AD-A012 471

NEMO MODEL 2000 ACRYLIC PLASTIC SPHERICAL HULL FOR MANNED SUBMERSIBLE OPERATION AT DEPTHS TO 3000 FEET

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Naval Undersea Center
San Diego, California

December 1974

NUC TP 451

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by

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REPORT DOCUMENTATION PAGE

TP 451

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TP June 1972 to December 1974

CNM DLP

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San Diego, CA 92132

ZF-61-412-001

Office of Naval Research
Arlington, VA 22217

December 1974

198

Unclassified

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Plastics
Structural Engineering
Submarine Engineering
Acrylic Technology
Submersible Hulls
Acrylic Hull
Underwater Vehicles
Structural Materials
Transparent Materials
Pressure Hulls

Nemo Model 2000 acrylic plastic pressure hull assembly is described and represents the latest addition to the Nemo hull series represented by Nemo Model 600 and 1000 hull assemblies. The 66 inch OD × 58 inch ID spherical acrylic hull with aluminum hatches has successfully withstood 24 hour long external hydrostatic pressurizations to 450, 900, 1350 and 1800 psi. Pressure cycling and short term destructive testing of 15 inch OD × 13 inch ID scale models has shown that the crackfree fatigue life is in excess

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of 1000 pressure cycles at depths to 3000 feet and the short term implosion pressure is in the range of 10,000 to 11,000 feet. Stress wave emissions have been found to be a good indicator of incipient failure.

Nemo Model 2000 spherical pressure hulls with panoramic visibility are considered to be acceptable for manned submersibles with an operational depth capability to 3000 feet. The cyclic fatigue life of such hulls is conservatively predicted to be at least 12×10^6 feet hours.

SUMMARY

Problem

Manned submersibles with spherical acrylic plastic hulls have been known since the conception of the Nemo Hull in 1961 to provide greater panoramic vision at lower cost than steel hulls of the same shape and size equipped with many small portholes. To utilize this concept in Fleet design, the Nemo Hull was officially approved for minimum depth dives to 600 feet and demonstrated capabilities to 1000 feet in 1971. To further benefit Fleet operation, design and fabrication techniques were required to ameliorate fatigue factors inherent to structural joints between plastic and metal parts and thereby achieve the maximum operating depth allowed by the physical properties of acrylic plastic.

Results

Successive technological innovations have yielded three Nemo Hull designs that can be incorporated into existing or planned submersible systems for certified man-rated operation to ocean depths of 1000, 2000, and 3000 feet. New hatch design details have decreased bending moments at metallic hatch acrylic hull interface and the use of polycarbonate gaskets in the acrylic plastic hatch seat has eliminated shear cracking. The latest of the Nemo Hull series, Model 2000, has a 66-inch outside diameter and a 58-inch inside diameter that yields a fatigue life of 12,000,000 feet hours over a projected 10-year life span and is capable of operation to the maximum depth allowed by the properties of acrylic plastic.

Recommendations

The Model 2000 Nemo Hull is recommended for manned operation at depths to 3000 feet. This latest design can now provide the Navy with a transparent hull for a wide variety of applications in undersea warfare, search, salvage, surveillance, and recovery missions.

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DEFINITION OF TERMS

ASTM	American Society for Testing of Materials
critical pressure	external hydrostatic pressure at which catastrophic failure of the pressure hull takes place
ft	feet; equals 30.48 cm
hoop stress	principal membrane stress oriented at right angles to the longitudinal stress
ID	inside diameter of acrylic sphere
in	inches; equals 2.54 centimeters
longitudinal stress	principal membrane stress whose direction passes through poles of the sphere
NCEL	Naval Civil Engineering Laboratory, Port Hueneme, CA
Nemo Hull	Acrylic plastic hull with one atmosphere interior for manned submersibles with the following primary characteristics: (1) spherical shape (2) modular assembly of bonded pentagons (3) polar openings closed by inserts, a hatch at the top and a plate at the bottom (4) bearing surfaces on metallic hatch form a spherical angle whose apex is at the sphere
OD	outside diameter of acrylic sphere
PMR	Pacific Missile Range, Point Mugu, CA
psi	pounds per square inch; equals 0.070 kg/cm^2
R_i	inside diameter of acrylic sphere
R_o	outside diameter of acrylic sphere
short-term pressure	pressurization at 100 psi/minute rate
t	thickness of acrylic sphere

INTRODUCTION

The idea of transparent pressure hulls for manned submersible operation became a reality in 1968 with the successful fabrication of the first full scale Nemo Hull shown in Figure 1. Since then, acrylic plastic pressure hulls of spherical shape have demonstrated competitive cost, unsurpassed panoramic visibility, and a large depth safety margin, which has given the Navy a cost-effective solution to submersible hull design.

Testing and evaluation of models and full scale Nemo Hulls continued until in 1970 the Model 600 Nemo Hull was officially approved by the U. S. Navy for manned operation to 600 feet,[1] although it demonstrated capabilities to 1000 feet, as pictured in operation in Figure 2. At that time, Nemo's endurance range beyond the standard 1000-foot minimum was inhibited by stress limitations inherent to joints between the acrylic hull and metallic hatches.[2-5] Further design studies were initiated to relieve this fatigue factor and extend the depth limit of the Nemo Hull to the maximum allowed by physical properties of the material for future work in deep ocean environments.

Subsequent work efforts during 1971-1972 resulted in the Model 1000 Nemo Hull with an optimized aluminum hatch and aluminum seating ring assembly. This model has been designed and stress analyzed for safe operations to 2000 feet. Both Models 600 and 1000 Nemo Hulls are recommended as cost-effective transparent hulls for submersible operations to, respectively, 1000 and 2000 feet.

The apex of development for the Nemo Hull culminated in 1974 with the Model 2000, the presentation of which is the purpose of this report. The results of experimental and analytical studies are presented for this acrylic plastic pressure hull, which is capable of manned submersible operation at depths to 3000 feet for at least 1000 times without fatigue cracks. The Model 2000 Nemo Hull provides the maximum safe operational depth with minimum weight to displacement and cost depth ratios for use with manned submersibles in undersea warfare, search, salvage, surveillance and recovery missions to 3000 feet.

New design techniques and fabrication procedures are presented along with documented test results. The main body of the report is concise but terse to afford the reader a summary of study highlights. A more detailed description of design studies, fabrication procedures, and hydrostatic tests are presented in, respectively, Appendixes A, B, C, and D. The report documents a major breakthrough in technology for submersible hulls with panoramic visibility.

BACKGROUND

The failure of an acrylic plastic spherical Nemo Hull can occur in three ways. The hull can implode instantaneously because of overpressurization accompanying the catastrophic loss of the depth control system on a submersible; this type of failure is classified as *short term failure* and the pressure at which the failure occurs as short term critical pressure. The hull can also implode after it has been subjected for a long period of time to a depth, which is greater than the operational pressure, but less than the short term critical pressure. This type of failure is classified as *long term creep failure*. Finally, the failure of the hull can be initiated by cracks resulting from repeated dives to operational depth. this type of failure is classified as *fatigue failure*.

Previous experimental studies have already generated the data for prediction of short term and long term creep failures in Nemo Hulls with t/D_o ratios in the 0.015-0.017, 0.03, 0.047-0.05 and 0.064-0.067 ranges.[6] In conjunction with short term and long term implosion studies some data was also generated on the initiation of fatigue cracks in the acrylic bearing surfaces for metallic hatches on hulls with t/D_o ratios in the 0.03-0.035 range (references 2, 3, 4, 5). On the basis of that data it was concluded that for all practical applications in acrylic plastic Nemo Hulls the operational depth limitation is imposed primarily by the fatigue life of acrylic bearing surfaces supporting the metallic hatch. It is this fatigue life that imposes the 1000-foot operational depth limit on the 2.5-inch thick Model 600 Nemo Hull assembly and the 2000-foot limit on the nominally 4-inch thick Model 1000 Nemo Hull; the fatigue life being in both cases 1000 dives of 4 hour duration each to the maximum operational depth without initiation of fatigue cracks.

Since the short term collapse depth of the nominally 2.5-inch thick hull is 4150 feet and of the nominally 4-inch thick hull is 10,000 feet, there was no doubt that there existed a sufficient reservoir of potential structural strength to warrant research on improving the fatigue life of the haten/hull interface. The effort to improve the fatigue life of Nemo Hulls was focused primarily on the Model 1000 Nemo Hull with a nominal 4-inch wall thickness,[7] as the potential operational depth improvement appeared to be higher here than in the Model 600 Nemo Hull with a nominal 2.5-inch thickness.

DISCUSSION

The objective of the study was to maximize the operational depth of the 66-inch diameter Nemo Hull with a 4-inch nominal wall thickness and maintain the minimum 1000 cycle fatigue life requirement specified for all acrylic plastic hulls.[5,6]

The approach selected was to (1) redesign the top and bottom aluminum inserts, (2) redesign the interface between the insert and the hull, and (3) imprfove the fabrication process for the hull. All of the modifications to the Nemo Hull design were to be evaluated experimentally and analytically.

The scope was to limit the study to two acrylic hull sizes: the 66-inch diameter, 4-inch thick, full scale operational hull and the 15-inch diameter, 1-inch thick model scale hull. The cyclic fatigue tests and the short term implosion tests were performed on the 15-inch diameter model scale hulls while the experimental determination of stress distribution and comparison with analytical stress calculations were conducted on the 66-inch diameter full scale operational hull.

DESIGN OF POLAR INSERTS

Although the existing design for polar inserts in the 66-inch diameter, nominally 4-inch thick Model 1000 Nemo Hull incorporated on the JOHNSON SEA-LINK submersible[7] was satisfactorily tested to a prooftest of 2000 feet, without yielding and probably could be used to greater depths, it contained a large number of undesirably high stress concentrations and thus was considered questionable for 3000-foot service. For a minimal cost, these hatches were modified for safe operation to 3000 feet.

The redesign of existing aluminum polar inserts for the 66-inch diameter, 4-inch thick hull (currently in service with the JOHNSON SEA-LINK submersible; see Ref. 7) consisted of redistributing the metal in the hatch and penetration plate so that the resultant of compressive membrane stresses in the acrylic hull would pass as close as possible to the centroid of the insert and thus generate only moderate bending moments in the insert; see Figure 3. A more detailed description of system design including schematic drawings is presented in Appendix A.

The new hull assembly was stress analyzed utilizing the finite element stress analysis program for arbitrary axisymmetric structures, called ZP-13,[8] as illustrated in Figure 4.

For this program the top hatch was idealized into 244 nodes and 399 elements, as shown in Figure 5, while the bottom plate was idealized into 228 nodes and 367 elements, shown in Figure 6. The maximum stresses in the aluminum hatch and bottom plate were calculated to occur at the central penetrations and at the junctions between the spherical aluminum shells and the circular flanges (again see Figs. 5 and 6). The highest stress in the plastic hull was predicted to occur on the interior surface at the point of contact between the aluminum flanges and the polycarbonate gasket.

The magnitude of the peak principal stresses in the top and bottom aluminum inserts when operating at a depth of 3000 feet was predicted to be 24,250 and 25,400 psi, respectively (values derived from extrapolation of stresses shown in Figs. 5 and 6). In both cases the peak principal stresses were located on the inside of the central hatch penetrations. These peak compressive hoop stresses were not considered dangerous at that location since the steel bulkhead penetrators would serve as reinforcements and carry some of the compressive stresses. The stresses at the juncture between the spherical surfaces on the hatch and bottom plate and their flanges were also substantial (20,000–23,000 psi), but they were well below the yielding point of aluminum. From an extrapolation of the stress values shown in Figures 7 and 8, the maximum compressive stress in the plastic hull was predicted to be longitudinal and of 10,900 psi magnitude. These stress levels were considered acceptable for operation of the manned Model 2000 Nemo Hull submersible to 3000 feet since the associated calculated safety factors, based on yielding of the aluminum and acrylic plastic, were approximately 1.5 for both materials.

DESIGN OF INSERT/HULL INTERFACE

The insert/hull interface successfully utilized in existing acrylic plastic submersibles NEMO, MAKAKAI, and JOHNSON SEA-LINK #1, consisted of direct contact between the metallic insert flange and the acrylic plastic.[2,9–11] Since the orientation of the interface was radial, shear stresses were minimized. Still, because of differences in structural rigidity between the metallic inserts and the plastic hull, some differential movement between the inserts and the acrylic hull, as well as bending of the hull, takes place which causes shear cracks to appear in those areas of the acrylic plastic that come in contact with the metallic inserts.

There were two options available for elimination of the shear cracks. One feasible approach was to replace the metallic inserts with discs made of acrylic plastic with the same rigidity and compressibility as the plastic hull. The other approach was to place a compliant gasket between the rigid metallic insert and the limber plastic hull. Of these two approaches, the use of gaskets was operationally more appealing as it allowed the retention of operationally proven metallic inserts with the desirable high heat transfer coefficients. This left only the selection of the right type and thickness of gasket.

The gasket finally selected for the Model 2000 Nemo Hull assembly was one-inch thick polycarbonate plastic (see Fig. 3, Appendix A). Polycarbonate plastic was chosen because of its toughness, resistance to crack propagation, and modulus of elasticity that matches that of acrylic plastic. Because of the 1-inch wall thickness, the gasket possessed sufficient inherent structural strength to prevent it from being extruded into the hull interior by outside hydrostatic pressure. Also, the circumferential flange on the exterior edge of the gasket serves as a seal retainer, which keeps the water from entering the joint between the polycarbonate gasket and the acrylic plastic hull. The seal consisted of room temperature vulcanizing silicone rubber dispensed from a tube into the space between the gasket flange and the acrylic hull.

IMPROVEMENT OF FABRICATION PROCESS

The fabrication process[1,2] developed for the first acrylic plastic Nemo submersible[1] was also used in the fabrication of the acrylic plastic hulls for MAKAKAI[9] and the JOHNSON SEA-LINK[7] and focused primarily on the attainment of tight dimensional tolerances for the sphericity of the hull exterior. The variation in thickness of individual spherical pentagon modules remained a function of commercial casting tolerances for individual plates. Because of this dependency, the thickness of individual spherical pentagons varied as much as ±0.250 of an inch.

The large variation in thickness was acceptable so long as it was economically acceptable to rate the operational depth capability of a Nemo Hull on the basis of minimum hull thickness, and the mismatch in thickness between individual spherical pentagons was not considered optically objectionable. However, when emphasis was placed on cost effectiveness of the acrylic hull as a structure and as an optical system, it became economically untenable to tolerate such a large variation in wall thickness. The thicker portions of the hull would have constituted additional ballast that detracted from the payload and added nothing to the depth capability. In addition, the mismatches in thickness between individual spherical pentagons would have created a noticeable optical distortion for the crew of the vehicle.

Obviously, the key to uniformity of wall thickness was to use thick acrylic plastic spherical pentagons of uniform thickness in the construction of the hull. Basically, there were three techniques available for attainment of uniformly thick spherical pentagons: (1) custom casting of acrylic plates to very tight dimensional tolerances, (2) grinding off-the-shelf acrylic plates to a uniform thickness, and (3) grinding spherical sectors to uniform curvature and thickness after thermoforming of plates. Of these three techniques the last one was found to produce the smallest thickness variation at approximately the same or less cost than required by the other techniques. The tolerances on hull thickness attained by grinding of formed spherical sectors were ±0.050 inches.

FABRICATION

Full Scale Assembly

Acrylic Hull

The 66-inch OD × 58-inch ID Model 2000 acrylic plastic Nemo Hull (see Figs. 9 and 10) was fabricated by Swedlow, Inc., basically in the same manner as the previously built Nemo Hulls.[12,13] The only improvements over the previous fabrication technique were the contour grinding of formed spherical sectors and placement of adhesive into the joints between spherical pentagons by means of hydrostatic pressure. Fabrication techniques, dimensional drawings, and relevant contract correspondence are presented in Appendix B.

Acrylite® plates manufactured by Monsanto served as basic construction material. The stringent material quality control procedures developed by NCEL and PMR for the prototype Model 600 Nemo Hull were applied here also.[2] Testing of material specimens showed that the 4.125 nominally thick Acrylite met the physical properties criteria listed in Table 1, as established by the Navy for acrylic plastic windows and pressure hulls in manned service.[2-5]

Because of improved fabrication techniques, not as many dimensional tolerances were required in building the Model 2000 Nemo Hull as were required for the Model 1000 Nemo Hull fabricated for the JOHNSON SEA-LINK submersible.[7] Thus, whereas the Model 1000 Nemo Hull thickness varied from 3.844 to 4.030 inches, the Model 2000 Nemo Hull varied only from 4.000 to 4.100 inches. Similarly, whereas the sphericity of Model 1000 Nemo Hull varied from 66.250 to 65.800, the Model 2000 Nemo Hull varied only from 66.095 to 65.900 inches. Assembly dimensions for the Nemo Model 2000 are listed in Table 2.

The only area that did not realize a significant improvement in the fabrication process was the bonding of joints between individual pentagons. A comparison of the 5456 to 7804 psi bond strength achieved for the 4-inch thick Model 1000 Nemo Hull[7] with that of the 5123 to 9116 psi bond strength attained for the Model 2000 Nemo Hull indicates that the strength of bonded joints in both hulls is about the same. This holds true also for the quality of the joint. Both the number and size of inclusions was about the same as shown in Figure 11 a and b. This indicates that although the technique of emplacing the adhesive into the joint and the polymerization regimen have been drastically changed since the fabrication of the first Model 600 Nemo Hull in 1968[2] the performance of the bonded joint has not. Since the entire Nemo Hull is under compression when submerged to operational depth, very little incentive exists to effect further improvements in the tensile qualities of the joints.

Table 1. Physical Properties of Acrylic Plastic Hull for 66 Inch OD × 58 Inch ID Nemo Model 2000

	Minimum	*Average*	*Maximum*
1. Properties of Plastic*			
ASTM D-638			
Ultimate Tensile Strength, psi	9,545	10,972	12,331
Elongation, percent	3.0	5.291	7.0
Modulus of Elasticity, psi	428,000	465,583	505,000
ASTM D-790			
Ultimate Flexural, psi	15,238	17,736	18,686
Modulus of Elasticity, psi	415,000	463,125	487,000
ASTM D-732			
Ultimate Shear Strength, psi	9,880	10,088	11,500
ASTM D-695			
Compressive yield, psi	17,700	18,416	19,600
Compressive modulus, psi	500,000	520,416	570,000
ASTM D-621			
Deformation under load: 4000 psi, 122°F for 24 hours	0.42	0.55	0.72
2. Properties of bonded joints**			
ASTM D-638			
Ultimate tensile strength, psi	5,123	7,[illegible]15	9,116

*Total of 120 specimens taken from 12 acrylic plastic plates with 4.125 × 48 × 60 inches nominal dimensions.

**Total of 12 specimens taken from test blocks bonded for quality control purpose.

Table 2. Dimensions of the 66 Inch OD × 58 Inch ID Hull for Nemo Model 2000 Assembly

1. Individual Pentagons

	*Thickness**		*Contour Deviation***	
Pentagon	*Maximum*	*Minimum*	*Maximum*	*Minimum*
A	4.070	4.035	0.075	0.005
B	4.075	4.040	0.070	0.010
C	4.070	4.020	0.070	0.010
D	4.100	4.050	0.100	0.030
E	4.070	4.050	0.070	0.010
F	4.110	4.005	0.040	0.020
G	4.060	4.030	0.150	0.050
H	4.065	4.010	0.100	0.020
I	4.090	4.060	0.100	0.010
J	4.070	4.050	0.100	0.020
K	4.050	4.000	0.100	0.020
L	4.030	4.000	0.090	0.010

2. Sphere Assembly

Spherical Deviations	*Maximum*	*Minimum*
Total of 5 Measurements	0.100	+0.095

*Total of 6 measurements per pentagon
**Total of 5 measurements per pentagon

Metallic Polar Inserts

The top hatch, top hatch ring, and bottom plate for the 66-inch OD hull were fabricated by machining 6061-T6 aluminum forgings, as pictured in Figures 12a, b and 13a, b (also see Appendix B). Material quality control of the aluminum forgings indicated a compressive yield strength of 36,300 psi and ultimate compressive strength of 43,100 psi. Special attention was paid to the machining of beveled seal seating surfaces to assure positive sealing and good bearing contact.

Polycarbonate Bearing Gasket

The bearing gaskets shown in Figure 14 between the metallic polar inserts and acrylic plastic hull were machined from polycarbonate plastic plates. Material quality control of the polycarbonate plates used as machining stock showed that the material was acceptable for this application. The physical properties are summarized in Table 3.

Table 3. Physical Properties of Polycarbonate Plastic Gaskets for 66 Inch OD × 58 Inch ID of Nemo Model 2000

	Minimum	*Average*	*Maximum*
ASTM D-638			
Ultimate Tensile Strength, psi	6,640	7,170	7,690
Elongation, percent	2.3	2.6	2.8
Modulus of Elasticity, psi	320,000	320,000	320,000
ASTM D-790			
Ultimate Flexural, psi	11,700	11,900	12,000
ASTM D-732			
Ultimate shear strength, psi	10,400	10,400	10,400
ASTM D-695			
Compressive yield, psi	12,500	12,800	13,000
Compressive modulus, psi	360,000	370,000	380,000
ASTM D-621			
Deformation under load, percent 4000 psi, 122°F for 24 hours	0.12	0.13	0.14
ASTM D-256			
Izod impact strength	0.67	0.76	0.85
ASTM D-570			
Water absorption, percent 24 hours	0.14	0.15	0.15

Since a polycarbonate plate of 6-inch thickness is currently not fabricated by industry, several half-inch thick plates were bonded together to form a 6-inch thick block. Although the bonding was performed by General Electric, the developer of polycarbonate plastic, the quality and strength of the joints were less than of the parent material. Additional efforts by Southwest Research Institute (SWRI) were made to improve the bonding technique, although these too failed to yield perfect joints. However, in view of the fact that the gasket is in compression when incorporated into the Model 2000 Nemo Hull assembly, less than perfect bonded joints were considered as acceptable for compressive loading service.

Scale Model Assembly

Acrylic Hull

The 15-inch OD × 13-inch ID acrylic plastic hulls were fabricated by the Technical Support Department of the Pacific Missile Range; Figure 15 pictures one of these hulls. The same thermoforming, machining, and bonding techniques were used to fabricate this scale model as were used in the fabrication of prototype models developed for the Nemo research program in 1965.[2] Quality control of acrylic plastic and of bonded joints showed that the scale model materials met the same specifications as did the full scale 66-inch diameter hull. Four scale models have been fabricated.

Metallic Polar Inserts

The polar inserts for the 15-inch OD model scale hulls were fabricated by machining aluminum and titanium forgings (see Appendix A). The 6061-T6 aluminum inserts were structural scale models of the aluminum polar inserts in the 66-inch diameter hull; see Figures 16a, b and 17a, b. The Ti-6Al-4V titanium inserts shown in Figure 18a, b, c, d represented simplified scale models of an alternate design for the 66-inch OD hull polar inserts, except that titanium was utilized instead of aluminum.

Polycarbonate Bearing Gaskets

The polycarbonate bearing gaskets (see Appendix A) were machined from 1-inch thick polycarbonate plates (Lexan CP-438). Common machine shop practices were used to achieve the desired finish and tolerances.

TEST PROGRAM

Model Scale Hulls

Static Tests

One 15-inch OD × 13-inch ID scale model hull, shown in Figure 19, was subjected to a series of hydrostatic tests which culminated in the implosion of the hull. The objectives of the static tests were to (1) establish the validity of aluminum hatch design for ocean depth operation to 3000 feet, (2) measure the stress wave emissions of the acrylic hull, (3) measure the creep of the hull at depths to 3000 feet, and (4) determine the short term implosion depth of the Model 2000 Nemo Hull assembly. To accomplish these objectives the scale model of the Model 2000 Nemo Hull was instrumented with 10 electric resistance strain gages and an acoustic transducer with a 160 kHz response capability, as shown in Figure 20.

Static tests were conducted at a room temperature range between 70–75 °F in the pressure test facilities of the Southwest Research Institute, San Antonio, Texas.

1. Pressurize the 15-inch OD × 13-inch ID Nemo Model 34 to 1350 psi at 100 psi/minute rate, hold for 4 hours at that pressure, depressurize at 100 psi/minute rate to 0 psi, allow to relax for 4 hours prior to next test.
2. Pressurize the 15-inch OD × 13-inch ID Nemo Model 34 to 900 psi at 100 psi/minute rate, hold for 4 hours at that pressure, depressurize at 100 psi/minute rate to 0 psi, allow to relax for 4 hours prior to next test.
3. Pressurize the 15-inch OD × 13-inch ID Nemo Model 34 to implosion at 100 psi/minute rate.

Cyclic Tests

Three 15-inch OD × 13-inch ID Nemo Hull scale models were subjected to a series of pressure cycling tests. The objective of the pressure cycling tests was to establish (1) the fatigue life of bearing surfaces in acrylic plastic hulls that are in direct contact with metallic polar inserts and (2) the fatigue life of bearing surfaces in acrylic plastic hulls that are not in direct contact with the metallic polar inserts but interface through a polycarbonate bearing gasket; an assembly drawing of these contact points is shown in Figure 21. To achieve these objectives, the bearing surfaces of the acrylic hulls were to be inspected at the conclusion of the pressure cycle tests.

Pressure cycling of the scale model consisted of a series of tests conducted at a room temperature range between 70–75 °F in the pressure test facilities of the Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California, performed as follows.

1. Pressurize the 15-inch OD × 13-inch ID Nemo Model No. 35 to 500 psi at 100 psi/minute rate; hold at this pressure for 4 hours; depressurize at 100 psi/minute rate to zero and relax at that pressure for 4 hours before initiating the next pressure cycle. Repeat the pressure cycle 1000 times.

2. Pressurize the 15-inch OD × 13-inch ID Nemo Model No. 36 to 1000 psi at 100 psi/minute rate; hold at this pressure for 4 hours, depressurize at 100 psi/minute rate to zero and relax at that pressure for 4 hours before initiating the next pressure cycle. Repeat the pressure cycle 1000 times.

3. Pressurize the 15-inch OD × 13-inch ID Nemo Model No. 37 to 1500 psi at 100 psi/minute rate; hold at this pressure for 4 hours; depressurize at 100 psi/minute rate to zero and relax at this pressure for 4 hours before initiating the next pressure cycle. Repeat the pressure cycle 1000 times.

Full Scale Hull

Static Tests

The 66-inch OD × 58-inch ID full scale Model 2000 Nemo Hull assembly was subjected to a series of hydrostatic tests at SWRI, which culminated with a 4000-foot depth proof test; Figure 22 pictures the Model 2000 Nemo Hull with the SWRI pressure vessel. The objectives of the static tests were to (1) establish experimentally the strains and stresses imposed on the Model 2000 Nemo Hull assembly at a 3000-foot operational depth for comparison with the analytically generated data and (2) prove that the full scale Model 2000 Nemo Hull assembly could withstand pressures to a depth of 3000 feet without permanent deformation. To accomplish these objectives, strains were to be recorded during all of the tests at 20 locations; the location of the strain gages on the Model 2000 Nemo Hull is shown in Figure 23.

The static test series consisted of the following tests conducted at a room temperature which ranged between 65–75°F in the pressure test facilities of the Southwest Research Institute, San Antonio, Texas:

1. Pressurize to 450 psi at 100 psi/minute rate, hold at that pressure for 24 hours, depressurize to 0 psi at 100 psi/minute rate, and relax at that pressure for 24 hours prior to beginning of next test.

2. Pressurize to 900 psi at 100 psi/minute rate, hold at that pressure for 24 hours, depressurize to 0 psi at 100 psi/minute rate, and relax at that pressure for 24 hours prior to beginning of next test.

3. Pressurize to 1350 psi at 100 psi/minute rate, hold at that pressure for 24 hours, depressurize to 0 psi at 100 psi/minute rate, and relax at that pressure for 24 hours prior to beginning of next test.

4. Pressurize to 1800 psi at 100 psi/minute rate, hold at that pressure for 24 hours, depressurize to 0 psi at 100 psi/minute rate, and relax at that pressure for 24 hours prior to beginning of next test.

No cyclic tests were performed on the full scale Model 2000 Nemo Hull assembly.

TEST OBSERVATIONS

Model Scale Tests

Stresses

The 15-inch OD × 13-inch ID Nemo Model 34 assembly performed satisfactorily at simulated depths to 3000 feet. The highest measured principal stress of -5086 psi in the acrylic hull was on the interior, located at the edge of the top polar opening (0.500 inches away from aluminum hatch) and orientated along the meridian of the sphere; recorded stress values are listed in Table 4 (also see Figure 19). It is worth noting, however, that its magnitude was approximately only 10 percent larger than the average stress of -4642 psi measured at the equator on the interior of the sphere. This can be explained by the fact that the stress riser effect of the metallic insert decays rapidly with distance from the hatch. Since the strain gage was located approximately 3 degrees away from the edge it did not measure the peak stress but rather the tail end of it.

The maximum stress of -15,714 psi in the polar aluminum inserts was measured on the inside surface, adjacent to the flange, in the bottom plate, and its orientation was in the longitudinal direction.

The highest measured stresses, both on the acrylic hull and the aluminum inserts during the simulated dive to 3000 feet, were well below the yield points of their respective materials. All strains were observed to return to zero upon completion of the relaxation period following the simulated dive to 3000 feet (see Table 4). For both the acrylic plastic and aluminum, the apparent safety factors, based on the short term yielding of material, were well in excess of 2. On the basis of these stress measurements it was concluded that (1) the proposed design of hatches was adequate for dives to 3000 feet and that (2) the whole full scale Model 2000 Nemo Hull assembly could be safety tested at least at depths to 3000 feet.

Implosion Resistance

The 15-inch OD × 13-inch ID Model 34 Nemo Hull imploded under short term pressure loading at a simulated depth of 10,600 feet. The assembly failed by general plastic instability; the fragmented model is shown in Figure 24. The highest measured stresses in the aluminum hatches, prior to implosion, were found to be at locations #4 and #7 (see Figure 19), and their magnitude was in the -35,000 to -39,000 psi range, as shown in Figure 25. The 10,600-foot short term implosion depth of Model 34 gives the scale model a 3.5 safety margin for catastrophic dives. Data reduction of the hydrostatic tests is documented in Appendix C.

Acoustic Emission

The 15-inch OD × 13-inch ID Model 34 was a good source of acoustic emission during the first pressurization to 1350 psi; Figure 26 presented a histogram of stress wave

Table 4. Strains in 15 Inch OD × 13 Inch ID Nemo Model #34 during Simulated Dive at Depths to 3000 Feet

Gages			Strain micro inches/inch		Stress (psi)	
No.	*Location*		*Hoop*	*Longitudinal*	*Hoop*	*Longitudinal*
1a	Equator, outside	A	-5,900*	-5,700*	-3,345*	-3,284*
		B	-6,700	-6,300		
		C	0	-100		
1b	Equator, inside	A	-8,200*	-8,000*	-4,681*	-4,604*
		B	-9,550	-8,900		
		C	+10	+25		
2b	Edge of top polar opening, inside	A	-6,900*	-9,500*	-4,286*	-5,086*
		B	-7,700	-1,100		
		C	-50	-100		
3b	Lip of flange, bottom plate: inside	A	-900*	+150*	-9,386*	-1,319*
		B	-900	+150		
		C	0	0		
4a	Root of flange, bottom plate: outside	A	-275*	-50*	-3,187*	-1,456*
		B	-275	+100		
		C	0	0		
4b	Root of flange, bottom plate: inside	A	-600*	-1,250*	-10,714*	-15,714*
		B	-700	-1,350		
		C	0	0		
5a	Root flange, top hatch, outside	A	-100*	malfunc-	-1,099*	-330*
		B	-100	tioning		
		C	0	s. gage 0		
5b	Root of flange, top hatch, inside	A	-1,100*	-200*	-12,747*	-5,824*
		B	-1,100	-200		
		C	0	0		
6b	Edge of bottom, polar opening, inside	A	-8,300*	-6,900*	-4,558*	-4,127*
		B	-9,200	-7,800		
		C	0	+250		
7b	Lip of flange, top hatch, inside	A	-1,300*	+300*	-13,297*	-989*
		B	-1,300	+300		
		C	0	0		

Note A*. Immediately after pressurization to 3000 foot depth
B. After four (4) hours at 3000 foot depth
C. After 16 hours of relaxation at 0 depth

emissions. When, after relaxation at 0 psi, Model 34 was pressurized to 900 psi no further acoustic emission bursts were recorded which indicated that the acrylic hull exhibits a very marked Kaiser effect.

During the final pressure test to implosion, Model 34 emitted significant numbers of acoustic emissions, although only after the pressure passed the 9500-foot depth mark. Thus, between 0 and 9500 feet there were less than 50 emissions, as shown in Figure 27. Obviously then, the impending implosion of the acrylic hull could have been stopped during the simulated dive at about 500 feet above implosion depth on the basis of the acoustic emission recording (see Fig. 26).

Cyclic Fatigue Crazing

Observation of 15-inch OD × 13-inch ID Models 35, 36 and 37, after 1000 simulated 4-hour long dives, shown in Figure 28, revealed that only Model 37 which was pressure cycled to a depth of 3360 feet had slight indication of cyclic fatigue, whereas Models 35 and 36 which were pressure cycled to, respectively, 1120 and 2240 feet showed no signs of cyclic fatigue. The cyclic fatigue in Model 37 exhibited slight crazing of its conical bearing surface in the polar opening of the acrylic hull, which was exposed to direct contact with the metallic insert, see Figure 29. The other polar opening in Model 37, in which the acrylic bearing surface was not in direct contact with the metallic insert did not craze. From this, it can be concluded that at a cyclic history of less than 1000 dives the polycarbonate gasket has a significant effect only when the maximum pressure in a dive is 3360 feet or more. At lesser depths the polycarbonate gasket also increases the fatigue life of the acrylic hull, although more than 1000 dives are required to show experimentally the beneficial effect of the polycarbonate gasket.

It is important to point out here that even in Model 37 which was the only specimen with signs of cyclic fatigue on the acrylic bearing surface, the fatigue exhibited itself in the form of barely noticeable crazing. Based on past experience,[5] it can be conservatively predicted that it would take at least another 1000 dives to 3360 feet before the crazing would deteriorate into cracks 1/2-inch deep and thus require remachining of the bearing surface.

Creep

The creep observed during 4 hour sustained loading to 1350 psi was significantly higher than during sustained loading to 900 psi, as shown in Figures 30 and 31. The magnitude of creep in both cases was about 15 percent of short term strain. As expected (magnitude of creep is a function not only of time but also of short term strain), creep was more substantial at the edges of polar openings than at the equator. Similarly, it was larger on the interior of the hull than on its exterior.

The creep returned to zero after several hours of relaxation at zero pressure, indicating that the creep observed did not represent permanent deformation of plastic.

Full Scale Tests

General Performance

The 66-inch OD × 58-inch ID Nemo Model 2000 withstood successfully the four successive 24-hour hydrostatic pressure loadings to 450, 900, 1350 and 1800 psi without any appearance of cracks in the acrylic and only minor surface cracking in the polycarbonate plastic bearing surfaces at the polar openings.

Strains

The magnitude of strains observed during the 24-hour pressurization tests is shown in Figure 32; recorded stress values are listed in Table 5. Stress range was predicted by (1) the ZIP-13 finite element computer program and (2) strains generated during the hydrostatic testing of the 15-inch OD × 13-inch ID Model 34. The fact that the acrylic hull of Model 34 was approximately 10 percent thicker than required by the 1:4.4 scaling factor had to be taken into consideration during comparison of strains measured on the 15-inch and 66-inch diameter hulls.

The highest strains in acrylic plastic were measured on the interior of the hull at the edge of the top polar opening. The strains at the edge of the bottom polar opening were about 10 percent less, reflecting the fact that the bottom aluminum plate is significantly less stiff than the top hatch. The ratios between longitudinal and hoop strains at both locations were in the 3:1–4:1 range.

The interior longitudinal strain at the top polar opening was 100 percent greater than the interior longitudinal strain at the equator, while the interior hoop strain at the top polar opening was 50 percent less than the interior hoop strain at the equator. The exterior longitudinal strain at the top polar opening was only 20 percent greater than the exterior longitudinal strain at the equator, while the exterior hoop strain at the top polar opening was 70 percent less than the exterior hoop strain at the equator. On the aluminum polar inserts the highest strain was measured on the interior surfaces of (1) the bottom plate at location #6 in longitudinal direction and (2) the top plate at location #13 in longitudinal direction (see Fig. 23).

Magnitude of *Creep* at the equatorial surfaces of the hull was approximately the same as that recorded for Model 34. It was for all practical purposes absent during the 24 hour pressurizations to 450 and 900 psi, but it became noticeable (20–25 percent increase over short term strain) during 1350 psi pressurization and was significant (25–30 percent increase) during 1800 psi pressurization, as can be seen in Figure 32a through l. The numerical value of strains on the interior surface at the equator after 24 hours of sustained loading was in the 2500–3000, 5000–6000, 9000–11,000 and 13,000–15,000 micro inches inch range for, respectively, 450, 900, 1350 and 1800 psi pressurizations. (See Figs. 32i and 32j.)

The numerical values of creep on the interior hull surface at the edges of top and bottom penetrations were higher than at the equator, but in terms of short term strain percentage they were not different from those at the equator. After 24 hours of sustained loading the longitudinal strains at penetrations were in the 4000–4500, 8000–10,000, 15,000–19,000 and 22,000–27,000 micro inches inch range for, respectively, 450, 900, 1350 and 1800 psi

Table 5. Stresses in 66 Inch OD × 58 Inch ID Nemo Model 2000 Assembly During the 24 Hour Dive to a Depth of 3000 Feet

Gages		*Stress (psi)*	
Hull Location	***Orientation***	***Upon reaching 3000 feet***	***After 24 hours***
#1 Inside	Hoop	-4,986	Stresses cannot be calculated because of creep in acrylic
	Longitudinal	-7,914*	
#1 Outside	Hoop	-2,348	
	Longitudinal	-3,819	
#2 Inside	Hoop	-5,476	
	Longitudinal	-5,290	
#2 Outside	Hoop	-4,214	
	Longitudinal	-4,186	
#3 Inside	Hoop	-4,486	
	Longitudinal	-6,714	
#3 Outside	Hoop	-1,900	
	Longitudinal	-3,400	
#4 Inside	Hoop	-5,595	
	Longitudinal	-5,438	
#4 Outside	Hoop	-4,086	
	Longitudinal	-4,014	
#5 Inside	Hoop	-10,495	-9,396
	Longitudinal	-11,648	-11,319
#5 Outside	Hoop	-5,000	-4,835
	Longitudinal	-5,000	-4,451
#6 Inside	Hoop	-13,626	-13,956
	Longitudinal	-17,088**	-18,187**
#6 Outside	Hoop	-6,264	-5,549
	Longitudinal	-5,879	-5,165
#7 Inside	Hoop	-13,297	-12,967
	Longitudinal	-10,989	-9,890
#7 Outside	Hoop	-6,429	-6,429
	Longitudinal	-6,429	-6,429

*Highest stress in acrylic hull (during conversion of strains to stresses $E = 400{,}000$ psi and $\mu = 0.4$ were applied).

**Highest stress in polar aluminum inserts (during conversion of strains to stresses $E = 10{,}000{,}000$ psi and $\mu = 0.3$ were applied).

Table 5. (Continued).

Gages			Stress (psi)	
Hull Location		*Orientation*	*Upon reaching 3000 feet*	*After 24 hours*
#8	Inside	Hoop	-13,022	-13,187
		Longitudinal	-3,407	-3,956
	Outside	Hoop	-3,516	-2,967
		Longitudinal	-55	+110
#9	Inside	Hoop	-10,549	-9,341
		Longitudinal	-15,165	-12,802
	Outside	Hoop	-4,780	-4,780
		Longitudinal	-5,934	-5,934
#10	Inside	Hoop	-10,549	-9,835
		Longitudinal	-10,165	-9,451
	Outside	Hoop	-4,670	-4,670
		Longitudinal	-3,901	-3,901
#11	Inside	Hoop	-10,165	-9,066
		Longitudinal	-10,549	-10,220
	Outside	Hoop	-3,736	-3,736
		Longitudinal	-4,121	-4,121
#12	Inside	Hoop	-11,429	-11,429
		Longitudinal	-11,429	-11,429
	Outside	Hoop	-3,956	-3,956
		Longitudinal	-3,187	-3,187
#13	Inside	Hoop	-11,758	-13,352
		Longitudinal	-12,527	-14,505
	Outside	Hoop	-3,956	-6,813
		Longitudinal	-3,187	-6,044
#14	Inside	Hoop	-12,692	-14,286
		Longitudinal	-12,308	-14,286
	Outside	Hoop	-4,670	-7,527
		Longitudinal	-3,901	-6,758

pressurizations (see Figs. 32b and 32d). Strains in acrylic returned essentially to zero after a 24-hour period of relaxation indicating that the creep in acrylic was not of a permanent nature even after the 24 hour sustained loading to 1800 psi hydrostatic pressure.

Stresses

The *maximum stress* measured on the *acrylic hull* (see Table 5) at the beginning of 24 hour pressurizations was −2339, −5043, −7914 and −10,962 psi at, respectively, 450, 900, 1350 and 1800 psi pressure loadings. The maximum stress, analyzed as typical for Nemo hulls,[14] is located on the interior surface of the hull at the edge of top polar opening and was oriented in the longitudinal direction. The stress on the interior equatorial surface was measured simultaneously as −1804, −3610, −5595 and −7757 psi. The magnitude of stress on the acrylic hull at the conclusion of the 24 hour pressurization periods is not known since there was considerable creep in the plastic which would make any classical stress calculations inaccurate.

The *maximum stress* on the aluminum inserts was measured on the interior of the bottom plate at location No. 6 in the longitudinal direction. The magnitude of the stress at the beginning of 24 hour pressurizations was −4967, −9890, −17,088 and −21,044 psi at, respectively 450, 900, 1350 and 1800 psi loadings. At the conclusion of the 24-hour pressurization periods the magnitude of the stress had changed to −3198, −9890, −18,187 and −18,846 psi, respectively. After the 24-hour relaxation periods following pressurizations to 450, 900 and 1350 psi, all stresses in aluminum returned essentially to zero, as listed in Table 6. A different case presented itself at the conclusion of the relaxation period following the 24-hour pressurization to 1800 psi. Here the stresses at interior location Nos. 6, 13 and 14 on aluminum inserts not only failed to return to zero (see Table 6) but showed residual positive stresses of significant magnitude, and the reasons for their presence are not known. A more detailed listing of stresses is presented in Appendix C.

The *comparison* of stresses calculated on the basis of experimental data and the ZIP-13 finite element computer program show good agreement for all locations on the acrylic hull. For locations on aluminum inserts the agreement is not as good. It appears that for the locations on the exterior of aluminum inserts the calculated stresses are generally lower than measured values, whereas for locations on the interior of the inserts the calculated values are generally higher. However, since the highest stresses measured on aluminum inserts were on the interior surface, the calculated values tend to be conservative in nature and, thus, useful in the design of pressurized Nemo Hulls. A complete listing of computer generated strains and stresses for the Model 2000 Nemo Hull assembly is presented in Appendix D.

Table 6. Residual Strains in Aluminum Plates and Hatches of the 66 Inch OD x 58 Inch ID Nemo Model 2000 after Repeated 24 Hour Long Pressurizations

		Gage Locations					
		No. 6 Inside		*No. 13 Inside*		*No. 14 Inside*	
Test		*Hoop*	*Longitudinal*	*Hoop*	*Longitudinal*	*Hoop*	*Longitudinal*
450 psi	A	-240	-380	-190	-200	-250	-140
	B	-170	-240	-120	-140	-250	-140
	C	+120	+150	+100	+110	+10	+80
	D	+160	+180	+130	+210	+80	+60
900 psi	A	-500	-750	-450	-500	-500	-500
	B	-500	-750	-450	-500	-500	-500
	C	0	+100	+50	+0	+50	0
	D	+50	+150	+100	+0	+100	50
1350 psi	A	-850	-1300	-800	-900	-900	-850
	B	-850	-1400	-900	-1050	-1000	-1000
	C	0	0	+0	-100	-100	-150
	D	0	0	+0	-150	-200	-200
1800 psi	A	-1050	-1400	-1000	-1150	-1150	-1100
	B	-1050	-1400	-850	-1050	-1050	-1000
	C	+50	+300*	+200*	+100*	+50*	+500*
	D	-50	+2350*	+1450*	+1350*	+1350*	+1250*

A Immediately after pressurization
B After 24 hours of sustained pressurization
C Immediately after pressure release
D After 24 hours of relaxation
* Questionable values, probably generated by malfunctioning bulkhead penetrators for instrumentation in Model 2000 Nemo Hull, or pressure vessel end closure.

TEST DATA DISCUSSION

Determination of Safe Operational Depth

In order for the chosen operational depth to be safe, many operational as well as hull performance parameters, must be considered and carefully calculated.

Hull Performance Parameters

The *short term critical pressure* at which catastrophic implosion of the hull occurs in an uncontrolled dive is the best known and easiest to obtain performance parameter of an acrylic hull. The short term critical pressure represents the ultimate depth beyond which a submersible cannot descend at any time. For the Model 2000 Nemo Hull the short term critical pressure has been experimentally established at approximately 10,000 feet. The actual short term implosion test was performed on the 15-inch Model 34, which imploded at 4700 psi external hydrostatic pressure. Since the scale model is about ten percent thicker than required, the extrapolated short term implosion pressure for the full scale Model 2000 Nemo Hull is around 4000 psi if the same pressurization procedure is used as for the scale model. However, since the pressurization schedule for Model 34 did not correspond to the typical 100 psi minute short term pressurization rate for acrylic hulls[2] (recording of strain data at 4500 and 4700 psi pressure levels delayed the pressurization by 5 minutes), the extrapolated short term collapse pressure for the Model 2000 Nemo Hull must be increased from 4000 psi to at least 4500. (Reference 6 indicates that the effect of delay in pressurization at pressures above 4500 psi is to reduce the short term implosion pressure of acrylic hull by about 100 psi for every minute of delay.) The 10,000-feet short term implosion depth gives the Model 2000 Nemo Hull the ability to bounce dive once under extreme emergency conditions probably to at least 8000 feet.

The *long term critical pressure of acrylic hulls* has been previously established[6] as a function of time and temperature. Because 100 hours is considered the maximum length of time that the crew of a submersible could survive under entrapment without new air support supplies, this time span will be used to establish a long term critical pressure. This pressure can be readily determined from a plot of experimental data generated by implosions of 15-inch OD × 13-inch ID Models 22, 23, 24, 25 and 34 as illustrated in Figure 33.[6] From the plot one can see that the implosion pressure of a scale model Nemo Hull under 2700 psi sustained loading at 70–75°F at ambient temperatures occurs after 100 hours. After application the 0.86 correction factor (based on plastic instability, takes into account the ten percent thicker hull of scale models), the projected 100 hour long term critical pressure of the Model 2000 Nemo Hull is 2320 psi in the 70–75°F ambient temperature range. In terms of depth it can then be stated that the Model 2000 Nemo Hull must be trapped for at least 100 hours at a depth of about 5000 feet before catastrophic failure occurs.

The *cyclic fatigue life* of acrylic hulls has been the subject of several studies since, as a rule, it is the determining factor in setting the safe operational depth of an acrylic hull. Since the cyclic fatigue life is not only a function of maximum pressure in the pressure cycle but also of duration and temperature, they all must be taken into consideration. Study of typical dive profiles for submersibles has established the fact that a submersible does not stay at maximum operational depth longer than 4 hours. The rest of the typical dive is taken up by launching, descent, ascent, docking and retrieval. The temperature can vary widely during a dive but at operational depths it is usually below 50 degrees. Since pressure cycling at 70-75°F is not only more conservative, but also more economical, it was used to establish the cyclic fatigue life of the Model 2000 Nemo Hull.

The testing of 15-inch Models 35, 36 and 37 has conclusively shown that crazing appears in the acrylic hull at the polar openings without the polycarbonate gasket only after 1000 pressure cycles of 8-hour duration (4 hours loading followed by 4-hours relaxation) to 1500 psi. No crazing was observed in the polar opening of the acrylic hull protected by the polycarbonate gasket. Judging by these results the minimum crack-free fatigue life of the 15-inch OD × 13-inch ID Models is 1000 cycles to a maximum operational depth of 3350 feet. Based on the scale model data, the 60-inch OD × 58-inch ID Model 2000 Nemo Hull can perform 1000 dives to 3000 feet without initiation of cracks in the acrylic hull.

Operational Performance Parameters

In view of the fact that preservation of the crew is the major consideration in the design of pressure hulls it is considered mandatory that the short-term and long-term critical pressures be beyond the depth to which the submersible may be accidentally submerged. Furthermore, it is considered reasonable and customary that the implosion depth for a long term (no more than 100 hours) disabled submersible be at least 50 percent greater than the maximum operational depth (safety factor of 1.5). For a short term loss of control, the implosion depth should be at least 100 percent greater than the maximum operational depths (safety factor of 2).

In addition to preserving the crew there are also the economics of the hull life to be considered. If the fatigue life was set at 100 dives it would prove economically unsound since it would allow the submersibles to operate only for a period of time less than two years, although at greater depths. Similarly, if the fatigue life was stipulated as 10,000 cycles it would give the submersible unlimited life but at the cost of very shallow operational depth, which would significantly lower its operational usefulness. It is the author's opinion that a specified crack-free fatigue life of 1000 cycles represents a sound economical compromise between the operational depth and life of the submersible. For the full scale Model 2000 Nemo Hull the crack-free fatigue life has been experimentally established as 1000 dives to a maximum operational depth of 3000 feet. Since the 3000-foot fatigue life depth is based on 4-hour long simulated dives, there is no need to apply any pressure cycle duration discounting factor to the experimentally established fatigue life depth of 3000 feet.

Based on the factors discussed above, the maximum operational depths should not exceed 4000 feet (8000 feet 2) for short term disablement criterion, 3330 feet (5000 feet 1.5) for long term disablement criterion, and 3000 feet (3000 feet 1) for the fatigue life criterion. Since it is the least permissible operational depth, based on any of the above three criteria, that determines the actual depth rating of the hull, fatigue becomes the determining factor for establishing the operation depth rating of the Model 2000 Nemo Hull. As a result 3000 feet is considered as the maximum operational depth rating for the Model 2000 Nemo Hull.

FINDINGS

1. The 66-inch OD × 58-inch ID spherical capsule assembly, Model 2000 Nemo Hull, fabricated from commercial grade (Plexiglas G or equivalent) acrylic plastic and equipped with polycarbonate gaskets between aluminum hatches and the acrylic plastic will withstand a minimum of 1000 dives (4 hours at maximum depth, followed by 4 hours at the surface) from 0 to 3000 feet without initiation of cracks in the acrylic hull.

2. At the safe maximum operational depth of 3000 feet the maximum compressive stresses in aluminum hatches and acrylic plastic hull are only equal to 49 and 52 percent of, respectively, aluminum and acrylic plastic yield strengths.

3. Model 2000 Nemo capsule assembly will w...stand accidental disablement at a depth of 5000 feet for at least 100 hours before catastrophic failure occurs. At greater depths the grace period prior to catastrophic failure is significantly shorter, as shown in Figure 33.

4. Model 2000 Nemo capsule assembly will withstand a temporary loss of control to a depth of 8000 feet for about 10 minutes before catastrophic failure occurs.

5. Model 2000 Nemo capsule assembly is an active acoustic stress wave emitter whose rate of acoustic emissions increases significantly just prior to short term implosion.

6. Permanent deformation of aluminum inserts (top hatch and bottom plate) takes place in areas of high stress concentrations when Model 2000 Nemo Hull is subjected to dives of 4000 feet.

7. Long term submersion of 24-hour duration, to 4000-foot depth, does not generate any cracks in the acrylic plastic hull or polycarbonate gaskets at the polar openings and the strains in acrylic plastic after a 24 hour relaxation period at atmospheric pressure retu..n essentially to zero.

CONCLUSION

Spherical acrylic plastic hulls of Nemo Hull design with a $t/r_o = 0.123$ thickness can be man-rated for a minimum of 1000 operational dives to a maximum operational depth of 3000 feet.

OPERATIONAL RECOMMENDATIONS

1. The Model 2000 Nemo capsule assembly should, during its operational life, never be subjected to depths greater than 3300 feet. The proof test should preferably utilize a test depth of 3300 feet. Under no conditions should the magnitude of proof-test depth exceed 3600 feet unless stronger polar inserts are substituted for the standard Model 2000 Nemo Hull aluminum inserts.

2. The cyclic crack free fatigue life of the Model 2000 Nemo Hull should be *conservatively* considered to be in excess of 12,000,000-feet-hours (1000 cycles × 3000 foot depth × 4 hours duty). At the conclusion of each dive, the recorded feet-hours should be subtracted from the initial 12,000,000-feet-hour fatigue life. When the sum of feet hour subtotals generated by dives equals 12,000,000-feet-hours, inserts and gaskets should be removed from the capsule and the entire hull subjected to a detailed visual examination.

If no cracks are observed at the penetrations in the hull, the capsule should be strain gaged, reassembled, prooftested to 3300 feet and resulting strains compared to those generated during the first proof test conducted immediately after fabrication of the capsule. Significant differences in strain behavior will be considered important evidence of hull deterioration and should result in significantly reduced depth rating. Cracks in bonded joints originating at inclusions will be repaired if their length exceeds 0.5 inches. Cracked polycarbonate gaskets should be replaced with new gaskets.

If no significant difference in strain behavior is observed, the capsule assembly will be returned to service with a 3000 foot operational depth rating and an additional 12,000,000-foot-hour fatigue life. When the 12,000,000-foot-hour life is used up the capsule assembly will be subjected to the same inspection and prooftesting procedures conducted at conclusion of the first 12,000,000-foot-hour period. If the results of the new inspection and prooftesting are satisfactory, the capsule will again return to service with a 3,000-foot depth rating and additional 12,000,000-foot-hour life.

The recertification process will be repeated until either cracks are observed in the bearing surfaces of acrylic hull during one of the inspections or the strains change significantly. If cracks are observed they will either be repaired by routing and recasting with resin prior to retesting of the hull, or they will be left in place and the hull's depth rating will be reduced to 600 feet.

Subsequently, the hull will be inspected without disassembly for signs of crack propagation every 100 dives. When the depth of any crack exceeds 1 inch, as pictured in Figure 34, the capsule will be taken out of service immediately and the cracks repaired either by enlarging the polar opening or by recasting cracked areas. If not repaired, such a hull can be recertified for service to 120 feet. If, during periodic inspections conducted every 100 dives, the depth of the crack at the penetration is found to exceed 2 inches the acrylic hull will either be repaired or declared unfit for manned operation at any depth.

3. Attempts should be made to ensure that operators be seated inside the Nemo Hull as close as possible to the center of the sphere in order to minimize optical distortion.[15] Camera mounting should be located at the center of the hull if wide angle panning with the camera is to be performed during the mission.

Objects in hydrospace will appear smaller and closer to the hull than they are in reality.[15] Some experience on the part of the crew will be required to judge the distances correctly between the hull and the objects in hydrospace.

4. Many functions of the equipment mounted externally to the submersible can be controlled by modulated light beams projected from the interior of the hull by the crew.[16] This type of arrangement will eliminate many electrical penetrators in the bottom plate and make the control of externally stored scientific equipment an operationally easy matter.

Figure 1. Acrylic plastic hull with the typical Nemo polar penetrations, metallic hatches, and spherical pentagon modular construction.

Figure 2. Nemo submersible, approved in 1970 by the U. S. Navy for manned operations to 600 feet.

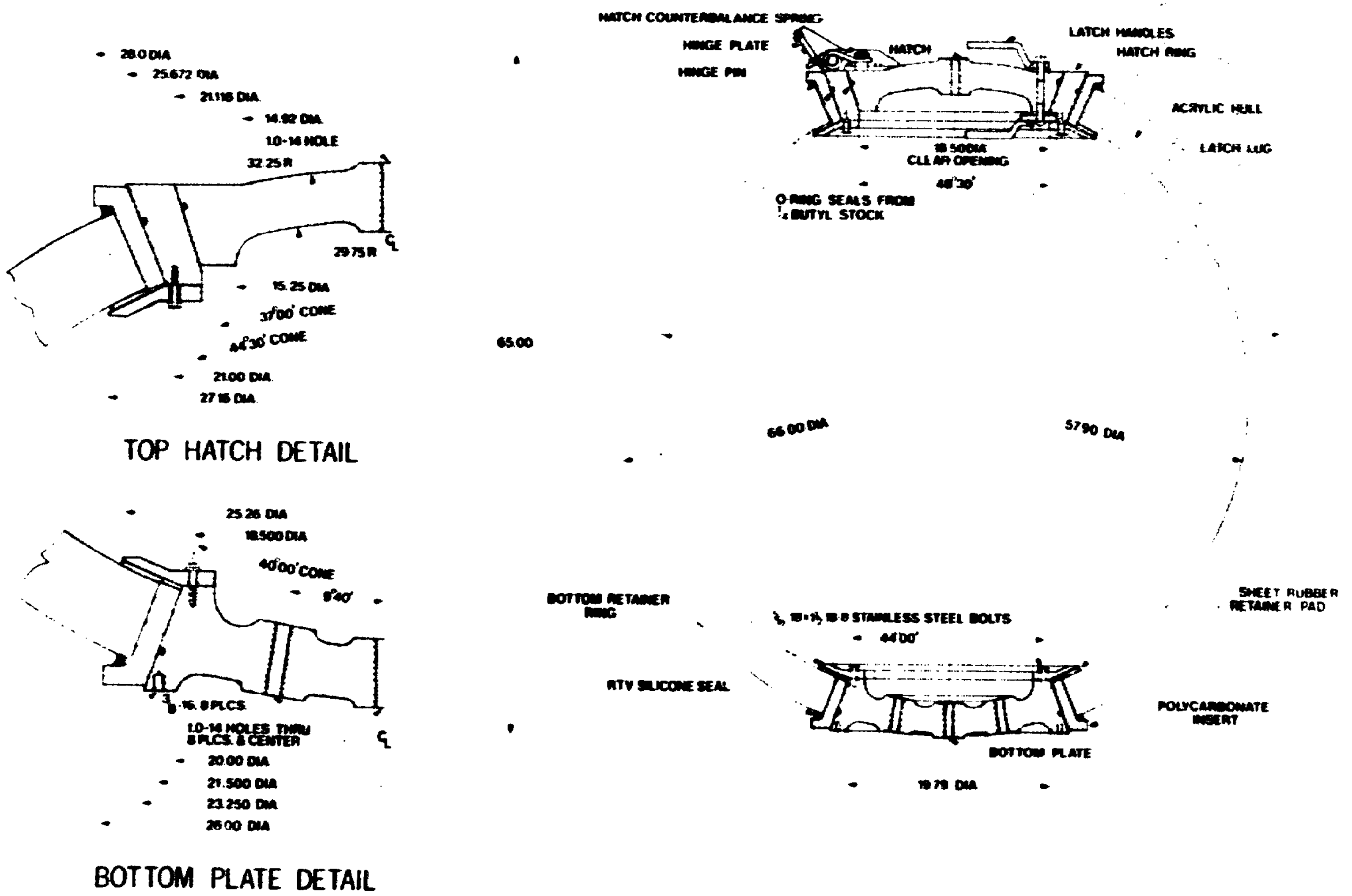


Figure 3. Schematic of the Model 2000 Nemo Hull.

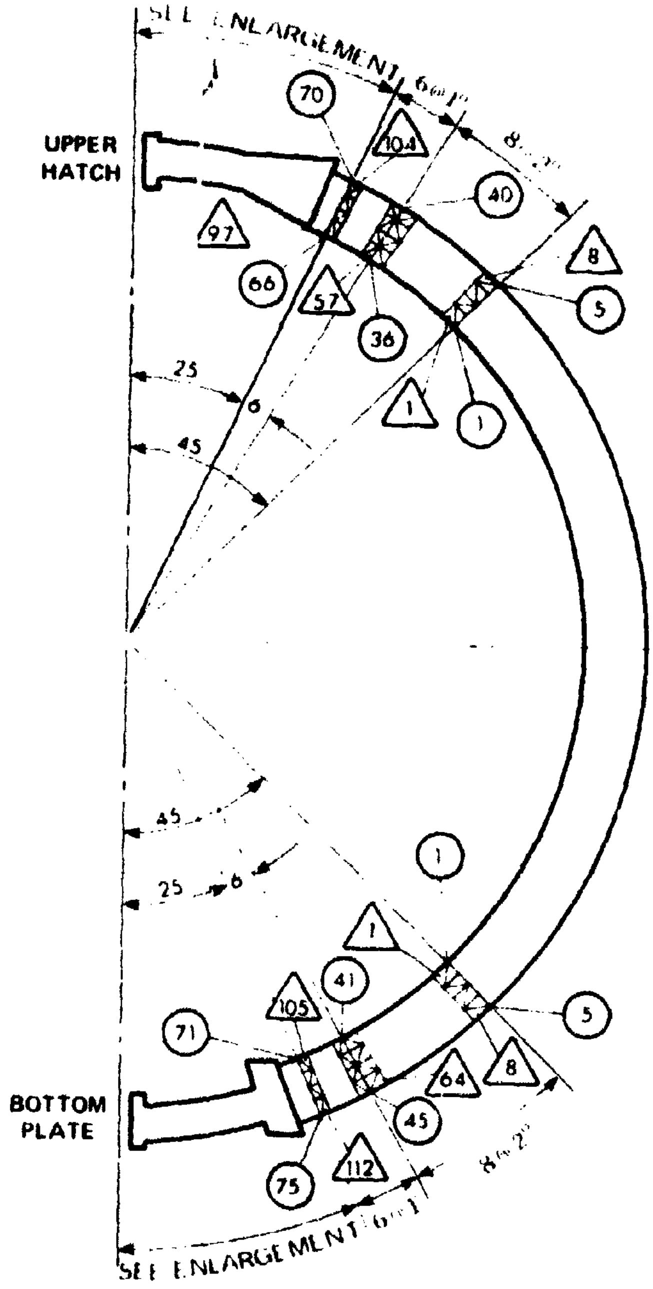


Figure 4 Idealized shape of the Model 2000 Nemo Hull assembly used in the ZP 13 finite element stress analysis.

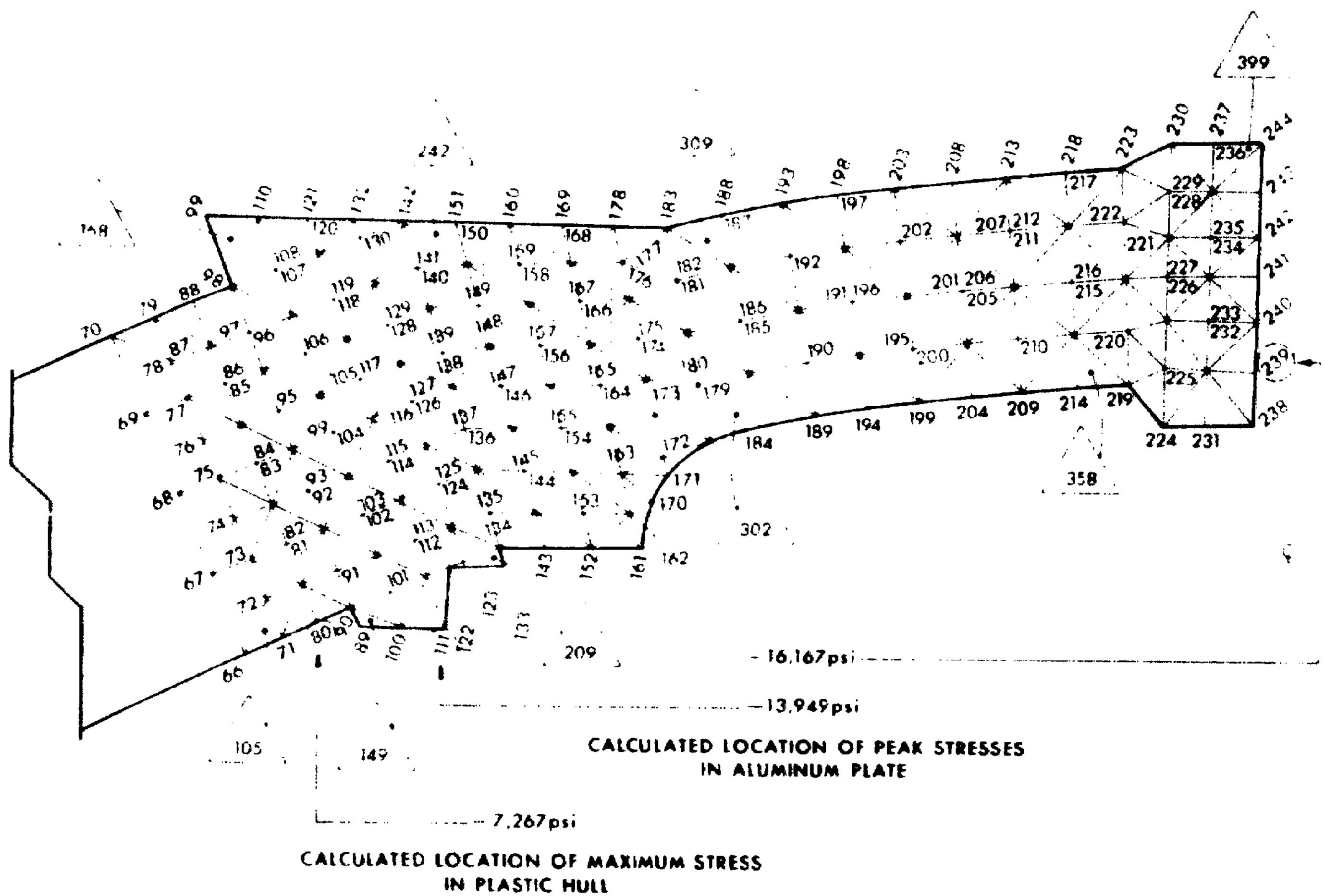


Figure 5. Idealized shape of the top hatch used in the ZP 13 finite element stress analysis of the Model 2000 Nemo Hull under simulated 900 psi external hydrostatic pressure.

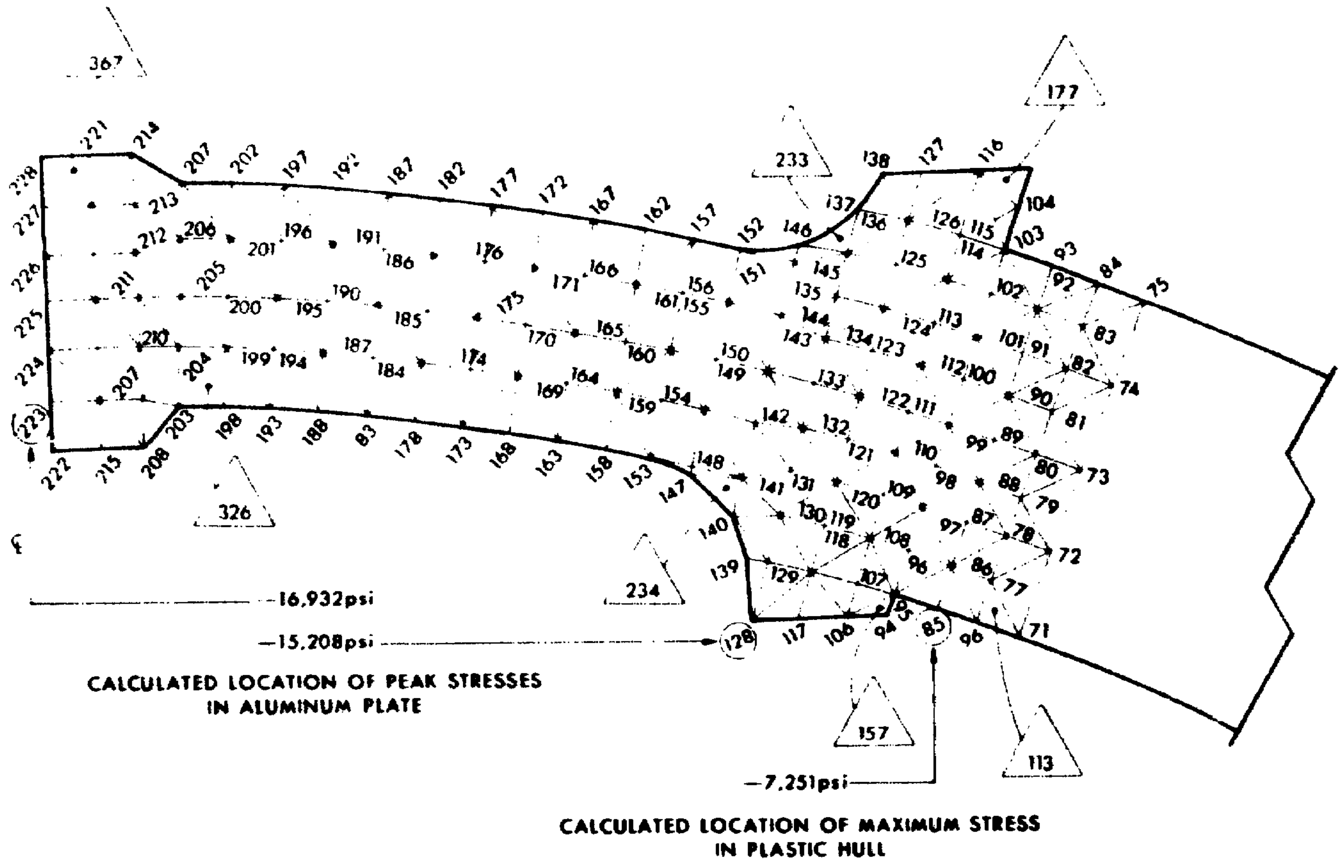


Figure 6. Idealized shape of the bottom plate used in the ZP 13 finite element stress analysis of the Model 2000 Nemo Hull under simulated 900 psi external hydrostatic pressure.

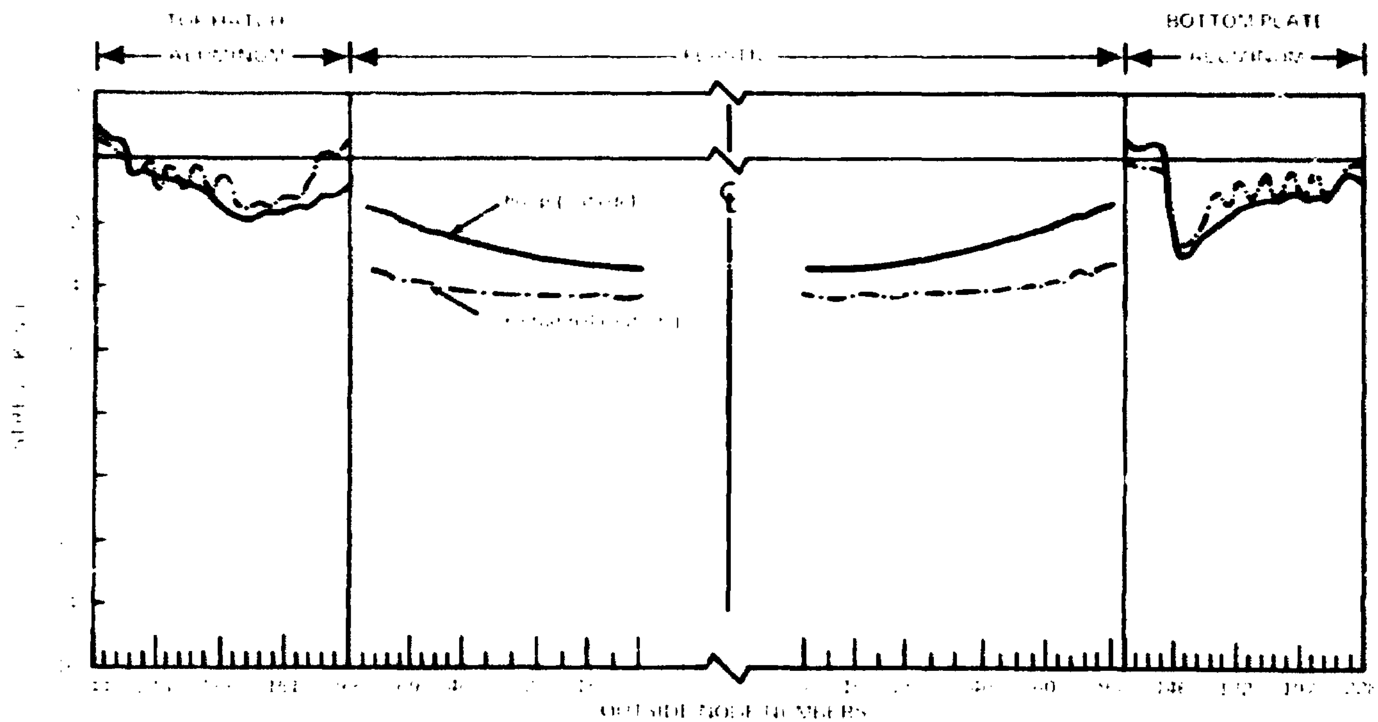


Figure 7. Calculated stress distribution in the Model 2000 Nemo Hull assembly under simulated 900 psi external hydrostatic pressure, outside surface.

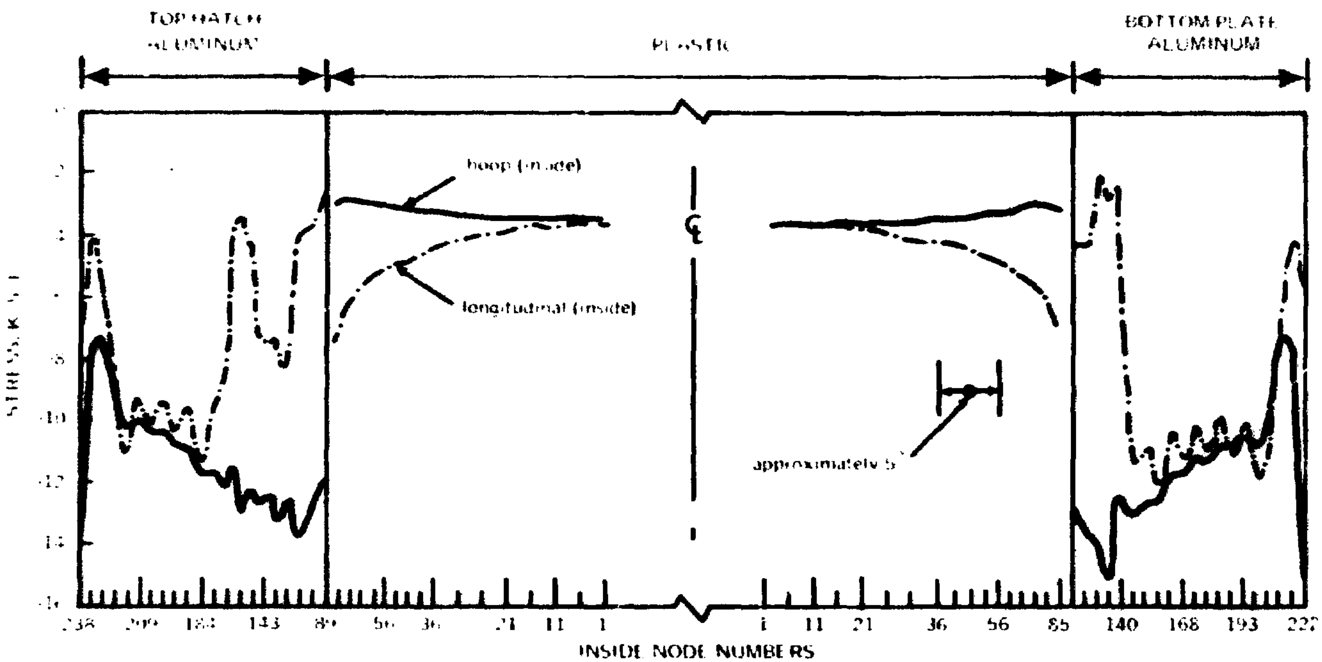


Figure 8. Calculated stress distribution in the Model 2060 Nemo Hull assembly under simulated 900 psi external hydrostatic pressure: inside surface.

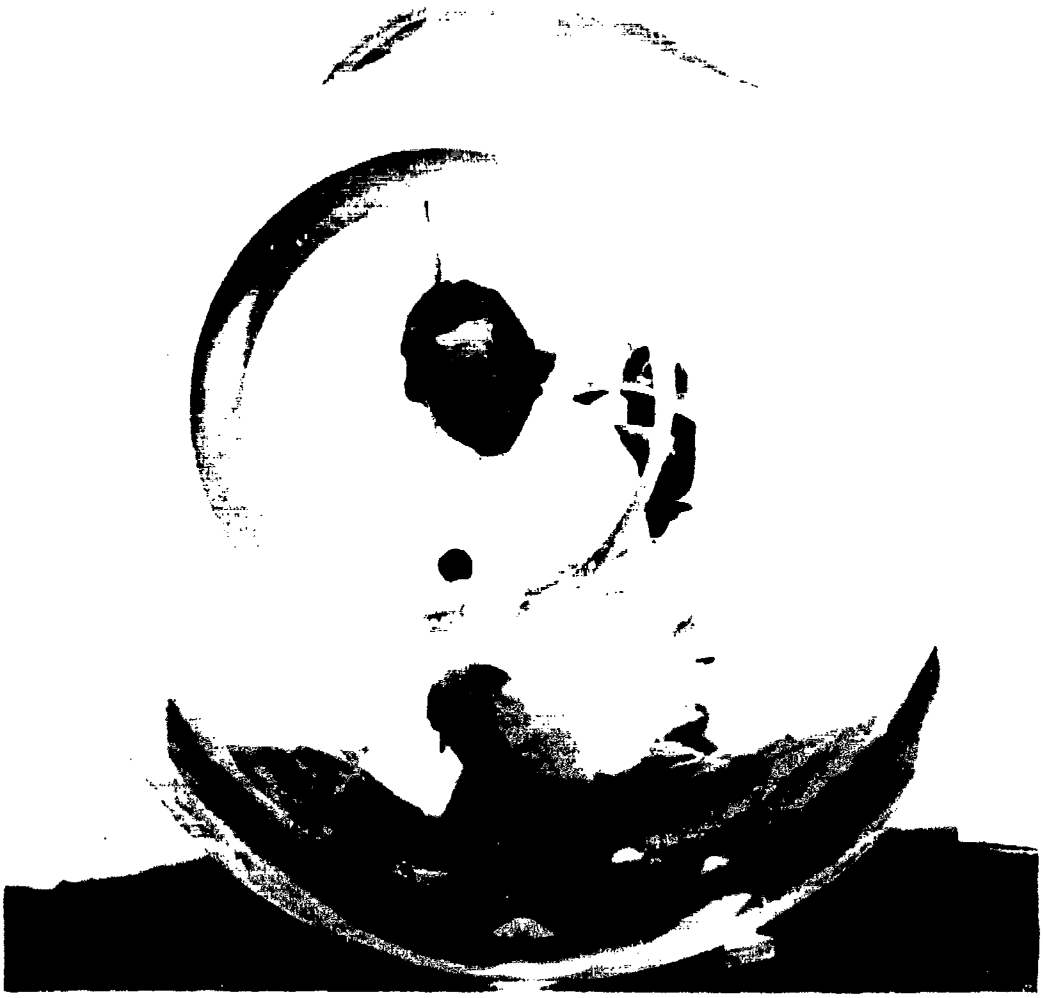


Figure 9. Assembled Model 2000 Nemo Hull undergoing final polishing.

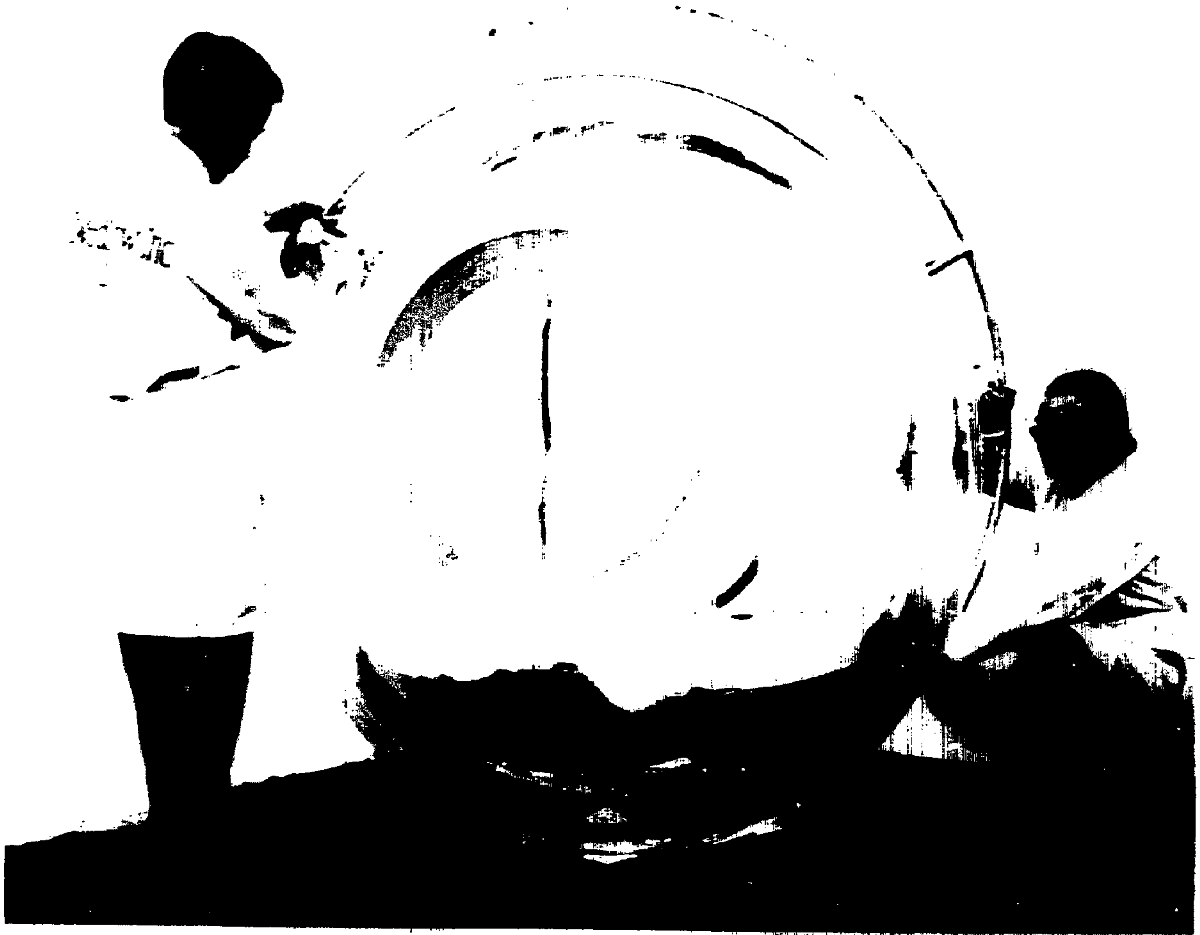
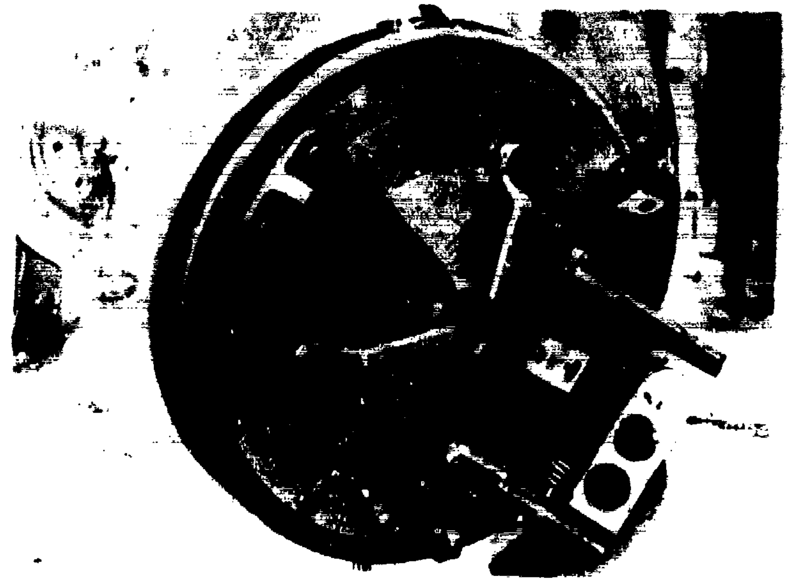
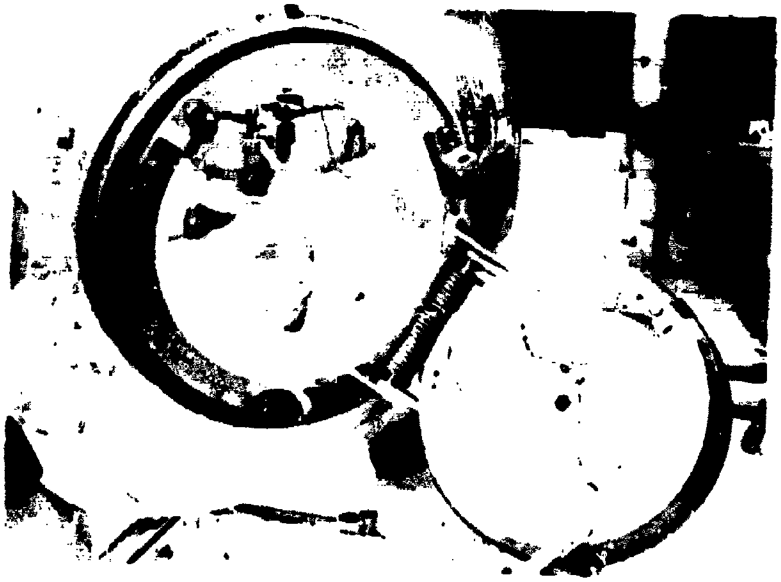


Figure 10   Inspection of Model 2000 Nemo Hull for out-of-roundness at Swedlow Inc.

Figure 11. Typical bonded joint between spherical pentagons.



(a) outside view



(b) inside view

Figure 12. Aluminum hatch for Model 2000 Nemo Hull.

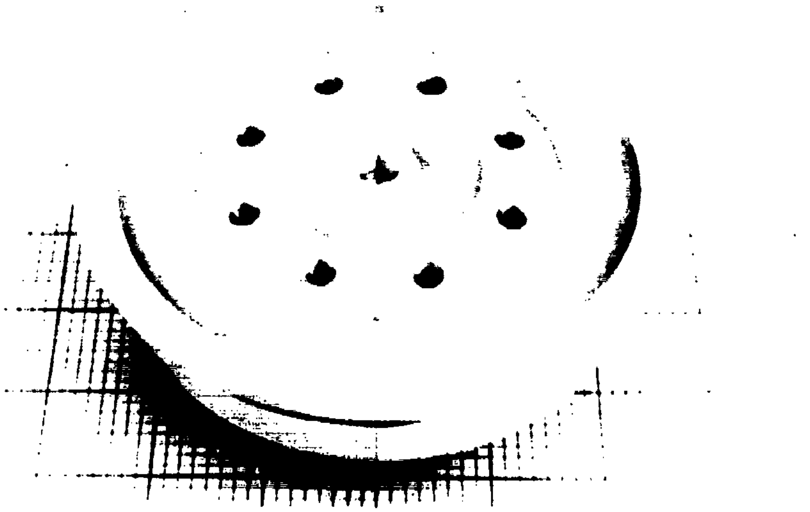
(a) outside view

(b) inside view

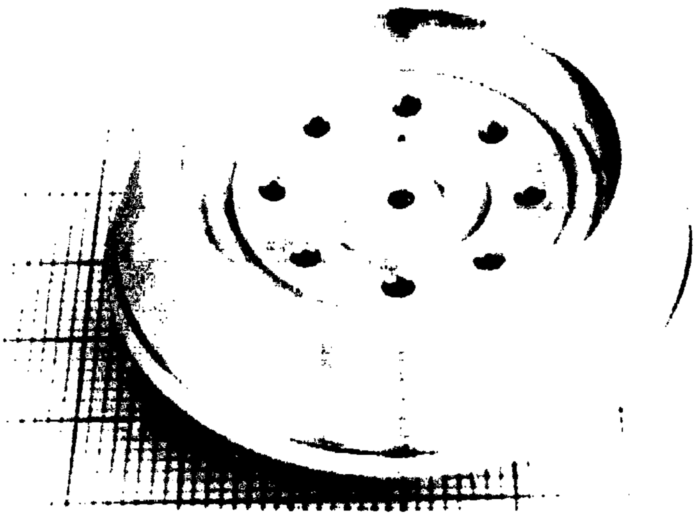
Figure 13. Aluminum bottom plate for Model 2000 Nemo Hull.

Figure 14. Bearing gasket for polar openings in the hull fabricated from polycarbonate plastic plates.

Figure 15. 15 inch OD X 13 inch ID Model 34 serving as scale model of the Model 2000 Nemo Hull assembly.



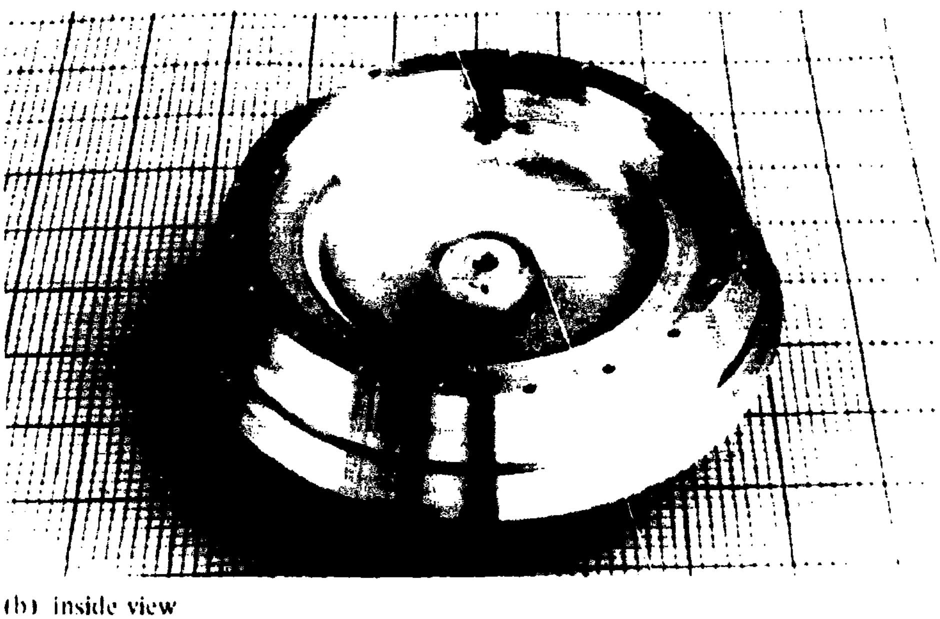
(a) outside view



(b) inside view

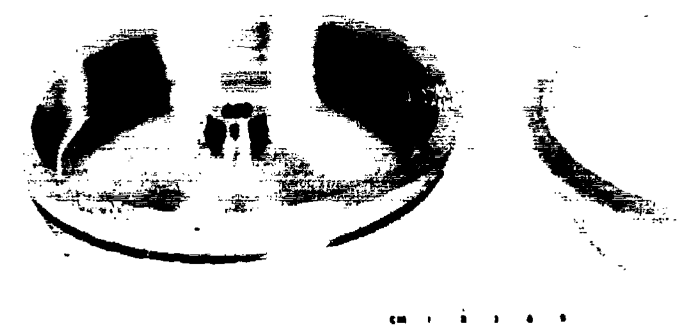
Figure 16. Aluminum bottom plate for 15 inch OD × 13 inch ID Model 34 serving as scale model of Model 2000 Nemo Hull assembly.

(a) outside view of hatch and retaining ring

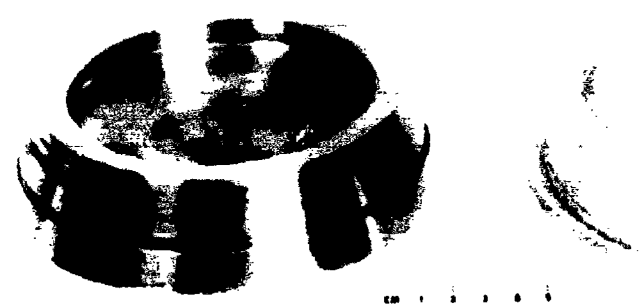


(b) inside view

Figure 17. Aluminum hatch for 15 inch OD × 13 inch ID Model 34 serving as scale model of Model 2000 Nemo Hull assembly.

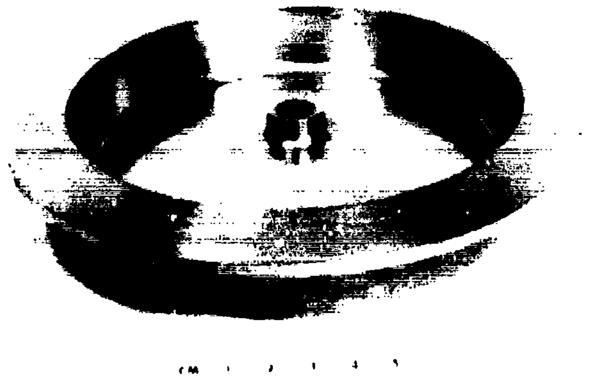


(a) exterior view of hatch designed for service with polycarbonate gasket

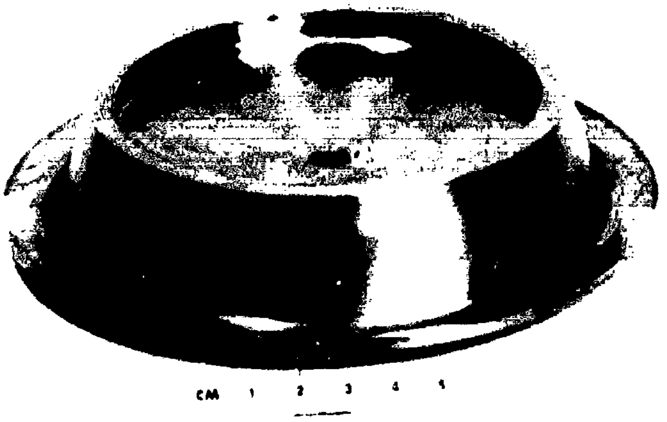


(b) interior view of hatch designed for service with polycarbonate gasket

Figure 18. Titanium hatch for 15 inch OD × 13 inch ID Models 35, 36 and 37.



(c) exterior view of hatch designed for service without a polycarbonate gasket



(d) interior view of hatch designed for service without a polycarbonate gasket

Figure 18. (Continued).

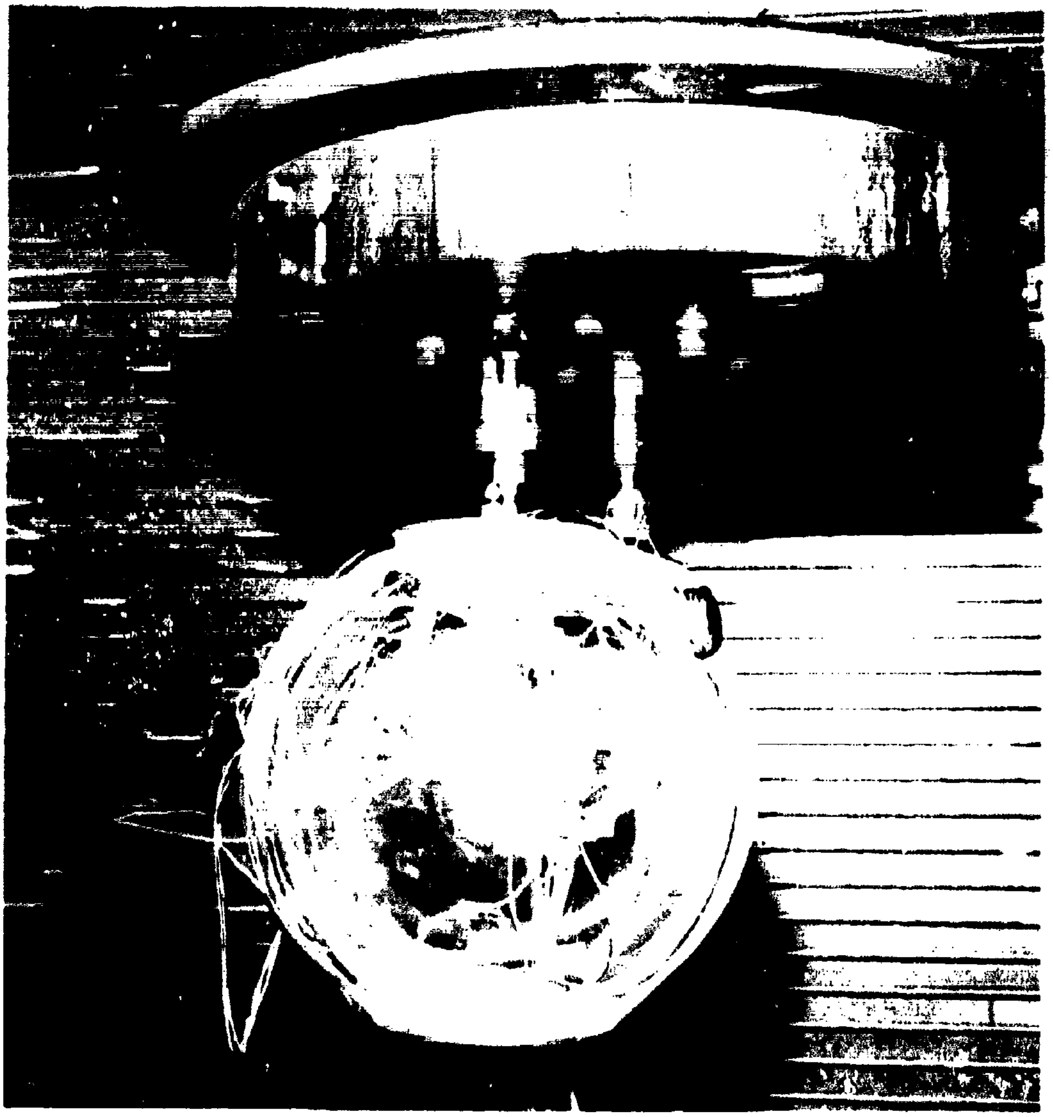
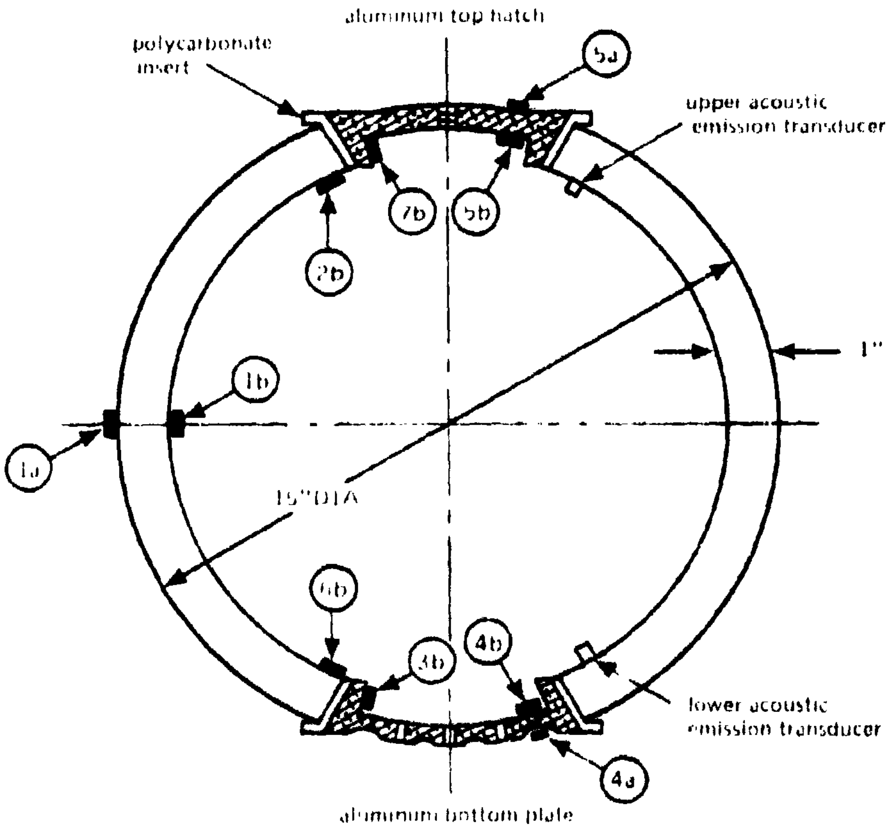


Figure 19. Test arrangement for hydrostatic testing of 15 inch OD × 13 inch ID Model 34 serving as scale model of Model 2000 Nemo Hull.

2b = 0.500 inches from edge of hatch
6b = 0.200 inches from edge of bottom plate



Note: Each number instrumented with 2 gage 90° rosettes

Figure 20. Location of strain gages on the 15 inch OD × 13 inch ID Model 34, serving as scale model of Model 2000 Nemo Hull.

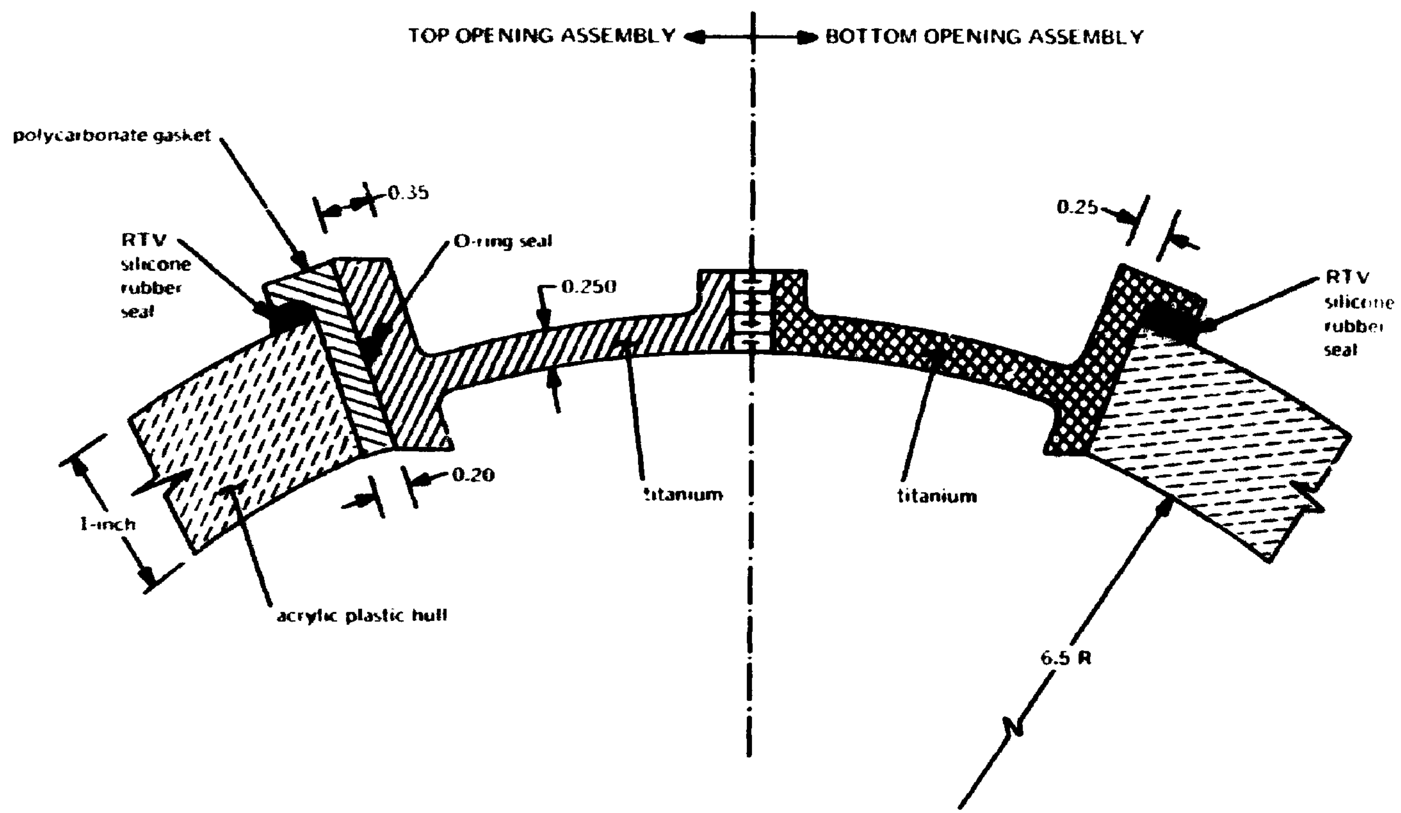
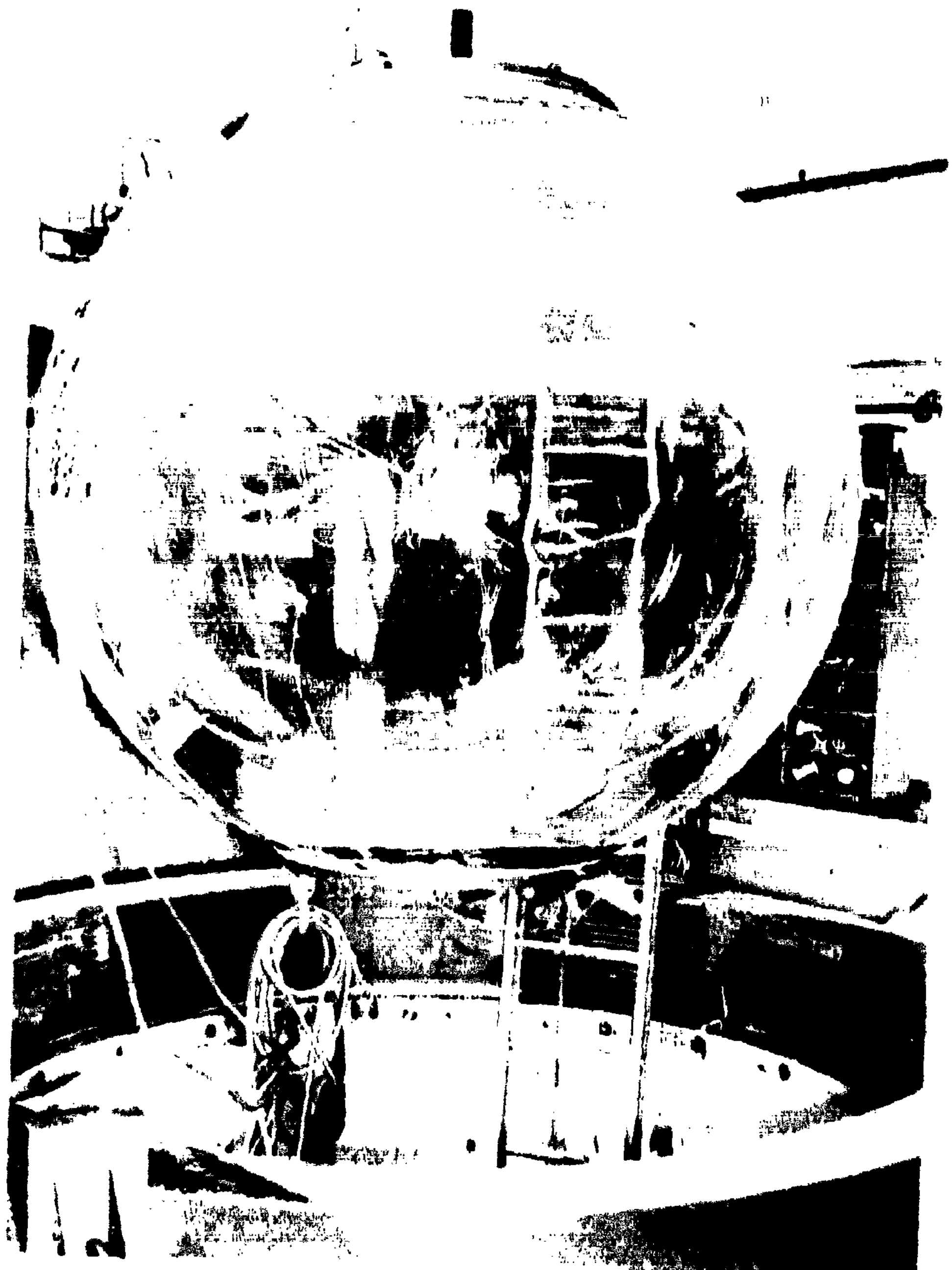
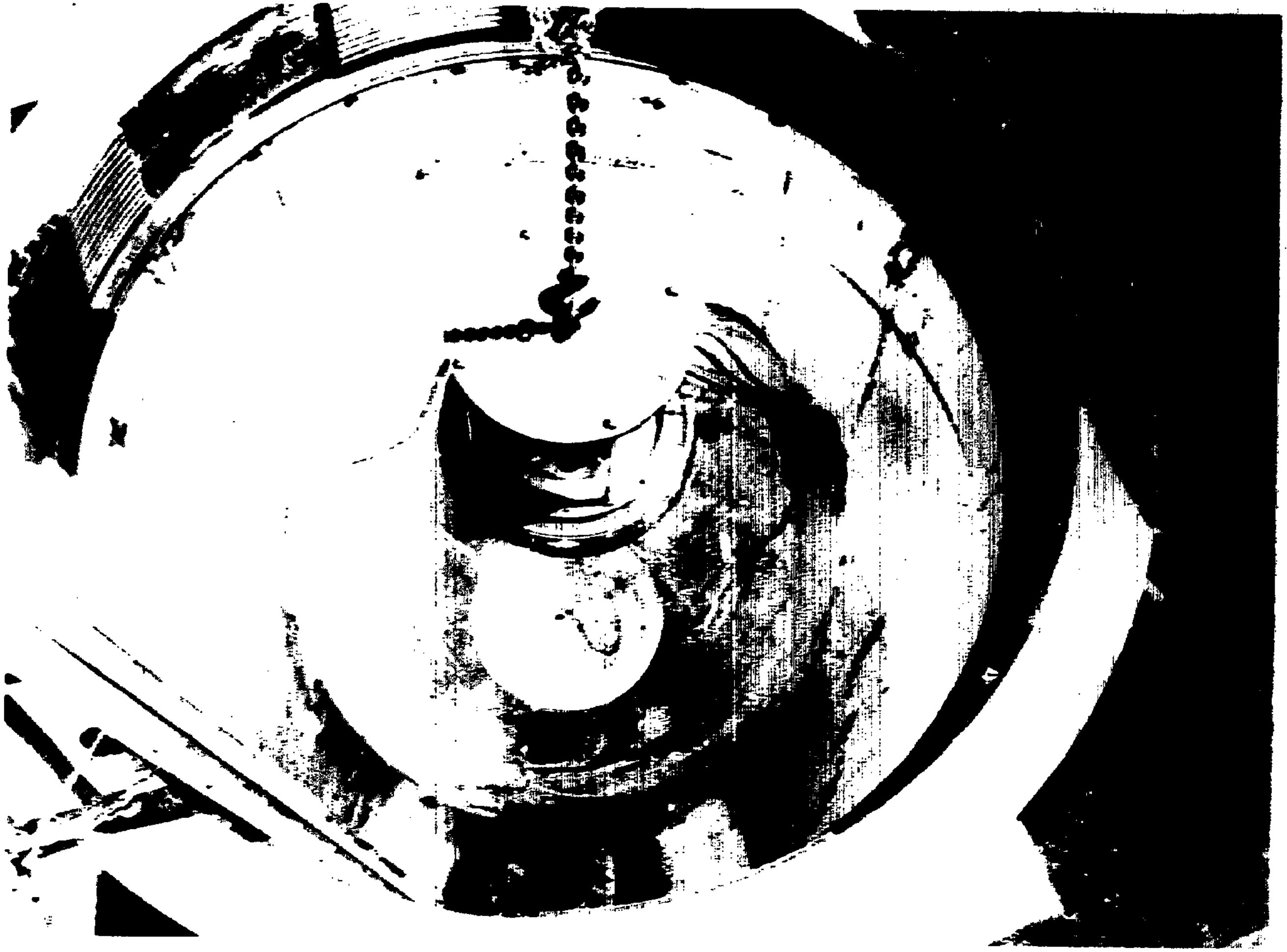


Figure 21. Typical hatches used in the 15 inch OD × 13 inch ID Models 35, 36 and 37 subjected to pressure cycling.



(a) instrumented assembly ready for placement in vessel

Figure 22. Testing of full scale Model 2000 Nemo Hull assembly in the 90 inch diameter pressure vessel at SWRI.



(b) Model 2000 Nemo *Hull* assembly in vessel

Figure 22. (Continued).

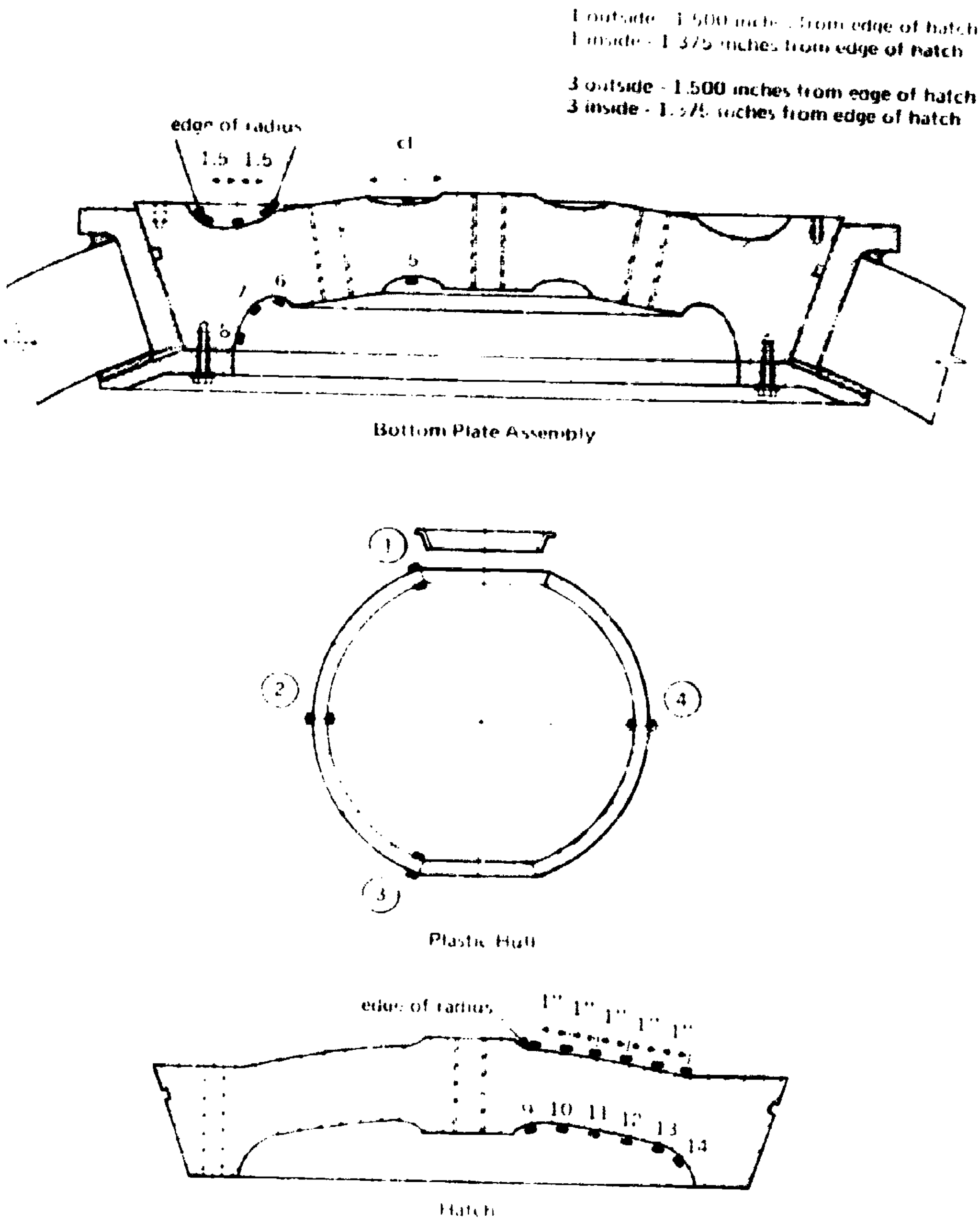


Figure 23. Location of strain gages on the 66 inch OD × 58 inch ID full scale Model 2000 Nemo Hull assembly.

Figure 24. Fragments of the 15 inch OD × 13 inch ID Model 34 after implosion at 4750 psi.

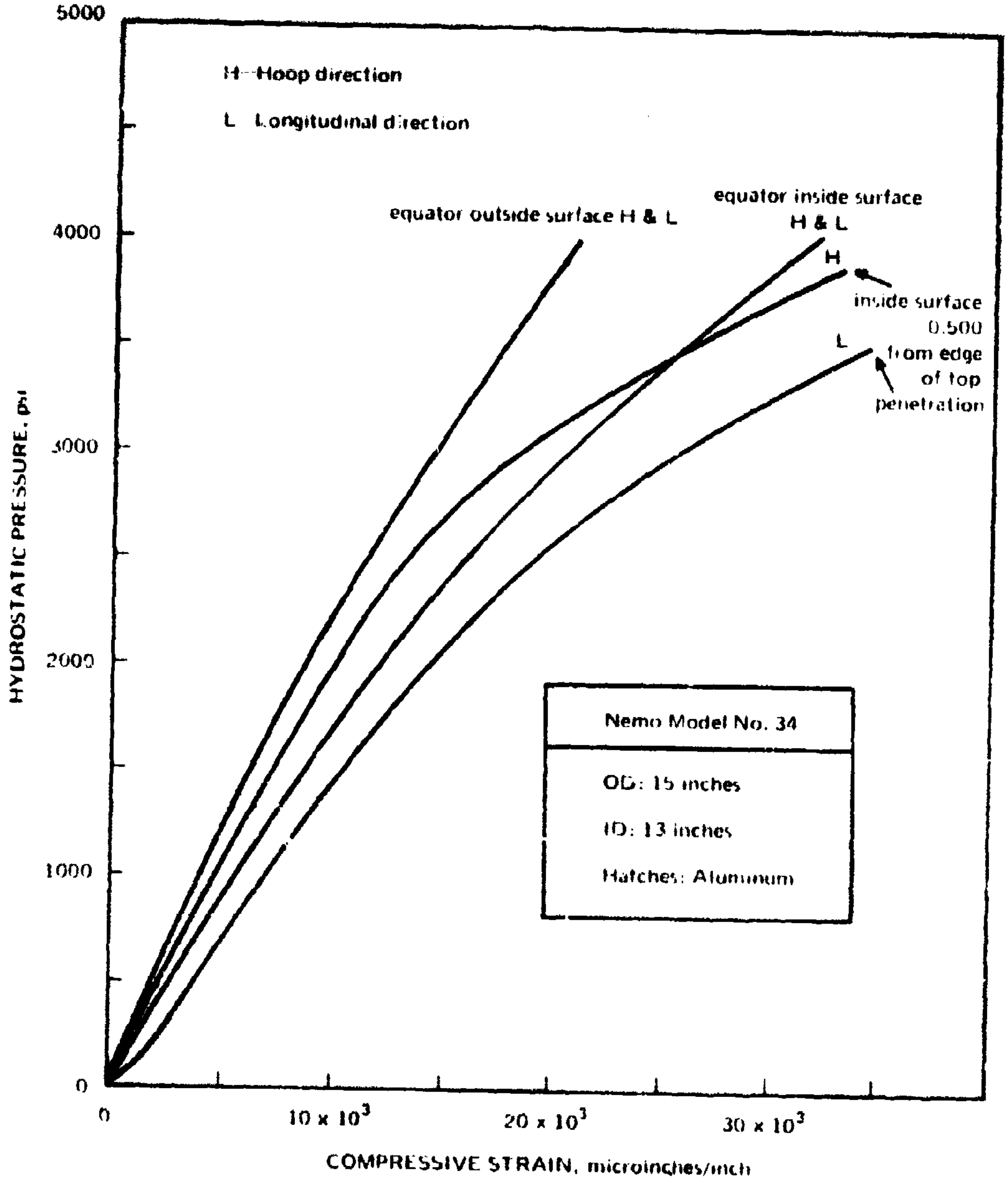


Figure 25. Strains in the 15 inch OD × 13 inch ID Model 34 serving as scale for Model 2000 Nemo Hull.

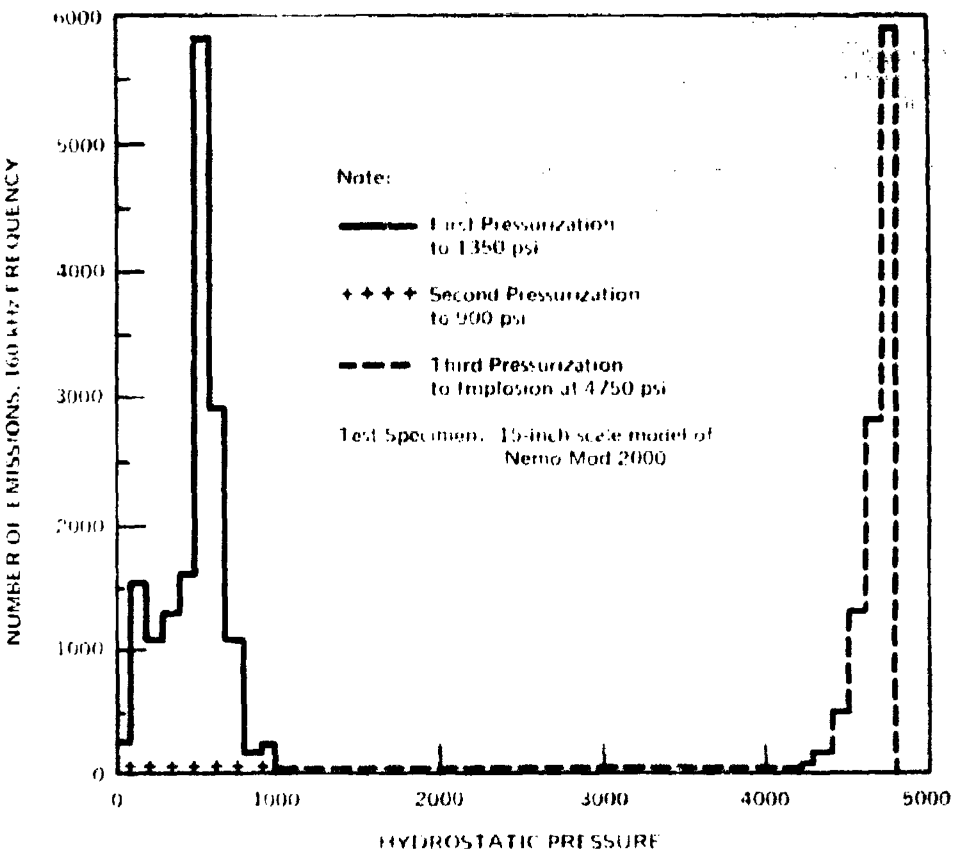


Figure 26. Histogram of stress wave emissions from 15 inch OD × 13 inch ID Model 34 of undergoing external pressure tests.

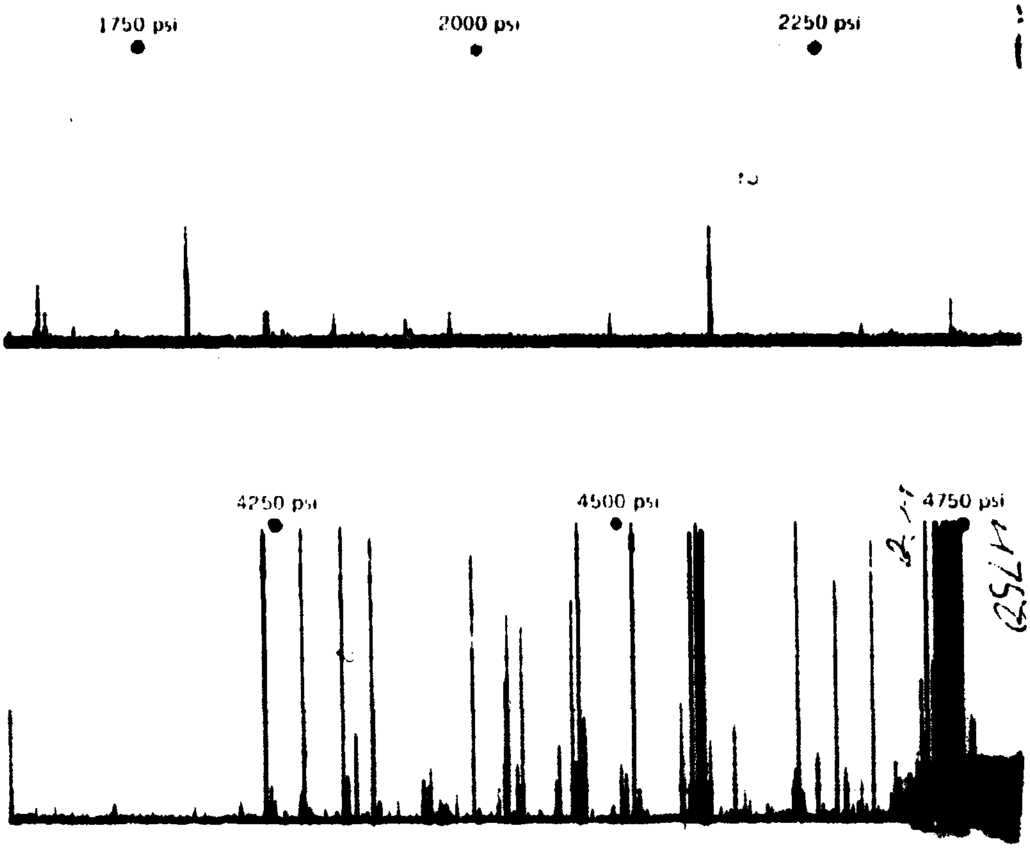


Figure 2[illegible]. Recording of stress wave emissions preceding the short term implosion of 15 inch OD × 13 inch ID Model 34 assembly at 4750 psi external hydrostatic pressure.

Figure 28. Inspection of bearing surfaces on 15 inch OD × 13 inch ID Models 36 and 37 after 1000 pressure cycles to, respectively, 900 and 1500 psi hydrostatic pressure.

Figure 29. Fatigue crazing of the acrylic bearing surface of the Model 37 hull after 1000 pressurizations of 4 hour duration each to 1500 psi; this acrylic bearing surface was in direct contact with the metallic hatch.

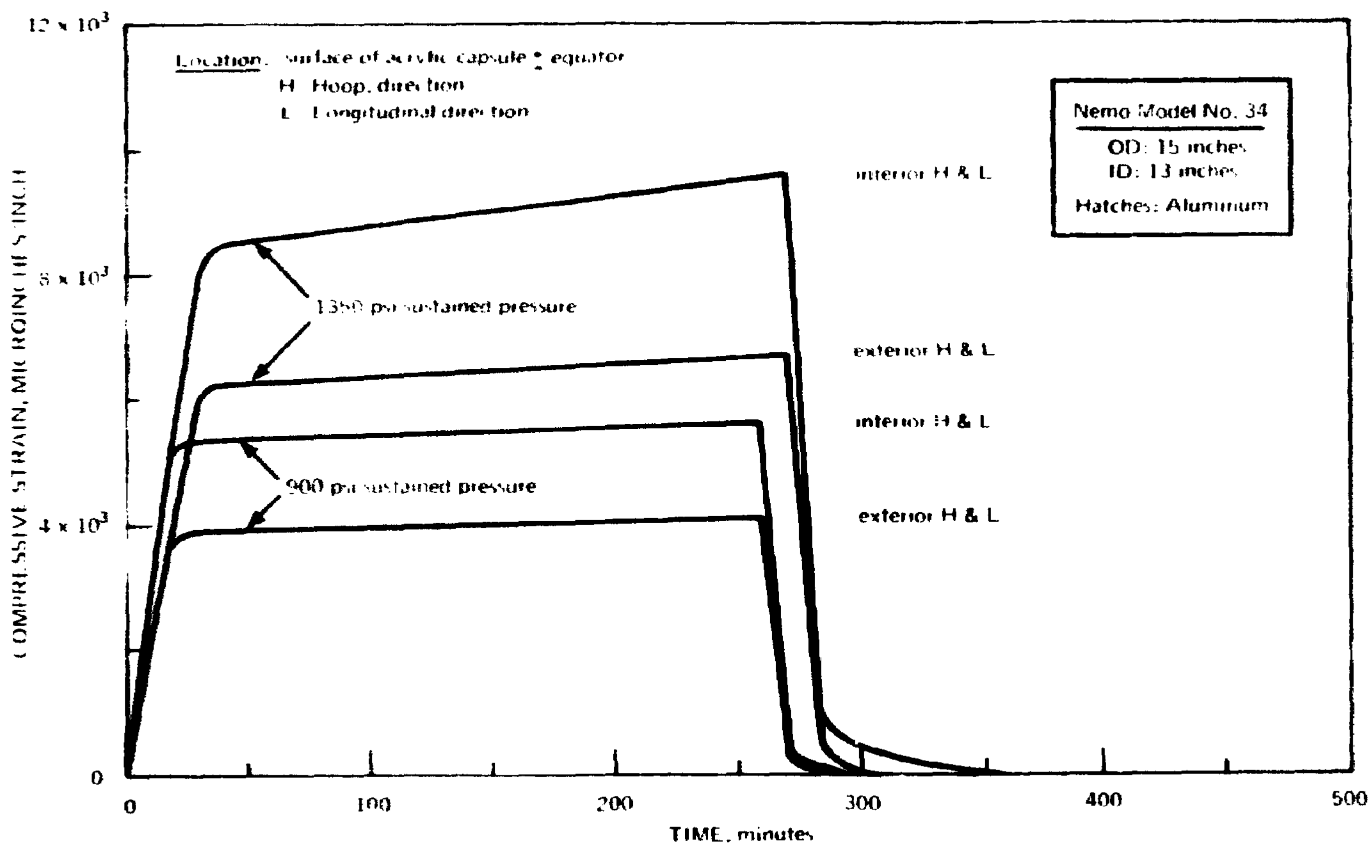


Figure 30. Creep of acrylic hull in 15 inch OD × 13 inch ID Model 34 under external hydrostatic pressure; measured on the interior and exterior surfaces at the equator.

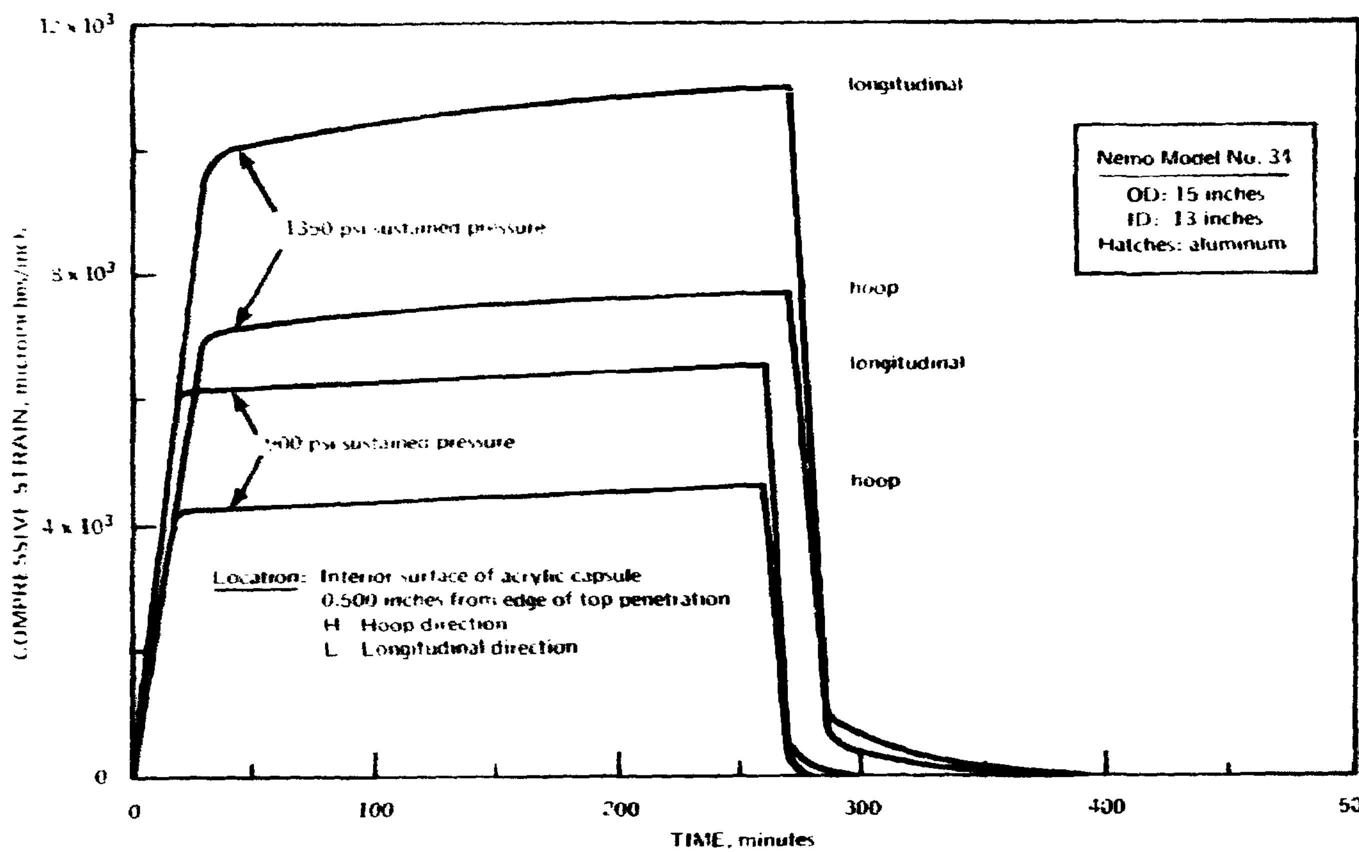
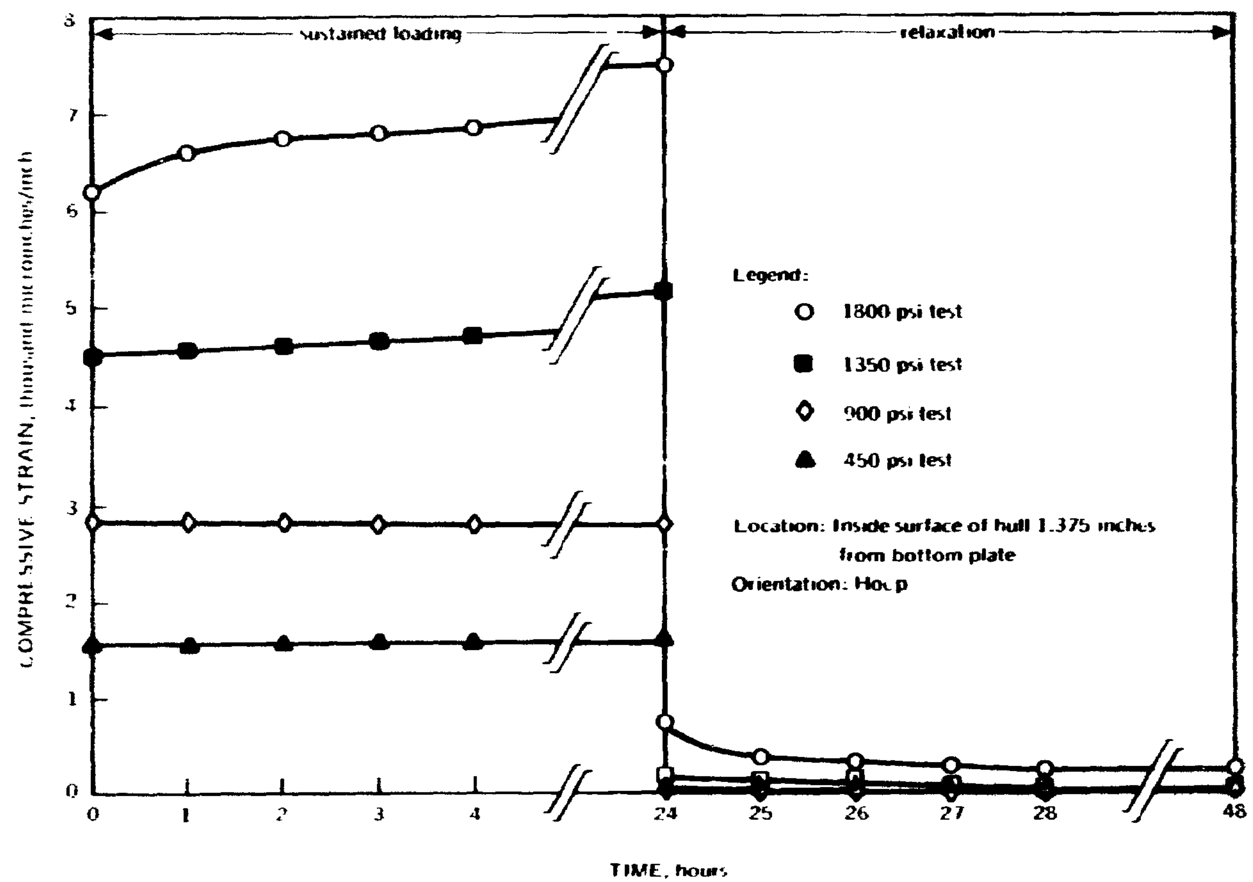
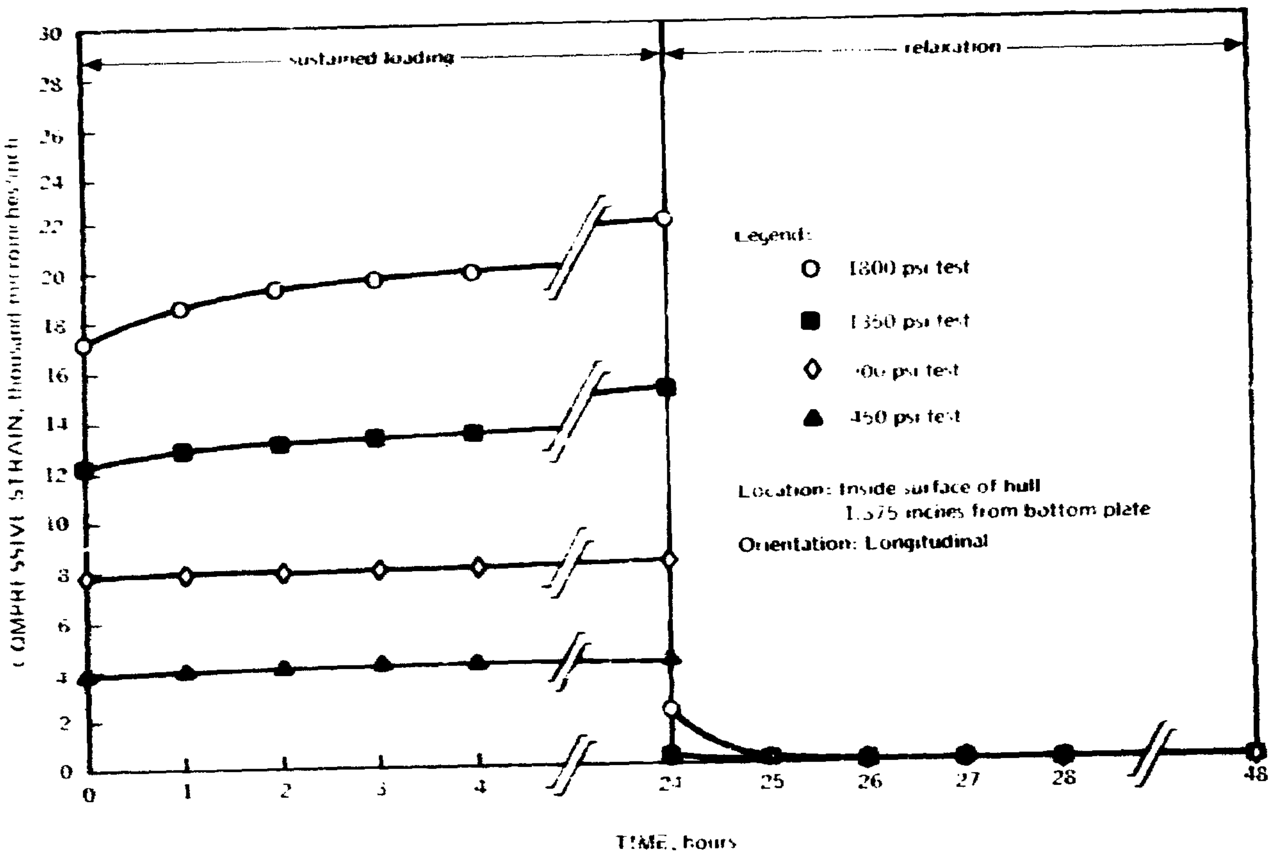


Figure 31. Creep of acrylic hull in 15 inch OD × 13 inch ID Model 34 under external hydrostatic pressure; measured on the interior surface at the edge of top polar penetration.



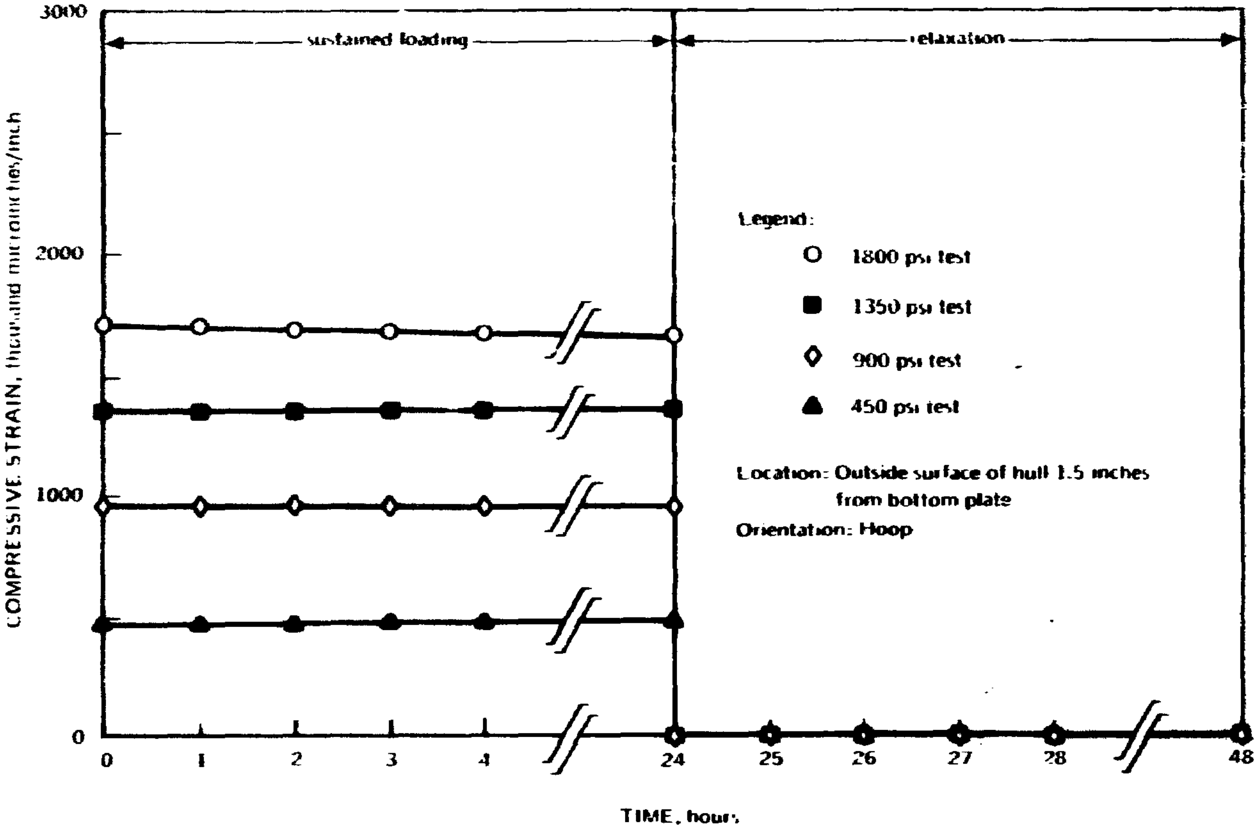
(a) inside surface: 1.375 inches from edge of bottom plate: *hoop*

Figure 32. Creep measured on the acrylic hull of the 66 inch OD × 58 inch ID Model 2000 Nemo Hull assembly during 24-hour long sustained loadings under external hydrostatic pressure.



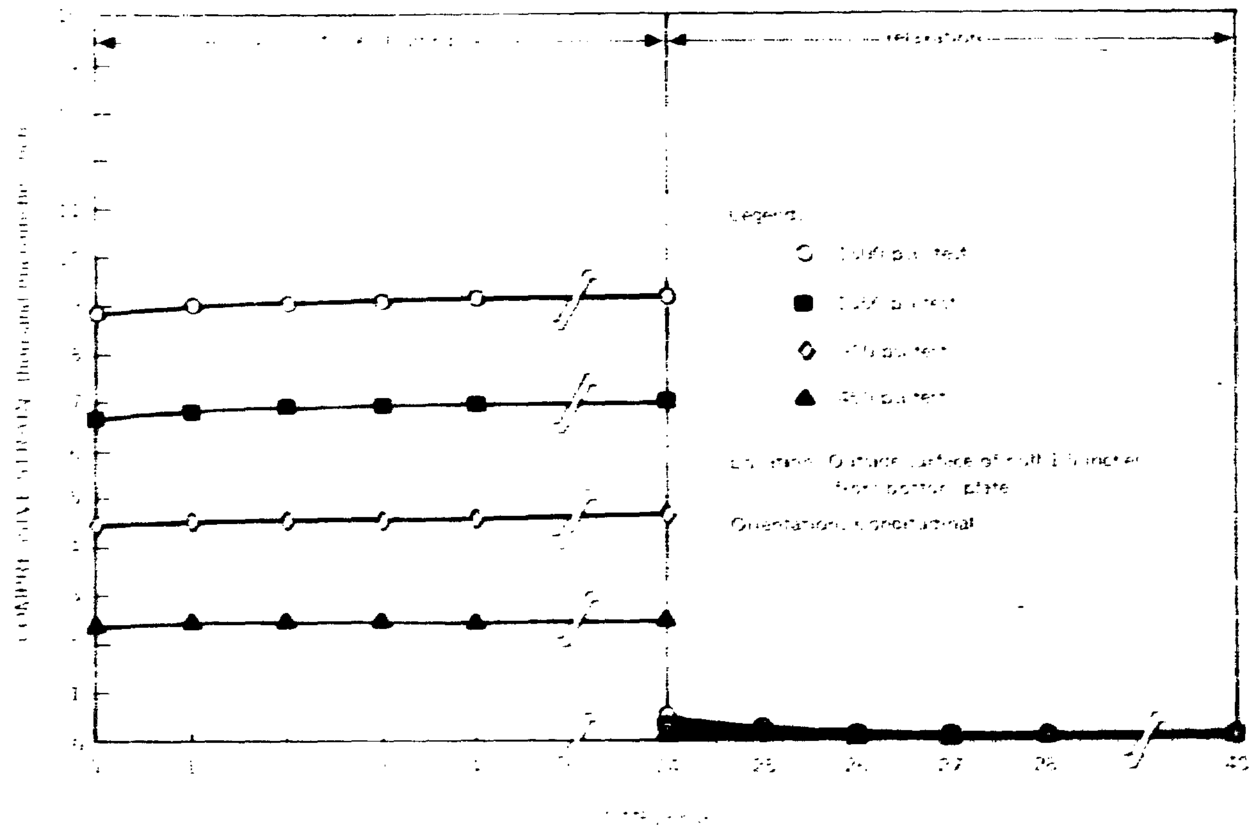
(b) inside surface: 1.375 inches from edge of bottom plate; *longitudinal*

Figure 32. (Continued).



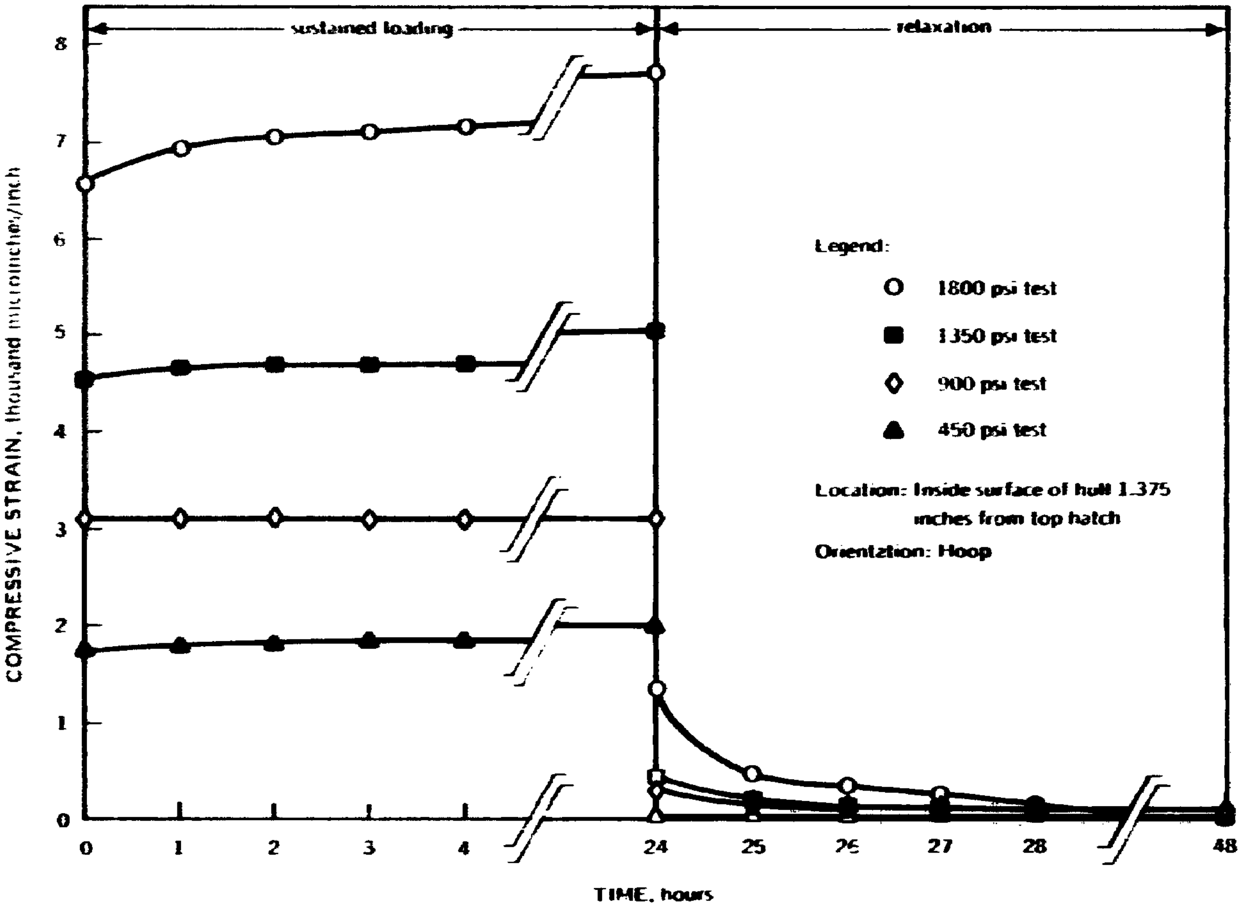
(c) outside surface: 1.500 inches from edge of bottom plate: *hoop*

Figure 32. (Continued).



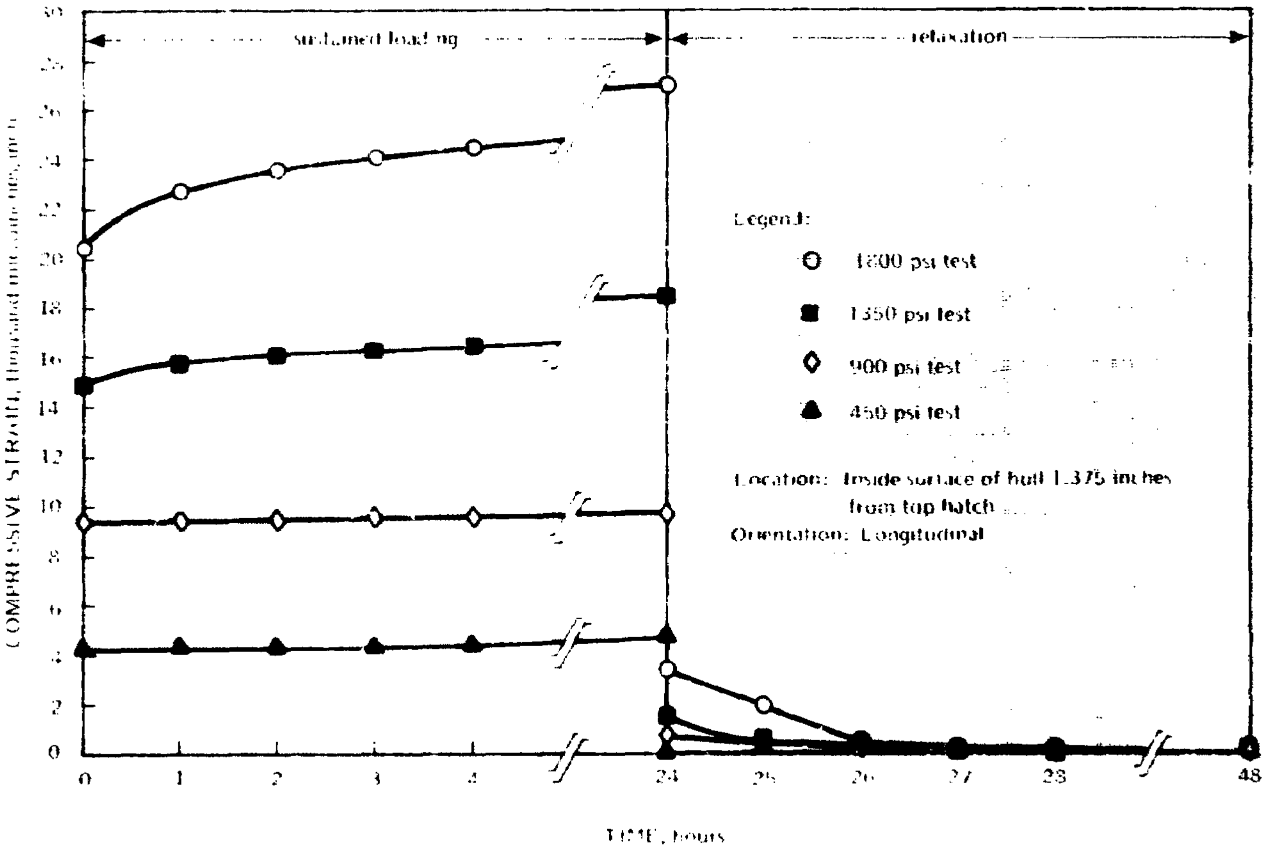
(f) [illegible] bottom plate, longitudinal

Figure 32. (Continued).



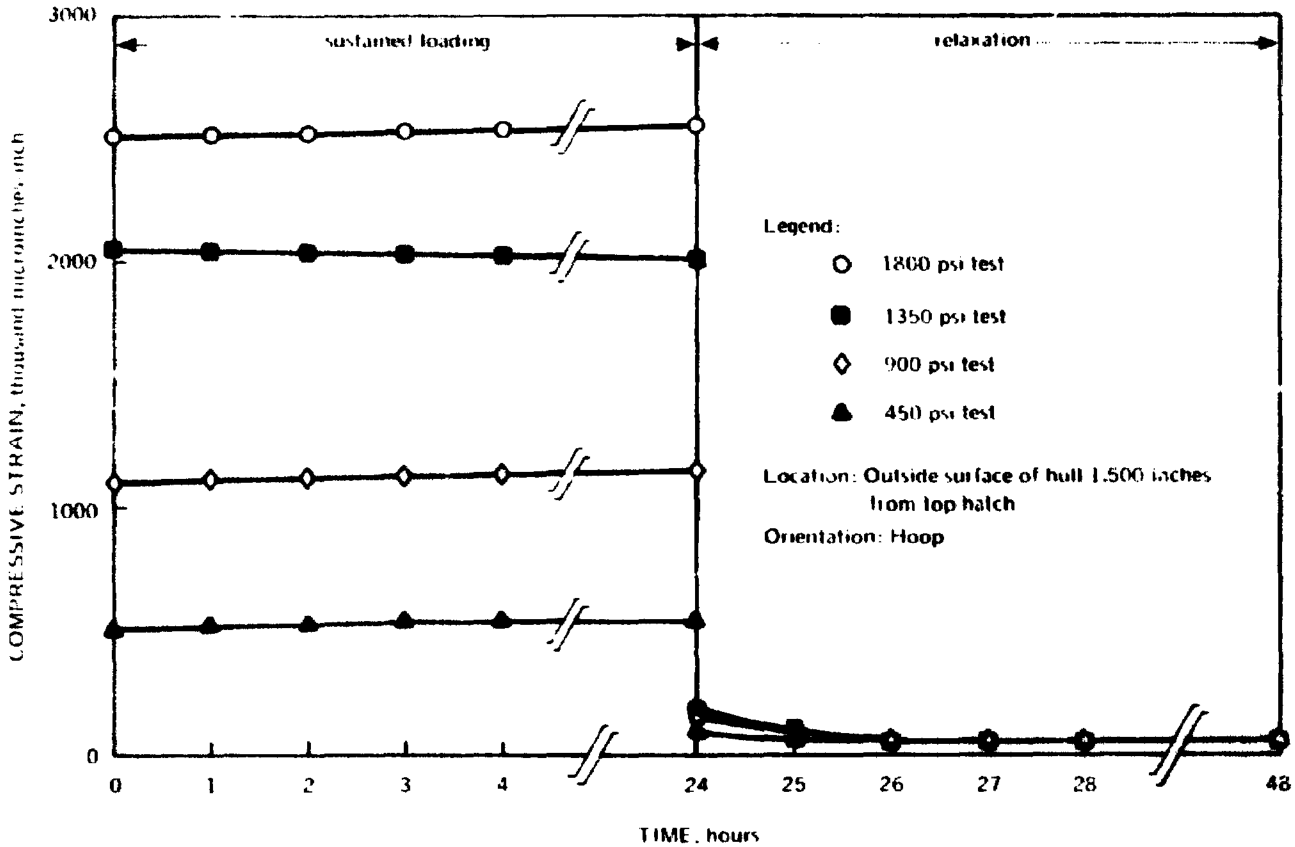
(e) inside surface: 1.375 inches from edge of top hatch: *hoop*

Figure 32. (Continued).



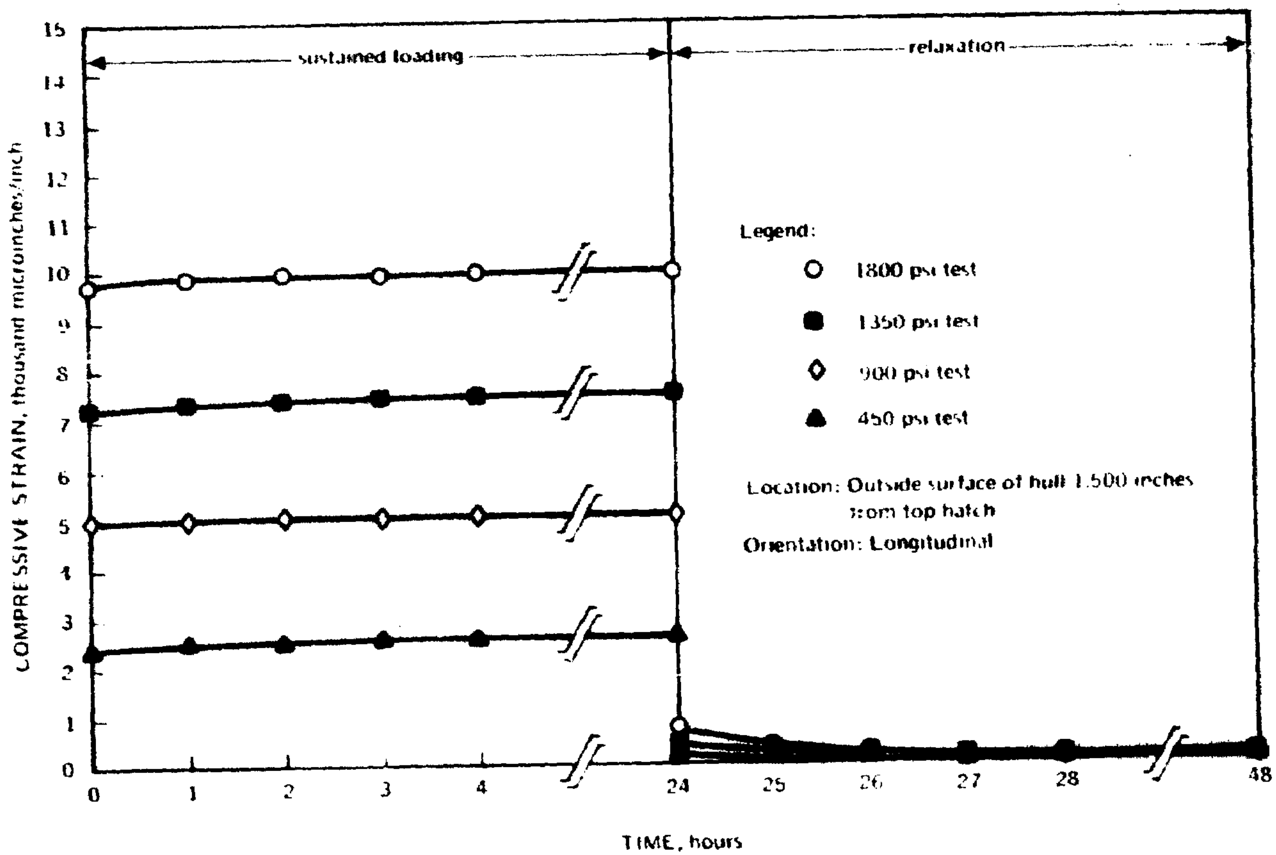
(f) inside surface: 1.375 inches from edge of top hatch: *longitudinal*

Figure 32. (Continued).



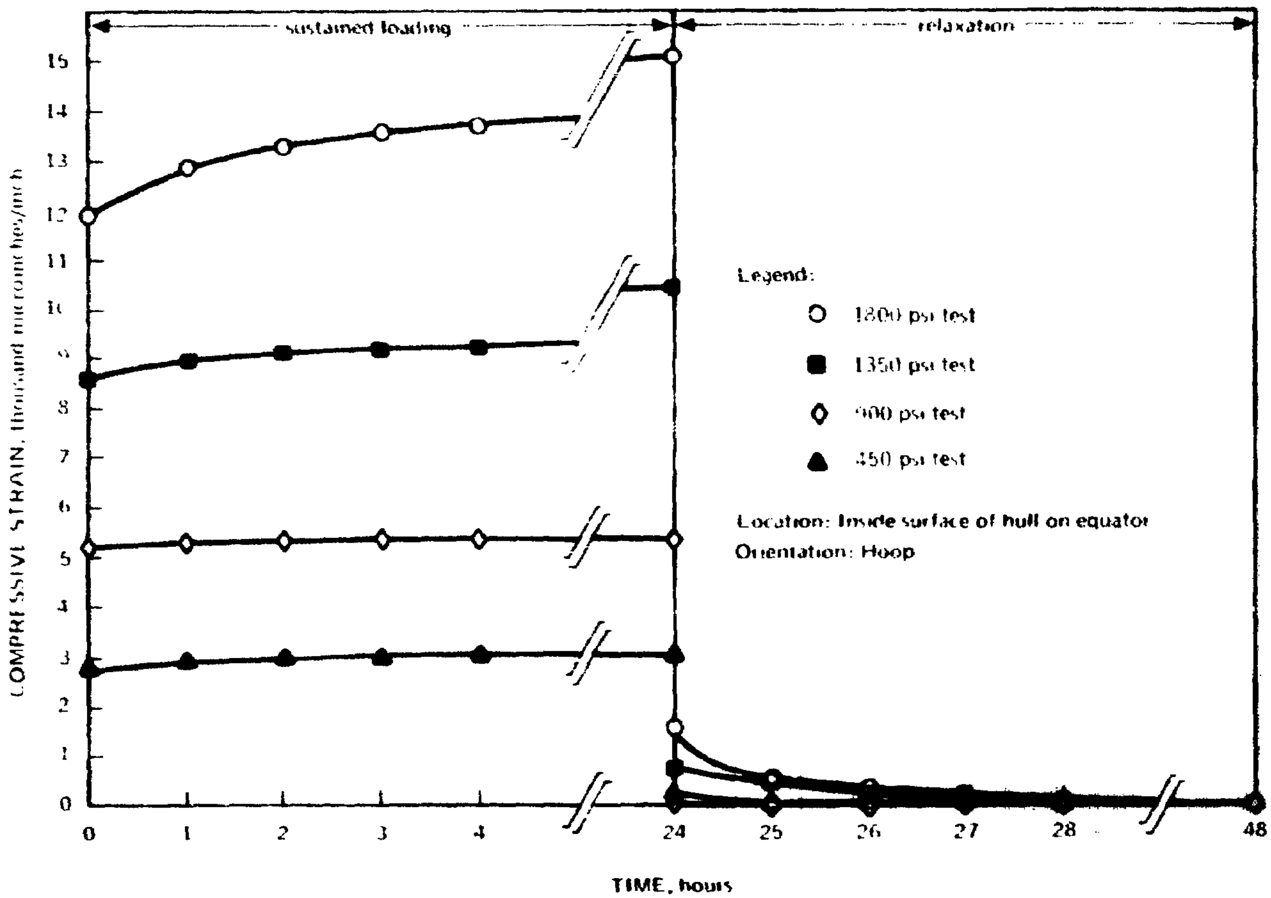
(g) outside surface: 1.500 inches from edge of top hatch: *hoop*

Figure 32. (Continued).



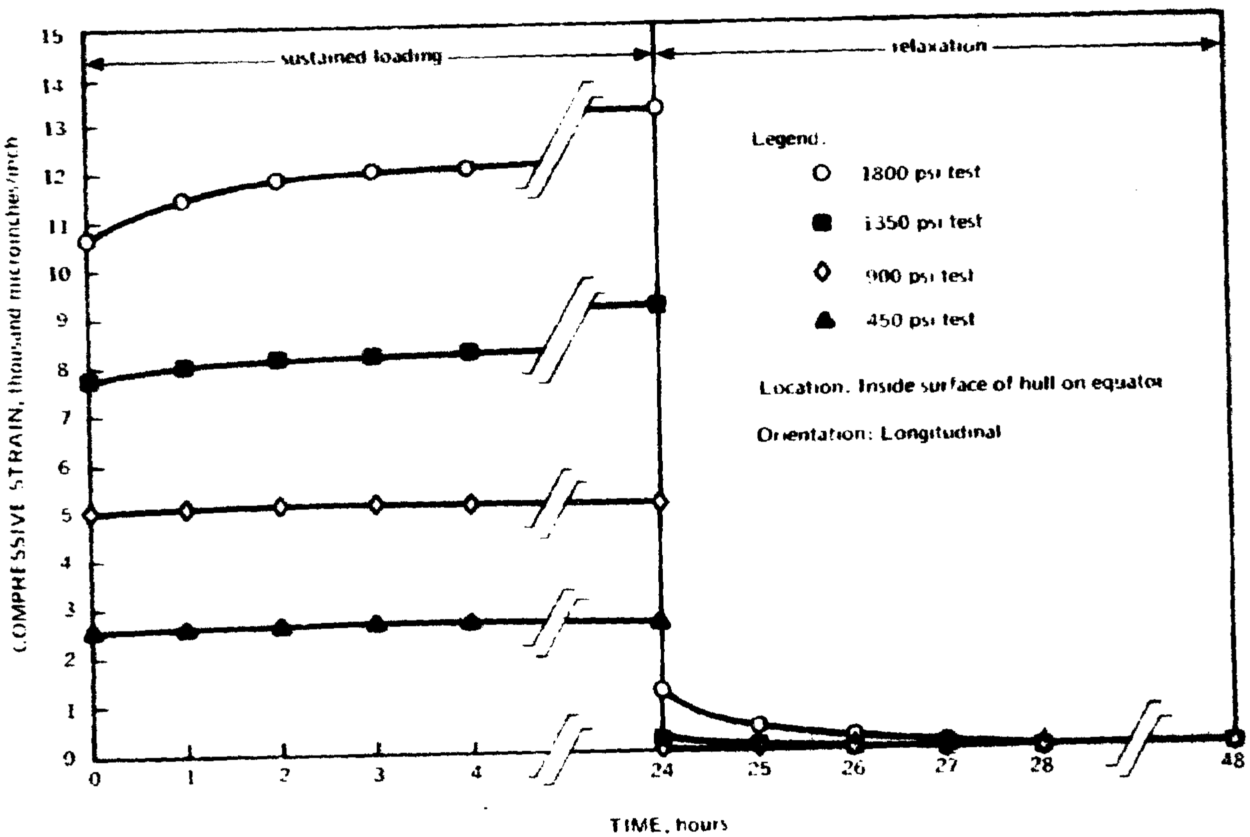
(h) outside surface: 1.500 inches from edge of top hatch: *longitudinal*

Figure 32. (Continued).



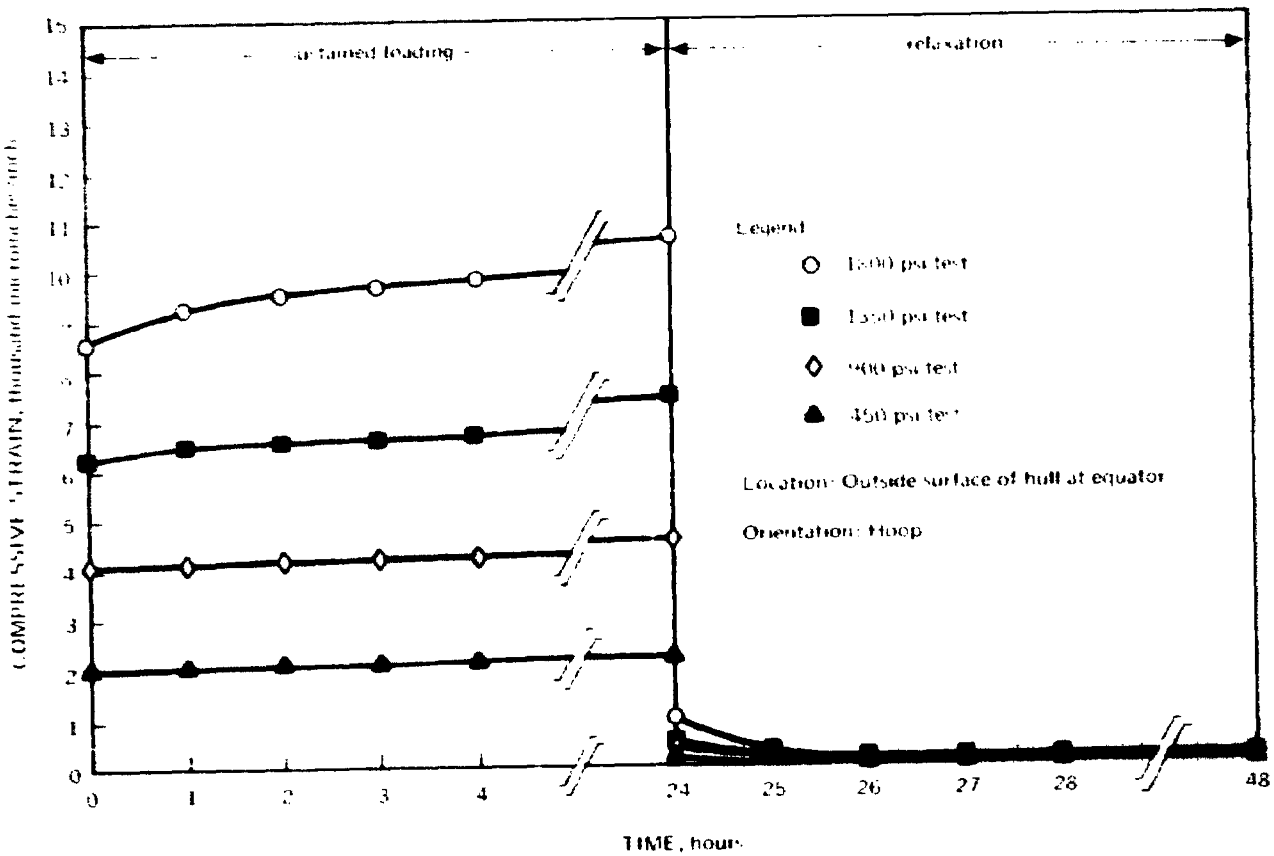
(i) inside surface: equator; *hoop*

Figure 32. (Continued).



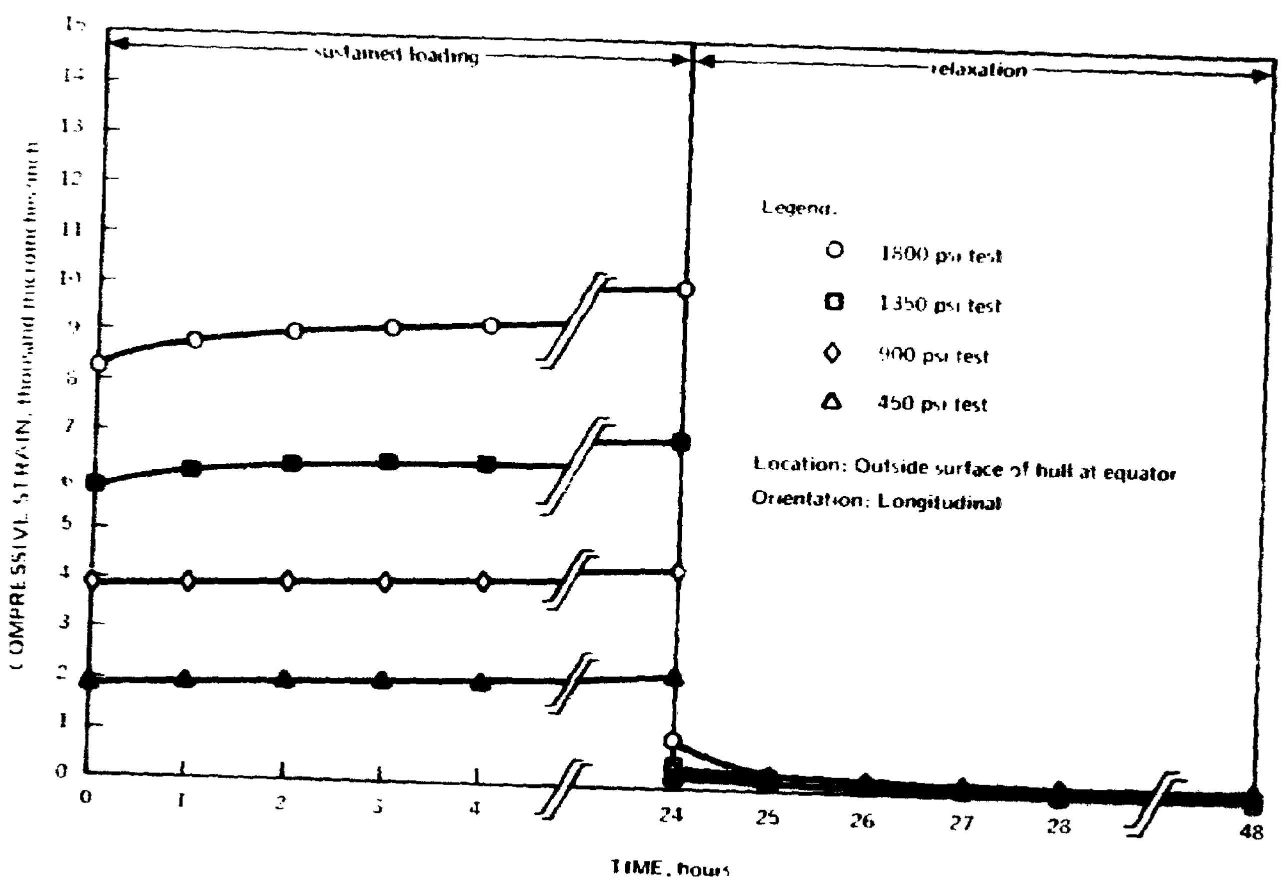
(j) inside surface; equator; *longitudinal*

Figure 32. (Continued).



(k) outside surface, equator; *hoop*

Figure 32. (Continued).



(f) outside surface; equator; *longitudinal*

Figure 32. (Continued).

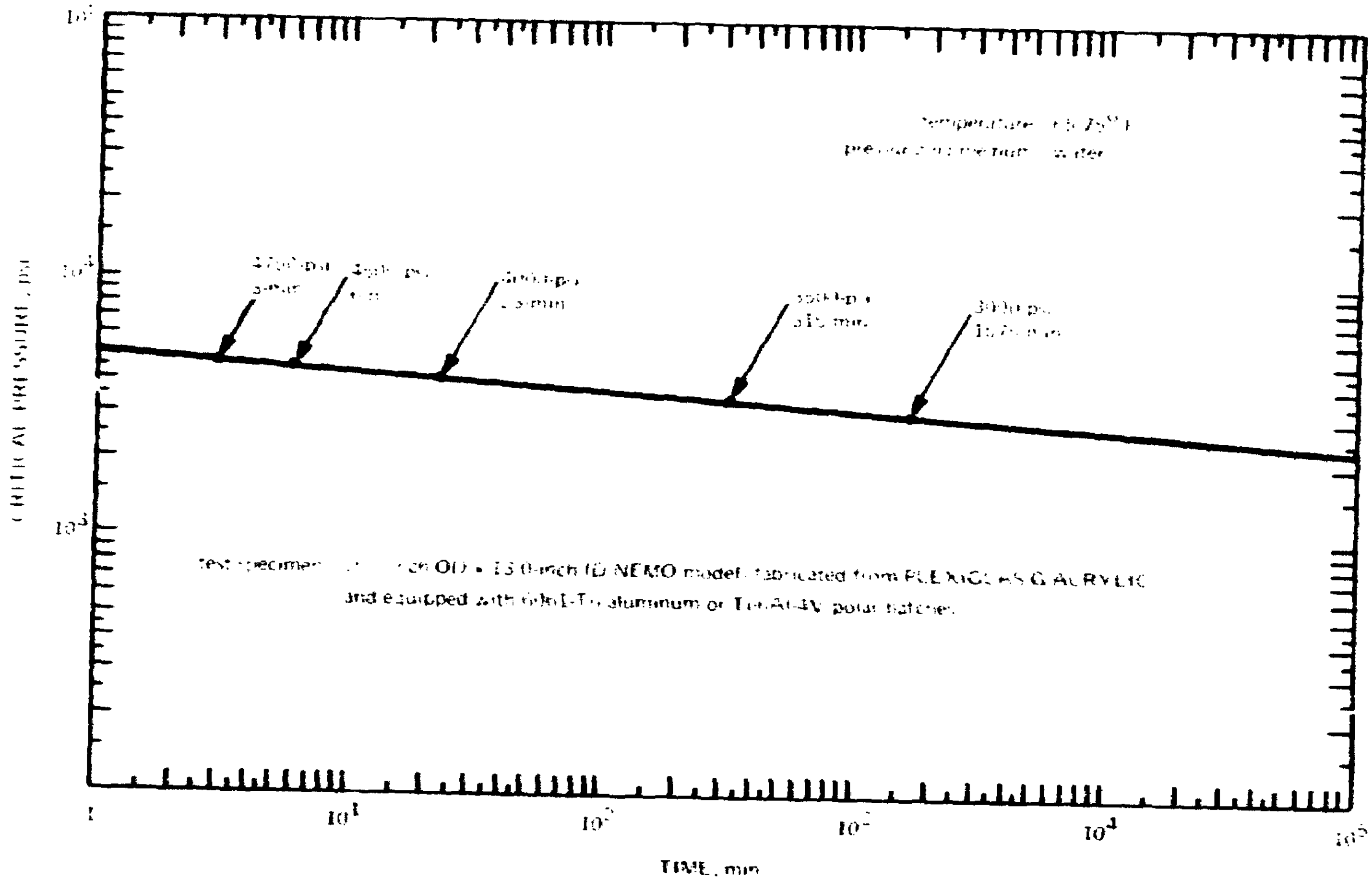


Figure 33. Long term critical pressure as a function of sustained loading duration.

Figure 34. Typical shear cracks in the bearing surface of an acrylic Nemo Hull generated by pressure cycling; when the cracks reach this size the acrylic hull should be removed from service and the bearing surface refinished. (Ref. 5. Nemo Hull Model 600 after pressure cycling to 2000 ft. depth.)

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15. American Society of Mechanical Engineers, Paper No. 70-UnT-A, "Optical Properties of a Spherical Plastic Underwater Observatory NEMO," by T. Trowbridge, December 1970

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APPENDIX A. DESIGN DETAILS OF NEMO MODEL 2000

15-Inch OD × 13-Inch ID Scale Models

The acrylic hull of the 15-inch OD × 13-inch ID scale model 34 was designed to be a faithful copy of the 66-inch OD × 58-inch ID Model 2000 Nemo Hull both in proportions and in method of construction (Figures 1A and 2A). It was to be fabricated in the same manner as the 66-inch OD × 58-inch ID hull by thermoforming spherical sectors from flat discs, machining pentagons from sectors, and finally assembling the spherical pentagons into a sphere by bonding the joints between adjoining pentagons with PS-30 self-polymerizing adhesive (Figure 3A).

The aluminum plates (Figures 4A, 5A, and 6A) for top and bottom polar openings in the 15-inch OD × 13-inch ID Model 34 were not faithfully scaled down models of the hatches in the 66-inch OD × 58-inch ID diameter Model 2000 Nemo Hull. Although structurally the 6061-T6 aluminum plates in the 15-inch OD × 13-inch ID Model 34 behave identically to the hatches in the 66-inch OD × 58-inch ID hull, some operational features of the large hatches have been omitted in the scale model plates. Thus, for example, the top aluminum plate 15-inch OD × 13-inch ID Model 34 has the same rigidity and proportions as the top hatch in the 66-inch OD × 58-inch ID Model 2000 Nemo Hull but does not disassemble into separate hatch and hatch ring components.

The construction of the 15-inch OD × 13-inch ID Models 35, 36, and 37 was identical to that of Model 34. The only difference between Model 34 and the other models lay in the design of the polar plates. The polar plates for Models 35, 36, 37 were structurally idealized hatches designed in titanium Ti-6Al-4V (Figure 7A). Since these models were to be used in cyclic pressure tests to determine the effect of depth on the performance of the polycarbonate gasket between the hatch and the acrylic bearing surface, each model was equipped with the polycarbonate gasket only for the top plate while the bottom plate in each model was designed to operate without a gasket. In this manner each model was designed to operate both with and without a gasket around the titanium plates. In this manner, each model would provide the data on the performance of acrylic bearing surfaces at a given pressure with and without polycarbonate gaskets (Figure 8A).

66-Inch OD × 58-Inch ID Operational Model

The 66-inch OD × 58-inch ID operational Model 2000 Nemo Hull was designed for economical construction within tight dimensional tolerances to maximize the operational depth of the assembly. The acrylic hull was designed to be constructed from 12 spherical pentagons bonded together with PS 18, PS 30 or any other self-polymerizing adhesive with 5000 psi minimum tensile strength (Figures 9A and 10A).

The polar aluminum assemblies were designed, like the polar insert assemblies in the previous Model 600 and Model 1000 Nemo Hulls, to serve as hatches for personnel entry and feed through plates for electrical and hydraulic control cables. Aluminum was chosen as the construction material because of its resistance to corrosion and attractive strength to weight ratio. The bottom feed through plate was equipped with 9 holes to accommodate 9 separate electrical or hydraulic feed throughs (Figure 11A). In addition, the feedthrough plate serves also as the foundation for any equipment contained within the capsule. The diameter of the top polar opening was selected to be ample enough even for a heavy set pilot or observer (Figure 12A). Because considerable exertion has been required of the crew in the past Nemo Hull designs to open the heavy hatch, a set of torsion springs was incorporated into the Model 2000 Nemo hatch assembly (Figure 12A). Also latch locks have been incorporated into the hatch handles to lock them securely in the open position when the hatch is open (Figure 13A).

All the parts of the hatch were made from 6061-T6 aluminum, except the Monel K-500 latch shafts, the 17-4 PH stainless hinge pin, steel counter balance springs, and poly-carbonate plastic gaskets (Figures 14A, 15A, 16A, 17A, 18A, 19A and 20A). Materials chosen for these applications matched well with the galvanic potential of aluminum, thus preventing unduly severe galvanic corrosion. As a rule all the bevel angle tolerances on polar insert components were specified to be ±15 minutes, a readily attainable tolerance with standard shop machining practices. During the subsequent assembly of the Model 2000 Nemo Hull structure it was found, however, that the ±15-degree angle tolerances resulted in incomplete surface contact between matching beveled structural components. As a result of this finding, it is recommended that the angle tolerance be decreased to ±7.5 degrees in future Model 2000 Nemo Hull assemblies.

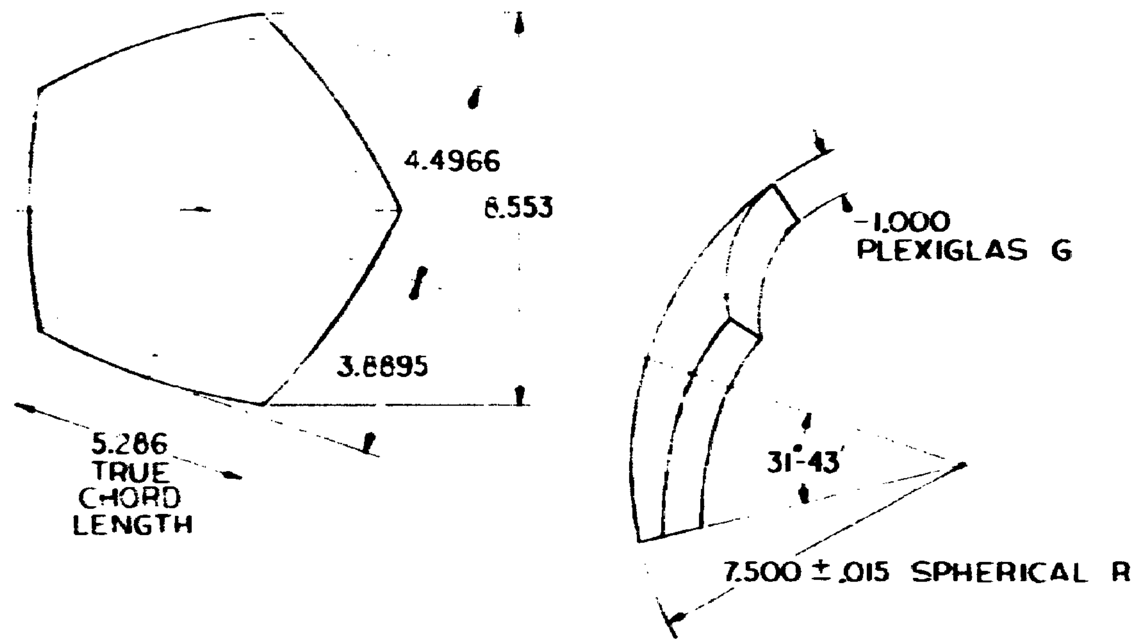


Figure 1A. Spherical pentagon for the 15-inch OD × 13-inch ID scale model of the Model 2000 Nemo Hull.

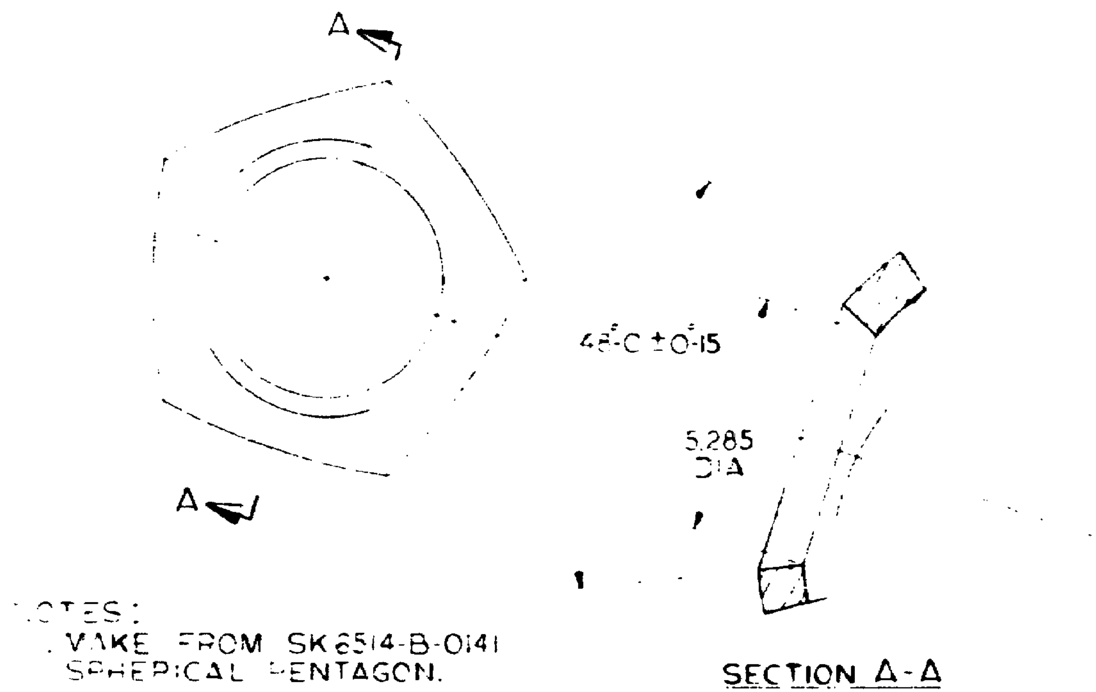


Figure 2A. Polar spherical pentagon for the 15-inch OD × 13-inch ID scale model of the Model 2000 Nemo Hull.

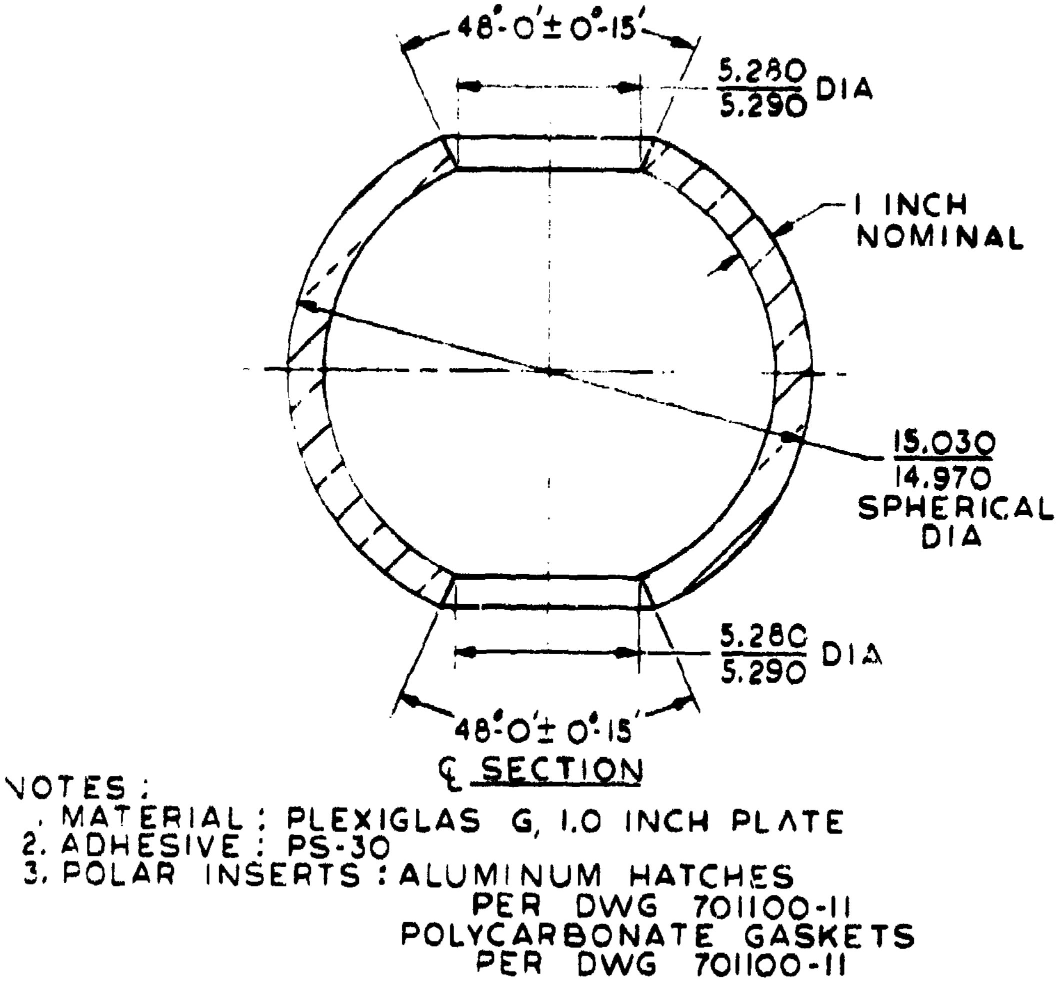


Figure 3A. Assembled hull of the 15-inch OD × 13-inch ID Model 34

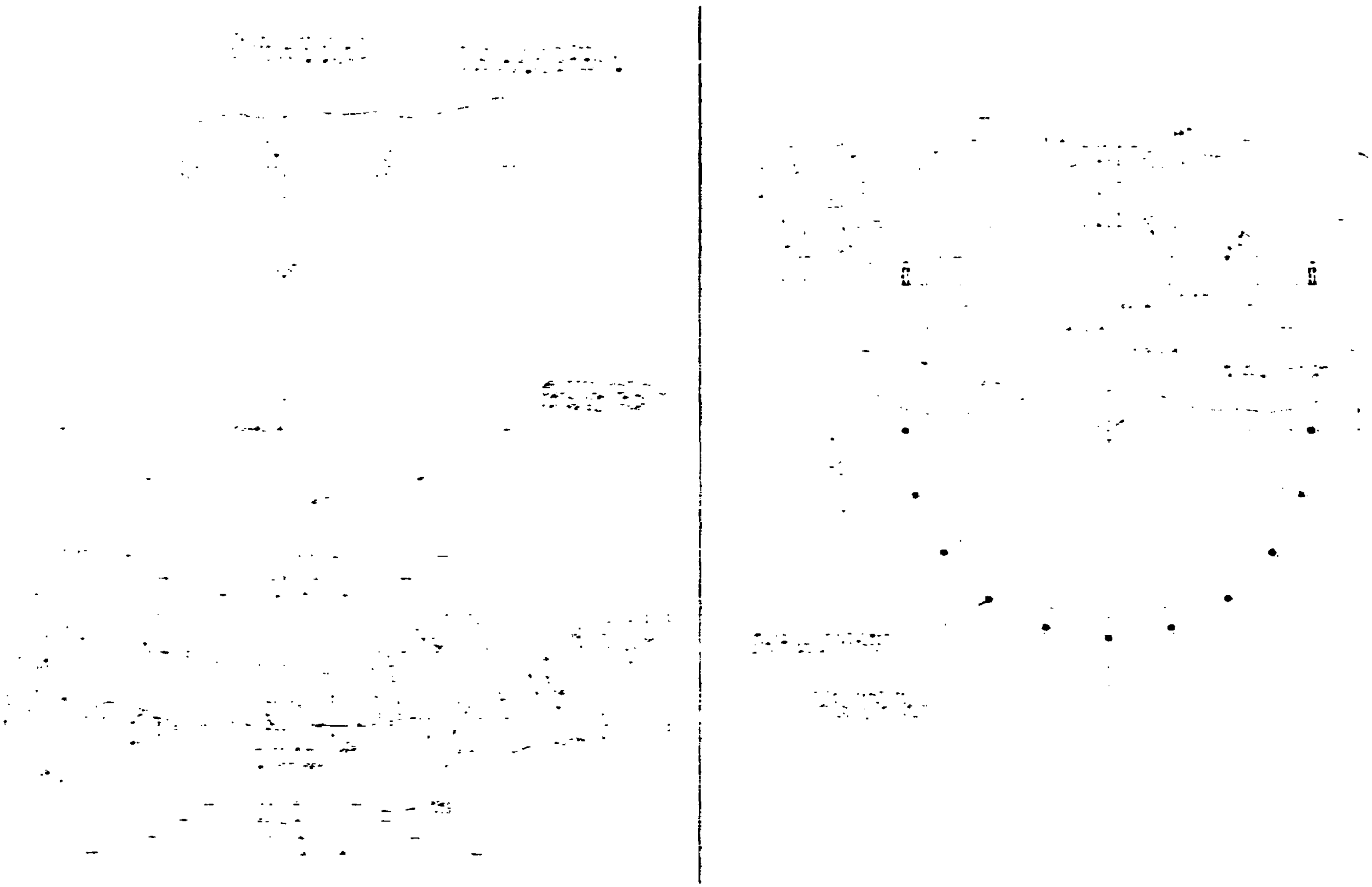


Figure 4A. Polar Aluminum Hatch Assemblies for the 15-inch OD × 13-inch ID Model 34.

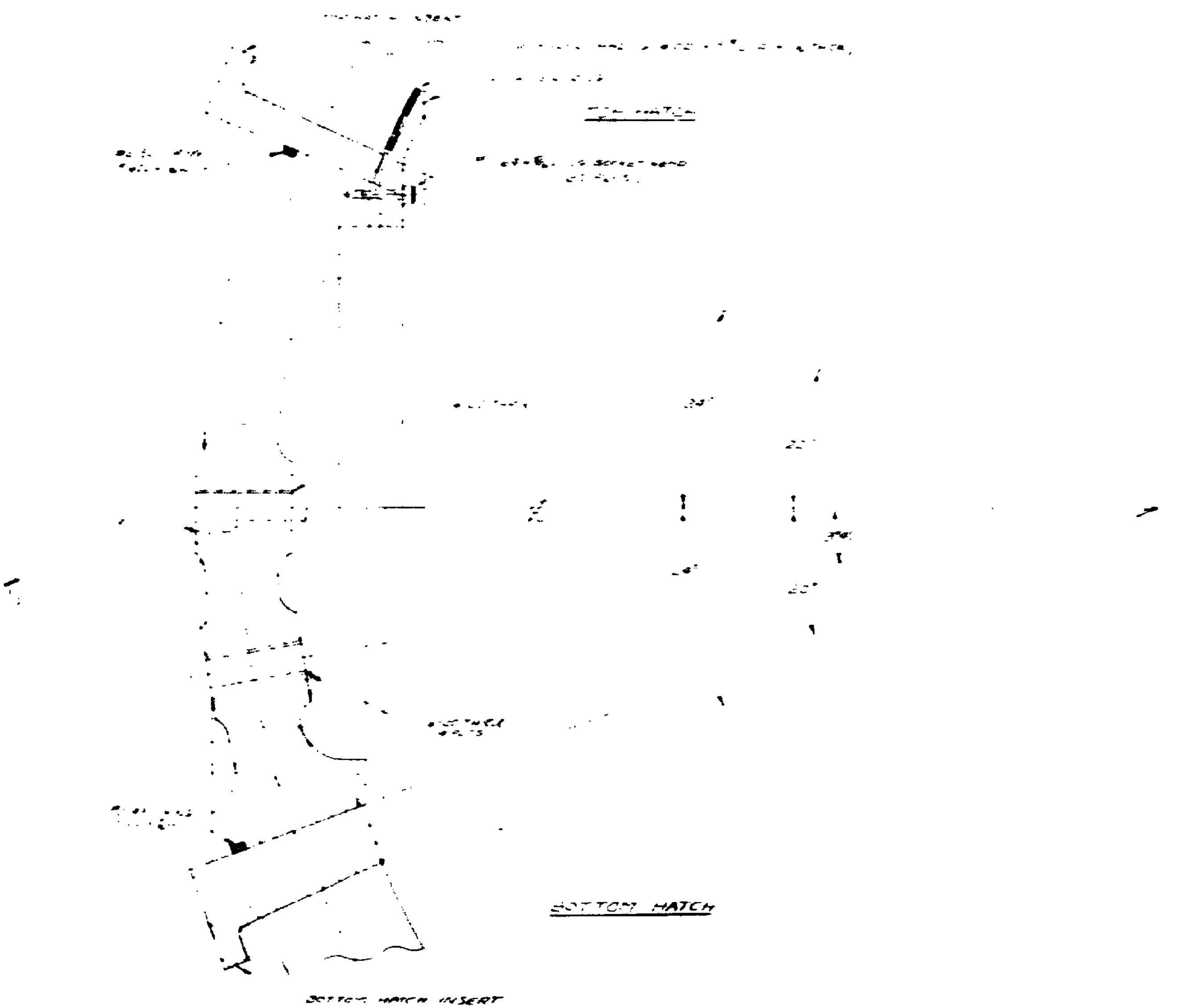


Figure 5A. Top and bottom aluminum hatches for the 15-inch OD × 13-inch ID Model 34.

Figure 6A. Polycarbonate polar gaskets and top hatch retaining ring for the 15-inch OD - 13-inch ID Model 34.

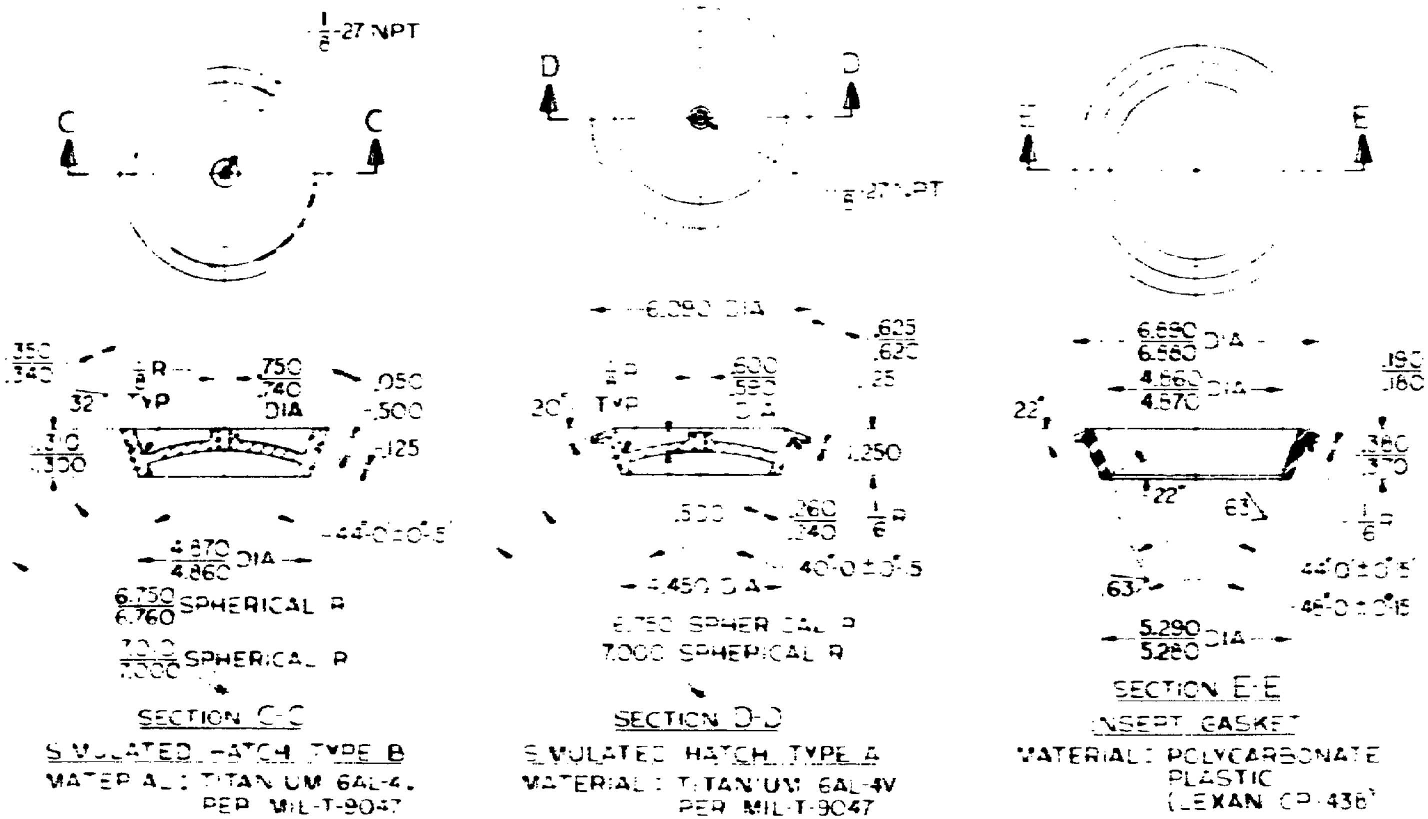


Figure 7A. Polar titanium hatches for service with 15-inch OD × 13-inch ID Models 35, 36 and 37. Note that Type A titanium hatch was designed for service without the polycarbonate gasket while Type B titanium hatch was designed to be used with a polycarbonate gasket.

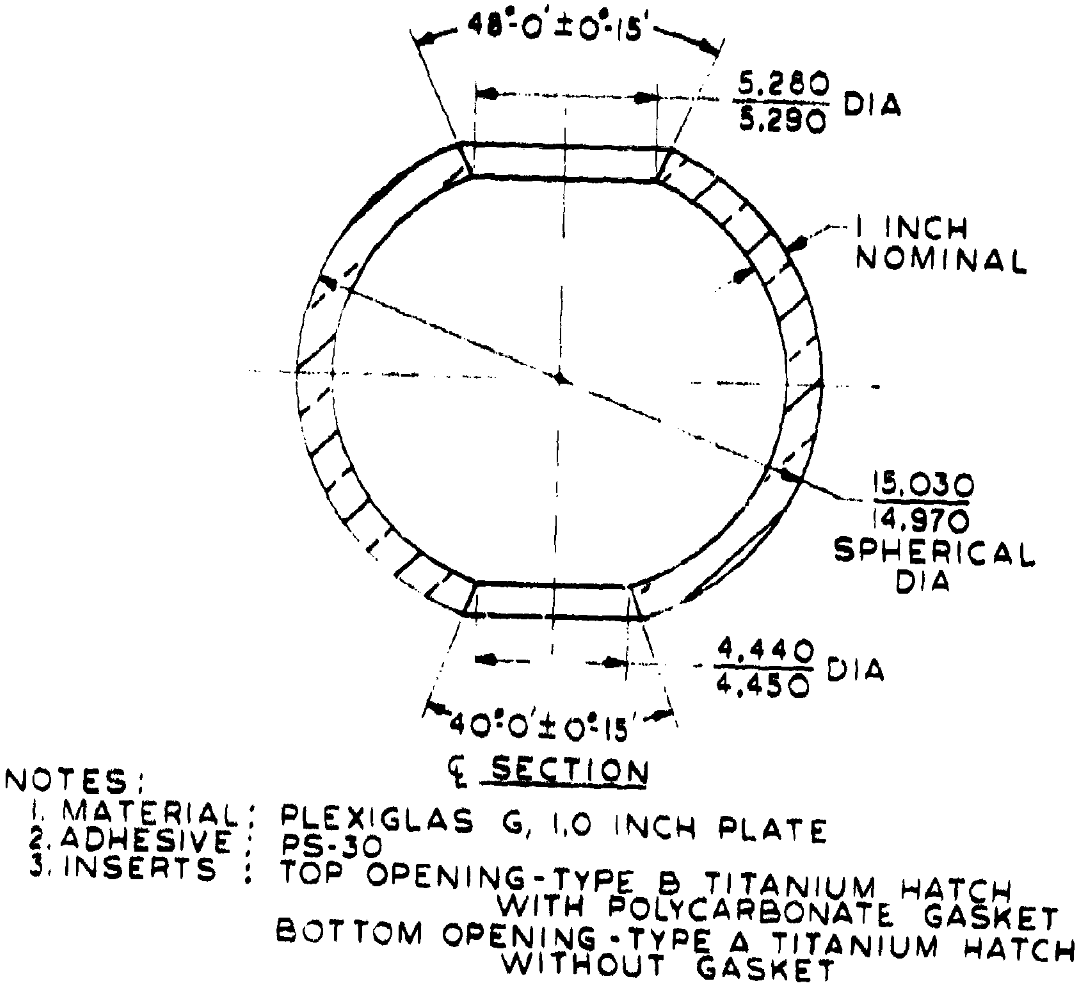


Figure 8A. Typical assembly of 15-inch OD × 13-inch ID Models 35, 36 and 37.

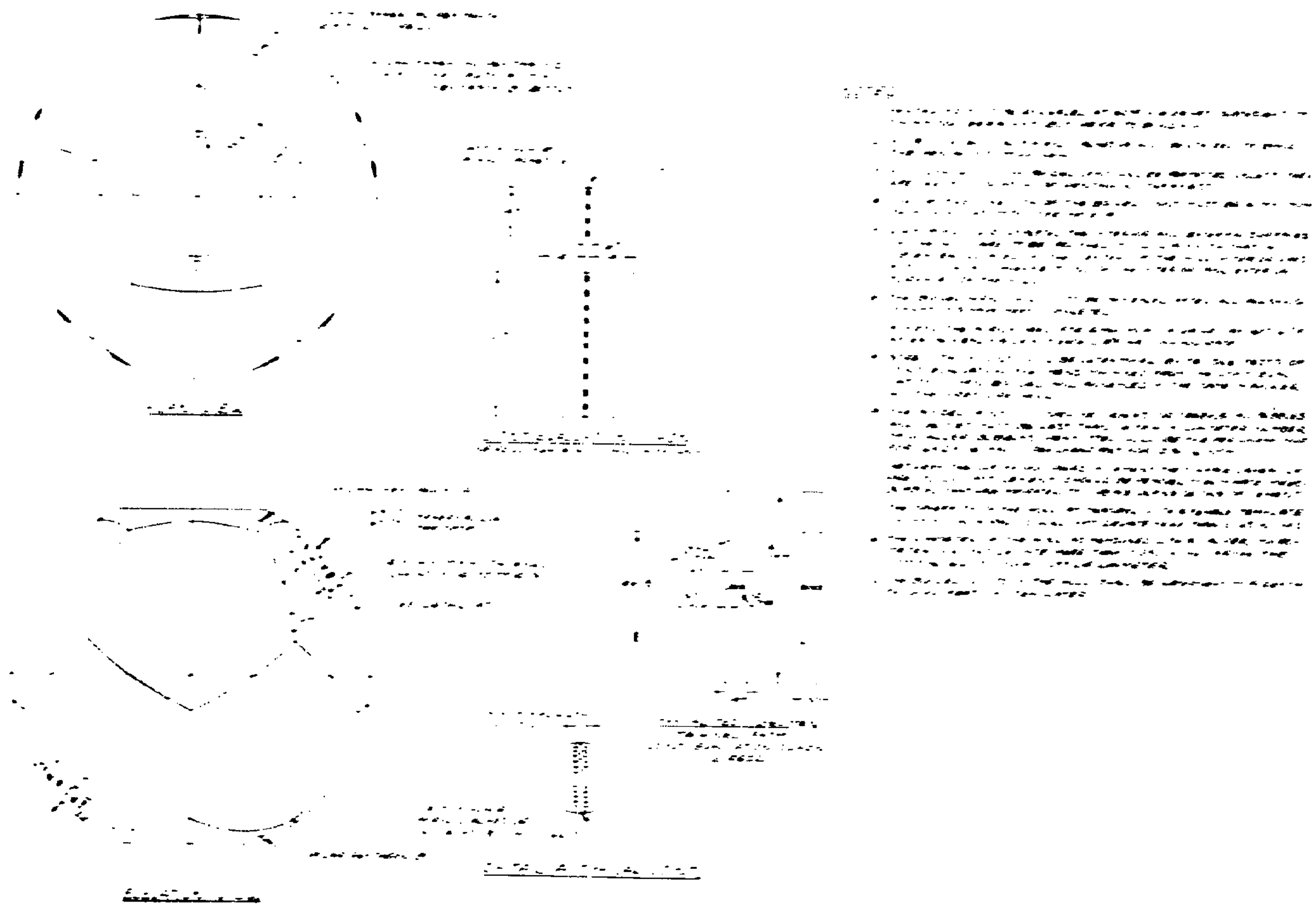


Figure 9A. Model 2000 acrylic Nemo Hull assembly, 66-inch OD × 58-inch ID.

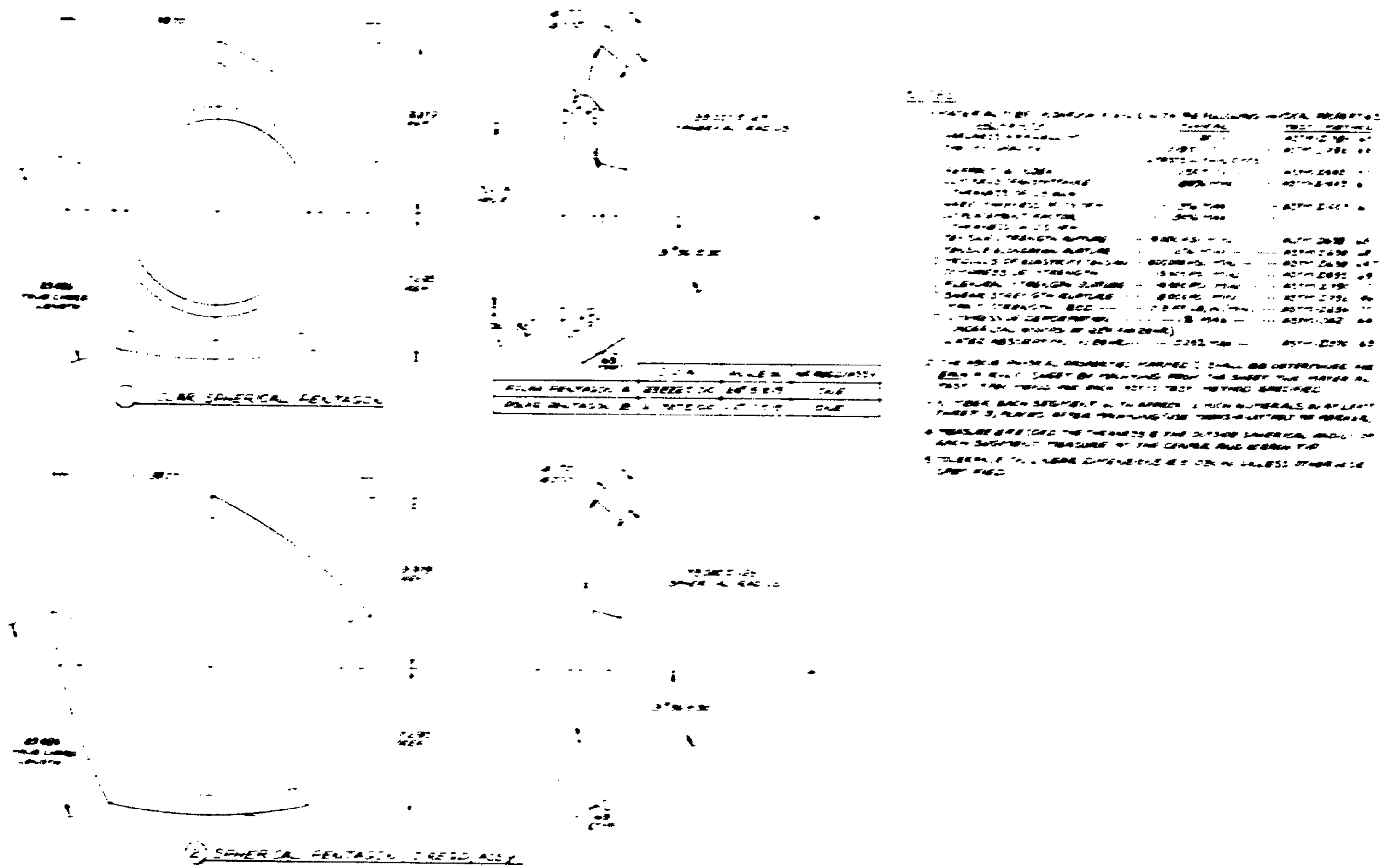


Figure 10A. Spherical pentagons for the 66-inch OD × 58-inch ID Model 2000 Nemo Hull.

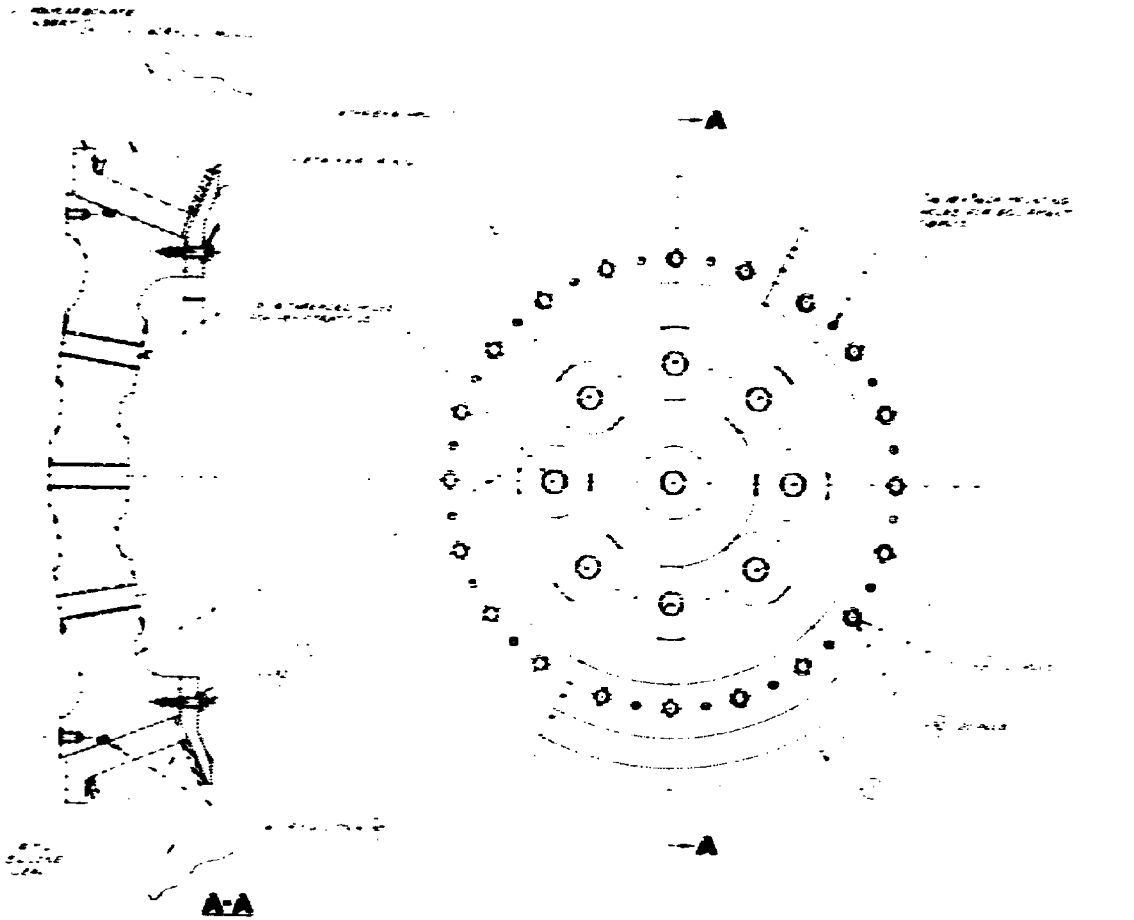


Figure 11A. Bottom plate assembly for the 66-inch OD × 58-inch ID Model 2000 Nemo Hull.

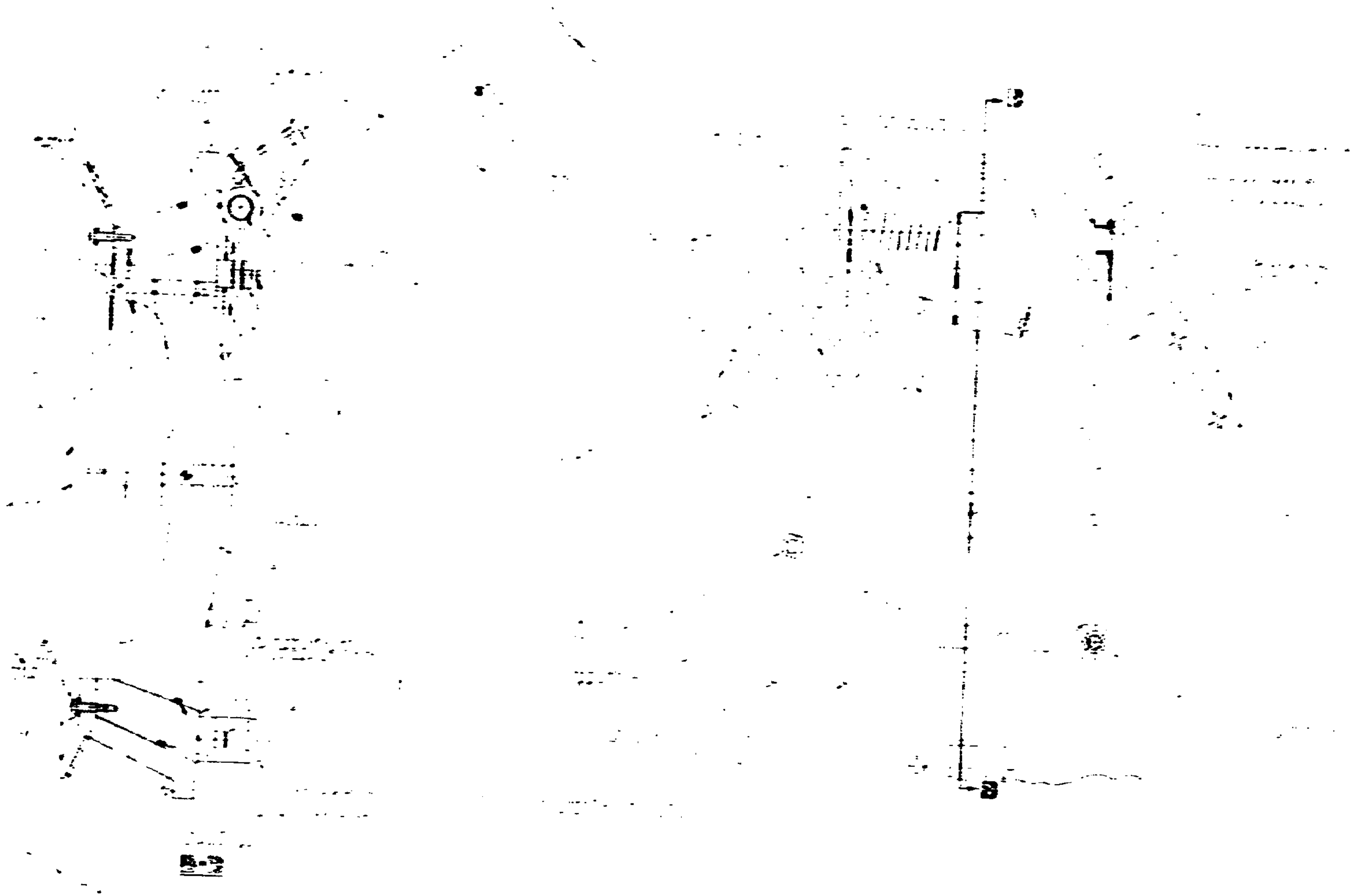


Figure 12A. Hatch assembly for the 66-inch OD × 58-inch ID Model 2000 Nemo Hull.

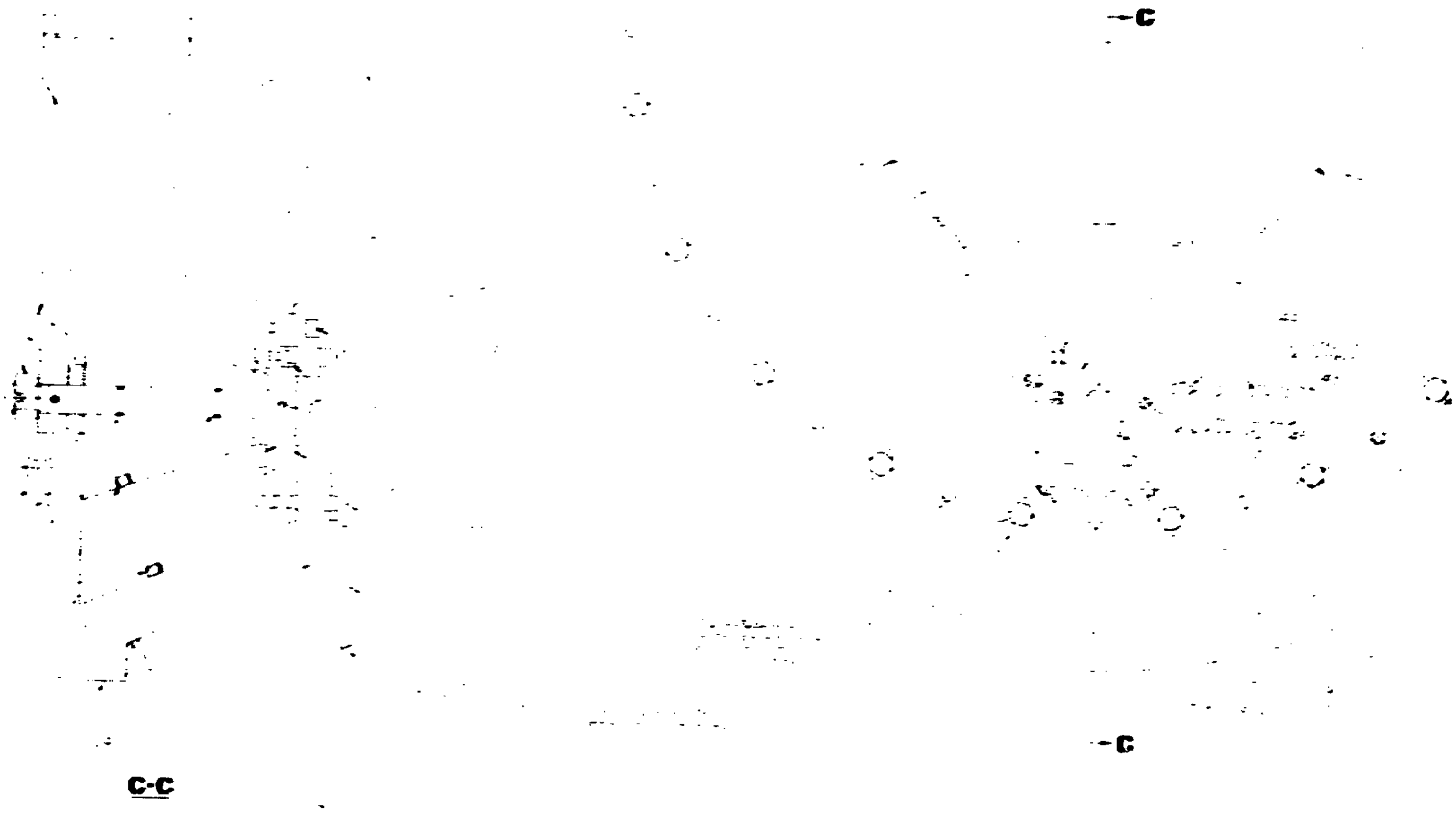


Figure 13A. Hatch lock assembly for the 66-inch OD - 58-inch ID Model 2000 Nemo Hull.

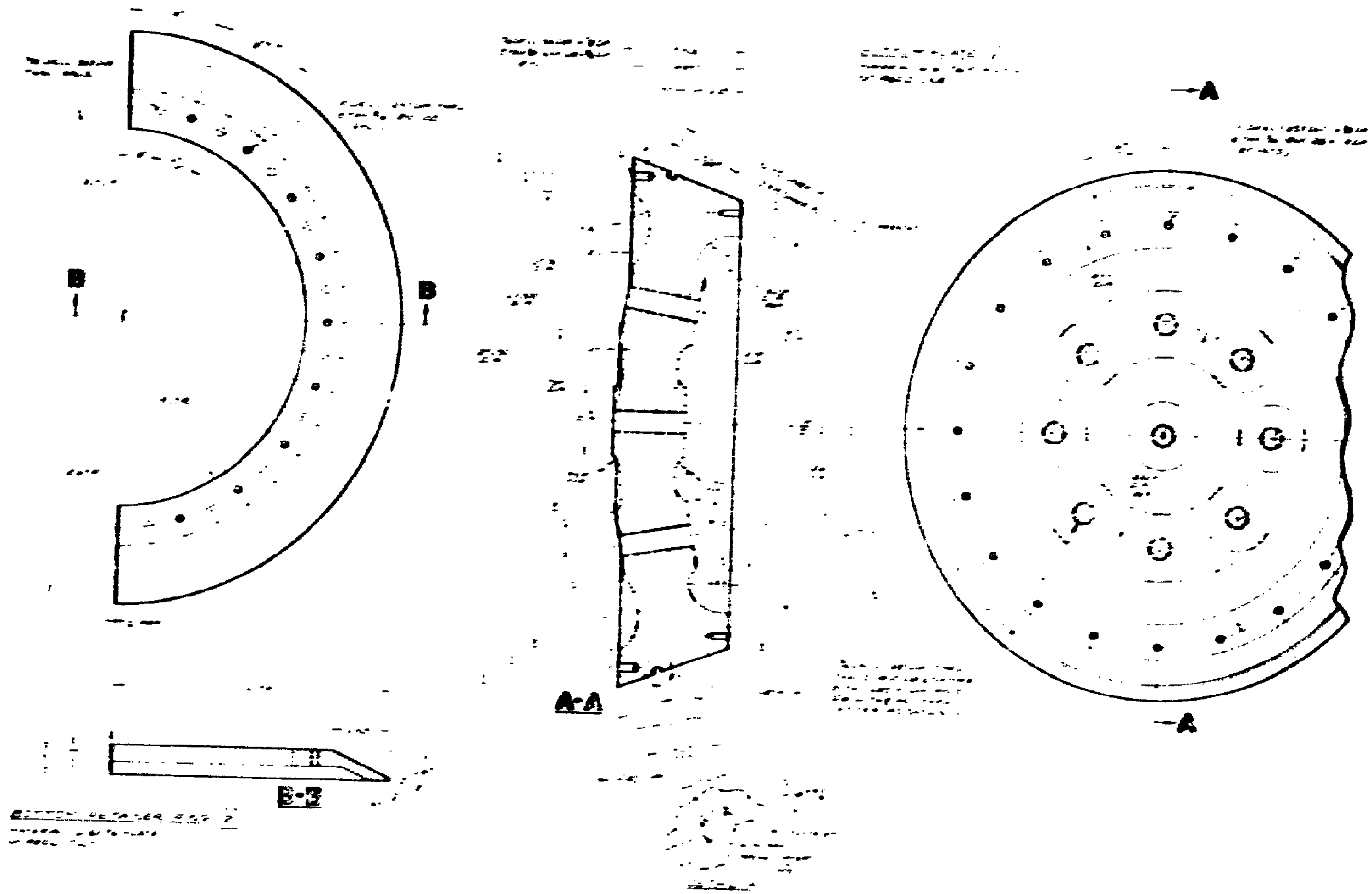


Figure 14A. Bottom plate and bottom retainer ring for the 60-inch OD × 58-inch ID Model 2000 Nemo Hull.

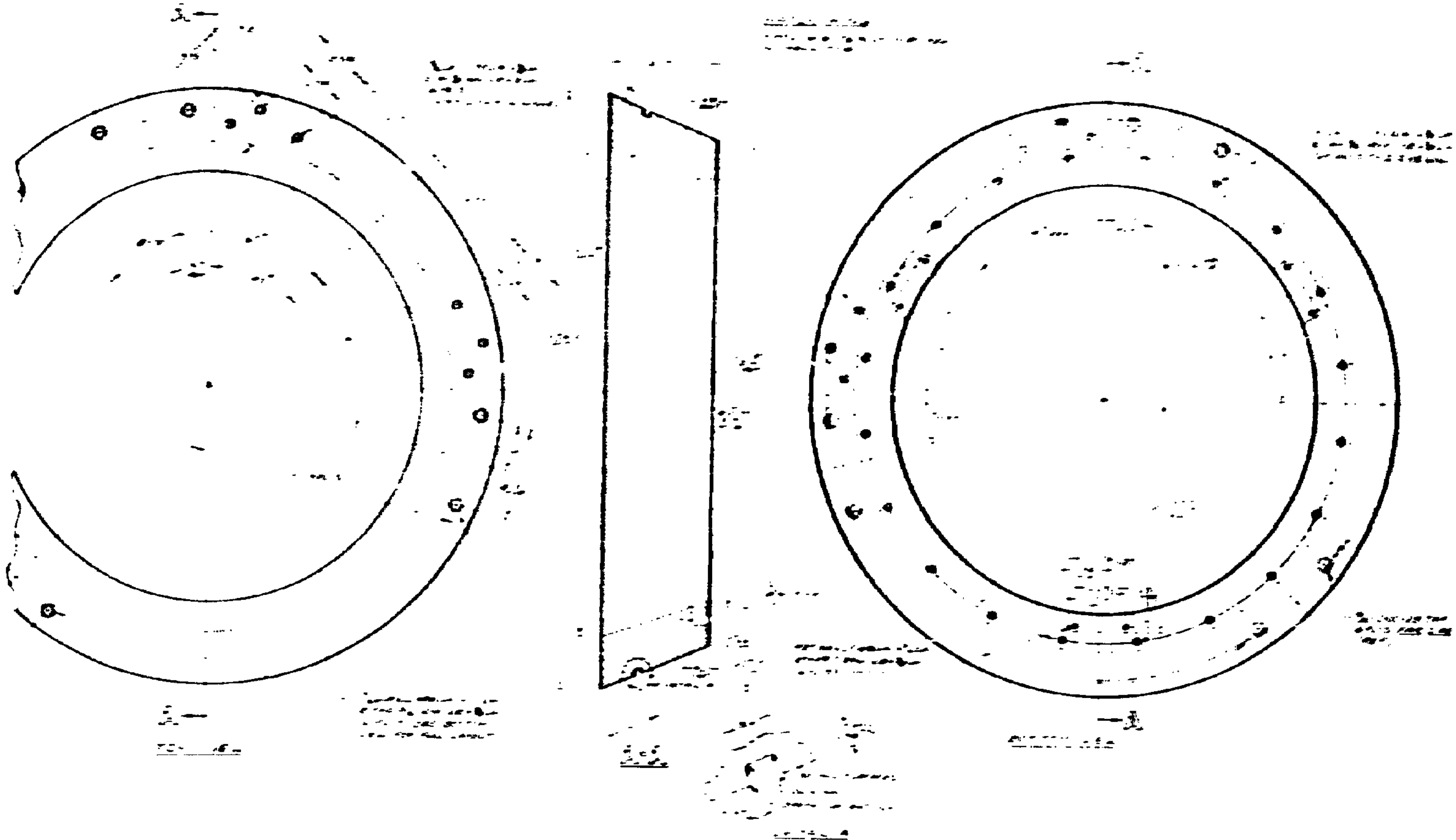


Figure 15A. Hatch ring for the 66-inch OD × 58-inch ID Model 2000 Nemo Hull.

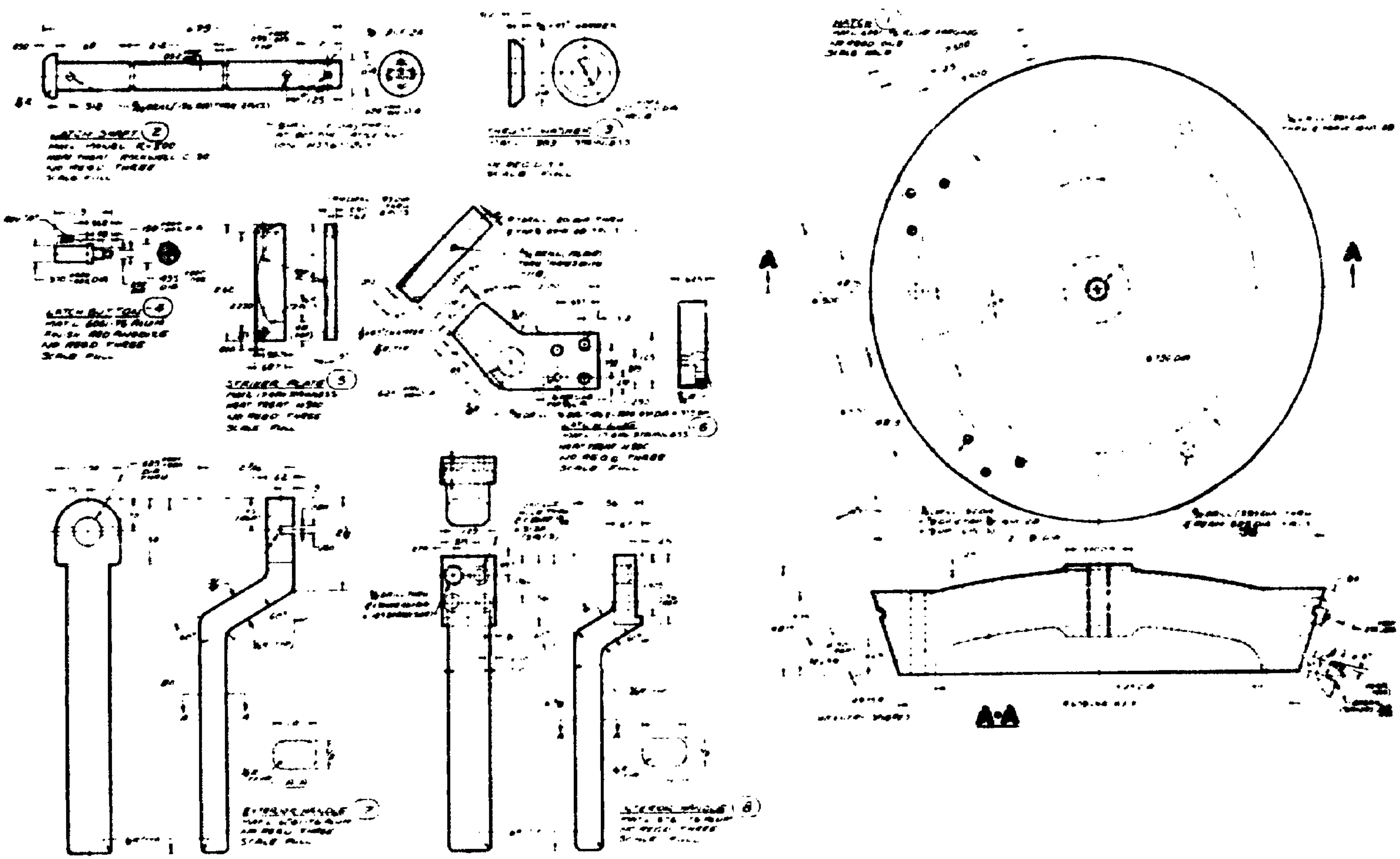


Figure 16A. Hatch and locking mechanism for the 66-inch OD × 58-inch ID Model 2000 Nemo Hull.

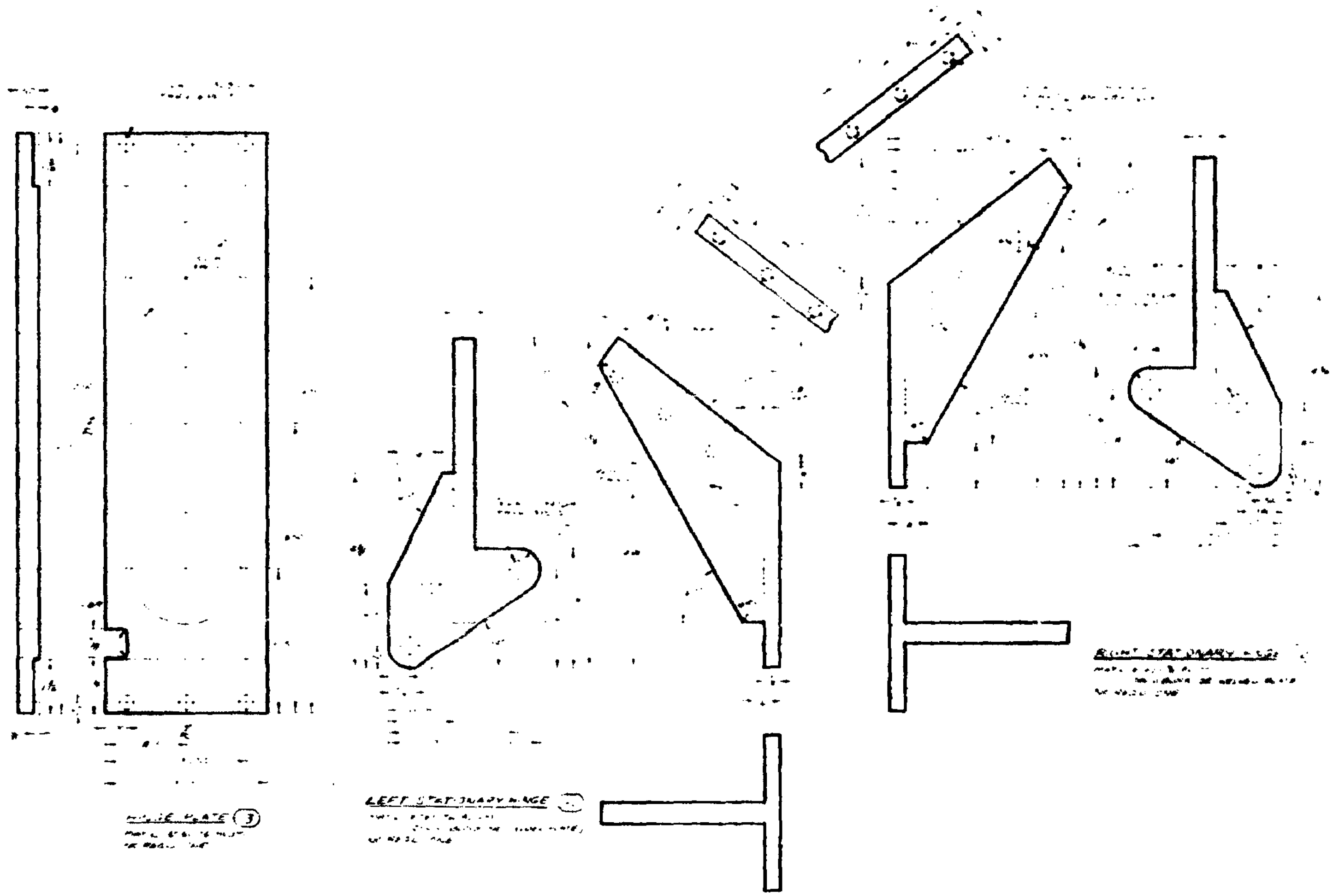


Figure 17A. Stationary hinges and hinge plate for the 66-inch OD × 58-inch ID Model 2000 Nemo Hull.

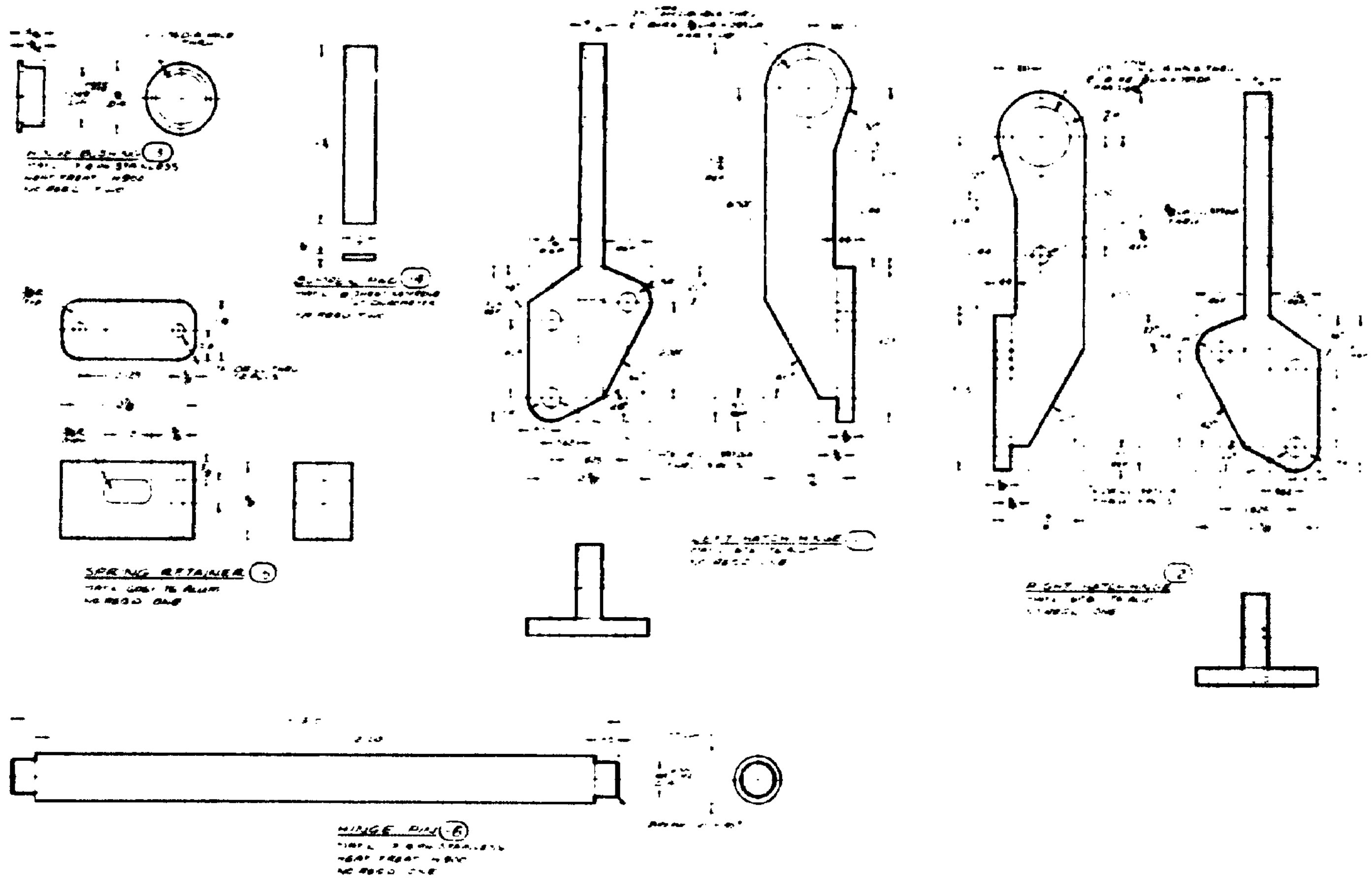


Figure 18A. Hatch hinge and hinge components for the 66-inch OD × 58-inch ID Model 2000 Nemo Hull.

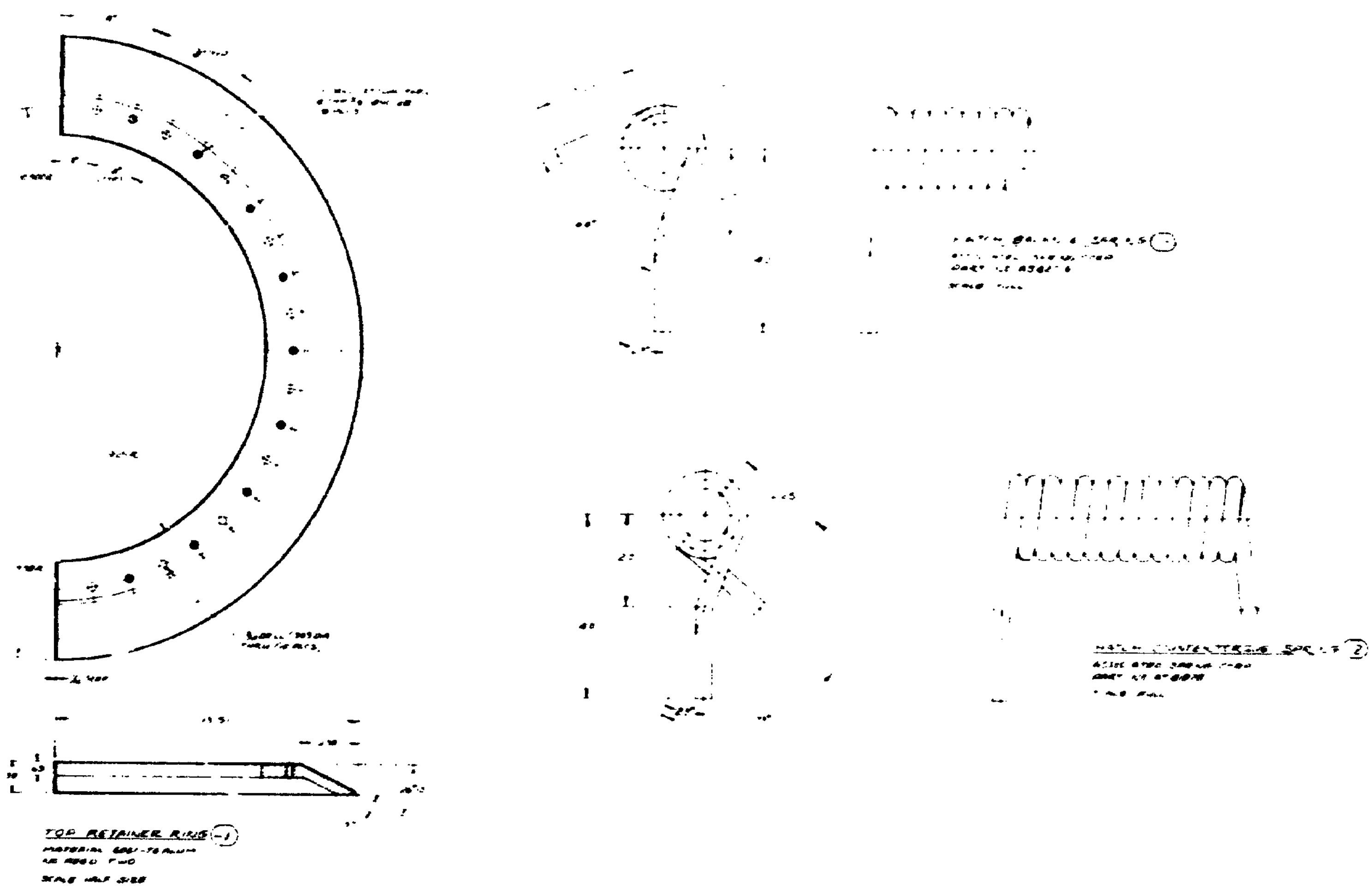


Figure 19A. Top retainer ring and counter balance springs for the 66-inch OD X 58-inch ID Model 2000 Nemo Hull.

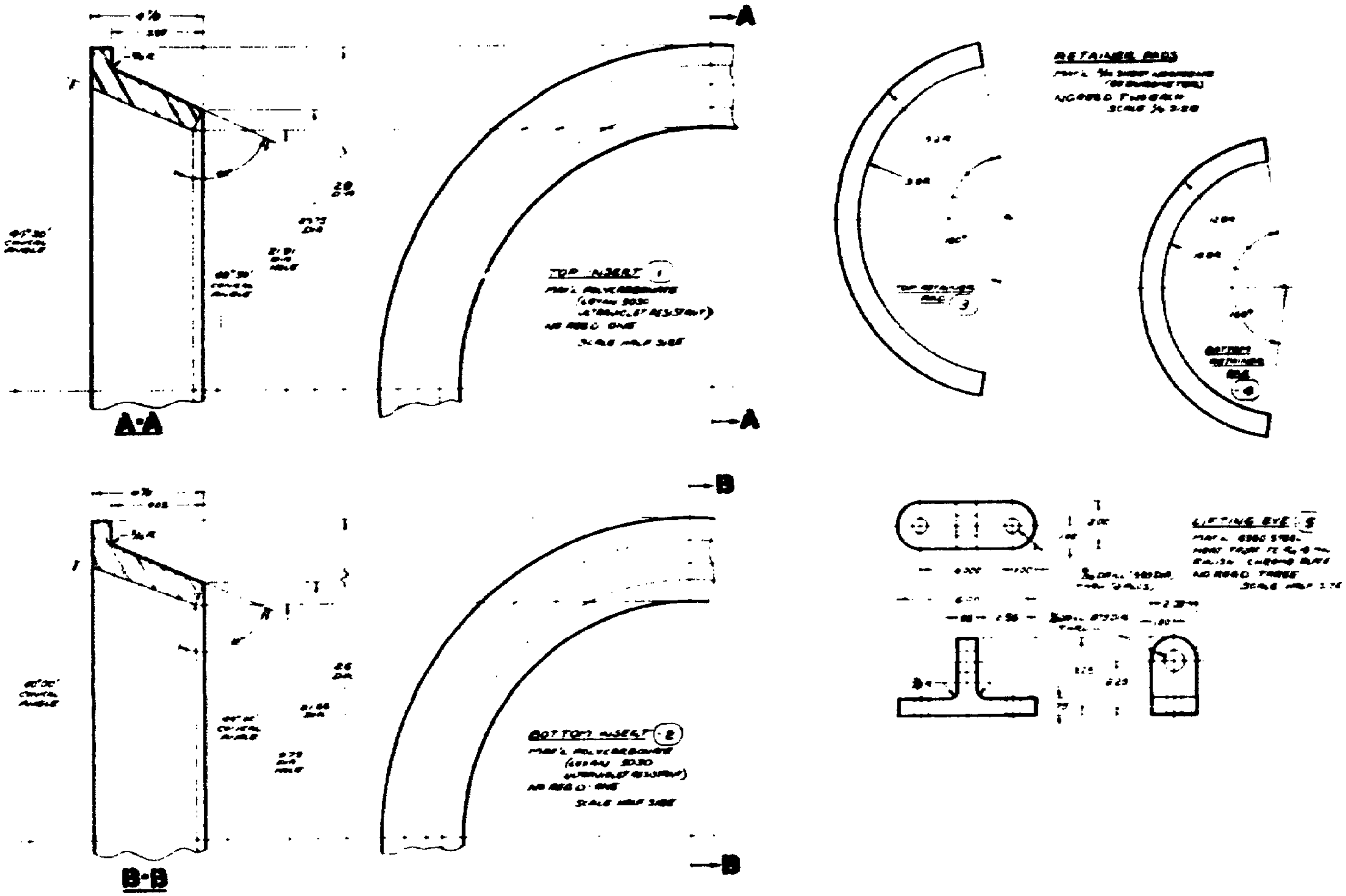


Figure 20A. Inserts, retainer pads, and lifting eye for the 66-inch OD × 58-inch ID Model 2000 Nemo Hull.

APPENDIX B. FABRICATION OF 66-INCH OD × 58-INCH ID MODEL 2000 NEMO HULL

The 66-inch OD × 58-inch ID Model 2000 Nemo Hull assembly was fabricated basically in the same manner as the first 66-inch OD × 51-inch ID Model 600 Nemo Hull assembly built in 1968 by the Technical Services of Pacific Missile Range, Point Mugu, California. The cardinal features of that fabrication process are (1) cutting of discs from flat acrylic stock (Figure 1B), (2) thermoforming these discs into spherical sectors by means of metallic vacuum mold (Figure 2B), (3) cutting of spherical sectors into spherical pentagons (Figure 3B), (4) bonding of 12 spherical pentagons into a spherical shell (Figure 4B), (5) machining of metallic inserts in the form of top hatch and bottom penetration plate (Figure 5B), and placement of those inserts into polar hull openings (Figure 6B).

One phase of the fabrication process that has given trouble over the years to Nemo fabricators is that of the bonding of assembled 12 spherical pentagons. The problems associated with this phase of fabrication stem from the fact that the thickness of spherical pentagons bordering on a joint is not the same and that the width of joints between pentagons is not uniform. Because of the noncomformity in pentagon thickness and joint width it was difficult to seal the joint effectively so that it would contain the selfpolymerizing adhesive without leakage and yet assure a free flow of adhesive downwards and of displaced air upwards.

Steps were taken during fabrication of the Model 2000 Nemo Hull to eliminate the problems posed by nonuniform pentagon thicknesses and joint widths. These steps consisted of the following operations:

1. machining of all formed spherical sectors to uniform thickness in a lathe.

2. use of 0.125-inch thick × 0.25-inch diameter acrylic discs as spacers between individual pentagons during final assembly.

3. bonding of acrylic plastic strips to edges of joints for forming of pressure tight joint.

4. placement under pressure of selfpolymerizing adhesive into the joint cavities.

Because of these additional fabrication processing operations the resulting acrylic sphere is more uniform in thickness, sphericity, and diameter. As a result of this uniformity, the finished acrylic hull can be rated to higher operational pressure than was feasibly able prior to this time. Because the improved fabrication process may be of interest to others, a verbatim reproduction of shop fabrication instructions is attached as enclosure 1B at the end of this Appendix.

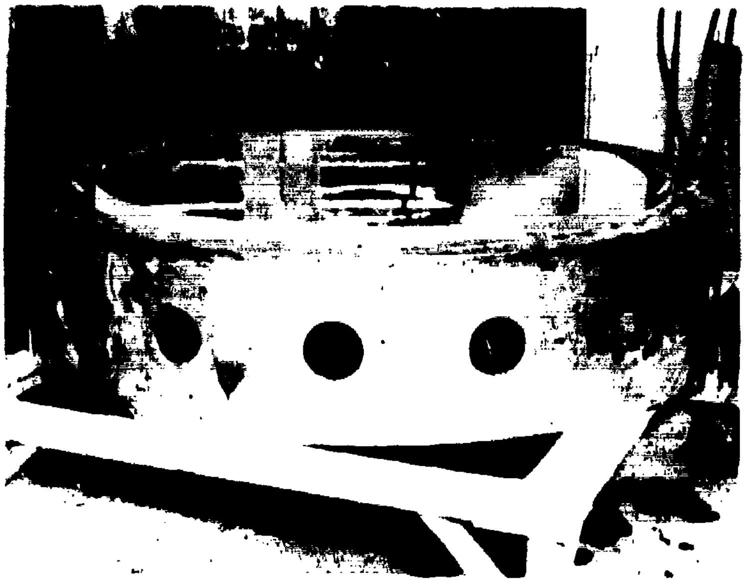
In parallel with the fabrication of the Model 2000 Nemo Hull, stringent quality control measures were adapted to assure a quality product and are attached as enclosures 2B through 9B. The quality control measures consisted of:

1. performing destructive tests on material coupons cut from each sheet of acrylic plastic to ascertain the material properties of plastic (enclosure 2B).

2. performing destructive tests on bonded material coupons to ascertain strength of bonded joints (enclosure 3B).

3. performing dimensional checks on the spherical hull to ascertain its adherence to specified dimensional tolerances. Samples of dimensional checks are shown for thickness of discs before annealing (enclosure 4B), thickness of disc after annealing (enclosure 5B), thickness of disc after forming (enclosure 6B), sphericity of disc after forming (enclosure 7B), thickness of spherical pentagon after machining (enclosure 8B) and diameter of bonded sphere after annealing (enclosure 9B).

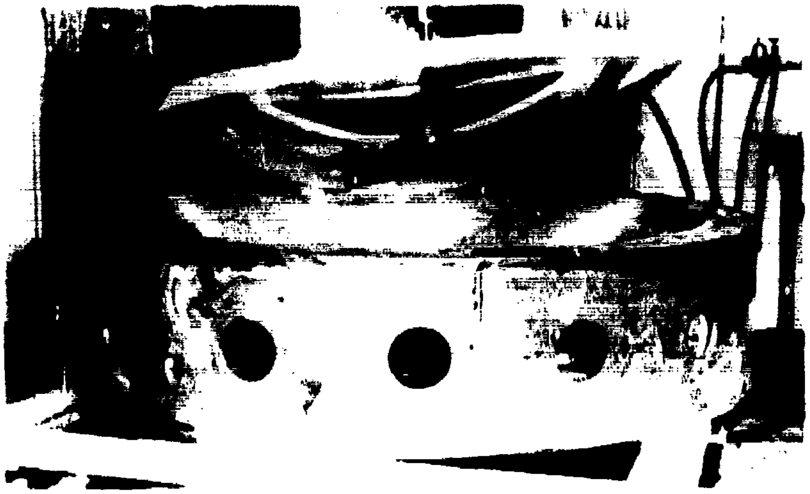
Figure 1B. Sawing of flat plates into circular discs of 46-inch diameter.



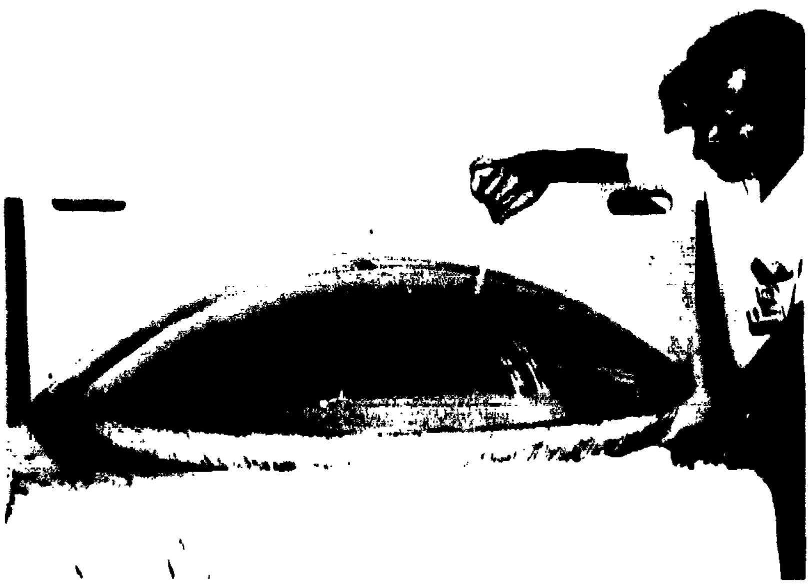
(a) Placement of disc into an aluminum female mold

(b) After forming the spherical sector is ready for removal from the mold

Figure 2B. Thermoforming of flat circular discs into spherical sectors.



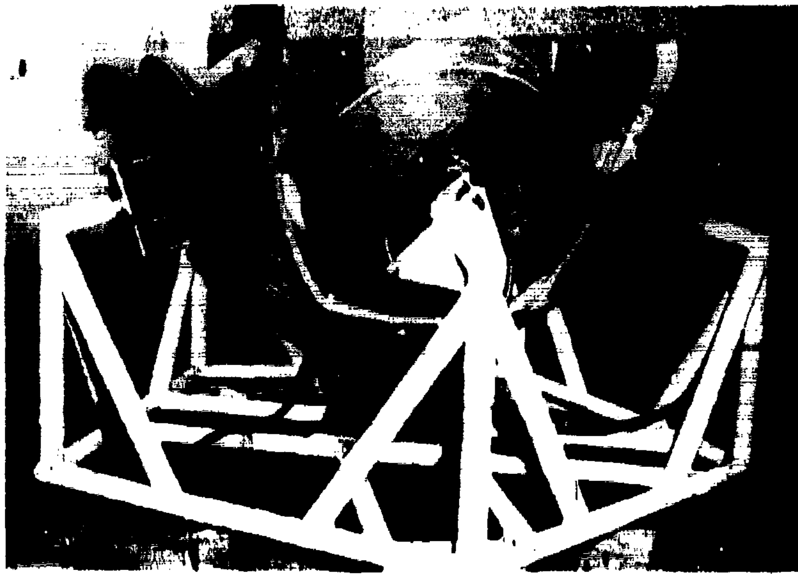
(c) The sector is picked up with a vacuum suction disc from the mold



(d) Checking of sphericity on the formed sector

Figure 2B. (Continued).

Figure 3B. Sawing the spherical sector into the form of a spherical pentagon.



(a) Bonding of six pentagons to form a hemisphere

(b) Bonding of two hemispheres to form a sphere

Figure 4B. Holding fixture for bonding of spherical pentagons; note the large vacuum suction discs for holding of individual pentagons.

(c) Completed sphere after removal from bonding fixture

Figure 4B. (Continued).

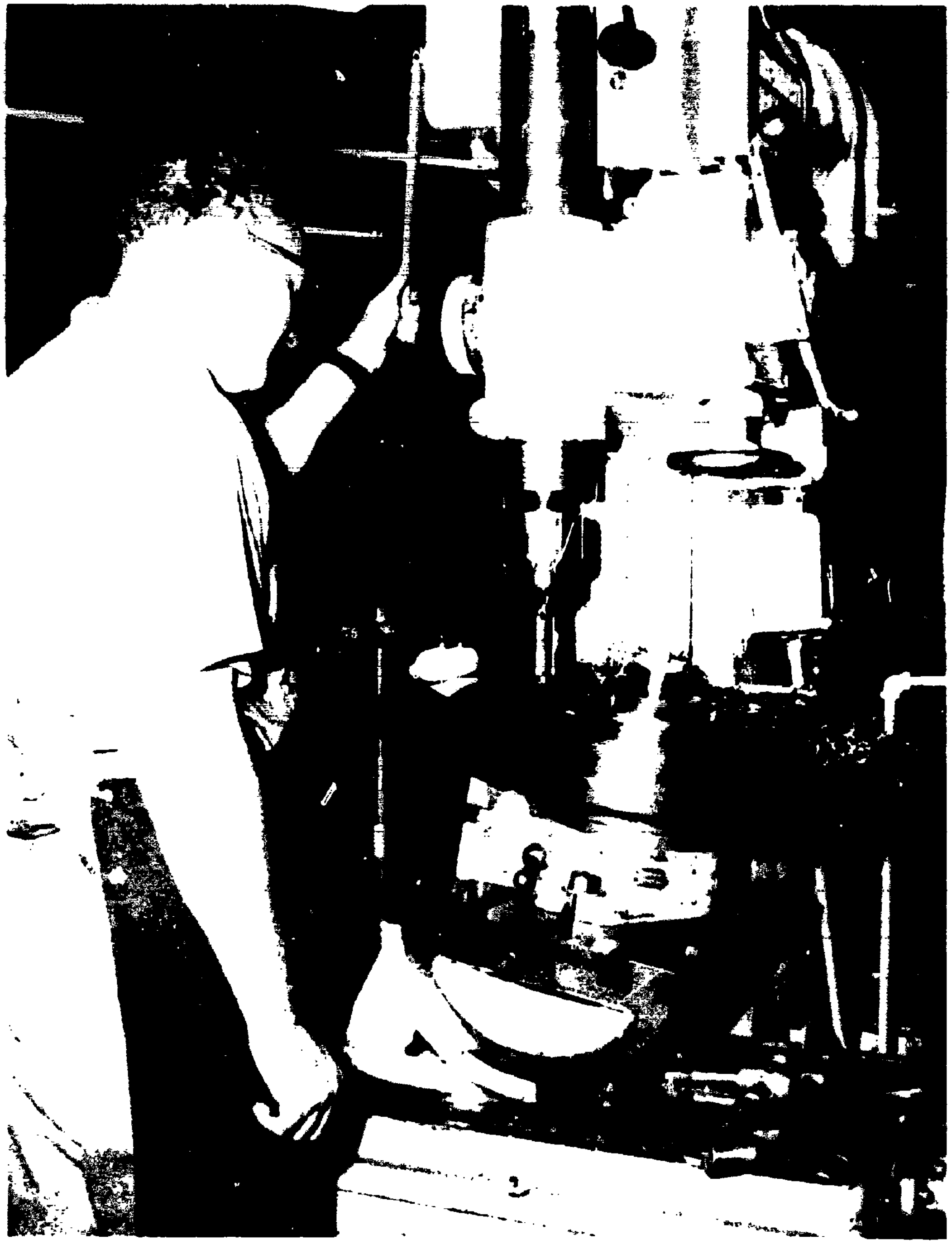
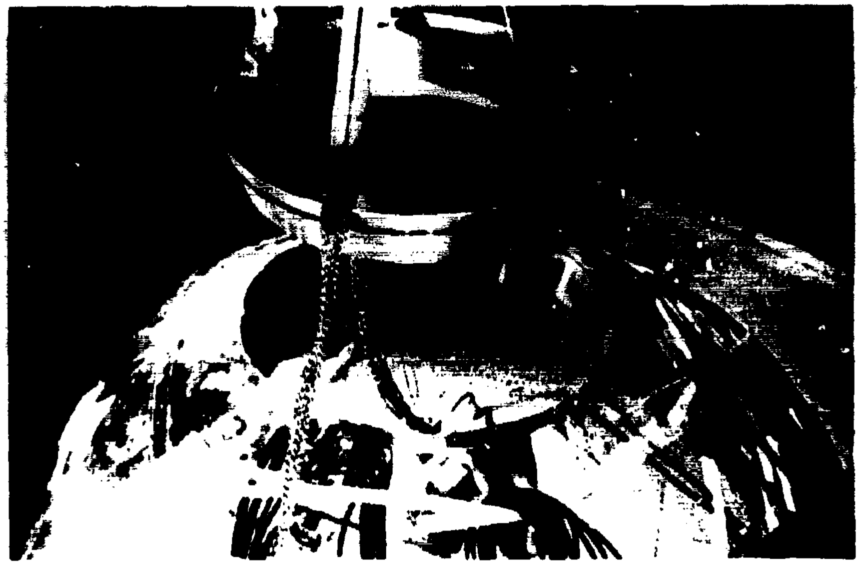
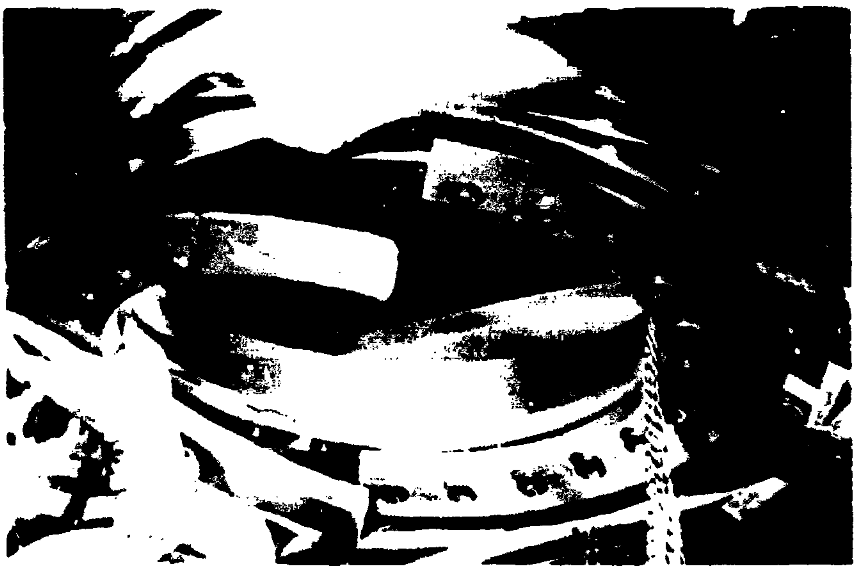


Figure 5B. Machining of metallic inserts for polar openings in the hull.

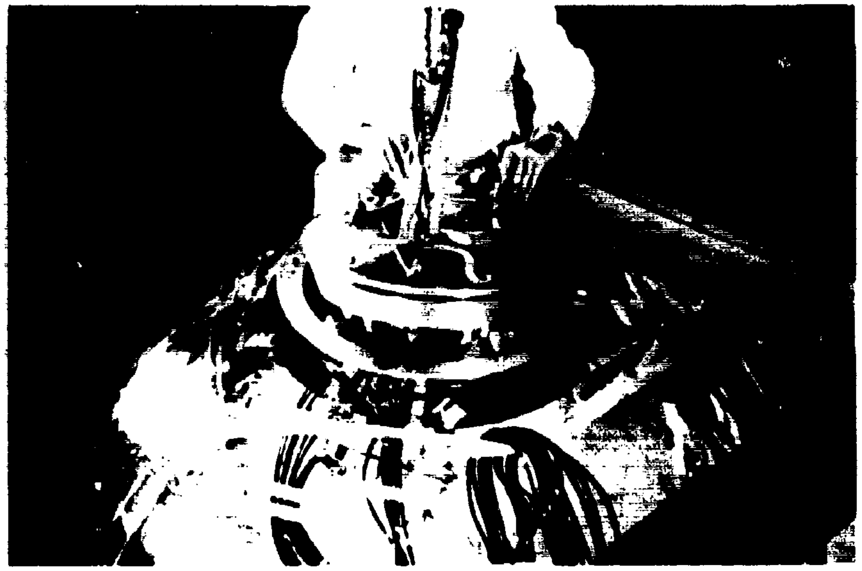


(a) Hatch seat being lowered in place

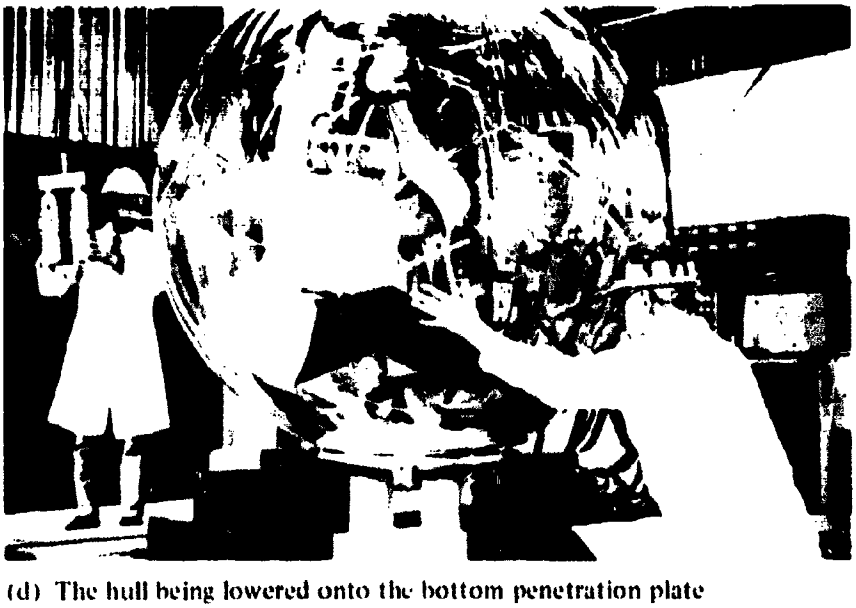


(b) Placement and bolting in place of hatch seat retaining flange

Figure 6B. Placement of metallic inserts into polar opening.



(c) Hatch assembly being attached to the hatch seat



(d) The hull being lowered onto the bottom penetration plate

Figure 6B. (Continued).

(e) Placement in place of retaining flange for bottom penetration plate

(f) Bolting of retaining flange for bottom penetration plate

Figure 6B. (Continued).

ENCLOSURE 1B

SHELDLOW's INSTRUCTIONS FOR WORKERS FABRICATING NEMO MOD 2000

1. Measure thickness of acrylic plate and chart at 12" intervals. Lay out a 46" diameter circle at the thickest part of the blank. Lay out nothing under 4.050 inches. Scribe SWU # on one cut off.
2. Bandsaw trim to line. Save one cut off that is scribed and send to C. Miller in Testing Lab.
3. Anneal the part at 325° F for 12 hours on a flat aluminum plate.
4. Inspect for thickness and chart at 12" intervals. Do not form plates under 4.170 inches.
5. Form per Forming Process Specification
6. Inspect for thickness (4.0 - 4.1) and contour.
7. Anneal @ 175° F for 24 hours.
8. Place part in machining fixture and align to marks. Drill three each 1/2" dia. holes and counterbore for 1/2" dia. Allen bolt. Bolt part down in three places.
9. Set up part and tracer template in Lucas lathe. Machine inside surface. Remaining thickness to be 4.050 minimum. Check contour readings to be sure part is 4.010 minimum at out of contour places. Part should be machined to 4.100 wherever possible and center section of part should not be cut as it will be under 4.100 thickness. Blend cut and uncut surfaces together with 360 grit wet sandpaper. This part must be polished to an optical finish after machining so the cut must be as smooth as possible.
10. Using vacuum lift place part in pentagon machine fixture and even up the edge of the part to the size of the fixture. Vacuum part into place on machining fixture. Make sure that hole in part comes out in the center of the piece to be cut off. Close air toggle clamps. Start saw and set feed at 25 inches per minute.
11. While cutting off first piece the saw may have a tendency to slow down or stop. If this happens, immediately press the return button, let the saw return and start the cut over. After cutting off the first piece, open

up the air toggle clamps and press the lever all the way to the left. This will lift the rotating part of the fixture slightly so that the index pin can be pulled and the part rotated to the next position. Continue this procedure until all five cuts have been made. Attach polar hole machining fixture to rotary table and place table on the milling machine. Two pentagons only. Place pentagon into machining fixture and bolt into place. Using a 7/8" dia. x 5" long end mill, cut a hole thru the part per the dimensions on NEMO Model 2000 Drawing #2003

12. Inspect for blueprint dimensions.
13. Anneal at 175°F for 24 hours.
14. Clean up.
15. Take to assembly room.
16. Place one (1) Polar Pentagon in center of assembly fixture and using the large Starrett No. 656-441 indicator attached to extension, set against 1/2" ball situated in center of assembly pad.
17. Making sure indicator is laying flat against holding pad and measure distance from 1/2" ball to the inside of cut out in pentagon.
18. When pentagon is centered, place "L" shaped clamps to hold pentagon in place and bolt tightly to keep pentagon from moving during assembly.
19. Obtain 1/8" thick x 1/4" diameter acrylic spacers and bond approximately 4" from each corner centered.

    NOTE: Two (2) spacers are needed per side only. If one pentagon has these blocks, then omit blocks to mating side.

    Use PS-30 cement - for bonding spacers.
20. Using the vacuum hand lift, place five (5) pentagons into assembly fixture and align with polar pentagon.
21. After alignment obtain large micrometer with Brown and Sharpe No. 8241-941 dial indicator from inspection box. Obtain the three rods from box (1) 22" (2) 23" and (3) 21". Assemble together and set dial indicator to read zero.

NOTE: Dial indicator will not set at zero-zero dial, but will set at 600, so turn dial indicator to read zero to 600.

22. Using dial indicator measure the diameter of the hemisphere and shim where necessary to read 66" + .25". Measure hemisphere.

    NOTE: Each pentagon must be measured to one situated directly across from from one to the other.

23. When hemisphere is within spherical tolerance of 66" ± .250", obtain Flex G acrylic strips 3/4" thick or S310 material 0.750" wide by 36" long. Take to Machining and rout a groove down the center length 1/8" wide x 1/2" deep.

24. Form these strips to fit both outside and inside surfaces of set pentagons. Using methylene cloride, bond the strips to the pentagons.

25. After all strips have been bonded to hemisphere, place a bead of PS-18 resin around all strips to prevent leaks after hemisphere has been filled with S-49 casting cement.

26. Drill an "F" size hole at lowest point of hemisphere. Place a 1/4" OD aluminum tube 3" long into hole and cement into place between pentagons.

27. Obtain 2000 grams of basic S-49 resin from resin mixing room-in-a new, clean gallon can: Mix 4 grams of benzoin (.2) and 10 grams of larurel peroxide (.5). Place lid on container. Take resin to the NEMO room which is a temperature controlled room @ a constant 72°F.

28. Place gallon can on converted edge attachment sander, and set atop the two (2) rollers. Turn switch on and let roll over night.

29. Place mixed S-49 as resin into pressure pot and attach nitrogen bottle to pot. Attach fill tube from pot to 1/4" OD Aluminum tube on sphere.

30. Apply five (5) pounds pressure.

31. Fill joints all around Polar Pentagon and allow resin to rise approximately one (1) inch above the upright joints. (This allows for shrinkage).

32. Clamp off tube.

33. Allow to cure in NEMO room until hard (approximately 24 hours). Room is

to be kept between 70°F and 75°F temperature.

34. Remove first hemisphere from cement fixture.

35. Rout joints on both outside and inside flush with pentagons.

36. Polish up all seams on both inner and outer surfaces.

37. Place six (6) new pentagons into assembly fixture and assemble same as first pentagon. Follow steps one (16) through twenty-two (36) above.

38. Place hemisphere Number one (1) on top of Number two (2) and check spherical diameter.

39. If hemispheres measure within tolerance of 66" $\pm$ .250", cut, fit and cement joint strips around equator of sphere leaving a funnel at the top of each bottom pentagon.

40. In obtaining and preparing S-49 resin, repeat Steps 27 and 28

41. To feed S-49 resin into the equator section of sphere, follow Steps 29 and 30 of Operation 5.

42. Allow resin to cure in NEMO room until hard (approximately 24 hours). Room is to be kept between 70°F and 75°F temperature.

43. Remove sphere from assembly fixture. Using the cell casting hoist, hook up lifting plate to hoist, fold lifting plate and insert into sphere. Making sure lifting plate will not damage sphere, lift sphere from fixture.

44. Machine, sand and polish all bonded areas.

45. Anneal sphere in a 175°F oven for 24 hours.

46. Inspect all cemented joints for voids larger than 1/4" in diameter.

47. Final clean up.

48. Final Inspection.

49. Wrap with Protec 10V.

ENCLOSURE 2B

SWEDLOW, INC.

Reference: 45-74-121
Date: March 18, 1974

TEST REPORT

CUSTOMER: Disbursing Officer, DCASR, Los Angeles
11099 So. La Cienega Boulevard
Los Angeles, California 90045

PURCHASE ORDER NO.: N00123-73-C-1671

MATERIAL TESTED: Remnants from each sheet used in fabrication of NEMO Model 2000 Hull

Test specimens were cut to rough dimensions using a bandsaw and to final dimensions (with the exception of tensile specimens) by means of a vertical mill, with a six-flute, carbide-tipped shell end-mill. Tensile specimens were routed to the configuration of a template which complies with dimensions set forth in A.S.T.M. D-638 for Type I specimens. Sharp edges were broken to about .005 inch. Machined surfaces were sanded, first with 280 grit paper, and finally with 600 grit Wet-or-Dry paper to remove tool marks. All specimens were annealed to remove any residual stresses introduced during machining.

Test specimens were conditioned, at a temperature of 73.5 ± 2°F and relative humidity of 50 ± 5%, for a period of 40 hours prior to testing.

Tensile, compressive and flexural values were obtained by means of a Tinius-Olsen Elect-O matic Testing Machine. Deformation under load values were obtained on a Tinius-Olsen tester designed for that particular test.

Respectfully submitted,

SWEDLOW, INC.

C. A. Miller, Supervisor
Physical Testing Laboratory

SWEDLOW, INC.

TEST REPORT

Date: March 18, 1974
Purchase Order No.: N00123-73-C-1671

FOR: NEMO Model 2000 Hull
Sales Order No.: 3-5940

Page 1

TENSILE: Conditioned 40 hours at 73°F and 50 Percent R. H.

ASTM D-638 tested at 0.05 In/Min

SHEET NO.	SPECIMEN SIZE (INCH)	LOAD (LBS)	ULTIMATE (PSI)	ELONGATION (PERCENT)	MODULUS (PSI)
021	1- .236 x .483	1330	11,668	7.0	447,000
	2- .242 x .478	1365	11,800	6.0	465,000
023	1- .247 x .481	1465	12,331	6.0	467,000
	2- .251 x .476	1360	11,382	6.0	437,000
024	1- .255 x .479	1400	11,461	5.5	437,000
	2- .254 x .482	1420	11,600	5.5	485,000
025	1- .253 x .481	1425	11,709	5.5	473,000
	2- .252 x .479	1420	11,764	5.0	490,000
026	1- .251 x .483	1415	11,671	5.5	474,000
	2- .252 x .481	1355	11,179	5.5	456,000
027	1- .252 x .479	1315	10,893	5.5	446,000
	2- .253 x .477	1275	10,565	5.5	495,000
028	1- .248 x .472	1235	10,551	5.0	498,000
	2- .252 x .474	1270	10,632	5.5	492,000
029	1- .253 x .471	1200	10,070	4.0	446,000
	2- .247 x .474	1185	10,121	4.0	449,000
034	1- .254 x .475	1290	10,692	5.5	475,000
	2- .247 x .475	1265	10,781	5.0	478,000
035	1- .250 x .479	1250	10,440	5.0	505,000
	2- .246 x .477	1120	9,545	3.0	428,000
036	1- .250 x .476	1280	10,756	5.5	454,000
	2- .251 x .477	1275	10,649	5.0	465,000
037	1- .249 x .475	1250	10,570	5.5	465,000
	2- .248 x .474	1235	10,504	5.5	447,000

SWEDLOW, INC.

NEMO Model 2000 Hull
S. O. No. 3-5940
Test Report, Continued

Page 2

FLEXURAL - Conditioned 40 Hours at 73°F and 50 Percent R. H.

ASTM D-790 - 4 inch span, test speed 0.11 In/Min

SHEET NO.	SPECIMEN SIZE (INCH)	LOAD (LBS)	ULTIMATE (PSI)	MODULUS (PSI)
021	1- .500 x .258	95.8	17,261	415,000
	2- .500 x .258	95.5	17,207	443,000
023	1- .498 x .258	101.3	18,326	444,000
	2- .491 x .257	82.3	15,238	442,000
024	1- .500 x .258	103.1	18,577	452,000
	2- .494 x .258	101.3	18,474	457,000
025	1- .501 x .257	102.0	18,508	433,000
	2- .502 x .258	103.1	18,503	445,000
026	1- .501 x .258	101.1	18,180	460,000
	2- .498 x .257	101.3	18,492	463,000
027	1- .493 x .256	96.3	17,883	459,000
	2- .495 x .256	98.0	18,127	477,000
028	1- .493 x .249	93.1	18,258	478,000
	2- .493 x .247	93.7	18,686	474,000
029	1- .494 x .246	92.4	18,048	479,000
	2- .495 x .249	93.6	18,306	475,000
034	1- .492 x .247	88.1	17,588	475,000
	2- .493 x .246	82.5	16,624	480,000
035	1- .495 x .248	78.7	15,511	487,000
	2- .494 x .247	90.6	18,047	484,000
036	1- .494 x .247	77.0	15,326	473,000
	2- .493 x .248	92.1	18,210	484,000
037	1- .492 x .248	91.4	18,113	469,000
	2- .495 x .248	92.2	18,194	467,000

NEMO Model 2000 Hull
S. O. No. 3-5940
Test Report, Continued

Page 3

DEFORMATION UNDER LOAD

ASTM D 621 - Tested as received at 122°F for 24 hours under 4000 psi load
Test Specimens: 1/2 Inch Cube

SHEET NO.		DEFORMATION (INCH) 10 SEC.	24 HOURS	DIFFER (IN)	MICROMETER READING (IN)	CALC. ORIG. THICKNESS (IN)	DEFORM. (%)
021	1-	0.0863	0.0889	0.0026	0.4998	0.5024	0.52
	2-	0.0822	0.0848	0.0026	0.5025	0.5051	0.51
023	1-	0.0857	0.0886	0.0029	0.4985	0.5014	0.58
	2-	0.0813	0.0842	0.0029	0.5020	0.5049	0.57
024	1-	0.0819	0.0843	0.0024	0.5013	0.5037	0.48
	2-	0.0764	0.0788	0.0022	0.5025	0.5047	0.44
025	1-	0.0755	0.0778	0.0023	0.5036	0.5059	0.45
	2-	0.0763	0.0787	0.0024	0.5023	0.5047	0.48
026	1-	0.0765	0.0795	0.0030	0.5014	0.5044	0.60
	2-	0.0752	0.0774	0.0022	0.5007	0.5029	0.44
027	1-	0.0684	0.0708	0.0024	0.5029	0.5053	0.47
	2-	0.0676	0.0699	0.0023	0.5036	0.5039	0.46
028	1-	0.0738	0.0761	0.0023	0.4980	0.5003	0.46
	2-	0.0708	0.0735	0.0027	0.5003	0.5030	0.54
029	1-	0.0691	0.0712	0.0021	0.5014	0.5035	0.42
	2-	0.0707	0.0733	0.0026	0.4997	0.5023	0.52
034	1-	0.0709	0.0743	0.0034	0.4986	0.5020	0.67
	2-	0.0720	0.0751	0.0031	0.4983	0.5014	0.61
035	1-	0.0714	0.0745	0.0031	0.4990	0.5021	0.61
	2-	0.0711	0.0744	0.0033	0.4980	0.5013	0.65
036	1-	0.0715	0.0747	0.0032	0.4975	0.5007	0.63
	2-	0.0698	0.0734	0.0036	0.4996	0.5032	0.72
037	1-	0.0708	0.0740	0.0032	0.4991	0.5023	0.64
	2-	0.0707	0.0740	0.0033	0.4982	0.5015	0.66

SHEAR STRENGTH

ASTM D-732 Rate of Test: 0.05 In/Min
Punch Diameter: 0.999 In. (1.000 In. Dia. disc punched out)

SHEET NO.		THICKNESS (INCH)	MAXIMUM LOAD (LBS)	SHEAR STRENGTH (PSI)
021	1-	0.259	8,240	10,100
	2-	0.253	8,250	10,400
023	1-	0.255	8,190	10,200
	2-	0.254	8,220	10,300
024	1-	0.254	8,190	10,300
	2-	0.256	8,260	10,300
025	1-	0.257	8,220	10,200
	2-	0.258	8,340	10,300
026	1-	0.254	8,830	11,100
	2-	0.255	8,210	10,300
027	1-	0.250	7,800	9,930
	2-	0.245	7,770	10,100
028	1-	0.245	8,220	10,700
	2-	0.254	8,440	10,600
029	1-	0.250	8,200	10,400
	2-	0.253	8,690	10,900
034	1-	0.253	8,870	11,200
	2-	0.254	8,770	11,000
035	1-	0.252	9,130	11,500
	2-	0.253	8,450	10,600
036	1-	0.255	9,100	11,400
	2-	0.253	8,670	10,900
037	1-	0.254	8,340	10,500
	2-	0.256	7,950	9,880

COMPRESSIVE PROPERTIES : Tested at Room Temperature

ASTM D-695 Rate of Test: 0.05 In/Min

SHEET NO.		SPECIMEN SIZE (INCH)	YIELD LOAD (LBS)	YIELD STRENGTH (PSI)	MODULUS (PSI)
021	1-	0.503 x 0.502 x 1.504	4,880	19,300	570,000
	2-	0.503 x 0.502 x 1.505	4,950	19,600	530,000
023	1-	0.500 x 0.503 x 1.502	4,630	18,400	520,000
	2-	0.501 x 0.503 x 1.502	4,590	18,200	500,000
024	1-	0.503 x 0.503 x 1.499	4,610	18,200	510,000
	2-	0.504 x 0.503 x 1.499	4,740	18,700	500,000
025	1-	0.505 x 0.505 x 1.502	4,660	18,300	510,000
	2-	0.504 x 0.504 x 1.500	4,780	18,800	510,000
026	1-	0.503 x 0.503 x 1.501	4,570	18,100	510,000
	2-	0.503 x 0.501 x 1.500	4,650	18,500	520,000
027	1-	0.504 x 0.506 x 1.502	4,650	18,200	510,000
	2-	0.506 x 0.504 x 1.504	4,690	18,400	520,000
028	1-	0.501 x 0.501 x 1.500	4,650	18,500	540,000
	2-	0.502 x 0.502 x 1.507	4,710	18,700	540,000
029	1-	0.502 x 0.502 x 1.506	4,810	19,100	530,000
	2-	0.502 x 0.502 x 1.506	4,610	18,300	500,000
034	1-	0.501 x 0.502 x 1.505	4,520	18,000	510,000
	2-	0.501 x 0.500 x 1.505	4,600	18,400	530,000
035	1-	0.502 x 0.501 x 1.506	4,650	18,500	520,000
	2-	0.503 x 0.503 x 1.506	4,480	17,700	530,000
036	1-	0.503 x 0.502 x 1.505	4,510	17,900	510,000
	2-	0.501 x 0.500 x 1.506	4,490	17,900	510,000
037	1-	0.501 x 0.502 x 1.505	4,640	18,400	530,000
	2-	0.503 x 0.502 x 1.503	4,510	17,900	530,000

ENCLOSURE 3B

SWEDLOW, INC.

Date: 21 May 1974

TEST REPORT

For: NEMO Model 2000 Hull

Purchase Order No. N00123-73-C-1671

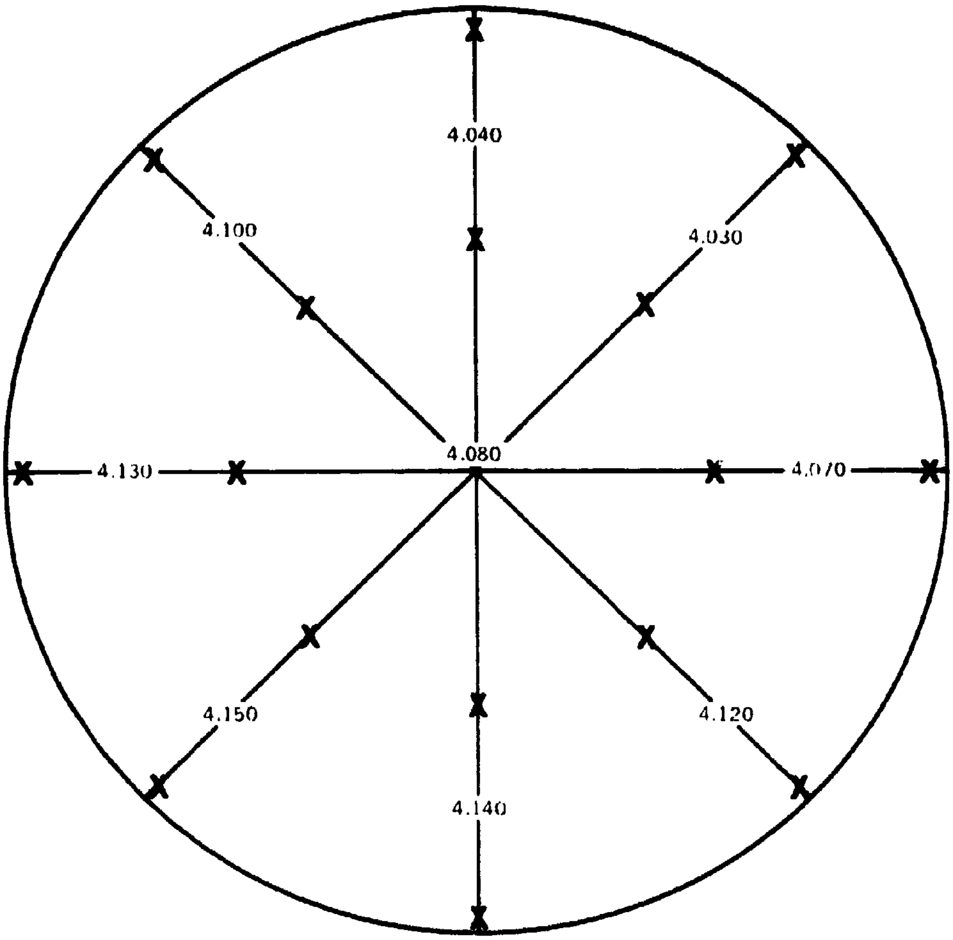
BONDED JOINT TENSILE STRENGTH

(Required : 5000 psi)

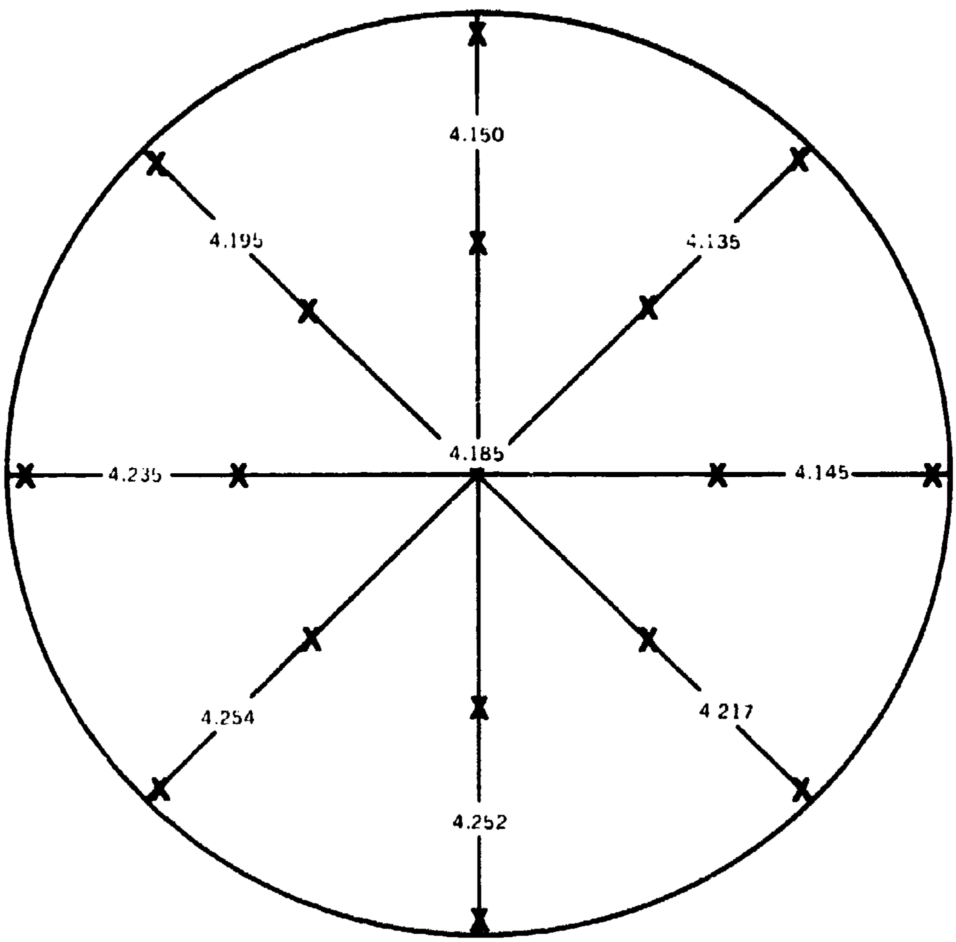
Test specimens were machined from the joint evaluation coupon which had been bonded and annealedin the same manner as the pressure hull. Specimens were of the dimensional configuration set forth in Sketch No. 2002. The testing speed used was 0.05 inch per minute.

Specimen	Widtn (In)	Thickness (In)	Load (Lbs)	Ultimate Strength (psi)	Mode of Failure
1	0.744	0.529	3015	7661	Cohesive
2	0.747	0.532	3210	8074	Acrylic
3	0.750	0.485	2825	7766	Cohesive
4	0.746	0.547	3720	9116	Cohesive
5	0.750	0.540	2075	5123	Cohesive
6	0.749	0.534	3550	8876	Cohesive
7	0.747	0.531	2920	7362	Cohesive
8	0.748	0.526	3240	8235	Cohesive
9	0.742	0.519	2365	6141	Cohesive
10	0.748	0.536	3320	8281	Cohesive
11	0.745	0.536	3390	8489	Cohesive
12	0.744	0.534	3440	8659	Cohesive
			Average	7815	

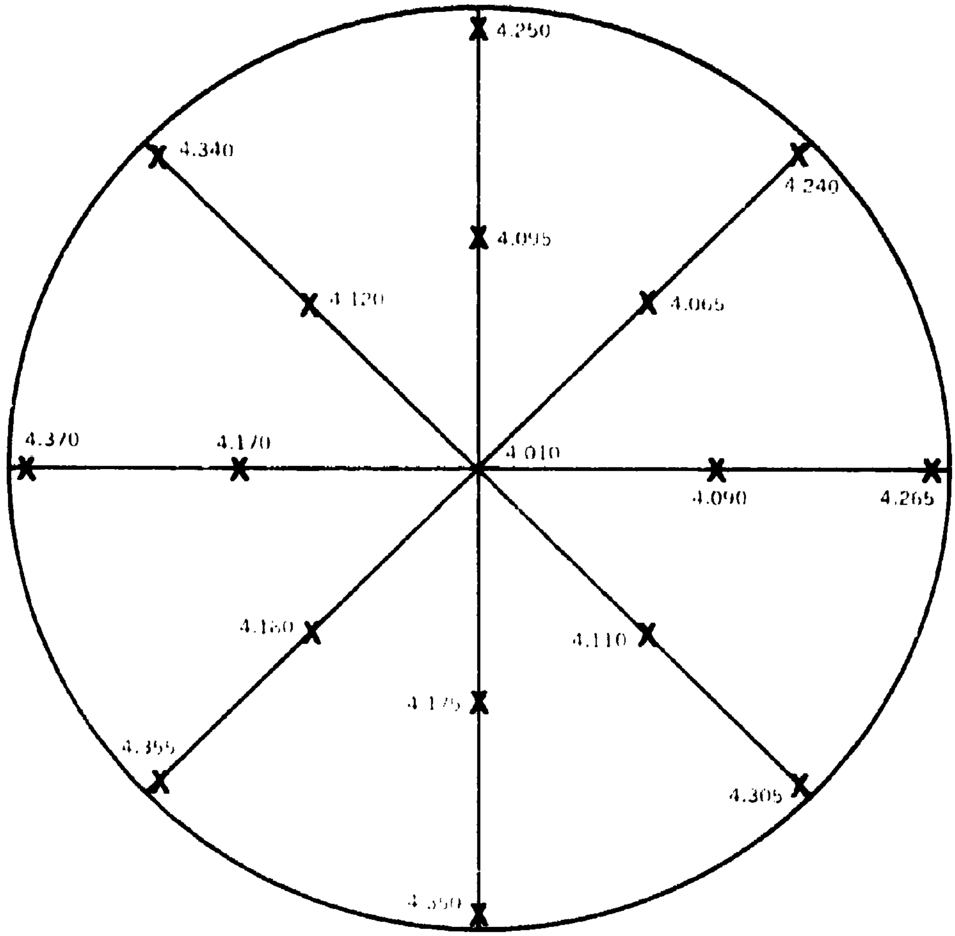
C. A. Miller, Supervisor
Testing Laboratory



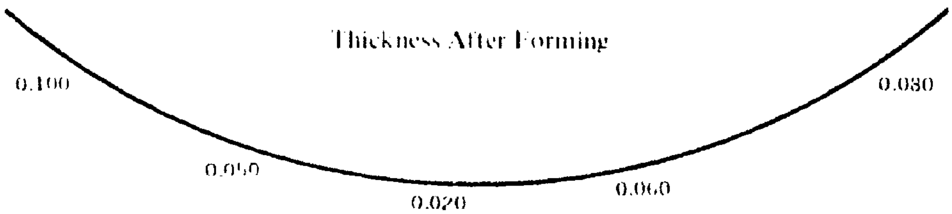
Thickness Before Annealing



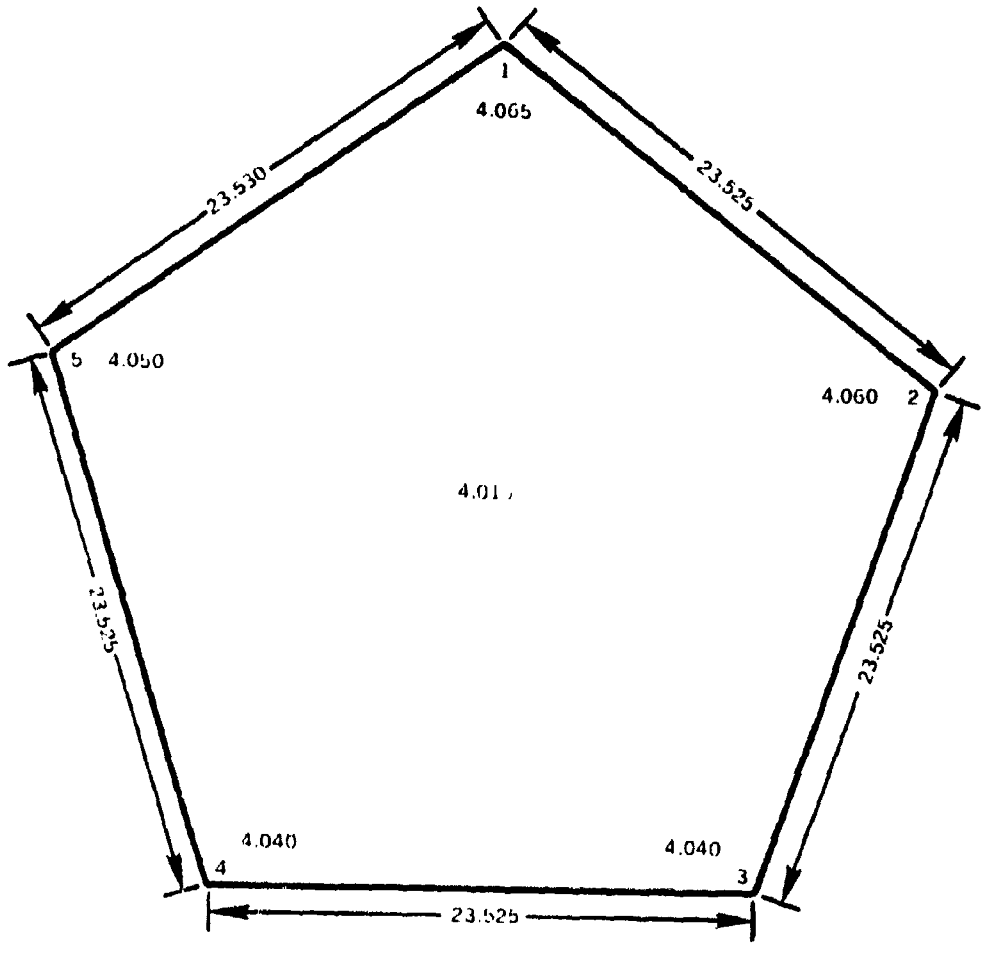
Thickness After Annealing



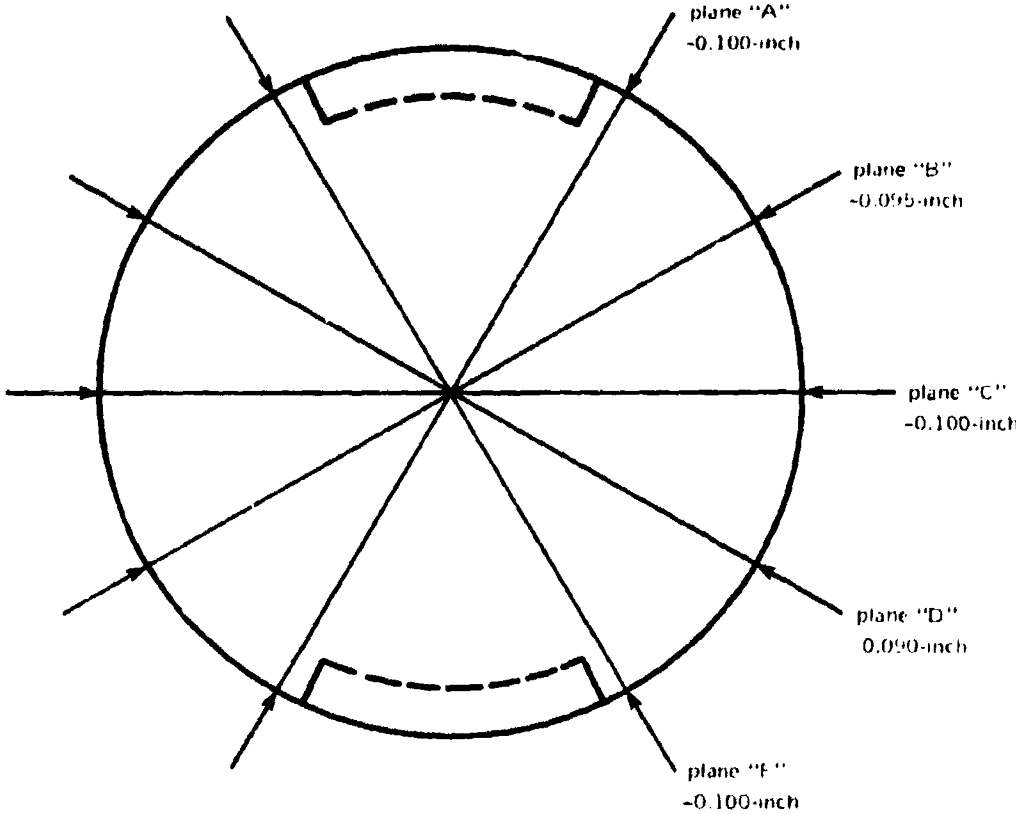
Thickness After Forming



Sphericity After Forming



Thickness After Machining



Diameter of the Finished Sphere

APPENDIX C. DATA FROM HYDROSTATIC TESTS

Both the 15-inch OD × 13-inch ID scale Model 34 and the 66-inch OD × 58-inch ID full scale Model 2000 Nemo Hulls were extensively instrumented with strain-gages (see Figs. 20 and 23 of main text) so that their structural performance under external hydrostatic pressure could be accurately measured and evaluated. Highlights of that data have been summarized (see Tables 4, 5 and 6) and discussed in the main body of the report.

Still, other researchers in the field of acrylic plastic pressure hulls may need to refer to some specific detail of that data not provided in the main body of the report. For this reason the data generated during some of the more severe hydrostatic tests has been selected for presentation here in Appendix C. For the 15-inch OD × 13-inch ID scale Model 34 the most severe as well as the most important test was pressurizing to implosion; this data is presented in Table 1C. The 66-inch OD × 58-inch ID full scale Model 2000 Nemo Hull has not been tested to implosion therefore this data is not available. Instead, the data from the long term pressurization cycles to 1350 and 1800 psi are shown in Tables 2C and 3C.

Data from 15-inch OD × 13-inch ID Model 34

Data Recording

The strain data was generated by subjecting the 15-inch OD × 13-inch ID Model 34 to external hydrostatic pressure rising at 100 psi/minute rate. During recording of strain data (which took about 2 minutes per recording) the pressure was held constant. The temperature of water used in pressurizing of Model 34 was in the 70–75°F range.

Data Interpretation

The most important observation that can be made of the strain data from Model 34 is that all the strains measured on the acrylic plastic as well as on aluminum were linear to well over 1400 psi, indicating that both materials were still in the elastic range when the simulated depth passed the 3000-foot mark. At simulated depth of 4000 feet most of the strains became markedly non-linear, and at 5000 feet the strains became exponential.

The linear behavior of strains to depths in the 3000–3300 foot range substantiates the postulate that the Model 2000 Nemo Hull design (and its scaled down version Nemo Model 34) is operationally safe to 3000 feet as all of the materials in the hull respond elastically in the 0–3000 foot range.

Data from 66-Inch OD × 58-Inch ID Model 2000 Nemo Hull

Data Recording

The strain data was generated by subjecting the 66-inch OD × 58-inch ID Model 2000 Nemo Hull to external hydrostatic pressure rising at 100 psi/minute rate. During recording of strain data (which took about 2 minutes per recording), the pressure was held con tant. The temperature of water used in pressurizing of the Model 2000 Nemo Hull was in the 70–75° F range.

Once the maximum pressure was reached further pressurization was stopped and the maximum pressure maintained for 24 hours. Readings were taken at 6 hour intervals, but only the last reading (taken 24 hours after initiation of long term loading) is shown on the data printout.

Readings were taken also during the depressurization which took place at 100 psi minute rate. Upon reaching 0 pressure the Model 2000 Nemo Hull assembly was allowed to relax for 24 hours while readings were taken every 6 hours (only the last relaxation reading is shown in the data printout).

Data Interpretation

The strains are linear to 3000 feet. The creep in acrylic plastic after 24 hours of sustained loading at 3000 feet was less than 20 percent of the short term strain at that depth. After reduction of pressure to 0 psi and 24 hour relaxation at 0 psi all strains returned to zero. Both the linearity of strain in the 0–3000 foot range and return of strains to zero at conclusion of the pressure cycle indicate that the Model 2000 Nemo Hull can be repeatedly pressurized without permanent deformation to 3000 feet.

When pressurized to 4000 feet there was some nonlinearity at depths beyond 3500 feet. The creep in acrylic plastic after 24 hours of sustained loading at 4000 feet was about 30 percent of the short term strain at that depth. After reduction of pressure to 0 and 24 hours of relaxation at 0 pressure most of the strains in acrylic and aluminum return essentially to zero (are within ±100 microinches of original zero). Only at some interior locations on aluminum components (location 6, 13, 14) were the remaining stresses positive and significantly high. No explanation has been found for their tensile character, or large magnitude.

The indications of nonlinearity during pressurization in the 3500–4000 foot depth range, excessive creep during long term pressurization at 4000 feet, and residual strains after relaxation at 0 depth indicate that pressurization of the Model 2000 Nemo Hull to 4000 feet subjects the assembly to excessive stresses. It is therefore postulated that the Model 2000 Nemo Hull assembly should not be prooftested in excess of 3600 feet for service at depths to 3300 feet.

Table 1C. Strains Measured on 15-Inch OD × 13-Inch ID Nemo Model 34

Load Psi	*Gage No. 1A-C*	*Gage No. 1A-L*	*Gage No. 1B-C*	*Gage No. 1B-L*	*Gage No. 2B-C*	*Gage No. 2B-L*	*Gage No. 3B-C*	*Gage No. 3B-L*	*Gage No. 4A-C*	*Gage No. 4A-L*
0	0	0	0	0	0	0	0	0	0	0
100	-500	-500	-550	-500	-1,800	-900	-80	0	-50	-50
200	-1,100	-1,000	-1,150	-1,100	-1,250	-2,100	-170	+10	-75	-75
300	-1,400	-1,500	-1,700	-1,800	-1,900	-2,700	-250	+20	-100	-100
400	-1,800	-1,900	-2,250	-2,350	-2,300	-3,300	-330	+30	-115	-120
500	-2,200	-2,250	-2,800	-2,900	-2,800	-3,950	-400	+50	-125	-130
600	-2,650	-2,650	-3,400	-3,500	-3,300	-4,600	-470	+70	-140	-150
700	-3,000	-3,050	-3,950	-4,000	-3,750	-5,100	-540	+90	-150	-150
800	-3,400	-3,400	-4,500	-4,500	-4,200	-5,750	-600	+110	-175	-150
900	-3,800	-3,800	-5,000	-5,100	-4,600	-6,400	-650	+130	-195	-120
1,000	-4,200	-4,200	-5,600	-5,700	-5,100	-7,050	-700	+150	-200	-100
1,100	-4,600	-4,600	-6,200	-6,200	-5,550	-7,650	-780	+150	-225	-75
1,200	-5,000	-5,000	-6,700	-6,800	-6,000	-8,350	-860	+150	-250	-50
1,300	-5,400	-5,400	-7,300	-7,300	-6,400	-8,950	-940	+150	-260	-30
1,400	-5,900	-5,800	-7,900	-7,900	-6,950	-9,700	-1,020	+130	-280	-20
1,500	-6,300	-6,200	-8,600	-8,500	-7,400	-10,400	-1,100	+110		
1,600	-6,700	-6,600	-9,100	-9,200	-7,900	-11,000	-1,190	+90		
1,700	-7,200	-7,000	-9,900	-9,900	-8,500	-11,850	-1,310	+70		
1,800	-7,750	-7,600	-10,600	-10,600	-9,200	-12,650	-1,400	+50		
1,900	-8,200	-8,000	-11,400	-11,500	-9,900	-13,600	-1,490	+30		
2,000	-8,800	-8,600	-12,200	-12,200	-10,500	-14,600	-1,600	+10		
2,200	-9,800	-9,500	-13,700	-13,800	-11,600	-16,500	-1,750	-10		
2,400	-10,000	-10,500	-15,200	-15,200	-12,800	-18,250	-1,900	-30		
2,600	-12,100	-11,700	-17,100	-17,800	-13,200	-21,000	-2,050	-50		
2,800	-13,400	-12,900	-18,600	-18,800	-15,800	-22,850	-2,150	-70		
3,200	-16,400	-15,600	-23,800	-22,700	-19,800	-28,900	-2,200	-90		
3,600	-18,600	-18,000	-27,100		-28,000	>-30,000	-2,250	-110		
4,000	-21,600	-20,200	>-30,000		>-30,000	>-30,000	-2,200	-120		

Location of gages shown on Figure 20, pg. 44.

Table 1C. (Continued).

Load Psi	*Gage No. 4B-C*	*Gage No. 4B-L*	*Gage No. 5A-C*	*Gage No. 5A-L*	*Gage No. 5B-C*	*Gage No. 5B-L*	*Gage No. 6B-C*	*Gage No. 6B-L*	*Gage No. 7B-C*	*Gage No. 7B-L*
0	0	0	0	0	0	0	0	0	0	0
100	-50	-180	-10	0	-80	-10	-800	-1,000	-90	90
200	-100	-300	-20	10	-160	-20	-1,500	-1,800	-210	150
300	-160	-400	-30	10	-240	-30	-2,000	-2,400	-300	150
400	-200	-500	-40	10	-330	-50	-2,500	-2,950	-400	190
500	-250	-590	-50	20	-410	-60	-3,000	-3,450	-490	190
600	-310	-700	-60	20	-490	-80	-3,600	-4,000	-590	220
700	-370	-790	-70	20	-570	-100	-4,100	-4,500	-600	230
800	-430	-900	-80	30	-650	-130	-4,600	-5,050	-710	230
900	-490	-1,010	-90	30	-710	-170	-5,100	-5,600	-900	240
1,000	-550	-1,100	-100	30	-780	-200	-5,700	-6,100	-1,000	240
1,100	-610	-1,190	-110	30	-840	-210	-6,150	-6,700	-1,110	240
1,200	-680	-1,270	-120	40	-920	-220	-6,800	-7,100	-1,220	250
1,300	-730	-1,350	-130	40	-1,000	-230	-7,200	-7,700	-1,330	250
1,400	-790	-1,430	-140	40	-1,090	-240	-7,800	-8,300	-1,440	250
1,500	-850	-1,520	-150	50	-1,180	-260	-8,250	-8,900	-1,550	270
1,600	-920	-1,620	-160	50	-1,280	-280	-8,750	-9,600	-1,600	290
1,700	-990	-1,710	-170	50	-1,320	-300	-9,300	-10,450	-1,720	320
1,800	-1,060	-1,800	-180	50	-1,370	-320	-9,900	-11,250	-1,830	350
1,900	-1,130	-1,950	-190	60	-1,550	-335	-10,600	-12,200	-1,900	430
2,000	-1,200	-2,050	-200	60	-1,630	-350	-11,200	-13,050	-2,020	500
2,200	-1,300	-2,400	-220	60	-1,800	-400	-12,500	-14,700	-2,270	600
2,400	-1,400	-2,600	-280	70	-2,000	-450	-13,900	-16,300	-2,470	700
2,600	-1,500	-2,800	-280	80	-2,200	-460	-15,700	-18,100	-2,700	850
2,800	-1,550	-2,900	-310	80	-2,340	-480	-17,550	-19,800	-2,860	900
3,200	-1,600	-3,100	-370	90	-2,500	-550	-23,100	-22,800	-3,250	1,000
3,600	-1,650	-3,250	-560	110	-2,500	-640	-27,500		-3,550	1,180
4,000	-1,600	-3,400	-530	120	-2,840	-550	>-30,000		-3,750	1,350

Table 2C. Strains Measured on the 66-Inch OD × 58-Inch ID Model 2000 Nemo Hull Under 24-Hour Long Hydrostatic Loading of 1350 Psi

E= .40 POISSONS RATIO= .40 GAGE NO.= 1=OUTSIDE

	LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
	0	0	0	0	0	0
	150	-300	-950	-324	-510	93
	300	-450	-1700	-538	-895	179
	450	-600	-2500	-762	-1305	271
	600	-800	-3300	-1010	-1724	357
	750	-950	-4100	-1233	-2133	450
	900	-1150	-4900	-1481	-2552	536
	1050	-1300	-5750	-1714	-2986	636
	1200	-1850	-6350	-2090	-3376	643
*	1350	-2050	-7200	-2348	-3819	736
*	1350	-2000	-7500	-2381	-3952	786
	1350	-2000	-7500	-2381	-3952	786
	1200	-1850	-7300	-2271	-3829	779
	1050	-1650	-6550	-2033	-3433	700
	900	-1500	-5650	-1790	-2976	593
	750	-1300	-4700	-1514	-2486	486
	600	-1250	-3800	-1319	-2048	364
	450	-900	-2950	-990	-1576	293
	300	-700	-2090	-714	-1086	186
	150	-450	-1100	-424	-610	93
**	0	-150	-350	-138	-195	29
**	0	0	0	0	0	0

*[denotes strains at the beginning and conclusion of 24 hour long sustained loading at 1350 psi

**[denotes strains at the beginning and conclusion of 24 hour long relaxation at 0 psi

EP1 hoop orientation

EP2 longitudinal orientation

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= .40 POISSONS RATIO= .40 GAGE NO.= 2-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-700	-700	-467	-467	0
300	-1400	-1400	-933	-933	0
450	-2100	-2050	-1390	-1376	-7
600	-2750	-2700	-1824	-1810	-7
750	-3450	-3400	-2290	-2276	-7
900	-4150	-4100	-2757	-2743	-7
1050	-4850	-4800	-3224	-3210	-7
1200	-5600	-5500	-3714	-3686	-14
1350	-6350	-6250	-4214	-4186	-14
1450	-7550	-7550	-5033	-5033	0
1350	-7550	-7550	-5033	-5033	0
1200	-7350	-7300	-4890	-4876	-7
1050	-6550	-6500	-4357	-4343	-7
900	-5750	-5700	-3824	-3810	-7
750	-4900	-4850	-3257	-3243	-7
600	-4050	-4000	-2690	-2676	-7
450	-3050	-2950	-2014	-1986	-14
300	-2150	-2100	-1424	-1410	-7
150	-1300	-1300	-867	-867	0
0	-450	-400	-290	-276	-7
0	0	0	0	0	0

Location of gages shown on Figure 23, pg. 48.

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= .40 POISSONS RATIO= .30 GAGE NO.= 3-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-200	-950	-276	-490	107
300	-400	-1650	-505	-862	179
450	-550	-2350	-718	-1224	257
600	-650	-3000	-881	-1552	336
750	-800	-3750	-1095	-1938	421
900	-950	-4500	-1310	-2324	507
1050	-1100	-5250	-1524	-2710	593
1200	-1200	-6000	-1714	-3086	686
1350	-1350	-6600	-1900	-3400	750
1350	-1350	-6950	-1967	-3567	800
1350	-1350	-6950	-1967	-3567	800
1200	-1300	-6800	-1914	-3486	786
1050	-1200	-6050	-1729	-3110	693
900	-1050	-5300	-1510	-2724	607
750	-850	-4500	-1262	-2305	521
600	-700	-3650	-1029	-1871	421
450	-600	-2800	-819	-1448	314
300	-450	-1900	-576	-990	207
150	-200	-1058	-295	-538	121
0	0	-250	-48	-119	36
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= .90 POISSONS RATIO= .90 GAGE NO.= 4-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-750	-700	-490	-476	-7
300	-1400	-1350	-924	-910	-7
450	-2050	-1950	-1348	-1319	-14
600	-2750	-2600	-1805	-1762	-21
750	-3400	-3300	-2248	-2219	-14
900	-4050	-3900	-2671	-2629	-21
1050	-4800	-4600	-3162	-3104	-29
1200	-5500	-5250	-3619	-3548	-36
1350	-6200	-5950	-4086	-4014	-36
1350	-7400	-6950	-4848	-4719	-64
1350	-7400	-6950	-4848	-4719	-64
1200	-7250	-6800	-4748	-4619	-64
1050	-6450	-6150	-4243	-4157	-43
900	-5650	-5350	-3710	-3624	-43
750	-4800	-4500	-3143	-3057	-43
600	-3950	-3750	-2595	-2538	-29
450	-3100	-2900	-2029	-1971	-29
300	-2200	-2050	-1438	-1395	-21
150	-1350	-1200	-871	-829	-21
0	-500	-450	-324	-310	-7
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,60 POISSONS RATIO= .30 GAGE NO.= 5-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-50	-100	-879	-1264	192
300	-100	-150	-1593	-1978	192
450	-150	-150	-2143	-2143	0
600	-200	-200	-2857	-2857	0
750	-250	-200	-3407	-3022	-192
900	-300	-250	-4121	-3736	-192
1050	-300	-250	-4121	-3736	-192
1200	-300	-300	-4286	-4286	0
1350	-350	-350	-5000	-5000	0
1350	-350	-300	-4835	-4451	-192
1350	-350	-300	-4835	-4451	-192
1200	-300	-300	-4286	-4286	0
1050	-300	-300	-4286	-4286	0
900	-250	-250	-3571	-3571	0
750	-250	-200	-3407	-3022	-192
600	-200	-200	-2857	-2857	0
450	-150	-100	-1978	-1593	-192
300	-50	-100	-879	-1264	192
150	-50	-50	-714	-714	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO.= 4=OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-50	-50	-714	-714	0
300	-100	-150	-1593	-1978	192
450	-150	-150	-2143	-2143	0
600	-200	-200	-2857	-2857	0
750	-250	-250	-3571	-3571	0
900	-300	-250	-4121	-3736	-192
1050	-350	-300	-4835	-4451	-192
1200	-400	-350	-5549	-5165	-192
1350	-450	-400	-6264	-5879	-192
1350	-400	-350	-5549	-5165	-192
1350	-400	-350	-5549	-5165	-192
1200	-400	-350	-5549	-5165	-192
1050	-400	-300	-5385	-4615	-385
900	-350	-300	-4835	-4451	-192
750	-300	-250	-4121	-3736	-192
600	-250	-200	-3407	-3022	-192
450	-150	-150	-2143	-2143	0
300	-50	-100	-879	-1264	192
150	-50	-50	-714	-714	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .33 GAGE NO.= 7-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-100	-50	-1269	-879	-192
300	-150	-100	-1978	-1593	-192
450	-150	-150	-2143	-2143	0
600	-250	-200	-3407	-3022	-192
750	-300	-250	-4121	-3736	-192
900	-350	-300	-4835	-4451	-192
1050	-350	-350	-5000	-5000	0
1200	-400	-400	-5714	-5714	0
1350	-450	-450	-6429	-6429	0
1350	-450	-450	-6429	-6429	0
1350	-450	-450	-6429	-6429	0
1200	-400	-450	-5879	-6264	192
1050	-350	-350	-5000	-5000	0
900	-350	-300	-4835	-4451	-192
750	-300	-250	-4121	-3736	-192
600	-250	-200	-3407	-3022	-192
450	-150	-150	-2143	-2143	0
300	-100	-100	-1429	-1429	0
150	-50	-50	-714	-714	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 | POISSONS RATIO= .30 | GAGE NO.= 8-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-50	50	-385	385	-385
300	-100	50	-934	220	-577
450	-150	100	-1319	604	-962
600	-200	100	-1868	440	-1154
750	-250	100	-2418	275	-1346
900	-300	100	-2967	110	-1538
1050	-300	150	-2802	659	-1731
1200	-350	100	-3516	-55	-1731
1350	-350	100	-3516	-55	-1731
1350	-300	100	-2967	110	-1538
1350	-300	100	-2967	110	-1538
1200	-300	100	-2967	110	-1538
1050	-300	100	-2967	110	-1[illegible]38
900	-250	50	-2582	-275	-1[illegible]34
750	-250	50	-2582	-275	-1154
600	-200	100	-1868	440	-1154
450	-150	50	-1484	55	-769
300	-100	50	-934	220	-577
150	-50	0	-549	-165	-192
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO.= 9=OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-50	-100	-879	-1269	192
300	-100	-150	-1593	-1978	192
450	-150	-200	-2308	-2692	192
600	-150	-250	-2473	-3242	385
750	-200	-300	-3187	-3956	385
900	-200	-350	-3352	-4505	577
1050	-250	-350	-3901	-4670	385
1200	-250	-400	-4066	-5220	577
1350	-300	-450	-4780	-5934	577
1350	-300	-450	-4780	-5934	577
1350	-300	-450	-4780	-5934	577
1200	-250	-400	-4066	-5220	577
1050	-200	-350	-3352	-4505	577
900	-200	-350	-3352	-4505	577
750	-150	-350	-2802	-4341	769
600	-150	-300	-2637	-3791	577
450	-150	-200	-2308	-2692	192
300	-100	-100	-1429	-1429	0
150	-50	-50	-714	-714	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00

POISSONS RATIO= .30

GAGE NO.= 10=OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-50	-100	-879	-1264	192
300	-50	-150	-1044	-1813	385
450	-100	-150	-1593	-1978	192
600	-100	-150	-1593	-1978	192
750	-200	-200	-2857	-2857	0
900	-250	-200	-3907	-3022	-192
1050	-300	-250	-4121	-3736	-192
1200	-300	-250	-4121	-3736	-192
1350	-350	-250	-4670	-3901	-385
1350	-350	-250	-4670	-3901	-385
1350	-350	-250	-4670	-3901	-385
1200	-300	-250	-4121	-3736	-192
1050	-300	-250	-4121	-3736	-192
900	-300	-200	-3956	-3187	-385
750	-250	-150	-3292	-2473	-385
600	-150	-100	-1978	-1593	-192
450	-50	-100	-879	-1264	192
300	-50	-100	-879	-1264	192
150	-50	-50	-719	-719	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO.= 11-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-50	-50	-714	-714	0
300	-100	-50	-1264	-879	-192
450	-150	-100	-1978	-1593	-192
600	-200	-150	-2692	-2308	-192
750	-200	-200	-2857	-2857	0
900	-200	-200	-2857	-2857	0
1050	-250	-250	-3571	-3571	0
1200	-250	-300	-3736	-4121	192
1350	-250	-300	-3736	-4121	192
1350	-250	-300	-3736	-4121	192
1350	-250	-300	-3736	-4121	192
1200	-250	-300	-3736	-4121	192
1050	-250	-250	-3571	-3571	0
900	-200	-200	-2857	-2857	0
750	-150	-150	-2143	-2143	0
600	-150	-100	-1978	-1593	-192
450	-100	-100	-1929	-1929	0
300	-100	-50	-1264	-879	-192
150	-50	-50	-714	-714	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO,= 12=OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-50	-50	-714	-714	0
300	-100	-100	-1429	-1429	0
450	-150	-100	-1978	-1593	-192
600	-150	-150	-2143	-2143	0
750	-200	-150	-2692	-2308	-192
900	-200	-200	-2857	-2857	0
1050	-250	-200	-3407	-3022	-192
1200	-250	-200	-3407	-3022	-192
1350	-300	-200	-3956	-3187	-385
1350	-300	-200	-3956	-3187	-385
1350	-300	-200	-3956	-3187	-385
1200	-300	-200	-3956	-3187	-385
1050	-250	-200	-3407	-3022	-192
900	-200	-200	-2857	-2857	0
750	-200	-150	-2692	-2308	-192
600	-150	-100	-1978	-1593	-192
450	-100	-50	-1264	-879	-192
300	-50	-50	-714	-714	0
150	-50	0	-549	-165	-192
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00

POISSONS RATIO= ,30

GAGE NO,= 13=OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-50	-100	-879	-1264	192
300	-100	-100	-1429	-1429	0
450	-100	-150	-1593	-1978	192
600	-150	-150	-2143	-2143	0
750	-150	-150	-2143	-2143	0
900	-200	-150	-2692	-2308	-192
1050	-250	-150	-3242	-2473	-385
1200	-250	-200	-3407	-3022	-192
1350	-300	-200	-3956	-3187	-385
'350	-500	-400	-6813	-6044	-385
1350	-500	-400	-6813	-6044	-385
1200	-450	-350	-6099	-5330	-385
1050	-350	-300	-4835	-4451	-192
900	-250	-250	-3571	-3571	0
750	-200	-150	-2692	-2308	-192
600	-150	-100	-1978	-1593	-192
450	-100	-50	-1264	-879	-192
300	-50	-50	-714	-714	0
150	-50	-50	-714	-714	0
C	0	0	0	0	0
C	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00

POISSONS RATIO= ,30

GAGE NO.= 14=OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-50	-100	-879	-1264	192
300	-100	-150	-1593	-1978	192
450	-150	-150	-2143	-2143	0
600	-200	-150	-2692	-2308	-192
750	-250	-200	-3407	-3022	-192
900	-250	-200	-3407	-3022	-192
1050	-300	-250	-4121	-3736	-192
1200	-300	-250	-4121	-3736	-192
1350	-350	-250	-4670	-3901	-385
1350	-550	-450	-7527	-6758	-385
1350	-550	-450	-7527	-6758	-385
1200	-500	-400	-6813	-604[illegible]	-385
1050	-400	-300	-5385	-4615	-385
900	-300	-200	-3956	-3187	-385
750	-250	-150	-3242	-2473	-385
600	-200	-150	-2692	-2308	-192
450	-100	-100	-1429	-1429	0
300	-50	-100	-879	-1264	192
150	-50	-50	-714	-714	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= .40 POISSONS RATIO= .40 GAGE NO.= 1-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-800	-1150	-600	-700	50
300	-1250	-2550	-1081	-1452	186
450	-1750	-4450	-1581	-2452	386
600	-2200	-6100	-2210	-3324	557
750	-2700	-7650	-2743	-4157	707
900	-3100	-9550	-3295	-5138	921
1050	-3400	-11250	-3762	-6005	1121
1200	-4100	-12950	-4419	-6948	1264
1350	-4550	-14800	-4986	-7914	1464
1350	-5050	-18200	-5871	-9629	1879
1350	-5050	-18200	-5871	-9629	1879
1200	-4900	-17150	-5600	-9100	1750
1050	-4750	-15250	-5167	-8167	1500
900	-4100	-12500	-4333	-6733	1200
750	-3750	-10750	-3833	-5833	1000
600	-3300	-8200	-3193	-4533	700
450	-2900	-5450	-2419	-3148	364
300	-2350	-3450	-1776	-2090	157
150	-1500	-1950	-1086	-1219	69
0	-450	-1450	-490	-776	143
0	0	-50	-10	-24	7

Table 2C. (Continued).

E= .90 POISSONS RATIO= .90 GAGE NO.= 2-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-1000	-900	-648	-619	-14
300	-1900	-1700	-1229	-1171	-29
450	-2800	-2550	-1819	-1748	-36
600	-3750	-3400	-2433	-2333	-50
750	-4600	-4250	-3000	-2900	-50
900	-5550	-5050	-3605	-3462	-71
1050	-6500	-5900	-4219	-4048	-86
1200	-7500	-6850	-4876	-4690	-93
1350	-8400	-7750	-5476	-5290	-93
1350	-10250	-9200	-6633	-6333	-150
1350	-10250	-9200	-6633	-6333	-150
1200	-9050	-8650	-5957	-5843	-57
1050	-7950	-7700	-5252	-5181	-36
900	-6900	-6750	-4571	-4529	-21
750	-5850	-5800	-3890	-3876	-7
600	-4700	-4900	-3171	-3229	29
450	-3550	-3850	-2424	-2510	43
300	-2600	-2700	-1752	-1781	14
150	-1650	-1450	-1062	-1005	-29
0	-600	-300	-343	-257	-43
0	-50	0	-24	-10	-7

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= .90 POISSONS RATIO= .40 GAGE NO.= 3-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-600	-1300	-533	-733	100
300	-1100	-2550	-1010	-1429	207
450	-1550	-3900	-1481	-2152	336
600	-2000	-5250	-1952	-2881	464
750	-2450	-6600	-2424	-3610	593
900	-2950	-7900	-2910	-4329	707
1050	-3400	-9350	-3400	-5100	850
1200	-3950	-10850	-3948	-5919	986
1350	-4500	-12300	-4486	-6719	1114
1350	-5150	-15100	-5329	-8171	1421
1350	-5150	-15100	-5329	-8171	1421
1200	-4950	-14800	-5176	-7998	1407
1050	-4300	-13050	-4533	-7033	1250
900	-3750	-11250	-3929	-6071	1071
750	-3150	-9550	-3319	-5148	914
600	-2550	-7700	-2681	-4152	736
450	-2000	-5850	-2067	-3167	550
300	-1350	-4000	-1405	-2162	379
150	-750	-2150	-767	-1167	200
0	-150	-300	-129	-171	21
0	0	0	0	0	0

Table 2C. (Continued)

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= .40 POISSONS RATIO= .40 GAGE NO.= 4=INSID

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-1000	-900	-648	-619	-14
300	-1950	-1750	-1262	-1205	-29
450	-2850	-2600	-1852	-1781	-36
600	-3750	-3500	-2452	-2381	-36
750	-4700	-4350	-3067	-2967	-50
900	-5650	-5250	-3690	-3576	-57
1050	-6550	-6100	-4281	-4152	-64
1200	-7550	-7100	-4948	-4819	-64
1350	-8550	-8000	-5595	-5438	-79
1350	-10400	-9500	-6762	-6505	-129
1350	-10400	-9500	-6762	-6505	-129
1200	-9950	-9350	-6519	-6348	-86
1050	-8900	-8300	-5819	-5648	-86
900	-7750	-7250	-5071	-4929	-71
750	-6600	-6100	-4305	-4162	-71
600	-5450	-5050	-3557	-3443	-57
450	-4350	-3900	-2819	-2686	-64
300	-3150	-2700	-2019	-1886	-64
150	-2050	-1500	-1262	-1108	-79
0	-700	-300	-390	-276	-57
0	-50	0	-24	-10	-7

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIOS .30 GAGE NO.= 5-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-50	-50	-719	-719	0
300	-150	-200	-2308	-2492	[illegible]
450	-200	-300	-3107	-3956	385
600	-300	-500	-4995	-6984	769
750	-400	-600	-6379	-7912	769
900	-450	-700	-7253	-9176	962
1050	-500	-750	-7967	-9890	962
1200	-650	-800	-9780	-10934	577
1350	-700	-850	-10995	-11648	577
1350	-600	-850	-9396	-11319	962
1350	-600	-850	-9396	-11319	962
1200	-600	-800	-9231	-10769	769
1050	-550	-750	-8516	-10055	769
900	-450	-650	-7088	-8626	769
750	-400	-550	-6209	-7363	577
600	-300	-450	-4788	-5934	577
450	-150	-300	-2637	-3791	577
300	-100	-200	-1758	-2527	385
150	-50	-50	-714	[illegible]	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00 POISSONS RATIO= .30 GAGE NO.= 6=INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-100	-100	-1929	-1929	0
300	-250	-350	-3901	-4670	385
450	-350	-500	-5495	-6648	577
600	-450	-650	-7088	-8626	769
750	-500	-800	-8132	-10440	1154
900	-600	-900	-9560	-11868	1154
1050	-700	-1050	-11159	-13846	1346
1200	-800	-1200	-12747	-15824	1538
1350	-850	-1300	-13626	-17088	1731
1350	-850	-1400	-13956	-18187	2115
1350	-850	-1400	-13956	-18187	2115
1200	-800	-1300	-13077	-16923	1923
1050	-700	-1150	-11484	-14995	1731
900	-600	-1000	-9890	-12967	1538
750	-500	-850	-8297	-10989	1346
600	-400	-700	-6703	-9011	1154
450	-350	-550	-5659	-7198	769
300	-250	-400	-4066	-5220	577
150	-100	-100	-1929	-1929	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO.= 7-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-100	-100	-1929	-1929	0
300	-200	-200	-2857	-2857	0
450	-300	-300	-4286	-4286	0
600	-450	-350	-6099	-5330	-385
750	-600	-450	-8077	-6923	-577
900	-700	-500	-9341	-7802	-769
1050	-800	-550	-10609	-8681	-962
1200	-900	-650	-12033	-10110	-962
1350	-1000	-700	-13297	-10989	-1154
1350	-1000	-600	-12967	-9890	-1538
1350	-1000	-600	-12967	-9890	-1538
1200	-900	-600	-11868	-9560	-1154
1050	-800	-500	-10440	-8132	-1154
900	-700	-450	-9176	-7253	-962
750	-600	-400	-7912	-6374	-769
600	-500	-350	-6648	-5495	-577
450	-400	-300	-5385	-4615	-385
300	-250	-200	-3407	-3022	-192
150	-100	-100	-1929	-1929	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00 POISSONS RATIO= .30 GAGE NO.= 8-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-100	50	-934	220	-577
300	-250	50	-2582	-275	-1154
450	-400	100	-4066	-220	-1923
600	-550	100	-5714	-714	-2500
750	-700	200	-7033	-110	-3462
900	-800	250	-7967	110	-4038
1050	-950	300	-9451	165	-4808
1200	-1050	100	-11209	-2463	-4423
1350	-1200	50	-13022	-3407	-4808
1350	-1200	0	-13187	-3956	-4615
1350	-1200	0	-13187	-3956	-4616
1200	-1100	100	-11758	-2527	-4616
1050	-1000	350	-9835	549	-5192
900	-850	300	-8352	495	-4423
750	-700	250	-6868	440	-3654
600	-550	150	-5549	-165	-2692
450	-400	150	-3901	330	-2115
300	-250	100	-2418	275	-1346
150	-100	50	-934	220	-577
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00 POISSONS RATIO= ,30 GAGE NO,= 9-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-50	-50	-714	-714	0
300	-150	-200	-2308	-2692	192
450	-200	-300	-3187	-3956	385
600	-300	-450	-4780	-5934	577
750	-350	-600	-5824	-7747	962
900	-400	-750	-6868	-9560	1346
1050	-450	-850	-7747	-10824	1538
1200	-500	-1050	-8956	-13187	2115
1350	-600	-1200	-10549	-15165	2308
1350	-550	-1000	-9341	-12802	1731
1350	-550	-1000	-9341	-12802	1731
1200	-550	-1000	-9341	-12802	1731
1050	-450	-900	-7912	-11374	1731
900	-400	-800	-7033	-10110	1530
750	-350	-650	-5989	-8297	1154
600	-300	-500	-4945	-6484	769
450	-250	-350	-3901	-4670	385
300	-150	-200	-2308	-2692	192
150	-60	-100	-879	-1264	192
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00 POISSONS RATIO= ,30 GAGE NO.= 10-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-100	-50	-1264	-879	-192
300	-200	-100	-2527	-1758	-385
450	-300	-200	-3956	-3187	-385
600	-350	-300	-4835	-4451	-192
750	-400	-400	-5714	-5714	0
900	-500	-500	-7143	-7143	0
1050	-550	-550	-7857	-7857	0
1200	-650	-650	-9286	-9286	0
1350	-750	-700	-10549	-10165	-192
1350	-700	-650	-9835	-9451	-192
1350	-700	-650	-9835	-9451	-192
1200	-650	-650	-9286	-9286	0
1050	-550	-550	-7857	-7857	0
900	-500	-500	-7143	-7143	0
750	-400	-450	-5879	-6264	192
600	-350	-350	-5000	-5000	0
450	-300	-250	-4121	-3736	-192
300	-200	-150	-2692	-2308	-192
150	-100	-50	-1264	-879	-192
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO.= 11-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-50	-50	-714	-714	0
300	-100	-200	-1758	-2527	385
450	-200	-250	-3022	-3407	192
600	-300	-350	-4451	-4836	192
750	-400	-450	-5879	-6264	192
900	-500	-550	-7308	-7692	192
1050	-550	-600	-8022	-8407	192
1200	-650	-700	-9451	-9836	192
1350	-700	-750	-10165	-10649	192
1350	-600	-750	-9066	-10220	577
1350	-600	-750	-9066	-10220	577
1200	-600	-700	-8901	-9678	385
1050	-550	-650	-8187	-8966	385
900	-500	-550	-7308	-7692	192
750	-450	-450	-6429	-6429	0
600	-350	-350	-5000	-5000	0
450	-250	-250	-3571	-3571	0
300	-150	-150	-2143	-2143	0
150	-50	-50	-714	-714	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00 POISSONS RATIO= ,30 GAGE NO.= 12-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-50	-50	-714	-714	0
300	-150	-200	-2308	-2692	192
450	-250	-250	-3571	-3571	0
600	-300	-350	-4451	-4835	192
750	-400	-450	-5879	-6264	192
900	-500	-550	-7308	-7692	192
1050	-600	-650	-8736	-9121	192
1200	-700	-700	-10000	-10000	0
1350	-800	-800	-11429	-11429	0
1350	-800	-800	-11429	-11429	0
1350	-800	-800	-11429	-11429	0
1200	-750	-750	-10714	-10714	0
1050	-650	-650	-9286	-9286	0
900	-550	-550	-7857	-7857	0
750	-450	-450	-6429	-6429	0
600	-350	-350	-5000	-5000	0
450	-250	-250	-3571	-3571	0
300	-150	-150	-2143	-2143	0
150	-50	-50	-714	-714	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00 POISSONS RATIO= .30 GAGE NO.= 13-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-100	-100	-1429	-1429	0
300	-200	-200	-2857	-2857	0
450	-300	-300	-4286	-4286	0
600	-400	-400	-5714	-5714	0
750	-500	-500	-7143	-7143	0
900	-550	-600	-8022	-8407	192
1050	-600	-700	-8901	-9670	385
1200	-700	-800	-10330	-11099	385
1350	-800	-900	-11758	-12527	385
1350	-900	-1050	-13352	-14505	577
1350	-900	-1050	-13352	-14505	577
1200	-800	-900	-11758	-12527	385
1050	-700	-750	-10165	-10549	192
900	-600	-600	-8571	-8571	0
750	-500	-500	-7143	-7143	0
600	-400	-400	-5714	-5714	0
450	-300	-300	-4286	-4286	0
300	-200	-150	-2692	-2308	-192
150	-50	-50	-714	-714	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 2C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO.= 14=INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
150	-100	-50	-1264	-879	-192
300	-200	-150	-2692	-2308	-192
450	-300	-200	-3956	-3187	-385
600	-400	-300	-5385	-4615	-385
750	-500	-400	-6813	-6044	-385
900	-600	-500	-8242	-7473	-385
1050	-700	-600	-9670	-8901	-385
1200	-800	-750	-11264	-10879	-192
1350	-900	-850	-12692	-12308	-192
1350	-1000	-1000	-14286	-14286	0
1350	-1000	-1000	-14286	-14286	0
1200	-900	-850	-12692	-12308	-192
1050	-750	-650	-10385	-9615	-385
900	-650	-550	-8936	-8107	-385
750	-500	-400	-6813	-6044	-385
600	-400	-300	-5385	-4615	-385
450	-300	-200	-3956	-3187	-385
300	-150	-100	-1978	-1593	-192
150	-50	-50	-714	-714	0
0	0	0	0	0	0
0	0	0	0	0	0

Table 3C. Strains Measured on the 66-Inch OD × 58-Inch ID Model 2000 Nemo Hull Under 24-Hour Long Sustained Loading of 1800 Psi

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= .40 POISSONS RATIO= .40 GAGE NO.= 1-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-250	-800	-271	-429	79
200	-300	-1250	-381	-652	136
300	-400	-1750	-524	-910	193
400	-450	-2250	-643	-1157	257
500	-550	-2750	-786	-1414	314
600	-650	-3250	-929	-1671	371
700	-750	-3850	-1090	-1976	443
800	-900	-4400	-1267	-2267	500
900	-1050	-4950	-1443	-2557	557
1000	-1100	-5450	-1562	-2805	621
1100	-1200	-6050	-1729	-3110	693
1200	-1350	-6500	-1881	-3352	736
1300	-1850	-6900	-2145	-3636	721
1400	-2000	-7400	-2362	-3905	771
1500	-2150	-8000	-2548	-4219	836
1600	-2300	-8700	-2752	-4581	914
1700	-2400	-9250	-2905	-4862	979
*[1800	-2500	-9750	-3048	-5119	1036
1800	-2500	-10000	-3095	-5230	1071
1800	-2500	-10000	-3095	-5230	1071
1700	-2400	-9650	-2981	-5052	1036
1600	-2350	-9250	-2881	-4852	986
1500	-2300	-8900	-2790	-4676	943
1400	-2200	-8500	-2667	-4467	900
1300	-2150	-8100	-2543	-4257	857
1200	-2000	-7700	-2419	-4048	814
1100	-1950	-7200	-2300	-3800	750
1000	-1900	-6600	-2162	-3505	671
900	-1750	-6000	-1976	-3190	607
800	-1700	-5500	-1857	-2943	543
700	-1600	-4950	-1705	-2662	479
630	-1500	-4400	-1552	-2381	414
500	-1400	-3800	-1390	-2076	343
400	-1300	-3250	-1238	-1795	279
300	-1250	-2700	-1110	-1524	207
200	-1100	-2000	-905	-1162	129
100	-950	-1250	-690	-776	43
**[0	-150	-750	-219	-386	86
.0	-50	150	5	62	-29

* denotes strains at the beginning and conclusion of 24 hour long sustained loading at 1900 psi

** denotes strains at the beginning and conclusion of 24 hour long sustained loading at 0 psi

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= .40 POISSONS RATIO .40 GAGE NO.= 2-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-450	-450	-300	-300	0
200	-850	-900	-576	-590	7
300	-1350	-1350	-900	-900	0
400	-1750	-1750	-1167	-1167	0
500	-2250	-2250	-1500	-1500	0
600	-2700	-2650	-1790	-1776	-7
700	-3150	-3150	-2100	-2100	0
800	-3603	-3600	-2400	-2400	0
900	-4150	-4050	-2748	-2719	-14
1000	-4550	-4500	-3024	-3010	-7
1100	-5100	-5000	-3381	-3352	-14
1200	-5500	-5450	-3657	-3643	-7
1300	-6050	-5950	-4014	-3986	-14
1400	-6550	-6450	-4348	-4319	-14
1500	-7050	-7000	-4690	-4676	-7
1600	-7650	-7550	-5081	-5052	-14
1700	-8200	-8100	-5448	-5419	-14
1800	-8650	-8600	-5757	-5743	-7
1800	-10900	-10650	-7219	-7148	-36
1800	-10900	-10650	-7219	-7148	-36
1700	-10550	-10300	-6986	-6914	-36
1600	-10050	-9850	-6662	-6605	-29
1500	-9650	-9500	-6405	-6362	-21
1400	-9200	-9050	-6105	-6062	-21
1300	-8800	-8650	-5838	-5795	-21
1200	-8350	-8200	-5538	-5495	-21
1100	-7900	-7750	-5238	-5195	-21
1000	-7300	-7150	-4838	-4795	-21
900	-6700	-6550	-4438	-4395	-21
800	-6200	-6050	-4105	-4062	-21
700	-5650	-5550	-3748	-3719	-14
600	-5000	-4900	-3314	-3286	-14
500	-4400	-4350	-2929	-2919	-7
400	-3800	-3950	-2562	-2605	21
300	-3200	-3300	-2152	-2181	14
200	-2500	-2600	-1686	-1714	14
100	-1800	-1950	-1229	-1271	21
0	-950	-1100	-662	-705	21
0	50	0	29	10	7

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= .40 POISSONS RATIO= .43 GAGE NO.S 3-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-100	-600	-162	-305	71
200	-200	-1100	-305	-662	129
300	-300	-1600	-448	-819	186
400	-400	-2000	-571	-1029	229
500	-500	-2500	-714	-1286	286
600	-600	-3000	-857	-1443	343
700	-700	-3450	-990	-1776	393
800	-770	-3900	-1110	-2009	447
900	-870	-4400	-1252	-2261	504
1000	-950	-4900	-1386	-2519	564
1100	-1050	-5450	-1530	-2795	629
1200	-1100	-5900	-1648	-3019	686
1300	-1200	-6400	-1790	-3276	743
1400	-1300	-6900	-1933	-3633	800
1500	-1400	-7400	-2076	-3790	857
1600	-1500	-7900	-2219	-4048	914
1700	-1600	-8460	-2362	-4305	971
1800	-1700	-8800	-2486	-4519	1019
1800	-1650	-9150	-2529	-4671	1071
1800	-1650	-9150	-2529	-4671	1071
1700	-1550	-8800	-2519	-4486	1036
1600	-1500	-8400	-2319	-4286	986
1500	-1400	-8000	-2190	-4076	943
1400	-1350	-7650	-2100	-3900	900
1300	-1250	-7200	-1967	-3667	850
1200	-1200	-6850	-1876	-3490	807
1100	-1100	-6400	-1743	-3257	757
1000	-1000	-5900	-1600	-3000	700
900	-900	-5450	-1467	-2767	650
800	-850	-5000	-1357	-2543	593
700	-750	-4550	-1229	-2310	543
600	-650	-4100	-1090	-2076	493
500	-550	-3600	-948	-1819	436
400	-450	-3100	-805	-1562	379
300	-350	-2600	-662	-1305	321
200	-200	-1950	-467	-967	250
100	-100	-1250	-286	-614	164
0	50	-450	-62	-205	71
0	0	300	57	143	-43

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= .40 POISSONS RATIO .40 GAGE NO.8 8-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-450	-450	-300	-300	0
200	-850	-850	-567	-567	0
300	-1350	-1250	-881	-852	-14
400	-1750	-1700	-1157	-1143	-7
500	-2250	-2150	-1481	-1452	-14
600	-2650	-2600	-1757	-1743	-7
700	-3150	-3100	-2090	-2076	-7
800	-3600	-3450	-2371	-2329	-21
900	-4050	-3900	-2671	-2629	-21
1000	-4450	-4300	-2938	-2895	-21
1100	-5000	-4800	-3295	-3238	-29
1200	-5450	-5250	-3595	-3538	-29
1300	-5950	-5750	-3929	-3871	-29
1400	-6400	-6200	-4229	-4171	-29
1500	-6900	-6650	-4552	-4481	-36
1600	-7500	-7200	-4943	-4857	-43
1700	-8050	-7750	-5310	-5224	-43
1800	-8550	-8200	-5633	-5533	-50
1800	-10600	-10000	-6952	-6781	-86
1800	-10600	-10000	-6952	-6781	-86
1700	-10250	-9700	-6729	-6571	-79
1600	-9800	-9250	-6429	-6271	-79
1500	-9400	-8900	-6171	-6029	-71
1400	-9000	-8450	-5895	-5738	-79
1300	-8500	-8050	-5581	-5452	-64
1200	-8150	-7650	-5338	-5195	-71
1100	-7650	-7200	-5019	-4886	-64
1000	-7050	-6700	-4633	-4533	-50
900	-6500	-6100	-4257	-4143	-57
800	-6000	-5650	-3933	-3833	-50
700	-5450	-5150	-3576	-3490	-43
600	-4850	-4550	-3176	-3090	-43
500	-4300	-4000	-2810	-2724	-43
400	-3700	-3450	-2419	-2348	-36
300	-3100	-2850	-2019	-1948	-36
200	-2400	-2200	-1562	-1505	-29
100	-1750	-1600	-1138	-1095	-21
0	-950	-800	-605	-562	-21
0	150	50	81	52	14

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO.= 5-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-50	-714	-714	0
200	-50	-50	-714	-714	0
300	-100	-100	-1429	-1429	0
400	-100	-100	-1429	-1429	0
500	-150	-150	-2143	-2143	0
600	-200	-150	-2692	-2308	-192
700	-200	-150	-2692	-2308	-192
800	-200	-200	-2857	-2857	0
900	-200	-200	-2857	-2857	0
1000	-250	-200	-3407	-3022	-192
1100	-300	-250	-4121	-3736	-192
1200	-300	-250	-4121	-3736	-192
1300	-300	-250	-4121	-3736	-192
1400	-350	-300	-4835	-4451	-192
1500	-350	-300	-4835	-4451	-192
1600	-400	-350	-5549	-5165	-192
1700	-400	-350	-5549	-5165	-192
1800	-400	-350	-5549	-5165	-192
1800	-400	-350	-5549	-5165	-192
1800	-400	-350	-5549	-5165	-192
1700	-350	-300	-4835	-4451	-192
1600	-350	-300	-4835	-4451	-192
1500	-350	-300	-4835	-4451	-192
1400	-300	-250	-4121	-3736	-192
1300	-300	-250	-4121	-3736	-192
1200	-350	-250	-4670	-3901	-385
1100	-300	-200	-3956	-3187	-385
1000	-300	-200	-3956	-3187	-385
900	-250	-150	-3242	-2473	-385
800	-200	-150	-2692	-2308	-192
700	-200	-150	-2692	-2308	-192
600	-150	-150	-2143	-2143	0
500	-150	-100	-1978	-1593	-192
400	-100	-100	-1429	-1429	0
300	-100	-50	-1264	-879	-192
200	-50	0	-549	-165	-192
100	0	0	0	0	0
0	50	100	879	1264	-192
0	-50	0	-549	-165	-192

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00

POISSONS RATIO= .30

GAGE NO.= 6=OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-100	-879	-1269	192
200	-50	-100	-879	-1269	192
300	-100	-150	-1593	-1978	192
400	-100	-150	-1593	-1978	192
500	-150	-150	-2143	-2143	0
600	-200	-200	-2857	-2857	0
700	-200	-200	-2857	-2857	0
800	-250	-250	-3571	-3571	0
900	-250	-250	-3571	-3571	0
1000	-300	-250	-4121	-3736	-192
1100	-300	-300	-4286	-4286	0
1200	-350	-300	-4835	-4451	-192
1300	-350	-300	-4835	-4451	-192
1400	-400	-350	-5549	-5165	-192
1500	-450	-350	-6099	-5330	-385
1600	-450	-400	-6264	-5879	-192
1700	-500	-400	-6813	-6044	-385
1800	-500	-450	-6978	-6593	-192
1800	-500	-450	-6978	-6593	-192
1800	-500	-450	-6978	-6593	-192
1700	-450	-400	-6264	-5879	-192
1600	-450	-400	-6264	-5879	-192
1500	-450	-400	-6264	-5879	-192
1400	-400	-350	-5549	-5165	-192
1300	-350	-350	-5000	-5000	0
1200	-350	-350	-5000	-5000	0
1100	-300	-350	-4451	-4835	192
1000	-250	-300	-3736	-4121	192
900	-250	-250	-3571	-3571	0
800	-250	-250	-3571	-3571	0
700	-200	-250	-3022	-3407	192
600	-150	-250	-2473	-3242	385
500	-100	-200	-1758	-2527	385
400	-100	-150	-1593	-1978	192
300	-50	-150	-1044	-1813	385
200	-50	-100	-879	-1269	192
100	0	-50	-165	-549	192
0	100	50	1269	879	192
0	50	0	549	165	192

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00 POISSONS RATIO= .30 GAGE NO.= 7=OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-50	-714	-714	0
200	-100	-50	-1264	-879	-192
300	-150	-100	-1978	-1593	-192
400	-150	-100	-1978	-1593	-192
500	-200	-150	-2692	-2308	-192
600	-250	-200	-3407	-3022	-192
700	-250	-250	-3571	-3571	0
800	-300	-250	-4121	-3736	-192
900	-300	-250	-4121	-3736	-192
1000	-300	-250	-4121	-3736	-192
1100	-350	-350	-5000	-5000	0
1200	-350	-350	-5000	-5000	0
1300	-400	-400	-5714	-5714	0
1400	-400	-400	-5714	-5714	0
1500	-450	-400	-6264	-5879	-192
1600	-500	-450	-6978	-6593	-192
1700	-500	-500	-7143	-7143	0
1800	-550	-500	-7692	-7308	-192
1900	-550	-450	-7527	-6758	-385
1800	-550	-450	-7527	-6758	-385
1700	-500	-400	-6813	-6044	-385
1600	-500	-350	-6648	-5495	-577
1500	-500	-350	-6648	-5495	-577
1400	-400	-300	-5385	-4615	-385
1300	-400	-300	-5385	-4615	-385
1200	-400	-300	-5385	-4615	-385
1100	-350	-300	-4835	-4451	-192
1000	-300	-250	-4121	-3736	-192
900	-300	-200	-3956	-3187	-385
800	-250	-150	-3242	-2473	-385
700	-200	-150	-2692	-2308	-192
600	-200	-100	-2527	-1758	-385
500	-150	-50	-1813	-1044	-385
400	-100	-50	-1264	-879	-192
300	-100	0	-1099	-330	-385
200	-50	50	-385	385	-385
100	-50	50	-385	385	-385
0	50	150	1044	1813	-385
0	-50	50	-385	385	-385

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO.= 8=OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	50	-385	385	-385
200	-100	100	-769	769	-769
300	-150	100	-1319	604	-962
400	-150	100	-1319	604	-962
500	-150	100	-1319	604	-962
600	-200	100	-1868	440	-1154
700	-200	100	-1868	440	-1154
800	-250	100	-2418	275	-1346
900	-250	150	-2253	824	-1538
1000	-250	150	-2253	824	-1538
1100	-300	150	-2802	659	-1731
1200	-300	200	-2637	1209	-1923
1300	-300	200	-2637	1209	-1923
1400	-350	200	-3187	1044	-2115
1500	-350	250	-3022	1593	-2308
1600	-400	200	-3736	879	-2308
1700	-450	200	-4286	714	-2500
1800	-450	200	-4286	714	-2500
1800	-400	250	-3571	1929	-2500
1800	-400	250	-3571	1929	-2500
1700	-350	200	-3187	1044	-2115
1600	-350	200	-3187	1044	-2115
1500	-300	150	-2802	659	-1731
1400	-250	200	-2088	1374	-1731
1300	-250	200	-2088	1374	-1731
1200	-250	200	-2088	1374	-1731
1100	-200	200	-1538	1538	-1538
1000	-200	200	-1538	1538	-1538
900	-150	200	-989	1703	-1346
800	-150	200	-989	1703	-1346
700	-150	200	-989	1703	-1346
600	-100	200	-440	1868	-1154
500	-100	200	-440	1868	-1154
400	-50	200	110	2033	-962
300	-50	150	-55	1484	-769
200	0	150	495	1648	-577
100	50	100	879	1264	-192
0	150	100	1978	1593	192
0	50	0	549	165	192

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO.= 4=OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-50	-714	-714	0
200	-50	-100	-879	-1264	192
300	-100	-150	-1593	-1978	192
400	-150	-150	-2143	-2143	0
500	-150	-200	-2308	-2692	192
600	-150	-200	-2308	-2692	192
700	-150	-200	-2308	-2692	192
800	-200	-250	-3022	-3407	192
900	-250	-250	-3571	-3571	0
1000	-250	-250	-3571	-3571	0
1100	-250	-300	-3736	-4121	192
1200	-250	-300	-3736	-4121	192
1300	-300	-350	-4451	-4835	192
1400	-300	-350	-4451	-4835	192
1500	-350	-400	-5165	-5549	192
1600	-350	-400	-5165	-5549	192
1700	-350	-450	-5330	-6099	385
1800	-400	-450	-5879	-6264	192
1800	-400	-450	-5879	-6264	192
1800	-400	-450	-5879	-6264	192
1700	-400	-400	-5714	-5714	0
1600	-400	-350	-5549	-5165	-192
1500	-400	-350	-5549	-5165	-192
1400	-350	-350	-5000	-5000	0
1300	-300	-350	-4451	-4835	192
1200	-300	-300	-4286	-4286	0
1100	-300	-250	-4121	-3736	-192
1000	-250	-250	-3571	-3571	0
900	-250	-200	-3407	-3022	-192
800	-200	-150	-2692	-2308	-192
700	-200	-150	-2692	-2308	-192
600	-200	-100	-2527	-1758	-385
500	-100	-100	-1429	-1429	0
400	-100	-50	-1264	-879	-192
300	-100	-50	-1264	-879	-192
200	-50	0	-549	-165	-192
100	0	50	165	549	-192
0	50	150	1099	1813	-385
0	0	50	165	549	-192

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO.= 10-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-50	-714	-714	0
200	-50	-100	-879	-1264	192
300	-100	-100	-1429	-1429	0
400	-100	-100	-1429	-1429	0
500	-100	-100	-1429	-1429	0
600	-150	-100	-1978	-1593	-192
700	-150	-150	-2143	-2143	0
800	-200	-150	-2692	-2308	-192
900	-200	-200	-2857	-2857	0
1000	-200	-150	-2692	-2308	-192
1100	-250	-200	-3407	-3022	-192
1200	-250	-200	-3407	-3022	-192
1300	-300	-200	-3956	-3187	-385
1400	-300	-200	-3956	-3187	-385
1500	-300	-200	-3956	-3187	-385
1600	-350	-250	-4670	-3901	-385
1700	-400	-250	-5220	-4066	-577
1800	-400	-250	-5220	-4066	-577
1800	-400	-250	-5220	-4066	-577
1800	-400	-250	-5220	-4066	-577
1700	-350	-200	-4505	-3352	-577
1600	-350	-200	-4505	-3352	-577
1500	-350	-200	-4505	-3352	-577
1400	-300	-150	-3791	-2637	-577
1300	-300	-150	-3791	-2637	-577
1200	-300	-150	-3791	-2637	-577
1100	-200	-100	-2527	-1758	-385
1000	-200	-100	-2527	-1758	-385
900	-200	-100	-2527	-1758	-385
800	-200	-100	-2527	-1758	-385
700	-100	-50	-1264	-879	-192
600	-100	-50	-1264	-879	-192
500	-100	-50	-1264	-879	-192
400	-100	-50	-1264	-879	-192
300	-100	0	-1099	-330	-385
200	-50	50	-385	385	-385
100	0	50	165	549	-192
0	50	100	879	1264	-192
0	-50	50	-385	385	-385

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.0E6 POISSONS RATIO= .30 GAGE NO.= 11-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-50	-714	-714	0
200	-100	-50	-1264	-879	-192
300	-100	-100	-1429	-1429	0
400	-100	-50	-1264	-879	-193
500	-100	-100	-1429	-1429	0
600	-150	-150	-2143	-2143	0
700	-100	-150	-1593	-1978	192
800	-150	-150	-2143	-2143	0
900	-200	-200	-2857	-2857	0
1000	-150	-200	-2308	-2692	192
1100	-200	-250	-3022	-3407	192
1200	-200	-250	-3022	-3407	192
1300	-200	-250	-3022	-3407	192
1400	-200	-250	-3022	-3407	192
1500	-200	-250	-3022	-3407	192
1600	-250	-300	-3736	-4121	192
1700	-250	-350	-3901	-4670	385
1800	-250	-400	-4066	-5220	577
1900	-250	-350	-3901	-4670	385
1800	-250	-350	-3901	-4670	385
1700	-250	-300	-3736	-4121	192
1600	-200	-300	-3187	-3956	385
1500	-250	-300	-3736	-4121	192
1400	-200	-250	-3022	-3407	192
1300	-200	-250	-3022	-3407	192
1200	-200	-200	-2857	-2857	0
1100	-150	-200	-2308	-2692	192
1000	-100	-150	-1593	-1978	192
900	-100	-150	-1593	-1978	192
800	-100	-150	-1593	-1978	192
700	-100	-50	-1264	-879	-192
600	-50	-50	-714	-714	0
500	-50	-50	-714	-714	0
400	-50	-50	-714	-714	0
300	-50	0	-549	-165	-192
200	0	0	0	0	0
100	50	50	714	714	0
0	100	100	1429	1429	0
0	150	0	1648	495	577

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00 POISSONS RATIO= .30 GAGE NO.= 12-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-150	-1099	-1813	385
200	-100	-150	-1593	-1978	192
300	-150	-150	-2193	-2193	0
400	-100	-150	-1593	-1978	192
500	-150	-200	-2308	-2692	192
600	-200	-200	-2857	-2857	0
700	-200	-200	-2857	-2857	0
800	-200	-200	-2857	-2857	0
900	-250	-200	-3407	-3022	-192
1000	-200	-200	-2857	-2857	0
1100	-250	-250	-3571	-3571	0
1200	-300	-200	-3956	-3187	-385
1300	-300	-250	-4121	-3736	-192
1400	-300	-250	-4121	-3736	-192
1500	-350	-250	-4670	-3901	-385
1600	-400	-250	-5220	-4066	-577
1700	-400	-300	-5385	-4615	-385
1800	-400	-300	-5385	-4615	-385
1800	-400	-300	-5385	-4615	-385
1800	-400	-300	-5385	-4615	-385
1700	-400	-250	-5220	-4066	-577
1600	-350	-250	-4670	-3901	-385
1500	-350	-250	-4670	-3901	-385
1400	-300	-200	-3956	-3187	-385
1300	-300	-200	-3956	-3187	-385
1200	-300	-200	-3956	-3187	-385
1100	-250	-200	-3407	-3022	-192
1000	-250	-200	-3407	-3022	-192
900	-200	-150	-2692	-2308	-192
800	-200	-150	-2692	-2308	-192
700	-150	-150	-2193	-2193	0
600	-150	-150	-2193	-2193	0
500	-100	-100	-1429	-1429	0
400	-100	-100	-1429	-1429	0
300	-100	-100	-1429	-1429	0
200	-50	-100	-879	-1264	192
100	0	-50	-165	-549	192
0	0	50	165	549	-192
0	-50	-50	-714	-714	0

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO.= 13-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-100	-879	-1264	192
200	-100	-100	-1929	-1929	0
300	-150	-150	-2143	-2143	0
400	-100	-150	-1593	-1978	192
500	-150	-150	-2143	-2143	0
600	-200	-150	-2692	-2308	-192
700	-200	-200	-2857	-2857	0
800	-200	-200	-2857	-2857	0
900	-250	-200	-3407	-3022	-192
1000	-250	-200	-3407	-3022	-192
1100	-300	-200	-3956	-3187	-385
1200	-300	-200	-3956	-3187	-385
1300	-350	-200	-4505	-3352	-577
1400	-350	-200	-4505	-3352	-577
1500	-350	-200	-4505	-3352	-577
1600	-400	-200	-5055	-3516	-769
1700	-400	-200	-5055	-3516	-769
1800	-400	-250	-5220	-4066	-577
1800	-400	-200	-5055	-3516	-769
1800	-400	-200	-5055	-3516	-769
1700	-400	-200	-5055	-3516	-769
1600	-400	-200	-5055	-3516	-769
1500	-400	-150	-4890	-2967	-962
1400	-350	-150	-4341	-2802	-769
1300	-300	-150	-3791	-2637	-577
1200	-300	-150	-3791	-2637	-577
1100	-300	-150	-3791	-2637	-577
1000	-250	-100	-3077	-1923	-577
900	-200	-100	-2527	-1758	-385
800	-200	-100	-2527	-1758	-385
700	-200	-50	-2363	-1209	-577
600	-150	-50	-1813	-1099	-385
500	-150	-50	-1813	-1099	-385
400	-150	-50	-1813	-1099	-385
300	-100	0	-1099	-330	-385
200	-100	0	-1099	-330	-385
100	-50	50	-385	385	-385
0	0	100	330	1099	-385
0	100	100	1429	1429	0

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO.= 14-OUTSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-100	-879	-1264	192
200	-100	-100	-1429	-1429	0
300	-150	-150	-1593	-1978	192
400	-100	-150	-1593	-1978	192
500	-150	-200	-2308	-2692	192
600	-200	-700	-4505	-8352	1923
700	-200	-200	-2857	-2857	0
800	-200	-200	-2857	-2857	0
900	-250	-200	-3407	-3022	-192
1000	-250	-200	-3407	-3022	-192
1100	-300	-200	-3956	-3187	-385
1200	-300	-200	-3956	-3187	-385
1300	-300	-250	-4121	-3736	-192
1400	-300	-250	-4121	-3736	-192
1500	-350	-250	-4670	-3901	-385
1600	-400	-250	-5220	-4066	-577
1700	-400	-250	-5220	-4066	-577
1800	-400	-300	-5385	-4615	-385
1900	-450	-250	-5769	-4231	-769
1900	-450	-250	-5769	-4231	-769
1700	-400	-250	-5220	-4066	-577
1600	-400	-250	-5220	-4066	-577
1500	-350	-250	-4670	-3901	-385
1400	-350	-200	-4505	-3352	-577
1300	-300	-200	-3956	-3187	-385
1200	-300	-150	-3791	-2637	-577
1100	-250	-150	-3242	-2473	-385
1000	-250	-150	-3242	-2473	-385
900	-200	-100	-2527	-1758	-385
800	-200	-100	-2527	-1758	-385
700	-200	-100	-2527	-1758	-385
600	-150	-50	-1813	-1099	-385
500	-100	-50	-1264	-879	-192
400	-100	-50	-1264	-879	-192
300	-50	0	-549	-165	-192
200	-50	0	-549	-165	-192
100	0	50	165	549	-192
0	0	100	330	1099	-385
0	50	0	549	165	192

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= .40 POISSONS RATIO= .30 GAGE NO.= 1-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-600	-700	-419	-448	19
200	-950	-1750	-786	-1019	119
300	-1200	-2700	-1095	-1538	221
400	-1500	-3650	-1448	-2119	336
500	-1850	-5000	-1833	-2733	450
600	-2100	-6100	-2162	-3308	571
700	-2450	-7350	-2567	-3967	700
800	-2750	-8450	-2919	-4448	819
900	-2050	-9550	-3176	-5098	957
1000	-3000	-11050	-3438	-5495	1029
1100	-3400	-12300	-4200	-6600	1200
1200	-3450	-13150	-4306	-7019	1315
1300	-4500	-14156	-4838	-7595	1379
1400	-4750	-15350	-5186	-8219	1519
1500	-5150	-16800	-5652	-8981	1664
1600	-5800	-17350	-6067	-9367	1650
1700	-6150	-19100	-6567	-10867	1850
1800	-6656	-20400	-7085	-10962	1979
1800	-7700	-26450	-8000	-14300	2750
1800	-7700	-26450	-8000	-14300	2750
1700	-7550	-26150	-8676	-13890	2657
1600	-7253	-25100	-8233	-13338	2550
1500	-6950	-23950	-7871	-12729	2429
1400	-6660	-23150	-7576	-12298	2367
1300	-6400	-22100	-7257	-11763	2293
1200	-6150	-21050	-6938	-11198	2184
1100	-5900	-19050	-6598	-10676	1903
1000	-5550	-18300	-6138	-9798	1829
900	-5400	-16950	-5890	-9100	1650
800	-5200	-15750	-5476	-8498	1507
700	-4950	-14550	-5129	-7871	1371
600	-4900	-13000	-4816	-7120	1157
500	-4650	-10250	-4167	-5767	808
400	-4150	-8050	-3662	-5008	671
300	-3650	-7600	-3138	-4298	579
200	-3400	-6050	-2733	-3033	358
100	-3250	-4750	-2452	-2081	219
0	-1350	-3450	-1300	-1480	300
0	50	250	71	129	-29

Table 3C (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= ,90 POISSONS RATIO= ,40 GAGE NO.= 2-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-650	-600	-429	-410	-7
200	-1200	-1100	-781	-752	-19
300	-1800	-1650	-1171	-1129	-21
400	-2400	-2200	-1562	-1505	-29
500	-3050	-2803	-1962	-1905	-29
600	-3600	-3350	-2352	-2281	-36
700	-4300	-3950	-2800	-2700	-50
800	-4900	-4450	-3181	-3062	-59
900	-5500	-5050	-3581	-3452	-64
1000	-6100	-5600	-3971	-3829	-71
1100	-6850	-6300	-4462	-4308	-79
1200	-7400	-6800	-4819	-4740	-86
1300	-8100	-7450	-5276	-5090	-93
1400	-8750	-8050	-5700	-5600	-100
1500	-9500	-8700	-6181	-5952	-114
1600	-10300	-9483	-6695	-6438	-129
1700	-11000	-10050	-7152	-6881	-136
1800	-11700	-10650	-7600	-7380	-150
1900	-14000	-13250	-9571	-9129	-221
1900	-14400	-13250	-9571	-9129	-221
1700	-14350	-12800	-9271	-8829	-221
1600	-13750	-12300	-8898	-8476	-207
1500	-13200	-11750	-8529	-8110	-207
1400	-12650	-11250	-8167	-7767	-200
1300	-12000	-10700	-7752	-7381	-186
1200	-11400	-10150	-7362	-7005	-179
1100	-10000	-9550	-6962	-6605	-179
1000	-9450	-8800	-6419	-6086	-164
900	-9200	-8150	-5933	-5633	-150
800	-8550	-7500	-5500	-5200	-150
700	-7850	-6850	-5043	-4757	-143
600	-7100	-6100	-4543	-4257	-143
500	-6200	-5400	-3981	-3752	-114
400	-5400	-4700	-3467	-3267	-100
300	-4600	-3900	-2933	-2733	-100
200	-3600	-3050	-2295	-2138	-79
100	-2700	-2250	-1719	-1586	-64
0	-1500	-1250	-1000	-900	-50
0	-150	-50	-81	-52	-14

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= .90 POISSONS RATIO .90 GAGE NO.= 3-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-400	-900	-362	-505	71
200	-700	-1650	-648	-919	136
300	-1050	-2450	-967	-1367	200
400	-1300	-3300	-1248	-1619	286
500	-1650	-4200	-1586	-2314	364
600	-1950	-5100	-1900	-2800	450
700	-2300	-6100	-2257	-3343	543
800	-2600	-7000	-2571	-3829	629
900	-2900	-7900	-2886	-4314	714
1000	-3250	-8850	-3233	-4833	800
1100	-3450	-10000	-3649	-5457	907
1200	-3950	-10950	-3940	-5919	986
1300	-4300	-11900	-4314	-6486	1086
1400	-4650	-12850	-4662	-7005	1171
1500	-5050	-14050	-5071	-7629	1279
1600	-5400	-15050	-5438	-8198	1379
1700	-5850	-16200	-5871	-8829	1479
1800	-6200	-17250	-6238	-9395	1579
1900	-7500	-21900	-7743	-11057	2057
1900	-7500	-21900	-7743	-11857	205
1700	-7250	-21200	-7490	-11476	1993
1600	-6900	-20300	-7152	-10901	1919
1500	-6650	-19450	-6871	-10529	1829
1400	-6400	-18650	-6600	-10100	1750
1300	-6050	-17800	-6271	-9629	1679
1200	-5750	-16950	-5967	-9167	1600
1100	-5400	-16050	-5629	-8671	1521
1000	-5000	-14900	-5219	-8098	1439
900	-4600	-13950	-4848	-7519	1336
800	-4250	-12950	-4490	-6976	1243
700	-3850	-11900	-4100	-6400	1150
600	-3450	-10750	-3690	-5776	1043
500	-3050	-9550	-3271	-5129	929
400	-2600	-8250	-2810	-4429	807
300	-2200	-7050	-2390	-3776	693
200	-1700	-5400	-1830	-2895	529
100	-1250	-3750	-1310	-2029	357
0	-700	-2100	-733	-1133	200
0	-200	550	10	224	-107

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

EF .90

POISSONS RATIO .30

GAGE NO.8 4=INSIDE

LOAD	ZP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-600	-600	-400	-400	0
200	-1200	-1150	-751	-752	0
300	-1800	-1700	-1181	-1152	-19
400	-2550	-2200	-1633	-1533	-19
500	-3050	-2800	-1986	-1919	-50
600	-3650	-3400	-2386	-2319	-36
700	-4350	-4000	-2833	-2733	-36
800	-4950	-4550	-3229	-3110	-50
900	-5550	-5150	-3629	-3510	-57
1000	-6200	-5750	-4048	-3919	-57
1100	-6900	-6450	-4519	-4386	-69
1200	-7500	-7000	-4985	-4768	-69
1300	-8200	-7650	-5362	-5205	-71
1400	-8850	-8300	-5798	-5688	-79
1500	-9556	-8950	-6252	-6081	-79
1600	-10350	-9700	-6776	-6590	-86
1700	-11150	-10400	-7290	-7076	-93
1800	-11850	-11100	-7757	-7501	-107
1800	-15050	-13850	-9805	-9462	-107
					-171
1800	-15050	-13850	-9805	-9462	-171
1700	-14550	-13350	-9471	-9129	-171
1600	-13950	-12800	-9081	-8752	-164
1500	-13350	-12250	-8690	-8376	-157
1400	-12850	-11750	-8367	-8043	-157
1300	-12250	-11150	-7957	-7643	-157
1200	-11600	-10600	-7543	-7257	-143
1100	-10950	-10000	-7119	-6848	-136
1000	-10050	-9200	-6630	-6295	-121
900	-9350	-8500	-6071	-5829	-121
800	-8650	-7850	-5619	-5386	-119
700	-7900	-7150	-5129	-4910	-107
600	-7050	-6350	-4567	-4367	-100
500	-6250	-5550	-4033	-3833	-100
400	-5450	-4800	-3510	-3329	-93
300	-4600	-4050	-2962	-2805	-79
200	-3600	-3100	-2305	-2162	-71
100	-2650	-2200	-1581	-1552	-64
0	-1500	-1150	-933	-833	-50
0	0	150	29	71	-21

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00 POISSONS RATIO= .30 GAGE NO.8 S-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-50	-714	-714	0
200	-60	-100	-879	-1264	192
300	-100	-150	-1593	-1978	192
400	-200	-250	-3022	-3407	192
500	-250	-300	-3736	-4121	192
600	-300	-400	-4615	-5385	385
700	-350	-450	-5330	-6099	385
800	-400	-550	-6209	-7363	577
900	-500	-600	-7473	-8242	385
1000	-550	-700	-8352	-9505	577
1100	-600	-800	-9231	-10769	769
1200	-650	-850	-9945	-11484	769
1300	-700	-900	-10659	-12198	769
1400	-750	-950	-11374	-12912	769
1500	-800	-1050	-12253	-14176	962
1600	-850	-1100	-12967	-14890	962
1700	-900	-1150	-13681	-15604	962
1800	-950	-1250	-14560	-16868	1154
1808	-950	-1250	-14560	-16868	1154
1800	-950	-1250	-14560	-16868	1154
1700	-900	-1200	-13846	-16154	1154
1600	-850	-1100	-12967	-14890	962
1500	-800	-1050	-12253	-14176	962
1400	-750	-1000	-11538	-13462	962
1300	-700	-900	-10659	-12198	769
1200	-650	-800	-9780	-10934	577
1100	-550	-750	-8516	-10055	769
1000	-500	-650	-7637	-8791	577
900	-450	-600	-6923	-8077	577
800	-400	-500	-6044	-6813	385
700	-350	-450	-5330	-6099	385
600	-250	-400	-4066	-5220	577
500	-200	-300	-3187	-3956	385
400	-150	-200	-2308	-2692	192
300	-100	-150	-1593	-1978	192
200	0	-50	-165	-549	192
100	50	0	549	165	192
0	50	0	549	165	192
0	0	-100	-330	-1099	385

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

T= 10.00 POISSONS RATIO= .30 GAGE NO.= 6-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-100	-879	-1269	192
200	-150	-150	-2193	-2193	0
300	-150	-250	-2973	-3292	305
400	-200	-350	-3352	-4505	577
500	-300	-500	-4995	-6984	769
600	-350	-550	-5659	-7198	769
700	-400	-700	-6703	-9011	1154
800	-450	-750	-7418	-9725	1154
900	-550	-850	-8046	-11154	1154
1000	-600	-950	-9725	-12418	1346
1100	-700	-1050	-11159	-13846	1346
1200	-750	-1100	-11868	-14560	1346
1300	-750	-1150	-12033	-15110	1538
1400	-800	-1250	-12912	-16374	1731
1500	-900	-1350	-14341	-17802	1731
1600	-950	-1400	-15055	-18516	1731
1700	-1000	-1500	-15934	-19780	1921
1800	-1050	-1600	-16813	-21099	2115
1800	-1050	-1400	-16159	-18046	1346
1800	-1050	-1400	-16159	-18046	1346
1700	-1000	-1300	-15276	-17582	1154
1600	-950	-1200	-14396	-16319	962
1500	-850	-1100	-12967	-14890	962
1400	-800	-950	-11923	-13077	577
1300	-750	-850	-11044	-11813	385
1200	-650	-750	-9615	-10385	385
1100	-600	-650	-8736	-9121	192
1000	-550	-550	-7857	-7857	0
900	-450	-450	-6429	-6429	0
800	-400	-350	-5549	-5166	-192
700	-350	-250	-4670	-3901	-385
600	-300	-150	-3791	-2637	-577
500	-200	0	-2198	-659	-769
400	-150	100	-1319	604	-962
300	-50	200	110	2033	-962
200	0	300	989	3297	-1154
100	50	400	1868	4560	-1346
0	50	300	1538	3462	-962
0	-50	2350	7198	25659	-9231

Table 3(. (Continued)

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00 POISSONS RATIO= .30 GAGE NO.= 7=INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-50	-714	-714	0
200	-100	-100	-1429	-1429	0
300	-200	-150	-2692	-2308	-192
400	-250	-200	-3407	-3022	-192
500	-350	-250	-4670	-3901	-385
600	-400	-300	-5385	-4615	-385
700	-500	-350	-6648	-5495	-577
800	-550	-400	-7363	-6209	-577
900	-600	-400	-7912	-6374	-769
1000	-700	-450	-9176	-7253	-962
1100	-800	-550	-10604	-8681	-962
1200	-850	-600	-11319	-9396	-962
1300	-900	-650	-12033	-10110	-962
1400	-950	-700	-12747	-10824	-962
1500	-1000	-750	-13462	-11538	-962
1600	-1050	-650	-14341	-12802	-769
1700	-1150	-850	-15440	-13132	-1154
1800	-1200	-900	-16154	-13846	-1154
1900	-1250	-950	-16868	-14560	-1154
1800	-1250	-950	-16868	-14560	-1154
1700	-1150	-850	-15440	-13132	-1154
1600	-1050	-750	-14011	-11703	-1154
1500	-1000	-700	-13297	-10989	-1154
1400	-950	-600	-12418	-9725	-1346
1300	-850	-550	-11159	-8846	-1154
1200	-800	-500	-10440	-8132	-1154
1100	-650	-400	-8462	-6538	-962
1000	-600	-350	-7747	-5824	-962
900	-550	-300	-7033	-5110	-962
800	-450	-250	-5769	-4231	-769
700	-400	-200	-5055	-3516	-769
600	-250	-150	-3242	-2473	-385
500	-200	-100	-2527	-1758	-385
400	-150	-50	-1813	-1044	-385
300	-100	0	-1099	-330	-385
200	0	50	165	549	-192
100	50	50	714	714	0
0	50	100	879	1264	-192
0	0	50	165	549	-192

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00 POISSONS RATIO= .30 GAGE NO.= B-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	50	-385	385	-385
200	-150	100	-1319	684	-962
300	-250	150	-2253	824	-1538
400	-300	150	-2802	659	-1731
500	-400	200	-3736	879	-2308
600	-500	250	-4670	1099	-2885
700	-600	250	-5769	769	-3269
800	-650	300	-6159	1154	-3654
900	-750	350	-7088	1374	-4231
1000	-850	350	-8187	1099	-4615
1100	-950	350	-9286	714	-5000
1200	-1050	350	-10385	385	-5385
1300	-1100	100	-11758	-2527	-4615
1400	-1150	100	-12308	-2692	-4808
1500	-1250	0	-13736	-4121	-4808
1600	-1300	-50	-14451	-4835	-4808
1700	-1350	-50	-15000	-5000	-5000
1800	-1450	-50	-16099	-5330	-5385
1800	[illegible]	-150	-16429	-6429	-5000
1800	-1450	-150	-16429	-6429	-5000
1700	-1400	100	-15055	-3516	-5769
1600	-1350	200	-14176	-2253	-5962
1500	-1250	200	-14077	-1923	-5577
1400	-1200	200	-12527	-1758	-5385
1300	-1050	250	-10714	-714	-5000
1200	-950	250	-9615	-385	-4615
1100	-800	300	-7802	659	-4231
1000	-700	350	-6538	1538	-4038
900	-600	400	-5275	2418	-3846
800	-550	400	-4725	2582	-3654
700	-500	450	-4011	3297	-3654
600	-450	450	-3462	3462	-3462
500	-350	450	-2363	3791	-3077
400	-300	450	-1813	3956	-2885
300	-200	400	-879	3736	-2308
200	-100	400	220	4066	-1923
100	-50	350	604	3681	-1538
0	-100	400	220	4065	-1923
0	0	400	1319	4396	-1538

Table 3C. (Continued.

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00 POISSONS RATIO= .30 GAGE NO.= 4-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-50	-714	-714	0
200	-100	-100	-1429	-1429	0
300	-100	-200	-1758	-2527	385
400	-150	-300	-2637	-3791	577
500	-200	-400	-3516	-5055	769
600	-250	-500	-4396	-6319	962
700	-300	-600	-5276	-7582	1154
800	-350	-700	-6154	-8846	1346
900	-400	-800	-7033	-10110	1538
1000	-450	-900	-7912	-11374	1731
1100	-500	-950	-8626	-12088	1731
1200	-550	-1050	-9505	-13352	1923
1300	-600	-1150	-10385	-14615	2115
1400	-650	-1300	-11429	-16429	2500
1500	-700	-1350	-12143	-17143	2500
1600	-750	-1450	-13022	-18407	2692
1700	-750	-1550	-13352	-19505	3077
1800	-800	-1650	-14231	-20769	3269
1800	-800	-1500	-13736	-19121	2692
1800	-800	-1500	-13736	-19121	2692
1700	-750	-1450	-13022	-18407	2692
1600	-750	-1300	-12527	-16758	2115
1500	-700	-1200	-11648	-15495	1923
1400	-650	-1100	-10769	-14231	1731
1300	-600	-1050	-10055	-13516	1731
1200	-550	-1000	-9341	-12802	1731
1100	-500	-850	-8297	-10989	1346
1000	-450	-800	-7582	-10275	1346
900	-400	-650	-6538	-8462	962
800	-350	-600	-5824	-7747	962
700	-350	-500	-5495	-6648	577
600	-250	-400	-4066	-5220	577
500	-200	-350	-3352	-4505	577
400	-150	-200	-2308	-2692	192
300	-150	-150	-2143	-2143	0
200	-100	-100	-1429	-1429	0
100	-50	0	-549	-165	-192
0	-50	0	-549	-165	-192
0	-150	0	-1648	-495	-577

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,6G | POISSONS RATIO= .30 | GAGE NO.= 10-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-50	-714	-714	0
200	-100	-100	-1429	-1429	0
300	-150	-150	-2143	-2143	0
400	-200	-200	-2857	-2857	0
500	-250	-250	-3571	-3571	0
600	-300	-300	-4286	-4286	0
700	-350	-350	-5000	-5000	0
800	-450	-400	-6264	-5879	-192
900	-500	-450	-6978	-6593	-192
1000	-550	-550	-7857	-7857	0
1100	-650	-600	-9121	-8736	-192
1200	-650	-650	-9286	-9286	0
1300	-700	-700	-10000	-10000	0
1400	-750	-750	-10714	-10714	0
1500	-800	-800	-11429	-11429	0
1600	-850	-850	-12143	-12143	0
1700	-900	-950	-13022	-13407	192
1800	-950	-1000	-13736	-14121	192
1800	-900	-900	-12857	-12857	0
1800	-900	-900	-12857	-12857	0
1700	-850	-800	-11978	-11593	-192
1600	-800	-750	-11264	-10879	-192
1500	-750	-700	-10549	-10165	-192
1400	-700	-650	-9835	-9451	-192
1300	-650	-600	-9121	-8736	-192
1200	-600	-550	-8407	-8022	-192
1100	-550	-500	-7692	-7308	-192
1000	-500	-450	-6978	-6593	-192
900	-450	-350	-6099	-5330	-385
800	-400	-300	-5385	-4615	-385
700	-350	-250	-4670	-3901	-385
600	-250	-200	-3407	-3022	-192
500	-250	-150	-3242	-2473	-385
400	-150	-100	-1978	-1593	-192
300	-100	-50	-1264	-879	-192
200	-100	0	-1099	-330	-385
100	-50	50	-385	385	-385
0	0	0	0	0	0
0	0	-150	-495	-1648	577

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO .30 GAGE NO.= 11-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	0	-549	-165	-192
200	-50	-50	-714	-714	0
300	-100	-100	-1429	-1429	0
400	-200	-150	-2692	-2308	-192
500	-250	-200	-3407	-3022	-192
600	-300	-250	-4121	-3736	-192
700	-350	-300	-4835	-4451	-192
800	-400	-400	-5714	-5714	0
900	-450	-450	-6429	-6429	0
1000	-550	-500	-7692	-7308	-192
1100	-650	-550	-8956	-8187	-385
1200	-650	-600	-9121	-8736	-192
1300	-700	-650	-9835	-9451	-192
1400	-750	-700	-10549	-10165	-192
1500	-750	-800	-10879	-11264	192
1600	-850	-850	-12143	-12143	0
1700	-850	-900	-12308	-12692	192
1800	-900	-950	-13022	-13407	192
1800	-900	-900	-12857	-12857	0
1800	-900	-900	-12857	-12857	0
1700	-800	-850	-11593	-11978	192
1600	-750	-800	-10879	-11264	192
1500	-700	-750	-10165	-10549	192
1400	-650	-700	-9451	-9835	192
1300	-600	-650	-8736	-9121	192
1200	-550	-600	-8022	-8407	192
1100	-500	-550	-7308	-7692	192
1000	-450	-450	-6429	-6429	0
900	-350	-400	-5165	-5549	192
800	-300	-350	-4451	-4835	192
700	-250	-300	-3736	-4121	192
600	-200	-250	-3022	-3407	192
500	-150	-150	-2143	-2143	0
400	-100	-100	-1429	-1429	0
300	-50	-50	-714	-714	0
200	0	0	0	0	0
100	50	50	714	714	0
0	50	50	714	714	0
0	50	0	549	165	192

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO .30 GAGE NO.8 1=INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-50	-719	-719	0
200	-100	-50	-1269	-879	-192
300	-150	-100	-1978	-1593	-192
400	-250	-150	-3242	-2473	-306
500	-300	-200	-3956	-3187	-305
600	-350	-250	-4670	-3901	-306
700	-400	-350	-5549	-5165	-192
800	-450	-400	-6264	-5879	-192
900	-500	-450	-6978	-6593	-192
1000	-600	-500	-8292	-7473	-305
1100	-700	-600	-8670	-8901	-306
1200	-700	-650	-9835	-9951	-192
1300	-750	-700	-10549	-10165	-192
1400	-800	-750	-11264	-10879	-192
1500	-850	-850	-12193	-12193	0
1600	-900	-900	-12857	-12857	0
1700	-950	-950	-13571	-13571	0
1800	-1000	-1000	-14286	-14285	0
1800	-1000	-950	-14121	-13736	-192
1800	-1000	-950	-14121	-13736	-192
1700	-950	-900	-13407	-13022	-192
1600	-850	-850	-12193	-12193	0
1500	-800	-800	-11429	-11429	0
1400	-750	-750	-10714	-10714	0
1300	-700	-650	-9835	-9951	-192
1200	-650	-600	-9121	-8736	-192
1100	-600	-550	-8407	-8022	-192
1000	-550	-500	-7692	-7308	-192
900	-500	-450	-6978	-6643	-192
800	-450	-400	-6264	-5879	-192
700	-400	-300	-5308	-4615	-192
600	-300	-250	-4121	-3736	-305
500	-250	-200	-3407	-3022	-192
400	-150	-150	-2193	-2149	-192
300	-100	-100	-1429	-1429	0
200	-50	0	-549	-165	0
100	0	0	0	0	-192
0	0	50	165	549	0
0	50	50	719	719	-192
					0

Table 3C. (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10.00 POISSONS RATIO= .30 GAGE NO.= 13-INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	-50	-714	-714	0
200	-50	-50	-714	-714	0
300	-100	-100	-1429	-1429	0
400	-150	-150	-2143	-2143	0
500	-250	-250	-3571	-3571	0
600	-350	-300	-4835	-4451	-192
700	-350	-400	-5165	-5549	192
800	-400	-450	-5879	-6264	192
900	-450	-500	-6593	-6978	192
1000	-550	-600	-8022	-8407	192
1100	-600	-700	-8901	-9670	385
1200	-650	-750	-9615	-10385	385
1300	-700	-800	-10330	-11099	385
1400	-750	-900	-11209	-12363	577
1500	-800	-950	-11923	-13077	577
1600	-900	-1000	-13187	-13956	385
1700	-950	-1050	-13901	-14670	385
1800	-1000	-1150	-14780	-15934	577
1800	-850	-1050	-12802	-14341	769
1800	-850	-1050	-12802	-14341	769
1700	-800	-1000	-12088	-13626	769
1600	-750	-900	-11209	-12363	577
1500	-700	-800	-10330	-11099	385
1400	-600	-750	-9066	-10220	577
1300	-550	-700	-8352	-9505	577
1200	-500	-650	-7637	-8791	577
1100	-400	-600	-6374	-7912	769
1000	-350	-500	-5495	-6648	577
900	-300	-450	-4780	-5934	577
800	-250	-350	-3901	-4670	385
700	-200	-300	-3187	-3956	385
600	-150	-250	-2473	-3242	385
500	-50	-150	-1044	-1813	385
400	0	-100	-330	-1099	385
300	50	-50	385	-385	385
200	100	0	1099	330	385
100	200	50	2363	1209	577
0	200	100	2527	1758	385
0	1450	1350	20385	19615	385

Table 3C (Continued).

STRAIN REDUCTION OF A TWO GAGE ROSETTE

E= 10,00 POISSONS RATIO= .30 GAGE NO.= 19=INSIDE

LOAD	EP1	EP2	SIGMA MAX	SIGMA MIN	TAU MAX
0	0	0	0	0	0
100	-50	0	-549	-165	-192
200	-100	0	-1099	-330	-385
306	-150	-50	-1813	-1099	-385
400	-200	-100	-2527	-1758	-385
500	-250	-150	-3242	-2473	-385
600	-350	-250	-4670	-2901	-385
700	-450	-300	-5934	-4780	-577
800	-500	-400	-6813	-6044	-385
900	-550	-450	-7527	-6758	-385
1000	-650	-500	-8791	-7637	-577
1100	-750	-600	-13220	-9066	-577
1200	-800	-650	-10934	-9780	-577
1300	-850	-700	-11648	-10495	-577
1400	-900	-800	-12527	-11758	-385
1500	-950	-900	-13907	-13022	-192
1600	-1050	-950	-14121	-13736	-192
1700	-1050	-1000	-14835	-14451	-192
1800	-1150	-1100	-16264	-15879	-192
1800	-1050	-1000	-14835	-14451	-192
1800	-1050	-1100	-15165	-15549	192
1700	-1000	-1050	-14451	-14036	192
1600	-900	-950	-13022	-13407	192
1500	-850	-850	-12143	-12143	0
1400	-800	-800	-11429	-11429	0
1300	-700	-750	-10165	-10549	192
1200	-650	-650	-9286	-9286	0
1100	-600	-600	-8571	-8571	0
1000	-550	-550	-7857	-7857	0
900	-450	-450	-6429	-6429	0
800	-400	-400	-5714	-5714	0
700	-350	-300	-4835	-4451	-192
600	-250	-250	-3571	-3571	0
500	-200	-150	-2692	-2308	-192
400	-150	-100	-1978	-1593	-192
300	-50	-50	-714	-714	0
200	0	0	0	0	0
100	50	50	714	714	0
0	50	50	714	714	0
0	1350	1250	18956	18187	385

APPENDIX D. DATA FROM FINITE ELEMENT STRESS ANALYSIS OF 66-INCH OD × 58-INCH ID MODEL 2000 NEMO HULL ASSEMBLY

Although the results of the finite element stress analysis for 66-inch OD × 58-inch ID Model 2000 Nemo Hull under 900 psi hydrostatic loading have been summarized in the text of the report (Figures 4 to 8) it was considered desirable to publish this data for the benefit of other plastic hull investigators. The data details the predicted stress and strains for both the top hatch (Figures 1D) and bottom penetration plate (Figure 2D). To correlate the stresses and strains shown on Figures 1D and 2D with physical locations on the Model 2000 Nemo Hull one has only to locate the corresponding node numbers on finite element meshes for top hatch (Figure 5) and bottom penetration plate (Figure 6).

Since the finite element stress analysis was based on the assumption that the stress-strain relationship of acrylic plastic is linear under short term loading in the 0–10,000 psi stress range, the calculated values for 900 psi hydrostatic loading (Figure 1D and 2D) can be extrapolated with reasonable confidence to 1350 psi hydrostatic loading representing the 3000 foot operational depth of the Model 2000 Nemo Hull. For hydrostatic loadings in excess of 1500 psi the extrapolation of values calculated for 900 psi is not recommended as the stress-strain relationship for acrylic plastic becomes non-linear at the stress values encountered in this loading range.

UPPER HATCH
NODES 1–54

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure IID. Predicted stress and strains for the top hatch.

UPPER HATCH
NODES 55-116

NODE	R	Z	LONGITUDINAL STRAIN	LONGITUDINAL STRESS	HOOP STRESS	HOOP STRAIN
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 1D. (Continued).

UPPER HATCH
NODES 117–178

NODE	R	Z	LONGITUDINAL STRAIN	LONGITUDINAL STRESS	HOOP STRESS	HOOP STRAIN
117	[illegible]	[illegible]	[illegible]	[illegible]	-5958.4428	-4.40591E-04
118	[illegible]	[illegible]	[illegible]	[illegible]	-4723.9310	-3.51981E-04
119	[illegible]	[illegible]	[illegible]	[illegible]	-3638.0662	-2.50782E-04
120	[illegible]	[illegible]	[illegible]	[illegible]	-2318.6754	-1.65752E-04
121	[illegible]	[illegible]	[illegible]	[illegible]	-1070.1167	-8.46414E-05
122	[illegible]	[illegible]	[illegible]	[illegible]	-12692.7512	-1.02499E-03
123	[illegible]	[illegible]	[illegible]	[illegible]	-13156.3404	-1.02087E-03
124	[illegible]	[illegible]	[illegible]	[illegible]	-10929.8497	-8.78126E-04
125	[illegible]	[illegible]	[illegible]	[illegible]	-9382.9120	-7.81353E-04
126	[illegible]	[illegible]	[illegible]	[illegible]	-8035.7280	-6.36109E-04
127	[illegible]	[illegible]	[illegible]	[illegible]	-6778.3109	-5.28317E-04
128	[illegible]	[illegible]	[illegible]	[illegible]	-5587.0081	-4.24479E-04
129	[illegible]	[illegible]	[illegible]	[illegible]	-4396.0653	-3.28533E-04
130	[illegible]	[illegible]	[illegible]	[illegible]	-3220.4543	-2.29[illegible]E-04
131	[illegible]	[illegible]	[illegible]	[illegible]	-1965.2096	-1.38154E-04
132	[illegible]	[illegible]	[illegible]	[illegible]	-1516.8464	-1.02225E-04
133	[illegible]	[illegible]	[illegible]	[illegible]	-13312.5309	-1.07331E-03
134	[illegible]	[illegible]	[illegible]	[illegible]	-12472.5415	-9.69613E-04
135	[illegible]	[illegible]	[illegible]	[illegible]	-10870.2603	-8.38411E-04
136	[illegible]	[illegible]	[illegible]	[illegible]	-8965.5090	-7.11345E-04
137	[illegible]	[illegible]	[illegible]	[illegible]	-7678.9275	-5.96147E-04
138	[illegible]	[illegible]	[illegible]	[illegible]	-6303.2062	-4.86955E-04
139	[illegible]	[illegible]	[illegible]	[illegible]	-5173.9170	-3.88540E-04
140	[illegible]	[illegible]	[illegible]	[illegible]	-3911.9743	-2.88490E-04
141	[illegible]	[illegible]	[illegible]	[illegible]	-2830.9965	-1.91296E-04
142	[illegible]	[illegible]	[illegible]	[illegible]	-1520.8954	-9.96420E-05
143	[illegible]	[illegible]	[illegible]	[illegible]	-12723.6517	-1.00679E-03
144	[illegible]	[illegible]	[illegible]	[illegible]	-11013.9649	-8.79085E-04
145	[illegible]	[illegible]	[illegible]	[illegible]	-9427.2466	-7.46007E-04
146	[illegible]	[illegible]	[illegible]	[illegible]	-7986.9447	-6.22253E-04
147	[illegible]	[illegible]	[illegible]	[illegible]	-6682.4110	-5.00708E-04
148	[illegible]	[illegible]	[illegible]	[illegible]	-5330.9695	-3.97200E-04
149	[illegible]	[illegible]	[illegible]	[illegible]	-4092.6445	-2.93710E-04
150	[illegible]	[illegible]	[illegible]	[illegible]	-2900.9966	-1.95262E-04
151	[illegible]	[illegible]	[illegible]	[illegible]	-1620.1791	-1.00020E-04
152	[illegible]	[illegible]	[illegible]	[illegible]	-12188.6716	-1.06822E-03
153	[illegible]	[illegible]	[illegible]	[illegible]	-10883.5630	-9.33713E-04
154	[illegible]	[illegible]	[illegible]	[illegible]	-9750.3437	-7.88652E-04
155	[illegible]	[illegible]	[illegible]	[illegible]	-8357.3207	-6.52012E-04
156	[illegible]	[illegible]	[illegible]	[illegible]	-6909.5907	-5.28619E-04
157	[illegible]	[illegible]	[illegible]	[illegible]	-5600.9527	-4.13083E-04
158	[illegible]	[illegible]	[illegible]	[illegible]	-4277.7891	-3.04658E-04
159	[illegible]	[illegible]	[illegible]	[illegible]	-3013.8203	-2.01401E-04
160	[illegible]	[illegible]	[illegible]	[illegible]	-1680.1903	-1.01878E-04
161	[illegible]	[illegible]	[illegible]	[illegible]	-13080.6782	-1.16387E-03
162	[illegible]	[illegible]	[illegible]	[illegible]	-11203.7331	-1.00094E-03
163	[illegible]	[illegible]	[illegible]	[illegible]	-10026.0817	-8.38721E-04
164	[illegible]	[illegible]	[illegible]	[illegible]	-8825.0017	-6.85983E-04
165	[illegible]	[illegible]	[illegible]	[illegible]	-7346.5747	-5.51880E-04
166	[illegible]	[illegible]	[illegible]	[illegible]	-5906.8394	-4.30174E-04
167	[illegible]	[illegible]	[illegible]	[illegible]	-4466.2178	-3.16055E-04
168	[illegible]	[illegible]	[illegible]	[illegible]	-3131.7328	-2.08408E-04
169	[illegible]	[illegible]	[illegible]	[illegible]	-1712.9714	-1.03627E-04
170	[illegible]	[illegible]	[illegible]	[illegible]	-13515.9304	-1.01550E-03
171	[illegible]	[illegible]	[illegible]	[illegible]	-12283.3669	-9.32136E-04
172	[illegible]	[illegible]	[illegible]	[illegible]	-11779.1033	-8.80481E-04
173	[illegible]	[illegible]	[illegible]	[illegible]	-9044.3459	-7.04454E-04
174	[illegible]	[illegible]	[illegible]	[illegible]	-7646.3750	-5.67726E-04
175	[illegible]	[illegible]	[illegible]	[illegible]	-6268.5938	-4.46433E-04
176	[illegible]	[illegible]	[illegible]	[illegible]	-4805.2147	-3.3[illegible]E-04
177	[illegible]	[illegible]	[illegible]	[illegible]	-3344.8567	-2.25611E-04
178	[illegible]	[illegible]	[illegible]	[illegible]	-1918.9996	-1.21607E-04

Figure 1D. (Continued).

UPPER HATCH

NODES 179-240

NODE	R	Z	LONGITUDINAL STRAIN	LONGITUDINAL STRESS	HOOP STRESS	HOOP STRAIN
179	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
180	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
181	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
182	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
183	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
184	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
185	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
186	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
187	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
188	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
189	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
190	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
191	[illegible]	[illegible]	[illegible]	[illegible]	-5775.5261	[illegible]
192	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
193	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
194	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
195	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
196	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
197	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
198	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
199	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
201	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
202	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
203	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-6.26254E-05
204	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-6.84076E-04
205	[illegible]	[illegible]	[illegible]	[illegible]	-7580.6013	-5.02411E-04
206	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-5.36440E-04
207	[illegible]	[illegible]	[illegible]	[illegible]	-1879.1635	-1.77769E-04
208	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.22653E-05
209	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-6.65178E-04
210	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-8.90644E-04
211	[illegible]	[illegible]	[illegible]	[illegible]	-505 .0155	-1.24028E-04
212	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.70471E-04
213	[illegible]	[illegible]	[illegible]	[illegible]	-598.5104	[illegible]
214	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
215	[illegible]	[illegible]	[illegible]	[illegible]	-7396.5972	-4.77613E-04
216	[illegible]	[illegible]	[illegible]	[illegible]	-4366.1044	[illegible]
217	[illegible]	[illegible]	[illegible]	[illegible]	-2679.5993	-1.65404E-04
218	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
219	[illegible]	[illegible]	[illegible]	[illegible]	-6994.5422	-5.75574E-04
220	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-4.43954E-04
221	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-3.30401E-04
222	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.70705E-04
223	[illegible]	[illegible]	[illegible]	[illegible]	-396.8596	-1.98048E-05
224	[illegible]	[illegible]	[illegible]	[illegible]	-7146.7926	-5.29306E-04
225	[illegible]	[illegible]	[illegible]	[illegible]	-8375.5191	-5.82920E-04
226	[illegible]	[illegible]	[illegible]	[illegible]	-4614.7672	-4.89082E-04
227	[illegible]	[illegible]	[illegible]	[illegible]	-4894.3954	-3.52477E-04
228	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2.06832E-04
229	[illegible]	[illegible]	[illegible]	[illegible]	-309.3383	-5.03982E-05
230	[illegible]	[illegible]	[illegible]	[illegible]	557.7692	5.32900E-05
231	[illegible]	[illegible]	[illegible]	[illegible]	-11040.8563	-8.07980E-04
232	[illegible]	[illegible]	[illegible]	[illegible]	-956.3047	-4.80060E-04
233	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-5.89444E-04
234	[illegible]	[illegible]	[illegible]	[illegible]	-5086.2821	-4.29122E-04
235	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2.57385E-04
236	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-7.53408E-06
237	[illegible]	[illegible]	[illegible]	[illegible]	344.6736	5.90629E-05
238	[illegible]	[illegible]	[illegible]	[illegible]	-11835.9041	[illegible]
239	[illegible]	[illegible]	[illegible]	[illegible]	-10167.8661	-1.33719E-03
240	[illegible]	[illegible]	[illegible]	[illegible]	-11460.7786	-1.05209E-03

Figure 1D. (Continued).

NODE	R	Z	LONGITUDINAL STRAIN	LONGITUDINAL STRESS	HOOP STRESS	HOOP STRAIN
241	[illegible]	[illegible]	[illegible]	[illegible]	-3302.9407	-6.53292E-04
242	[illegible]	[illegible]	[illegible]	[illegible]	-6041.8957	-4.78373E-04
243	[illegible]	[illegible]	[illegible]	[illegible]	-2492.5735	-1.86135E-04
244	[illegible]	[illegible]	[illegible]	[illegible]	1029.2964	8.36687E-05

UPPER HATCH
NODES 241-244

Figure 1D. (Continued).

NODAL COORDINATES

LOWER PLATE

NODE	X	Z	Longitudinal Strain	Longitudinal Stress	Hoop Stress	Hoop Strain
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

LOWER PLATE
NODES 1–54

Figure 2D. Predicted stress and strains for bottom penetration plate.

NODE	R	Z	LONGITUDINAL STRAIN	LONGITUDINAL STRESS	HOOP STRESS	HOOP STRAIN
55	[illegible]	[illegible]	-2.44151E-0[illegible]	[illegible]	-2368.1943	-2.33432E-03
56	12.7124	[illegible]	-9.67451E-0[illegible]	-4877.762	-[illegible]9.9706	-4.34086E-03
57	[illegible]	26.4638	-9.[illegible]	[illegible]	-2335.7585	-3.62443E-03
58	[illegible]	27.4626	-8.54015E-04	-4949.991	-[illegible]705.6404	-3.04676E-03
59	[illegible]	24.7619	-7.42449E-04	-4175.174	-2480.4011	-2.53534E-03
60	[illegible]	[illegible]	-7.12951E-04	-4041.519	-2201.8162	-2.34616E-03
61	[illegible]	26.7921	-9.01851E-04	[illegible]	-3196.8056	-4.01608E-0[illegible]
62	[illegible]	27.1947	-9.42496E-04	-4979.746	-2467.0120	-3.28631E-03
63	[illegible]	24.7955	-8.42449E-04	-4594.567	-2601.6770	-2.70821E-03
64	13.5244	[illegible]	[illegible]	-4199.351	-2452.3312	-2.22237E-03
65	13.9444	[illegible]	[illegible]	-4914.644	-2100.0426	-1.73561E-03
66	11.7459	[illegible]	-1.16496E-03	-5379.113	-[illegible]30.3654	[illegible].64338E-03
67	[illegible]	[illegible]	[illegible]	[illegible]	-2759.9626	-2.89642E-03
68	[illegible]	24.4149	-9.18961E-04	-4869.249	-2509.3867	-2.34728E-03
69	13.6156	24.2145	-7.49771E-04	-4016.339	-2227.6474	-1.87458E-03
70	13.4224	[illegible]	-6.44[illegible]E-04	-3469.[illegible]	-1949.3543	-1.42446E-03
71	11.4312	26.6444	-1.12240E-03	-5545.652	-[illegible]35.1541	-3.21224E-03
72	11.7214	27.6151	-1.07070E-03	-5039.421	-2151.8[illegible]	-2.45939E-03
73	12.1127	28.5457	-9.10071E-04	-4764.654	-2418.1[illegible]	-1.93505E-03
74	[illegible]	29.4542	-7.4057E-04	-4154.44	[illegible]	[illegible]
75	12.8441	30.3767	[illegible]	-3969.[illegible]	[illegible].5033	[illegible]
76	[illegible]	26.4444	-1.26231E-03	-6124.423	-2944.2539	-2.[illegible]328E-03
77	[illegible]	27.4524	-1.21356E-03	-5642.632	-2775.6[illegible]	-2.28787E-03
78	11.2362	27.8155	-1.12294E-03	-5698.427	[illegible]	-1.96314E-03
79	11.4255	28.2741	-1.71070E-03	-5164.[illegible]	-2487.6837	-1.71860E-03
80	11.6124	[illegible]	-9.42084E-04	-4848.584	-2392.58[illegible]	-1.50948E-03
81	11.80[illegible]1	29.2261	-8.75245E-04	-4485.274	-2155.8815	-1.3[illegible]306E-03
82	11.9874	[illegible]	-7.99398E-04	-4107.[illegible]	-2029.1135	-1.14637E-03
83	12.1797	30.1395	-7.14418E-04	-3711.592	-1762.6422	-9.64454E-04
84	12.3427	[illegible]	-6.47888E-04	-3312.491	-1624.44[illegible]	-7.94959E-04
85	10.3927	27.7238	-1.52448E-03	-7251.457	-3135.2059	-2.56482E-03
86	[illegible]	27.5976	-1.37338E-03	-6994.671	-2721.6[illegible]6	-1.63254E-03
87	10.7617	28.0074	-1.11456E-03	-5641.[illegible]	-2614.2474	-1.42822E-03
88	[illegible]	28.4242	-1.71218E-03	-5222.125	-2441.7751	-1.23914E-03
89	11.1094	28.9910	-9.21688E-04	[illegible]	-2264.5843	-1.06828E-03
90	11.2444	29.4274	-8.45108E-04	-4455.312	-229[illegible].8[illegible]	-[illegible].99736E-04
91	11.4678	29.8244	-7.73668E-04	[illegible]	-1896.9618	-7.78425E-04
92	11.6492	30.3914	-6.97338E-04	-3374.244	-1702.04[illegible]	-6.1[illegible]
93	11.8261	30.8582	-6.24368E-04	-3344.[illegible]	-1519.2830	-5.02206E-04
94	9.6331	27.0162	-8.44272E-04	-4334.714	-12904.3074	-1.18847E-03
95	9.9186	27.2511	-5.1[illegible]398E-04	-4418.667	-9424.8996	-1.09803E-03
96	10.0896	27.72[illegible]9	-6.56718E-04	-6189.18	-7186.4579	-9.69679E-04
97	10.2676	28.1978	-5.73566E-04	-5564.6[illegible]	-6122.3294	-8.36648E-04
98	10.4316	28.6626	-4.99108E-04	-5210.37[illegible]	-5435.0885	-7.16721E-04
99	10.6026	29.1305	-4.66708E-04	-4747.523	-4[illegible]3.2604	-6.01837E-04
100	10.7736	29.6029	-4.18908E-04	-4455.762	-4191.2160	-4.90137E-04
101	10.9444	30.[illegible]	-3.87756E-04	-3994.253	-3601.1472	-3.97614E-04
102	11.1157	30.5[illegible]	-3.45098E-04	-3556.313	-3102.0464	-3.00313E-04
103	11.2867	31.[illegible]49	-2.24598E-04	-2475.589	-2514.4309	-1.98499E-04
104	11.4577	31.4797	9.29668E-05	-10.194	-1519.7179	-9.36621E-05
105	11.6287	31.9495	9.28178E-05	422.965	-109.3408	-4.73497E-06
106	9.3178	27.0617	2.70893E-05	-4327.590	-13601.2316	-1.20629E-03
107	9.4915	27.4200	-8.14958E-05	-4733.307	-12378.0248	-1.10271E-03
108	9.6049	27.8929	-1.93063E-04	-5266.758	-11052.4048	-9.62755E-04
109	9.7677	28.3656	-2.59018E-04	-5779.511	-9675.8467	-8.25728E-04
110	9.9250	28.8383	-2.66258E-04	-5071.719	-8319.2223	-6.97848E-04
111	10.0926	29.3111	-2.58048E-04	-4724.427	-7158.6530	-5.81623E-04
112	10.2444	29.7838	-2.40228E-04	-4304.010	-6051.7859	-4.72547E-04
113	10.4182	30.2566	-2.12348E-04	-3773.673	-4958.3352	-3.69785E-04
114	10.5817	30.7294	-1.30448E-04	-2820.445	-3830.5302	-2.69106E-04
115	10.7437	31.2021	-5.34348E-05	-1577.436	-2441.1379	-1.48171E-04
116	10.9874	31.9119	5.88058E-05	256.719	318.5787	-1.61227E-05

LOWER PLATE
NODES 55-116

Figure 2D. (Continued).

LOWER PLATE
NODES 116-178

NODE	R	Z	LONGITUDINAL STRAIN	LONGITUDINAL STRESS	HOOP STRESS	HOOP STRAIN
117	8.7761	27.9130	[illegible]	[illegible]	-1402?.010?	-1.359?0E-03
118	8.9615	27.58??	[illegible]	[illegible]	-1217?.6055	[illegible]
119	9.1160	28.5562	[illegible]	[illegible]	-11110.2074	-9.63350E-04
120	9.2705	28.5317	[illegible]	[illegible]	-96??.?36?	[illegible]
121	9.4257	29.0072	[illegible]	[illegible]	-8391.3637	-6.81830E-04
122	9.5795	29.4620	[illegible]	[illegible]	-7074.03??	-5.59??2E-04
123	9.7340	29.9583	[illegible]	[illegible]	-5637.0761	-4.474??E-04
124	9.8885	30.4338	[illegible]	[illegible]	-4602.4574	-3.39962E-04
125	10.0431	30.9093	[illegible]	[illegible]	-3346.1466	-2.3836.E-04
126	10.1976	31.3849	[illegible]	[illegible]	-1912.1793	[illegible]
127	10.3675	31.9076	[illegible]	[illegible]	-273.992?	-?.46937E-05
128	8.2791	27.7634	[illegible]	[illegible]	-15??6.877?	[illegible]
129	8.7708	27.7328	[illegible]	[illegible]	-12547.6457	-1.14761E-03
130	8.6257	28.2111	[illegible]	[illegible]	-11271.6440	-9.68043E-04
131	8.7712	28.6891	[illegible]	[illegible]	-10089.5583	-8.36163E-04
132	8.9173	29.1673	[illegible]	[illegible]	-8461.9645	-6.63952E-04
133	9.0635	29.6456	[illegible]	[illegible]	-7066.4837	-5.38178E-04
134	9.2097	30.1236	[illegible]	[illegible]	-5626.9567	[illegible]
135	9.3559	30.6018	[illegible]	[illegible]	-4367.5820	-3.12378E-04
136	9.5021	31.0799	[illegible]	[illegible]	-2934.0406	[illegible]
137	9.6683	31.5581	[illegible]	[illegible]	-1526.1493	-?.06564E-04
138	9.9389	31.9?01	[illegible]	[illegible]	-363.8600	-2.89666E-05
139	8.2369	27.8058	[illegible]	[illegible]	-12406.6078	-1.16769E-03
140	8.1900	28.219?	[illegible]	[illegible]	-12???.486?	-1.03925E-03
141	8.2002	28.5975	[illegible]	[illegible]	-11515.2820	-8.79033E-04
142	8.3725	29.1483	[illegible]	[illegible]	-8999.7878	-6.62331E-04
143	8.5448	29.7941	[illegible]	[illegible]	-7041.3076	-5.15351E-04
144	8.7170	30.1939	[illegible]	[illegible]	-5201.7506	-3.68363E-04
145	8.8893	31.0007	[illegible]	[illegible]	-3839.9188	-2.29??1E-04
146	8.9444	31.1924	[illegible]	[illegible]	-2976.9305	[illegible]
147	7.6700	28.6347	[illegible]	[illegible]	-13077.4914	-9.14419E-04
148	7.6994	28.7363	[illegible]	[illegible]	-12575.2348	-8.71300E-04
149	7.8616	29.3900	[illegible]	[illegible]	-9409.1195	-6.66415E-04
150	8.0234	29.9437	[illegible]	[illegible]	-7089.9932	-4.96655E-04
151	8.1852	30.5474	[illegible]	[illegible]	-5012.9357	-3.43232E-04
152	8.3468	31.1511	[illegible]	[illegible]	-3134.1139	-2.00172E-04
153	7.1821	28.0701	[illegible]	[illegible]	-12731.9406	-8.50584E-04
154	7.3329	28.6766	[illegible]	[illegible]	-9386.6405	-6.50606E-04
155	7.4838	30.0831	[illegible]	[illegible]	-6965.2272	-4.76917E-04
156	7.6347	30.6896	[illegible]	[illegible]	-4725.6134	-3.20516E-04
157	7.7856	31.2961	[illegible]	[illegible]	-2554.4933	-1.72203E-04
158	6.6619	28.9965	[illegible]	[illegible]	-12550.7194	[illegible]
159	6.8019	29.6036	[illegible]	[illegible]	-9344.1831	-6.31684E-04
160	6.9410	30.2128	[illegible]	[illegible]	-6763.2438	-4.58546E-04
161	7.0810	30.8219	[illegible]	[illegible]	-4425.9522	-2.98043E-04
162	7.2210	31.4310	[illegible]	[illegible]	-2070.2821	[illegible]
163	6.1397	29.1096	[illegible]	[illegible]	-11747.2758	-7.99523E-04
164	6.2686	29.7211	[illegible]	[illegible]	-9021.3042	-6.13920E-04
165	6.3976	30.3327	[illegible]	[illegible]	-6556.8679	-4.39623E-04
166	6.5266	30.9442	[illegible]	[illegible]	-4189.4720	-2.79689E-04
167	6.6556	31.5558	[illegible]	[illegible]	-1908.6411	-1.26952E-04
168	5.6159	29.2152	[illegible]	[illegible]	-11738.6278	-?.80317E-04
169	5.7334	29.8240	[illegible]	[illegible]	-8800.4791	-5.94060E-04
170	5.8513	30.4429	[illegible]	[illegible]	-6126.3360	-4.23064E-04
171	5.9693	31.0565	[illegible]	[illegible]	-3956.6594	-2.61206E-04
172	6.0874	31.6703	[illegible]	[illegible]	-1554.2827	-1.11304E-04
173	5.0893	29.3115	[illegible]	[illegible]	-11243.0807	-7.59624E-04
174	5.1962	29.9272	[illegible]	[illegible]	-8596.4122	-5.78009E-04
175	5.3032	30.5433	[illegible]	[illegible]	-6128.3382	-4.05558E-04
176	5.4101	31.1588	[illegible]	[illegible]	-3789.3467	-2.47132E-04
177	5.5170	31.7746	[illegible]	[illegible]	-1553.8145	-9.65634E-05
178	4.5616	29.4962	[illegible]	[illegible]	-11286.5406	-7.43480E-04

Figure 2D. (Continued).

LOWER PLATE
NODES 179-228

NODE	R	Z	LONGITUDINAL STRAIN	LONGITUDINAL STRESS	HOOP STRESS	HOOP STRAIN
179	[illegible]	[illegible]	[illegible]	[illegible]	-6399.8929	-5.60372E-04
180	[illegible]	[illegible]	[illegible]	[illegible]	-5473.5157	[illegible]
181	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].7174	[illegible].6048E-04
182	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
183	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]0854.1564	[illegible].25153E-04
184	[illegible]	[illegible]	[illegible]	[illegible]	-6250.[illegible]	-5.47[illegible]E-04
185	[illegible]	[illegible]	[illegible]	[illegible]	-5813.6075	-3.76010E-04
186	[illegible]	[illegible]	[illegible]	[illegible]	-351[illegible]	[illegible]E-04
187	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-7.59141E-05
188	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]0954.[illegible]	-7.09756E-04
189	[illegible]	[illegible]	[illegible]	[illegible]	-4101.896[illegible]	-5.31900E-04
190	[illegible]	[illegible]	[illegible]	[illegible]	-6[illegible]59.4674	-3.[illegible]E-04
191	[illegible]	[illegible]	[illegible]	[illegible]	-3402.8076	[illegible].13304E-04
192	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].5061	[illegible]E-05
193	[illegible]	[illegible]	[illegible]	[illegible]	-1[illegible]504.[illegible]	-6.[illegible]E-04
194	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]E-04
195	[illegible]	[illegible]	[illegible]	[illegible]	-561[illegible]	-3.59646E-04
196	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]E-04
197	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].6378	-6.[illegible]E-05
198	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-6.[illegible]E-04
199	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]2592	[illegible]E-04
200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-3.6[illegible]E-04
201	[illegible]	[illegible]	[illegible]	[illegible]	-33[illegible].78[illegible]	[illegible].09[illegible]E-04
202	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]947E-05
203	[illegible]	[illegible]	[illegible]	[illegible]	-33[illegible].665[illegible]	-5.95[illegible]E-04
204	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]E-04
205	[illegible]	[illegible]	[illegible]	[illegible]	-5603.[illegible]	-3.[illegible]E-04
206	[illegible]	[illegible]	[illegible]	[illegible]	-3365.4[illegible]	[illegible]169[illegible]E-04
207	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]35[illegible].859[illegible]	[illegible].752654E-05
208	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]230.[illegible]	-5.3504[illegible]E-04
209	[illegible]	[illegible]	[illegible]	[illegible]	-6753.42[illegible]	-6.[illegible]E-04
210	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].6653	-5.35[illegible]E-04
211	[illegible]	[illegible]	[illegible]	[illegible]	-5647.4550	-3.[illegible]E-04
212	[illegible]	[illegible]	[illegible]	[illegible]	-3625.0875	[illegible].54[illegible]E-04
213	[illegible]	[illegible]	[illegible]	[illegible]	-1936.8245	[illegible].21[illegible]E-04
214	[illegible]	[illegible]	[illegible]	[illegible]	-563.56[illegible]	[illegible].052[illegible]E-05
215	[illegible]	[illegible]	[illegible]	[illegible]	-6096.3900	-6.957[illegible]E-04
216	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].0300	[illegible]E-04
217	[illegible]	[illegible]	[illegible]	[illegible]	-7789.5426	-6.43[illegible]E-04
218	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-4.[illegible]E-04
219	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-3.[illegible]E-04
220	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].764[illegible]	[illegible]5560[illegible]E-04
221	[illegible]	[illegible]	[illegible]	[illegible]	-552.9774	[illegible]E-05
222	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]76.4[illegible]	-1.[illegible]E-03
223	[illegible]	[illegible]	[illegible]	[illegible]	-16932.[illegible]	-1.[illegible]E-03
224	[illegible]	[illegible]	[illegible]	[illegible]	-14[illegible]35.[illegible]	[illegible]E-03
225	[illegible]	[illegible]	[illegible]	[illegible]	-11[illegible]	-9.[illegible]E-04
226	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-6.[illegible]E-04
227	[illegible]	[illegible]	[illegible]	[illegible]	-8539.[illegible]	-3.49656E-04
228	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]E-05

Figure 2D. (Continued).