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Stress concentrations around an axisymmetrically attached nozzle on a glass reinforced plastic hemispherical dome

Combley, James Harold

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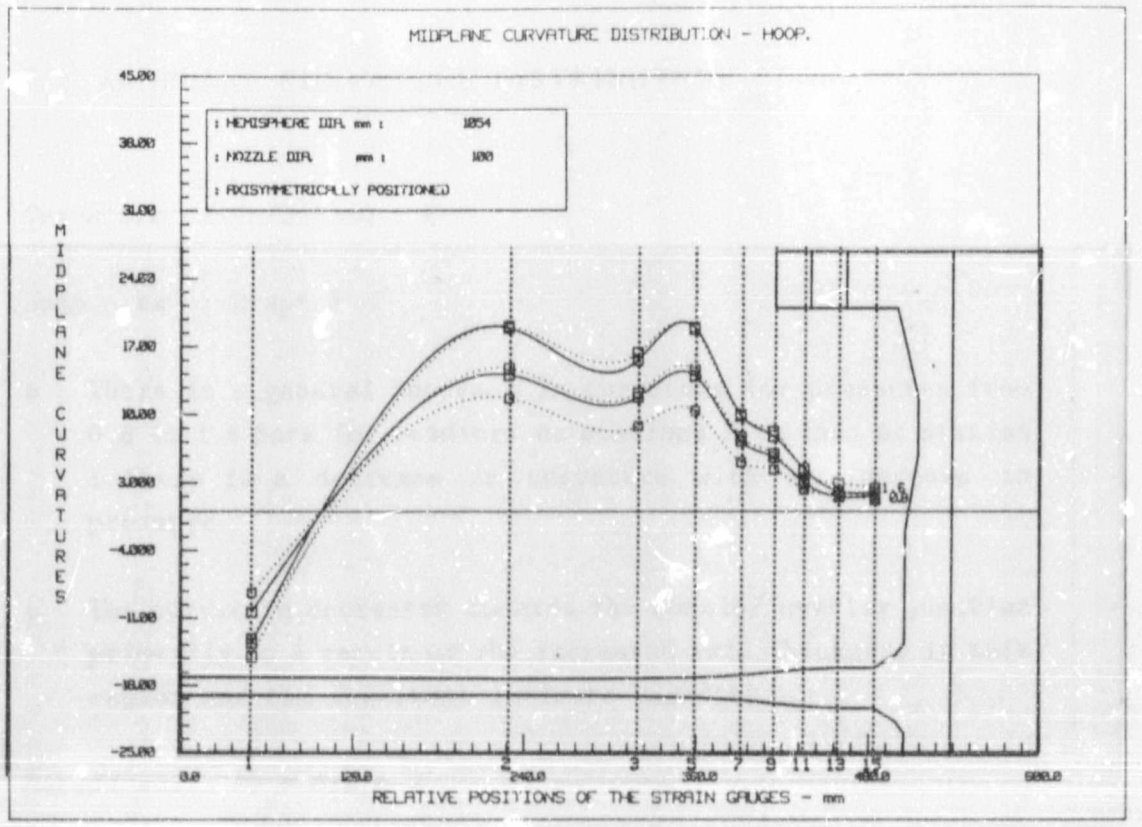
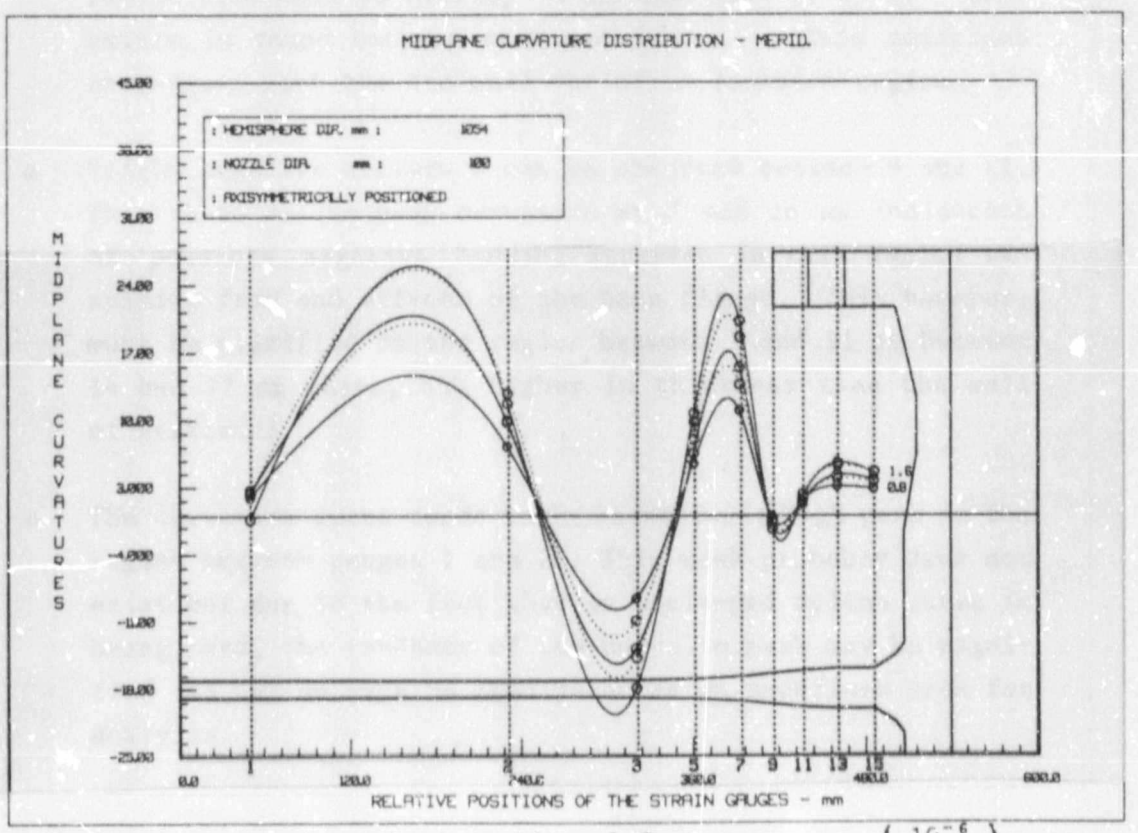


Graph 1. Distribution of Hoop Curvature. $(.10^{-6})$



Graph 2. Distribution of Meridional Curvature. $(.10^{-6})$

3.2 MIDPLANE CURVATURE DISTRIBUTION

Curvature Distribution : k

Hoop - kx : Graph 1

- There is a general increase in curvature for pressures from 0.8 to 1.6 bars for readings at stations 2 to 15. At station 1 there is a decrease in curvature with an increase in pressure.

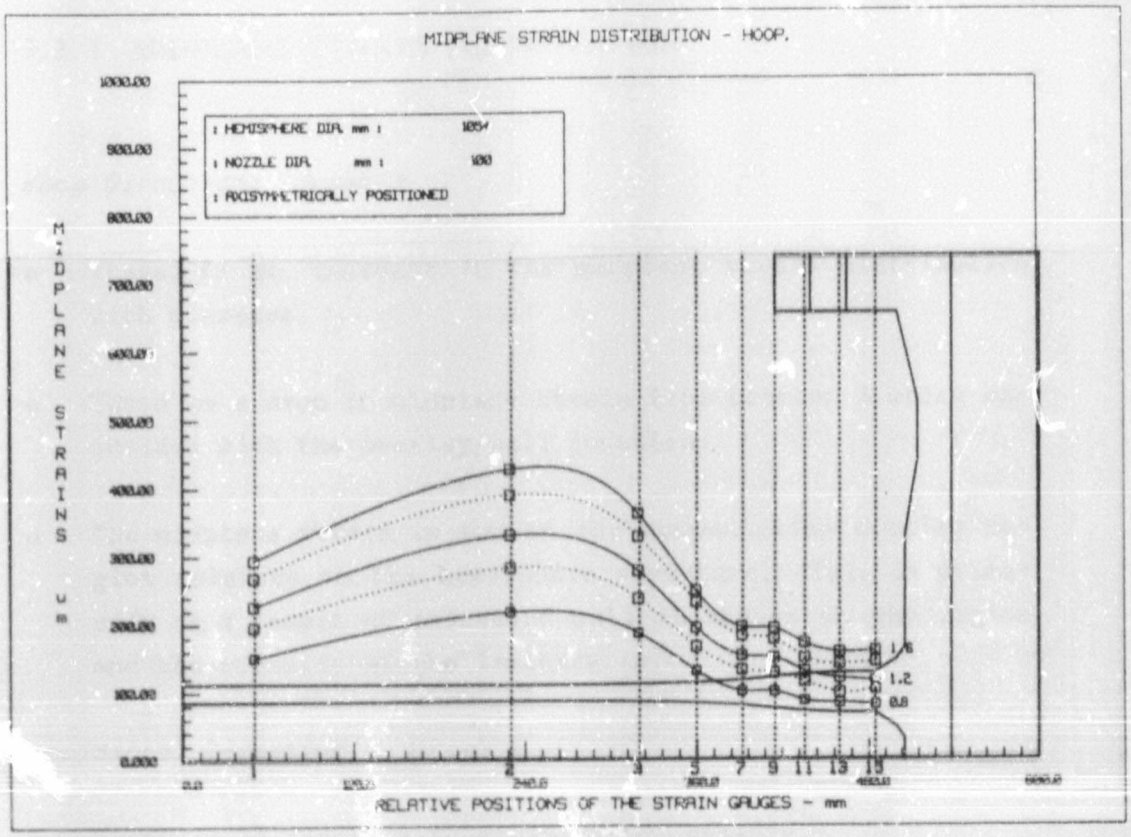
- The curvature decreases towards the nozzle/ overlay junction primarily as a result of the increased wall thickness in this region and the resultant laminate rigidity.

Meridional - ky = Graph 2

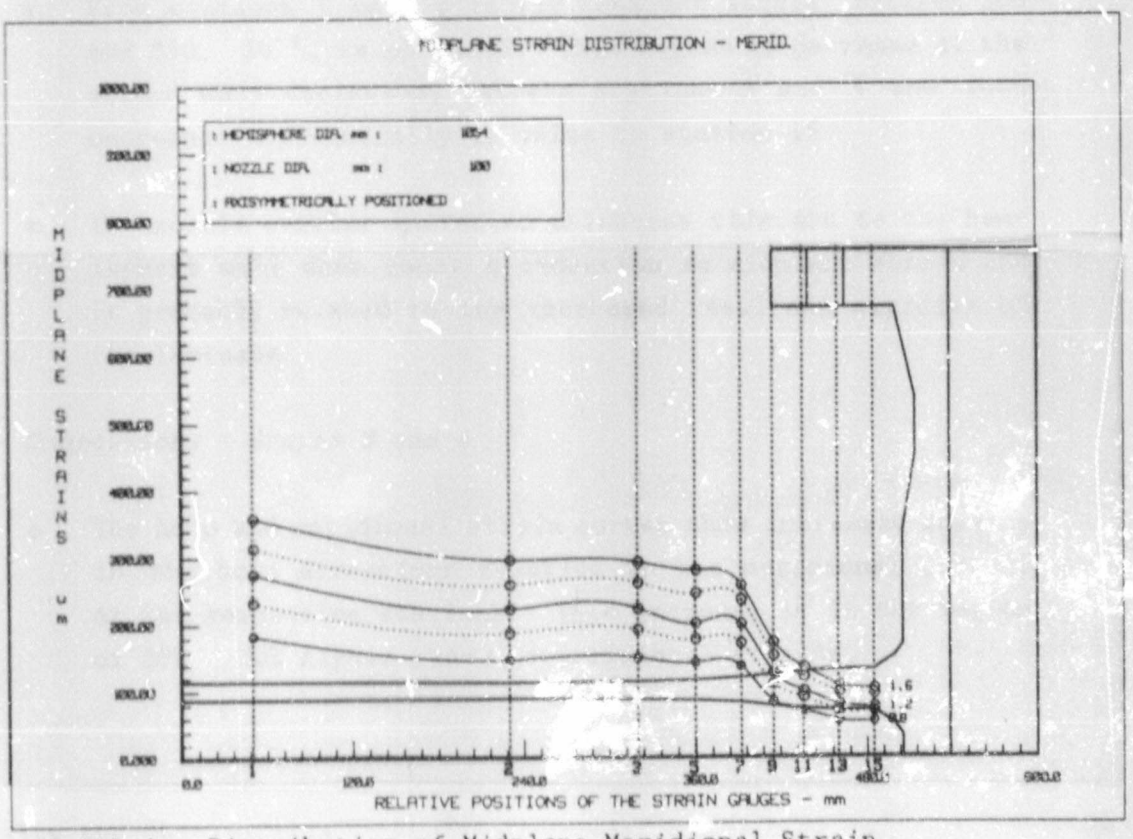
- The region between 3 and 5 is the 1st junction of wall variation from wall to overlay. A maximum peak of 25.10^{-6} curvature is found between stations 5 and 7. This coincides once again with the 2nd wall variation junction region.

- Slight negative curvature can be observed between 9 and 11. This is 8% of the peak curvature at 7 and is an indication of possible negative bending stresses in this region resulting from end effects of the base flange. This however, must be clarified as the region between 9 and 11 is between 14 and 17 mm thick, 50% higher in thickness than the wall of station 3.

- The curvature curve tends to an excessively high peak in the region between gauges 1 and 2. This peak probably does not exist but due to the fact that an unclamped spline curve is being used, the tendency of the curve to peak may be magnified and can as such be considered as an undefined area for analysis.



Graph 3. Distribution of Midplane Hoop Strain.



Graph 4. Distribution of Midplane Meridional Strain.

3.2.1 MIDPLANE STRAIN DISTRIBUTION

Hoop Direction: Graph 3

- There is an increase in the midplane strain distribution with pressure.

- There is a drop in midplane strain from station 3 which coincides with the overlay/wall junction.

- The midplane strain is low in the compensation overlay region relative to the hemisphere structure. This is primarily as a result of increased wall thickness in the region and the rigidity of the laminate.

Meridional Direction : Graph 4

- There is an increase in strain with pressure.

- From stations 1 to 5 a fairly constant strain, between 300 and 350. 10^{-6}, is obtained. This begins to decrease at the second wall variation, between stations 3 and 5 and then decreases exponentially in value to station 15.

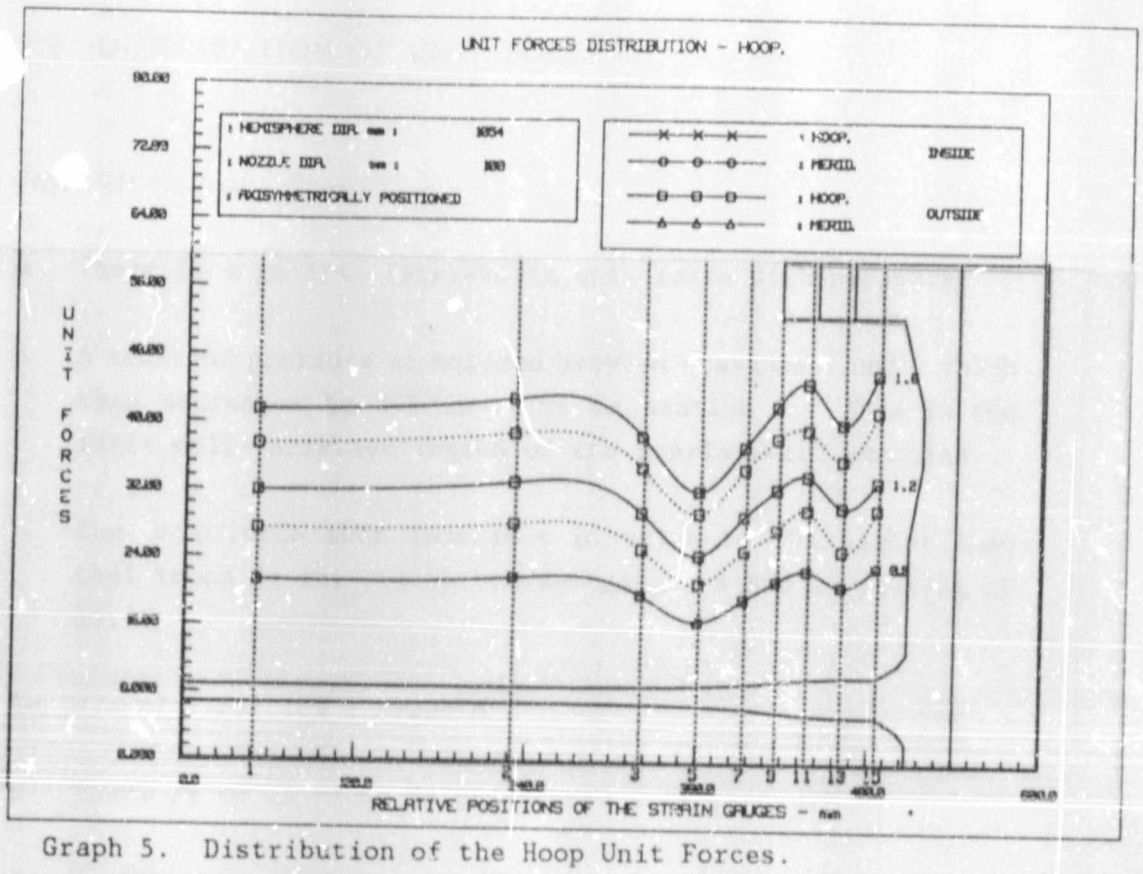
- The nozzle overlay increased thickness relative to the hemisphere wall does cause a reduction in midplane strain and is probably related to the increased resultant rigidity of the laminate.

Comparisons : Graphs 3 and 4

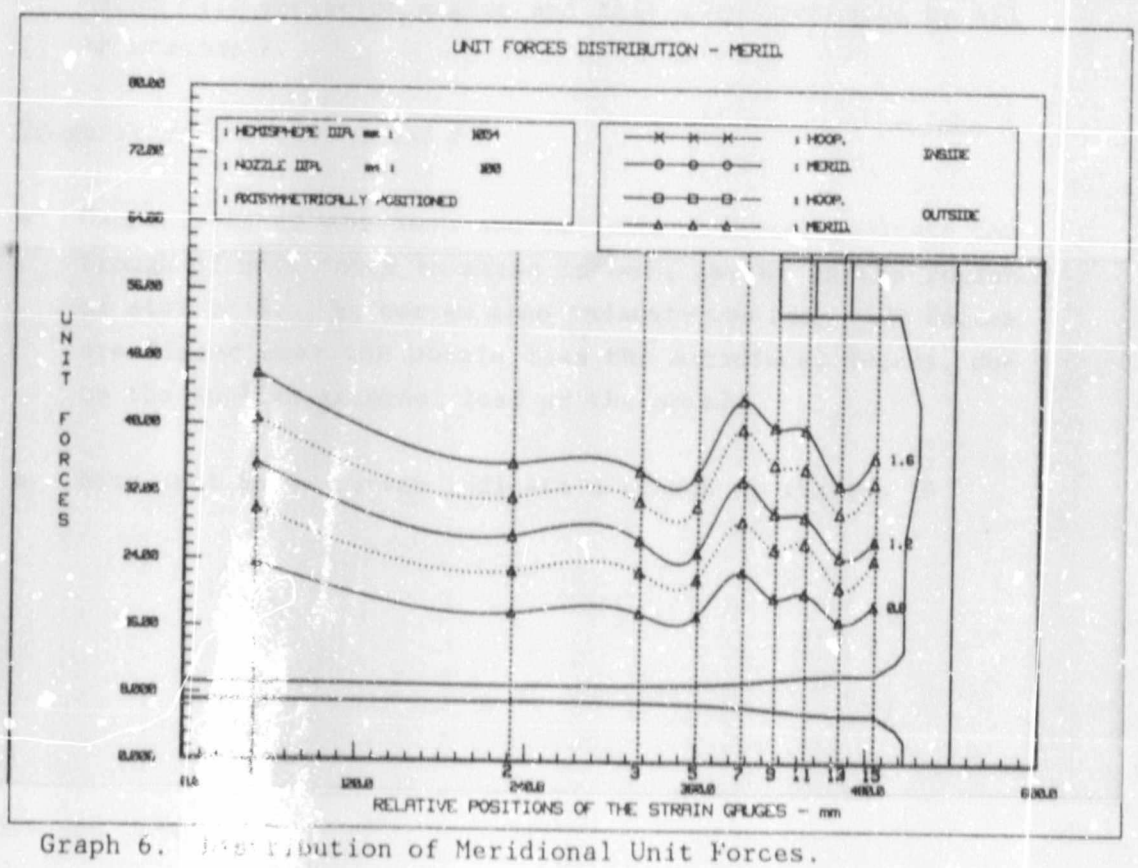
- The hoop and meridional strain curves show increased strains in the hoop directions relative to the meridional strains at the respective stations. This increase is in the region of 20% - 30% higher than the meridional strains.

- It is also noted that the decrease in strain in the hoop direction begins at the first wall variation of the overlay wall junction whereas in the meridional the decrease occurs at the second wall variation.

- It is predicted that the strain curves would closely resemble the plane stress curves for the same principal directions. This is predicted as the curvature values are relatively low in comparison to the strain values, of the order 14 x . This would mean that the stress should decrease near the nozzle due to the overlay. However, this would not indicate the influence of the bending stress on the total stress in the region of the nozzle. In a later section the stresses for a pressure of 1.6 bars will be separated into their bending and plane stress components and their distribution and contributions to the total stress analysed.



Graph 5. Distribution of the Hoop Unit Forces.



Graph 6. Distribution of Meridional Unit Forces.

3.3 DISTRIBUTION OF UNIT FORCES.

Hoop Direction : Graph 5

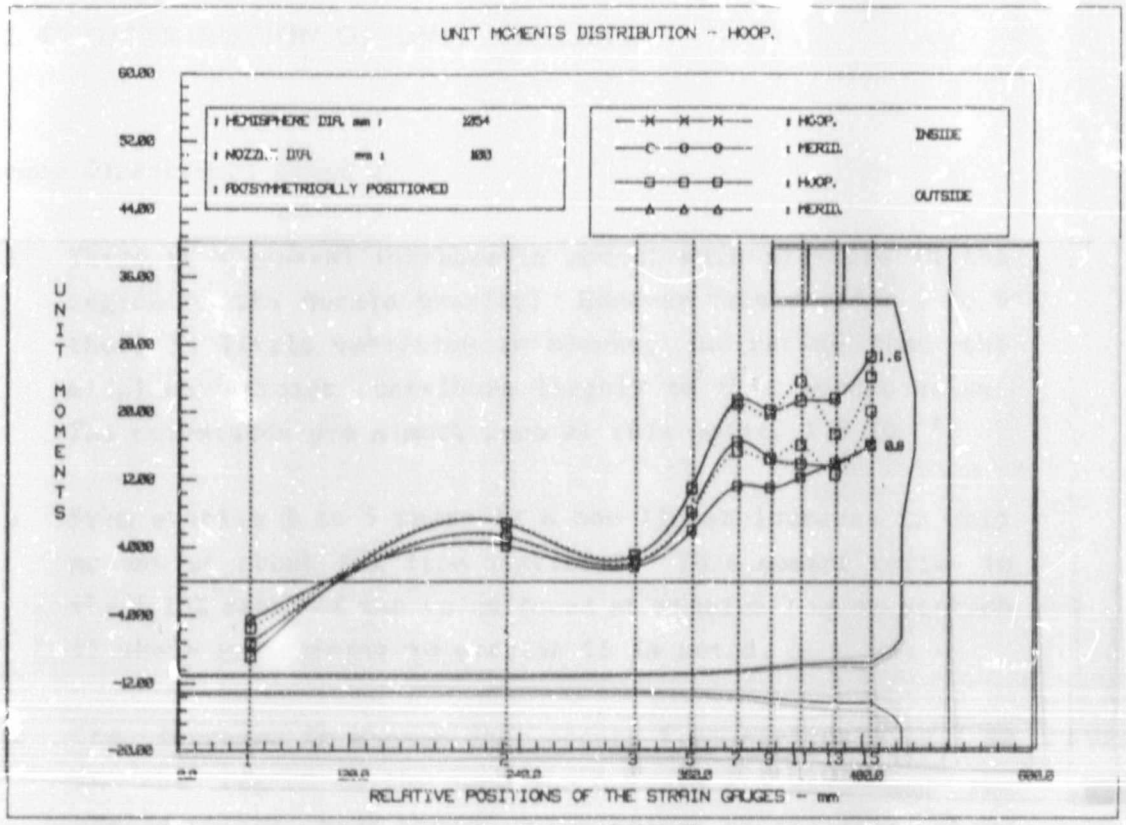
- There is a general increase in unit force with pressure.
- A constant pressure is noticed between stations 1 and 2 which then decreases by 20% in value to station 5. This is the first wall variation region of the overlay/wall junction.
- The unit force then increases in value to 10% higher than that found in the region between gauges 1 and 2, peaking at 15.

Meridional Direction : Graph 6

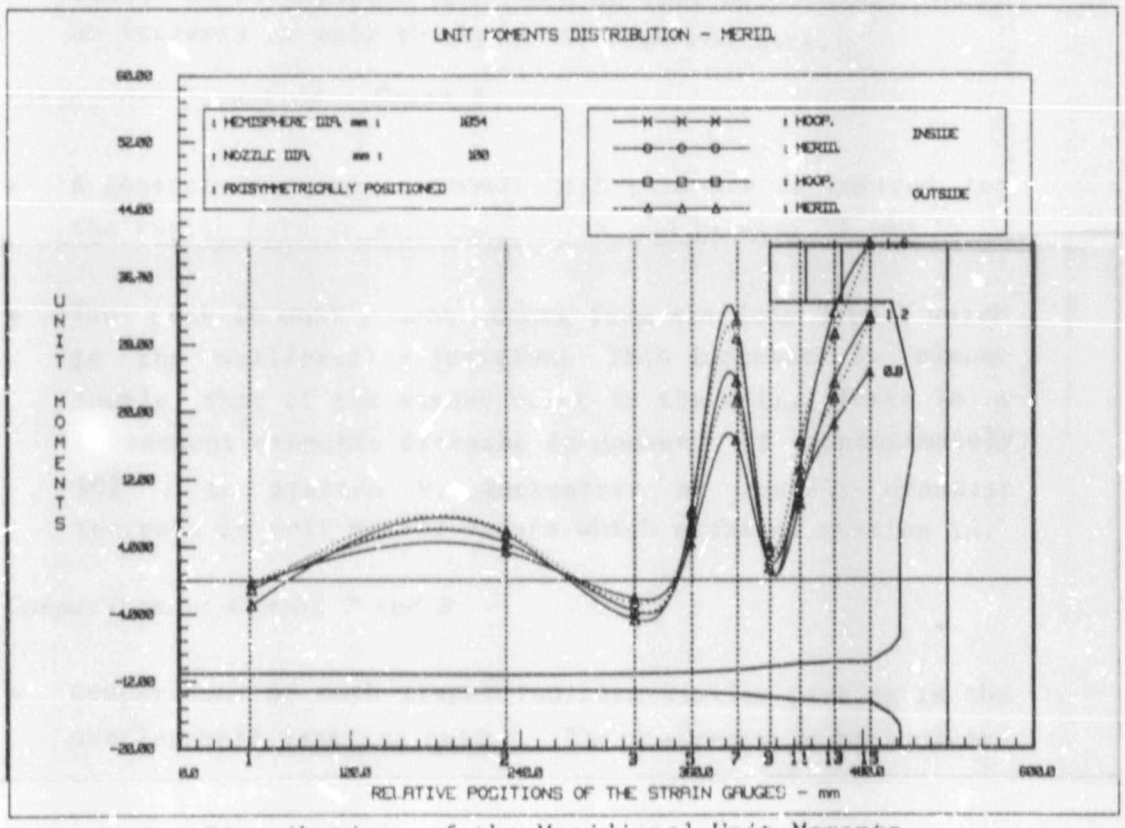
- There is an increase in unit force with pressure.
- A decrease of force occurs between stations 3 and 5, the first wall variation region and this then increases by 44% to station 7.

Comparisons : Graphs 5 and 6

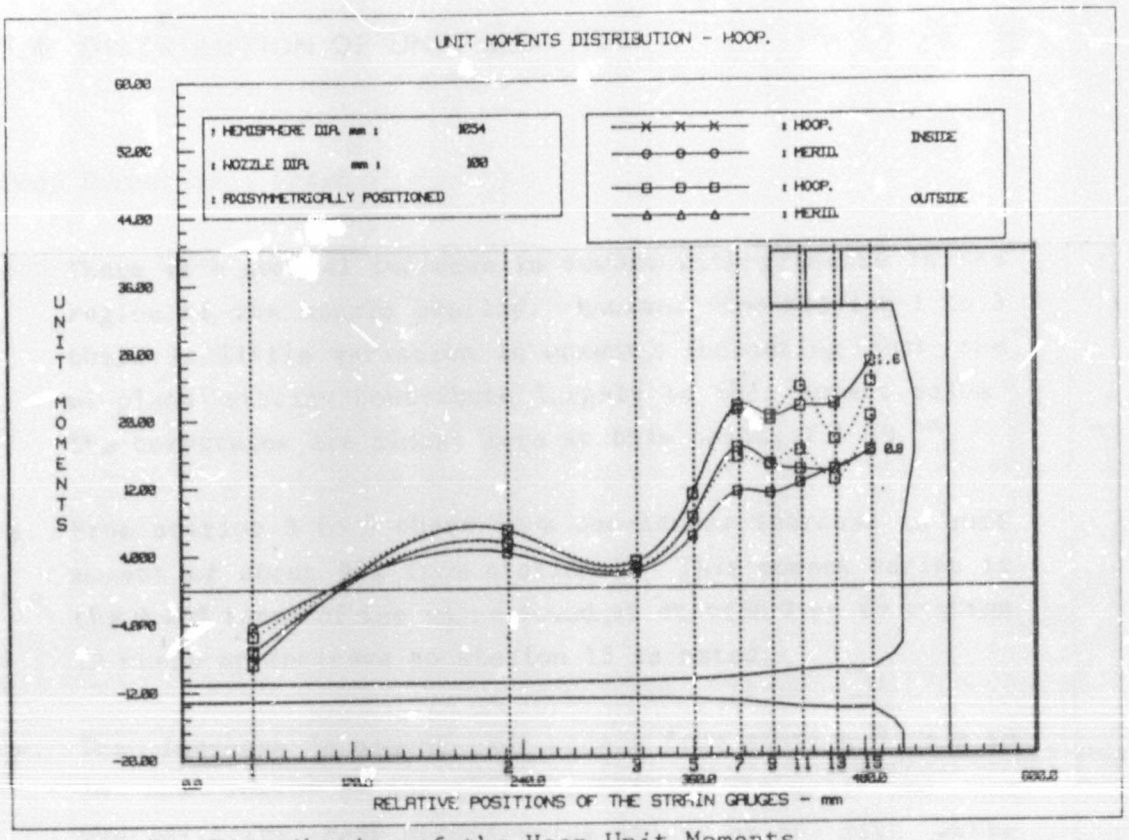
- Comparisons of the hoop and meridional forces indicate the trough of unit force to arise in both curves in the region of station 5. The curves also indicate the hoop unit forces are higher near the nozzle than the meridional forces, due to the applied external load of the nozzle.
- Both unit force curves indicate a trough at station 13.



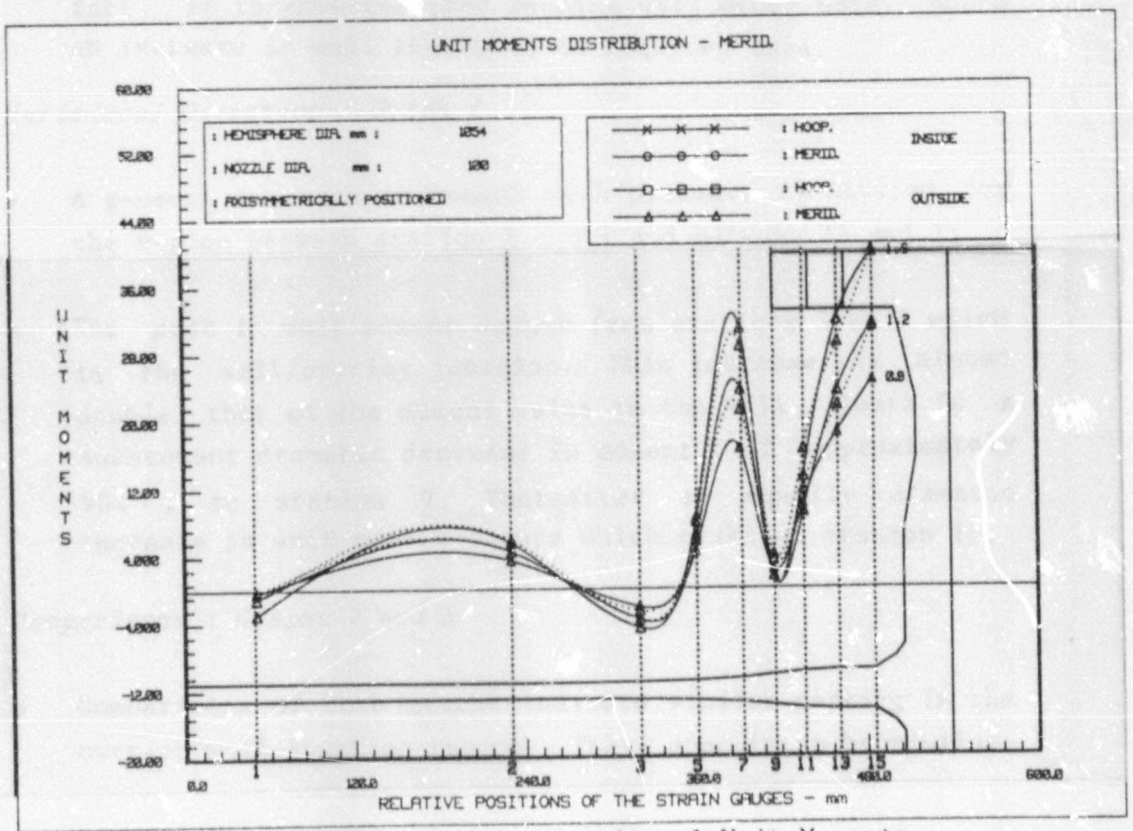
Graph 7. Distribution of the Hoop Unit Moments.



Graph 8. Distribution of the Meridional Unit Moments.



Graph 7. Distribution of the Hoop Unit Moments.



Graph 8. Distribution of the Meridional Unit Moments.

3.4 DISTRIBUTION OF UNIT MOMENTS

Hoop Direction : Graph 7

- There is a general increase in moment with pressure in the region of the nozzle overlay. However from station 1 to 3 there is little variation in moment, indicating that the midplane strains contribute largely to this moment value. The curvatures are almost zero at this point, $1.5\ 10^{-6}$.

- From station 3 to 5 there is a non-linear increase in unit moment of about 90% from station 3. This moment varies in the ± 20% range of the value found at station 7 up to station 13 where an increase to station 15 is noted.

- The increase in moment that occurs from station 3 to 7 is in the region of the junction between the wall and the overlay. The peak moment value arises at the site where the nozzle is attached to the hemisphere. Due to this fact, it is expected that bending will occur here, hence an increase in wall thickness is required here.

Meridional Direction : Graph 8

- A general increase in moment with pressure is noticed for the region between station 5 and 9 and between 11 and 15.

- The peak in unit moment occurs from stations 3 to 7 which is the wall/overlay junction. This increase is almost double that of the moment value in the wall. There is a subsequent dramatic decrease in moment, of approximately 90% , to station 9. Thereafter an equally dramatic increase in unit moment occurs which peaks at station 15.

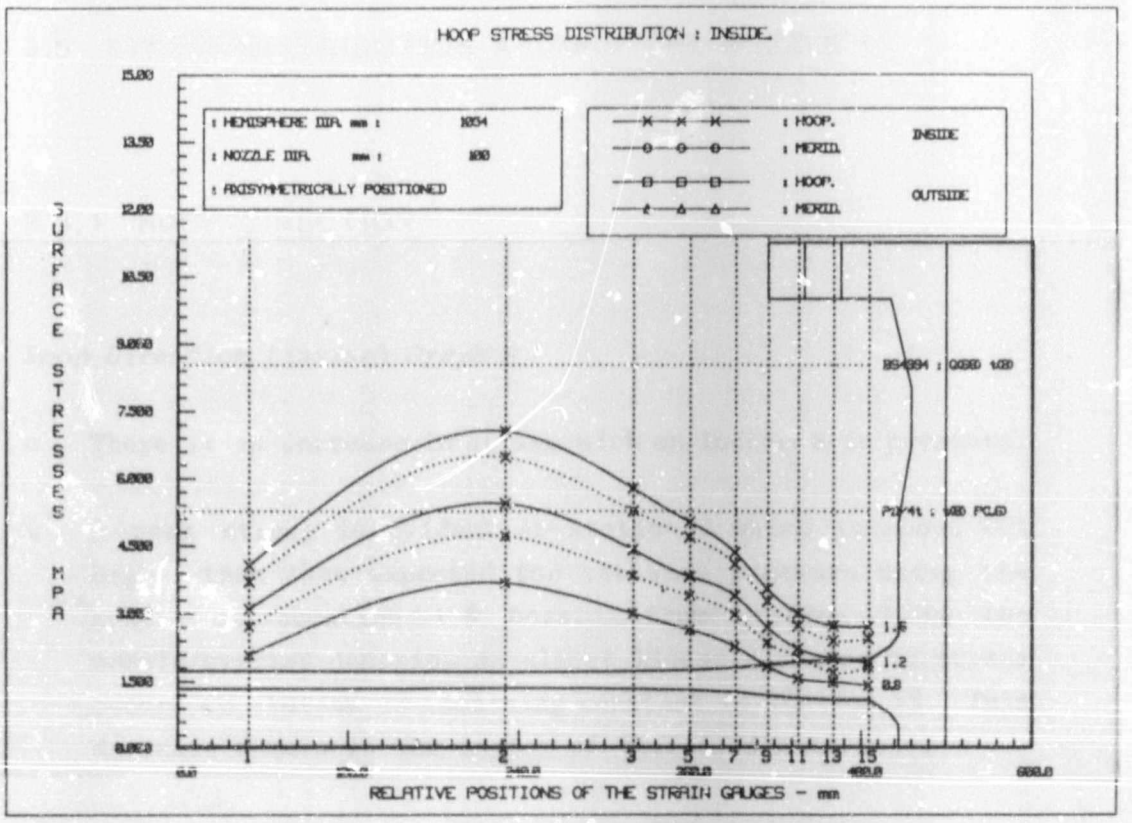
Comparisons : Graphs 7 and 8

- Comparisons of both graphs indicate similar peaking in the overlay/wall junction region. There appears to be similar-

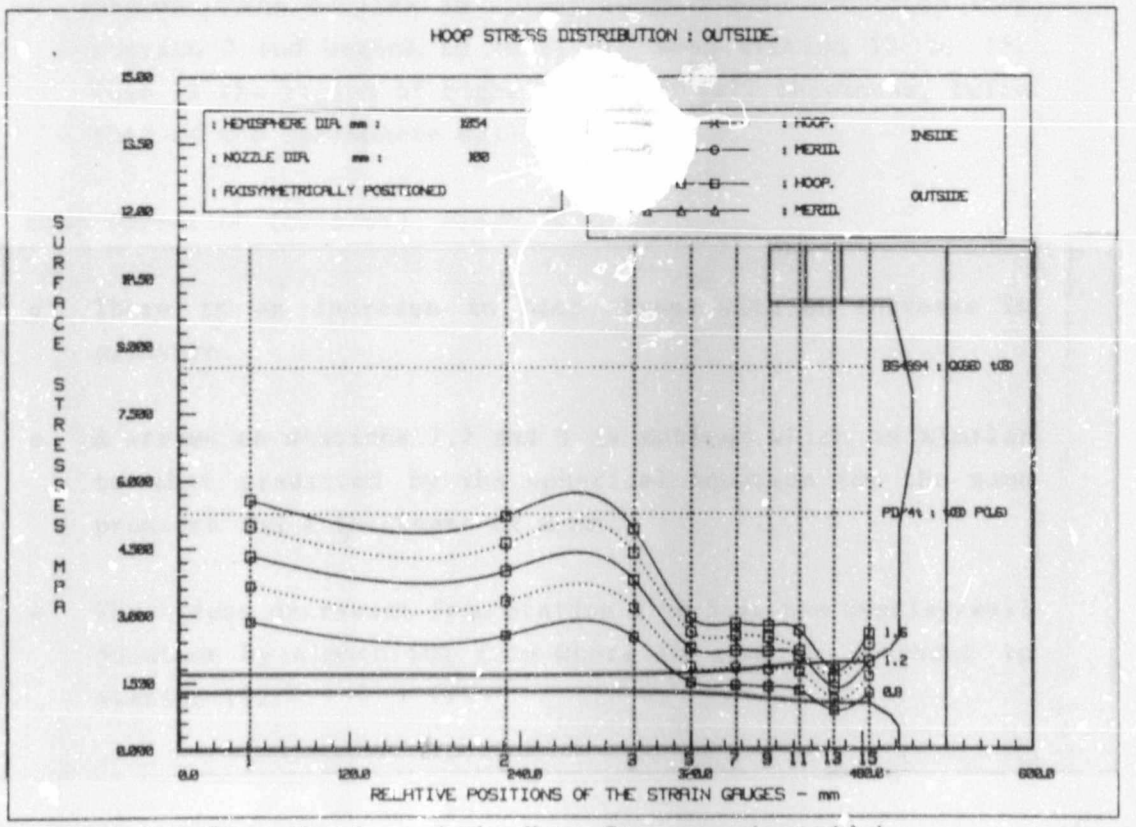
ity in the curve trends from station 1 to 3 with little change in value with an increase in pressure.

- Both curves indicate a maximum moment value at station 15.

- When analysing the contributions of the coupling and bending matrices to the moment value it is seen that despite the curvature and strain values decrease in the region of the nozzle there is still an increase in moment value. This is directly related to the bending and coupling matrix values increasing, as thickness contribution to there magnitude vary quadratically and cubically respectively.



Graph 9. Distribution of the Hoop Stresses (inside).



Graph 10. Distribution of the Hoop Stresses (outside).

3.5 STRESS DISTRIBUTION AROUND THE NOZZLE

3.5.1 HOOP DIRECTION

Hoop Direction (inside) Graph 9

- There is an increase in stress with an increase in pressure.
- A peak stress is evident at station 2 which is about 40% higher than that expected for the same pressure using the sphere at equation 1.6 bars. From station 3 to the nozzle/overlay junction an almost linear decrease in stress occurs to station 13 remaining constant to station 15. This decrease occurs in the region of increased thickness.
- The stress at station 15 is almost 50% that of the expected wall stress of the hemisphere due to compensation of this region. The decline in stress becomes more increased from station 7 and begins to level off from station 13 to 15. This is the region of highest overlay wall thickness, twice that of the hemisphere wall.

Hoop Direction (outside) Graph 10

- There is an increase in hoop stress with an increase in pressure.
- A stress on stations 1,2 and 3 is noticed which is similar to that predicted by the spherical equation for the same pressure and a thickness of 8 mm.
- The stress decreases from station 3 to 5 at the overlay/wall junction by almost 50% from where it remains constant to station 11.

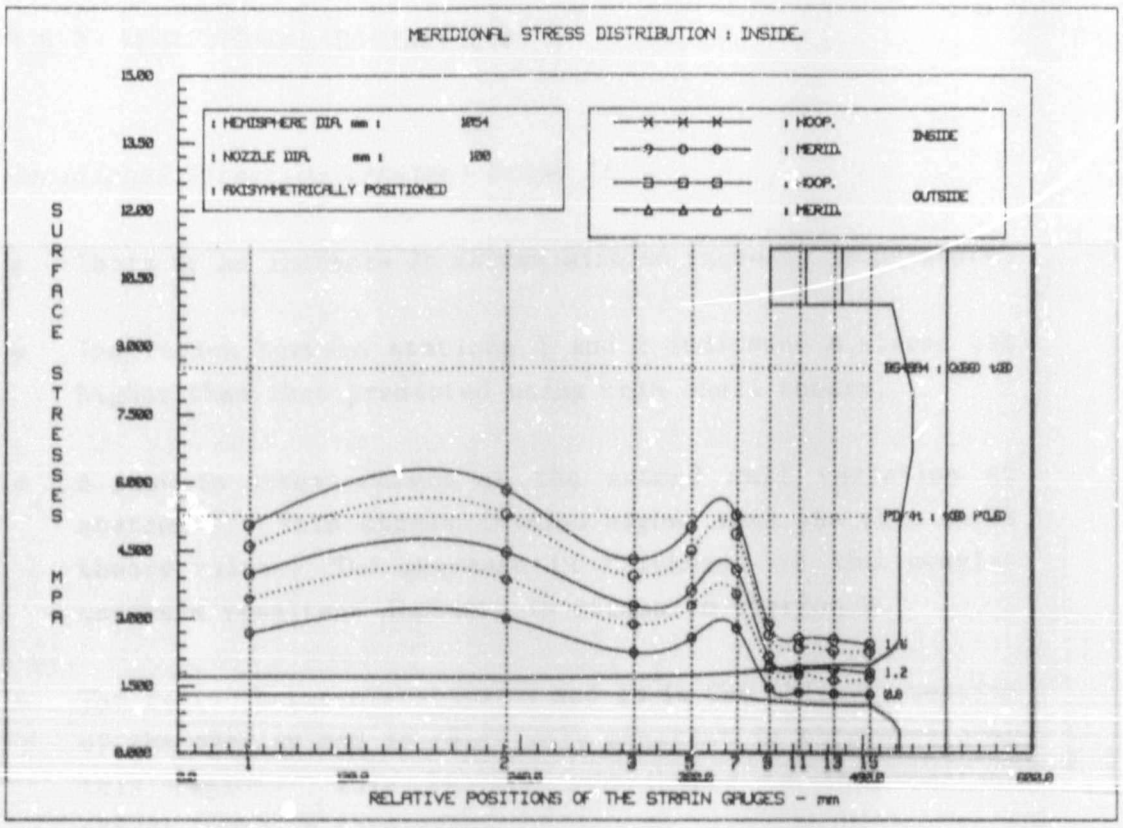
- The stress remains relatively constant from station 5 to 15 despite the variation in wall thickness in this region.

Comparison : Graphs 9 and 10

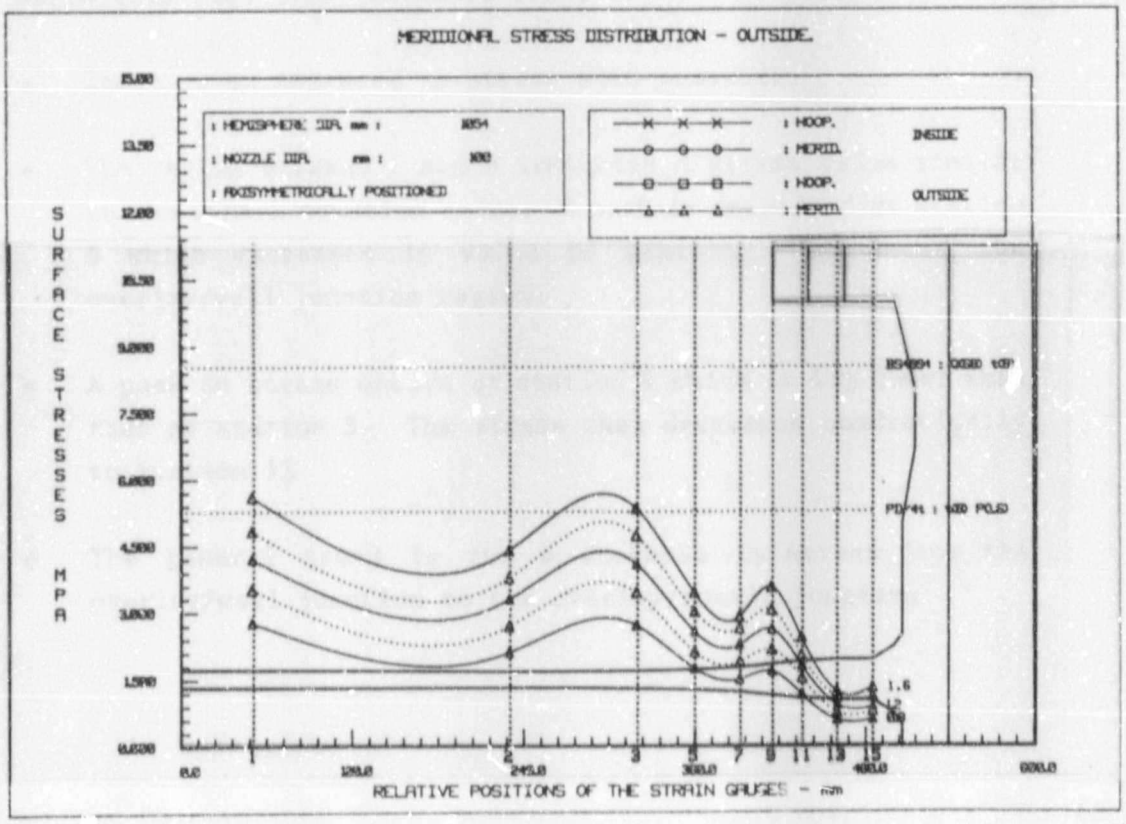
- The inside and outside stress curves indicate a marked difference in trends. While both show a decrease in stress near the nozzle region equivalent to 50% that of the sphere equation estimate, the region between stations 1 and 11 show the largest differences. The positive bending which occurs in this region is due to the positive curvature value. This provides tensile stress values on the inside and compressive stress components on the outside of the hemisphere wall. These when combined with the plane stress cause the increased stress values inside the hemisphere and decreased values outside.

- The hemisphere designed for a pressure of 2 bars remains well within the stress requirements of BS4994 at 1.6 bars. However, when using BS4994 and a design pressure of 1.6 bars and hemisphere wall thickness of 8 mm yields a stress of 6.85 MPa , Appendix C.

  This value is similar to that found at station 2 and could effectively be considered as the design stress of the hemisphere.



Graph 11. Distribution of the Meridional Stresses (inside)



Graph 12. Distribution of the Meridional Stresses (outside)

3.5.2 MERIDIONAL DIRECTION

Meridional Direction (inside) Graph 11

- There is an increase in stress with an increase in pressure.
- The region between stations 1 and 2 indicates a stress 23% higher than that predicted using thin shell theory.
- A peak in stress occurs at the second wall variation at station 7. This stress is also higher than the thin shell theory value. The increase in thickness of the overlay causes a resultant decrease in stress to station 9.
- The region between stations 9 and 13 is the thickest section of the overlay and is relatively constant in thickness over this region. This largely contributes to the constant stress found in this area.

Meridional Direction (outside) Graph 12

- There is an increase in stress with pressure.
- The region between 1 and 3 indicates a stress value similar to the sphere equation value. A peak is indicated at station 5 which decreases in value to station 7 which is the overlay/wall junction region.
- A peak in stress occurs at station 9 which is 45% lower than that at station 3. The stress then decreases quadratically to station 15.
- The general trend is for a decrease in stress from the overlay/wall junction to the overlay/nozzle junction.

Comparison : Graphs 11 and 12

- Both curves suggest the outside stress to be about 45% lower than the inside wall stress, in the nozzle overlay region.

- The stress peak outside the hemisphere occurs at the first wall variation region whereas it is evidenced at the second wall variation inside the shell.

- The stresses do not exceed the thin shell theory prediction by more than 10% and are well below the predicted stress of 6.8 MPa using BS4994. The stresses thus closely follow the stress requirements stipulated by theory for thin shells.

Close:

The stress curves are indicative of overall stress distributions around the nozzle region. No indication is given of the bending and plane stress components and how the total stress value is affected by them.

For this reason it was seen necessary to use the 1.6 bar stress curves and separate them up into their stress components. This would provide more relevant information to the extent of bending stress in the nozzle region and clarify salient characteristics of overall stress curves.

Author Combley James Harold
Name of thesis Stress Concentrations Around An Axisymmetrically Attached Nozzle On A Glass Reinforced Plastic Hemispherical Dome. 1987

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