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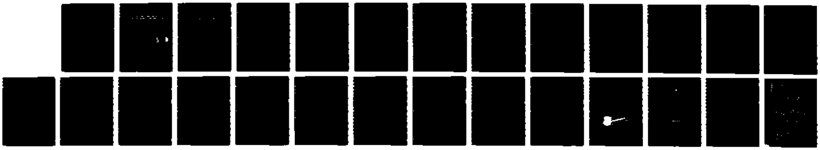

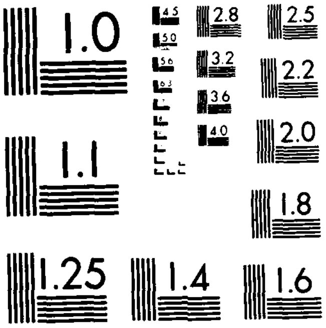

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STRUCTURAL ANALYSIS OF THE WALLEYE MARK 13 CONTAINER COVER

by
J. J. Labra, Ph.D., P.E.
P. A. Cox
W. L. Hamer

FINAL REPORT
SwRI Project 15-7958-810

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for
United States Navy
Pacific Missile Test Center (PMTC)
Pt. Mugu, California 93042

August 1984

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Approved:

James D. Michie

J. D. Michie, Director
Department of Structural Systems

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[illegible] polyvinyl chloride

This report covers a detailed structural analysis of the WALLEYE MARK 13 container cover assembly ~~which~~, included limited nondestructive thermal testing to delineate ~~PVC~~ material dimensional stability to elevated temperatures. In addition, a detailed review of existing cover assembly inspection and repair procedure data was, performed. The structural analysis investigated the concentrated stress sensitivity of the cover assembly to (undersized) width/length variations. In particular, cover stress concentrations were delineated which could occur during "latching down" procedures of the cover to the base assembly. The stress analysis of the cover assembly demonstrated a significant sensitivity of cover stress levels to cover width and length variations from its base assembly, while the thermal testing suggested a possible cause of the failure problem, the proposed maintenance, inspection and repair procedures defined in NAVAIR Technical Manual 11-70KAA-1 should significantly reduce the potential of crack reoccurrence. However, geometric irregularities

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associated with difficult-to-repair cracks within the aluminum extrusion could be the source of crack re-initiation under normal cradle operational conditions.

Polyvinyl chloride, Guided [illegible]
Dimensional stability, [illegible]

TABLE OF CONTENTS

I. SUMMARY

Southwest Research Institute is performing for PMTC [as special tasks for the Nondestructive Testing Information Analysis Center (NTIAC)] several studies involved with the collection of data on the maintainability and structural integrity of various missile related systems. This report covers a detailed structural analysis of the WALLEYE MARK 13 container cover assembly which included limited thermal testing to delineate PVC material dimensional stability to elevated temperatures. In addition a detailed review of existing cover assembly inspection and repair procedure data was performed.

The structural analysis investigated the concentrated stress sensitivity of the cover assembly to (undersized) width/length variations. In particular, cover stress concentrations were delineated which could occur during "latching down" procedures of the cover to the base assembly. Simulated, PVC material failure occurred at the cover corners when width and length dimensions each varied 0.344 inches smaller than design specifications. Accordingly, assuming the base assembly is within specification, the cover width and length dimensions should be within .344 inches or less of the overall base width and length dimensions. Notably, this does not include any margin of safety. For a M.S. of 0.5 the width and length of each cover should not be smaller than the design specifications by 0.23 or more inches.

Increases in width and length tolerances between cover and base assemblies can be realized through locally thickening of the cover corner regions. As an example, an increase of the corner lower edge thickness from 0.13 to 0.20 inches and the 0.10-inch specification [1] to 0.15 inches resulted in permissible W/L tolerance variations of up to

0.386 inches. However, an overall cradle cover thickness enhancement did not show a reduction in corner stress concentrations. This was due to a general stiffening of the cover which neutralized the beneficial aspects of increasing the net section area through the wall thickness of the cover.

The stress analysis of the cover assembly demonstrated a significant sensitivity of cover stress levels to cover width and length variations from its base assembly. To gain insight into what might be the cause of the dimensional difference between cover and base assemblies, limited nondestructive thermal testing was performed on manufacturer supplied Kydex material. Results include the following:

° The materials appear to be sensitive to direction. The dimensional instability noted along the shorter dimensions, e.g., width, suggests a thermal shrinkage effect which could be a major cause of the documented dimensional differences between cover and base assemblies.

° At 90°F for 72 hours PVC specimen shrinkage was as high as 3.7 percent. At 200°F, this shrinkage increased to 5.45 percent.

While the above thermal testing suggests a possible cause of the failure problem, the proposed maintenance, inspection and repair procedures as defined in NAVAIR Technical Manual 11-70KAA-1 should significantly reduce the potential of crack reoccurrence. Specifically, the documented cracking is in essence, increasing the width and length of the cover so as to properly fit upon the base assembly. As long as these crack voids are not mechanically closed prior to making reinforced bonding repairs, the cradle dimensions will not return to the original (non-cracked) values. This in turn should reduce the potential of recracking of repaired cradle covers.

It is noted that problems could arise since the cracking initiates within the aluminum extrusion. Cover repair in this region may be difficult and, hence, total filling of PVC fissues within the extrusion may not be realized; leaving geometric irregularities where the crack initially originated. These irregularities could, in turn, be the source of crack initiation under normal cradle operational conditions.

II. BACKGROUND

Southwest Research Institute (SwRI) for the Pacific Missile Test Center (PMTC) was tasked to perform a structural analysis of the WALLEYE MARK 13 container cover assembly (Figure 1). Cracking of the covers has been documented by Navy personnel. Recently, a PMTC investigation [2] demonstrated that typically, new cover assemblies varied in length and width from 0.125 inches to 0.562 inches. To delineate the sensitivity of the width/length (W/L) tolerance variations to tensile or flexural failures, a finite element modeling analysis was undertaken. In addition, sample acrylic - PVC alloy material was nondestructively tested for dimensional stability and weight change at elevational temperatures.

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2. H.K. Maynard and S. Danwoody, "Report on Walleye Mark 13 Container Cover Measurements," June, 1984.

III. COVER MATERIAL PROPERTIES

A literature review as well as Institute discussions with the recommended material manufacturers defined the following modulus of elasticity (E), and flexural (F_u) and tensile (T_u) strengths;

	E(ksi)	G(ksi)	Fu(ksi)	Tu(ksi)
Royalite (R57)	250	150	7.5	5.7
Kydex 100	310	150	9.7	6.0

Notably, no manufacturer information on either shear modulus (G) or Poisson ratio was available. The value shown is based on Institute personnel experience with PVC material.

IV. FINITE ELEMENT MODEL

To model the cover assembly SwRI utilized the MSC-NASTRAN general purpose finite element code. Because of bending induced in the cover when it is locked down upon the base [2], isoparametric four-node plate bending elements (CQUAD4) were extensively utilized in the generation of the model (Figure 2). As shown, due to the geometry of the cover, a one-quarter symmetry model of the assembly was permissible. So as to delineate any high stress gradients in the critical corner region of the cover, a finer mesh of elements was included. To model the circular ribbing across the width of the cover assembly, equivalent beam (CBEAM) elements were used. Triangular plate (CTRIA3) elements were included only for transition regions so as to reduce the number of elements in the model.

Overall, the model consists of 804 CQUAD4, 172 CTRIA3 and 44 CBEAM elements with a corresponding 954 active grid or nodal points. Thickness of the shell was defined as 0.1 inches except for the lower edge or rim of the cover where specifications [1] call for a 0.130 minimum thickness.

V. BOUNDARY CONDITIONS AND PRESCRIBED DISPLACEMENTS

As noted, because of the geometry symmetry of the cover assembly, only one-quarter of the unit warranted modeling. To assure the appropriate structural response under a priori prescribed displacements, the boundary conditions excluded rotations about the x and z axes along edge 1 (Figure 2) and rotations about the y and z axes along edge 2. Along with these constraints, zero displacements in the y-direction along edge 1 and in the x-direction along edge 2 were imposed.

Based on the findings in [2], for all simulations prescribed displacements were imposed along the lower edge of the cover assembly. These displacements simulate the pulling outward and rotation of the cover when it is clamped down onto the base assembly. This phenomenon may occur if significant dimensional (width and length) differences exist between cover and the aluminum extrusion (seal ring) or base assembly. The design of the seal ring and base assembly is such that the vertical loading induced by the latch locks is reacted primarily by the base and is believed not contributing to the failure problem.

VI. SIMULATION FINDINGS

1. Present Cover Design

A series of simulations were performed (Table 1) varying the prescribed nodal displacements as well as the number of nodes given the initial displacements. Case no. 1 included initial displacements analogous to the maximum width (δy) and length (δx) variations of cover no. 2 as reported in reference 2. Because of the quarter symmetry model, the imposed displacements are half of the measured values. It is further noted that nodal points along the corner radius were not given initial displacements.

The result as given in Table 1 show a peak bending stress of 6.7 ksi at element 19 (Figure 3). With typical flexural strengths of 7.5 ksi for Royalite R57 and 9.7 ksi for Kydex 100, results from case 1 suggest that the imposed lateral (width) and longitudinal (length) displacements are not sufficient to cause failure.

Because of the above, case 2 was run to consider cover edge warping effects in addition to the width/length (W/L) variations. As shown in Table 1, when the cover width edge (Figure 4) had an imposed vertical displacement from .005 to 055 in., the resultant peak stress level increased to 8.39 ksi (element 19). While this equates to apparently a 24 percent increase in stress over case 1, it was considered unlikely to be a major contributing factor in causing the documented failures.

The third case was performed with added constraints over what was considered in cases 1 and 2. For both cases 1 and 2, the corner edge was allowed to respond freely as a result of the lateral and longitudinal displacements. In case 3, however, a set of multipoint constraint (MPC) equations were included. These equations impose a dependency between the lateral and longitudinal displacements and the radial displacements of the corner edge nodes. This better reflects actual in situ conditions when the cover is clamped down on the container base.

Results for case 3 show a significant increase in stress concentration at two locations along the corner's edge. Element 19 with a bending stress of 8.26 ksi is 10 percent greater than the flexural strength of Royalite (R57). The peak tensile stress at element 15 is more significant. The recorded 7.64 ksi stress is 34 and 27 percent higher than the ultimate tensile strength of the Royalite and Kydex materials, respectively. It is further noted that the high tensile stress area (element 15) is at the lower edge region of the corner where the thickness specification [1] is 0.13 inches and which is encapsulated within the aluminum sealing rail (extrusion). Crack repair in this region may be difficult if at all possible.

Because of the above, the remaining simulations were performed with the same corner MPC equations included in the model as defined in case 3. To gain insight into the variations in peak stress as a function of the documented width and length variations [2], cases 4 and 5 were performed. In case 4 the minimum recorded W/L deviations of .250 inches and .125 inches were included. In case 5 the maximum W/L values of .500 inches and .562 inches were utilized.

Results from case 4 (Table 1) show peak bending and tensile stress levels well below the ultimate values for the two PVC materials. Notably, however, none of the covers measured in [2] had W/L variations limited to .250 and .125 inches, respectively. For case 5, using the maximum documented W/L variations, a peak tensile stress of 8.63 ksi and peak bending stress of 8.75 ksi were simulated.

With material ultimate strengths of 5.7 ksi (tensile) and 7.5 ksi (flexural), the above concentrated stresses exceed these limits by 51 and 17 percent, respectively.

In case 6 a uniform width and length variation of 0.200-in was imposed on the model. Because of linearity associated with the analysis, the resulting peak stress of 3.31 ksi can be extrapolated to tensile failure of the material.* For an ultimate tensile stress of 5.7 ksi, a corresponding W/L differences of 0.344 inches from design specifications between the sealing ring and cover will be sufficient to fail the cover when it is clamped to the container base.

2. Geometric Design Variations

The aforementioned simulations all considered the present cover design with respect to wall thickness. To gain insight into potential changes such as overall thickness or localized (corner) thickness buildup, additional simulations were performed.

In Case 7 the cover wall thicknesses were increased 30 percent, viz., from 0.13 to 0.17 inches and 0.10 to 0.13 inches. While this increases the net section area through the wall of the cover, it also, however, stiffens the structure. Accordingly, as shown in Table 1 the results are a slight increase in concentrated stress levels at the corner.

In case 8, elements 13 through 36 (Figure 3) were increased in thickness by 50 percent, viz., 0.13 inches to 0.20 inches and the 0.10-inch specification to 0.15 inches. In this instance there was a reduction in corner peak stress levels. At the lower edge (element 15), the stress was reduced by 17 percent while the stress at element 24 was reduced by 11

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*Bending stresses are slightly higher than tensile stresses for cases 6-9, but are not critical because of better flexural strength characteristics of the material.

TABLE 1

SIMULATION SUMMARY

Case No.	Length/Width Variation (inches)		Peak Stress (ksi)	Element Location No.*	Comments
	δx (Length)	δy (Width)			
1	.562	.375	6.7 (Bending)	19	max. W/L values for cover no. 2 [1]
2	.562	.375	8.39 (Bending)	19	cover no. 2 with .005 to .05 vertical warping
3	.562	.375	8.26 (Bending) 7.64 (Tensile)	19 15	cover no. 2 with MPC restraints included
4	.125	.250	3.54 (Bending) 3.10 (Tensile	24 17	min. W/L variations [1]
5	.562	.500	8.75 (Bending) 8.63 (Tensile)	19 15	max. W/L variations [1]
6	.200	.200	3.31 (Tensile) 3.25 (Tensile)	24 15	uniform W/L displacement
7	.200	.200	3.34 (Tensile) 3.33 (Tensile)	24 15	wall thicknesses increased from 0.1 to 0.13 and 0.13 to 0.17 inches
8	.200	.200	2.95 (Tensile) 2.70 (Tensile	24 15	wall thickness at lower corner increased from 0.1 to 0.15 and 0.13 to 0.20 inches
9	.200	.200	2.52 (Tensile) 2.42 (Tensile)	24 15	wall thickness at lower corner increased from 0.1 to 0.2 and 0.13 to 0.25 inches

*Refer to Figure 3.

percent. Notably, such a reinforcement of the corner would allow for less stringent W/L tolerance requirements for the cover. For this case (8), W/L tolerances between corner and container base of less than 0.386 inches would prevent cracking of the material.

In the last simulation case (9), the lower edge thickness (elements 13 through 18, Figure 3) was 0.25 inch while the adjacent thickness was defined at 0.20 inches (elements 19 through 36). This increase in corner thickness resulted in a 24-percent decrease in concentrated stress in element 24 and a 26-percent decrease in stress at element 15. With respect to W/L tolerances for the cover this equates to 0.452 inch variation* between cover and base assembly which will fail the cover during latching procedures.

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*Based on 5.7 ksi ultimate tensile strength.

VII. THERMAL TESTING

1. Kydex Properties and Manufacturing Techniques

Kydex is the trademark name for a polyvinyl chloride - acrylic alloy. It is fabricated by extrusion. PVC and PMMA (polymethylmethacrylate) pellets are melted and blended by an extruder. The mixing extruder can produce Kydex pellets or Kydex sheet, or another extrusion operation can be used to produce sheet from the Kydex pellets.

Kydex sheet emerges from the extrusion die in a semi-molten state, and is cooled rapidly as it emerges. Cooling may be done by blowing air over the sheet. Normally the sheet is pulled from the end away from the extruder to help maintain planarity until the sheet is cool enough to maintain its shape. This state would, at most, be reached a few inches from the extrusion die.

The PMMA is commonly known as Plexiglas. Plexiglas is noted for its ability to thermoform into complex shapes. It also has a remarkable feature known as elastic memory. If a thermoformed sheet is reheated to a critical temperature it will return to its former flat configuration. At this temperature the sheet has softened but is not near to being melted. Because Kydex is about one-half PMMA, it possesses a similar memory.

2. Test Findings

Due to the sensitivity of the cover assembly to W/L tolerance variations as shown from the finite element analysis, SwRI performed limited nondestructive thermal testing of PVC alloy material. Two sheets of Kydex material, approximately 4" x 5" x 1/8" were tested for dimensional stability and weight change at elevated temperatures. One specimen was tested at 200°F, another at 90°F, dry heat. It is believed the 200°F exposure is a maximum temperature condition the Kydex material could be subjected to under service conditions. The 90°F specimen was exposed separately and continuously for 72 hours. The two specimens prepared from one Kydex sample were cut along the same length and width orientation. Apparent resin orientation did not appear in the sample nor were reinforcing fibers present.

The determination of shrinkage or elongation in the Kydex was carried out according to the following method. Three measurements of each dimension, of each specimen, were taken to ±0.001 in. and averaged. Also, a four-inch arc and a two-inch arc, 90 degrees apart, were scribed on the face of each specimen. The scriber used, consisted of two needle points, rigidly held about 4 inches apart, parallel to each other, and perpendicular to the long axis of a 5/16-inch stainless steel rod, a similar scriber was used that point to the inscribed arc on the face of the specimen was measured to ±0.001 inch. The specimens were tested in a horizontal position. The same measuring procedure was used after exposure. The mass was taken on a Mettler balance, ±0.01 mg, before and after exposure.

The percent change in values measured after exposure are listed below:

Parameters	Exposure	Change %	Exposure	Change %
Length	72 hours	+0.19	72 hours	-1.02
Width	90°F±1°	-1.40	200°F±°	-2.64
Thickness		+1.00		+1.60
2-in. Arc		-3.70		-5.45
4-in. Arc		+0.84		+0.85
Mass		-0.06		-0.21

Although only two data points were established, this material appears to be sensitive to direction. In both tests the short dimensions, width and short arc, were affected the most.

Cover assemblies for a naval weapon cradle fabricated from this material in a large one-piece cover indicate a deep drawn forming is necessary. The dimensional instability noted along the shorter dimensions after two ageing tests suggests a shrinkage effect which could occur also to covers in service.

VIII. RESULTS, CONCLUSIONS AND RECOMMENDATIONS

Based on the study performed by SwRI, pertinent results, conclusions and recommendations are as follows:

Results and Conclusions:

Cover width and length dimensions less than NAVAIR specifications [1] by .344 inches or more, can result in PVC corner cracking during latching down procedures.

To realize a margin of safety (M.S.) of 0.5, cover width and length dimensions should be within 0.23 inches of specifications.

Reoccurrence of cracking in repaired covers may result if the crack voids are not totally filled; in particular, the region encapsulated within the aluminum extrusion. Recracking if any, would probably be over a longer period of time during infield use of the cover. Crack reinitiation would stem from the voids not wholly filled within the extrusion during repair procedures.

As described in Section VII.1, because of the elastic memory of Kydex, a residual stress can result from the cover manufacturing extrusion process, especially from the pulling operation. It would be expected then that an off-the-shelf sheet of Kydex, when heated to a critical temperature would show dimensional changes resulting from the elastic memory effect. For Kydex which has been thermoformed, a similar effect would be expected. When the temperature is raised to a certain critical temperature, the elastic memory effect would cause a shape change tending to return the sheet to its original flat configuration.

As with a flat sheet, a thermoformed cradle cover, when exposed to high temperatures would tend to change shape. Accordingly, while the cover dimensional variations may exist when manufactured, there is a good probability that the problem occurs due to thermally induced dimensional changes after the covers leave the manufacturer. (Testing could be performed to determine what the critical temperature is at which time the elastic memory effects of the PVC are significant.)

Recommendations:

Repair, inspection and maintenance procedures as defined in Technical manual 11-70KAA-1 should preclude reoccurrence of cover cracking. Notably, the cover should be latched down to the base assembly before bonding to assure the crack voids are fully opened during repair operations. The cover should remain latched down until the plastic filling is totally dry.

For future cover manufacturing, a design specification of 0.20 inches in lieu of 0.13 inches [1] for the corner regions would significantly help in reducing, if not eliminating, the number of cover failures.

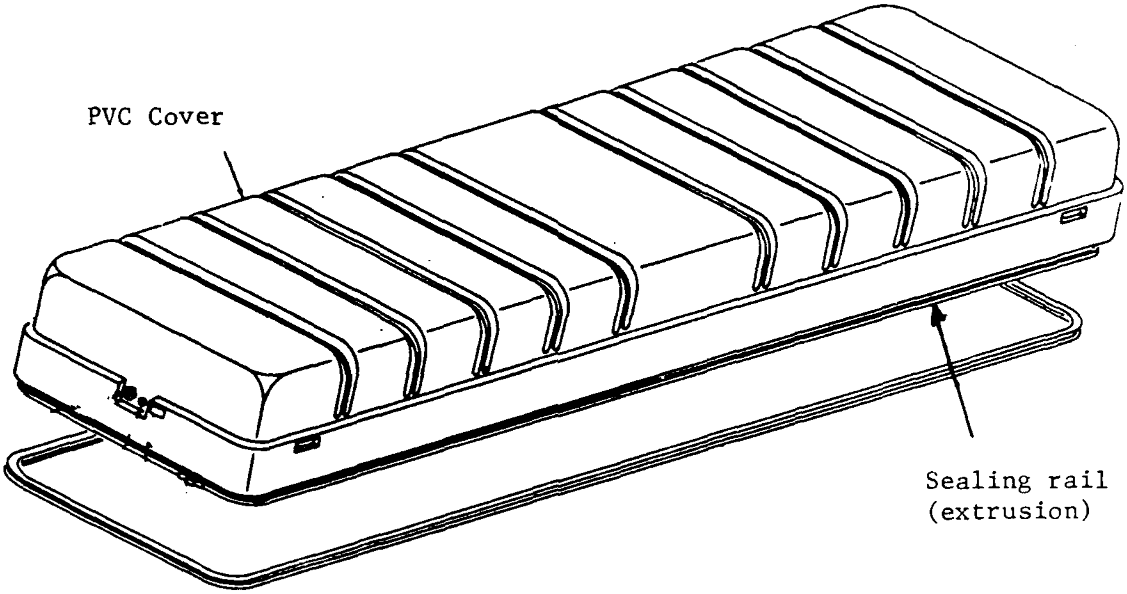

FIGURE 1. CRADLE COVER

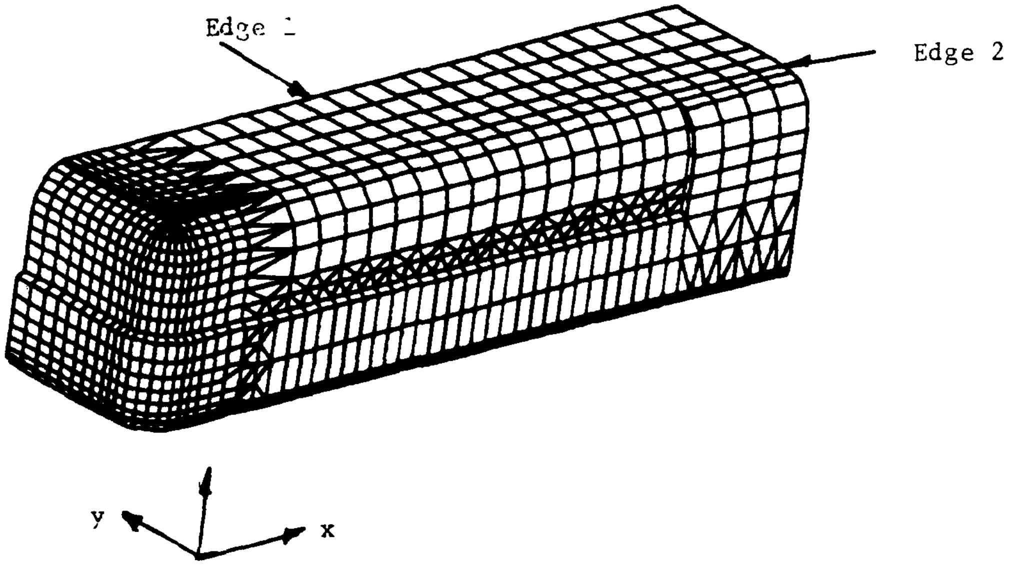

FIGURE 2. FINITE ELEMENT MODEL
(Quarter Symmetry)

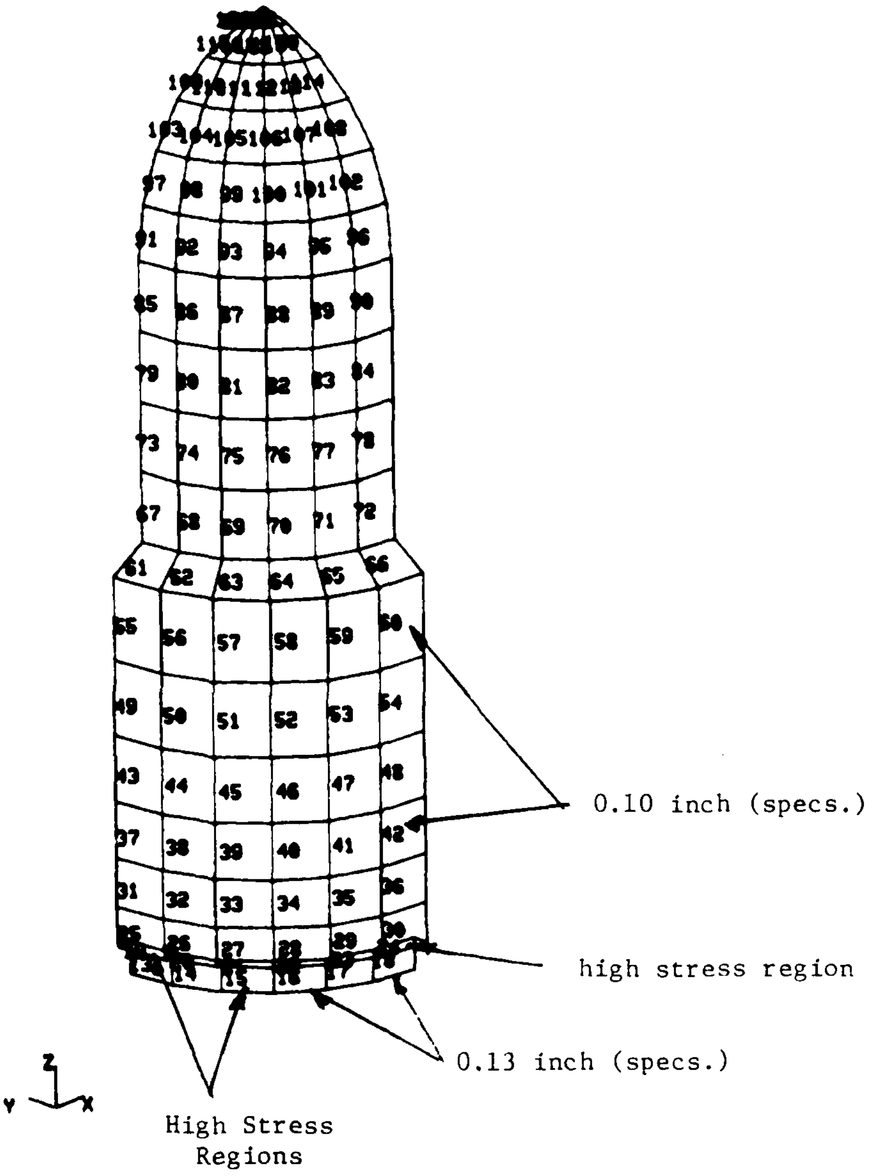

FIGURE 3. CORNER FINITE ELEMENTS

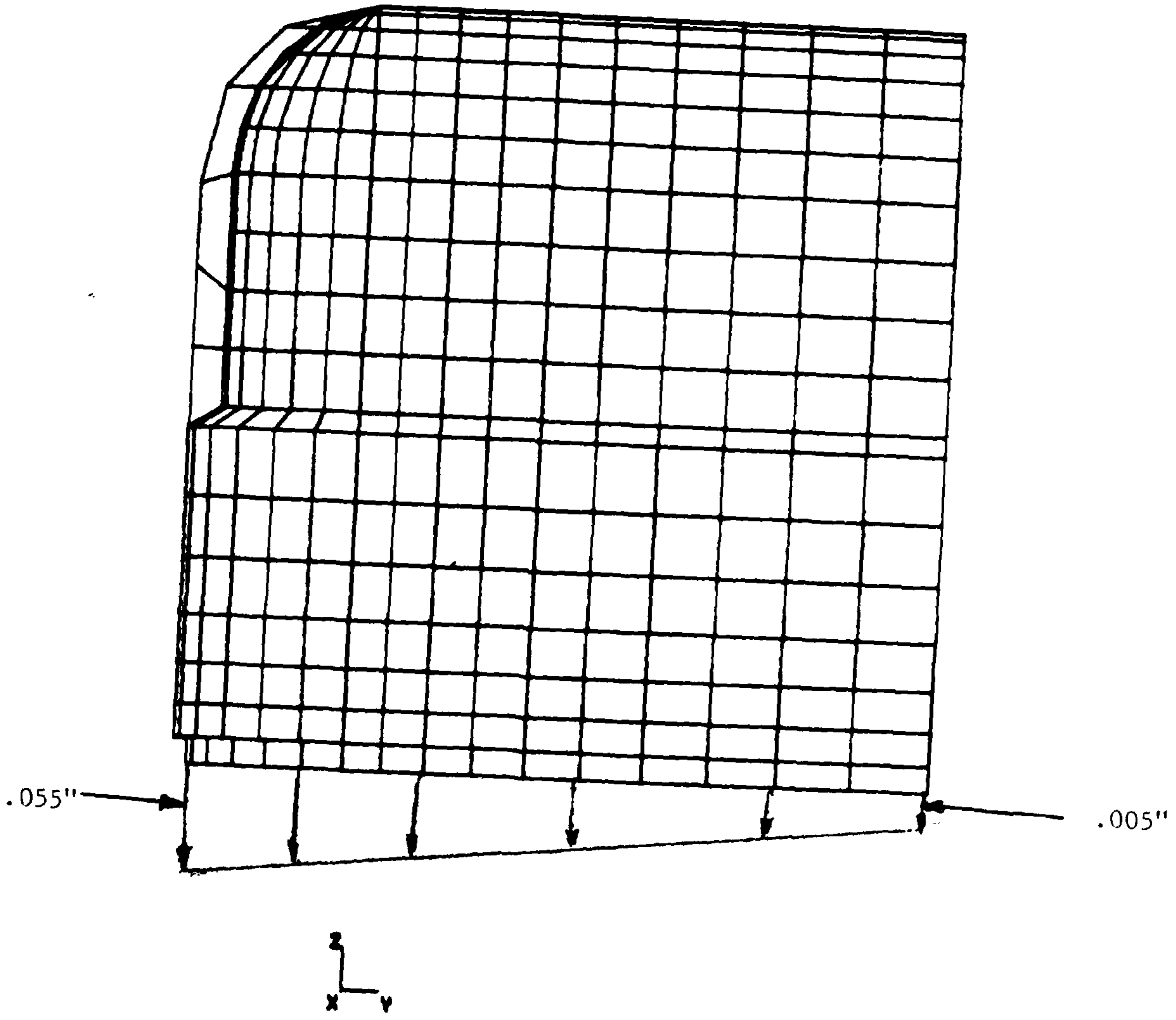

FIGURE 4. WIDTH EDGE WARPING

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