR ALL AXES)
1 LINTS // 93H AXISON(I) FLAG(I) DELTA M LIM1 LIM2
2 A-WIG(I) C-WIG(I) C-E(I) / 82X,
20HREAL IMAG. / /
100 FORMAT (1I10, 35H SETS OF INPUT DATA FOR MONITORING)
1 // 90H AXISON(N) FLAG(N) DELTA M LIM1 LIM2

C

IR = 1
WRITE (NPOT, 50) NAXIS

110 READ (NPIT, 10) IAX(IR), IFA(IR)
READ (NPIT, 20) X11(IR), ETA1(IR), ZETA1(IR)
1 WRITE (NPOT, 60) IAX(IR), IFA(IR), X11(IR), ETA1(IR), ZETA1(IR)
1 IF (IR .EQ. NAXIS) GO TO 120
1 IR = IR + 1
GO TO 110

C

120 CONTINUE
IF (NC .EQ. 0) GO TO 160
WRITE (NPOT, 22)
1 I I
WRITE (NPOT, 90) NC

130 READ (NPIT, 10) JAX(I), IFF(I)
READ (NPIT, 30) NDI, MI, AIT(I), CIT(I), CIE(I)
CORRECTION FACTORS (E1GC) 02/03/76

WRITE (NPUT,70) JAX(I), IFF(I), NDI*, MI , AIT(I),

I = 1
CIT(I), CIE(I)

READ (NPUT,10) (LIMI(J, II), J = 1, 2)
IF (LIMI(I, II) .LE. KODE) GO TO 150
WRITE (NPUT,12) (LIMI(J, II), J = 1, 2)
II = II + 1
GO TO 140

C 150 CONTINUE
IIIMAX = II - 1

COMPUTE ELEMENTS OF THE SA-I-J MATRIX (DIM. NC-BY-NP)
AND SAVE MATRIX ON TAPE NTSAIJ IN ROW ORDER

FLAGF = IFF(I) + 1
IR = JAX(I)
FLAGA = IFA(IR)+ 1
C
DO 1 = 1
CALL SROW(FLAGA, FLAGF, XI1, ETA1; ZETA1, CG, SG, CIT
1 , X, Y, Z, DELA, LIMI, IIIMAX, I
2 , NP, IR, XI2, ETA2, ZETA2, SAI)

WRITE (NTSNIJ) NDI, MI, SAI
IF (I .EQ. NC) GO TO 160
I = I + 1
GO TO 130

C 160 CONTINUE
IF (NMON .EQ. 0) GO TO 200
WRITE (NPUT,22)

SAI MATRIX COMPLETE (DIMENSION NC-BY-NP)
SAVED ON TAPE NTSAIJ IN ROW ORDER

IF (IDO .EQ. 2) GO TO 200
IDO = 2
REWIND NTSAIJ
N = 1
WRITE (NPUT,100) NMON

170 READ (NPUT,10) NAX(N), IFN(N)
READ (NPUT,40) NDN*, MN , ANT(N), CNT(N),
1
WRITE (NPUT,80) (LABEL(M, N), M = 1, 10)

180 READ (NPUT,10) (LIMN(J, NN), J = 1, 2)
IF (LIMN(I, NN) .LE. KODE) GO TO 190
WRITE (NPUT,12) (LIMN(J, NN), J = 1, 2)
CORRECTION FACTORS (ELGC) 02/03/76

NN = NN + 1
GO TO 180
190 CONTINUE
NNMAX = NN - 1

COMPUTE ELEMENTS OF THE SA-N-J MATRIX (DIM. NMON-BY-NP)

AND SAVE MATRIX ON TAPE NTSANJ IN ROW ORDER

FLAGF = IFN(N) + 1
IR = NAX(N)
FLAGA = IFA(IR) + 1

CALL SROW(FLAGA, FLAGF, X1, ETA1, ZETA1, CG, SG, CNT
10 X, NP, Y, Z, DELA, LIAR, NNMAX, N)

2 WRITE (NTSANJ) NDN, MN, SAI

IF (N.EQ. NMON) GO TO 200

N = N + 1
GO TO 170

200 CONTINUE

SAN MATRIX COMPLETE (DIMENSION NMON-BY-NP)
S------- SAVE ON TAPE NTSANJ

IF (IPRINT.EQ. 0) GO TO 270
IF (NC.EQ. 0) GO TO 220

REWIND NTSAIJ
WRITE (NPOT, 240)
DO 210 I = 1, NC
READ (NTSAIJ) NDI, MI, SAI
WRITE (NPOT, 260) (SAI(J), J = 1, NP)

210 CONTINUE

220 CONTINUE
IF (NMON.EQ. 0) GO TO 270

REWIND NTSAIJ
WRITE (NPOT, 250)
DO 230 I = 1, NMON
READ (NTSANJ) NDN, MN, SAI
WRITE (NPOT, 260) (SAI(J), J = 1, NP)

230 CONTINUE

REWIND NTSAIJ
REWRITE NTSAIJ

240 FORMAT (IH1 // 18H SAI MATRIX ROWS / )
250 FORMAT (IH1 // 18H SAI MATRIX ROWS / )
260 FORMAT (8F13.6)

270 CONTINUE
RETURN
END

SUBROUTINE SBAR(NTSB1J, NTAPDI, NC, NP, NS, FLAGP, FLAGT, FLAGW, SBAR0040
CORRECTION FACTORS (E1GC) 02/03/76

1 1, IGO, SQRRT, AIW, SAI, DI, W, DELCPB, SBI  ) SBAR0050

NTSB1J TAPE NUMBER CONTAINING ROWS OF THE S-BAR MATRIX SBAR0060
NTAPDI TAPE NUMBER CONTAINING ROWS OF THE INVERSE-D MATRIX SBAR0070
NC NUMBER OF CONSTRAINTS SBAR0080
NP NUMBER OF DELTA-CP ELEMENTS SBAR0090
NS LENGTH OF THE S-BAR MATRIX ROWS SBAR100
FLAGP OPTION FLAG FOR DELTA-CP AND/OR PRE- OR POST-
MULTIPLYING CORRECTIONS SBAR102
FLAGT OPTION FLAG FOR WEIGHTS SBAR103

FLAGW OPTION FLAG FOR NORMALWASH INPUT SBAR105
I INTERMEDIATE INDEX SBAR106
IGO 1 FOR SYMMETRIC MODES, 2 FOR ANTISYMMETRIC MODES SBAR107
SQRIT SQRIT( ) -- SEE EQUATIONS FOR DEFINITION SBAR108
AIW CONSTRAINTING EFFECTIVENESS SBAR109
SAI A ROW OF THE SAI MATRIX (INTEGRATES DELTA-CP INTO COEFFICIENTS) SBAR110
DI A ROW OF THE INVERSE-D MATRIX SBAR112
W A COLUMN OF THE NORMALWASH MATRIX SBAR113
DELCPB A COLUMN OF THE LIFTING PRESSURE COEFFICIENTS, SBAR114
DEL-CP-BAR

DIMENSION SQRRT(350), COMPLEX SAI(NP), DI(NP), W(NP), DELCPB(NP), SBI(NS), SAXDI
INTEGER FLAGP, FLAGT, FLAGW SBAR116

DATA EPSLON, AIFIX / .0001, 10000, /

***

IF (FLAGP .EQ. 1 .OR. FLAGP .EQ. 4) GO TO 20

**********

FLAGP = 0, 2, 3 OPTIONS (PRE-MULTIPLY BRANCH)

DO 10 J = 1, NP
SAXDI = SAI(J) * DELCPB(J)
SBI(J) = SAXDI / SQRRT(J)

10 CONTINUE

GO TO 60

**********

FLAGP = 1, 4 OPTIONS (POST-MULTIPLY BRANCH)

20 CONTINUE
CALL POSN( NTAPDI, IGO )

DO 40 J = 1, NP
READ (NTAPDI) DI

DO 30 K = 1, NP
SBI(K) = SBI(K) + SAI(J) * DI(K)

30 CONTINUE
CORRECTION FACTORS (E1GC) 02/03/76

40 CONTINUE
IF (FLAGP .EQ. 4) GO TO 60
DO 50 J = 1, NP
SBI(J) = SBI(J) * W(J) / SQRTT(J)
50 CONTINUE

60 CONTINUE
JJ = NP + 1
IF (AIW .LE. EPSLON) GO TO 70
SBI(JJ) = (1.0 - AIW) / AIW
GO TO 60
70 SBI(JJ) = AIFIX
80 CONTINUE

C ONE ROW OF THE S-BAR-I-J MATRIX IS COMPLETE
---
WRITE IT ON TAPE NTSBIJ

WRITE (NTSBIJ, SBI
WRITE (6,90)
WRITE (6,100) (SBI(J), J = 1, NS)
90 FORMAT (1HO 1// 18H ONE S-BAR ROW / )
100 FORMAT (8FI13.6)
RETURN
END

SUBROUTINE SDBL(NSCRCH, NUTL, MASTSB, NTPHIJ, NTAPW, NTSAIJ, NTAPDI, IGO, FLAGW, FLAGP, FLAGT, NC, NP, NS, NEM, SQRTT, AIT, DELA, SBB, SBI, SAI, DI, W, PHI, DELCPB, WORK)

NUTL  UTILITY (SCRATCH) TAPE NUMBER
MASTSB TAPE NUMBER CONTAINING THE SBB MATRIX ROWS
NTPHIJ TAPE NUMBER CONTAINING THE PHI MATRIX COLUMNS
NTAPW TAPE NUMBER CONTAINING THE W MATRIX COLUMNS
NTSAIJ TAPE NUMBER CONTAINING THE SAI MATRIX ROWS
NTAPDI TAPE NUMBER CONTAINING THE INVERSE-D MATRIX ROWS
IGO  1 FOR SYMMETRIC MODES, 2 FOR ANTISYMMETRIC MODES
FLAGW OPTION FLAG FOR NORMALWASH INPUT
FLAGP OPTION FLAG FOR DCP-INPUT AND/OR PRE- OR POST-
FLAGT OPTION FLAG FOR WEIGHTS
NC  NUMBER OF CONSTRAINTS
NP  NUMBER OF DELTA-CP ELEMENTS
NS = MAX (NP+NC, NEM+NC)
NEM  NUMBER OF CORRECTION FACTOR MODES
SQRTT = SQRTT( ) -- SEE EQUATIONS FOR DEFINITION
AIT  CONSTRAINT EFFECTIVENESS
DELA BOX AREAS
SBB  A ROW OF THE S-DOUBLE-BAR MATRIX
SBI  A ROW OF THE S-BAR MATRIX
SAI  A ROW OF THE SAI MATRIX
DI  A ROW OF THE INVERSE-D MATRIX
W  A COLUMN OF THE W MATRIX (NORMALWASH)
PHI  A COLUMN OF THE PHI MATRIX
CORRECTION FACTORS (E1GC) 02/03/76

DO 200 I = 1, NC
AIW = A1(I)
CALL ZEROUT( SBI, NS, 1, 0 )
READ (NTSAIJ) NOI, MI, SAI

C 150 CONTINUE
DO 160 J = 1, NP
160 DELCPB(J) = WORK(J, MI)
GO TO 190, 170, 190, 170, IFP
C 170 CONTINUE
CALL POSN( NTAPW, IGO )
DO 180 M = 1, MI
180 READ (NTAPW) W

C 190 CONTINUE
CALL SBAR(NTSB1J, NTAPDI, NC, NP, NS, FLAGP, FLAGT, FLAGW, I1, IGO, SQRTR, AIW, SAI, DI, W, DELCPB, SBI )

C 200 CONTINUE
IF (NEM .EQ. 0) GO TO 290

C REWIND NUTL
REWIND MASTSB
DO 205 J = 1, NP
205 DELCPB(J) = WORK(J, 1 )
NEMI = NEM + 1
NEMNC = NEM + NC
WRITE (6, 300) NC, NEMNC
DO 280 I = 1, NC
REWIND NTPH1J
READ (NUTL ) SBI'
CALL ZEROUT( SBB, NS, 1, 0 )
DO 260 K = 1, NEM
READ (NTPH1J) MODEND, PHI
IF (FLAGP .EQ. 4) GO TO 220
DO 210 J = 1, NP
SBB(K) = SBB(K) + SBI(J) * PHI(J)
210 CONTINUE
GO TO 260

C 220 CONTINUE
EL = (0.0, 0.0)
DO 230 L = 1, NP
EL = EL + PHI(L) * DELCPB(L)
230 CONTINUE

C CALL ZEROUT( PHIBAR, 350, 1, 0 )
DO 240 M = 1, NP
PHIBAR(M) = PHI(M) * EL
240 CONTINUE
WRITE (NSCRCH) K, (PHIBAR(M), M = 1, NP)
CORRECTION FACTORS (EIGC) 02/03/76

C
DO 250 J = 1, NP
SBB(K) = SBB(K) + SBI(J) * PHIBAR(J)
C
250 CONTINUE
C
260 CONTINUE
DO 270 K = NEM1, NEMNC
NPK = NP + K - NEM
SBB(K) = SBI(NPK)
C
270 CONTINUE
WRITE (MASTSB) SBB
WRITE (6, 310) I, (K, SBB(K), K = 1, NEMNC)
C
280 CONTINUE
REWIND MASTSB
C
290 CONTINUE
REWIND NTSBIJ
FORMAT (IH1 // 6H THE, I4, 4H BY, I4, 22H S-DOUBLE-BAR MATRX)
11X / ) ]
FORMAT (//8H ROW, I4 // (3 ( I6, 2E14.6 )) )
IF (FLAGP .EQ. 4) REWIND NSCRCH
RETURN
END
SUBROUTINE SROWFLAGA, FLAGF, X11 , ETA1 , ZETA1, CG, SG, CTL1
1 2
: NP ; IR ; XI2 ; ETA2 ; ZETA2 ; SAI )
C
FLAGA 0, AXIS ENDPOINTS ARE INPUT
1; DIRECTION COSINES ARE INPUT
C
FLAGF 0; CIE IS A FORCE IN DIRECTION OF AXIS
1; CIE IS A MOMENT ABOUT AXIS
C
XI1, ETA1, ZETA1 AXIS ENDPOINT COORDINATES
CG, SG COSINE- SINE OF BOX DIHEDRAL ANGLES
C
CTIL CONSTANT USED TO NONDIMENSIONALIZE INTEGRATED DATA
X, Y, Z COORDINATES OF THE PRESSURE POINTS (BOXES)
C
DELA BOX AREAS
LI M FIRST- AND LAST BOX NUMBERS FOR THE INTEGRATION OF
THE DELTA-CP VALUES
C
IIMAX NUMBER OF LI MI SETS INPUT FOR ONE CONSTRAINT
I INTERMEDIATE INDEX
C
NP NUMBER OF DELTA-CP VALUES
C
IR ROW INDEX OF SAI MATRIX
C
XI2, ETA2, ZETA2 SECOND AXIS ENDPOINT COORDINATES WHEN
FLAGF=0, DIRECTION COSINES WHEN FLAGF=1
C
SAI A ROW OF THE INTEGRATION MATRIX (SA-I, OR SA-NJ)
C
INTEGER FLAGA, FLAGF
DIMENSION XI1 (25), ETA1(25), ZETA1(25), CG(NP), SG(NP)
1 , XI2(25), ETA2(25), ZETA2(25), CTIL(35)
DIMENSION X(NP), Y(NP), Z(NP), DELA(NP), LIMI(2, 35)
C
COMPLEX SAI(NP)
CORRECTION FACTORS (E1GC) 02/03/76

C
GO TO (10,20), FLAGA
10 XID = XI2 (IR) - XI1 (IR)
ETA2 = ETA2 (IR) - ETA1 (IR)
ZETAD = ZETA2 (IR) - ZETA1 (IR)
P = SQRT(XID**2 + ETA2**2 + ZETAD**2)
COSAI = XID / P
COSBI = ETA2 / P
COSGI = ZETAD / P
GO TO 30
C
20 CONTINUE
COSAI = XI2 (IR)
COSBI = ETA2 (IR)
COSGI = ZETA2 (IR)
30 CONTINUE
II = 1
DO 90 J = 1, NP
ABJ = 0.0
40 CONTINUE
LIM1 = LIM1(1, II)
LIM2 = LIM1(2, II)
IF (J .GE. LIM1 .AND. J .LE. LIM2) GO TO 50
IF (II .EQ. IIMAX) GO TO 80
II = II + 1
GO TO 40
C
50 CONTINUE
GO TO (60,70), FLAGF
60 CONTINUE
ABJ = (-COSBI * SG(J) + COSGI * CG(J)) / CTIL(I)
GO TO 80
70 CONTINUE
XDIF = X(J) - XI1 (IR)
YDIF = Y(J) - ETA1 (IR)
ZDIF = Z(J) - ZETA1 (IR)
ABJ = (COSAI * (YDIF * CG(J) + ZDIF * SG(J))
1 / 2
-COSBI * (XDIF * CG(J))
-COSGI * (XDIF * SG(J))} / CTIL(I)
80 CONTINUE
II = 1
SAI(J) = CMPLX(ABJ*DELA(J), 0.0)
90 CONTINUE
RETURN
END

SUBROUTINE WEYT(NP, NC, NEM, NELIMS, NMON, NAXIS, NMIN, WEYT0000
1, NMAX, NS, NPIT, NPOT, W
2, DI, CCP, EPS, PHI, SAI
3, DCPTIL, DELCPB, COL, CIE, DCMOD
4, EBMN, EBMAX, EB, ELIM, SBB
5, SBI, S, SBMAT, DCI, WORK

C
CORRECTION FACTORS (E1GC) 02/03/76

NP  NUMBER OF DELTA-CP ELEMENTS
NC  NUMBER OF CONSTRAINTS
NEM  NUMBER OF CORRECTION FACTOR MODES
NELMS  NUMBER OF INPUT CARDS FOR EBMIN, EMAX PAIRS
NMON  NUMBER OF SETS OF MONITORING DATA
NAXIS  NUMBER OF AXES FOR USE IN INTEGRATION OF DELTA-CP NMIN  = MAX ( 1, NELMS)
NMAX  = MAX ( NC, NMIN, 10 )
NS  = MAX ( NC, NMIN, NMAX )
NPIT  DATA SET NUMBER OF THE SYSTEM INPUT DATA SET
NPOT  DATA SET NUMBER OF THE SYSTEM OUTPUT DATA SET
W  A COLUMN OF THE NORMAL WASH MATRIX
DI  A ROW OF THE INVERSE-D MATRIX
DCP  ARRAY OF DELTA-CP ELEMENTS (THEORETICAL VALUES)
EPS  EPSILON ARRAY (INCREMENTAL WEIGHT FACTORS)
PHI  A COLUMN OF THE PHI MATRIX (WEIGHT FACTOR MODE SHAPES)
SAI  INTEGRATION MATRIX ROW
DCPTIL  PRESSURES MODIFIED BY WEIGHT MATRIX
DELCBP  LIFTING PRESSURE COEFFICIENTS
CIE  ARRAY OF THE INPUT VALUES C-I(E)
DCMOD  ARRAY OF THE MODIFIED DELTA-C VALUES
EBMIN  MINIMUM VALUE ALLOWED FOR EPSILON
EBMAX  MAXIMUM VALUE ALLOWED FOR EPSILON
EBEBBAR  EPSILON-BAR ARRAY (INCREMENTAL WEIGHT FACTORS)
EBELEM  ARRAY OF THE MODIFIED EPSILON VALUES
SSB  A ROW OF THE S-DOUBLE-BAR MATRIX
SBI  A ROW OF THE S-BAR MATRIX
SBMAT  2-D COMPLEX WORK ARRAY, NC-BY-NC
DCI  ARRAY OF THE DELTA-C VALUES
WORK  2-D COMPLEX ARRAY, NP-BY-NMAX, IN WHICH THE LIFTING PRESSURE COEFFICIENT MATRIX (DELCBP)
       COLUMNS ARE STORED

DIMENSIONS

X(350), Y(350), Z(350), GA(350), SC(350), SG(350),
DEL(350), ROW(350), AIT(350), JARR(350)

1
2

LIMK(2, 100), LIML(2, 100), LABEL(10, 35), SQRTT(350) WEYT0440

1
2

W(NP), D(NP), DC(NP), EPS(NP), PHI(NP), SAI(NP),
DELCBP(NP), DELCBP(NP), COL(NP), CIE(NP), DCMOD(NP)

1
2

EBMIN(NMIN), EBMIN(NMIN), EBMIN(NMIN), EBLMIN(NS), SBB(NS), SBB(NS)

1
2

SCI(NC, NS), SBI(NC, NC), SBMAT(NC, NC), DCI(NC)

1

WORK(NP, NMAX), B(35), CE(35)

INTEGER

FLAGA, FLAGB, FLAGP, FLAGT, FLAGW, FLAGF, FLAGI, FLAGD

DATA

KODE, NUL1, NUL2, NTSAI, NTSAI, NTSAI, NTPHIJ, NTPHIJ, MASTSB

1
2

NEWNB, NTGEO, NTGEO, NTGEO, NTGEO, NTGEO, NTGEO, NTGEO, NTGEO

1
2

JARR / 350 * 0 /, SQRTT / 350 * 1 /, LINES / 48 /,
DATA LABEL / 350 * 1H /, PRE, POST / 4HPRE, 4HPOST /

10 FORMAT ( BI10 )
20 FORMAT ( BI10, 4F10.0 )
CORRECTION FACTORS (E1GC) 02/03/76

30 FORMAT ( // 27H CONTROL FLAGS -- // ) WETY0580
40 FORMAT ( // 45H FLAGB = 0 CORRECTION FACTORS CALCULATED ) WETY0590
50 FORMAT ( // 75H FLAGB = 1 DATA MONITORED ONLY - NO CORRECTION WETY0600
10 FACTORS ) WETY0610
52 FORMAT ( // 75H FLAGB = 2 DATA MONITORED - CORRECTION FACTORS WETY0612
11 TAKEN FROM TAPE ) WETY0614
60 FORMAT ( // 75H FLAGP = 0 PREMULTIPLIER - PRESSURE AND GEOMETR WETY0620
1Y TAKEN FROM TAPE ) WETY0630
70 FORMAT ( // 75H FLAGP = 1 POSTMULTIPLIER - DT INVERSE AND GEOM WETY0640
1TRY TAKEN FROM TAPE ) WETY0650
80 FORMAT ( // 75H FLAGP = 2 PREMULTIPLIER - DT INVERSE AND GEOM WETY0660
1TRY TAKEN FROM TAPE ) WETY0670
90 FORMAT ( // 75H FLAGP = 3 PREMULTIPLIER - PRESSURE AND GEOMETR WETY0680
1Y TAKEN FROM CARDS ) WETY0690
92 FORMAT ( // 75H FLAGP = 4 NEW POSTMULTIPLIER - DT INVERSE AND WETY0692
1GEOMETRY TAKEN FROM TAPE ) WETY0694
100 FORMAT ( // 50H FLAGT = 0 WEIGHTS ARE A FUNCTION OF THE LOADS ) WETY0700
110 FORMAT ( // 50H FLAGT = 1 WEIGHTS = 1.0 ) WETY0710
120 FORMAT ( // 60H FLAGW = 0 NORMAL WASH TAKEN FROM TAPE (IF NEEDED ) WETY0720
1DEDD ) WETY0730
130 FORMAT ( // 60H FLAGW = 1 NORMAL WASH TAKEN FROM CARDS (IF NEEDED ) WETY0740
1DEDD ) WETY0750
134 FORMAT ( // 10H IPRINT, = 12, 23H (DETAIL PRINT FLAG ) ) WETY0756
140 FORMAT ( // 27H CONTROL DIMENSIONS -- // ) WETY0760
1 10 10 H NP = 14 / 10H NC = 14 / WETY0770
2 10 10 H NEM = 14 / 10H NELMS = 14 / WETY0780
3 10 10 H NMON = 14 / 10H NAXIS = 14 / ) WETY0790
150 FORMAT ( // 34H LIST OF INPUT/OUTPUT TAPES -- // ) WETY0800
1 19H GEOMETRY TAPE = i3/i19H DELTA-CP TAPE = i3 / WETY0810
2 19H W TAPE = i3/i19H D- INVERSE TAPE = i3 / WETY0820
3 19H CORR. FACTORS = i3 / WETY0822
160 FORMAT ( i4, 19, 112, 4F16.6 ) WETY0830
170 FORMAT ( i4, 19, 23H EPSILON LIMITS -- // ) WETY0840
1 48H K LIM-1(K) LIM-2(K) EPSILON-BAR-MIN, WETY0850
2 17X, 15H EPSILON-BAR-MAX / 32X, 20H REAL IMAG. WETY0860
3 12X, 20H REAL IMAG. / ) WETY0870
180 FORMAT ( I1H /// 32H CARD-READ OPTION IS SPECIFIED // 6H ) WETY0880
1 6X, 1HX, 12X, 1HY, 12X, 1HZ, 11X, 5H GAMMA, 8X, 7H DELTA-A / ) WETY0890
190 FORMAT ( 6F10.0 ) WETY0900
200 FORMAT ( 8F13.6 ) WETY0910
210 FORMAT ( 1H1 /// 8F13.6 ) WETY0920
220 FORMAT ( 1H1 /// 34H SYMMETRIC DELTA-CP MATRIX / ) WETY0930
230 FORMAT ( 1H0 /// 34H ANTISYMMETRIC DELTA-CP MATRIX / ) WETY0940
240 FORMAT ( // 9H COLUMN = 13 / ) WETY0950
C READ AND WRITE CONTROL FLAGS
C READ (NPIT,10) FLAGB, FLAGP, FLAGT, FLAGW, FLAGI, IPRINT
WRITE (NPOT,30)
IF (FLAGB = 0) WRITE (NPOT,40)
IF (FLAGP = 0) WRITE (NPOT,50)
IF (FLAGT = 0) WRITE (NPOT,22)
IF (FLAGW = 0) WRITE (NPOT,60)
C
CORRECTION FACTORS (EIGC)  02/03/76

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IF (FLAGP .EQ. 1) WRITE (NPOT,70)
IF (FLAGP .EQ. 2) WRITE (NPOT,80)
IF (FLAGP .EQ. 3) WRITE (NPOT,90)
IF (FLAGP .EQ. 4) WRITE (NPOT,92)
IF (FLAGT .EQ. 0) WRITE (NPOT,100)
IF (FLAGT .EQ. 1) WRITE (NPOT,110)
IF (FLAGW .EQ. 0) WRITE (NPOT,120)
IF (FLAGW .EQ. 1) WRITE (NPOT,130)
WRITE (NPOT,134) IPRINT
WRITE CONTROL DIMENSIONS
WRITE (NPOT,140) NP, NC, NEM, NELIMS, NMDN, NAXIS
READ NUMBER OF MODES AND WRITE LIST OF INPUT/OUTPUT TAPES
READ (NPIT, 10) NMSYM, NMASYM
WRITE (NPOT,150) NTGEOM, NTDCP, NTAPW, NTAPDI, NTAPCF

C IFP = FLAGP + 1
IF (FLAGP .EQ. 3) GO TO 310
C READ GEOMETRY TAPE
C REWIND NTGEOM
READ (NTGEOM) LENGTH
CALL RECD(NNTGEOM, X,  LENGTH )
CALL RECD(NNTGEOM, Y,  LENGTH )
CALL RECD(NNTGEOM, Z,  LENGTH )
CALL RECD(NNTGEOM, GMA, LENGTH )
CALL RECD(NNTGEOM, DELA, LENGTH )
IF (FLAGP .NE. 0) GO TO 500
IF (FLAGT .EQ. 0) GO TO 500
REWIND NTDCP
REWIND NEWDCP
READ (NTDCP) LENGTH, NMSYM, NMASYM
WRITE (NEWDCP) LENGTH, NMSYM, NMASYM
MODCP = NMSYM + NMASYM
DO 300 J = 1, MODCP
READ (NTDCP) ROW
DO 290 I = 1, NP
290 DCP(I) = CMPLX(ROW(I), 0.0)
WRITE (NEWDCP) DCP
300 CONTINUE
REWIND NEWDCP
NTDCP = NEWDCP
GO TO 500
310 CONTINUE
REWIND NUTL1
REWIND NTDCP
WRITE (NPOT,180)
```

C
CORRECTION FACTORS (E1GC) 02/03/76

READ GEOMETRY ARRAYS AND DELTA-CP MATRIX FROM CARDS

DO 330 I = 1, NP
READ (NPIT, 190) X(I), Y(I), Z(I), GMA(I), DELA(I)
WRITE (NPOT, 210) I, X(I), Y(I), Z(I), GMA(I), DELA(I)
330 CONTINUE

WRITE (NTDCP) NP, NMSYM, NMASYM
IGO = 1
IF (NMSYM .EQ. 0) GO TO 390
MODES = NMSYM
WRITE (NPOT, 220)
340 CONTINUE

DO 380 J = 1, MODES
WRITE (NPOT, 240) J
IF (FLAI .NE. 0) GO TO 350
READ (NPIT, 190) (DCP(I), I = 1, NP)
GO TO 370
350 READ (NPIT, 190) (ROW(I), I = 1, NP)
DO 360 I = 1, NP
DCP(I) = CMPLX(ROW(I), 0.0)
360 CONTINUE
WRITE (NPOT, 200) (DCP(I), I = 1, NP)
WRITE (NTDCP) (DCP(I), I = 1, NP)
380 CONTINUE

390 CONTINUE
IF (IGO .EQ. 2 .OR. NMASYM .EQ. 0) GO TO 400
IGO = 2
MODES = NMASYM
WRITE (NPOT, 230)
GO TO 340
400 CONTINUE

LENGTH = NP

DO 510 I = 1, LENGTH
CG(I) = COS(GMA(I))
SG(I) = SIN(GMA(I))
510 CONTINUE

IF (NC .EQ. 0 AND NMON .EQ. 0) GO TO 520
REWIND NTSAIJ
REWIND NTSANJ
CALL SAIJ(NPIT, NPOT, NTSAIJ, NTSANJ, NC, NP, NMON, NAXIS, 1 AIT, CIE, X, Y, Z, CG, SG, DELA, FLAGA, FLAGF, KODE, IPRINT)
2 LABEL, SAI

520 CONTINUE
IF (NELIMS .EQ. 0) GO TO 540
K = 1
CORRECTION FACTORS (E1GC) 02/03/76

WRITE (NPOT, 170) LIMK(1, K), LIMK(2, K), EBMIN(K), EBMAX(K), K
WRITE (NPOT, 160) K, LIMK(1, K), LIMK(2, K), EBMIN(K), EBMAX(K)
IF (K .EQ. NELIMS) GO TO 540
K = K + 1
GO TO 530

C 540 CONTINUE
C IF (NEM .EQ. 0) GO TO 550
C CALL PHIJ(NPIT, NPOT, NTPHIJ, NEM, NP, KODE, MODES, 1
X, Y, Z, PHI

C 550 CONTINUE
NRDW = NP
IF (FLAGP .EQ. 0 .OR. FLAGP .EQ. 3) GO TO 560
IF (FLAGW .NE. 1) GO TO 560
C REWIND NTAPDI
READ (NTAPDI)
NCOL = MAXO(NMSYM, NMASYM)
REWIND NTAPW
C CALL WSWA(NPIT, NPOT, NUTL1, NTAPW, KODE, NP, NCOL, NMAX, 1
NMSYM, NMASYM, WORK)
C THE TAPE NTAPW CONTAINS THE TWO W-MATRICES, WS AND WA,
PRECEDED BY THE NUMBERS NP, NMSYM, NMASYM

C 560 CONTINUE
NX = NS
IF (NEM .NE. 0) NX = NEM + NC
IGO = 1
NMODE = NMSYM
IF (NMSYM .NE. 0) GO TO 562
IGO = 2
NMODE = NMASYM
562 CONTINUE
IF (FLAG .NE. 0) GO TO 600
C REWIND NTAPCF
GO TO (580, 570, 580, 580, 570), IFP
570 WRITE (NTAPCF) POST
GO TO 590
580 WRITE (NTAPCF) PRE
590 CONTINUE
WRITE (NTAPCF) NP, NMSYM, NMASYM
600 CONTINUE
C CALL DCPB(NTDCP, NTAPW, NTAPDI, IGO, FLAGP, FLAGW, NROW,
1 NMODE, NMAX, DCP, COL, WORK)
IF (FLAG .NE. 0) GO TO 612
CORRECTION FACTORS (E1GC) 02/03/76

CALL DELC(NTSAIJ, NPOT, NC, NP, NMODE, NMAX, CIE, DCl, S AI, WORK)

DO 610 I = 1, NS
   ELIM(I) = (0.0, 0.0)
610 CONTINUE

IF (FLAGB .EQ. 0) GO TO 616
616 CONTINUE
IF (FLAGP .NE. 4 .OR. NEM .EQ. 0) GO TO 672

CALL SDBL(NUTL1, NUTL2, MASTSB, NTPHIJ, NTAPW, NTSAIJ, NTAPDI,
   IGL, FLAGM, FLAGP, FLAGT, NC, NP, NS, NEM, SQRTT, AIT,
   DELA, SBB, SBI, SAI, DI, W, PHI,
   DELCPB, WORK)

IF (FLAGB .NE. 0) GO TO 672

CALL GINV(NPOT, MASTSB, NC, NS, NX, DCI,
   EB, CIE, S, SBMATS

DO 630 I = 1, NP
   EB(I) = EB(I) / SQRTT(I)
630 CONTINUE

IF (NELMS .EQ. 0) GO TO 670

CALL EDBL(NPOT, NELMS, NP, NS, LIMK, JARR, NNSMOD,
   EBMIN, EBMAX, EB, ELIM

IF (NSMOD .EQ. 0) GO TO 650

CALL MODF( NC, NS, MASTSB, NEWTSP, JARR, SQRTT,
   ELIM, SBB, DCI, DCMOD

CALL GINV(NPOT, NEWTSP, NC, NS, NX, DCIMOD,
   EB, B, S, SBMATS

GO TO 620

620 CONTINUE

DO 660 IB = 1, NS
660 EB(IB) = EB(IB) + ELIM(IB)

670 CONTINUE

NTAPE = NTPHIJ
IF (FLAGP .EQ. 4) NTAPE = NUTL1

CALL EPSJ(NTAPE, NP, NEM, NMAX,
   EB, EPS, PHI

672 CONTINUE
CORRECTION FACTORS (E1GC) 02/03/76

CALL   DCPT(NPOT, LINES, IGO, FLAGB, FLAGP, NMODE, NP, NUTL1, W)  R0YI3650
1 NUTL2, NTAPDI, NTAPW, NTAPCF, X, Y, Z, GMA, DELA, NMAX, W   W0YI3460
2 NEM, W, DI, EPS, DELCPB, DCPTIL, WORK, EB ) W0YI3740

C IF (NM0N .EQ. 0) GO TO 690
C CALL CEMN(NPOT, IGO, NMODE, NTSANJ, NP, NMON, LABEL, NUTL2, W  WEYI3520
1 SA1, DCPTIL, CE ) W0YI3530

690 CONTINUE
C IF (IG0 .EQ. 2 OR NMASYM .EQ. 0) GO TO 700
C NMODE = 2
C GO TO 800
C CONTINUE

700 CONTINUE
C RETURN
END

SUBROUTINE WSWA(NPIT, NPOT, NUTL1, NTAPW, KODE, NP, NCOL, NMAX, W  W0SA0040
1 NMSYM, NMASYM, W0SA0050

NPIT DATA SET NUMBER OF THE SYSTEM INPUT DATA SET
NPOT DATA SET NUMBER OF THE SYSTEM OUTPUT DATA SET
NUTL1 UTILITY (SCRAP) TAPE NUMBER
NTAPW TAPE NUMBER CONTAINING COLUMNS OF THE W MATRIX
KODE = -1
NP NUMBER OF ROW ELEMENTS IN THE W MATRIX
NCOL NUMBER OF COLUMNS IN THE W MATRIX
NMAX MAXIMUM NUMBER OF COLUMNS IN THE W MATRIX
NMASYM NUMBER OF SYMMETRIC MODES
NMASYM NUMBER OF ANISOMETRIC MODES
W 2-D COMPLEX ARRAY CONTAINING THE W MATRIX

COMPLEX WIN(100), W( NP , NMAX)
DIMENSION MODE(100), IDELW(100), LIMW(2, 100)
1 FORMAT (4I10, 4F10.0)
20 FORMAT (1H1// 23H --W-- IS CARD INPUT // 26H MODE DELTA
LIMIL, 15X, 5H-W--35X, 18HREAL IMAG. )
30 FORMAT (16, 218, 16, 4F14.6)
40 FORMAT (1H1//6H 'THE', '14, 41H COLUMNS OF THE SYMMETRIC
1 MATRIX )
50 FORMAT (/ 8H COLUMN , I4 / ( 3 (16, 2E14.6 )) )
60 FORMAT (1H1//6H 'THE', '14, 41H COLUMNS OF THE ANISOMETRIC
1 MATRIX )
62 FORMAT (1H1// )
C J = 1
WRITE (NPOT,20)

CONTINUE
READ (NPIT,10) MODE(J), IDELW(J), LIMW(1,J), LIMW(2,J), WIN(J)
IF (MODE(J) .LE. KODE) GO TO 80
WRITE (NPOT,30) MODE(J), IDELW(J), LIMW(1,J), LIMW(2,J), WIN(J)
J = J + 1
CORRECTION FACTORS (E1GC) 02/03/76

GO TO 70
80 CONTINUE
NROW = NP
REWIND NULT1
DO 100 N = 1, NMAX
DO 90 M = 1, NROW
W(M, N) = (0.0, 0.0)
90 CONTINUE
100 CONTINUE
JMAX = J - 1
NDEL = 1
IGO = 1
110 CONTINUE
MDMAX = 0
DO 130 J = 1, JMAX
ND = IDELW(J)
IF (ND .NE. NDEL) GO TO 130
MD = MODE(J)
L1 = LIMW(1, J)
L2 = LIMW(2, J)
IF (MDMAX .LT. MD) MDMAX = MD
DO 120 L = L1, L2
W(L, MD) = WIN(J)
120 CONTINUE
C 130 CONTINUE
C WRITE (NULT1), W
GO TO (140, 150), IGO
140 CONTINUE
C NMSYM = MDMAX
NDEL = -1
IGO = 2
GO TO 110
150 CONTINUE
NMSYM = MDMAX
REWIND NULT1
REWIND NTAPW
WRITE (NTAPW) NROW, NMSYM, NMSYM
C NMD = NMSYM
IGO = 1
WRITE (NPOT, 40) NMSYM
160 CONTINUE
READ (NULT1) W
DO 170 NM = 1, NMD
C WRITE (NTAPW) (W(M, NM), M = 1, NROW)
WRITE (NPOT, 50) NM, (I, W(I, NM), I = 1, NROW)
IF (NM .NE. NMD) WRITE (NPOT, 62)
170 CONTINUE
C
CORRECTION FACTORS (E1GC) 02/03/76

GO TO (180,190), IGO
180 CONTINUE
IF (NMASYM .EQ. 0) GO TO 190
WRITE (NPOT,60) NMASYM
NMD = NMASYM
IGO = 2
GO TO 160
C
190 CONTINUE
REWO ND NTAPW
RETURN
END

SUBROUTINE ZEROUT(WRK, LEN, LOOP, ITAPE)

WORK COMPLEX ARRAY TO BE INITIALIZED TO ZEROS
LEN LENGTH OF ARRAY WORK
LOOP NUMBER OF TIMES THE ARRAY WORK IS TO BE WRITTEN ON
ITAPE TAPE NUMBER ON WHICH THE ARRAY WORK IS SAVED

DO 10 I = 1, LEN
WORK(I) = (0.0, 0.0)
10 CONTINUE
IF (ITAPE .EQ. 0) RETURN
C
DO 20 L = 1, LOOP
WRITE (ITAPE) (WORK(I), I = 1, LEN)
20 CONTINUE
RETURN
END
REFERENCES


Unsteady Aerodynamics for Aeroelastic Analyses of Interfering Surfaces, Tønsberg, Norway, 3-4 November 1970.


Figure 3. - Effect of applying local Mach Number to the boundary conditions and the kernel of the classic theory.
Figure 4. - Comparison of classic theory and two variations of the present method with experimental data for the steady case.
Figure 5. - Comparison of classic theory and the present method ($M_\infty$) (with and without second order Bernoulli correction) with experimental data.
Figure 6. Comparison of various theories with experimental data for the oscillatory control surface case.
Comparison of classic theory and the present method $(M_{\infty})$ with experimental data for the oscillatory case.

$M_{\infty} = 0.85$

$k_r = 0.06$

- Magnitude
- Phase
Figure 8. - Comparison of two variations of the Present transonic method with data and classic theory for the oscillatory case.
Figure 9. - Comparison of experimental and theoretical lift coefficient for an airfoil with a deflected 25% chord flap.
Figure 10 - Comparison of experimental and theoretical pitching (about c/4) and hinge moment (about 3 c/4) coefficient for an airfoil with a deflected 25% chord flap.
Figure 11. - Comparison of experimental and theoretical lift coefficient for an airplane with deflected 25% chord wing.

---

Real

Imaginary

0.064

0.062

0.060

0.059

0.057

---

Experiment [13]

Present Method (Mö)

Tract, Farr, Albano [12]
Figure 12. - Comparison of experimental and theoretical pitching moment (about \( \frac{c}{4} \)) and hinge moment (about \( 3\frac{c}{4} \)) coefficient for an airfoil with an oscillating control surface.
Figure 13. - Experimental, Theoretical and Corrected Pressure Loadings for Angle of Attack Using Premultiplying Correction Factors
Figure 14. - Experimental, Theoretical and Corrected Pressure Loadings for Angle of Attack Using Postmultiplying Correction Factors
Figure 15. Experimental, Theoretical and Corrected Pressure Loadings for Flap Rotation Using Premultiplying Correction Factors.

- Experiment $k_r = 0$
- Uncorrected Theory
- Corrected Theory - 2 constraints
- Corrected Theory - 5 constraints
Figure 16. - Experimental, Theoretical and Corrected Pressure Loadings for Flap Rotation Using Postmultiplying Correction Factors.
Figure 17. - Real Part of Experimental, Theoretical and Corrected Pressure Loadings for Angle of Attack Using Premultiplying Correction Factors
Figure 18. - Imaginary Part of Experimental, Theoretical and Corrected Pressure Loadings for Angle of Attack Using Premultiplying Correction Factors
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Figure 20. - Imaginary Part of Experimental, Theoretical and Corrected Pressure Loadings for Angle of Attack Using Postmultiplying Correction Factors
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Figure 23. - Real Part of Experimental, Theoretical and Corrected Pressure Loadings for Flap Rotation Using Postmultiplying Correction Factors
Figure 24. Imaginary Part of Experimental, Theoretical and Corrected Pressure Loadings for Flap Rotation Using Postmultiply Correction Factors.
Figure 25. - Comparison of experimental data with corrected and uncorrected theory for a swept wing operating at subsonic speeds and $\alpha = 4^\circ$. 

\[ M_\infty = 0.8 \]
\[ k_r = 0.0 \]
Figure 26. - Comparison of experimental data with corrected and uncorrected theory for a swept wing operating at subsonic speeds at $\alpha = 4^0$. 

- $M_\infty = 0.8$
- $k_r = 0.0$
Figure 27. - Comparison of experimental data with corrected and uncorrected theory for a swept wing operating at subsonic speeds with a leading edge droop of 6°.
Figure 28. - Comparison of experimental data with corrected and uncorrected theory for a swept wing operating at subsonic speeds at $\alpha = 10^\circ$. 

- Experiment [18]
- Uncorrected Theory
- Pre. Corrected
- New Post. Theory
- Pre. for $\alpha = 4^\circ$

$M_\infty = 0.8$
$k_r = 0.0$
Figure 29. - Comparison of corrected and uncorrected classic theory and Present Method \( M_\infty \) with experimental data.
Figure 30. - Comparison of experimental data with corrected theory; the corrections being based on static and oscillatory data.
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$k_r = 0.0$
Figure 40. - Effect of applying correction factors obtained at $M_\infty = 0.5$ to other Mach Numbers for the Present Method ($\tilde{M}_\infty$)
Figure 41. - Results of applying postmultiplying correction factors (New) obtained at $M = 0.5$ and premultiplying factors obtained at $M = 0.875$ to theory.
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Figure 44. - Comparison of experimental data with corrected and uncorrected theory for an arrow wing with camber operating at supersonic speeds.
Figure 45. Comparison of experimental data with corrected and uncorrected theory for an Arrow wing in pitch.
Figure 46. - Camber changes inferred by New Postmultiplying correction factors as applied to an Arrow wing operating at supersonic speeds and $\alpha = 10^0$. 

$M_\infty = 2.05$

$k_r = 0.0$

$\alpha = 10^0$

$\delta$
Axes Data

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<th>$y_1$ (1)</th>
<th>$z_1$ (1)</th>
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<th>$\cos \beta$</th>
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Lift and Moment Data

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<td>$c_{h3/4}$</td>
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Figure 47. - Graphical and Tabulated Data for Program Test Cases
**Title and Subtitle**
CORRECTION FACTOR TECHNIQUES FOR IMPROVING AERODYNAMIC PREDICTION METHODS

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**Abstract**
A method for correcting discrete element lifting surface theory to reflect given experimental data is presented. Theoretical pressures are modified such that imposed constraints are satisfied (e.g., lift, moment, etc.) while minimizing the changes to the pressures. Several types of correction procedures are presented and correlated; (1) scaling of pressures; (2) scaling of downwash values and (3) addition of an increment to the downwash that is proportioned to pressure. Some special features are included in these methods and they include: (1) consideration of experimental data from multiple deflection modes, (2) limitation of the amplitudes of the correction factors and (3) the use of correction factor mode shapes. These methods are correlated for cases involving all three Mach Number ranges using a FORTRAN IV computer program. Subsonically, a wing with an oscillating partial span control surface and a wing with a leading edge droop are presented. Transonically a two-dimensional airfoil with an oscillating flap is considered. Supersonically an arrow wing with and without camber is analyzed.

In addition to correction factor methods an investigation is presented dealing with a new simplified transonic modification of the two-dimensional subsonic lifting surface theory. Correlations are presented for an airfoil with an oscillating flap.

**Key Words** (Suggested by Author(s))
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Oscillatory aerodynamics
Control surface aerodynamics
Semiempirical aerodynamic corrections
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