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NATIONAL INSTITUTE OF STANDARDS
THE UNDERWATER SHOCK ANALYSIS CODE
(USA-VERSION 3)
A Reference Manual

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Lockheed Missiles and Space Co., Inc.
3251 Hanover Street
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# THE UNDERWATER SHOCK ANALYSIS CODE

## Final Report for Period

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## ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report constitutes a reference manual for the third version of the Underwater Shock Analysis (USA) Code, a computer program for calculation of the transient response of a totally or partially submerged structure to a spherical shock wave of arbitrary pressure profile and source location. The code considers the structure to be linear-elastic and treats the surrounding fluid as an infinite acoustic medium. A discrete-element (finite-element, finite-
20. ABSTRACT (Continued)

difference) computational model is used for the structure, while the computa-
tional model for the fluid is based upon either of the Doubly Asymptotic
Approximations.
PREFACE

The authors express their appreciation to Dr. K. C. Park for his consultation and to Dr. C. L. Yen for providing the modal results for the infinite-cylinder problem and constructing the finite-element structural models used in the examples.
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SECTION I
INTRODUCTION

This report documents the third version of a computer program, the Underwater Shock Analysis (USA) Code, that calculates the transient response of a totally or partially submerged structure to a spherical shock wave of arbitrary pressure-profile and source location. The structure is considered to be linear-elastic and the surrounding fluid is treated as an infinite or semi-infinite acoustic medium. The computational model for the structure is constructed through the use of an auxiliary discrete-element (finite-element, finite-difference) code of choice [1,2], while that for the fluid is constructed through the use of the Doubly Asymptotic Approximation (DAA₁) or the Improved Doubly Asymptotic Approximation (DAA₂) [3,4].

As implied above, this manual constitutes a revision of [5], the original manual for the USA Code. In addition to various maintenance upgrades introduced into the code since it was first developed, the following extensions have been incorporated: 1) Fluid surface elements for wet-surface segments of revolution that permit a circumferential expansion of structural surface motions into an arbitrary number of Fourier components; this allows the inclusion of both beam-like and bar-like motions of the structure as a special case; 2) An imaging formulation that extends DAA analysis to problems involving partially submerged structures and structures totally submerged near the fluid's free surface; 3) A model for the effects of bulk cavitation on incident-wave excitation that provides a complete description of fluid-particle velocity consistent with the occurrence of surface cutoff; 4) The introduction of the DAA₂; and 5) Out-of-core processing of the fluid equation system.

1.1 DOUBLY SYMPTOTIC APPROXIMATION

The principal advantage of the DAA₁ and DAA₂ is that they model the acoustic medium surrounding the structure as a membrane covering the wet surface of the structure. Hence fluid motion is described merely in terms of wet-surface response variables, which are then linked by compatibility relations to the structural response variables. Furthermore, this description is a simple matrix ordinary differential equation with desirable computational properties.

The principal disadvantage of the DAA₁ is that it constitutes an approximation to the "exact" boundary-element representation of the surrounding medium [6,7]. The DAA₁ does approach exactness for both high-frequency (early-time) and low frequency (late-time) structural motions, however, and effects a smooth transition between the two asymptotes. In addition, it has exhibited satisfactory accuracy in a variety of check calculations [4,6,8]. Hence, in view of its desirable computational properties, the DAA₁ is considered suitable for engineering analysis.
The DAA\textsubscript{2} is an improved approximation that is based upon the DAA\textsubscript{1}; however, it can describe the intermediate frequency range better than the DAA\textsubscript{1}. Computationally it has been used to study the response of the infinite cylindrical shell under a plane wave step loading in which significant improvements in accuracy have been noted. Analytical studies of spherical shell response [4] also show such marked improvement.

1.2 STAGGERED SOLUTION PROCEDURE

The governing matrix equation for structural response is a second-order differential equation in time, while that for fluid response is a first-order ordinary differential equation. Simultaneous solution of these equations by direct step-by-step numerical integration, however, is unacceptably expensive. Hence the USA code utilizes a staggered solution procedure [9] for step-by-step solution of the equations in time.

Now a staggered solution procedure involves a response extrapolation at each time step, which usually leads to numerical instability for time increments exceeding a critical value. Because this critical value may be unacceptably small for many computations, the governing equations for fluid response have been modified in such a way that unconditional stability is achieved. Thus, through avoidance of both direct simultaneous solution and conditional stability constraints, highly efficient computation is possible for the greatest variety of cases.

As an illustration of the capabilities of USA, a transient response calculation has been performed for a 2490 degree-of-freedom (DOF) structural model with a stiffness-matrix average half-bandwidth of 85 DOF. The central-processing-unit (CPU) time on a Univac 1108 required for the 280 time-step calculation (with a single change in time increment during the calculation) was 28 minutes. The corresponding time on a CDC 6600, on which the code also operates, would be about 10 minutes.

1.3 INPUT/OUTPUT

The USA Code requires three types of input data in order to perform its function. First, structural mesh-geometry, mass-matrix and stiffness-matrix data must be provided by the structural analysis code used by the analyst. Second, fluid mesh-geometry and boundary-element data must be furnished. Finally, location of the fluid's free surface, charge standoff, incident pressure-profile, and time integration specifications must be provided.

The code, in its turn, outputs structural displacement and velocity histories, and fluid pressure histories for the wet surface. Response data post-processors furnish pseudo-velocity shock spectra, and response-history and shock-spectrum plots. In addition, post-processors embedded in the structural analysis code may be used to obtain, for example, stress and strain response histories, as well as stress/strain-history and stress/strain-computer plots. As
currently configured, the USA Code can routinely handle problems with as many as 3000 Structural and 400 fluid DOF within a core allocation of 65000 decimal words.

1.4 SPECIAL FEATURES

A number of special features are incorporated in the code. First, a capability has been provided to handle a fluid mesh on the wet surface that is not coincident with the surface mesh for the structural model. This permits, for example, the use of a refined structural mesh in a region of high stress gradients, even though a relatively coarse mesh is retained for the fluid.

Second, options for variable-increment time integration and computation restart are furnished. The former allows the use of small time increments during periods where the response is expected to be varying rapidly in time, and the use of large time increments for periods characterized by a slowly varying response. The latter permits the division of a response computation into segments, so that the analyst may examine the results at selected points along the way. Such examination is facilitated by the use of the "printer-plot" routine that augments the usual printout data with response plots "drawn" by the printer.

Third, the code incorporates fluid boundary elements for both general and body-of-revolution wet-surface geometries [10]. This feature is especially useful for compartment-by-compartment analysis of a submarine. Such an analysis utilizes a general-structure discrete-element model of a particular compartment of interest, with the remainder of the submarine modeled as a bar/beam. Hence, a detailed analysis of an entire submarine may be performed with several discrete-element models of moderate size, avoiding the use of a single gigantic model.

Fourth, the analyst can use either the DAA\textsubscript{1} or DAA\textsubscript{2} through input of a single scalar parameter to take advantage of the enhanced accuracy demonstrated by the latter in computations for idealized geometries.

Fifth, out-of-core processing for both the structural and fluid equation systems frees the user from concern over core limitations on the number of structural and fluid elements in his model.

Sixth, free-field shock wave input to the structure is associated with a spherical wave and can be input for use with linear interpolation or cubic spline fitting routines. Pressure histories for exponentially decaying incident waves can be automatically generated. Fluid pressure and particle velocity histories corresponding to the input shock are displayed for the user with the "printer-plot" software mentioned above.

Seventh, routines embedded in USA can be used to facilitate coupling with any linear structural analyzer provided that the stiffness matrix is made available row by row (or,
column by column). These routines assemble the matrix in the partitioned skyline format required by USA. In addition, the stiffness matrix can be displayed for check purposes.

1.5 SPECIAL NON-FEATURES

Some features of modest complexity have yet to be incorporated into the USA Code. First, an option for automatic time-step integration would free the analyst from having to select integration time increments in accordance with his expectations regarding response behavior. Second, the ability to handle very large problems would be useful in those cases where structural segmentation is not possible. Third, a capability to treat banded structural mass and damping matrices would be helpful, in order to accommodate structural analyzers that produce such matrices. Fourth, a means to handle the matrices produced by acoustic elements based on a pressure formulation [11,12] is desirable, in that such elements permit highly efficient modeling of internal fluid volumes. Finally, a capability to treat localized nonlinear structural behavior, such as that exhibited by nonlinear equipment mounts, would permit highly efficient treatment of such behavior; for widespread nonlinear effects, however, recourse must be made to a fully nonlinear code, such as USA-STAGS [13].

An important feature of greater complexity has yet to be introduced into the code. This is a treatment of hull cavitation, which may substantially affect structural response for incident shock waves of short duration. The introduction of this feature requires the accurate treatment of highly nonlinear phenomena, and presents a challenging task for future work.
SECTION II

THEORY

This section describes the theoretical foundation of the USA Code. It is constructed as an overview, with coverage of details left to referenced papers and reports.

2.1 STRUCTURAL RESPONSE EQUATION

The matrix ordinary differential equation for the dynamic response of a linear-elastic structure is [1]

\[ \mathbf{M}_S \ddot{\mathbf{x}} + \mathbf{C}_S \dot{\mathbf{x}} + \mathbf{K}_S \mathbf{x} = \mathbf{f} \]  

(2.1)

where \( \mathbf{x} \) is the structural displacement vector, \( \mathbf{M}_S \), \( \mathbf{C}_S \) and \( \mathbf{K}_S \) are the structural mass, damping and stiffness matrices, respectively, \( \mathbf{f} \) is the external force vector, and a dot denotes a temporal derivative. Generally, \( \mathbf{M}_S \), \( \mathbf{C}_S \) and \( \mathbf{K}_S \) are highly banded, symmetric matrices of large order; at present, the USA Code considers \( \mathbf{M}_S \) to be diagonal and \( \mathbf{C}_S \) to be zero.

For excitation of a submerged structure by an acoustic wave, \( \mathbf{f} \) is given by

\[ \mathbf{f} = -\mathbf{G} \mathbf{A}_f (\mathbf{P}_I + \mathbf{P}_S) \]  

(2.2)

where \( \mathbf{P}_I \) and \( \mathbf{P}_S \) are nodal pressure vectors for the wet-surface fluid mesh pertaining to the (known) incident wave and the (unknown) scattered wave, respectively, \( \mathbf{A}_f \) is the diagonal area matrix associated with elements in the fluid mesh, and \( \mathbf{G} \) is the transformation matrix that relates the structural and fluid nodal surface forces. More will be said about \( \mathbf{G} \) in the next subsection.

2.2 DAA₁ EQUATION

The Doubly Asymptotic Approximation may be written [3,4]

\[ \mathbf{M}_f \ddot{\mathbf{u}}_S + \rho c \mathbf{A}_f \mathbf{P}_S = \rho c \mathbf{M}_f \dot{\mathbf{u}}_S \]  

(2.3)

where \( \mathbf{u}_S \) is the vector of scattered-wave fluid-particle velocities normal to the structure's wet surface, \( \rho \) and \( c \) are the density and sound velocity of the fluid, respectively, and \( \mathbf{M}_f \) is the symmetric fluid mass matrix for the wet-surface fluid mesh. This matrix is produced by a boundary-element treatment of Laplace's equation for the irrotational flow generated in an infinite, inviscid, incompressible fluid.
by motions of the structure's wet surface; it is fully populated with non-zero matrix elements. When transformed into structural coordinates, the fluid mass matrix yields the added mass matrix, which, when combined with the structural mass matrix, yields the virtual mass matrix for motions of a structure submerged in an incompressible fluid [14].

As mentioned in Section I, the approximate relation (2.3) is called "doubly asymptotic" because it approaches exactness in both the high-frequency (early-time) and low-frequency (late-time) limits. For high-frequency motions, \( |\dot{p}_S| >> |p_S| \), so that (2.3) approaches the relation \( p_S = \rho c u_S \), which is the correct limit for short acoustic wavelengths. For low-frequency motions, \( |\dot{p}_S| << |p_S| \), so that (2.3) approaches the incompressible-flow relation \( A_f p_S = M_f \dot{u}_S \), which is the correct limit for long acoustic wavelengths.

For excitation by an incident acoustic wave, \( u_S \) is related to structural response by the kinematic compatibility relation

\[
\mathcal{G}^T \dot{x} = u_I + u_S
\]  

(2.4)

where the superscript "T" denotes matrix transposition. Equation (2.4) expresses the constraint that normal fluid-particle velocity match normal structural velocity on the wet surface of the structure. The fact that the transformation matrix relating those velocities is \( \mathcal{G}^T \) follows from the invariance of virtual work with respect to either of the wet surface coordinate systems. Generally, \( \mathcal{G} \) is a rectangular matrix whose height greatly exceeds its width, inasmuch as the number of structural DOF usually exceeds considerably the number of fluid DOF.

2.3 INTERACTION EQUATIONS

The introduction of (2.2) into (2.1) and (2.4) into (2.3) yields the interaction equations

\[
\begin{align*}
M_S \ddot{x} + C_S \dot{x} + K_S x &= - \mathcal{G} A_f (p_I + p_S) \\
M_f \ddot{p}_S + \rho c A_f p_S &= \rho c M_f (\mathcal{G}^T \dot{x} - \dot{u}_I)
\end{align*}
\]  

(2.5)

These equations may be solved simultaneously at each time step by the transfer of \( -\mathcal{G} A_f p_S \) and \( \rho c M_f \mathcal{G}^T \dot{x} \) to the left sides of their respective equations. Such a procedure is exceedingly expensive, however, because of the large connectivity of the coefficient matrix involved. As mentioned in Section I, efficient computation is possible through the application of a staggered solution procedure that is unconditionally stable with respect to the choice of time increment.

The simplest implementation of the staggered solution procedure recommended in [9] may be effected as follows. \( M_S \) is taken to be diagonal and, to allow for the possibility that \( M_S \) may have zero entries for rotational DOF, \( \mathcal{G} \) is constructed such that only the transla-
tional DOF for the structure couple with the fluid DOF [see (2.4)]; then the first of (2.5) may be partitioned to obtain \( Q_x \), which may then be introduced into the second of (2.5).

Premultiplication of the resulting equation by \( \frac{1}{pc} A_f \) then yields

\[
\frac{1}{pc} A_f \dot{p}_s + (D_{f1} + D_s) p_s = -A_f G^T M^{-1}_s (C_s \dot{x} + K_s x) - (D_s p_1 + A_f \dot{u}_1)
\]

(2.6)

where \( D_{f1} = A_f M^{-1}_f A_f \) and \( D_s = A_f G^T M^{-1}_s G A_f \) are symmetric, and where \( M^{-1}_s \) is a diagonal matrix with each nonzero element given as the reciprocal of the corresponding nonzero element of \( M_s \) and each zero element mirroring the corresponding zero element of \( M_s \). The first of (2.5) and (2.6) are herein termed "the augmented interaction equations".

2.4 SPHERICAL INCIDENT WAVE

Each element of the vectors \( P_{I} \) and \( \dot{u}_I \) for a spherical incident wave are given by

\[
P_{Ii}(t) = \frac{S}{R_i} p_I \left( t - \frac{R_i - S}{c} \right)
\]

\[
\dot{u}_{Ii}(t) = \left[ \frac{1}{pc} \dot{p}_{Ii}(t) + \frac{1}{\rho R_i} p_{Ii}(t) \right] y_i
\]

(2.7)

where \( S \) is the "charge standoff", i.e., the distance between the origin of the incident spherical wave and the nearest point on the structure's wet surface, \( R_i \) is the distance from the origin of the incident spherical wave to the \( i \)th fluid node on the wet surface, \( y_i \) is the cosine of the angle between the vector corresponding to \( R_i \) and the wet-surface normal at the \( i \)th fluid node, and \( p_I(t) \) is the incident-wave pressure-profile defined at \( R_i = S \). For a shock wave, \( p_I(t) \) is discontinuous at \( t = 0 \) and the \( \dot{u}_{Ii}(t) \) contain singularities.

In order to remove shock-wave singularities from \( \dot{u}_I \) in (2.6), a modified pressure vector is defined as

\[
P_M = \Gamma P_I + P_S
\]

(2.8)

where \( \Gamma \) is a diagonal matrix with direction-cosine elements \( y_i \). The introduction of (2.8) into (2.6) and the first of (2.5), followed by utilization of the second of (2.7) then yields the modified, augmented, interaction equations

\[
\frac{1}{pc} A_f \dot{P}_M + (D_{f1} + D_s) P_M = -A_f G^T M^{-1}_s (C_s \dot{x} + K_s x) - \dot{H} p_1
\]

(2.9)

\[
\frac{1}{pc} A_f \dot{P}_M = -A_f G^T M^{-1}_f (C_f \dot{x} + K_f x) - \dot{H} p_1
\]

2-3
in which I is the identity matrix, and

$$\mathbf{H} = \mathbf{D}_s - (\mathbf{D}_s + \mathbf{D}_f) \frac{1}{\rho} \mathbf{A}_f \mathbf{R}^{-1} I$$  \hspace{1cm} (2.10)

where \( \mathbf{R} \) is the diagonal matrix formed by the distances \( R_i \). Equations (2.9) (with \( C_s = 0 \)) are the equations solved by the USA Code to determine the structural responses \( \mathbf{x} \) and \( \mathbf{\dot{x}} \), and the wet-surface pressures \( \mathbf{p} = (\mathbf{I} - I) \mathbf{p}_I + \mathbf{p}_M \).

### 2.5 FREE SURFACE EFFECTS

When a structure is partially submerged, or when a totally submerged structure lies near the free surface of a semi-infinite fluid, imaging techniques may be utilized to ensure that the total pressure vanishes at the free surface. (This implies that the effects of gravity are negligible in this class of problems, which they generally are.) In this case, the interactive system consists of an infinite fluid domain, the structure \( S_+ \), and its image \( S_- \) (see Figure 2-1). The incident wave now consists of a (positive) primary wave plus a (negative) image wave, the latter emanating from the image of the primary wave's origin. Zero pressure at the free surface is therefore maintained if the motions of \( S_- \) are constrained to be opposite to those of \( S_+ \).

The kinetic energy \( T_s \), the Rayleigh dissipation function \( D_s \), the potential energy \( V_s \), and the work potential \( \Pi_s \), for the structural system \( S_+ + S_- \) are given by

\[
T_s = \frac{1}{2} (\dot{\mathbf{x}}_+^T \mathbf{M}_s \mathbf{\dot{x}}_+ + \dot{\mathbf{x}}_-^T \mathbf{M}_s \mathbf{\dot{x}}_-)
\]

\[
D_s = \frac{1}{2} (\dot{\mathbf{x}}_+^T \mathbf{C}_s \mathbf{\dot{x}}_+ + \dot{\mathbf{x}}_-^T \mathbf{C}_s \mathbf{\dot{x}}_-)
\]

\[
V_s = \frac{1}{2} (\mathbf{x}_+^T \mathbf{K}_s \mathbf{x}_+ + \mathbf{x}_-^T \mathbf{K}_s \mathbf{x}_-)
\]

\[
\Pi_s = -2 \mathbf{x}_+^T \mathbf{f}_+ - \mathbf{x}_-^T \mathbf{f}_-
\]

The appropriate constraints are \( \mathbf{x}_- = -\mathbf{x}_+ \) and \( \mathbf{f}_- = -\mathbf{f}_+ \), so that (2.11) become

\[
T_s = \frac{1}{2} \dot{\mathbf{x}}_+^T \mathbf{M}_s \mathbf{\dot{x}}_+
\]

\[
D_s = \frac{1}{2} \dot{\mathbf{x}}_+^T \mathbf{C}_s \mathbf{\dot{x}}_+
\]

\[
V_s = \mathbf{x}_+^T \mathbf{K}_s \mathbf{x}_+
\]

\[
\Pi_s = -2 \mathbf{x}_+^T \mathbf{f}_+
\]

2-4
The DAA kinetic energy $T_f$ and work potential $\Pi_f$ for the fluid system may be written as

$$T_f = \frac{1}{2} u_S^T M_f u_S$$

$$\Pi_f = -u_S^T A_f p_S - \frac{1}{\rho c} u_S^T M_f \dot{p}_S$$

(2.13)

where

$$M_f = \begin{bmatrix} M & M' \\ M' & M \end{bmatrix}, \quad A_f = \begin{bmatrix} A & O \\ O & A \end{bmatrix}$$

(2.14)

and an asterisk denotes temporal integration. The submatrix $M$ accounts for added mass coupling between wet-surface elements on $S_+$ and, similarly, between elements on $S_-$; $M'$ accounts for added mass coupling between elements on $S_+$ and elements on $S_-$. The constraints for the fluid system are

$$u_S = \begin{bmatrix} 1 & -1 \end{bmatrix} u_{S+}, \quad p_S = \begin{bmatrix} 1 & -1 \end{bmatrix} p_{S+}$$

(2.15)

so that (2.13) becomes

$$T_f = u_{S+}^T (M - M') u_{S+}$$

$$\Pi_f = -2 u_{S+}^T [A p_{S+} + \frac{1}{\rho c} (M - M') \dot{p}_{S+}]$$

(2.16)

The application of Lagrange's equation [15] to (2.12) and (2.16) now yields

$$M_s \ddot{x}_+ + C_s \dot{x}_+ + K_s x_+ = f_+$$

$$\frac{1}{\rho c} (M - M') \dot{p}_{S+} + A p_{S+} = (M - M') \dot{u}_{S+}$$

(2.17)

Also, (2.2) and (2.4) must be modified to include the effects of both the incident primary and image waves. This gives

$$f_+ = -G A (p_{I+}^+ - p_{I+}^- + p_{S+})$$

$$G \begin{bmatrix} x_+ \end{bmatrix} = u_{I+}^+ + u_{I+}^- + u_{S+}$$

(2.18)

where, e.g., $p_{I+}^-$ denotes incident-wave pressure on $S_+$ associated with the image wave. The introduction of (2.18) into (2.17) then yields the doubly asymptotic interaction equations for problems involving a free surface.
\[ M_S \ddot{x}_+ + C_S \dot{x}_+ + K_S x_+ = C A (P_{I+}^+ + P_{I+}^- + P_{S+}) \]  
(2.19)  

\[ (M - M') \dot{P}_{S+} + \rho c A P_{S+} = \rho c (M - M') (C^T \ddot{x}_+ - u_{I+}^+ - u_{I+}^-) \]

A comparison of (2.19) with (2.5) reveals that the effects of the free surface are embodied in the image-wave pressure and fluid-particle-velocity vectors, and in the modified added-mass matrix.

Finally, augmentation of (2.19) to secure unconditional stability, followed by introduction of the modified pressure [cf. (2.8)]

\[ P_M = \sum_{+} P_{I+}^+ + \sum_{-} P_{I+}^- + P_{S+} \]  
(2.20)

to remove shock-wave singularities, proceeds as described in Subsections 2.3 and 2.4. The modified, augmented interaction equations corresponding to (2.9) for the infinite fluid medium are then readily obtained.

It is important to mention at this point that the DAA formulation just described does not account for high-frequency scattered waves from \( S_- \) that impinge upon \( S_+ \). For most floating structures, such waves are not generated, as the wet surfaces of \( S_+ \) and \( S_- \) usually intersect to form a convex surface; they are generated, however, for a totally submerged structure lying near the free surface. Even so, it has been shown that, as far as structural response is concerned, the effects of the scattered wave are generally negligible [16]. In other words, the response is basically driven by the incident primary and image waves.

2.6 BULK CAVITATION

In the absence of bulk cavitation, the imaging method serves as a useful device to model the reflection of free-field waves from the fluid's free surface. The occurrence of bulk cavitation near the surface, however, changes that simple acoustic reflection problem into a complex reflection-refraction problem, as indicated in Figure 2-2. If refraction distortions produced by a relatively thin cavitated region are not too severe, however, bulk cavitation effects will still appear to the structure as emanating from an image source.

Experimental records of free-field pressure histories for compact charges exhibit the behavior shown in Figure 2-3 [17]. The dashed line denotes the history produced by a negative-image model, while the horizontal line indicates that the effect of bulk cavitation is to "cut off" the pressure at a cavitation threshold. The approximate treatment introduced here involves pre-examination of the image-based free-field pressure at the
Figure 2-3 Free-Field Pressure as a Result of Free-Surface Reflection

Figure 2-4 Geometry of Primary and Image Waves
standoff point, i.e., the point on the submerged structure closest to the charge. Whenever that pressure becomes negative to the extent that its magnitude exceeds the absolute ambient pressure at that depth, a positive contribution is incorporated into the negative-image source so that the free-field pressure at the standoff point never dips below the cavitation threshold. When the structure's overall dimensions are small relative to the distance from the structure to the cavitated region, the effects of the positive contribution will not vary appreciably in the vicinity of the structure.

The preceding discussion leads to the following development. The two-source model of Figure 2-4 yields as the free-field pressure at any point \( P \)

\[
p_{P}(t) = \frac{S}{R_{+}} p_{+}(t - \frac{R_{+} - S}{c}) + \frac{S}{R_{-}} p_{-}(t - \frac{R_{-} - S}{c})
\]

(2.21)

where \( p_{+}(t) = p_{-}(t) = 0 \) for \( t < 0 \). At the standoff point, (2.21) becomes

\[
p_{Q}(t) = p_{+}(t) + \frac{S}{S_{-}} p_{-}(t - \frac{S_{-} - S}{c})
\]

(2.22)

Now \( p_{-}(t) = -p_{+}(t) \) as long as the resulting \( p_{Q}(t) \) exceeds the cavitation threshold so that "cutoff" does not occur; otherwise, \( p_{Q}(t) \) remains at the threshold value \(-p_{A} + \gamma Z\)

where \( p_{A} \) is atmospheric pressure and \( \gamma \) is the fluid's weight density. Hence, during the "cutoff period",

\[
p_{-}(t) = -\frac{S_{-}}{S} [p_{+}(t + \frac{S_{-} - S}{c}) + p_{A} + \gamma Z]
\]

(2.23)

The model just described fits a prescribed free-field pressure history at the standoff point in such a way that surface cutoff effects appear to the structure as emanating from an image source. Because the model is complete, it also provides the free-field fluid-particle-velocity information required for DAA calculations. The usefulness of the model has been demonstrated from the results of free-field tests specifically designed to produce both pressure and fluid-particle-velocity data [18].

2.7 USA-DAA\textsubscript{2} IMPLEMENTATION

The Improved Doubly Asymptotic Approximation [DAA\textsubscript{2}] can be written as [4]

\[
\dot{M}_{f} \ddot{\epsilon}_{S} + \rho c A_{f} \dot{\epsilon}_{S} + \rho c \Omega_{f} \dot{A}_{f} \dot{\epsilon}_{S} = \rho c [\dot{M}_{f}(G_{x} - \dot{u}_{x}) \Omega_{f} M_{f}(G_{x} - \dot{u}_{x})]
\]

(2.24)
where

\[ \Omega_f = \eta \rho c A_f \mathbf{M}^{-1}_f \]  

(2.25)

All vector and matrix quantities in the above are related to the same finite element wet-surface fluid mesh as that used for the lowest order DAA (DAA_1) described in Section 2.2.

Note that DAA_2 is a second-order equation, whereas DAA_1 is a first-order equation. In addition, DAA_2 includes a new scalar parameter \( \eta \) that appears in (2.25). It can be established from physical considerations that it must be bounded as

\[ 0 \leq \eta \leq 1 \]  

(2.26)

A precise choice of \( \eta \) is apparently not prescribed by any fundamental principle. Hence it must be regarded at this time as a factor which may be adjusted to achieve optimum accuracy for a particular problem. In [4], it is observed that \( \eta = 1 \) leads to the best accuracy for a spherical shell.

In order to implement DAA_2 (2.24) is first integrated once in time and multiplied through by \( A_f \mathbf{M}^{-1}_f \). Equation (2.25) is then substituted into the result and a new variable, the scattered pressure integral \( q_s \), is defined by

\[ q_s = P_s \]  

(2.27)

where an asterisk denotes temporal integration. The result is

\[ \bar{A}_f \ddot{q}_s + \rho c D_{f1} \dot{q}_s + \eta \rho c^2 D_{f2} q_s = \]

\[ \rho c \bar{A}_f (C^T \dot{x} - \dot{u}_1) + \eta \rho c^2 D_{f1} (C^T \dot{x} - u_1) \]  

(2.28)

where

\[ D_{f2} = \bar{A}_f \mathbf{M}^{-1}_f \bar{A}_f \mathbf{M}^{-1}_f \]  

(2.29)
It is noted that (2.28) is symmetric and that $D_{f1}$ has already been defined following (2.6).

To avoid shock-wave singularities in $\dot{u}_I$, the relation for a spherical shock is used as

$$\rho c \dot{u}_I = \Gamma (\dot{p}_I + cR^{-1} p_I)$$

while the modified pressure-integral vector is defined as

$$\mathbf{a}_M = \mathbf{a}_S + \Gamma \mathbf{p}_I$$

Substitution of (2.30), (2.31) into (2.28) then gives

$$\ddot{A}_f M + \rho c D_{f1} \dot{A}_f M + \eta \rho^2 c^2 D_{f2} A_M =$$

$$\rho c A_f C_{\hat{\eta}} \ddot{x} + \eta \rho^2 c^2 D_{f1} C_{\hat{\eta}} \dot{x} + c [ (1 - \eta) \rho D_{f1} - A_f R^{-1} ] \Gamma \mathbf{p}_I$$

$$+ \eta \rho^2 c^2 (D_{f2} - \frac{1}{\rho} D_{f1} R^{-1}) \Gamma \mathbf{p}_I$$

where the identity

$$R^{-1} \Gamma = \Gamma R^{-1}$$

has been used in (2.32), as both matrices are diagonal. Associated with (2.32) is the structural equation of motion

$$M_{\hat{\eta}} \ddot{x} + C_{\hat{\eta}} \dot{x} + K_{\hat{\eta}} x = -G A_f [ \dot{q}_M + (I - \Gamma) \mathbf{p}_I ]$$

Equations (2.32) and (2.34) define the $\text{DAA}_{2}$-modified interaction equations that are solved according to the staggered solution strategy; hence an examination of stability must be conducted. It has been shown that the step-by-step integration of (2.32) and (2.34) is conditionally stable; however, no systematic study of stability has yet been undertaken. In view of the fact that unconditional stability was achieved for USA-$\text{DAA}_{1}$ by augmentation, and that (2.24) is essentially the $\text{DAA}_{1}$ with a correction term, augmentation of (2.32) was carried out in the same manner as that used for $\text{DAA}_{1}$.
Accordingly, (2.34) is first solved for $\ddot{x}$ and substituted into (2.32) to give

\[
A_f \dddot{x}_M + \rho c (D_{f1} + D_s) \ddot{x}_m + \eta \rho^2 c^2 D_{f2} \dddot{x}_m = \\
- \rho c A_f G^T H^{-1}_s (C_x + K_s \dot{x}) + \eta \rho^2 c^2 D_{f1} G^T \dot{x} \\
- \rho c (D_s - [D_s + (1 - \eta) D_{f1} - \frac{1}{\rho} A_f R^{-1}] \Gamma \Gamma) \pi \\
+ \eta \rho^2 c^2 (D_{f2} - \frac{1}{\rho} D_{f1} R^{-1}) \Gamma \pi^*
\]  

(2.35)

where $D_s$ has already been defined following (2.6).

Equations (2.34) and (2.35) are the DAA$_2$-modified, augmented interaction equations that have been implemented in the USA Code.
SECTION III
ORGANIZATION

The USA Code has been written in standard FORTRAN IV for use on both Univac and CDC computers. Machine dependency has been isolated in one utility program described below. Program modularity has been strictly enforced, with communication between computational modules controlled by means of a data management system.

The basic structure of the code is shown in Fig. 3-1. The structural preprocessor is a separate code selected by the user to provide the computational model for the structure. The skyline utility merely reformats $M_g$ and $K_g$ as provided by the structural preprocessor for processing by the USA Code (recall that $C_g$ is taken as zero). The fluid mass preprocessor forms $A_f$, $M_f$, $D_{f1}$, $D_{f2}$ and $C$ using a virtual memory simulator for out-of-core processing, while the matrix augmentation preprocessor forms $D$ and $A_f C^T M^{-1}$ [see (2.9)]. The main processor is the time integrator, which forms $\Gamma$ and $\mathbb{H}$ and then solves (2.9) in step-by-step fashion using the staggered solution procedure. The response postprocessor provides tabular and graphic output for the computed kinematic responses as well as pseudo-velocity shock spectra. Finally, the data manager controls the flow of data between processors. More detailed descriptions of the various program components follow, while information required for utilization of the code is contained in Appendices A through D.

3.1 THE DATA MANAGER DMGASP

DMGASP is a self-contained utility module that functions as a manager of auxiliary storage and as the focal point for all block input/output activities [19]. Constituting the lowest level of the NOSTRA Data Management System [20], it carries out the direct transfer of data blocks between core and peripheral storage. (The terminology "direct transfer" is used here to denote unformatted and unbuffered data transmission.) The basic auxiliary storage management operations embodied in DMGASP are

- Activate storage device
- Position device
- Read data block from device
- Write data block on device
- Deactivate device

In the USA Code, DMGASP is operated as a stand-alone I/O package that receives directives directly from the master processors. Assembly language versions of DMGASP currently exist for UNIVAC 1100 EXEC-8, CDC SCOPE 3.4 (NOS/BE), and CDC NOS operating systems; hence the USA Code may be used only on these systems at this time.
Figure 3-1. Organization of USA Code
3.2 THE VIRTUAL MEMORY SIMULATOR VMSYST

VMSYST is a virtual storage simulator for computers that are not built around a virtual memory system [21]. All data in the virtual system is partitioned into pages, which are blocks of consecutive data words of a fixed page size. Pages residing in core in the page buffer are called active pages. Inactive pages are resident in auxiliary storage only. In this utility the page and page buffer sizes can be conveniently adjusted to suit the application. Input and output to auxiliary storage is handled by DMCASP; otherwise VMSYST is written in transportable FORTRAN.

The primary advantage of a virtual memory system is the efficient processing of many small records such as columns or rows of large full matrices that can be treated as vectors. In essence VMSYST keeps track of whether a desired block of data is resident in core in the page buffer, or, has been moved to an external storage device by DMCASP. If it is not currently resident in the page buffer, VMSYST retrieves it and makes it available to the application program. This double movement of data is the major price paid for the benefits of the virtual system.

In USA, VMSYST is used for the out-of-core generation of the fluid mass matrix described in Section 3.5.

3.3 THE STRUCTURAL PREPROCESSOR

This is a user-provided code that assembles the structural mass and stiffness matrices and generates information that relates the internal and external descriptions of the structural DOF. Input typically includes

- Mesh geometry
  - Coordinate systems
  - Node locations
- Element definitions
  - Type
  - Connectivity
- Material properties
  - Mass density
  - Moduli
- Constraints
  - Symmetry conditions
  - Element external constraints
  - Element internal constraints
Fluid internal to the submerged structure must be included in the structural model. At this time, USA treats only diagonal mass matrices associated with a lumped mass representation of the structure, and only single precision matrices can be processed.

3.4 THE SKYLINE UTILITY

This preprocessor converts the structural mass and stiffness matrices generated by the structural preprocessor into the internal "skyline" format required by the USA time integration processor [22,23]. As there are a variety of ways to store large, sparse, symmetric matrices, virtually any structural preprocessor that is to be used with the USA Code will require a utility package to change the storage format. At this time, conversion utilities have been written for SPAR [24], NASTRAN [25] and GENSAM [26]. User instructions for constructing the skyline utility for other structural codes are given in Appendix E. As is noted there, USA now contains a set of utilities to facilitate this process.

Figure 3.1 shows 2 paths to mass storage from the skyline utility. The SPAR converter uses DMGASP for both input and output, whereas the NASTRAN converter uses unformatted buffered FORTRAN commands for input and DMGASP for output.

Constraints are also handled differently in these two utilities. NASTRAN provides a reduced stiffness matrix which already incorporates any prescribed constraints. SPAR does not; however, USA has the ability to apply constraints due to symmetry or attachment to ground during the time integration. Structural DOF that must be set to zero are flagged by the skyline utility [23].

3.5 THE FLUID MASS PREPROCESSOR FLUMAS

This code constructs the fluid mass matrix for a structure submerged in an infinite, inviscid, incompressible fluid by the boundary element technique [14]. In addition, FLUMAS can form the mass matrix for a body in the vicinity of a fluid free surface through the use of imaging techniques. Out-of-core processing is facilitated by use of the virtual memory system VMSYST so that core size is not a limitation on the number of fluid DOF. The code also generates fluid mesh data and a set of transformation coefficients relating the structural and fluid DOF. The computation of these coefficients is based upon the use of centroidal nodes for the fluid elements and the assumption of a bilinear variation of displacement over the surface of each structural element. This assures that the description of the fluid pressure forces in the two mesh systems is statically equivalent without inducing moments at the structural nodes. Finally, the code generates the symmetric matrices $D_{f1}$ and $D_{f2}$ that appear in the computational form of the $\text{DAA}_1$ and $\text{DAA}_2$ equations which involve the inverse of the fluid mass matrix.

3-4
FLUMAS contains a refined formulation for the fluid mass matrix that includes the primary effects of element curvature. In addition, it has the capability to treat structures containing both general geometry and arbitrary axis, multi-branch, multi-harmonic surface-of-revolution components, as described in [10]. The code can also efficiently construct the fluid mass matrix for a body with one or two planes of symmetry by using a mesh which covers 1/2 or 1/4 of the surface. Symmetric or anti-symmetric fluid motions can then be imposed on the portions of the surface not covered by the mesh. Two-dimensional "plane-strain" behavior of long cylinders can also be simulated. The code contains an automatic mesh generator for cylindrical surfaces and an improved error exit control that facilitates fluid mesh debugging. Finally, a useful diagnostic tool in the code is the capability to solve the fluid-boundary-mode problem \( M_f u = \lambda \mathbf{A}_f u \) [14].

Typical input data for this processor includes:

- **Mesh geometry**
  - Fluid Wet-Surface Mesh
  - Structure Wet-Surface Mesh

- **Element definitions**
  - General curved surface
  - Surface of revolution

- **Material property**
  - Mass density
  - \( \text{DA}_{A_2} \) parameter

- **Constraints**
  - Location of free surface
  - Half model
  - Quarter model
  - Long cylinder
  - Node reassignment in fluid-structure transformation

A detailed description of the required input data is given in Appendix A.

3.6 THE AUGMENTED MATRIX PREPROCESSOR AUGMAT

This processor accepts data from the structural and fluid analyzers to construct the specific matrices required for solution of the augmented Eqs. (2.9) or (2.34)/(2.35). The output of this code includes not only the required matrices in skyline form, but also a distillation of the output from both the structural and fluid processors. This has been done so that only one permanent file need be referenced as input to the time integrator; this results in improved data handling and core usage. In contrast to earlier versions of USA, AUGMAT does not form the fluid matrices \( D_{f1} \) and \( D_{f2} \) but rather puts...
them in the skyline format required by SKYPUL. $D_{f1}$ and $D_{f2}$ are now formed only in FLUMAS. The structural stiffness matrix can also be displayed in AUGMAT for checkout purposes. Input to this code involves the following information:

- Mass matrices
  - Fluid
  - Structure

- Structural DOF correspondence table
  - External and internal node descriptions
  - Factorization order
  - DOF reduction due to constraints

- Fluid mesh geometry
  - Global coordinates of fluid nodes
  - Direction cosines for nodal surface normals
  - Areas of fluid elements

- Fluid/structure DOF transformation coefficients

- Fluid material properties
  - $D_{A2}$ parameter

- Constraints
  - Half model
  - Quarter model

Although this constitutes a substantial amount of information, almost all of it is retrieved from permanent data files. A detailed discussion of the required input data is contained in Appendix B.

3.7 THE TIME INTEGRATION PROCESSOR TIMINT

This main processor constitutes an implementation of the unconditionally stable staggered solution technique developed in [9] for $D_{A1}$. The primary output is a set of permanent data files that contain nodal values for structural displacement, structural velocity and wet-surface pressure at every time step. In addition, parallel files are created that retain restart information at time intervals dictated by the user. The code has a variable time step capability and can treat a spherical incident wave of arbitrary pressure profile and source location. Exponentially decaying waves can also be treated by providing magnitude and decay information. In addition, incident wave pressure and particle velocity are tabulated and displayed with a "printer-plot" package. If the body is in the vicinity of a free surface, unloading due to reflection of the incident
The computational strategy for the staggered solution procedure is embodied in the following eight steps, assuming the solution is known at time $t$:

1. Estimate the unknown structural restoring force $K_s x$ at $t + \Delta t$ from the extrapolation of current and past values.

2. Transform this extrapolation into fluid node values and form the right-hand side of the fluid equation, which also involves the known incident pressure at $t + \Delta t$.

3. Solve the fluid equation and obtain a preliminary estimate of the total pressure vector at $t + \Delta t$.

4. Transform fluid pressures into structural nodal forces.

5. Solve the structural equation for the displacement and velocity vectors at $t + \Delta t$.

6. Transform the computed structural restoring forces at $t + \Delta t$ into fluid node values and reform the right-hand side of the fluid equation.

7. Re-solve the fluid equation and obtain refined values for the total pressures at $t + \Delta t$.

8. Save system responses.

Steps 1, 3, and 5 constitute the basic staggered solution technique, while Steps 2 and 4 are required because of the difference between the fluid and structural surface meshes. The iteration on the fluid solution reflected in Steps 6 and 7 has been added to enhance accuracy. Inasmuch as the computation time is overwhelmed by the structural solution requirements, this requires only a small increase in total run time. The use of a three-point extrapolation method in Step 1 also improves accuracy, as discussed in [9].

Implicit integration algorithms have been used for both the fluid and structural equations. The former is treated with the 3-step Park method [27] while the latter is treated with the "JO" implementation of the trapezoidal rule [28].

Typical input to this processor includes:

- Incident wave characteristics.
Location of source
Location of standoff
Pressure profile
Linear interpolation
Cubic spline fit
Exponentially decaying wave

- Time step information
  - Start and finish times
  - Time increment values

- Restart data

- Display directives
  - Displacements
  - Velocities
  - Pressures

Detailed user information concerning TIMINT is given in Appendix C.

3.8 THE RESPONSE POSTPROCESSOR POSTPR

This utility is responsible for the listing and "printer-plot" as well as "vector-plot" graphic display of selected system responses and pseudo-velocity shock spectra. Output files containing the structural displacement field at user-specified instants in time may also be created from the response history files to provide "snapshots" of the deformed structure. Some of the same capabilities are also embedded in the TIMINT processor for immediate selective scanning of the output. POSTPR, however, is used for more detailed examination of the results at a later time. As a complete display of all structural and fluid DOF histories for even a moderate size problem could run into thousands of pages of output, care must be exercised in the selection of data to be displayed. Usage of this code is discussed in Appendix D.
SECTION IV

EXAMPLE PROBLEMS

This section presents results generated by the USA Code for three idealized underwater and free surface shock problems. The structure studied in the first problem is a hollow circular beam of finite length, while that involved in the second and third problems is an infinite, circular cylindrical shell. In all cases, the structure is excited by a transverse, plane step-wave of unit incident pressure and material properties are used that correspond to a steel shell immersed in water. The input data are normalized so that the density and speed of sound for the fluid both equal unity; hence, the density, Young's modulus, and Poisson's ratio for the structural material are taken as 7.85, 98.125, and 0.3, respectively. The radius and wall thickness of the beam and the cylinder are 1 and 0.01, respectively, while the length of the beam is 9. In order to assess the accuracy of the computational results, selected response histories are compared with those obtained by other methods.

4.1 CIRCULAR BEAM

The response variable of primary interest in this problem is the late-time asymptotic translational velocity \( V_m \) of the structure. An analytical expression for this quantity may be obtained from (2.5) by taking \( \mathbf{x} = \mathbf{y}_P \mathbf{v}(t) \), where \( \mathbf{y}_P \) is the vector of direction cosines relating the translational motions of the structural nodes and the direction of propagation of the plane incident wave. (The elements of \( \mathbf{y}_P \) that pertain to the rotational DOF are, of course, zero.) The introduction of this relation into the first of 2.5, followed by premultiplication of the resulting equation by \( \mathbf{y}_P^T \), then yields

\[
m_s \mathbf{\dot{v}} = -\mathbf{y}_P^T \mathbf{C} \mathbf{A}_f (\mathbf{p}_I + \mathbf{p}_S)
\]

where \( m_s = \mathbf{y}_P^T M_L \mathbf{y}_P \); this follows from the fact that \( \mathbf{C}_S \mathbf{y}_P = \mathbf{K}_S \mathbf{y}_P = 0 \).

After the wave front of the plane step-wave has enveloped the structure, i.e., for \( t > t_e \),

\[
\begin{align*}
\mathbf{p}_I & = \rho c \mathbf{U}_I \mathbf{1} \\
\mathbf{p}_* & = \rho c \mathbf{U}_I (t_1 - t_A) \\
\mathbf{U}_I & = \mathbf{U}_I \mathbf{y}_P
\end{align*}
\]

where \( \mathbf{U}_I \) is the fluid particle velocity characterizing the step-wave, \( \mathbf{1} \) is the unity vector, the asterisk denotes the temporal integral of the quantity beneath it, \( t_A \) is the vector of incident-wave arrival times for the fluid surface elements, and \( \mathbf{y}_P \) is the vector of direction cosines relating the normals of the fluid elements to propagation vector of
the plane incident wave. In addition, \(|\tilde{P}_S| \ll |P_S|\) for late-time motions (see Section 2.2), so that the second of (2.5) becomes

\[ P_S = A_f^{-1} M_f (C^T Y_P \dot{v} - \dot{u}_f), \quad t > t_e \]  

(4.3)

The introduction of this relation into (4.1) then yields

\[ (m_s + m_a) \dot{v} = -Y_p^T A_f P_{I1} + Y_P^T M_f \dot{u}_f, \quad t > t_e \]  

(4.4)

where the added mass \( m_a = Y_p^T M_f Y_p \). But, from (4.4), \( Y_p^T Y_p = Y_p \), so that \( m_a \) is also given as \( m_a = Y_p M_p Y_p \).

With \( Y_p^T Y_p = Y_p \), the first of (4.2) yields \( Y_p^T A_f P_{I1} = \rho c U Y_p^T A_f = 0 \), inasmuch as the wet surface of the structure is closed. Hence, the right side of (4.4) vanishes for \( t > t_e \), which gives the expected result \( \dot{v} = 0 \). This prompts the use of integrated forms of (4.1) and (4.3) (with quiescent initial conditions), which yields, instead of (4.4),

\[ (m_s + m_a) v = -Y_p^T A_f \dot{u}_f + Y_p M_p \dot{u}_f, \quad t > t_e \]  

(4.5)

The introduction of the second and third of (4.2) into this equation then provides the desired expression for late-time asymptotic translational velocity

\[ V_\infty = \frac{m_d + m_a}{m_s + m_a} U_I \]  

(4.6)

where the structure's displaced mass \( m_d \) may be shown to be expressible as \( m_d = \rho c Y_p^T A_f (t_L - t_A) \). Note that (4.6) is a general result, applicable to any wet-surface geometry.

Two different uniform mesh geometries were used to study the circular beam. Ten- and twenty-node models were constructed with beam elements provided by the structural analyzer SPAR [29]. The corresponding fluid models contained 11 and 21 elements of equal size, with 12 and 24 circumferential integration points (see [10]). In each case there was a fluid element on each end to account for axial motion while all the rest were evenly distributed along the length. For the beam considered, \( m_s = 4.439 \) and \( m_d = 28.274 \); with \( m_a \) determined as \( m_a = Y_p M_p Y_p \), mesh geometry has a small effect on the value calculated for \( V_\infty \). It was found that \( m_a = 24.509 \) for the coarse mesh and \( m_a = 24.332 \) for the fine mesh, which yield \( V_\infty = 1.823 \) and \( V_\infty = 1.828 \), respectively.

In the response calculations, a constant time step of 0.1 (20 steps per envelopment period) was used for both models; the results are shown in Figures 4-1 and 4-2. Velocities at the ends of the beam are higher than those at the center because the three-dimensional flow field at the ends offers less resistance to the plane wave excitation than the two-dimensional flow field at the center. It is noted that the responses of both
Figure 4-1 Transverse Velocity of Finite Beam, Coarse Mesh
Figure 4-2 Transverse Velocity of Finite Beam, Halved Mesh
models are similar although those for the finer mesh appear to tend to the rigid body asymptotic velocity more precisely.

The USA(3) Code can also treat the bar response of the circular beam and to illustrate this capability the axial displacement response of the end under the side-on loading is shown in Figure 4-3 for the coarse mesh problem only. The expected static displacement is easily determined from the physical characteristics of the problem to be 2.293 and it is noted that the computational result is settling down to that value. However, the time required for this to happen is much greater than the time for the beam to achieve the expected transverse velocity shown in Figure 4-1. This is because the axial frequency of the beam is low due to the entrained fluid. The natural frequency of this system can easily be found by Rayleigh's method as follows.

Under a harmonic excitation \( u = Bx \sin \omega t \) the maximum potential energy \( U_{\text{max}} \) and the maximum kinetic energy \( T_{\text{max}} \) can be shown to be

\[
U_{\text{max}} = \frac{1}{2} B^2 AE \ell
\]

\[
T_{\text{max}} = \frac{1}{24} B^2 Ap \ell^3 \omega^2 + \frac{1}{8} B^2 m_f \ell^2 \omega^2
\]

where \( u \) is the axial displacement measured from one end, \( x \) is the axial coordinate, \( \omega \) is the circular frequency, \( t \) is time, \( A \) is the cross-sectional area, \( E \) is Young's modulus, \( \ell \) is the bar/beam length and \( m_f \) is the fluid added mass for the axial breathing mode of the bar/beam. Equating \( U_{\text{max}} \) to \( T_{\text{max}} \) then gives a value for the period \( P_{\text{wet}} \) as

\[
P_{\text{wet}} = P_{\text{dry}} \sqrt{1 + \frac{3 m_f}{m_s}}
\]

where

\[
P_{\text{dry}} = \frac{\pi \ell}{\sqrt{\rho/3E}}
\]

\[
m_s = \rho A \ell
\]

For the problem at hand \( P_{\text{dry}} = 4.617 \), \( m_f = 4.913 \), and \( m_s = 4.493 \) which gives \( P_{\text{wet}} = 9.597 \), about twice as long as the dry period. It is noted from the peak-to-peak times shown in Figure 4-3 that the computational result is in excellent agreement.
Figure 4-3 Axial Displacement at End of Finite Beam, Coarse Mesh
4.2 SUBMERGED INFINITE CYLINDRICAL SHELL

For this problem, a 72-node, 36-element SPAR model with a uniform circumferential mesh was constructed. The length of the cylindrical shell equalled the circumferential dimension of the square plate elements used for the model; hence the shell was one element long. Kinematic constraints of zero axial displacement and no end rotation were enforced through the skyline utility, as described in Section 3.3. The fluid model consists of 36 equally-spaced elements around the circumference; the two-dimensional nature of the infinite shell geometry was simulated by exercising an option in the fluid pre-processor FLUMAS that adds fictitious elements in the axial direction.

Two-dimensional $n=0$, 1, and 2 modal response results were generated by circumferential Fourier decomposition of USA-generated responses. For comparison DAA analytical solutions were generated by the method described in [8] and [30]. The primary response variables of interest were radial displacement for $n=0$, radial and tangential velocity for $n=1$, and radial and tangential displacement for $n=2$. A time step of 0.025 was used up to $t=1$; for $t$ between 1 and 2 this was increased 0.05, and for $t$ greater than 2 a time step of 0.1 was used.

The USA and corresponding analytical results are shown, harmonic by harmonic, in Figures 4-4 through 4-8. In all cases the maximum errors made by USA fall into the range of 1 to 2%.

4.3 SEMI-SUBMERGED INFINITE CYLINDRICAL SHELL

Analytical solutions for the problem of a shock-wave-excited, infinite, circular cylindrical shell whose axis lies in the plane of the free surface of a semi-infinite acoustic medium may readily be obtained. The appropriate geometry for an imaging representation of this problem is shown in Figure 4-9. An earlier treatment is described in [31], where the stiffness of the shell is neglected and an approximate expression is obtained for the asymptotic value for vertical rigid-body translational velocity. In this subsection it is shown that both exact and approximate solutions for the infinite-fluid case may be used directly to obtain solutions for the case of a semi-infinite fluid, as follows.

The shell and fluid variables are first expanded in circumferential harmonics as
Figure 4-4  n=0 Radial Displacement of Infinite Cylinder in Infinite Fluid
Figure 4-5  \( n=1 \) Radial Velocity of Infinite Cylinder in Infinite Fluid
Figure 4-6  $n=1$ Tangential Velocity of Infinite Cylinder in Infinite Fluid
Figure 4-7  n=2 Radial Displacement of Infinite Cylinder in Infinite Fluid
Figure 4-8  n=2 Tangential Displacement of Infinite Cylinder in Infinite Fluid
Figure 4-9 Geometry of Free Surface Problem for Plane Wave Impinging Upon Infinite Cylinder
\[
\begin{aligned}
\begin{pmatrix}
w(\theta,t) \\
v(\theta,t) \\
p(r,\theta,t) \\
p_1(r,\theta,t) \\
u_1(r,\theta,t)
\end{pmatrix} = \sum_{n=0}^{\infty} \begin{pmatrix}
w_n^c(t) \cos n\theta & w_n^s(t) \sin n\theta \\
v_n^s(t) \sin n\theta & v_n^c(t) \cos n\theta \\
p_n^c(t) \cos n\theta + p_n^s(t) \sin n\theta \\
p_n^c(r,t) \cos n\theta + p_n^s(r,t) \sin n\theta \\
\sin n\theta \pi(r,t) + u_n^c(r,t) \cos n\theta + u_n^s(r,t) \sin n\theta
\end{pmatrix}
\end{aligned}
\] (4.9)

where \( w \) and \( v \) are the radial and circumferential shell displacements, respectively, \( p \) is the total fluid pressure and \( p_1 \) and \( u_1 \) are the pressure and radial fluid-particle velocity of the incident wave. Because this is a linear problem, the solution consists of the superposition of two infinite-fluid solutions, the time-dependent part of which will be denoted by a superscript \( I \). The result is

\[
\begin{aligned}
\begin{pmatrix}
w(\theta,t) \\
v(\theta,t) \\
p(r,\theta,t) \\
\end{pmatrix} &= \sum_{n=0}^{\infty} (-1)^n \begin{pmatrix}
w_n^I(t) \cos n(\theta-\gamma) \\
v_n^I(t) \sin n(\theta-\gamma) \\
p_n^I(r,t) \cos n(\theta-\gamma)
\end{pmatrix} \\
\sum_{n=0}^{\infty} (-1)^n \begin{pmatrix}
w_n^I(t) \cos n(\theta+\gamma) \\
v_n^I(t) \sin n(\theta+\gamma) \\
p_n^I(r,t) \cos n(\theta+\gamma)
\end{pmatrix}
\end{aligned}
\] (4.10)

The multipliers \((-1)^n\) are required if the results of [3,4,30,32,33] are used to provide the infinite-fluid solutions for step-wave excitation. This is because of the convention adopted there that the incident wave first contacts the cylinder at \( \theta = \pi \). It should be noted that (4.10) holds for any plane-wave input if the infinite-fluid solution can be found and no cavitation occurs in the fluid.

The trigonometric terms in (4.10) can easily be simplified to give

\[
\begin{aligned}
\begin{pmatrix}
w(\theta,t) \\
v(\theta,t) \\
p(r,\theta,t)
\end{pmatrix} &= 2 \sum_{n=1}^{\infty} (-1)^n \sin n\gamma \begin{pmatrix}
w_n^I(t) \sin n\theta \\
v_n^I(t) \cos n\theta \\
p_n^I(r,t) \sin n\theta
\end{pmatrix}
\end{aligned}
\] (4.11)

Note from (4.10) that the solution for \( n=0 \) is identically zero. Also note that if the time-dependent part of the free surface solution is denoted by a superscript \( F \), then

\[
\begin{aligned}
\begin{pmatrix}
w_n^F(t) \\
v_n^F(t) \\
p_n^F(r,t)
\end{pmatrix} &= (-1)^n 2 \sin n\gamma \begin{pmatrix}
w_n^I(t) \\
v_n^I(t) \\
p_n^I(r,t)
\end{pmatrix}
\end{aligned}
\] (4.12)
This extremely simple result applies to exact solutions produced by the residual potential method \[3,30,32\], approximate solutions produced by the DAA \[3,4\], and the approximate post-envelopment solutions given in \[33\].

For a USA-Code treatment of this problem, a 40-node, 19-element SPAR half-model was constructed consisting of one 5° plate element, seventeen 10° plate-elements and a second 5° plate-element. The angle $\gamma$ was taken as 45°. In other respects, this analysis paralleled that of the totally submerged cylindrical shell described in Subsection 4.2.

Velocity responses for $n=1$ are shown in Figures 4-10 and 4-11, while displacement results for $n=2$ are shown in Figures 4-12 and 4-13. The level of USA-Code error for $n=1$ is about 1%; it is of interest to note that the approximate asymptotic velocity provided by the analysis of \[31\] is $V_m = 2.623$, which is about 10% high.

The $n=2$ post-envelopment solution during the final phase of shell envelopment is quite sensitive to temporal and spatial discretization details. This sensitivity is reflected in the level of USA-Code error exhibited in Figures 4-12 and 4-13, and is associated with the pressure discontinuity at the front of the step-wave. The error here is somewhat greater than that in Figures 4-7 and 4-8, as both the incident wave and its negative image are now involved.

4.4 DAA$_2$ STUDIES

As an initial test of USA-DAA$_2$, the infinite-cylinder case has also been run and physical response variables have been Fourier-decomposed to produce modal responses. For comparison, corresponding exact solutions have been obtained analytically by the residual potential (RP) method \[30\]. Comparisons are shown in Figures 4-14 through 4-18.

The difference between the family of doubly asymptotic solutions and the exact solution shown in Figure 4-14 is intrinsic to the infinite cylinder and occurs because of the infinite value of the $n=0$ fluid mass coefficient. Hence the interaction consists only of the high frequency asymptote of the DAA family. For a finite cylinder, the fluid mass for the breathing mode is always finite, so that the low-frequency contribution of the DAA family does participate.
Velocity responses for $n=1$ are shown in Figures 4-15 and 4-16, where it is noted that $r=0$ (DAA) and $n=1$ provide rather wide bounds on the exact solution in the intermediate time range, while a value of $n=1/2$ is remarkably close to the exact solution. In Figures 4-17 and 4-18, the displacement responses do not show such wide differences between $n=1/2$ and $n=1$; however, they both demonstrate a striking superiority over the DAA result. It would appear from this limited evidence that $n=1/2$ is probably optimum for the infinite cylinder case.

In closing, it should be emphasized that a study of the stability of (2.34) and (2.35) has yet to be undertaken. However, the results obtained thus far are very encouraging in this regard. No indication of instability whatsoever was encountered in generating the infinite cylinder results in which the time step was doubled twice during the run, as was done in the DAA runs.
Figure 4-10  n=1 Radial Velocity of Infinite Cylinder at Surface of Semi-Infinite Fluid
Figure 4-11  $n=1$ Tangential Velocity of Infinite Cylinder at Surface of Semi-Infinite Fluid
Figure 4-12  n=2 Radial Displacement of Infinite Cylinder at Surface of Semi-Infinite Fluid
Figure 4-13  \( n=2 \) Tangential Displacement of Infinite Cylinder at Surface of Semi-Infinite Fluid
Figure 4-14. $n=0$ Radial Displacement Response
Figure 4-15. n=1 Radial Velocity Response
Figure 4-16. \( n=1 \) Tangential Velocity Response
Figure 4-17. $n=2$ Radial Displacement Response

- USA DAA1, $\eta = 0$
- USA DAA2, $\eta = 1/2$
- USA DAA2, $\eta = 1$
- ANALYTICAL RP, EXACT
Figure 4-18. n=2 Tangential Displacement Response
REFERENCES


APPENDIX A
USER INFORMATION FOR THE FLUID PREPROCESSOR FLUMAS

This appendix includes a copy of the users manual, and a sample input deck and subsequent output for the infinite cylindrical shell problem presented in Section 4.
FLUMAS

THIS FUNCTIONAL COMPONENT OF THE UNDERWATER SHOCK ANALYSIS CODE
CONSTRUCTS THE FLUID MASS MATRIX FOR A STRUCTURE SUBMERGED IN AN
INFINITE, INVIScid, INCOMPRESSIBLE FLUID BY THE BOUNDARY ELEMENT
TECHNIQUE. IT ALSO GENERATES FLUID MESH DATA AND A SET OF
TRANSFORMATION COEFFICIENTS THAT RELATE THE STRUCTURAL AND FLUID
DEGREES OF FREEDOM ON THE WET SURFACE. THE CODE HAS THE CAPABILITY
TO TREAT STRUCTURES CONTAINING BOTH SURFACE-OF-REVOLUTION (SOR)
AND GENERAL-GEOMETRY (GEN) COMPONENTS. THE CODE CAN CONSTRUCT THE
FLUID MASS MATRIX FOR BOTH QUARTER AND HALF MODELS WITH
ARBITRARILY ASSIGNED SYMMETRY OR ANTISYMMETRY CONDITIONS, AND CAN
SIMULATE THE TWO-DIMENSIONAL PLANE STRAIN BEHAVIOR OF LONG
CYLINDERS. THE PRESENCE OF A FREE SURFACE IN THE VICINITY OF THE
SUBMERGED STRUCTURE CAN ALSO BE ACCOUNTED FOR. A VERY USEFUL
DIAGNOSTIC TOOL CONTAINED WITHIN THE CODE IS THE ABILITY TO SOLVE
THE FLUID BOUNDARY MODE EIGENVALUE PROBLEM

MAXIMUM VALUES

MAXIMUM NUMBER OF STRUCTURAL GRID POINTS .......... 1000
MAXIMUM NUMBER OF GENERAL SURFACE ELEMENTS ....... 400
MAXIMUM NUMBER OF SURFACE OF REVOLUTION SEGMENTS .... 200
MAXIMUM NUMBER OF SURFACE OF REVOLUTION BRANCHES ... 6

WARNING FROM THE PROGRAMMER GENERAL

THIS CODE CONTAINS THE SPECIAL 'INVENTORY' CARD NOT FOUND IN
OTHER BUNDLES OR 'EXEC' FILES. IT IS A DATA MANAGEMENT UTILITY MODULE THAT
WILL ACTIVATE AND DEACTIVATE ALL AUXILIARY STORAGE DATA FILES
REFERENCED BY THE CODE. HENCE THE NAMES OF SUCH FILES SHOULD NOT
APPEAR ON ANY CONTROL CARDS IN THE RUN STREAM WHICH MIGHT NORMALLY
ACTIVATE AND DEACTIVATE THE FILES. THE USER IS ALSO CAUTIONED THAT
PREVIOUSLY CREATED FILES MUST ALREADY BE RESIDENT IN THE SYSTEM
BEFORE THE RUN IS INITIATED. IF A FILE HAS BEEN ROLLED-OUT TO TAPE.
DMGASP WILL ATTEMPT TO HAVE THE FILE ROLLED-IN EVERY 15 SECONDS
FOR UP TO 6 MINUTES ON THE UNIVAC 1100-EXEC OPERATING SYSTEM.
IF AN EXISTING DATA FILE HAS NOT BEEN REFERENCED FOR SOME TIME IT
IS THEREFORE GOOD POLICY TO SIMPLY ACTIVATE AND DEACTIVATE THE
FILE BEFORE EXECUTION OF THIS CODE. IF THE USER ATTEMPTS TO CREATE
A NEW DATA FILE WITH A NAME WHICH IS ALREADY ASSIGNED TO AN
EXISTING FILE, THE UNIVAC VERSION OF DMGASP WILL MODIFY THE NAME
OF THE FILE GENERATED BY THIS RUN TO AVOID ANY CONFLICT. FILE NAME
DUPLICATION WILL CAUSE NO PROBLEM ON THE CDC SCOPE OPERATING
SYSTEM AS A NEW CYCLE WILL SIMPLY CATALOG A NEW COPY OF THE SAME FILE.
ON THE OTHER HAND THE CDC 6600 SYSTEM IS SIMILAR TO UNIVAC IN THIS
 REGARD AND THE RUN WILL ABORT SINCE THE NAME-CHANGING FEATURE OF
DMGASP HAS NOT BEEN IMPLEMENTED FOR NOS. QUALIFIER-FIENAME IS THE
REQUIRED INPUT DATA FORMAT FOR ALL UNIVAC PERMANENT FILE NAMPS.
ON CDC SCOPE, THE QUALIFIER IS INTERPRETED AS THE USERS ID, WHICH
IN MOST INSTALLATIONS CAN BE SELECTED ALMOST ARBITRARILY. ON CDC
NOS, THE QUALIFIER IS INTERPRETED AS THE USERS CATALOG NUMBER.
WHICH IS USUALLY PRESCRIBED BY THE INSTALLATION. A CYCLE NUMBER
CAN ALSO BE APPENDED TO GIVE THE FORM QUALIFIER-FIENAME(CYCLE)
ON CDC SCOPE

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PROGRAM SIZE

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ALL ARRAYS REFERENCED IN THIS CODE THAT ARE PROBLEM DEPENDENT
RESIDE IN BLANK COMMON. THE SIZE OF BLANK COMMON IS DETERMINED BY
A PARAMETER STATEMENT IN THE MAIN PROGRAM FOR THE UNIVAC 1100-05
VERSION, HENCE A RECOMPIATION IS NECESSARY TO INCREASE OR
DECREASE CORE ALLOCATION. IN THE CDC 6600 VERSION RECOMPIATION IS
UNNECESSARY AS THE LENGTH OF BLANK COMMON IS SET BY A FIELD LENGTH
REQUEST IN THE CONTROL CARD DECK

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DEFINITION OF INPUT PARAMETERS

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INPUT VARIABLE NAMES GIVEN BELOW ARE GENERALLY THOSE WHICH ARE
ALSO USED IN THE CODING AND THE VARIABLE TYPES CORRESPOND TO
STANDARD FORTRAN USAGE:

A = ALPHANUMERIC
E = FLOATING POINT
F = FIXED POINT
I = INTEGER
L = LOGICAL

VARIABLE  TYPE      DESCRIPTION
---------  -------    ------------------
NSTRC      I          NUMBER OF STRUCTURAL Node OR GRID POINTS
WHOSE GLOBAL COORDINATES ARE TO BE READ AS INPUT DATA FROM CARDS, AT THE VERY LEAST THE SUM OF NSTRF AND NSTRF (SEE REGION MUST INCLUDE ALL THE WEI NODES, I.E., THOSE LYING ON THE FLUID-STRUCTURE CONTACT BOUNDARY. IF THE ULTIMATE PURPOSE OF THIS RUN IS TO CONDUCT AN UNDERWATER SHOCK ANALYSIS WITH THE USA CODE FOR THE STRUCTURE IN QUESTION THEN IT IS ADVISABLE TO INCLUDE IN THE INPUT TO THIS PROCESSOR ALL OF THE INTERNAL OR/51 STRUCTURAL NODE POINTS AS WELL IN ORDER TO FACILITATE POST PROCESSING OF THE TRANSIENT RESPONSE ANALYSIS FOR THE DRY STRUCTURE, THIS NUMBER MAY ALSO INCLUDE ADDITIONAL NODE POINTS THAT ARE NOT PART OF THE STRUCTURAL MODEL BUT WHICH ARE NECESSARY TO DEFINE THE FLUID MESH. HOWEVER SUCH ADDITIONAL NODES SHOULD APPEAR LAST AS THEY ARE NOT REQUIRED BY ANY OTHER USA PROCESSOR AND ARE THEREFORE ULTILY DELITED.

NSTRF I NUMBER OF STRUCTURAL NODE OR GRID POINTS WHOSE GLOBAL COORDINATES ARE TO BE READ FROM A PERMANENT FILE (SEE GRDINAM), ADDITIONAL NODE POINTS THAT ARE NOT PART OF THE STRUCTURAL MODEL ARE NOT PERMITTED IN THIS DATA SET IF ACTUAL STRUCTURAL NODE POINT DATA IS ALSO INPUT FROM CARDS. THIS IS DUE TO THE FACT THAT THE FILE DATA IS READ FIRST THEN THE DATA FROM CARDS AND ANY ADDITIONAL NON-STRUCTURAL NODE POINTS MUST APPEAR LAST IN THE GRID POINT LIST. THIS FILE MUST ALWAYS BE REFERENCED WHEN INTERFACING WITH STAGS.

NGEN I NUMBER OF GENERAL FLUID DEGREES OF FREEDOM WHOSE ASSOCIATED ELEMENTS CANNOT BE FORMED BY AN AUTOMATIC MESH GENERATION PROCEDURE.

NBRA I NUMBER OF DISTINCT SURFACE OF REVOLUTION AXES OR BRANCHES.

NCYL I NUMBER OF GENERAL FLUID CONTROL POINTS WHICH LIE ON A RIGHT CIRCULAR CYLINDRICAL SURFACE WHOSE ASSOCIATED RECTANGULAR ELEMENTS COVER THE ENTIRE LATERAL SURFACE. SUCH ELEMENTS CAN BE FORMED BY AN AUTOMATIC MESH GENERATION SCHEME WHICH IS EXHIBITED IN THE CODE STRUCTURAL GRID POINT COORDINATES NEED NOT BE INPUT IN THIS CASE UNLESS DICTATED BY OTHER CIRCUMSTANCES.

NHAS I STARTING CIRCUMFERENTIAL HARMONIC FOR SURFACE OF REVOLUTION ELEMENTS.

NHAF I FINAL CIRCUMFERENTIAL HARMONIC FOR
<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
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<td>1</td>
</tr>
<tr>
<td>NFUN</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1 - EITHER SINE OR COSINE WILL BE USED ACCORDING TO VALUE OF ITRG DESCRIBED BELOW</td>
</tr>
<tr>
<td></td>
<td>2 - BOTH SINE AND COSINE FUNCTIONS WILL BE USED</td>
</tr>
<tr>
<td>ITRG</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1 - COSINE FUNCTION IS USED</td>
</tr>
<tr>
<td></td>
<td>2 - SINE FUNCTION IS USED</td>
</tr>
<tr>
<td>NSEG</td>
<td>1</td>
</tr>
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<td>NCIR</td>
<td>1</td>
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<tr>
<td>HAFMOD</td>
<td>L</td>
</tr>
<tr>
<td>QUAMOD</td>
<td>TRUE IF THE FLUID MESH INPUT GEOMETRY CORRESPONDS TO A QUARTER MODEL, OTHERWISE FALSE. THE XZ AND YZ PLANES ARE CONSIDERED TO BE THE PLANS OF SYMMETRY OF THE MODEL BY DEFAULT. IF NECESSARY, A COORDINATE ROTATION CAN BE APPLIED TO SATISFY THIS REQUIREMENT (SEE ROTMOD BELOW). IF NCOL IS NOT EQUAL TO ZERO SUCH A ROTATION MUST BE USED IN CONJUNCTION WITH THE QUARTER MODEL. THIS ROTATION WILL NOT AFFECT THE ORIENTATION OF THE FLUID MESH REFERENCE AXES IN SUBSEQUENT USA PROCESSING.</td>
</tr>
<tr>
<td>PCHCMS</td>
<td>TRUE IF THE DIAGONAL GENERALIZED AREA MATRIX IS TO BE PUNCHED OUT ON CARDS FOR INPUT TO NASTRAN, OTHERWISE FALSE.</td>
</tr>
<tr>
<td>NASTAM</td>
<td>TRUE IF THE FLUID MASS MATRIX OR ITS MANIPULATED FORM WHICH APPEARS IN THE DAA EQUATION IS TO BE PUT IN THE PERMANENT FILE DESIGNATED BY FLUNAM IN A FORMAT WHICH CAN BE READ BY NASTRAN, OTHERWISE FALSE.</td>
</tr>
<tr>
<td>STOMAS</td>
<td>TRUE IF THE FLUID MASS MATRIX ITSELF IS TO BE PUT IN PERMANENT STORAGE, OTHERWISE FALSE. IN CONTRAST TO EARLIER VERSIONS OF THIS CODE THIS PARAMETER CAN BE SET TO FALSE FOR NORMAL OPERATION OF THE USA CODE.</td>
</tr>
<tr>
<td>STOMV</td>
<td>TRUE IF THE MANIPULATED FORM OF THE FLUID MASS MATRIX WHICH APPEARS IN THE DAA EQUATION IS TO BE PUT IN PERMANENT STORAGE, OTHERWISE FALSE. THIS MATRIX CONSISTS OF THE INVERTED FLUID MASS MATRIX THAT HAS BEEN PRE- AND POST-MULTIPLIED BY THE DIAGONAL FLUID ELEMENT AREA MATRIX AND THEN MULTIPLIED BY BOTH THE MASS DENSITY AND THE SPEED OF SOUND OF THE FLUID. IN CONTRAST WITH EARLIER VERSIONS OF THIS CODE THIS PARAMETER MUST BE SET TO TRUE FOR NORMAL OPERATION OF THE USA CODE.</td>
</tr>
<tr>
<td>FRWFL</td>
<td>TRUE IF THE PERMANENT FILE CONTAINING THE FLUID MASS MATRIX ON ITS MANIPULATED FORM IS TO BE CREATED BY BUFFERED, UNFORMATTED FORTRAN WRITE STATEMENTS, OTHERWISE FALSE AND DGMASP WILL CREATE THE FILE.</td>
</tr>
<tr>
<td>FRWTGE</td>
<td>TRUE IF THE PERMANENT FILE CONTAINING THE FLUID MESH GEOMETRY IS TO BE CREATED BY BUFFERED, UNFORMATTED FORTRAN WRITE STATEMENTS, OTHERWISE FALSE AND DGMASP WILL CREATE THE FILE.</td>
</tr>
</tbody>
</table>
FMTGR  L  TRUE IF THE PERMANENT FILE CONTAINING
      STRUCTURAL GRID POINT COORDINATES HAS
      BEEN CREATED BY BUFFERED, UNFORMATTED
      FORTRAN WRITE STATEMENTS, OTHERWISE FALSE
      IN WHICH CASE IT IS ASSUMED THAT CMGASP
      WAS USED TO CREATE THE FILE, CONSULT A
      LISTING OF THE SUBROUTINE READ3 FOR THE
      FILE STRUCTURE THAT IS EXPECTED WHICH
      DIFFERS FOR THE TWO POSSIBLE CASES. THIS
      FILE MUST EXIST FOR INTERFACING WITH STAGS

FRESUR  L  TRUE IF FREE SURFACE EFFECTS ARE TO BE
      INCLUDED IN THE FLUID MASS MATRIX,
      OTHERWISE FALSE. THE VARIABLES DEPTH,
      UXFS, UYFS, AND UZFS ARE USED TO DEFINE
      THE LOCATION AND ORIENTATION OF THE FREE
      SURFACE. THIS OPTION CANNOT BE USED
      SIMULTANEOUSLY WITH HAPAI = .TRUE.

RENUMB  L  TRUE IF SOME RENUMBERING OF THE STRUCTURAL
      NODE NUMBERS MUST BE CARRIED OUT AFTER THE
      FLUID-STRUCTURE TRANSFORMATION DATA HAS
      BEEN GENERATED, OTHERWISE FALSE. THIS
      OPTION IS IMPORTANT IF THE USE OF A
      PARTICULAR STRUCTURAL NODE NUMBER IS
      CONVENIENT TO DEFINE THE FLUID ELEMENT.
      RENUMBERING A NEARBY STRUCTURAL NODE SHOULD
      NOT BE USED FOR FORCE APPLICATION DURING THE
      UNDERWATER SHOCK ANALYSIS TIME INTEGRATION
      RUN. THIS CASE IS PARTICULARLY IMPORTANT
      IF THE TAD POINTS IN QUESTION ARE JOINED
      BY A RIGID LINK AND THE STRUCTURAL POINT
      ORIGINALLY USED TO DEFINE THE FLUID-FISH
      IS ELIMINATED FROM THE STIFFNESS MATRIX BY
      A CONSTRAINT EQUATION. WITHOUT THE USE OF
      THIS OPTION THE APPROPRIATE FORCE WOULD
      NOT BE APPLIED TO THE EQUATIONS OF MOTION

STOGMT  L  TRUE IF THE FLUID MASS CEMETERY AND
      FLUID-STRUCTURE TRANSFORMATION DATA IN TO
      PUT IN PERMANENT STORAGE, OTHERWISE FALSE

ROTGEQ  L  TRUE IF THE FLUID MASS CEMETERY IS TO BE
      REFERRED TO A SET OF GLOBAL COORDINATE
      AXES WHICH IS DIFFERENT FROM THAT OF THE
      BASIC INPUT DATA FOR ALL I/I PROCESSING (SEE GEOM). OTHERWISE FALSE

ROTQUA  L  TRUE IF THE FLUID MASS CEMETERY IS TO BE
      REFERRED TO A SET OF GLOBAL COORDINATE
      AXES WHICH IS DIFFERENT FROM THAT OF THE
      BASIC INPUT DATA ONLY FOR COMPUTATION OF
      THE FLUID MASS MATRIX (SEE QUAND). OTHERWISE FALSE. THIS OPTION IS TO BE USED
      IF A QUARTER MODEL IS REQUIRED AND THE
      INPUT DATA REFERENCE AXES DO NOT COINCIDE
      WITH THE DEFAULT SYMMETRY AXES. THIS
FLUNAM A NAME OF PERMANENT MASS STORAGE FILE WHICH
WILL CONTAIN THE FLUID MASS MATRIX

GEDNAM A NAME OF PERMANENT MASS STORAGE FILE WHICH
WILL CONTAIN THE FLUID MESH GEOMETRY AND
FLUID-STRUCTURE TRANSFORMATION DATA

GREDNAM A NAME OF PERMANENT MASS STORAGE FILE WHICH
CONTAINS THE GLOBAL COORDINATES OF THE
STRUCTURAL GRID POINTS

DAANAM A NAME OF PERMANENT MASS STORAGE FILE WHICH
WILL CONTAIN THE MULTIPLIED DAA FORM OF
THE FLUID MASS MATRIX

NVEC 1 NUMBER OF FLUID BOUNDARY MODE EIGENVECTORS
DESIRED. THESE ARE ORDERED STARTING WITH
THE LOWEST ORDER MODES FIRST. IF ALL THE
MODES ARE DESIRED THE USER CAN JUST SET
NVE = 1 TO 1000 AND THE CODE WILL
AUTOMATICALLY REDUCE THIS NUMBER TO THE
ORDER OF THE FLUID MASS MATRIX. THIS IS
CONVENIENT WHEN THE MODEL CONTAINS 5 IN
ELEMENTS FOR SEVERAL HAPTONICS AND/or
THE USER DOES NOT WANT TO
SPEND TIME COUNTING UP THE TOTAL. THIS IS
RECOMMENDED ONLY FOR SMALL OR INTERMEDIATE
SIZE PROBLEMS. FOR LARGE PROBLEMS PRINTING
OF ONLY THE FIRST 10 EIGENVECTORS IS
RECOMMENDED. AS IT IS ONLY THE FIRST FEW
ARE GENERALLY USEFUL TO VERIFY SYMMETRIES
AND OTHER FEATURES OF THE MODEL, THE FIRST
ONE IS ALWAYS A BREATHER TYPE MODE UNLESS
THE FLUID MODEL CONSISTS SOLELY OF DIAM
THE OR ELEMENTS

NUMZ 1 NUMBER OF FICTITIOUS ELEMENTS TO BE ADDED
IN AXIAL DIRECTION WHICH INCREASE THE
HAP LENGTH OF THE SURFACE FOR THE
SIMULATION OF A TWO DIMENSIONAL PLAIN
STRAIN FLUID MASS MATRIX. THESE ELEMENTS
DO NOT INTRODUCE NEW DEGREES OF FREEDOM

ZLEN E,F LENGTH OF FICTITIOUS AXIAL ELEMENTS USED
IN THE SIMULATION OF A 2D DIMENSIONAL
PLAIN STRAIN FLUID MASS MATRIX

CQ E,F USED FOR FLUID MESH MODELS WITH PLANS OF
SYMMETRY. CQ TAKES ON THE VALUE OF EITHER
PLUS OR MINUS ONE TO DENOTE SYMMETRIC OR
ASYMMETRIC FLOW CONDITIONS IN EACH
FLUID REGION INCLUDING THOSE THAT ARE NOT
EXPLICITLY CONTAINED IN THE MODEL. FOR A
QUARTER MODEL 4 VALUES ARE REQUIRED, ONE
DEPTH E,F
MAGNITUDE OF PERPENDICULAR DISTANCE FROM
THE ORIGIN OF COORDINATES TO THE PLANE OF
A FREE SURFACE OR THE PLANE OF SYMMETRY
FOR A HALF MODEL

CXFS, CYFS, E,F
DIRECTION COSINES OF A UNIT VECTOR NORMAL
TO THE PLANE OF A FREE SURFACE OR THE
PLANE OF SYMMETRY FOR A HALF MODEL AND
POINTING OUT OF THE FLUID REGION
EXPLICITLY CONTAINED IN THE MODEL. THEY
MUST BE RELATIVE TO THE GLOBAL CARTESIAN
COORDINATES OF THE FLUID MESH. IF ANY
COORDINATE ROTATIONS ARE APPLIED TO THE
FLUID MESH GEOMETRY (SEE ROGUE AND
ROTQA) THESE QUANTITIES WILL ALSO BE
TRANSFORMED

PATH E,F
AVERAGE ATMOSPHERIC PRESSURE THAT IS USED
ULTIMATELY TO TEST FOR DUNK CAVITATION IN
THE UNDERWATER SHOCK ANALYSIS

GRAVAC E,F
ACCELERATION DUE TO GRAVITY

GEOANG E,F
EULERIAN ANGLES OF ROTATION USED TO
DESCRIBE A PERMANENT COORDINATE
TRANSFORMATION FOR THE FLUID MESH
GEOMETRY. THREE VALUES EXPRESSED IN
DEGREES ARE REQUIRED. THE FIRST IS THE
ROTATION ABOUT THE ORIGINAL X AXIS, THE
SECOND IS THE ROTATION ABOUT THE LINE
COINCIDENT WITH THE CURRENT ORIENTATION
OF THE ORIGINAL Y AXIS AFTER THE FIRST
ROTATION, AND FINALLY THE THIRD IS THE
ROTATION ABOUT THE LINE COINCIDENT WITH
THE CURRENT ORIENTATION OF THE ORIGINAL Z
AXIS AFTER THE FIRST TWO ROTATIONS.
ALTHOUGH THIS METHOD MAY BE SOMEWHAT
CONVENIENT FOR ARBITRARY SPATIAL
ORIENTATIONS ALMOST ALL CASES OF PRACTICAL
INTEREST WILL DEAL ONLY WITH VALUES OF 0,
90, AND OR 180 DEGREES

QUAANG E,F
EULERIAN ANGLES OF ROTATION USED TO
DESCRIBE A TEMPORARY COORDINATE
TRANSFORMATION FOR THE FLUID MESH
GEOMETRY (SEE GEOANG ABOVE FOR PRECISE
DEFINITION). IF A QUARTER MODEL IS
REQUIRED AND THE MESH HAS BEEN GENERATED
AUTOMATICALLY FOR A CYLINDRICAL SURFACE
BOUNDED BY 0 AND 180 DEGREES THEN THE
APPROPRIATE ANGLES TO USE HERE WOULD BE
90, 90, AND 0

NSHIFT I
A PARAMETER THAT IS ADDED TO THE VALUE OF
NUST (SEE BELOW) IN THE NUMBERING OF
<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSEQ</td>
<td>Structural grid point number</td>
</tr>
<tr>
<td>NS</td>
<td>Indicator to denote type of coordinate system grid point data is referred to. Allowable values are:</td>
</tr>
<tr>
<td>XC, YC, ZC</td>
<td>Cartesian coordinates of structural grid point if NS = 0, if NS = 1, 2, or 3 these are the radial, circumferential, and axial coordinates respectively in a polar cylindrical system. The circumferential angle must be expressed in degrees and be measured from the y, z, or x axis respectively according to whether NS is equal to 1, 2, or 3. If the point in question is interior to the wet surface or is not used in the definition of the fluid, all of the coordinates themselves are not required.</td>
</tr>
<tr>
<td>NEL</td>
<td>General fluid element index which runs from 1 to NGEN in sequential order</td>
</tr>
<tr>
<td>NC</td>
<td>Number of corner points of general fluid element, currently restricted to the values 3 or 4. See fluid element library. The corner points will equally participate in the fluid-structure transformation.</td>
</tr>
<tr>
<td>NN</td>
<td>Number of additional structural points associated with a particular general fluid element, currently having permissible values of 0, 1, 2, 3, and 4. If KRTN = 0 (see below and fluid element library). If KRTN IS NOT EQUAL TO ZERO THEN IT MAY HAVE ANY VALUE UP TO 12 FOR RECTANGLES AND 13 FOR TRIANGLES. THESE ADDITIONAL POINTS</td>
</tr>
</tbody>
</table>

FLUID ELEMENTS AUTOMATICALLY GENERATED FOR CYLINDRICAL SURFACES. THIS OPTION IS USEFUL IF A FLUID MESH HAS BEEN CONSTRUCTED WITH BOTH GEN ELEMENTS AND CYLINDRICAL SURFACE ELEMENTS AND THEN GEN ELEMENTS ARE REMOVED OR ADDED LATER IN A RECODING EFFORT. SINGLE GEN ELEMENTS APPEAR FIRST IN THE ELEMENT LIST THE USE OF THIS PARAMETER ELIMINATES ANY NEED TO CHANGE THE NUMBERING SCHEME ON DATA CARDS FOR CYLINDRICAL SURFACE ELEMENTS. NSHIFT MAY BE POSITIVE, NEGATIVE, OR ZERO.
ALWAYS PARTICIPATE IN THE FLUID-STRUCTURE
TRANSFORMATION. IT IS EXTREMELY IMPORTANT
TO THE UNDERWATER SHOCK ANALYSIS THAT ALL
WETTED STRUCTURAL NODES LOCATED WITHIN AND
ON THE BORDERS OF THE FLUID ELEMENT BE
INCLUDED IN NN EVEN IF THE CASE KTRN NOT
EQUAL TO ZERO MUST BE INVOKED

KURV I FLUID ELEMENT CURVATURE FLAG. ACCEPTABLE
VALUES ARE:
0 - FLAT ELEMENT
1 - CURVED ELEMENT, CODE WILL DETERMINE
AVERAGE CURVATURE OF ELEMENT FROM
NEIGHBOR POINT LOCATIONS. DO NOT USE
THIS OPTION IF NN = 0
2 - CURVED ELEMENT, USER MUST INPUT
PRINCIPLE RADII OF CURVATURE. IF
EITHER RADIUS IS SET TO 10000 OR
GREATER THEN ITS ASSOCIATED
CURVATURE WILL BE SET TO ZERO

KTRN I SHOULD HAVE THE VALUE OF ZERO UNDER NORMAL
CIRCUMSTANCES WHEN THE FLUID-STRUCTURE
TRANSFORMATION COEFFICIENTS ARE COMPUTED
BY THE CODE. IF KTRN IS NONZERO THEN THESE
COEFFICIENTS ARE DETERMINED BY HAND FOR
THE ELEMENT IN QUESTION AND MUST BE READ
AS INPUT DATA. THIS MUST BE DONE IF THE
ELEMENT DOES NOT FIT ANY OF THE STANDARD
 PATTERNS IN THE FLUID ELEMENT LIBRARY. A
 DISCUSSION OF HOW TO DO THIS IN AN
APPROXIMATE FASHION IS GIVEN BELOW (SEE
TRAN)

NODE I NODE POINT NUMBERS OF FLUID ELEMENT CORNER
POINTS TAKEN IN COUNTER CLOCKWISE
DIRECTION. IN GENERAL THE SIDE DEFINED
BY THE FIRST TWO CORNER POINTS SHOULD BE
ROUGHLY ORIENTED IN THE DIRECTION OF ONE
OF THE PRINCIPAL AXES OF THE ELEMENT SO AS
TO KEEP THE PRODUCT OF INERTIA OF THE
ELEMENT SMALL RELATIVE TO ITS PRINCIPAL
MOIRES OF INERTIA. IF THIS RULE IS NOT
FOLLOWED IT IS POSSIBLE THAT THE FLUID -
STRUCTURE TRANSFORMATION, ARRAY FOR THE
ELEMENT WILL BE ILL CONDITIONED. ASSIGN A
NEGATIVE VALUE TO ANY NODE NUMBER THAT IS
NOT PART OF THE STRUCTURAL FINITE ELEMENT
MODEL SO THEY WILL NOT PARTICIPATE IN THE
FLUID-STRUCTURE TRANFORMATION. AT
PRESENT SUCH POINTS CAN ONLY BE USED IN
CONJUNCTION WITH 6 - NODE QUADRILATERALS.
SLE FLUID ELEMENT LIBRARY

ITEM I NODE POINT NUMBERS OF FLUID ELEMENT
NEIGHBOR POINTS AGAIN TAKEN IN COUNTER
CLOCKWISE ORDER STARTING FROM FIRST CORNER
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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<tbody>
<tr>
<td>639</td>
<td>POINT. ANY INTERIOR POINTS MUST APPEAR</td>
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<tr>
<td>640</td>
<td>LAST. SEE FLUID ELEMEKT LIBRARY</td>
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<tr>
<td>642</td>
<td>RAD1</td>
</tr>
<tr>
<td>644</td>
<td>RAD2</td>
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<td>650</td>
<td>ECCEN</td>
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THE ABOVE PROCESS ALWAY AND THEN ADD THE
RESULTING COEFFICIENT FOR THE POINT IN
A QUESTION TO THAT FOR ITS NEAREST
CONTRIBUTION COULD EVEN BE DIVIDED BETWEEN
TWO OR MORE NODE POINTS ONCE COMPUTED.
THE ORDER OF INPUT TO THE CODE MUST AGREE
WITH THE ORDER TAKEN FIRST BY THE CORNER
POINT NODE NUMBERS (SEE NODE) AND THEN BY
THE NEIGHBOR POINT NODE NUMBERS (SEE ITEM)
CONSECUTIVELY.

NTCY 1
NUMBER OF STRUCTURAL NODE POINTS THAT
COUPLE WITH A CURVED RECTANGULAR FLUID
ELEMENT WHICH IS TO BE AUTOMATICALLY
FORMED FOR AN AXIAL SEGMENT OF A RIGHT
CIRCULAR CYLINDRICAL SURFACE. AVAILABLE
OPTIONS ARE:

2 - STRUCTURAL NODES WILL BE ON MIDPOINT
OF CURVED SIDES
4 - STRUCTURAL NODES WILL BE AT CORNERS
6 - FLUID ELEMENT WILL OVERLAP TWO (2)
STRUCTURAL ELEMENTS. VARIABLE KFUN
BELLOW ALSO REQUIRED IN THIS CASE
9 - FLUID ELEMENT WILL OVERLAP FOUR (4)
STRUCTURAL ELEMENTS. TWO IN THE
AXIAL DIRECTION AND TWO IN THE
CIRCUMFERENTIAL DIRECTION

KFUN 1
DEScribes manner in which a six node
RECTANGULAR FLUID ELEMENT OVERLAYS TWO
RECTANGULAR STRUCTURAL ELEMENTS.
PERMISSIBLE VALUES ARE:

1 - CONFIGURATION CONSISTS OF TWO
STRUCTURAL ELEMENTS IN AXIAL
DIRECTION
2 - CONFIGURATION CONSISTS OF TWO
STRUCTURAL ELEMENTS IN
CIRCUMFERENTIAL DIRECTION

KROT 1
IF KROT = 0 THE Z DIRECTION WILL BE TAKEN
AS THE AXIS FOR AUTOMATICALLY GENERATED
ELEMENTS OVER A CYLINDRICAL SURFACE. IF
KROT IS NOT EQUAL TO ZERO A ROTATION OF
AXES WILL BE PERFORMED (SEE CYLANG)

KARC 1
A VALUE OF ZERO USED UNDER NORMAL
CONDITIONS INDICATES THAT THE AREA
ASSOCIATED WITH AUTOMATICALLY GENERATED
CYLINDRICAL SURFACE ELEMENTS IS TO BE
CALCULATED USING THE CHORD WHICH AGREES
WITH WHAT MOST STRUCTURAL FINITE ELEMENT
CODES ASSUME. A VALUE OTHER THAN ZERO WILL
SPECIFY THAT THE ARC LENGTH IS TO BE USED
INSTEAD. THE DIFFERENCE BETWEEN THESE TWO
CASES IS GENERALLY VERY SMALL FOR ANY

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REASONABLE CIRCUMFERENTIAL SPACING OF THE
ELEMENTS. THE LATTER CAN GENERATE A
SLIGHTLY MORE ACCURATE FLUID MASS MATRIX
HOWEVER THE FORMER CAN GIVE A SLIGHTLY
BETTER STRUCTURAL RESPONSE CALCULATION

NCRC  I  NUMBER OF CIRCUMFERENTIAL GENERAL ELEMENTS
TO BE FORMED AUTOMATICALLY FOR AN AXIAL
SEGMENT OF A RIGHT CIRCULAR CYLINDRICAL
SURFACE

NLAST  I  NUMBER OF LAST FLUID ELEMENT IN SURFACE
HEX WHICH PRECEDES THE INPUT FOR THIS
AXIAL SEGMENT. NLAST CAN HAVE THE VALUE OF
ZERO IF REQUIRED

NSTART  I  NUMBER OF STRUCTURAL GRID OR NODE POINT AT
BOTTOM LEFT HAND CORNER OF THE FIRST OF
THIS SET OF CIRCUMFERENTIAL GENERAL FLUID
ELEMENTS. IF NTGY = 2 THIS IS THE NODE AT
THE MIDPOINT OF THE LEFT HAND SIDE

NDAX1  I  INCREMENT TO BE APPLIED TO NSTART IN
DESIGNATING THE NUMBER OF THE
CORRESPONDING STRUCTURAL NODE AT THE FIRST
ROW OF CIRCUMFERENTIAL STRUCTURAL NODES TO
THE RIGHT OF NSTART IN THE AXIAL DIRECTION

NDCR  I  INCREMENT TO BE APPLIED TO NSTART IN
DESIGNATING THE NUMBER OF THE
CORRESPONDING STRUCTURAL NODE AT THE FIRST
ROW OF AXIAL STRUCTURAL NODES ABOVE NSTART
IN THE CIRCUMFERENTIAL DIRECTION. FOR THE
CASE NTGY = 6 WITH KFRN = 2, OR NTGY = 9
IT IS ASSUMED THAT NDCR IS THE SAME FOR
EACH CIRCUMFERENTIAL INCREMENT

NDAX2  I  INCREMENT TO BE APPLIED TO NSTART + NDAX1
IN DESIGNATING THE NUMBER OF THE
CORRESPONDING STRUCTURAL NODE AT THE
SECOND ROW OF CIRCUMFERENTIAL STRUCTURAL
NODES TO THE RIGHT OF NSTART IN THE AXIAL
DIRECTION. THIS CASE IS CHARACTERIZED BY
LITY - 6 WITH KFRN = 1, OR NTGY = 9.
OTHERWISE NDA2 CAN BE LET TO ZERO

RAD  E,F  RADIUS OF CIRCULAR CYLINDRICAL SURFACE

AXL1  E,F  AXIAL COORDINATE OF THE FIRST ROW OF
STRUCTURAL NODES IN THE CIRCUMFERENTIAL
DIRECTION THAT COUPLE WITH A PARTICULAR
SET OF CYLINDRICAL SURFACE GENERAL
ELEMENTS. THIS ROW WILL FORM THE LEFT
AXIAL BOUNDARY OF THE SET OF FLUID
ELEMENTS

AXL2  E,F  AXIAL COORDINATE OF THE SECOND ROW OF
STRUCTURAL NODES IN THE CIRCUMFERENTIAL
DIRECTION THAT COUPLE WITH A PARTICULAR
SET OF CYLINDRICAL SURFACE GENERAL
ELEMENTS, THIS ROW WILL FORM THE RIGHT
AXIAL BOUNDARY OF THE SET OF FLUID
ELEMENTS IF NT CY = 2, NT CY = 4, OR
NT CY = 6 WITH KF UN = 2. IF NT CY = 6 WITH
KF UN = 1, OR NT CY = 9 THIS ROW WILL LIE
WITHIN THE INTERIOR OF THE FLUID ELEMENT
AND THE STRUCTURAL NODES AT THIS LOCATION
WILL BE CONSIDERED AS NEIGHBOR POINTS IN
THE FLUID STRUCTURAL TRANSFORMATION ARRAY

THET S E, F
ANGLE IN DEGREES THAT SPECIFIES THE
STARTING BOUNDARY FOR A SET OF GENERAL
ELEMENTS AROUND THE PARTIAL CIRCUMFERENCE
OF A RIGHT CIRCULAR CYLINDRICAL SURFACE.
THE X AXIS IS DEFINED AS ZERO AND THET S
CAN BE NEGATIVE IF DESIRED. THIS OPTION IS
IMPORTANT AS A DISCONTINUITY OF 360
DEGREES IN THE ANGULAR FUNCTION AT THE X
AXIS IS NOT PERMITTED

THETF E, F
ANGLE IN DEGREES THAT SPECIFIES THE
FINISHING BOUNDARY FOR A SET OF GENERAL
ELEMENTS AROUND THE PARTIAL CIRCUMFERENCE
OF A RIGHT CIRCULAR CYLINDRICAL SURFACE.
THE X AXIS IS DEFINED AS ZERO AND THETF
MUST BE POSITIVE, HOWEVER IT CAN BE EITHER
LARGER OR SMALLER THAN THE MAGNITUDE OF
THET S

AXL 3 E, F
AXIAL COORDINATE OF THE THIRD ROW OF
STRUCTURAL NODES IN THE CIRCUMFERENTIAL
DIRECTION THAT COUPLE WITH A PARTICULAR
SET OF CYLINDRICAL SURFACE GENERAL
ELEMENTS. IF AXL 3 IS NON-ZERO THEN IT MUST
BE ALGEBRALLY GREATER THAN AXL 2 AND
THEN ROW WILL THEN FORM THE RIGHT AXIAL
BOUNDARY OF THE SET OF FLUID ELEMENTS.
THIS CASE IS CHARACTERIZED BY NT CY = 6
WITH KF UN = 1, OR NT CY = 9

CYLANG E, F
Eulerian ANGLES OF ROTATION USED TO ORIENT
THE AXIS OF CYLINDRICAL SURFACE GENERAL
ELEMENTS (SEE GEOMS FOR GENERAL
DEFINITION), IN THE FOLLOWING SPECIAL
CASES OF IMPORTANCE THE DESIRED AXIS IS
SHOWN IN THE LEFT HAND COLUMN WHILE THE
APPROPRIATE ANGLES ARE GIVEN TO THE RIGHT:

\[
\begin{align*}
 x &= 90, 180, 90 \quad \text{OR} \quad 0, +/-90, 0 \\
 y &= 0, 90, 90 \quad \text{OR} \quad +/-90, 0, 0 \\
 z &= \text{NO INPUT, SET KROI = 0}
\end{align*}
\]

THIS OPTION IS NECESSARY WHEN USING STAGS
AS THE STRUCTURAL PROCESSOR IN ITS DEFAULT
MODE IN WHICH CASE IT USES THE X DIRECTION
AS THE CYLINDER AXIS.
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>B71</td>
<td>N1</td>
<td>I</td>
</tr>
<tr>
<td>B72</td>
<td>N2</td>
<td>I</td>
</tr>
<tr>
<td>B73</td>
<td>R1</td>
<td>E,F</td>
</tr>
<tr>
<td>B74</td>
<td>R2</td>
<td>E,F</td>
</tr>
<tr>
<td>B75</td>
<td>NSET</td>
<td>I</td>
</tr>
<tr>
<td>B76</td>
<td>N3</td>
<td>I</td>
</tr>
<tr>
<td>B77</td>
<td>ISEG</td>
<td>I</td>
</tr>
<tr>
<td>B78</td>
<td>NUMCHG</td>
<td>I</td>
</tr>
<tr>
<td>B79</td>
<td>NODOLD</td>
<td>I</td>
</tr>
<tr>
<td>B80</td>
<td>NODNEW</td>
<td>I</td>
</tr>
</tbody>
</table>

**GRID POINT NUMBER OF STRUCTURAL NODE THAT**

**DEFINES THE BEGINNING OF A SURFACE OF**

**REVOLUTION BRANCH OR SEGMENT**

**GRID POINT NUMBER OF STRUCTURAL NODE THAT**

**DEFINES THE END OF A SURFACE OF REVOLUTION**

**BRANCH OR SEGMENT**

**RADIUS TO WET SURFACE FROM AXIS OF SURFACE OF REVOLUTION ELEMENT AT STRUCTURAL GRID POINT DEFINING THE START OF A SURF BRANCH OR SEGMENT**

**RADIUS TO WET SURFACE FROM AXIS OF SURFACE OF REVOLUTION ELEMENT AT STRUCTURAL GRID POINT DEFINING THE END OF A SURF BRANCH OR SEGMENT**

**NUMBER OF DATA CARDS REQUIRED TO DEFINE SURFACE OF REVOLUTION FLUID ELEMENTS ALONG THE LENGTH OF A PARTICULAR SURF BRANCH OR AXIS. IF NSET = 1 IT IS ASSUMED THAT THE PHYSICAL CONFIGURATION OF THE SURF BRANCH IS AS DESCRIBED BELOW UNDER ISEG**

**GRID POINT NUMBER OF STRUCTURAL NODE THAT DEFINES THE AXIS OF THE SURFACE OF REVOLUTION BRANCH IN CONJUNCTION WITH N1. IF N2 = N1, THIS CASE CORRESPONDS TO A DISC**

**NUMBER OF SURFACE OF REVOLUTION ELEMENTS THAT CAN BE DEFINED BETWEEN TWO AXIAL STATIONS SUCH THAT THE RADIUS OF THE SURFACE VARIES LINEARLY ALONG THE LENGTH AND THAT EVERY PAIR OF INTERMEDIATE ADJACENT STRUCTURAL NODE NUMBERS DIFFER BY A COMMON INCREMENTAL VALUE. THIS NEED NOT BE EQUALLY SPACED ALONG THE AXIS AS THE STRUCTURAL NODES MAY NOT NECESSARILY BE EQUALLY SPACED ALONG THE AXIS**

**NUMBER OF STRUCTURAL GRID POINTS THAT MUST BE RENUMBERED IN THE FLUID-STRUCTURE TRANSFORMATION DATA**

**STRUCTURAL GRID POINT NUMBER THAT IS TO BE CHANGED TO NODNEW IN THE FLUID-STRUCTURE TRANSFORMATION DATA**

**NEW STRUCTURAL GRID POINT NUMBER ASSIGNED TO FLUID-STRUCTURE TRANSFORMATION DATA IN PLACE OF NODOLD. THIS GRID POINT MUST ALREADY BE PART OF THE STRUCTURAL NODE全球坐标数据输入从卡DSN0/PERMANENT FILE**
**INPUT DATA CARD DECK**

**ALL INPUT DATA EXCEPT ALPHANUMERIC DATA MUST BE RIGHT JUSTIFIED**

**IN EIGHT (8) COLUMN FIELDS WHICH CAN OCCUPY THE ENTIRE CARD.**

**ALPHANUMERIC DATA MUST BE LEFT JUSTIFIED IN TWENTY (20) COLUMN**

**FIELDS. FILE NAME PLUS QUALIFIER IS CURRENTLY RESTRICTED TO**

**EIGHTEEN (18) CHARACTERS FOR UNIVAC OPERATION WHILE NINETEEN (19)**

**CHARACTERS MAY BE USED FOR CDC OPERATION**

**NOTE THAT THERE IS A DESCRIPTIVE ENTRY IN THE FIRST FIELD OF SOME**

**INPUT CARDS AND THAT THE DATA FOR THAT CARD ACTUALLY BEGINS IN THE**

**SECOND FIELD. THIS OCCURS IN SUBROUTINES READST, GENELM, CYLEO**

**AND SORTINP IN WHICH THE DESCRIPTOR IS GRID, GEN, CYL, AND SOR**

**RESPECTIVELY. THIS PRACTICE IS A RESULT OF CHOOSING THE 'GRID'**

**CARDS TO BE IDENTICAL TO THE INPUT TO NASTRAN FOR CONVENIENCE IN**

**INTERFACING WITH THAT CODE. THE 'GEN', 'CYL' AND 'SOR' CARDS HAVE**

**NOTHING TO DO WITH NASTRAN AND THE USAGE OF SUCH LABELS HERE IS**

**FOR IDENTIFICATION ONLY**

**GENERAL PROBLEM DEFINITION (SUBROUTINE AINPT):**

**------------------------------------------**

**72 COLUMN ALPHANUMERIC TITLE**

**NSTRC NSTRF NGEN NBRA NCYL**

**IF NBRA NOT = 0 INCLUDE THE FOLLOWING THREE CARDS**

**NHAS NHAF NHAI NFUN JTRG**

**NSEG(1), I=1,NBRA**

**NCIR(1), I=1,NBRA**

**RHO CEE DAA2**

**PRGMT PRTRN PRTAMF CALCMT PRDGE**

**EIGMAF TWODIM HAFMOD QUAMOD**

**PLCHDS NASTAM STNAM STDV**

**FRWFIN FRWRTG FRTGR FRESUR**

**RENUMB STGTMG ROTAEO ROPOQ**

**FLUNAM GEONAM GRONAM DAANAM**

**IF EIGMAF * .TRUE. INCLUDE THE FOLLOWING CARD**

**NVEC**

**IF TWODIM * .TRUE. INCLUDE THE FOLLOWING TWO CARDS**

**NUMZ ZLEN**

**IF QUAMOD * .TRUE. INCLUDE THE FOLLOWING CARD**

**CD(1), I=1,4**

**IF HAFMOD * .TRUE. INCLUDE THE FOLLOWING TWO CARDS**
987  CQ(I), I=1,2
988  DEPTH CXFS CYFS CZFS
989  IF FREQUR = .TRUE. INCLUDE THE FOLLOWING TWO CARDS
990  DEPTH CXFS CYFS CZFS
991  PATM GRAVAC
992  IF POT.LEO = .TRUE. INCLUDE THE FOLLOWING CARD
993  GEOAYG(I), I=1,3
994  IF ROT:UA = .TRUE. INCLUDE THE FOLLOWING CARD
995  QUANG(I), I=1,3
996  IF NCYL NOT = 0 READ THE FOLLOWING CARD
997  NSHIFT
998  STRUCTURAL NODE COORDINATES (SUBROUTINE READST):  
999  -----------------------------
1000  IF NSTRC NOT = 0 INCLUDE THE FOLLOWING CARDS
1001  GRID NSEQ NS XC YC ZC )  TOTAL = NSTRC
1002  :
1003  :
1004  :
1005  :
1006  :
1007  GENERAL ELEMENT DEFINITION (SUBROUTINE GENELM):  
1008  -----------------------------
1009  IF NGEN NOT = 0 READ THE FOLLOWING CARDS
1010  GEN NEL NC NN KURV KTRN |  TOTAL NUMBER OF
1011  NODE(I), I=1,NC |  SETS = NGEN
1012  ITEM(I), I=1,NN |  :
1013  :
1014  :
1015  :
1016  :
1017  CYLINDRICAL SURFACE GENERAL ELEMENTS (SUBROUTINE CYLGED):  
1018  -----------------------------
1019  IF NCYL NOT = 0 READ THE FOLLOWING CARDS FOR EACH AXIAL SEGMENT
1020  CYL NTSC KFUN KROT KARC
1021  NNC NLAST NSTART NDA1 NDCR NDA2
1022  RAD AXL1 AXL2 THET THETF AXL3
1023  IF KROT NOT = 0 READ THE FOLLOWING CARD
CYLANT(I), I=1,3

SURFACE-OF-REVOLUTION ELEMENT DEFINITION (SUBROUTINE SRINP):

IF NBRK NOT = 0 READ THE FOLLOWING CARDS FOR EACH SRK BRANCH

SURF N1 N2 R1 R2 NSET

IF N1 = N2 READ THE FOLLOWING CARD

N3

IF NSET = 1 OMIT THE FOLLOWING CARD

N1 N2 R1 R2 [SEG ] TOTAL = NSET

STRUCTURAL NODE RENUMBERING (SUBROUTINE AMGEOM):

IF RENUM = .TRUE. READ THE FOLLOWING CARDS

NUMCHG

NODOLD NODNEW

TOTAL = NUMCHG
### Fluid Element Library

The corner points of each of the element types shown below are assumed to lie in the same plane and the direction of the unit normal vector is taken to be positive as coming up from the page and out into the fluid region. The viewer is thus placed in the same relative position as a scuba diver gazing at the side of a sunken treasure ship. The node order for input must always be in the counterclockwise direction as shown because the right hand rule is used in the code to determine the positive outward direction. Note that corner points are taken first, then any other points which may be involved in the fluid-structure transformation follow. You may play connect-the-dots with your pencil to make the figures more legible if you wish.

#### Basic Fluid Element Configurations:

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#### Basic Fluid Element Configurations with Additional Transformation Points:

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| Quadrilateral |

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| Quadrilateral |
The following discussion is provided as an aid to user understanding of the sample output that is included here.

The first item needing explanation is the block subdivision table. During construction of the mass matrix the code must determine whether a particular fluid DOF pertains to a GEN (includes both GEN and CYL elements) or SOR element. In the latter case, it must also store the branch or axis of the element, its harmonic, and also whether that DOF corresponds to a cosine or sine function. DOF with similar characteristics are naturally kept together in the same block. When the mass matrix is automatically processed in an out of core mode GEN elements are also partitioned into blocks for computational convenience.

The parameters appearing in the block subdivision table are:

- ISUB - block number
- ITYP - GEN or SOR
- IBEG - first row of block
- IROW - number of rows in block
- IBRA - SOR branch or axis
- IHAR - harmonic number
- IFUN - COS or SIN

Next, the terms appearing under "Fluid Mesh Geometric Arrays" are defined as:

- NCOR - number of corner points for a particular fluid element
- X,Y,Z - global cartesian coordinates of the fluid element centroidal control point
- NX,NY,NZ - components of the outward unit normal vector for the fluid element
- NTRA - number of structural node points that are coupled to a particular fluid element for the purpose of force application
- A00,A20,A11,A02 - area and moments and product of inertia of fluid element. Used internally for construction of the fluid mass matrix and of the fluid-structure transformation coefficients for general elements. For SOR elements, these values are for the sub-elements
- BII,CII - diagonal terms of B and C matrices used for the construction of fluid mass matrix (see [14])

When SOR elements are included in the fluid mesh the following new terms will appear in the output:
NSOR - number of SOR element
NFLU - DOF in fluid mass matrix
RAD - radius of fluid element control point from axis of revolution
NCIR - number of integration points or sub-elements used in circumferential direction

Local Fluid-Structure Transformation Coefficients appear next. This is a summary that indicates which structural nodes couple with a particular fluid control point and the weighting factor for each. The weighting factors must always sum to unity for any fluid control point.

The generalized areas that follow are simply AOO for GEN elements. For SOR elements with IHAR = 0 they are AOO*NCIR; for all other SOR elements they become 0.5*AOO*NCIR.

The eigenvalues and eigenvectors that follow the listing of the added mass matrix correspond to the "Fluid Boundary Mode" problem [14]. For the infinite cylindrical shell problem presented here, the exact eigenvalues should behave as 1/n with corresponding modes cos nθ and sin nθ. The first eigenvalue listed, 0.11831+04, is an approximation to 0 for n=0 and it can be seen that the subsequent eigenvalues are relatively well behaved.

If a table labeled "SUMMARY OF I-O ACTIVITY" appears in the output, this indicates that automatic out-of-core processing has taken place. In such a case the "Fluid Boundary Mode" problem is not solved and its diagnostic characteristics are unavailable to the user. If there are any serious errors in the fluid mesh geometry that have remained undetected through the generation of the mass matrix these may show up in the construction of the matrix Dfl [see Eq. (2.6)], i.e., the occurrence of factorization errors for the elements in question.
FLUAMES RUN FOR INFINITE CYLINDER SIMULATION

MAXIMUM FLUID NODES = 69
SCRATCH ALLOCATION - 10000

FLUID MASS DENSITY = 1.00000000+01
FLUID SOUND SPEED = 1.00000000+01
DA42 SCALAR FACTOR = 5.00000000+00

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PHCOS (H)USTAM STOMAS STCINV
F     F     F

FRWFL FRWGR FSTOMS FSTCIN
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REHUB STOMAT RSTGD RSTQU
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**MATRIX ADJACENCY IN REAL EQUATIONS:**

**A-35**
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**Auxiliary Storage Table**

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- 1 Active Devices (0 Full)
- 0 TP-OPS, 16 Writes, 1 Reads, 5050 Cyl-OPS X:0
- Free CYL=DAAM.
APPENDIX B
USER INFORMATION FOR THE AUGMENTED MATRIX PREPROCESSOR AUGMAT

This appendix includes a copy of the users manual, and a sample input deck and subsequent output for the infinite cylindrical shell problem presented in Section 4.
AUGNAT

This functional component of the underwater shock analysis code accepts data from the fluid mass matrix processor and the structural analyzer to construct the specific constants and arrays that are used in the staggered solution procedure for the transient response analysis of submerged structures.

This program was developed and coded by John A. Deruntz, Jr., of Lockheed Missiles and Space Co., Research Labs in Palo Alto, California. Please consult with author before making changes and also report any malfunctions or problems. Write in care of Lockheed Palo Alto Research Laboratory, Bldg 205, Dept 52-33, 3251 Hanover St., Palo Alto, Calif., 94304 or call 415-493-4411 Ext. 45069 or 45133. September, 1980.

Warning from the programmer general

This code contains the special ingredient DMGASP not found in other brands. DMGASP is a data management utility module that will activate and deactivate all auxiliary storage data files referenced by the code. Hence the names of such files should not appear on any control cards in the run stream which might normally activate and deactivate the files. The user is also cautioned that previously created files must already be resident in the system before the run is initiated. If a file has been rolled-out to tape DMGASP will attempt to have the file rolled-in every 15 seconds for up to 6 minutes on the Univac 1100/00-10 operating system. If an existing data file has not been referenced for some time it is therefore good policy to simply activate and deactivate the file before execution of this code. If the user attempts to create a new data file with a name which is already assigned to an existing file, the Univac version of DMGASP will modify the name of the file generated by this run to avoid any conflict. File name duplication will cause no problem on the CDC scope operating system as scope will simply catalog a new cycle of the same file. On the other hand the CDC NO system is similar to Univac in this regard and the run will abort since the name-changing feature of DMGASP has not been implemented for NOS. Qualifier+filename is the required input data format for all Univac permanent file names. On CDC scope, the qualifier is interpreted as the users ID, which in most installations can be selected almost arbitrarily. On CDC NOS, the qualifier is interpreted as the users catalog number, which is usually prescribed by the installation. A cycle number can also be appended to give the form qualifier+filename(cycle) on CDC scope.
## Program Size

ALL ARRAYS REFERENCED IN THIS CODE THAT ARE PROBLEM DEPENDENT RESIDE IN BLANK COMMON. THE SIZE OF BLANK COMMON IS DETERMINED BY A PARAMETER STATEMENT IN THE MAIN PROGRAM FOR THE UNIVAC 1100-05 VERSION, HENCE A RECOMPIATION IS NECESSARY TO INCREASE OR DECREASE CORE ALLOCATION. IN THE CDC 6600 VERSION RECOMPIATION IS UNNECESSARY AS THE LENGTH OF BLANK COMMON IS SET BY A FIELD LENGTH REQUEST IN THE CONTROL CARD DECK.

## Definition of Input Parameters

INPUT VARIABLE NAMES GIVEN BELOW ARE GENERALLY THOSE WHICH ARE ALSO USED IN THE CODING AND THE VARIABLE TYPES CORRESPOND TO STANDARD FORTRAN USAGE:

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
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</thead>
<tbody>
<tr>
<td>STRNAM</td>
<td>A</td>
<td>NAME OF PERMANENT MASS STORAGE FILE WHICH CONTAINS THE STRUCTURAL MASS AND STIFFNESS MATRICES AS WELL AS BOOKKEEPING INFORMATION RELATING THE INTERNAL AND EXTERNAL DEGREES OF FREEDOM, WHEN INTERFACING WITH THE NON-LINEAR STRUCTURAL ANALYZER STAYS THE STIFFNESS MATRIX IS NOT PRESENT</td>
</tr>
<tr>
<td>FLNAM</td>
<td>A</td>
<td>NAME OF PERMANENT MASS STORAGE FILE WHICH CONTAINS THE MANIPULATED DAA FORM OF THE FLUID MASS MATRIX</td>
</tr>
<tr>
<td>GEMNAM</td>
<td>A</td>
<td>NAME OF PERMANENT MASS STORAGE FILE WHICH CONTAINS THE FLUID-MESH GEOMETRY AND FLUID-STRUCTURE TRANSFORMATION DATA</td>
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<td>PENUMA</td>
<td>A</td>
<td>NAME OF PERMANENT MASS STORAGE FILE CREATED BY THIS PROCESSOR WHICH CONTAINS ALL THE INFORMATION REQUIRED TO CONDUCT THE UNDERWATER SHOCK ANALYSIS OF THE STRUCTURE IN QUESTION EXCEPT FOR THE LACITATION AND INTEGRATION DATA</td>
</tr>
<tr>
<td>FRWST</td>
<td>L</td>
<td>TRUE IF THE PERMANENT FILE CONTAINING THE STRUCTURAL MASS AND STIFFNESS MATRICES</td>
</tr>
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</table>
SYMCON L
TRUE IF TRANSLATIONAL CONSTRAINTS MUST BE
APPLIED TO STRUCTURAL NODES DUE TO
SYMMETRY CONDITIONS IF HALF OR QUARTER
MODELS ARE BEING USED. OTHERWISE FALSE.
CONSTRAINTS ON ROTATIONAL STRUCTURAL
FREE RAMS DO NOT ENTER THE AUGMENTED
MATRICES. CONSTRAINTS MUST BE APPLIED ONLY
IF NIG0S = 0 (SEE BELOW)

PRTAUG L
TRUE IF AUGMENTED FORM OF MATRICES
APPEARING IN THE FLUID EQUATIONS ARE TO BE
PRINTED IN FULL. OTHERWISE FALSE IN WHICH
CASE ONLY THE MATRIX MASTER RECORD AND THE
DIAGONAL TERMS ARE PRINTED. THE FIRST
MATRIX SHOWN IS THE INVERSE FORM OF THE
STRUCTURAL MASS AND IT IS THE ONLY SPARSE
MATRIX IN THE FLUID EQUATIONS. HENCE A MAP
OF ITS CONNECTIVITY IS ALWAYS SHOWN. THE
NEXT MATRIX IS A COMBINATION OF BOTH THE
FLUID AND STRUCTURE INVERSE MASS MATRICES.
FOR DAA2 RUNS TWO ADDITIONAL MATRICES
APPEAR THAT INVOLVE ONLY THE FLUID MASS
INVERSE. THE FIRST COMES DIRECTLY FROM THE
DAA1 EQUATION WHILE THE SECOND IS ITS
ITERATED FORM THAT APPEARS IN THE DAA2
EQUATION. IT IS RECOMMENDED THAT A VALUE
OF FALSE BE USED UNDER NORMAL CONDITIONS

PRTGNT L
TRUE IF FLUID MESH GEOMETRY DATA IS TO BE
LISTED. OTHERWISE FALSE

PRTTN L
TRUE IF FLUID-STRUCTURE TRANSFORMATION
DATA IS TO BE LISTED. OTHERWISE FALSE

PRTSTF L
TRUE IF SKYLINE STRUCTURAL STIFFNESS
MATRIX IS TO BE DISPLAYED. OTHERWISE
FALSE. WHEN INTERFACING WITH STAGES THIS
VARIABLE MUST ALWAYS BE TAKEN AS FALSE
SINCE THE GLOBAL STIFFNESS OPERATOR DOES
NOT EXIST IN THE SAME FORM AS THAT FOR USA
IN THE STAND ALONE CONFIGURATION

DA A2 E.F
A PARAMETER BOUNDED BY ZERO AND UNITY THAT
GOVERNS THE USE OF THE IMPROVED DOUBLY
ASYMPTOTIC APPROXIMATION. A VALUE OF ZERO
REDUCES THE FLUID SOLUTION TO THE STANDARD
DOUBLY ASYMMETRIC APPROXIMATION. HOWEVER A
PRECISE CHOICE FOR THIS PARAMETER IS NOT
GIVEN BY ANY FUNDAMENTAL PRINCIPLE. IT HAS
BEEN OBSERVED THAT A VALUE OF 1.0 LEADS TO
THE BEST ACCURACY FOR A SPHERICAL SHELL
WHILE A VALUE OF 0.5 SEEMS TO BE BEST FOR
THE INFINITE CYLINDRICAL SHELL. IT CAN BE
SHOWN THAT THIS SCALAR PARAMETER DOES HAVE
A RELATIONSHIP WITH THE DIAGONAL LOCAL
CURVATURE MATRIX FOR THE FLUID ELEMENTS.
IF A VALUE OF ZERO WAS USED IN THE FLUID
MASS RUN AND A DGA2 RUN IS DESIRED THEN
THE FLUID MASS PROCESSOR MUST BE RERUN
WITH A NONZERO VALUE BEFORE FURTHER
COMPUTATION CAN TAKE PLACE.

NSTR  I  NUMBER OF NODE POINTS IN STRUCTURAL MODEL

NSFR  I  NUMBER OF STRUCTURAL DEGREES OF FREEDOM,
WHEN INTERFACING WITH STAGS THIS WILL BE
SIX (6) TIMES THE VALUE OF NSTR

NFRE  I  THE LARGEST DEGREE OF FREEDOM INDEX AT ANY
STRUCTURAL NODE WHICH IS REFERENCED IN THE
ANALYSIS. FREEDOMS 1, 2, AND 3 ARE ASSUMED
TO BE TRANSLATIONAL WHILE 4, 5, AND 6 ARE
RESERVED FOR ROTATIONS. ALWAYS USE SIX (6)
WHEN INTERFACING WITH STAGS

NFTR  I  THE LARGEST TRANSLATIONAL DEGREE OF
FREEDOM INDEX AT ANY NODE WHICH IS
REFERENCED IN THE ANALYSIS. ALWAYS USE
THREE (3) WHEN INTERFACING WITH STAGS

MXWD  I  NUMBER OF WORDS PER BLOCK TO BE USED FOR
PARTITIONED SKYLINED FLUID MATRICES.
GENERALLY USE SOME MULTIPLE OF 448 TO
ACCOMODATE EITHER THE 28 WORD SECTOR ON
UNIVAC OR THE 64 WORD PRU ON CDC SO THAT
FILE SIZE IS MINIMIZED

NUMBLK I  NUMBER OF BLOCKS OR MATRIX VALUE RECORDS
INTO WHICH THE SKYLINED STRUCTURAL
STIFFNESS MATRIX HAS BEEN PARTITIONED

NWDBLK I  MAXIMUM BLOCK SIZE FOR SKYLINED STRUCTURAL
STIFFNESS MATRIX

NSETLC I  NUMBER OF DATA SETS NEEDED TO DEFINE THE
TYPE OF STRUCTURAL COORDINATE SYSTEM WITH
WHICH ANY PARTICULAR GENERAL FLUID ELEMENT
MUST INTERFACE. THIS DATA IS NOT REQUIRED
FOR SURFACE OF REVOLUTION FLUID ELEMENTS
BUT INCLUDES ANY FLUID ELEMENTS THAT WERE
GENERATED AUTOMATICALLY IN FLUMAS FOR A
CYLINDRICAL SURFACE

NOICOS I  DESIGNATES THE TYPE OF COORDINATE SYSTEM
USED IN THE STRUCTURAL SOLUTION.
ACCEPTABLE VALUES ARE:

0 - GLOBAL COORDINATES
1 - LOCAL COORDINATES WITH THE FIRST
DEGREE OF FREEDOM NORMAL TO THE
FLUID-STRUCTURE CONTACT BOUNDARY
2 - LOCAL COORDINATES WITH THE SECOND
DEGREE OF FREEDOM NORMAL TO THE
FLUID-STRUCTURE CONTACT BOUNDARY
3 - LOCAL COORDINATES WITH THE THIRD DEGREE OF FREEDOM NORMAL TO THE
FLUID-STRUCTURE CONTACT BOUNDARY

AT THIS TIME OPTIONS 1, 2, OR 3 MAY BE USED ONLY FOR RIGHT CIRCULAR CYLINDERS OR SPHERES. MORE LATITUDE IN THESE CHOICES IS ULTIMATELY PLANNED. FOR USAGE WITH STAGS A VALUE OF 0 MUST ALWAYS BE USED AS STAGS CARRIES OUT ITS OWN GLOBAL TO LOCAL TRANSFORMATION. GLOBAL COORDINATES ARE AUTOMATICALLY SET IN THIS PROCESSOR FOR ALL SURFACE OF REVOLUTION FLUID ELEMENTS

JSTART I FIRST OF ONE OR MORE FLUID ELEMENTS HAVING THE SAME VALUE OF NDICOS

JSTOP I LAST OF ONE OR MORE FLUID ELEMENTS HAVING THE SAME VALUE OF NDICOS

JINC I INCREMENT TO BE APPLIED IN ASSIGNING THE VALUE OF NDICOS TO FLUID ELEMENTS IN THE RANGE FROM JSTART TO JSTOP

NUMCON I NUMBER OF DATA SETS REQUIRED TO DEFINE THE CONSTRAINTS TO BE APPLIED TO TRANSLATIONAL STRUCTURAL DEGREES OF FREEDOM DUE TO SYMMETRY CONDITIONS. THESE CONSTRAINTS NEED BE APPLIED ONLY TO STRUCTURAL NODES ON THE WET SURFACE

ICON I WILL HAVE THE VALUE 1, 2, OR 3 DEPENDING UPON WHETHER THE TRANSLATIONAL CONSTRAINT IS TO BE APPLIED IN THE X, Y, OR Z GLOBAL COORDINATE DIRECTION. ONLY ONE CONSTRAINT IS ALLOWABLE AT A STRUCTURAL NODE AT THIS TIME HOWEVER THIS LIMITATION IS NOT PARTICULARLY RESTRICTIVE. CONSTRAINTS TO THE AUGMENTED MATRICES ARE REQUIRED ONLY IF A FLUID ELEMENT ASSOCIATED WITH A PARTICULAR STRUCTURAL NODE IS ORIENTED SUCH THAT THE UNIT OUTWARD NORMAL VECTOR OF THE FLUID ELEMENT HAS A COMPONENT PERPENDICULAR TO THE SYMMETRY PLANE. FOR EXAMPLE, A QUARTER CYLINDER MODEL WOULD REQUIRE A CIRCUMFERENTIAL CONSTRAINT BUT NOT AN AXIAL ONE

NSTART I FIRST OF ONE OR MORE STRUCTURAL NODES HAVING THE SAME VALUE OF ICON

STOP I LAST OF ONE OR MORE STRUCTURAL NODES HAVING THE SAME VALUE OF ICON

NINC I INCREMENT TO BE APPLIED IN ASSIGNING THE VALUE OF ICON TO STRUCTURAL NODES IN THE RANGE FROM NSTART TO NSTOP
**INPUT DATA CARD DECK**

---

**ALL INPUT DATA EXCEPT ALPHANUMERIC DATA MUST BE RIGHT JUSTIFIED**

**ALPHANUMERIC DATA MUST BE LEFT JUSTIFIED IN TWENTY (20) COLUMN FIELDS. FILE NAME PLUS QUALIFIER IS CURRENTLY RESTRICTED TO**

**EIGHTEEN (18) CHARACTERS FOR UNIVAC OPERATION WHILE NINETEEN (19) CHARACTERS MAY BE USED FOR CDC OPERATION**

**GENERAL PROBLEM DEFINITION (MAIN PROGRAM PREPROC):**

---

**72 COLUMN ALPHANUMERIC TITLE**

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<tr>
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<th>FLNAM</th>
<th>GEDNAM</th>
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<tbody>
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---

**PRTPNT**

A VALUE OF ONE (1) WILL PRODUCE A DISPLAY OF THE DIAGONAL LOCATION POINTERS OF THE SKYLED STRUCTURAL STIFFNESS MATRIX. OTHERWISE SET TO ZERO UNDER NORMAL CONDITIONS

**PRTVAL**

A VALUE OF ONE (1) WILL PRODUCE A DISPLAY OF THE SKYLED STRUCTURAL STIFFNESS MATRIX. OTHERWISE SET TO ZERO AND ONLY THE DIAGONAL TERMS WILL BE PRINTED BY DEFAULT. USE A NON-ZERO VALUE ONLY FOR DIAGNOSTIC REASONS OR FOR VERY SMALL PROBLEMS AS THE AMOUNT OF OUTPUT CAN BE ENORMOUS

**MAPVAL**

A VALUE OF ONE (1) WILL PRODUCE A MAP-TYPE DISPLAY OF MATRIX VALUES TO SHOW THE CONNECTIVITY ALONE, OTHERWISE SET TO ZERO UNDER NORMAL CONDITIONS

**MVR1**

INDEX OF FIRST MATRIX VALUE RECORD TO BE DISPLAYED. UNDER NORMAL CONDITIONS USE A VALUE OF ZERO AND THE CODE WILL START THE DISPLAY AT THE BEGINNING OF THE MATRIX. USE A NON-ZERO VALUE ONLY WHEN A SPECIFIC SET OF BLOCKS IS TO BE PRINTED FOR SOME DIAGNOSTIC REASON

**MVR2**

INDEX OF LAST MATRIX VALUE RECORD TO BE DISPLAYED. UNDER NORMAL CONDITIONS USE A VALUE OF ZERO AND THE CODE WILL DISPLAY TO THE END OF THE MATRIX. USE A NON-ZERO VALUE ONLY WHEN A SPECIFIC SET OF BLOCKS IS TO BE PRINTED FOR SOME DIAGNOSTIC REASON
MAWD

IF PRSTF = .TRUE. INCLUDE THE FOLLOWING CARD
NUMBLK NWDBLK

IF THE FLUID MODEL CONSISTS OF ONLY SURFACE OF REVOLUTION ELEMENTS
SKIP THE FOLLOWING SET OF CARDS
NSETLC
NDICOS JSTART JSTOP JINC ) TOTAL = NSETLC

SET SYMMETRY CONSTRAINTS (SUBROUTINE CONSTR):
-----------------------------------------------

IF SYMCON = .TRUE. INCLUDE THE FOLLOWING CARDS
NUMCON
ICON NSTART NSTOP NINC ) TOTAL = NUMCON

DISPLAY SKYLINED STRUCTURAL STIFFNESS MATRIX (SUBROUTINE STFMAT):
---------------------------------------------------------------------

IF PRSTF = .TRUE. INCLUDE THE FOLLOWING CARDS
PRTPNT PRTVAL MAPVAL
MVR1 MVR2
The following discussion is provided as an aid to user understanding of the sample output that is included here.

After a summary of the fluid mesh geometry arrays (see Appendix A) the first item needing explanation is that entitled "Fluid Element Wetted Freedom Indicator". This is simply a listing of the input variable NDICOS (see user manual) for each fluid element.

The section "Structural Grid Point Numbers Associated With Internal Sequence Numbers" contains a correspondence table that relates the internal sequence numbers assigned by the fluid mass processor with the external structural node number assigned by the user.

The next item entitled "Grid Point and Freedom Number for Each Row of Stiffness Matrix" identifies an integer vector that is constructed by the user in the Skyline Utility (see Figure 3-1, also Appendix E). For each structural equation the entry in the vector consists of ten times the structural node number plus the local degree of freedom number.

The last item requiring explanation is the "Freedom/Equation Correspondence Table". This is an integer matrix of 6 rows and as many columns as there are structural node points. Any particular row corresponds to a local degree of freedom number while a column corresponds to the internal sequence number for a particular external node number. The matrix entry for any particular set of row and column is the structural equation number for that pair.

Depending upon user input the structural stiffness matrix (identifier "STIF") may then be displayed as well as the appropriate fluid matrices. The matrix called TMIT corresponds to $D_s$ [see Eq. (2.6)], while DFDS denotes the sum of $D_s$ and $D_{fl}$ [see Eq. (2.6)]. In DAA2 runs $D_{fl}$ is labeled DAA1 while $D_{f2}$ is labeled DAA2.
@ADD,P CYLAUGDAT

AUGMAT RUN FOR INFINITE CYLINDER SIMULATION

+++ @ ASG,AX CYL*GEOM.
+++ @ USE 14,CYL*GEOM.

USER OPTIONS FOR THIS RUN:

FRWTST SYMCON PRNTDG
F F F
PRNGMT PRRTAN PRNSTF
T T T

THIS IS A DAA1 RUN

FLUID MASS DENSITY = .10000000+01
FLUID SOUND SPEED = .10000000+01

2735 WORDS OF STORAGE REQUIRED FOR THIS RUN

+++ @ ASG,UPR CYL*PREP., F/ 4/TRK/1024
+++ @ USE 16,CYL*PREP.

*******************************************************************************
+ AUXILIARY STORAGE TABLE +
*******************************************************************************

+LDI EDN(2+EFN) IFN EC GP SEC CDLOC WHAT LIMIT READ WRITTEN +
+12 CYL*GEOM 14 36 AX 28 36 14 65536 706 0 +
+14 CYL*PREP 16 36 UPR28 9 0 65536 0 0 +
+
+2 ACTIVE DEVICES (0 FULL)
+0 TP-OPS, 0 WRITES, 13 READS, 766 KWORDS (FD +
*******************************************************************************

+++ @ FREE CYL*GEOM.

FLUID MESH GEOMETRIC ARRAYS:

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<th>Y</th>
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**GENERALIZED FLUID AREAS:**

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**DIAGONAL STRUCTURAL MASS MATRIX:**

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- **Cols:** 432

## Matrix Attributes:
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- **Storage:** Real
- **Multil:** No

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- **Word 4:** 4
- **Word 5:** 5
- **Word 6:** 6
- **Word 7:** 7
- **Word 8:** 8
- **Word 9:** 9
- **Word 10:** 10

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WORD 11   WORD 12  WORD 13  WORD 14  WORD 15  WORD 16  WORD 17  WORD 18  WORD 19  WORD 20  
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WORD 21   WORD 22  WORD 23  WORD 24  WORD 25  WORD 26  
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#### MASTER RECORD OF MATRIX TMT

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- **CDLS:** Size-4
- **MTX ATTRIBUTES:** Single Symm.
- **MAXVAR:** MARSIZ
- **NUM MOD:** NUMR

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**EASY HDR:** 000444 36 36

**MVR PREFIX:** AUGM 26 37 36 44

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### Notes

- The document appears to be related to matrix calculations, specifically the structure of a mass-inverse matrix, with various records and headers indicating the structure of the matrix and its attributes.
- The matrix is likely used in a computational or engineering context, where the mass-inverse matrix is a key component in solving certain types of problems, such as those involving dynamic systems or structural analysis.
- The table format shows the matrix's components, with each column and row entry indicating specific values that contribute to the overall structure of the matrix.
- The document includes technical jargon such as "MTT," "CDLS," and "MTX ATTRIBUTES," indicating a focus on describing the matrix's characteristics and attributes.
- The "MVR" section provides details on the matrix's extent and access, which are crucial for understanding how the matrix is stored and accessed in memory or computational environments.
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| MVR PREFIX: AUGM | 26 | 24 | 276 | 448 |

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**MVR PREFIX:** AUGM 26 11 285 44B

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**Auxiliary Storage Table**

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+LOI EDN(Q<FFN) IFN EC OP SEC COLOC NEXT LIMIT READ WRITEN +
  10 CYL*DAAM 12 35 AX 28 47 128 65536 1295 0 +
  14 CYL*PREP 16 36 UPR28 13 131 65536 0 3208 +
  16 UNIT18 13 30 T 28 28 28 16384 778 778 +
  18 UNIT20 20 30 T 28 72 72 16384 4748 3492 +
+
  4 ACTIVE DEVICES ( 0 FULL)
  0 TP-OPS, 0 WRITES, 145 READS, 32190 WORDS XFD +

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

+++ 0 FREE UNIT18.
+++ 0 FREE UNIT20.

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

+AUXILIARY STORAGE TABLE

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

+LOI EDN(Q<FFN) IFN EC OP SEC COLOC NEXT LIMIT READ WRITEN +
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  14 CYL*PREP 16 36 UPR28 9 131 65536 0 3510 +
+
  2 ACTIVE DEVICES ( 0 FULL)
  0 TP-OPS, 0 WRITES, 145 READS, 32432 WORDS XFD +

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

+++ 0 FREE CYL*PREP.

----------------------------------------
SUMMARY OF DATA STORED ON PERMANENT FILE
  *** CYL*PREP ***
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<td>FREEDOM EQUATION CORRESPONDENCE TABLE</td>
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<td>SKYDUL INV AND INV FOR DAA VIRTUAL MASS INV</td>
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APPENDIX C
USER INFORMATION FOR THE TIME INTEGRATION PROCESSOR TIMINT

This appendix includes a copy of the users manual, and a sample input deck and subsequent output for the infinite cylindrical shell problem presented in Section 4.
TIMINT

This functional component of the underwater shock analysis code conducts a step-by-step direct numerical time integration of the governing equations of submerged structures exposed to spherical shock waves of arbitrary pressure profile and source location. The fluid equations utilize the well-known doubly asymptotic approximation (DAA) while the structure itself may be treated by a variety of linear or nonlinear program modules that carry out the spatial analysis at each time step. The code uses the staggered solution procedure wherein the structural response equations and the fluid response equations are solved separately at each time step through extrapolation of the terms which couple the two systems.

This program was developed and coded by John A. Gerlitz, Jr., of Lockheed Missiles and Space Co. Research Labs in Palo Alto, California. Please consult with author before making changes and also report any malfunctions or problems. Write in care of Lockheed Palo Alto Research Laboratory, Bldg 203, Dept 52-33, 3251 Hanover St., Palo Alto, Calif., 94304 or call 415-333-4311 Ext 45169 or 45133. September, 1980.

Maximum Values

Maximum number of input pressure data points:

- Infinite fluid: 402
- Free surface problem: 201

Maximum number of cubic spline time points:

- Infinite fluid: 102
- Free surface problem: 91

Maximum number of different time step sizes: 10

Maximum number of previous response files: 9

Maximum number of transient response displays: 100

Run time information
THE FOLLOWING INFORMATION IS PROVIDED FOR THE ESTIMATION OF CPU
TIME IN SECONDS TO WHICH MUST BE ADDED INPUT/OUTPUT CHARGES,
CORE-BLOCK TIME, EXECUTIVE REQUESTS, FILE CHARGES, ETC. THE RULE
TO FOLLOW IS TO ESTIMATE CPU TIME AND THEN INCREASE THIS TO ARRIVE
AT AN APPROXIMATE SYSTEM CHARGE ESTIMATE. FOR SMALL PROBLEMS THE
SYSTEM CHARGES CAN EASILY DOMINATE AND A LARGE FACTOR WOULD HAVE
TO BE APPLIED TO THE RUN TIME COMPUTED BELOW. FOR FAIRLY LARGE
PROBLEMS (250C DOF) THIS FACTOR DROPS DOWN TO ABOUT TWO (2) FOR
UNIVAC OPERATION

THE ESTIMATES FOR STRUCTURAL FACTORIZATION AND ADVANCEMENT TIMES
GIVEN BELOW DO NOT APPLY TO THE USA-STAGS SYSTEM. PLEASE CONSULT A
STAGS MANUAL

DEFINITION OF VARIABLES REQUIRED FOR RUN TIME COMPUTATION:

NSTEP
NUMBER OF TIME STEPS

NTINC
NUMBER OF DIFFERENT TIME STEP INCREMENTS

NDISP
NUMBER OF DEGREES OF FREEDOM FOR WHICH TRANSIENT
RESPONSE HISTORIES ARE TO BE DISPLAYED AT CONCLUSION
OF RUN

NSFR
NUMBER OF DEGREES OF FREEDOM OF STRUCTURAL SYSTEM

NFLU
NUMBER OF DEGREES OF FREEDOM OF FLUID SYSTEM

BAVE
AVERAGE HALF BAND WIDTH OF STRUCTURAL STIFFNESS
MATRIX

BRMS
ROOT MEAN SQUARE HALF BAND WIDTH OF STRUCTURAL
STIFFNESS MATRIX. USE AVERAGE HALF BAND WIDTH IF
THIS QUANTITY IS NOT READILY AVAILABLE

TCPU
TOTAL CENTRAL PROCESSING UNIT TIME REQUIRED FOR
LISTED ITEMS NFLOW

TCPU = TPRE + NTINC*(TFS+TFF) + NSTEP*(TAS+TAF) + TDISP

TPRE
CPU TIME SPENT ON PRE-PROCESSING BEFORE TIME
INTEGRATION COVARIANCES

TPRE = 1000.*CS*(NSFR+NFLU)

TFS
TIME REQUIRED TO FACTOR STRUCTURAL EQUATION SYSTEM

TFS = CS*NSFR*BRMS**2/2.

TAS
TIME REQUIRED FOR ADVANCEMENT OF ONE TIME STEP FOR
STRUCTURAL SYSTEM

TAS = 3.*CS*NSFR*BAVE

TFF
TIME REQUIRED TO FACTOR FLUID EQUATION SYSTEM

TFF = CS*NFLU**3/6.
TAF  TIME REQUIRED FOR ADVANCEMENT OF ONE TIME STEP FOR
    FLUID SYSTEM
TAF = CS*NFLU**2

TDISP  CPU TIME SPENT ON DISPLAY OF RESPONSE HISTORIES
TDISP = 500.*CS*NSTEP*NDISP

CS  UNIT OPERATION CONSTANT IN SECONDS, CONSISTING OF A
    FLOATING ADDITION, A FLOATING MULTIPLY, AND INDEXING

VALUES OF CONSTANT CS

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AT THIS TIME THE CODE OPERATES ONLY IN SINGLE
PRECISION

IN ADDITION TO BILLABLE CHARGES DUE TO EXECUTION OF THIS CODE
THERE WILL PROBABLY BE A DAILY CHARGE FOR PERMANENT FILE STORAGE.
RESPONSE AND RESTART FILES CREATED BY THIS CODE CAN BE EXTREMELY
LENGTHY HENCE SUCH OUTPUT FROM LARGE RUNS SHOULD BE TRANSFERRED TO
TAPE AT THE EARLIEST OPPORTUNITY TO MINIMIZE THESE CHARGES

WARNING FROM THE PROGRAMMER GENERAL

THIS CODE CONTAINS THE SPECIAL INGREDIENT DMGASP NOT FOUND IN
OTHER BRANDS. DMGASP IS A DATA MANAGEMENT UTILITY MODULE THAT
WILL ACTIVATE AND DEACTIVATE ALL AUXILIARY STORAGE DATA FILES
REFERENCED BY THE CODE. HENCE THE NAMES OF SUCH FILES SHOULD NOT
APPEAR ON ANY CONTROL CARDS IN THE RUN STREAM WHICH MIGHT NORMALLY
ACTIVATE AND DEACTIVATE THE FILES. THE USER IS ALSO CAUTIONED THAT
PREVIOUSLY CREATED FILES MUST ALREADY BE RESIDENT IN THE SYSTEM
SCFOR THE RUN IS INITIATED. IF A FILE HAS BEEN ROLLED-OUT TO TAPE
DMGASP WILL ATTEMPT TO HAVE THE FILE ROLLED-IN EVERY 15 SECONDS
FOR UP TO 6 MINUTES ON THE UNIVAC 1100-EXEC 8 OPERATING SYSTEM.
IF AN EXISTING DATA FILE HAS NOT BEEN REFERENCED FOR SOME TIME IT
IS THEREFORE GOOD POLICY TO SIMPLY ACTIVATE AND DEACTIVATE THE
FILE BEFORE EXECUTION OF THIS CODE. IF THE USER ATTEMPTS TO CREATE
A NEW DATA FILE WITH A NAME WHICH IS ALREADY ASSIGNED TO AN
EXISTING FILE, THE UNIVAC VERSION OF DMGASP WILL MODIFY THE NAME
OF THE FILE GENERATED BY THIS RUN TO AVOID ANY CONFLICT. FILE NAME
DUPLICATION WILL CAUSE NO PROBLEM ON THE CDC SCOPE OPERATING
SYSTEM AS SCOPE WILL SIMPLY CATALOG A NEW CYCLE OF THE SAME FILE.
ON THE OTHER HAND THE CDC NOS SYSTEM IS SIMILAR TO UNIVAC IN THIS REGARD AND THE RUN WILL ABORT SINCE THE NAME-CHANGING FEATURE OF DMGASP HAS NOT BEEN IMPLEMENTED FOR NOS. QUALIFIER+FILENAME IS THE REQUIRED INPUT DATA FORMAT FOR ALL UNIVAC PERMANENT FILE NAMES. ON CDC SCOPE, THE QUALIFIER IS INTERPRETED AS THE USERS ID, WHICH IN MOST INSTALLATIONS CAN BE SELECTED ALMOST ARBITRARILY. ON CDC NOS, THE QUALIFIER IS INTERPRETED AS THE USERS Catalog Number, WHICH IS USUALLY PRESCRIBED BY THE INSTALLATION. A CYCLE NUMBER CAN ALSO BE APPENDED TO GIVE THE FORM QUALIFIER+FILENAME/CYCLE' ON CDC SCOPE

\[ \text{PROGRAM SIZE} \]

**DEFINITION OF INPUT PARAMETERS**

INPUT VARIABLE NAMES GIVEN BELOW ARE GENERALLY THOSE WHICH ARE ALSO USED IN THE CODING AND THE VARIABLE TYPES CORRESPOND TO STANDARD FORTRAN USAGE:

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRLNAM</td>
<td>A</td>
<td>NAME OF PRE-PROCESSED NAM Storage File Containing All Fluid and Structure Data That Does Not Depend Upon the Shock Input and Time Integration Parameters</td>
</tr>
<tr>
<td>POSNAM</td>
<td>A</td>
<td>NAME OF MASS Storage File Available for Post-Processing Which Contains System Responses</td>
</tr>
<tr>
<td>STRNEW</td>
<td>A</td>
<td>Leave Blank for Normal Usage, Otherwise This Is the Name of a Different Structural Stiffness Matrix File That is to Be Used in the Time Integration Run Rather Than</td>
</tr>
<tr>
<td>RESNAM</td>
<td>A</td>
<td>NAME OF MASS STORAGE FILE THAT CONTAINS INFORMATION FOR RESTARTING THE TRANSIENT RESPONSE ANALYSIS</td>
</tr>
<tr>
<td>--------</td>
<td>---</td>
<td>-----------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>WRNAM</td>
<td>A</td>
<td>NAME OF MASS STORAGE FILE UPON WHICH RESTART DATA IS TO BE WRITTEN. IF LEFT BLANK THEN RESTART DATA WILL BE WRITTEN ON THE FILE DENOTED BY RESNAM</td>
</tr>
<tr>
<td>XE, YE, ZE E.F</td>
<td>CARTESIAN COORDINATES OF THE LOCATION OF SPHERICAL CHARGE IN FLUID MESH SYSTEM</td>
<td></td>
</tr>
<tr>
<td>SX, SY, SZ E.F</td>
<td>CARTESIAN COORDINATES OF THE CHARGE STANDOFF POINT IN THE FLUID MESH SYSTEM. THIS IS THE POINT ON THE STRUCTURE THAT IS CLOSEST TO THE CHARGE. THE INTEGRATION PROCESS STARTS AT TIME EQUAL TO ZERO WITH THE SPHERICAL WAVE JUST TOUCHING THE STRUCTURE AT THIS POINT ASSOCIATED WITH THE MINIMUM DISTANCE TO THE CHARGE</td>
<td></td>
</tr>
<tr>
<td>EXPWAV</td>
<td>L</td>
<td>TRUE IF THE INCIDENT PRESSURE PULSE IS EXPRESSED IN THE FORM OF AN EXPONENTIALLY DECAYING FUNCTION. OTHERWISE FALSE</td>
</tr>
<tr>
<td>SPLINE</td>
<td>L</td>
<td>TRUE IF THE INCIDENT PRESSURE PULSE IS DESCRIBED BY A CUBIC SPLINE FUNCTION. CARE SHOULD ALWAYS BE TAKEN WITH THE CHOICE OF INPUT DATA POINTS SINCE THIS ALGORITHM WILL PRODUCE A CONTINUOUS FUNCTION THAT CAN OSCILLATE WILDLY AROUND AREAS OF RAPID CHANGE. IN SUCH CASES IT IS IMPORTANT TO CLUSTER DATA POINTS IN THESE AREAS</td>
</tr>
<tr>
<td>JPHIST</td>
<td>I</td>
<td>NUMBER OF INCIDENT PRESSURE HISTORY DATA POINTS. SEE ABOVE FOR MAXIMUM NUMBER ALLOWED BY CORE ALLOCATION</td>
</tr>
<tr>
<td>DTHIST</td>
<td>E.F</td>
<td>TIME INTERVAL ASSOCIATED WITH ANY TWO SUCCESSIVE INCIDENT PRESSURE HISTORY DATA POINTS</td>
</tr>
<tr>
<td>PNORM</td>
<td>E.F</td>
<td>CONSTANT MULTIPLICATIVE FACTOR TO BE APPLIED TO THE INPUT PRESSURE HISTORY DATA POINTS</td>
</tr>
</tbody>
</table>
| PHIST | E.F | INCIDENT PRESSURE HISTORY DATA POINTS. THE VALUES USED IN THE TIME INTEGRATION PROCESS ARE THE PRODUCT OF PHIST AND PNORM TO ALLOW FOR THE POSSIBILITY THAT THE
INPUT DATA MAY HAVE BEEN EXPERIMENTALLY
OBTAINED AT A POINT WHICH IS NOT EQUAL TO
SC ZERO. PZERO MUST THEREFORE REFLECT THE
1/R SCALED DIFFERENCE BETWEEN SC AND THE
LOCATION OF THE PRESSURE SENSOR DURING THE
PULSE CHARACTERIZATION EXPERIMENT. IF THE
INCIDENT PRESSURE GOES TO ZERO AT SOME
POINT AND REMAINS THERE THEN DATA NEED
ONLY BE PROVIDED FOR THAT TIME SPAN AND
THE CODE WILL AUTOMATICALLY ENSURE THAT
THE INCIDENT PRESSURE REMAINS ZERO
THEREAFTER. WHEN RESTARTING THE TRANSIENT
ANALYSIS THE REQUIRED INCIDENT PRESSURE
DATA IS IDENTICAL TO THAT USED IN THE
INITIAL RUN. IF SPLINE IS FALSE THEN THE
PRESSURE HISTORY DATA MUST BE EQUALLY
SPACED IN TIME WITH THE INCREMENT DT/HIST.
IF SPLINE IS TRUE THE PRESSURE HISTORY
DATA CAN BE UNEQUALLY SPACED ACCORDING TO
DATA PROVIDED IN TIMES (SEE BELOW). WHEN
USING THE SPLINE CAPABILITY THE LAST
PRESSURE DATA POINT MUST BE ZERO SO THAT
THE CODE CAN AUTOMATICALLY GENERATE ZERO
PRESSURES BEYOND THAT POINT. OTHERWISE AN
OUT-OF-RANGE ERROR EXIT WILL BE TAKEN.

PZERO  E,F  PEAK VALUE OF PRESSURE FOR EXPONENTIALLY
DECAYING INCIDENT PULSE

DECAY  E,F  DECAY TIME FOR EXPONENTIALLY DECAYING
INCIDENT PRESSURE PULSE. THIS IS THE TIME
IT TAKES FOR THE PRESSURE TO DROP TO 1/E
(ABOV -.3678) OF ITS PEAK VALUE

TIMES  E,F  TIME VALUES ASSOCIATED WITH UNEQUALLY
SPACED INCIDENT PRESSURE HISTORY VALUES

NTINT  I  NUMBER OF TIME STEP SIZES TO BE USED IN
THE INTEGRATION PROCESS. SEE ABOVE FOR
MAXIMUM NUMBER ALLOWED BY CORE ALLOCATION

STRTIM  E,F  THE STARTING TIME AT WHICH ANY PARTICULAR
STEP SIZE IS TO BE USED UNTIL IT IS EITHER
SUPERCEDED BY ANOTHER STEP SIZE OR THE
ENTIRE TRANSIENT ANALYSIS HAS BEEN
COMPLETED

DELTIM  E,F  TIME STEP SIZE ASSOCIATED WITH STRTIM
ABOVE

FININT  E,F  TIME AT WHICH THE PRESENT ANALYSIS IS TO
BE TERMINATED

NSAVER  I  FREQUENCY OF SAVING SYSTEM RESPONSES ON
PERMANENT FILE POSNAM. NSAVER EXPRESSED IN
NUMBER OF TIME STEPS

NRESET  I  FREQUENCY OF SAVING RESTART INFORMATION
<table>
<thead>
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<th>Line</th>
<th>Description</th>
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</thead>
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<tr>
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<tr>
<td>352</td>
<td>LOCVERG</td>
</tr>
<tr>
<td>367</td>
<td>LOCRES</td>
</tr>
<tr>
<td>375</td>
<td>LOCWRT</td>
</tr>
<tr>
<td>392</td>
<td>FORWRT</td>
</tr>
<tr>
<td>398</td>
<td>DISPLA</td>
</tr>
<tr>
<td>402</td>
<td>NPREVT</td>
</tr>
</tbody>
</table>
A NEW RESPONSE FILE, THE USE OF NPREVT
ENSURES THAT ANY TRANSIENT RESPONSE
DISPLAY MADE IN CONJUNCTION WITH THE TIME
INTEGRATION RUN WILL INCLUDE THE ENTIRE
HISTORY AVAILABLE FROM THAT FILE AND NOT
JUST THE PORTION COMPUTED DURING THE
CURRENT RUN. IF POSNAM CONTAINS THE
COMPLETE TRANSIENT SOLUTION BACK TO TIME
ZERO THEN NPREVT MUST BE THE NUMBER OF
TIME STEPS PLUS ONE TO ACCOUNT FOR THE
FACT THAT THE INITIAL CONDITIONS APPEAR IN
THE FIRST RECORD. IF THIS RUN IS THE VERY
FIRST OF A PARTICULAR SHOCK ANALYSIS THEN
NPREVT WILL BE ZERO

NPREVF I  NUMBER OF RESPONSE FILES FROM PREVIOUS
RUNS THAT MAKE UP THE DESIRED TRANSIENT
ANALYSIS DISPLAY. DO NOT ADD IN THE
CURRENT RUN AS THIS IS DONE BY THE CODE.
NPREVF PRESENTLY CANNOT EXCEED NINE (9)

NTIMES I  THE NUMBER OF RESPONSE RECORDS THAT ARE
STORED IN ANY PARTICULAR RESPONSE FILE.
THESE MUST BE ORDERED CHRONOLOGICALLY FOR
INPUT. NTIMES WILL GENERALLY BE THE NUMBER
OF TIME STEPS MADE DURING THE TIME THE
FILE WAS CREATED EXCEPT IF THE FILE GOES
BACK TO TIME EQUAL TO ZERO. IN THIS CASE
NTIMES IS EQUAL TO THE NUMBER OF TIME
STEPS PLUS ONE TO ACCOUNT FOR THE FIRST
RECORD THAT CONTAINS THE INITIAL
CONDITIONS

XVPNAM A  NAMES OF PREVIOUS RESPONSE FILES THAT MAKE
UP A CONTINUOUS SET OF TRANSIENT DATA.
ORDERED CHRONOLOGICALLY. DO NOT INCLUDE
POSNAM IN THIS LIST

LISTRE L  TRUE IF TRANSIENT RESPONSE HISTORIES ARE
TO BE LISTED IN TABULAR FORM. OTHERWISE
FALSE

PRTPLT L  TRUE IF PRINTER PLOTS ARE TO BE GENERATED
FOR TRANSIENT RESPONSE HISTORIES.
OTHERWISE FALSE

NWETHS I  NUMBER OF STRUCTURAL HISTORIES (EITHER
DISPLACEMENTS OR VELOCITIES) TO BE
DISPLAYED FOR WHICH THE APPROPRIATE
STRUCTURAL FREEDOMS CAN BE IDENTIFIED
INTERNALY THROUGH THE FREEDOM/EQUATION
CORRESPONDENCE TABLE. ALL STRUCTURAL NODES
WHICH PARTICIPATE IN THE FLUID-STRUCTURE
TRANSFORMATION WILL FALL INTO THIS
CATEGORY AS WELL AS ANY OTHERS Whose GRID
POINT COORDINATES WERE ENTERED AS DATA FOR
| NDRHS | I | NUMBER OF STRUCTURAL HISTORIES (EITHER DISPLACEMENTS OR VELOCITIES) TO BE DISPLAYED FOR WHICH THE APPROPRIATE STRUCTURAL FREEDOMS CANNOT BE IDENTIFIED INTERNALLY THROUGH THE FREEDOM/EQUATION CORRESPONDENCE TABLE. DRY STRUCTURE NODE POINTS CAN FALL INTO THIS CATEGORY IF THE USER DID NOT INCLUDE THEM IN THE DATA STREAM FOR THE FLUID MASS PROCESSOR. IN THIS CASE ONE MUST IDENTIFY THE INTERNAL SEQUENCE NUMBER APPROPRIATE TO THE DESIRED DEGREE OF FREEDOM BY A MYSTICAL PROCESS WHICH INVOLVES THE INTIMATE KNOWLEDGE OF THE ELIMINATION ORDER AND ANY REDUCTION OF THE NUMBER OF ACTIVE FREEDOMS DUE TO THE APPLICATION OF CONSTRAINTS. MORAL OF THE STORY - RUN ALL STRUCTURAL GRID POINTS THROUGH THE FLUID MASS PROCESSOR EVEN IF THEY NEVER GET WET |
| NUMSET | I | NUMBER OF DATA SETS USED TO DEFINE RESPONSE DISPLAYS FOR SEVERAL DEGREES OF FREEDOM THAT DIFFER BY A CONSTANT INCREMENT. THIS FEATURE CAN BE USED TO SIMPLIFY INPUT DATA TO SHOW A NUMBER OF TRANSIENT RESULTS AT DIFFERENT PLACES ALONG A GENERATOR OF A CYLINDER OR TORUS. THE CIRCUMFERENCE AT ANY AXIAL STATION |
| NODOUT | I | EXTERNAL IDENTIFICATION NUMBER OF STRUCTURAL NODE FOR WHICH A TIME HISTORY DISPLAY IS DESIRED |
| NFROUT | I | STRUCTURAL DEGREE OF FREEDOM NUMBER FOR WHICH A TIME HISTORY DISPLAY IS DESIRED |
| NEQHST | I | INTERNAL SEQUENCE NUMBER DETERMINED BY HAND FOR STRUCTURAL DEGREES OF FREEDOM WHICH ARE TO BE DISPLAYED AND ARE NOT INCLUDED IN THE FREEDOM/EQUATION CORRESPONDENCE TABLE FOR REASONS KNOWN ONLY TO THE USER |
| NODFIR | I | FIRST OF SEVERAL EQUALLY INCREMENTED NODE NUMBERS AT WHICH OUTPUT IS DESIRED |
| NODLAS | I | LAST OF SEVERAL EQUALLY INCREMENTED NODE NUMBERS AT WHICH OUTPUT IS DESIRED |
| NODINC | I | INCREMENT TO BE APPLIED IN ASSIGNING NODE NUMBERS FOR OUTPUT |
| NPRESS | I | NUMBER OF FLUID PRESSURE HISTORIES TO BE DISPLAYED |
| NEQHPR | I | FLUID CONTROL POINT NUMBER FOR WHICH A |
TIME HISTORY DISPLAY IS DESIRED FOR THE TOTAL PRESSURE.

SCALEF L TRUE IF MULTIPLICATIVE CONSTANT FACTORS ARE TO BE APPLIED TO THE DISPLAYED VALUES OF THE STRUCTURAL DISPLACEMENTS AND VELOCITIES, TOTAL FLUID Pressures AND/OR TIME. OTHERWISE FALSE. SUCH FACTORS ARE NOT APPLIED TO THE PERMANENT FILES CONTAINING THE RESPONSE HISTORIES.

RESFAC E.F MULTIPLICATIVE LENGTH CONVERSION FACTOR TO BE APPLIED TO THE DISPLAYED VALUES OF THE STRUCTURAL DISPLACEMENT AND VELOCITY HISTORIES.

PREFAC E.F MULTIPLICATIVE PRESSURE CONVERSION FACTOR TO BE APPLIED TO THE DISPLAYED VALUES OF THE TOTAL PRESSURE HISTORIES.

TIMFAC E.F MULTIPLICATIVE TIME CONVERSION FACTOR TO BE APPLIED TO THE DISPLAYED VALUES OF THE TIME AXIS FOR ALL THE TRANSIENT RESPONSE HISTORIES.

INPUT DATA CARD DECK

ALL INPUT DATA EXCEPT ALPHANUMERIC DATA MUST BE RIGHT JUSTIFIED IN EIGHT (8) COLUMN FIELDS WHICH CAN OCCUPY THE ENTIRE CARD. ALPHANUMERIC DATA MUST BE LEFT JUSTIFIED IN TWENTY (20) COLUMN FIELDS. FILE NAME PLUS QUALIFIER IS CURRENTLY RESTRICTED TO EIGHTEEN (18) CHARACTERS FOR UNIVAC OPERATION WHILE NINETEEN (19) CHARACTERS MAY BE USED FOR CDC OPERATION.

GENERAL PROBLEM DEFINITION (SUBROUTINE INPDAT):

72 COLUMN ALPHANUMERIC TITLE
PRENAM POSNAM STRNEW
RESNAM WRTNAM
X0 Y0 Z0
SX SY SZ
EXPWAV SPLINE
UPHIST PNORM
PHIST(I), I=1,UPHIST

IF SPLINE = .FALSE. READ THE FOLLOWING CARD

DTHIST

IF EXPWAV = .FALSE. READ THE FOLLOWING CARDS

PHIST(I), I=1,UPHIST
IF EXPWAV = .TRUE. READ THE FOLLOWING CARD
PZERO DECAY
CUBIC SPLINE INCIDENT PRESSURE HISTORY DATA (SUBROUTINE CSPRES):
---------------------------------------------------------------
IF SPLINE = .TRUE. READ THE FOLLOWING CARDS
TIMES(I), I=1,NPHIST
PHIST(I), I=1,NPHIST
GENERAL PROBLEM DEFINITION (SUBROUTINE INPDAT):
-------------------------------------------------------
NTINT
START DELTIM
.
.
TOTAL = NTINT
FINTM
NSAVE NRESET
LOCBE G LOCR E LOCWR T
FORWR T
POST PROCESSING (SUBROUTINE POSTRE):
------------------------------------------
DISPLAY
IF DISPLAY = .FALSE. THIS TERMINATES THE INPUT DATA DECK
PREVT NPREV F
IF NPREVF NOT = 0 READ THE FOLLOWING CARDS
TIMES(I), I=1,NPREVF
XPNAM(I), I=1,NPREVF
POST PROCESSING (SUBROUTINE RESDSP):
-------------------------------
LISTRE PRTPLT
POST PROCESSING (SUBROUTINE STROSP):
------------------
NWETHS NDRYHS NUMSET
NODOUT NFRQUT
.
.
TOTAL = NWETHS
.
.
NODOUT NFRQUT NDRYHS
.
.
TOTAL = NDRYHS
.
.
THIS SET FOR
.
.
IF NUMSET = 0 OMIT THE FOLLOWING CARD
.
.
NFRQUT NODFIR NODLAS NODINC

NWETHS NDORHS NUMSET
NODOUT NFROUT
TOTAL = NWETHS
NODOUT NFROUT NEQMST
TOTAL = NDRYHS
IF NUMSET = 0 OMIT THE FOLLOWING CARD
NFROUT NDFIR NDLAS NODINC
POST PROCESSING (SUBROUTINE RESOSP):

NPREHS NUMSET
NEQMPR
TOTAL = NPREHS
IF NUMSET = 0 OMIT THE FOLLOWING CARD
NDFIR NDLAS NODINC
POST PROCESSING (SUBROUTINE FILBUF):

SCALEF
IF SCALEF = .TRUE. READ THE FOLLOWING CARD
RESFAC PREFAC TIMFAC
The following discussion is provided as an aid to user understanding of the sample output that is included here.

First, the amount of storage required for the run given in the output refers solely to the blank common that is set in the main program, UNWASH. An error exit is taken if insufficient storage is available and the user must see that more is provided either by a recompilation on UNIVAC 1100-OS or by a field length request on CDC.

Sector address information for the response and restart files that is listed at various places in the output is extremely important for subsequent restart runs.

The next item needing discussion is the transient response tabular listings. The desired responses are displayed in matrix form so that each row contains the entire history of a particular degree of freedom except for the first row which is time. Each column therefore contains the instantaneous values of the complete set of response variables desired at a particular time. Each row is identified by the structural or fluid node and its degree of freedom. The letters D, V, and P stand for displacement, velocity and pressure, respectively.

Although printer plots of the transient response results can be displayed as part of the run such output has been deferred to the post-processing phase in Appendix D for this sample problem.
<table>
<thead>
<tr>
<th></th>
<th>TIMINI RUN FOR INFINITE CYLINDER SIMULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CYL=PREP</td>
</tr>
<tr>
<td>2</td>
<td>CYL=POST</td>
</tr>
<tr>
<td>3</td>
<td>CYL=REST</td>
</tr>
<tr>
<td>4</td>
<td>10000.</td>
</tr>
<tr>
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<tr>
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</tbody>
</table>

@QOT

@ADD,P CYLINTDAT
TIMINT RUN FOR INFINITE CYLINDER SIMULATION

+++ ✿ ASG.AX ✿ CYL*PREP.
+++ ✿ USE ✿ 16.CYL*PREP.

THIS IS A DAA1 RUN

CHARGE LOCATION DATA:

XC = 0.10000000+05
YC = 0.00000000
ZC = 0.00000000
SC = 0.99990000+04

PRESSURE HISTORY DATA: DTHIST = 0.50000000+02

<p>| | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<td></td>
</tr>
</tbody>
</table>

INCIDENT PRESSURE AND PARTICLE VELOCITY:

T | T | T | T | T | T | T | T | T | T |
---|---|---|---|---|---|---|---|---|---|
100000 | .00000 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 |
200000 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 |
300000 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 | .10000+01 |

C-16
INCIDENT PARTICLE VELOCITY:

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<th>0</th>
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<th>16.7</th>
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<th>50.0</th>
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</thead>
<tbody>
<tr>
<td>*</td>
<td>t</td>
<td>*</td>
<td>t</td>
<td>*</td>
<td>t</td>
<td>*</td>
<td>t</td>
</tr>
</tbody>
</table>

+++ * ASG,T  UNIT20..
+++ * USE  20,UNIT20.
+++ * ASG,UP CYL*POST..
+++ * USE  12,CYL*POST.
+++ * ASG,UP CYL*REST..
+++ * USE  14,CYL*REST.
+++ * ASG,AX CYL*SKY.
+++ * USE  22,CYL*SKY.

12536 WORDS OF STORAGE REQUIRED FOR THIS RUN

+++ * ASG,T  UNIT19..
+++ * USE  19,UNIT19.
+++ * ASG,T  UNIT13..
+++ * USE  13,UNIT13.
+++ * ASG,T  UNIT18..
+++ * USE  18,UNIT18.
+++ * FREE  UNIT13.
RESTART DATA FOR T = .750000 WRITTEN AT LOCATION 0 ON PERMANENT FILE CYL=REST

POST PROCESSING RESPONSE FILE LOCATION IS 1054

+++ • ASG.T UNIT13. F4/ 4/TRK/ 256
+++ • USE 13,UNIT13.
+++ • FREE UNIT13.

RESTART DATA FOR T = 2.000000 WRITTEN AT LOCATION 121 ON PERMANENT FILE CYL=REST

POST PROCESSING RESPONSE FILE LOCATION IS 2074

+++ • ASG.T UNIT13. F4/ 4/TRK/ 256
+++ • USE 13,UNIT13.
+++ • FREE UNIT13.

RESTART DATA FOR T = 5.000000 WRITTEN AT LOCATION 242 ON PERMANENT FILE CYL=REST

POST PROCESSING RESPONSE FILE LOCATION IS 3094

SECTOR ADDRESS OF RESPONSE FILE CYL=POST AT EXIT IS 3094

SECTOR ADDRESS OF RESTART FILE CYL=REST AT EXIT IS 363

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++* AUXILIARY STORAGE TABLE +++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
LOI EDW(C)CN) IFN CC OP SEC CLOGC NEXT LIMIT READ WRITTEN +
+ 10 CYL=POST 14 36 UP 20 3094 3044 65536 0 92173 +
+ 12 CYL=REST 14 36 UP 20 363 363 65536 0 9939 +
+ 14 CYL=PR1P 16 36 AX 28 63 192 65536 246532 0 +
+ 16 UNIT18 18 36 T 28 96 516 16384 2733896 48384 +
+ 17 UNIT19 19 36 T 28 16 48 16384 405849 4032 +
+ 18 UNIT30 20 36 T 28 48 48 16384 120528 117936 +
+ 20 CYL=KSY 22 36 AX 28 613 640 16384 1500387 0 +

7 ACTIVE DEVICES (0 FULL) +
+ 0 TP-OPS, 584 WRITES, 3329 HEADS, 5327117 WORDS XFO +

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

+++ • FREE CYL=POST. +
+++ • FREE CYL=REST. +
+++ • ASG.AX CYL=POST. +
+++ • USE 12,CYL=POST.
APPENDIX D
USER INFORMATION FOR THE POSTPROCESSOR POSTPR

This appendix includes a copy of the users manual, and a sample input deck and subsequent output for the infinite cylindrical shell problem presented in Section 4.
# Program Size

All arrays referenced in this code that are problem dependent reside in blank common. The size of blank common is determined by a parameter statement in the main program for the Univac 1100-05 version, hence a recompilation is necessary to increase or decrease core allocation. In the CDC 6600 version recompilation is unnecessary as the length of blank common is set by a field length request in the control card deck.

## Definition of Input Parameters

Input variable names given below are generally those which are also used in the coding and the variable types correspond to Standard Fortran usage:

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>NFIL</td>
<td>I</td>
<td>Number of response files that make up the desired transient analysis display. NFIL presently cannot exceed ten (10).</td>
</tr>
<tr>
<td>NTIMES</td>
<td>I</td>
<td>The number of response records that are stored in any particular response file. These must be ordered chronologically for input. NTIMES will generally be the number of time steps made during the time the file was created except if the file goes back to time equal to zero. In this case NTIMES is equal to the number of time steps plus one to account for the first record that contains the initial conditions.</td>
</tr>
<tr>
<td>PRED</td>
<td>A</td>
<td>Name of pre-processed mass storage file containing all fluid and structure data.</td>
</tr>
<tr>
<td>XFPNAM</td>
<td>A</td>
<td>Names of response files that make up a continuous set of transient data, ordered chronologically.</td>
</tr>
<tr>
<td>FORWR</td>
<td>L</td>
<td>True if permanent files denoted by XFPNAM.</td>
</tr>
<tr>
<td>DISPLA</td>
<td>L</td>
<td>TRUE IF SELECTED TRANSIENT RESPONSE HISTORIES ARE TO BE DISPLAYED. OTHERWISE FALSE. THIS VARIABLE MUST BE TRUE EVEN IF PSEUDO VELOCITY SHOCK SPECTRA ARE THE ONLY VELOCITY HISTORIES TO BE USED FOR THIS COMPUTATION.</td>
</tr>
<tr>
<td>DEFORM</td>
<td>L</td>
<td>TRUE IF A PERMANENT FILE IS TO BE CREATED THAT CONTAINS A CHRONOLOGICAL SUCCESSION OF RECORDS EACH OF WHICH CONSISTS OF THE COMPLETE DISPLACEMENT FIELD AT SPECIFIC TIMES WITHOUT ANY EXTRANEOUS TIME OR BOOKKEEPING DATA. SUCH A FILE CAN BE IMAGINED AS A SERIES OF SNAPSHOTS OF THE DEFORMED STRUCTURE THROUGHOUT THE SHOCK ANALYSIS. THIS CAPABILITY CANNOT BE USED IF FORWR IS TRUE.</td>
</tr>
<tr>
<td>LISTRE</td>
<td>L</td>
<td>TRUE IF TRANSIENT RESPONSE HISTORIES ARE TO BE LISTED IN TABULAR FORM. OTHERWISE FALSE.</td>
</tr>
<tr>
<td>PRTPLT</td>
<td>L</td>
<td>TRUE IF PRINTER PLOT IS TO BE GENERATED FOR TRANSIENT RESPONSE HISTORIES. OTHERWISE FALSE.</td>
</tr>
<tr>
<td>VECPLT</td>
<td>L</td>
<td>TRUE IF PLOTS ARE TO BE GENERATED FOR TRANSIENT RESPONSE HISTORIES. OTHERWISE FALSE. A PLOT PACKAGE IS NOT PROVIDED WITH THE USB CODE AND IT IS THE USER'S RESPONSIBILITY TO COMPLETE THIS FEATURE IN A CALL FROM SUBROUTINE RESHOK IF DESIRED. THE EXISTING CALL USES 'DISPLA' SOFTWARE.</td>
</tr>
<tr>
<td>NWEHIS</td>
<td>I</td>
<td>NUMBER OF STRUCTURAL HISTORIES (EITHER DISPLACEMENTS OR VELOCITIES) TO BE DISPLAYED FOR WHICH THE APPROPRIATE STRUCTURAL FREEDOMS CAN BE IDENTIFIED INTERNALLY THROUGH THE FREEDOM/EQUATION CORRESPONDENCE TABLE. ALL STRUCTURAL NODES WHICH PARTICIPATE IN THE FLUID-STRUCTURE TRANSFORMATION WILL FALL INTO THIS CATEGORY AS WELL AS ANY OTHERS WHOSE GRID POINT COORDINATES WERE ENTERED AS DATA FOR THE FLUID MASS PROCESSOR.</td>
</tr>
<tr>
<td>NDYRMS</td>
<td>I</td>
<td>NUMBER OF STRUCTURAL HISTORIES (EITHER DISPLACEMENTS OR VELOCITIES) TO BE DISPLAYED FOR WHICH THE APPROPRIATE STRUCTURAL FREEDOMS CANNOT BE IDENTIFIED INTERNALLY THROUGH THE FREEDOM/EQUATION CORRESPONDENCE TABLE. DRY STRUCTURE NODES</td>
</tr>
</tbody>
</table>
175 POINTS CAN FALL INTO THIS CATEGORY IF THE
176 USER DID NOT INCLUDE THEM IN THE DATA
177 STREAM FOR THE FLUID MASS PROCESSOR. IN
178 THIS CASE ONE MUST IDENTIFY THE INTERNAL
179 SEQUENCE NUMBER APPROPRIATE TO THE DESIRED
180 DEGREE OF FREEDOM BY A MYSTICAL PROCESS
181 WHICH INVOLVES THE INTIMATE KNOWLEDGE OF
182 THE ELIMINATION ORDER AND ANY REDUCTION
183 OF THE NUMBER OF ACTIVE FREEDOMS DUE TO
184 THE APPLICATION OF CONSTRAINTS. MORAL OF
185 THE STORY - RUN ALL STRUCTURAL GRID POINTS
186 THROUGH THE FLUID MASS PROCESSOR EVEN IF
187 THEY NEVER GET WET

188 NUMSET I

189 NUMBER OF DATA SETS USED TO DEFINE
190 RESPONSE DISPLAYS FOR SEVERAL DEGREES OF
191 FREEDOM THAT DIFFER BY A CONSTANT
192 INCREMENT. THIS FEATURE CAN BE USED TO
193 SIMPLIFY INPUT DATA TO SHOW A NUMBER OF
194 TRANSIENT RESULTS AT DIFFERENT PLACES
195 ALONG A GENERATOR OF A CYLINDER OR AROUND
196 THE CIRCUMFERENCE AT ANY AXIAL STATION

197 NODOUT I

198 EXTERNAL IDENTIFICATION NUMBER OF
199 STRUCTURAL NODE FOR WHICH A TIME HISTORY
200 DISPLAY IS DESIRED

201 NFROUT I

202 STRUCTURAL DEGREE OF FREEDOM NUMBER FOR
203 WHICH A TIME HISTORY DISPLAY IS DESIRED

204 NEQST I

205 INTERNAL SEQUENCE NUMBER DETERMINED BY
206 HAND FOR STRUCTURAL DEGREES OF FREEDOM
207 WHICH ARE TO BE DISPLAYED AND ARE NOT
208 INCLUDED IN THE FREEDOM/EQUATION
209 CORRESPONDENCE TABLE FOR REASONS KNOWN
210 ONLY TO THE USER

211 NODFIR I

212 FIRST OF SEVERAL EQUALLY INCREMENTED NODE
213 NUMBERS AT WHICH OUTPUT IS DESIRED

214 NODLAST I

215 LAST OF SEVERAL EQUALLY INCREMENTED NODE
216 NUMBERS AT WHICH OUTPUT IS DESIRED

217 NODINC I

218 INCREMENT TO BE APPLIED IN ASSIGNING NODE
219 NUMBERS FOR OUTPUT

220 NPRESHS I

221 NUMBER OF FLUID PRESSURE HISTORIES TO BE
222 DISPLAYED

223 NEQPFR I

224 FLUID CONTROL POINT NUMBER FOR WHICH A
225 TIME HISTORY DISPLAY IS DESIRED FOR THE
226 TOTAL PRESSURE

227 SCALEF L

228 TRUE IF MULTIPLICATIVE CONSTANT FACTORS
229 ARE TO BE APPLIED TO THE DISPLAYED VALUES
230 OF THE STRUCTURAL DISPLACEMENTS AND
231 VELOCITIES. TOTAL FLUID PRESSURES AND/OR
232 TIME. OTHERWISE FALSE. SUCH FACTORS ARE
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>233</td>
<td>RESFAC</td>
<td>E,F</td>
</tr>
<tr>
<td>234</td>
<td>MULTIPLICATIVE LENGTH CONVERSION FACTOR TO BE APPLIED TO THE DISPLAYED VALUES OF THE STRUCTURAL DISPLACEMENT AND VELOCITY HISTORIES</td>
<td></td>
</tr>
<tr>
<td>236</td>
<td>PREFAC</td>
<td>E,F</td>
</tr>
<tr>
<td>238</td>
<td>MULTIPLICATIVE PRESSURE CONVERSION FACTOR TO BE APPLIED TO THE DISPLAYED VALUES OF THE TOTAL PRESSURE HISTORIES</td>
<td></td>
</tr>
<tr>
<td>240</td>
<td>TIMFAC</td>
<td>E,F</td>
</tr>
<tr>
<td>243</td>
<td>MULTIPLICATIVE TIME CONVERSION FACTOR TO BE APPLIED TO THE DISPLAYED VALUES OF THE TIME AXIS FOR ALL THE TRANSIENT RESPONSE HISTORIES</td>
<td></td>
</tr>
<tr>
<td>249</td>
<td>SHSPEC</td>
<td>L</td>
</tr>
<tr>
<td>250</td>
<td>TRUE IF PSEUDO-VELOCITY SHOCK SPECTRA ARE ALSO DESIRED FOR STRUCTURAL FREEDOMS WHOSE VELOCITY RESPONSE IS TO BE DISPLAYED. OTHERWISE FALSE</td>
<td></td>
</tr>
<tr>
<td>249</td>
<td>SHLIST</td>
<td>L</td>
</tr>
<tr>
<td>249</td>
<td>TRUE IF PSEUDO-VELOCITY SHOCK SPECTRA ARE TO BE LISTED IN TABULAR FORM. OTHERWISE FALSE</td>
<td></td>
</tr>
<tr>
<td>258</td>
<td>SHPRPL</td>
<td>L</td>
</tr>
<tr>
<td>259</td>
<td>TRUE IF PRINTER PLOTS ARE TO BE GENERATED FOR PSEUDO-VELOCITY SHOCK SPECTRA. OTHERWISE FALSE</td>
<td></td>
</tr>
<tr>
<td>262</td>
<td>SHVCPPL</td>
<td>L</td>
</tr>
<tr>
<td>263</td>
<td>TRUE IF VECTOR PLOTS ARE TO BE GENERATED FOR PSEUDO-VELOCITY SHOCK SPECTRA. OTHERWISE FALSE (SEE VELPLT)</td>
<td></td>
</tr>
<tr>
<td>266</td>
<td>FREQW</td>
<td>E,F</td>
</tr>
<tr>
<td>267</td>
<td>LOWER LIMIT OF FREQUENCY RANGE TO BE SCANNED FOR PSEUDO-VELOCITY SHOCK SPECTRA</td>
<td></td>
</tr>
<tr>
<td>268</td>
<td>FREQUP</td>
<td>E,F</td>
</tr>
<tr>
<td>269</td>
<td>UPPER LIMIT OF FREQUENCY RANGE TO BE SCANNED FOR PSEUDO-VELOCITY SHOCK SPECTRA</td>
<td></td>
</tr>
<tr>
<td>271</td>
<td>DFREQ</td>
<td>E,F</td>
</tr>
<tr>
<td>273</td>
<td>FREQUENCY INCREMENT TO BE USED IN GENERATING PSEUDO-VELOCITY SHOCK SPECTRA</td>
<td></td>
</tr>
<tr>
<td>276</td>
<td>SNPNAM</td>
<td>A</td>
</tr>
<tr>
<td>277</td>
<td>NAME OF PERMANENT FILE TO BE CREATED CONTAINING STRUCTURAL SNAPSHOT DATA</td>
<td></td>
</tr>
<tr>
<td>280</td>
<td>NSNAP</td>
<td>I</td>
</tr>
<tr>
<td>281</td>
<td>NUMBER OF TIMES FOR WHICH THE DISPLACEMENT FIELD IS TO BE WRITTEN IN THE PERMANENT FILE DENOTED BY SNPNAM</td>
<td></td>
</tr>
<tr>
<td>283</td>
<td>PRTDIS</td>
<td>L</td>
</tr>
<tr>
<td>284</td>
<td>TRUE IF STRUCTURAL DISPLACEMENT FIELD IS TO BE PRINTED FOR EACH SNAPSHOT, OTHERWISE FALSE</td>
<td></td>
</tr>
<tr>
<td>286</td>
<td>TIME</td>
<td>E,F</td>
</tr>
<tr>
<td>287</td>
<td>TIME AT WHICH SNAPSHOT IS DESIRED, MUST BE ORDERED CHRONOLOGICALLY</td>
<td></td>
</tr>
</tbody>
</table>
**INPUT DATA CARD DECK**

**ALL INPUT DATA EXCEPT ALPHANUMERIC DATA MUST BE RIGHT JUSTIFIED**
**IN EIGHT (8) COLUMN FIELDS WHICH CAN OCCUPY THE ENTIRE CARD.**
**ALPHANUMERIC DATA MUST BE LEFT JUSTIFIED IN TWENTY (20) COLUMN**
**FIELDS. FILE NAME PLUS QUALIFIER IS CURRENTLY RESTRICTED TO**
**EIGHTEEN (18) CHARACTERS FOR UNIVAC OPERATION WHILE NINETEEN (19)**
**CHARACTERS MAY BE USED FOR CDC OPERATION**

**TASK DEFINITION (MAIN PROGRAM POSTPR):**

**72 COLUMN ALPHANUMERIC TITLE. ONLY THE FIRST 48 WILL APPEAR ON PLOTS**
**NFILES**
**NTIMES: I, I=1,NFILES**
**PRENUM**
**XVPIAM: I, I=1,NFILES**
**FORWR DIPLA DEFORM**

**TRANSIENT RESPONSE DISPLAY (SUBROUTINE RSMTH):**

**IF DISPLAY = .FALSE., SKIP ALL INPUT FROM HERE TO SUBROUTINE SNAPPY**
**LISTRE PRDTLT VECPLT**

**TRANSIENT RESPONSE DISPLAY (SUBROUTINE STDSIM):**

**IF NUMSET = 0 OMIT THE FOLLOWING CARD**
**NFRINT NODFIR NODLAS NGUINC**

**NFRINT NODFIR NODLAS**

**NFRINT NODFIR NODLAS**

**NFRINT NODFIR NODLAS**

**NFRINT NODFIR NODLAS**

**TRANSIENT RESPONSE DISPLAY (SUBROUTINE RSMTH):**

**---**

---
NPREHS NUMSET
NEQMPR
:
:
:
:
IF NUMSET = 0 OMIT THE FOLLOWING CARD
NODFIR NODLAS NODINC
TRANSIENT RESPONSE DISPLAY (SUBROUTINE FILBUF):
SCALEF
IF SCALEF = .TRUE. READ THE FOLLOWING CARD
RESFAC PREFAC TIMFAC
PSEUDO VELOCITY SHOCK SPECTRA (SUBROUTINERESSHA):
SHSPEC
IF SHSPEC = .TRUE. READ THE FOLLOWING CARDS
SHLIST SHPRL SHVCPL
FREQLW FREQUP DFREQ
SNAPSHOT FILE CREATION (SUBROUTINE SNAPPY):
IF DEFORM = .FALSE. THIS TERMINATES THE INPUT DATA DECK
SNPM
NSNP
PRDIS
TIME
:
:
TOTAL = NSNP
The following discussion is provided as an aid to user understanding of the sample output that is included here.

The input deck shown on the next page requests vector plots for both the transient response histories and pseudo-velocity shock spectra. This is appropriate if the DISSPLA plot package is available at the user installation. Otherwise appropriate modifications must either be made to use a different plot package or the input deck should be modified. In any case the printer plot package is resident in USA.

The format used for listing the pseudo-velocity shock spectra is similar to that used for the display of the transient response histories shown in Appendix C except that the first row is now frequency rather than time.
### Pseudo-Velocity Shock Spectra:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>1/1 S</td>
<td>.00000</td>
<td>.25000+01</td>
<td>.50000+01</td>
<td>.75000+01</td>
<td>1.00000+01</td>
<td>1.25000+01</td>
<td>1.50000+01</td>
<td>1.75000+01</td>
<td>2.00000+01</td>
</tr>
<tr>
<td>F</td>
<td>1/1 S</td>
<td>.00000</td>
<td>.25000+01</td>
<td>.50000+01</td>
<td>.75000+01</td>
<td>1.00000+01</td>
<td>1.25000+01</td>
<td>1.50000+01</td>
<td>1.75000+01</td>
<td>2.00000+01</td>
</tr>
<tr>
<td>F</td>
<td>19/1 S</td>
<td>.42658+01</td>
<td>.85316+01</td>
<td>1.28174+01</td>
<td>1.70640+01</td>
<td>2.13678+01</td>
<td>2.56296+01</td>
<td>2.98492+01</td>
<td>3.40273+01</td>
<td>3.81641+01</td>
</tr>
<tr>
<td>F</td>
<td>19/2 S</td>
<td>.00000</td>
<td>.10902+02</td>
<td>.16811+01</td>
<td>.19895+01</td>
<td>.17.34+01</td>
<td>.168+501</td>
<td>.16114+01</td>
<td>.16114+01</td>
<td>.16114+01</td>
</tr>
<tr>
<td>F</td>
<td>37/1 S</td>
<td>.84337+00</td>
<td>.143+2+03</td>
<td>.16059+01</td>
<td>.159+99+01</td>
<td>.147+501</td>
<td>.14021+01</td>
<td>.1325+401</td>
<td>.125+701</td>
<td>.1190+00</td>
</tr>
</tbody>
</table>

**Note:** The table above lists pseudo-velocity shock spectra for different values of F. Each row represents a different F value, with the corresponding pseudo-velocity shock spectra provided in the subsequent columns. The table structure is designed to facilitate quick reference for engineering applications involving shock wave propagation and fluid dynamics.
APPENDIX E
USER INSTRUCTIONS FOR INTERFACING WITH USA

To use the Underwater Shock Analysis (USA) Code in its linear stand-alone mode, the user must first construct a permanent data file that contains the structural mass and stiffness matrices and some assorted bookkeeping information. The purpose of this appendix is to describe the structure of the file and to specify how it is to be created. At this time utility routines that carry out this task have been written for SPAR, NASTRAN and GENSAM. An abbreviated form of this file is also required when USA is coupled with a non-linear structural analyzer and such an interface also exists for STAGS.

USA contains the data management utility module DMGASP that carries out all data transfer activities between core and peripheral storage. This is done by unformatted and unbuffered data transmissions and it is imperative that DMGASP be used to create the structural interface file. Otherwise the user must supply or have access to a similar means of direct transfer. Section 3 of [19] contains a comprehensive discussion of the half-dozen or so DMGASP commands that are required to activate, position, write upon, read from, and free a peripheral storage device. Subsidiary commands also exist for error handling and listing of selected information pertaining to auxiliary storage.

The current configuration of USA uses a diagonal mass matrix associated with a lumped mass representation of the structure, assumes that there is no velocity dependent structural damping, and further, only, single precision matrices may be processed. In addition, if the stiffness matrix has been reordered or reduced in any way for input to USA the mass matrix must also be reordered or condensed so that its degrees of freedom (DOF) are the same and appear in the same order as in the stiffness matrix. Finally, the stiffness matrix must be placed in a multi-block* skyline format as discussed in the SKYPUL manual [23]. This description consists of a Matrix Master Record (MMR) followed by a series of Matrix Value Records (MVR) which contain the numerical values of the matrix. These are the only constructs the user need be concerned with; all others required are already embedded in USA. During construction of the MMR a logical device index (LDI) must be set in the record which USA will access later. For UNIVAC operation, this should be set equal to twenty (20), while for CDC operation this should be set as two (2).

The USA code now includes four routines in the AUGMAT processor that can be used to facilitate assembly of the MMR and the MVR for any symmetric matrix. The routine BLKSKY is used to sequentially call SETPAR which determines the skyline profile, SETMMR which

* For small problems a single block is permissible.
constructs the matrix master record and finally SETMVR which produces the matrix value records. However, the user must ensure that the matrix can be provided row by row (or column by column) with any and all zeroes filled in. Please contact the developer for further details.

The file structure required is shown in Table E-1 where NDOF stands for the number of structural DOF which USA must process. NMMR is the number of words in the matrix master record, and NWBL is the number of words in each matrix value record (which is expected to be the same for each record). NWBL should also be an integer multiple of 448 for most efficient use of storage.

The Grid Point/DOF vector consists of an integer value for each global DOF from 1 through NDOF that is constructed as ten times the external node number plus the local DOF number that apply to that particular structural equation.

For example, if the 87th DOF to appear in the mass and stiffness matrices corresponds to the second degree of freedom at a node identified externally as 4637 then the 87th entry in the Grid Point/DOF vector would be 46372. Local translational degrees of freedom should be numbered 1-3, rotational degrees of freedom should be numbered from 4-6 and any others should be numbered with 7-9. If more than 9 degrees of freedom are carried at any node it is a simple matter to change the factor of ten to one hundred in a few places in USA to accommodate this.

It should be noted that records 1-4 are always accessed by the USA pre-processor AUGMAT before the time integration phase of the analysis commences*. This portion of the file is required for both USA in the linear stand-alone mode, and for USA when it is interfaced with a nonlinear structural analyzer. In this latter case, the fifth and succeeding records do not exist.

There is a minor difference in the way that the fifth and succeeding records are constructed in the SPAR and NASTRAN utilities. In the SPAR interface one pass is made through the stiffness matrix to first determine its connectivity and set up the bookkeeping to construct the MMR. The MMR is then written and a second pass is made through the matrix to write the MVR’s immediately following the MMR. In the NASTRAN interface only one pass is made through the stiffness matrix. Hence, the MMR is not constructed until all the MVR’s have been written. To follow the order required by Table E-1 space is left in the file for the MMR to be written in its proper order on the file after the entire set of MVR’s have been written. Because of this there will generally be a buffer area of irrelevant data (garbage) between the MMR and the first MVR on a NASTRAN file in contrast to a SPAR file.

* The fifth and succeeding records can be accessed in AUGMAT if the user wishes to check the stiffness matrix.

E-2
<table>
<thead>
<tr>
<th>Record</th>
<th>Number of Words</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>NDOF</td>
</tr>
<tr>
<td>2</td>
<td>NDOF</td>
<td>Diagonal Mass Matrix</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>NDOF</td>
</tr>
<tr>
<td>4</td>
<td>NDOF</td>
<td>Grid Point/DOF Vector</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>NMMR</td>
</tr>
<tr>
<td>6</td>
<td>NMMR</td>
<td>Matrix Master Record for Stiffness Matrix</td>
</tr>
<tr>
<td>7</td>
<td>NWBL</td>
<td>First Matrix Value Record for Stiffness Matrix</td>
</tr>
<tr>
<td>.</td>
<td>NWBL</td>
<td>Second Matrix Value Record for Stiffness Matrix</td>
</tr>
<tr>
<td>.</td>
<td>NWBL</td>
<td>Last Matrix Value Record for Stiffness Matrix</td>
</tr>
</tbody>
</table>
The amount of space currently allowed for the MMR on a NASTRAN skyline file is 10 PRU's (640 words) on CDC and 10 sectors (280 words) on UNIVAC. These values translate into a current limit of 283 and 80 skyline blocks for the two systems, respectively. If more capability is desired the statement MMRPRU = 10 at the beginning of subroutine KDD of the NASTRAN skyline utility can be increased to suit the user's needs.

The SKYPUL processor has the ability to apply constraints due to symmetry or attachment to ground during the time integration. Structural DOF that are to remain zero must have their associated diagonal location pointers (LDP) flagged with a negative sign during construction of the MVR and it is highly recommended that this capability be included in every USA structural interface utility.
THE UNDERWATER SHOCK ANALYSIS CODE (USA-VERSION 3): A REFERENCE—ETC(U) SEP 80 J A DERUNTZ, T L BEERS, C A FELIPPA DNA-001-78-C-0029
DEPARTMENT OF THE ARMY (Continued)

Chief of Engineers
Department of the Army
ATTN: DAEN-RDE
ATTN: DAEN-MCE-D

Deputy Chief of Staff for Ops & Plans
Department of the Army
ATTN: DAMO-NC

Deputy Chief of Staff for Rsch Dev & Acq
Department of the Army
ATTN: DAMA

Engineer Studies Ctr
Department of the Army
ATTN: DAEN-FES, LTC Hatch

Harry Diamond Labs
Department of the Army
ATTN: DELHD-I-1-TL
ATTN: DELHD-N-P

U.S. Army Concepts Analysis Agency
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