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STATIC ANALYSIS OF A SONAR DOME RUBBER WINDOW

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SUMMARY

The application of NASTRAN (level 16.0.1) to the static analysis of a sonar dome rubber window (SDRW) is demonstrated. The assessment of the conventional model (neglecting the enclosed fluid) for the stress analysis of the SDRW is made by comparing its results to those based on a sophisticated model (including the enclosed fluid). The fluid is modeled with isoparametric linear hexahedron elements with approximate material properties whose shear modulus is much smaller than its bulk modulus. The effect of the chosen material property for the fluid on the results obtained is also discussed.

INTRODUCTION

The SDRW (or window) of a ship (fig. 1) is a rubber composite structure. It is used for protecting the sonar device inside it and giving a small amount of the transmission loss to the acoustic wave. The rubber composite used for the SDRW has steel wires of cross-ply construction as its structural reinforcing members (fig. 2). The maximum amount of the reinforcements used in the window is subject to the specification of its acoustic performance requirement.

The internal pressurization of the window from its enclosed fluid (sea water) becomes necessary to generate its additional structural stiffness and rigidity. Designers prefer to have the internal pressure being greater than the external pressure induced from a ship's operation. However, the maximum allowable internal pressure depends on the amount of the steel wires used in the window. Under some severe loading conditions such as slamming and impact, external pressures on some areas of the window exceed its internal pressure. The enclosed fluid is, therefore, expected to play an important role on sustaining its structural integrity.

The conventional model, in which the enclosed fluid is not included, is adequate for analyzing the window of a ship under a normal operation. It does not give us satisfactory results as the window is subject to severe loads. So, more reliable results are only available for this severe loading situation, if a sophisticated model which includes the internal fluid of the window, is used. In this paper, simple models instead of complete and complicated models will be presented for demonstrating the application of NASTRAN to the static analysis of a SDRW.

CONVENTIONAL MODEL

The complete model for a type of a SDRW is shown in figure 3. This model is for a complete window structure which is attached to the ship structure. The enclosed fluid is not included in the model. It has been used for the preliminary evaluation on the structural integrity of the SDRW subject to various static loads. They are: hydrostatic forces, internal pressure, forces induced from the weight of the window, the enclosed fluid and other hardwares, steady state hydrodynamic forces, the equivalent static forces induced from the slamming and impact on the window, and the combinations of some loads as mentioned.

The window is modeled with quadrilateral and triangular plate elements (CQUAD2 and CTRIA2). Their anisotropic material properties (MAT2) are obtained based on the rubber composite theory (ref. 1 and 2). Some properties are obtained with the use of Halpin-Tsai equations (ref. 3). The appropriate boundary conditions are implemented with SPC or SPC1. The loads on the window can easily be input with GRAV, PLOAD2 and FORCE.

The results, obtained from the conventional model for the case of the window under normal operational loads, are satisfactory. However, excessive and unreasonable deformations compared to the observed are obtained if the window is under severe loads. Thus, the external loads on some areas of the window are greater than its internal loads. Its maximum displacements are greater than the thickness of the window. A better model is, therefore, required for obtaining more realistic solutions. After some consideration, a feasibility study of the model which includes the enclosed fluid, was made.

SOPHISTICATED MODEL

It was developed by adding isoparametric linear hexahedron elements (CIHEX1) for the enclosed fluid to the conventional model. These elements are considered as a special isotropic solid whose shear modulus being much smaller than its bulk modulus. Because of NASTRAN's limitation on MAT1, its approximate Poisson's ratio chosen to be very close to .5 (ref. 4) and Young's modulus, which is determined with the chosen Poisson's ratio and its exact bulk modulus, are used. The continuity of the translational displacements of the corresponding grid points at the fluid-structure interfaces are constrained with MPC. The fluid boundaries are constrained with SPC.

A demonstrated model has been developed for evaluating the feasibility of using a complete sophisticated model for the static analysis of the SDRW structure. This demonstrated model is shown in figure 4. Two loading cases on this model are considered in this paper. They are: (1) a uniform internal pressure, and (2) a combined load of an internal pressure and a non-uniform external pressure induced from the slamming.

SAMPLED PROBLEM

The simplified sophisticated model used for the demonstration of NASTRAN's capability on the SDRW analysis is shown in figure 4. Two circular arcs are for the window structure. Their dimensions are given in figure 4. The internal pressure is 22.4 (27.1 for the combined load case) N/cm^2. The maximum external pressure is 40.3 N/cm^2 exerting on one side of the window. The minimum thickness of the window model is 1.27 cm.

The results obtained from the sophisticated model will be compared to those from a simplified conventional model. They will also be compared to those from the same model with air as the enclosed fluid. The Young's modulus and the Poisson's ratio used for sea water is .1368 N/cm^2 and .4999999. Those for air is .844-4 N/cm^2 and .4999999.

RESULTS AND DISCUSSION

Only the critical results obtained will be discussed in this section. They are: displacements, reaction forces and moments, and membrane stresses (more important information than element stresses for designing rubber composite structures). The membrane stresses are obtained thru a post-processor excluding the bending stresses in element stresses. The effect of the approximate Poisson's ratio used for the fluid (sea water) on the results from the sophisticated model will also be discussed.

From the results given in table 1, we can find that the enclosed water, which has a relatively high compressibility, can sustain the window shape under the severe load. Due to the low compressibility of air, the window filled with air from the sophisticated model yields results about the same as those from the conventional one under both loading cases. As the window is under an internal pressure which gives a small deformation, the conventional model should be good enough for analyzing the window. Under the severe load, the sophisticated model should be used. Its enclosed fluid can: (1) decrease critical displacements, reaction forces and membrane stresses on the loading side and increase those on the non-loading side, (2) decrease critical reaction moments substantially on the loading side, (3) move the maximum displacement and membrane stress to the non-loading side of the window.

The effect of the approximate Poisson's ratio chosen for the enclosed fluid on the critical results are given in table 2. A small increment in the Poisson's ratio for sea water inside the window can: (1) increase critical displacements, (2) change reaction forces and moments negligibly, and (3) increase membrane stresses slightly.

FINAL REMARKS

NASTRAN has been used as a design/analysis tool for the SDRW. Satisfactory results can be obtained if a proper model is used. For time and cost-saving purposes, a conventional model which only includes the window structure can be used. If the displacements of the window exceeds its wall thickness, a sophisticated model which includes the enclosed fluid should be used for obtaining better solutions. The method as demonstrated in this paper gives us reasonably good results compaired to those from engineering experience. The approximate Poisson's ratio of the enclosed fluid is recommended to be .4999999. With this approach, a costly differential stiffness or other approaches may be avoided.

The method developed by Everstine et al. (ref. 5) has been considered. This method can assure the continuity of normal displacements and pressures at the interface of the window and the enclosed fluid from the structure and the fluid elements. The technique implementing this method for the titled subject is being developed.

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TABLE 1. CRITICAL RESULTS

Loading Cases	1	2	
Displacements (cm)			
A	.463	12.81	-13.38
B	.463	12.70	-13.27
C (loading side)	.446	.379	-.26
C (non-loading side)	.446	.605	
Reaction Forces (N) and Moments (N-cm)	(F)	(F)	(M)
A	2.22+4	1.35+4	2.97+5
B	2.22+4	1.35+4	2.95+5
C (loading side)	1.73+4	1.66+4	8.14+3
C (non-loading side)	1.73+4	2.26+4	2.81+3
Membrane Stresses (N/cm^2)			
A	2,454	1,344	
B	2,454	1,342	
C (loading side)	1,703	1,253	
C (non-loading side)	2,454	2,566	

where A is for the window model, B is for the window-air model, and C is for the window-sea water model.

TABLE 2. EFFECT OF POISSON'S RATIO ON CRITICAL RESULTS

Loading Cases	1	2
Displacements (cm)		
D	.376	.505
E	.432	.595
F	.446	.605
Reaction Forces (N)		
D	1.7 +4	2.24+4
E	1.71+4	2.24+4
F	1.73+4	2.26+4
Membrane Stresses (N/cm^2)		
D	1,642	2,419
E	1,673	2,534
F	1,703	2,566

where D, E and F are for Poisson's ratio being equal to .4999, .499999 and .999999 respectively.

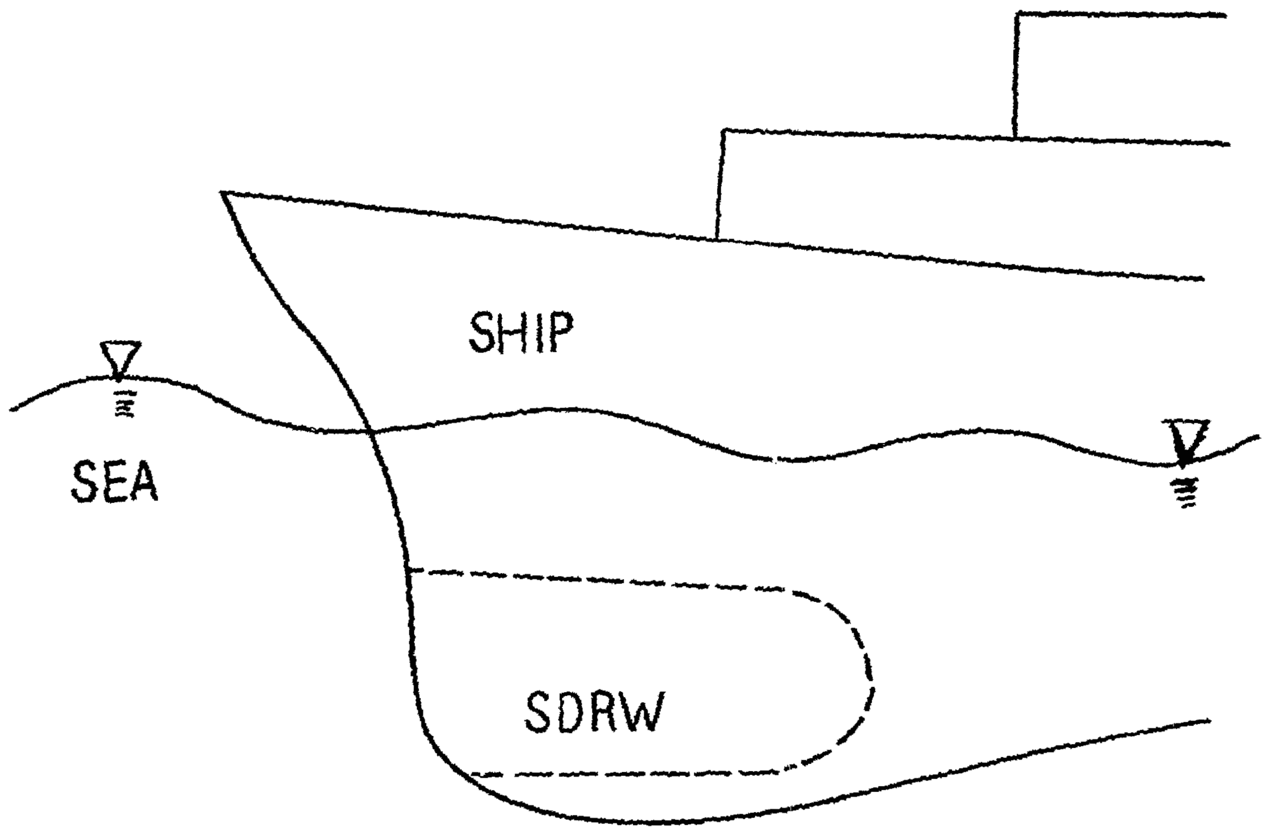

Figure 1. A Sonar Dome Rubber Window

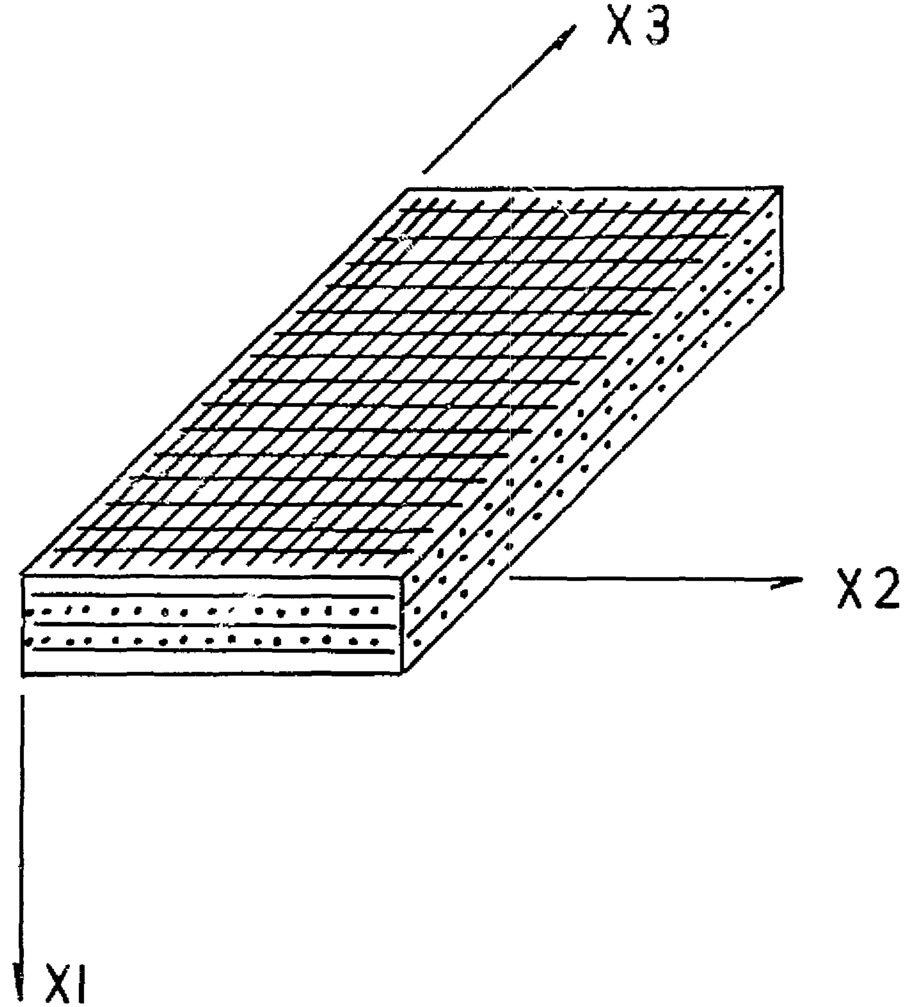

Figure 2. Cross-Ply Construction of Rubber Composite

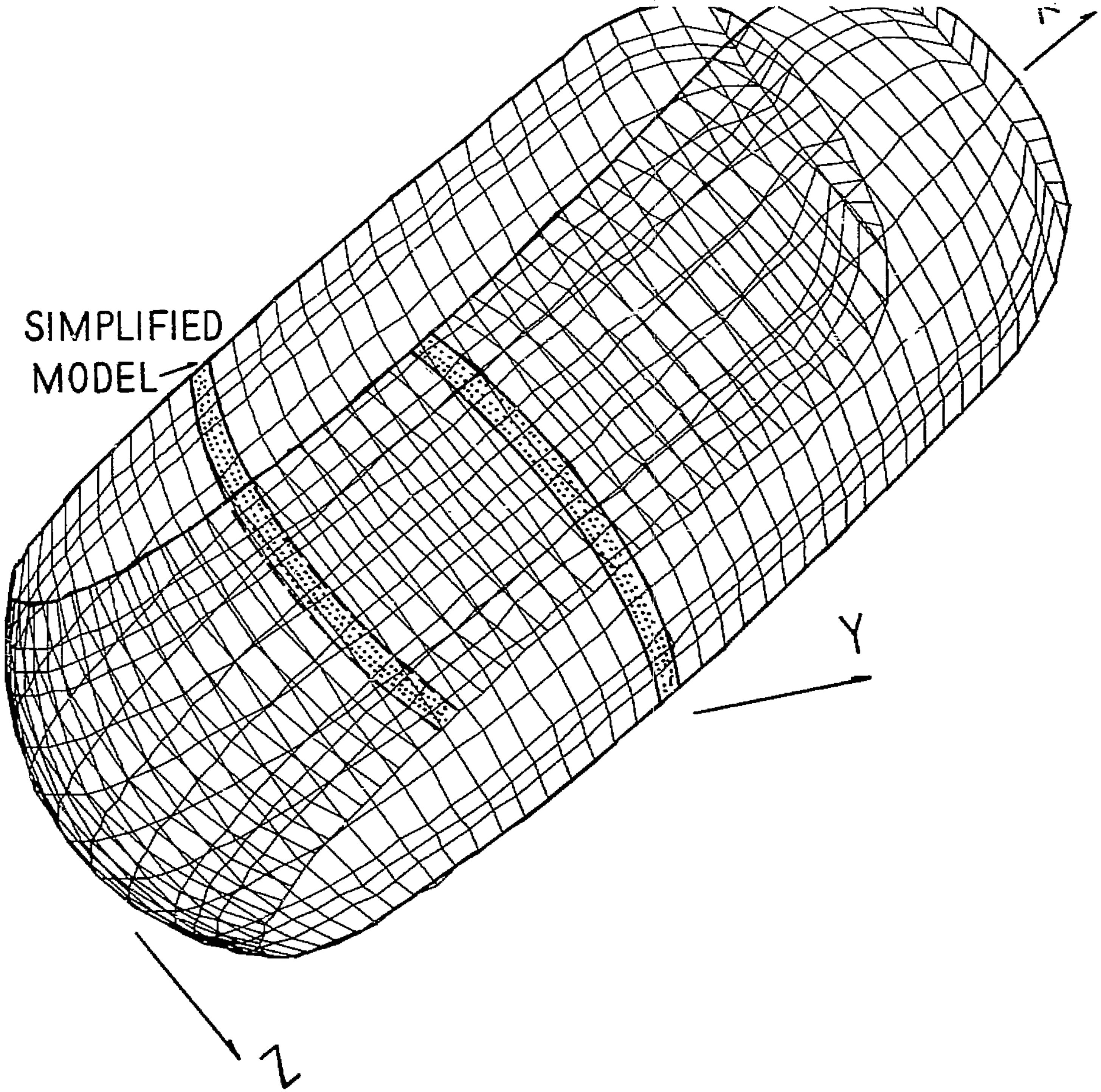

Figure 3. NASTRAN Model of A Sonar Dome Rubber Window

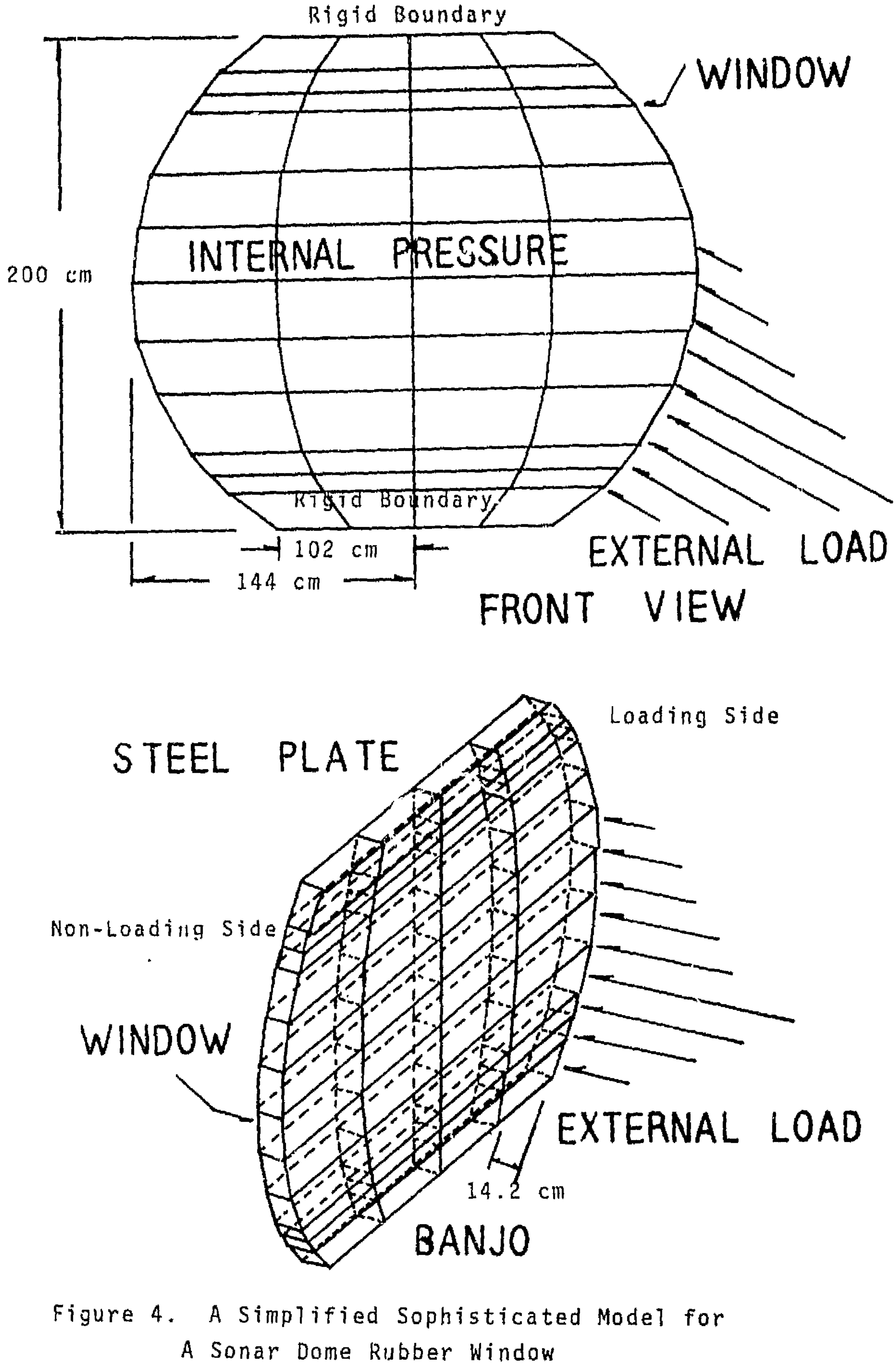

Figure 4. A Simplified Sophisticated Model for
A Sonar Dome Rubber Window

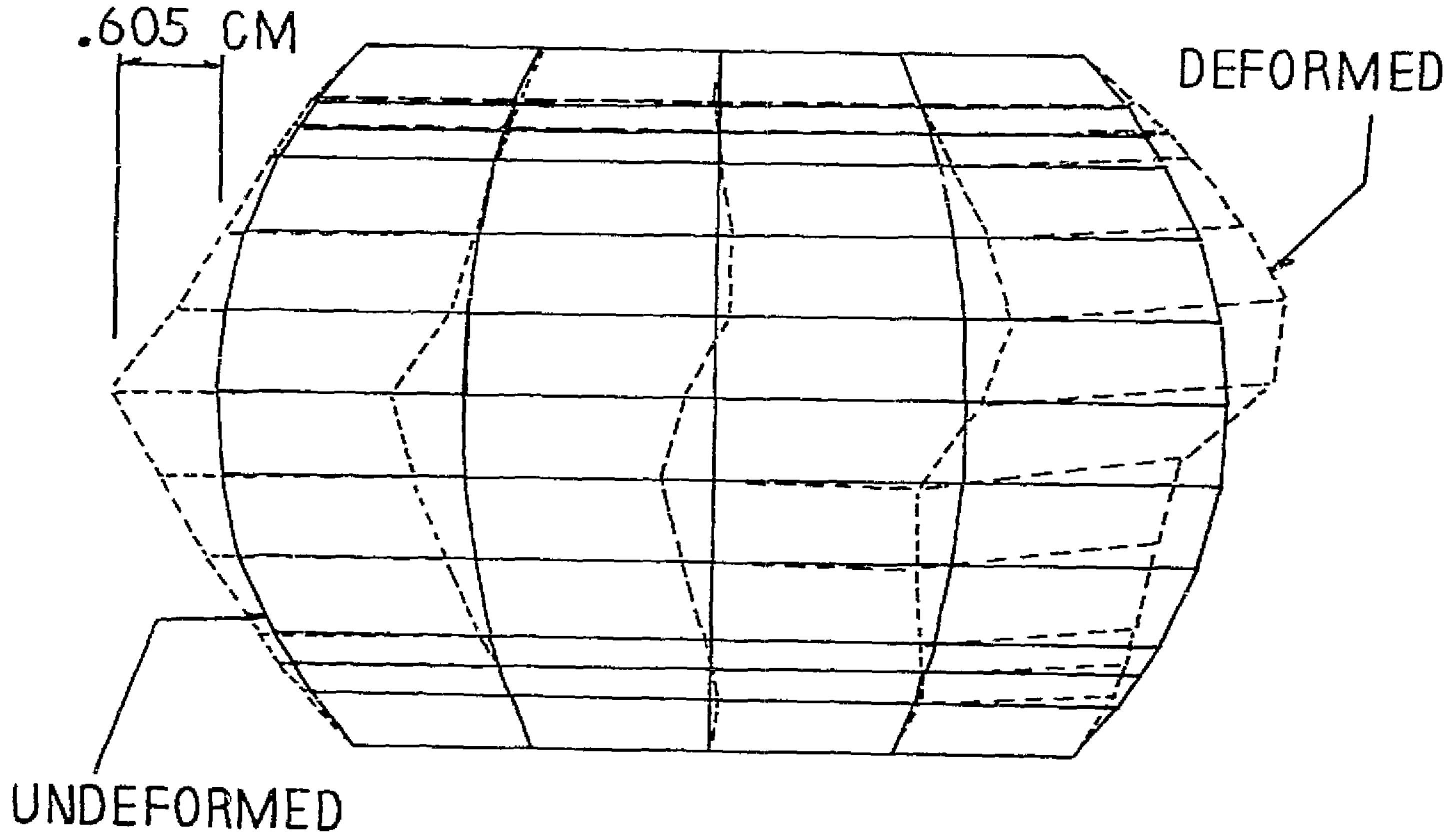

Figure 5. Deformed Shape of The Window Filled with Sea Water

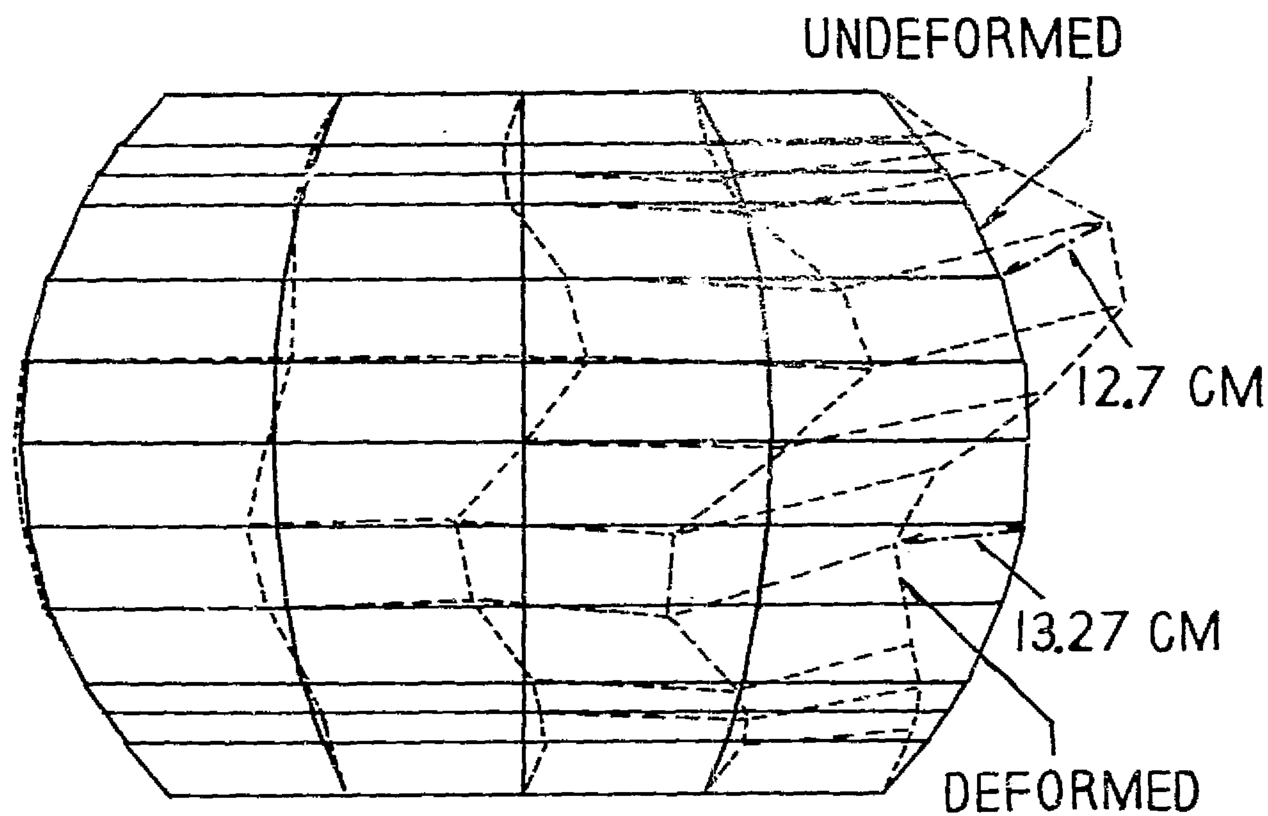

Figure 6. Deformed Shape of The Window Filled with Air