

TREATMENT OF STATIC PRELOAD EFFECTS IN ACOUSTIC RADIATION AND SCATTERING

by

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ABSTRACT

NASHUA is a coupled finite element/boundary element capability built around NASTRAN for calculating the low frequency, far-field acoustic pressure field radiated or scattered by an arbitrary submerged 3-D elastic structure subjected to either internal time-harmonic mechanical loads or external time-harmonic incident loadings. This paper describes the addition to NASHUA of the capability to take into account the effects of static preload on the stiffness of the structure. The static preload is accounted for using NASTRAN's differential stiffness matrix and implemented by merging parts of NASTRAN's differential stiffness rigid formats into the direct frequency response calculation, some of which is done in NASTRAN. The general solution approach calculates structural and fluid impedances with no approximation other than discretization. The surface fluid pressures and normal velocities are first calculated by coupling a NASTRAN finite element model of the structure with a discretized form of the Helmholtz surface integral equation for the exterior fluid. Far-field pressures are then evaluated from the surface solution using an asymptotic form of the Helmholtz exterior integral equation. The effects of adding static preload (e.g., hydrostatic pressure) to the calculation are illustrated for an internally-driven spherical shell.

INTRODUCTION

Two basic problems in numerical structural-acoustics are (1) the calculation of the acoustic pressure field radiated by a general submerged three-dimensional elastic structure subjected to internal time-harmonic loads, and (2) the calculation of the far-field acoustic pressure scattered by an elastic structure subjected to an incident time-harmonic wave train. The most common, as well as the most accurate, general approach for solving these problems is to couple a finite element model of the structure with a boundary element model of the surrounding fluid.¹⁻⁵ This is the approach taken by NASHUA, which is a boundary element program built around NASTRAN, a widely-used finite element computer program for structural dynamics.

Two previous papers described the basic development for acoustic radiation and scattering.^{4,5} Here we describe the addition to NASHUA of the capability to take into account in the analysis the effects of a static

preload on the stiffness of the structure. The static preload (which may be due, for example, to hydrostatic pressure) is accounted for by using NASTRAN's differential stiffness matrix and is implemented by merging parts of NASTRAN's differential stiffness rigid formats into the direct frequency response calculation, some of which is done in NASTRAN.

In general, the NASHUA procedure uses NASTRAN to generate the structure's stiffness, mass, and damping matrices and to perform various matrix manipulations. Other programs are used to generate the fluid matrices, perform the field calculations, and display the results. The procedure is highly automated, so that a finite element model of a dry structure can often be converted for structural-acoustic analysis with NASHUA in a few hours.

THEORETICAL APPROACH

The basic theoretical development for NASHUA's radiation and scattering approach has been presented in detail previously.^{4,5} Here, for completeness, we summarize the overall approach and describe the addition of the hydrostatic preload effects.

The Surface Solution

Consider an arbitrary submerged three-dimensional elastic structure subjected to either internal time-harmonic loads or an external time-harmonic incident pressure wave train. If the structure is modeled with finite elements using NASTRAN, the resulting matrix equation of motion for the structural degrees of freedom (DOF) can be written as

$$Zv = F - GAp, \tag{1}$$

where Z = structural impedance matrix (dimension $s \times s$),

v = complex amplitude of the velocity vector for all structural DOF (wet and dry) in terms of the coordinate systems selected by the user ($s \times r$),

F = complex amplitude of the vector of mechanical forces applied to the structure ($s \times r$),

G = rectangular transformation matrix of direction cosines to transform a vector of outward normal forces at the wet points to a vector of forces at all points in the coordinate systems selected by the user ($s \times f$),

A = diagonal area matrix for the wet surface ($f \times f$), and

p = complex amplitude of total pressures (incident + scattered) applied at the wet grid points ($f \times r$).

In this equation, the time dependence $\exp(i\omega t)$ has been suppressed. In the above dimensions, s denotes the total number of independent structural DOF (wet and dry), f denotes the number of fluid DOF (the number of wet points), and r denotes the number of load cases. In general, surface areas, normals, and the transformation matrix G are obtained in NASHUA from the NASTRAN calculation of the load vector resulting from an outwardly directed static unit pressure load on the structure's wet surface.

In Eq. 1, the structural impedance matrix Z , the matrix which converts velocity to force, is given by

$$Z = (-\omega^2 M + i\omega B + K)/i\omega, \quad (2)$$

where M , B , and K are the structural mass, viscous damping, and stiffness matrices, respectively, and ω is the circular frequency of excitation. For structures with a nonzero loss factor, K is complex. A standard NASTRAN finite element model of the structure supplies the matrices K , M , and B .

The total fluid pressure p satisfies the Helmholtz differential equation

$$\nabla^2 p + k^2 p = 0, \quad (3)$$

where $k = \omega/c$ is the acoustic wave number, and c is the speed of sound in the fluid. Equivalently, p is the solution of the Helmholtz integral equation^{2,6}

$$\int_S p(\underline{x})(\partial D(r)/\partial n) dS - \int_S q(\underline{x}) D(r) dS = \begin{cases} p(\underline{x}')/2 - p_I, & \underline{x}' \text{ on } S \\ p(\underline{x}'), & \underline{x}' \text{ in } E \end{cases} \quad (4)$$

where S and E denote surface and exterior fluid points, respectively, p_I is the incident free-field pressure, r is the distance from \underline{x} to \underline{x}' (Fig. 1), D is the Green's function

$$D(r) = e^{-ikr}/4\pi r, \quad (5)$$

$$q = \partial p/\partial n = -i\omega\rho v_n, \quad (6)$$

ρ is the mass density of the fluid, and v_n is the outward normal component of velocity on S . As shown in Fig. 1, \underline{x} in Eq. 4 is the position vector for a

typical point P_j on the surface S , \underline{x}' is the position vector for the point P_i which may be either on the surface or in the exterior field E , the vector $\underline{r} = \underline{x}' - \underline{x}$, and \underline{n} is the unit outward normal at P_j . We denote the lengths of the vectors \underline{x} , \underline{x}' , and \underline{r} by x , x' , and r , respectively. The normal derivative of the Green's function D appearing in Eq. 4 can be evaluated as

$$\partial D(r)/\partial n = (e^{-ikr}/4\pi r) (ik + 1/r) \cos \beta, \quad (7)$$

where β is defined as the angle between the normal \underline{n} and the vector \underline{r} , as shown in Fig. 1.

The substitution of Eqs. 6 and 7 into the surface equation (4) yields

$$\begin{aligned} p(\underline{x}')/2 - \int_S p(\underline{x}) (e^{-ikr}/4\pi r) (ik + 1/r) \cos \beta \, dS \\ = i\omega\rho \int_S v_n(\underline{x}) (e^{-ikr}/4\pi r) dS + p_I, \end{aligned} \quad (8)$$

where \underline{x}' is on S . This integral equation relates the total pressure p and normal velocity v_n on S . If the integrals in Eq. 8 are discretized for numerical computation (the details of which were presented previously⁴), we obtain the matrix equation

$$E p = C v_n + p_I \quad (9)$$

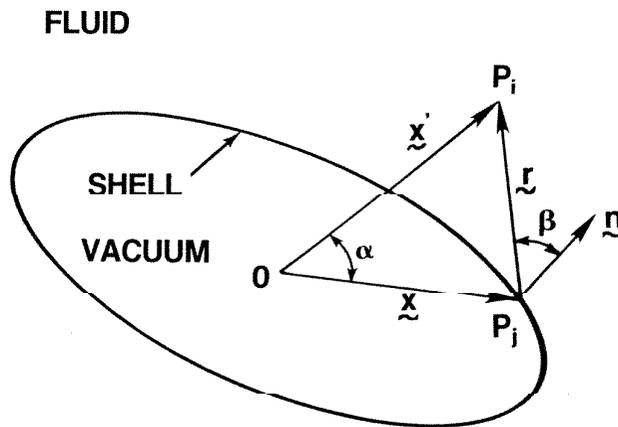


Figure 1 - Notation for Helmholtz Integral Equation

on S , where p is the vector of complex amplitudes of the total pressure on the structure's wet surface, E and C are fully-populated, complex, non-symmetric, frequency-dependent matrices, and p_I is the complex amplitude of the incident pressure vector, if any. The number of unknowns in this system is f , the number of wet points on the fluid-structure interface.

The normal velocities v_n in Eq. 9 are related to the total velocities v by the same rectangular transformation matrix G :

$$v_n = G^T v, \quad (10)$$

where T denotes the matrix transpose. If velocities v and v_n are eliminated from Eqs. 1, 9, and 10, the resulting equation for the coupled fluid-structure system is

$$(E + CG^T Z^{-1} GA)p = CG^T Z^{-1} F + p_I. \quad (11)$$

Since the left-hand side coefficient matrix and the right-hand side of this equation depend on geometry, material properties, and frequency, this equation can be solved to yield the total surface pressures p . Since the two right-hand side terms in Eq. 11 correspond to mechanical and incident loadings, respectively, only one of the two terms would ordinarily be present for a given case. The details of the calculation of the incident pressure vector p_I for scattering problems were presented in an earlier paper⁵ and will not be repeated here.

The vector v of velocities at all structural DOF can then be recovered by solving Eq. 1 for v :

$$v = Z^{-1} F - Z^{-1} GA p. \quad (12)$$

Surface normal velocities v_n may be recovered by substituting this solution for v into Eq. 10.

Hydrostatic Pressure Effects

The primary effect of hydrostatic pressure on the dynamics of a submerged structure is to decrease the stiffness of the structure. This decrease, in turn, results in a shift of the resonant frequencies of the shell. NASHUA accounts for this effect by replacing the elastic stiffness matrix K in Eq. 2 with the sum of K and the NASTRAN differential stiffness matrix K_d . Since the user specifies a unit pressure loading on the structure's wet surface (for the purpose of identifying the wet surface and calculating the areas and normals), sufficient information is available to compute K_d , given the desired

hydrostatic pressure. The NASHUA implementation assumes that the pressure is applied uniformly over the wet surface; that is, no depth dependence is accounted for.

If we let P denote the static load vector resulting from the application of the unit outward pressure on the structure's wet surface, the corresponding displacement vector u_s is the solution of

$$K_e u_s = P, \quad (13)$$

where K_e is the real part of the elastic stiffness matrix K . This solution (u_s) is then used by the NASTRAN functional module DSMC1 to compute the differential stiffness matrix K_{d0} associated with the unit pressure load. The differential stiffness matrix K_d for the desired hydrostatic pressure p_h is then

$$K_d = - p_h K_{d0}, \quad (14)$$

where the minus sign results from the convention that p_h is positive in compression. The final step is the replacement (by equivalencing) of the complex stiffness K by $K + K_d$.

The stiffness matrix K_e is singular for structures which are not sufficiently restrained to prevent rigid body motion, a common occurrence. Since K_e must be nonsingular to solve Eq. 13, the difficulty is resolved by temporarily replacing K_e with the sum of K_e and a diagonal matrix having small positive real numbers on the diagonal. These numbers are 10^{-6} times the corresponding diagonal entries in K_e . This approach relieves the user of having to be concerned with free-body supports for free-free structures. The correction is temporary since it is used only to generate the static solution needed for the differential stiffness calculation and not for the subsequent coupled analysis.

It is important to ensure that the applied hydrostatic pressure p_h is below the lowest buckling load for the structure, since otherwise the differential stiffness matrix K_d would be meaningless. This buckling load can be determined by a separate NASTRAN analysis using Rigid Format 5.

The Far-Field Calculation

With the solution for the total pressures and velocities on the surface, the exterior Helmholtz integral equation, Eq. 4, can be integrated to obtain the radiated (or scattered) pressure at any desired location \underline{x}' in the exterior field. We first substitute Eqs. 6 and 7 into Eq. 4 to obtain a form suitable for numerical integration:

$$p(\underline{x}') = \int_S [i\omega\rho v_n(\underline{x}) + (ik + 1/r)p(\underline{x}) \cos \beta] (e^{-ikr}/4\pi r) dS, \quad (15)$$

where all symbols have the definitions used previously, and \underline{x}' is in the exterior field. Thus, with the total pressure p and normal velocity v_n on the surface S , the radiated or scattered pressure at \underline{x}' can be determined by numerical quadrature using Eq. 15.

In applications, however, the field pressures generally of interest are in the far-field, so we use an asymptotic form^{4,7,8} of this equation instead of Eq. 15:

$$p(\underline{x}') = (ike^{-ikx'}/4\pi x') \int_S [\rho c v_n(\underline{x}) + p(\underline{x}) \cos \beta] e^{ikx \cos \alpha} dS, \quad (16)$$

where α is the angle between the vectors \underline{x} and \underline{x}' (Fig. 1), and, for points in the far-field, $\cos \beta$ is computed using

$$\cos \beta \rightarrow \underline{n} \cdot \underline{x}' / x'. \quad (17)$$

Summary of Theoretical Approach

The NASHUA solution procedure uses NASTRAN to generate the matrices K , M , B , and F and to generate sufficient geometry information so that the matrices E , C , G , A , and p_I can be computed by a separate program called SURF. K includes the differential stiffness effects of the hydrostatic preload, if any. Then, NASTRAN DMAP is used to form the matrices appearing in Eq. 11, which is solved for the total pressures p using the block solver OCSOLVE⁹ written by E.A. Schroeder of the David Taylor Research Center especially for this problem. Next, NASTRAN DMAP is used to recover the surface normal velocities v_n and the vector v of velocities at all structural DOF (NASTRAN's "g-set"). This step completes the surface solution. Then, with this solution for the total pressures and velocities on the surface, the asymptotic (far-field) form of the Helmholtz exterior integral equation is integrated in program FAROUT to compute the far-field radiated pressures. Various tables and graphical displays are generated.

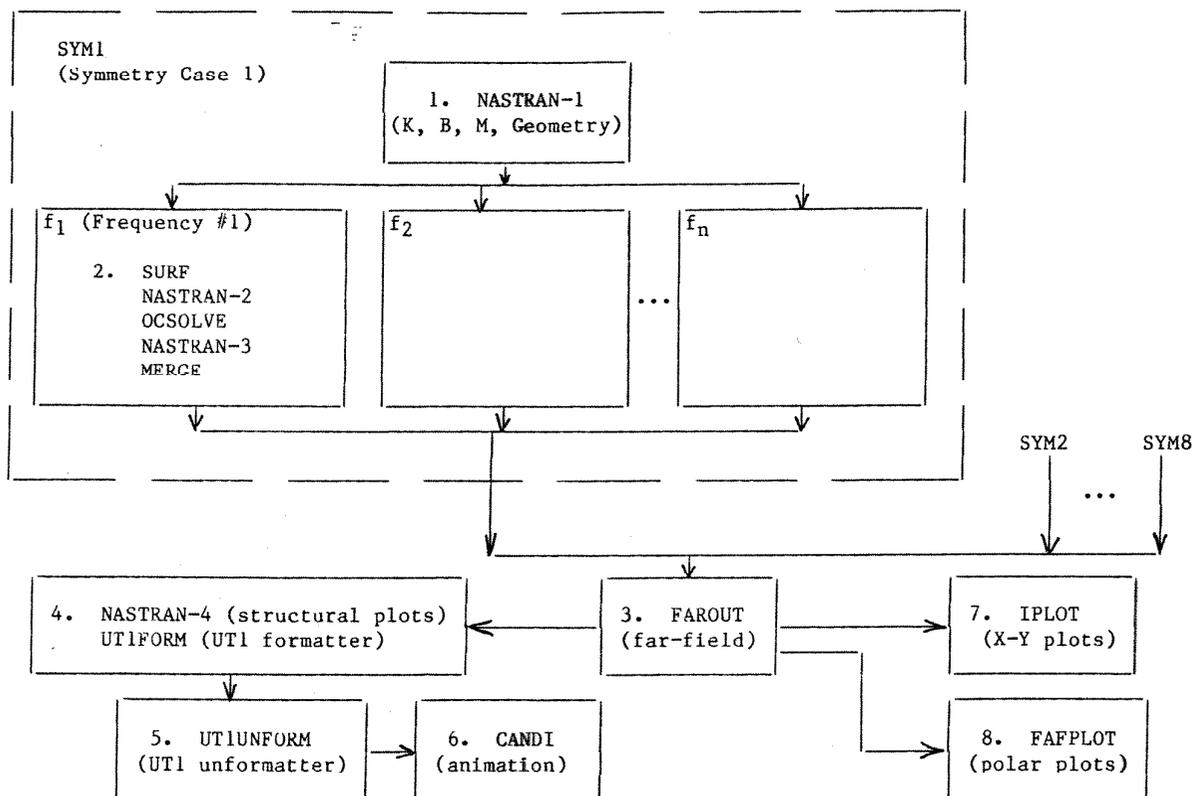
OVERVIEW OF NASHUA SOLUTION PROCEDURE

The overall organization and setup of the solution procedure is summarized in Fig. 2. NASTRAN appears four times in the procedure; to distinguish one NASTRAN execution from another, the integers 1-4 are appended to NASTRAN in the figure.

A separate NASTRAN model is prepared and run (Step 1 in Fig. 2) for each unique set of symmetry constraints. Since up to three planes of reflective

symmetry are allowed, there would be one, two, four, or eight such runs. Step 1 generates files containing geometry information and a checkpoint file for subsequent use in the other steps.

For each symmetry case and drive frequency, the Step 2 sequence is run in a single job. The SURF program reads the geometry file generated by NASTRAN in Step 1 and, using the Helmholtz surface integral equation, generates the fluid matrices E and C for the exterior fluid, the area matrix A, the structure-fluid transformation matrix G, the incident pressure vector p_I , and a geometry file to be used later by FAROUT in Step 3 for the field calculation. SURF is followed by a NASTRAN job which takes the matrices K, M, B, and F from Step 1 and the matrices E, C, A, G, and p_I from SURF and forms the matrices in Eq. 11, which is solved for the total surface pressure vector p by program OCSOLVE.⁹ The OCSOLVE program is a general block solver for large, full, complex, nonsymmetric systems of linear, algebraic equations. The program was designed to be particularly effective on such systems and executes on CDC computers about 20 times faster than NASTRAN's equation solver, which was not designed for efficient solution of such systems of



NOTE: Each solid block is a separate job submission.

Figure 2 - Summary of NASHUA Solution Procedure

equations. NASTRAN is then re-entered in Step 2 with p so that the velocities v and v_n can be recovered using DMAP operations. The surface pressures, normal velocities, and full g-set displacements are then reformatted, sorted, and merged into a single file (for each symmetry case) using program MERGE. Recall that there are one, two, four, or eight possible symmetry cases.

Steps 1 and 2 are repeated for each symmetry case. After all symmetry cases have been completed and merged, program FAROUT (Step 3) is run to combine the symmetry cases and to integrate over the surface. FAROUT uses as input the geometry file generated by SURF (Step 2) and the surface solutions from the one, two, four, or eight files generated by MERGE (Step 2). The far-field pressure solution is obtained by integrating the surface pressures and velocities using the asymptotic (far-field) form of the exterior Helmholtz integral equation, Eq. 16. Output from FAROUT consists of both tables and files suitable for various types of plotting.

The remaining steps in the NASHUA procedure are for graphical display. Deformed structural plots of the frequency response are obtained by restarting NASTRAN (Step 4) with the checkpoint file from Step 1 and a results file from FAROUT. In addition, animated plots can be generated on the Evans & Sutherland PS-330 graphics terminal using the CANDI program (Step 6) written for the DEC/VAX computer by R.R. Lipman of DTRC.¹⁰ If the rest of NASHUA is run on a computer other than the VAX, the NASTRAN UT1 file passed to CANDI must first be formatted (Step 4) for transfer to the VAX computer and then unformatted (Step 5) for reading by CANDI.

X-Y plots of various quantities (both surface and far-field) versus frequency may be obtained using the general purpose interactive plotting program IPLOT¹¹ (Step 7). Polar plots of the far-field sound pressure levels in each of the three principal coordinate planes can also be generated using the interactive graphics program FAFPLOT¹² (Step 8) written by R.R. Lipman.

DMAP ALTER

Several DMAP alters are used in the overall NASHUA procedure. However, the only alter affected by a static preload is that of Step 1, which makes available to NASHUA several geometry data blocks and computes the structural matrices K, M, and B. The hydrostatic pressure option is invoked with the addition of only one bulk data card, a parameter card on which the new parameter HSP (the hydrostatic pressure) is defined. In general, the complete alter for NASTRAN's direct frequency response rigid format now involves two modifications, the generation of the static load vector resulting from the application of the unit pressure load and the calculation of the differential stiffness matrix K_d so that the elastic stiffness matrix K can be replaced by the sum of K and K_d . For the 1987 release of NASTRAN, the following alter is used:

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ALTER 1 $ NASHUA STEP 1, COSMIC 1987 RF8 (REVISED 12/14/87)
ALTER 2,2 $ DELETE PRECHK
ALTER 21,21 $ REPLACE GP3
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GP3      GEOM3,EQEXIN,GEOM2/SLT,GPTT/S,N,NOGRAV/NEVER=1 $ SLT
ALTER   117,117 $ REPLACE FRRD
SSG1    SLT,BGPD,CTM,SIL,EST,MPT,GPTT,EDT,MGG,CASECC,DIT/
        PG/LUSET/NSKIP $ PG
SSG2    USET,GM,YS,KFS,GO,DM,PG/QR,PO,PS,PL $ PL
OUTPUT2  BGPDT,EQEXIN,USET,PG,PL $
OUTPUT2  CTM,ECT,,, $
OUTPUT2  ,,,, //-9 $
PARAMR  //*EQ*//C,Y,HSP=0./0.////NOHSP $
COND    LBL4D,NOHSP $ SKIP DIFF. STIFF. IF NO HYDROSTATIC PRESSURE
PARAMR  //*COMPLEX//C,Y,HSP=0./0./HSPC $ HSP+1*0
DIAGONAL KAA/KDIAG/*SQUARE*/1.0 $
ADD     KAA,KDIAG/KAAD/(1.E-6,0.) $
RBMG2   KAAD/LLL $ FACTOR KAA
SSG3    LLL,KAAD,PL,LOO,KOO,PO/ULV,UOOV,RULV,RUOV/OMIT/V,Y,IRES=-1/
        1/S,N,EPSI $ STATIC SOLUTION
SDR1    USET,PG,III,V,UOOV,YS,GO,GM,PS,KFS,KSS,/HGV,PGG,QG/1/
        *BKLO* $ RECOVER DEPENDENT DISPLACEMENTS
TA1     ECT,EPT,BGPD,CTM,SIL,GPTT,CSTM/X1,X2,X3,ECPT,GPCT/LUSET/
        NOSIMP/O/NOGENL/GENEL $ TABLES FOR DIFF. STIFFNESS
DSMG1   CASECC,GPTT,SIL,EDT,UGV,CSTM,MPT,ECPT,GPCT,DIT/KDGG/
        S,N,DSCSET $ DIFF. STIFF. MATRIX
EQUIV   KDGG,KDNN/MPCF2/MGG,MNN/MPCF2 $ EQUIV IF NO MPC'S
COND    LBL1D,MPCF2 $ TRANSFER IF NO MPC'S
MCE2    USET,GM,KDGG,,,/KDNN,,, $ MPC'S ON DIFF. STIFF.
LABEL   LBL1D $
EQUIV   KDNN,KDFF/SINGLE/MNN,MFF/SINGLE/ $ EQUIV. IF NO SPC'S
COND    LBL2D,SINGLE $ TRANSFER IF NO SPC'S
SCE1    USET,KDNN,,,/KDFF,KDFS,KDSS,,, $ SPC'S AND DIFF. STIFF.
LABEL   LBL2D $
EQUIV   KDFF,KDAA/OMIT/MFF,MAA/OMIT $ EQUIV. IF NO OMIT
COND    LBL3D,OMIT $ TRANSFER IF NO OMIT
SMP2    USET,GO,KDFF/KDAA $ OMIT AND DIFF. STIFF.
LABEL   LBL3D $
PARAMR  //*SUBC*///MHSPC//HSPC $ NEGATE HYDROSTATIC PRESSURE
ADD     KDD,KDAA/NEWKDD//MHSPC $ ADD ELASTIC K AND DIFF. STIFF.
ADD     KFS,KDFS/NEWKFS//MHSPC $ ADD ELASTIC K AND DIFF. STIFF.
EQUIV   NEWKDD,KDD//NEWKFS,KFS $
LABEL   LBL4D $ END OF DIFF. STIFF. EFFECTS (HSP)
DIAGONAL KDD/IDENT/*SQUARE*/0. $ D-SET IDENTITY
ADD     IDENT,/IDM $ ANOTHER D-SET IDENTITY
ADD     IDENT,/ZERO/(0.0,0.0) $ D-SET ZERO MATRIX
FRRD    CASEXX,USETD,DLT,FRL,GMD,GOD,IDENT,ZERO,IDM.,DIT/
        UDVF,PSF,PDF,PPF/*DISP*/*DIRECT*/LUSETD/MPCF1/
        SINGLE/OMIT/NONCUP/FRQSET $ PDF, KDD=MDD=I, BDD=0
CHKPNT  MDD,KDD,BDD,PDF,PSF,PPF,EQDYN,USETD,GOD,GMD $
CHKPNT  KFS,BGPD,ECT,EQEXIN,GPECT,SIL $
EXIT    $
ENDALTER $

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EXAMPLE

Here we illustrate the effect of a hydrostatic pressure preload on the dynamics of a submerged structure by solving the acoustic radiation problem of a submerged thin spherical shell with a distributed internal driving force, as shown in Fig. 3. The particular problem solved has a uniform internal pressure load applied over the polar angle $\gamma = 36$ degrees.

We solve with NASHUA the problem with the following characteristics:¹³

$a = 5$ m	shell radius
$h = 0.15$ m	shell thickness
$E = 2.07 \times 10^{11}$ Pa	Young's modulus
$\nu = 0.3$	Poisson's ratio
$\rho_s = 7669$ kg/m ³	shell density
$\eta = 0$	shell loss factor
$\rho = 1000$ kg/m ³	fluid density
$c = 1524$ m/s	fluid speed of sound
$p_0 = 1$ Pa	internal pressure
$\gamma = 36^\circ$	extent of internal pressure
$p_h = 1 \times 10^8$ Pa	hydrostatic pressure

The same shell was used previously^{4,5} for the validation of the basic radiation and scattering capability in NASHUA. One octant of the shell was modeled with NASTRAN's CTRIA2 membrane/bending elements as shown in Fig. 4. With 20 elements along each edge of the domain, the model has 231 wet points and 1263 structural DOF. Three planes of symmetry were imposed. The application of NASTRAN's buckling analysis (Rigid Format 5) to this shell

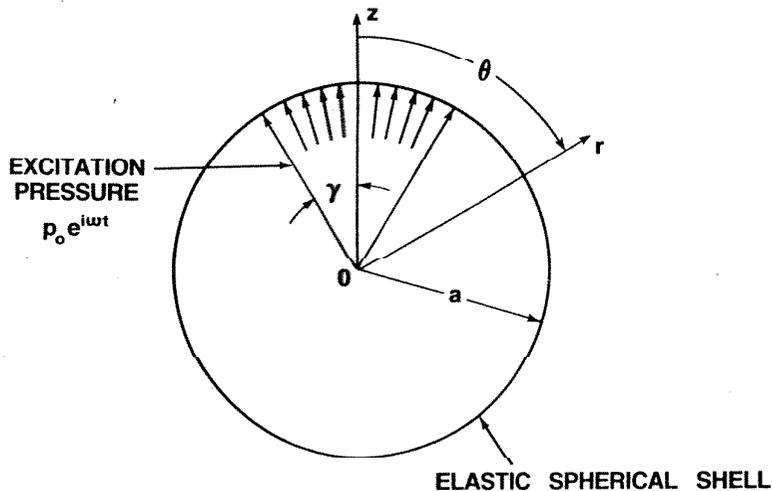


Figure 3 - Submerged Elastic Spherical Shell Driven over Sector

showed that the hydrostatic pressure preload p_h is about 41% of the lowest buckling load of 2.42×10^8 Pa.

The NASHUA model was run for 19 drive frequencies in the nondimensional frequency range $ka = 1.0$ to $ka = 2.05$, where a is the shell radius. This frequency range was selected because it includes the first two submerged resonances of the shell (at $ka = 1.606$ and $ka = 1.999$) and is below all the discrete critical frequencies at which the surface Helmholtz integral equation (4) is invalid.^{14,15} In Fig. 5 we compare the far-field radiated pressure on the polar axis as computed by NASHUA (including the effects of hydrostatic preload) with a converged series solution as computed by Henderson's RADSPHERE program,¹⁶ which assumes zero preload. (Since it was shown previously^{4,5} that, for zero preload, NASHUA and RADSPHERE yielded essentially identical results for this problem, it was more economical to use RADSPHERE, rather than NASHUA, to generate the unpressurized solution. RADSPHERE was developed from equations published in the Junger and Feit book.¹⁷) The ordinate in Fig. 5 is the normalized pressure $|p_r r / p_0 a|$, where p_r is the far-field pressure radiated outward along the polar axis at distance r from the origin, and p_0 is the magnitude of the internal pressure applied internally over the sector. Clearly, the effect of the hydrostatic preload is to lower slightly the frequencies of the resonances.

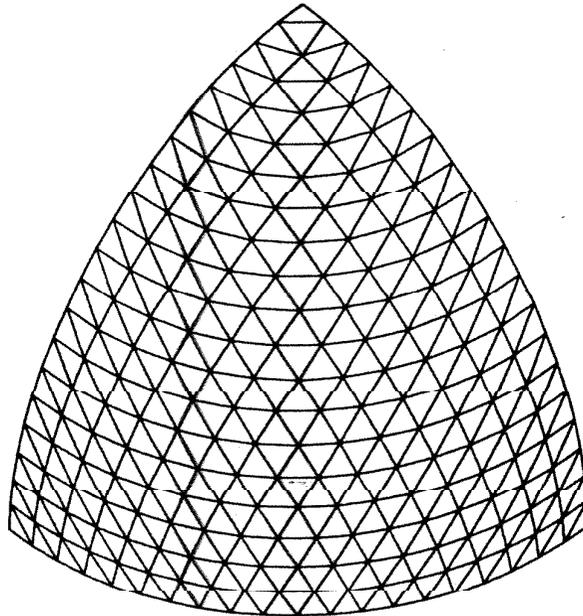


Figure 4 - Finite Element Model of One Octant of Spherical Shell

DISCUSSION

NASHUA is a very general capability built around NASTRAN for predicting the acoustic sound pressure field radiated or scattered by arbitrary three-dimensional elastic structures subjected to time-harmonic loads. Sufficient automation is provided so that, for many structures of practical interest, an existing NASTRAN structural model can be adapted for NASHUA acoustic analysis within a few hours.

One of the major benefits of having NASHUA linked with NASTRAN is the ability to integrate the acoustic analysis of a structure with other dynamic analyses. Thus the same finite element model can be used for modal analysis, frequency response analysis, linear shock analysis, and underwater acoustic analysis. In addition, many of the pre- and postprocessors developed for use with NASTRAN become available for NASHUA as well.

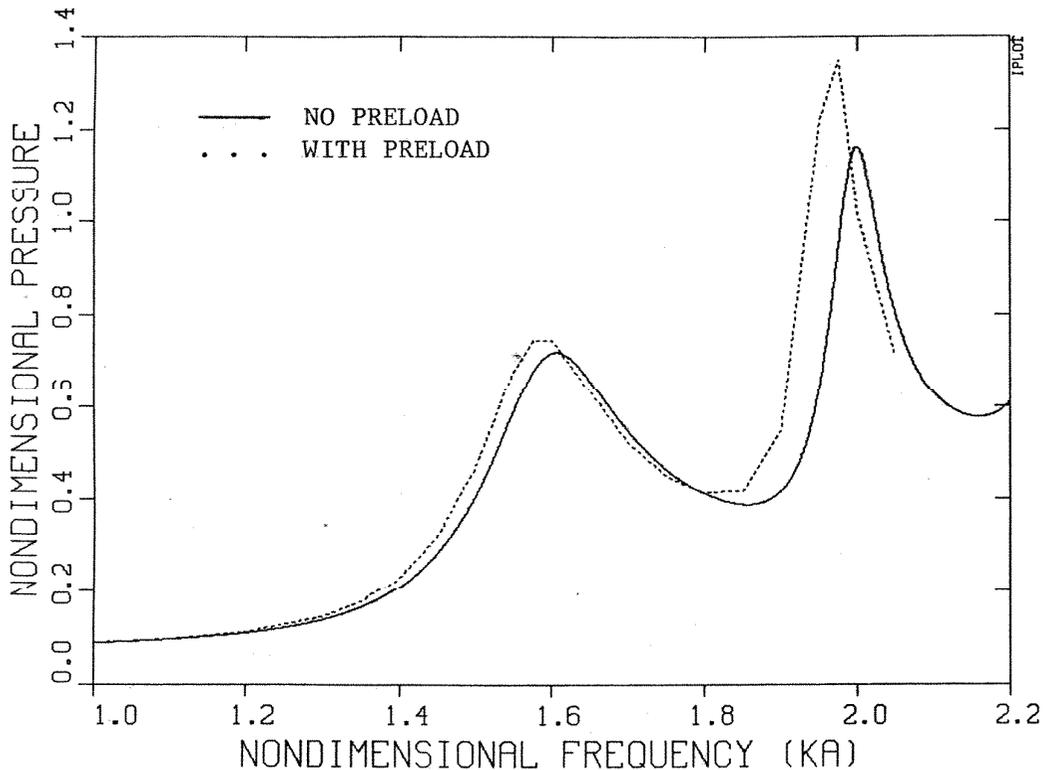


Figure 5 - Normalized Far-Field Pressure $|p_{rr}/p_{0a}|$ Radiated Outward Along the Polar Axis with and without a Hydrostatic Preload; Solid Curve Is Solution without Preload, and Dotted Curve Is Solution with Preload.

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