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Program 12 Design of Cryogenic Tanks for Space Vehicles

Shell Structures Analytical Modeling

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V312-7202

Objectives

The initial objective of this project was to investigate the use of superplastically formed corrugated hat-section stringers and frames in place of integrally machined stringers over separate frames for the tanks of large launch vehicles subjected to high buckling loads. The ALS has been used as an example.

The objective of the follow-on project is to study methods of designing shell structures subjected to severe combinations of structural loads and thermal gradients, with emphasis on novel combinations of structural arrangements and materials. Typical applications would be to fuselage sections of high speed civil transports and to cryogenic tanks on the National Aerospace Plane.

SECOND ANNUAL NASA-UVA LA^{2}ST PROGRAM MEETING

CRYOGENIC TANK BUCKLING ANALYSIS, BENCHMARK TESTS FOR THERMALLY LOADED FINITE ELEMENTS, AND PROPOSED STUDY OF METHODOLOGIES FOR DESIGN OF SHELL STRUCTURES FOR THERMAL ENVIRONMENTS.

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Dr. M. J. Shuart (NASA)

Department of Mechanical and Aerospace Engineering
School of Engineering and Applied Science
University of Virginia, Charlottesville, VA 22901.
9-10 July, 1991

Research Objectives

Initial: To investigate the use of superplastically formed corrugated hat-section stringers and frames in place of integrally machined stringers over separate frames for the tanks of large launch vehicle subject to high buckling loads. The ALS has been used as an example.

Revised: To study methods of designing shell structures subjected to severe combinations of structural loads and thermal gradients, with emphasis on novel combinations of structural arrangements and materials. Typical applications would be to fuselage sections of high speed civil transports and to cryogenic tanks on the National Aerospace Plane.

Progress on the buckling of tanks of large launch vehicles.

It had been shown previously that superplastically formed corrugated hat-section stringers could replace integrally machined stringers and equivalent beam properties were determined. Using these properties, both for stringers and for frames, the allowable compression loads on a 30 foot diameter tank have been determined and have been shown to be adequate. The proposed design would eliminate a costly machining process and would replace the deep frames which would otherwise have to be built into the tank structure.

Progress on benchmark test

Previous work in this area has been performed by MacNeil and Harder, but they did not include thermal loading or the effect of thermal loading on material properties. The MacNeil/Harder tests are being revised to include thermal loads and new tests are being derived. The "exact" solutions for comparison are from closed form solutions and highly accurate numerical solutions. Eventually comparison with experimental results is possible.

Progress on Design of shell structures subject to thermal loads

An evaluation of analytical methods has been started, in which benchmark tests for the SPAR elements used in the COMET program have been compared with exact solutions, and with elements for other finite element programs.

Proposed program

Our proposed program includes benchmark tests, literature search, selection of finite element programs, evaluation of design methods and of candidate designs for tanks and shell structures using linear theory. Configurations may include straight and tapered cylinders, various types of stiffeners and frames, double walled skins, composites, various combinations of insulation. Environments may include various pressure and temperature gradients. Certain models may be used to compare different finite elements or to search for optimum materials.

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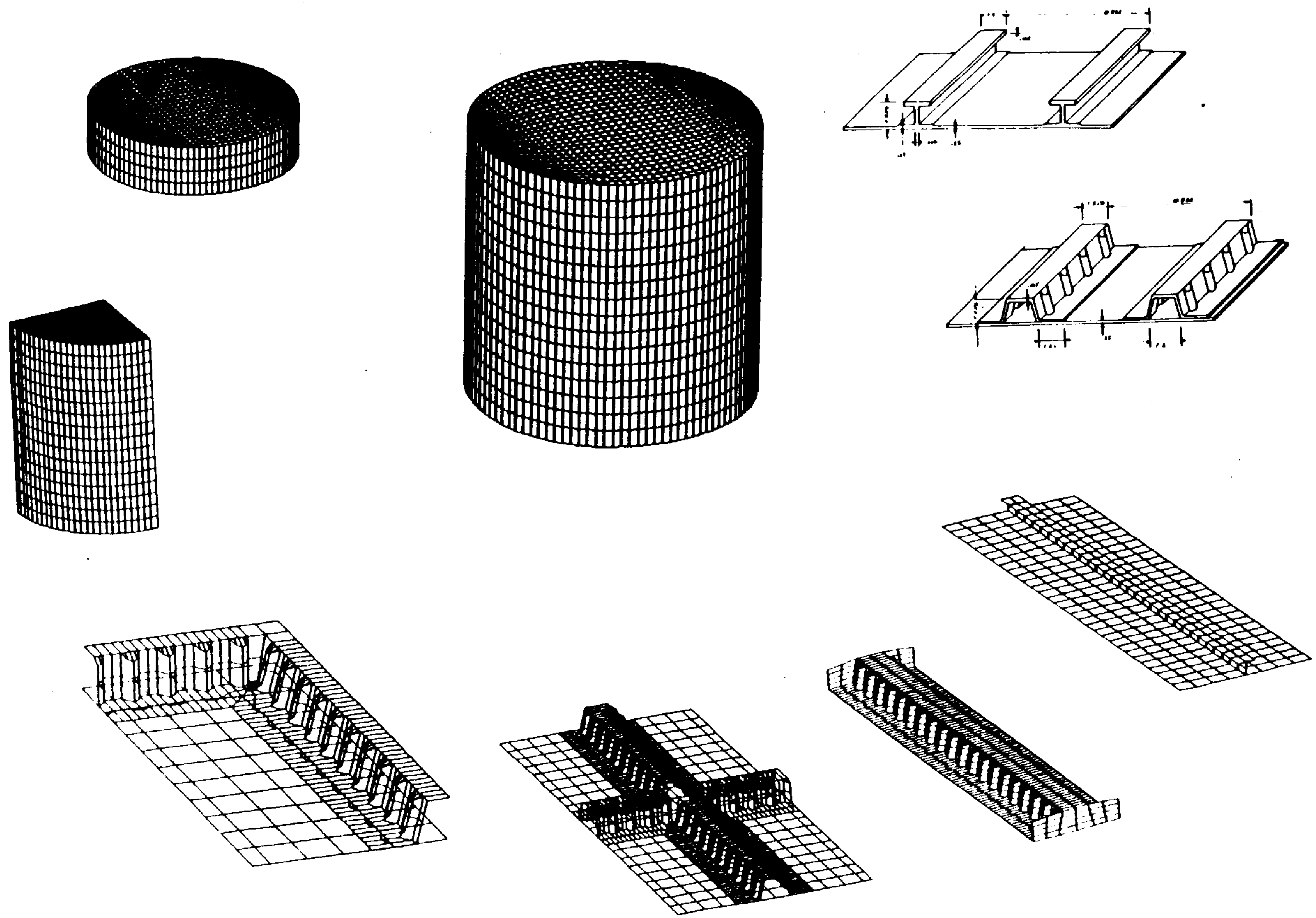
Outline

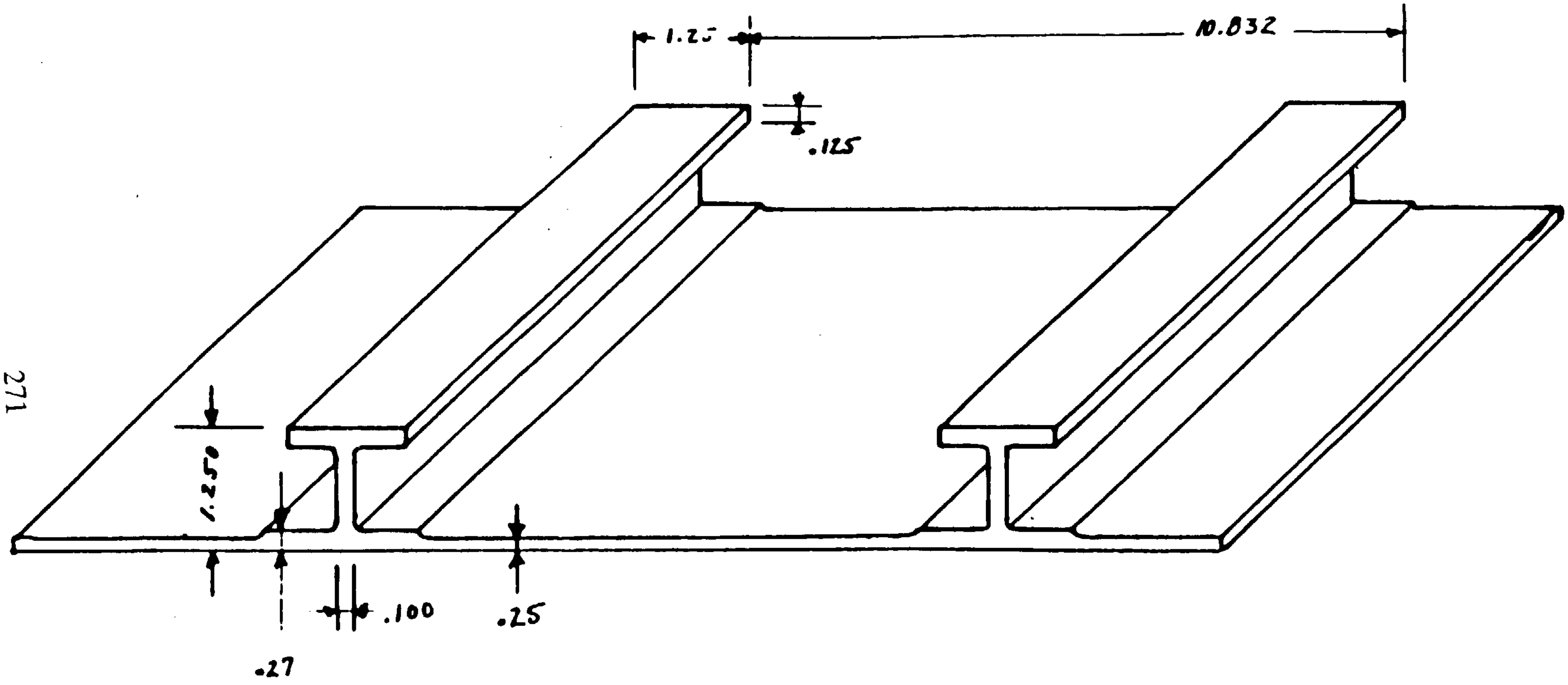
Concluding Results of the Cryogenic Tank Buckling Analysis

Benchmark Tests for Thermally Loaded Structural Elements

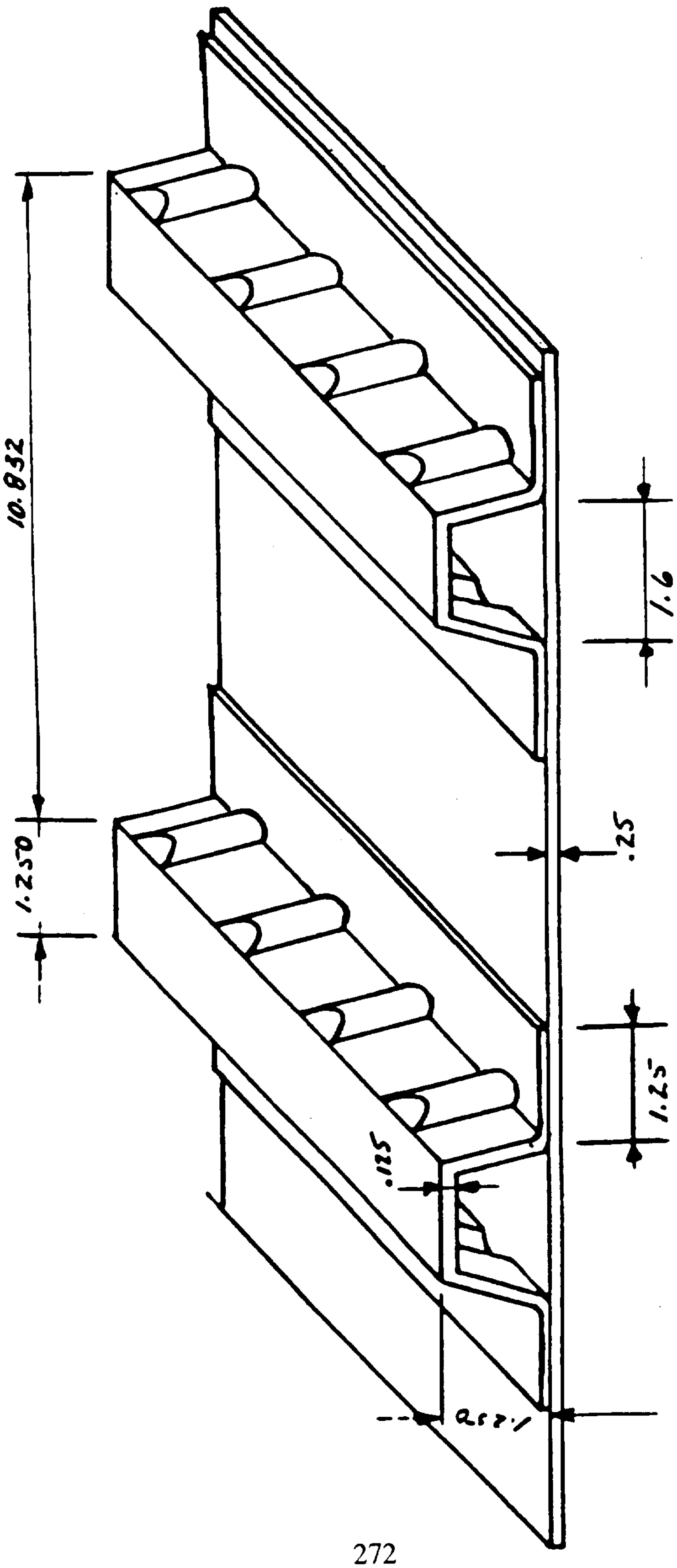
MODELLING OF SUBSTRUCTURES



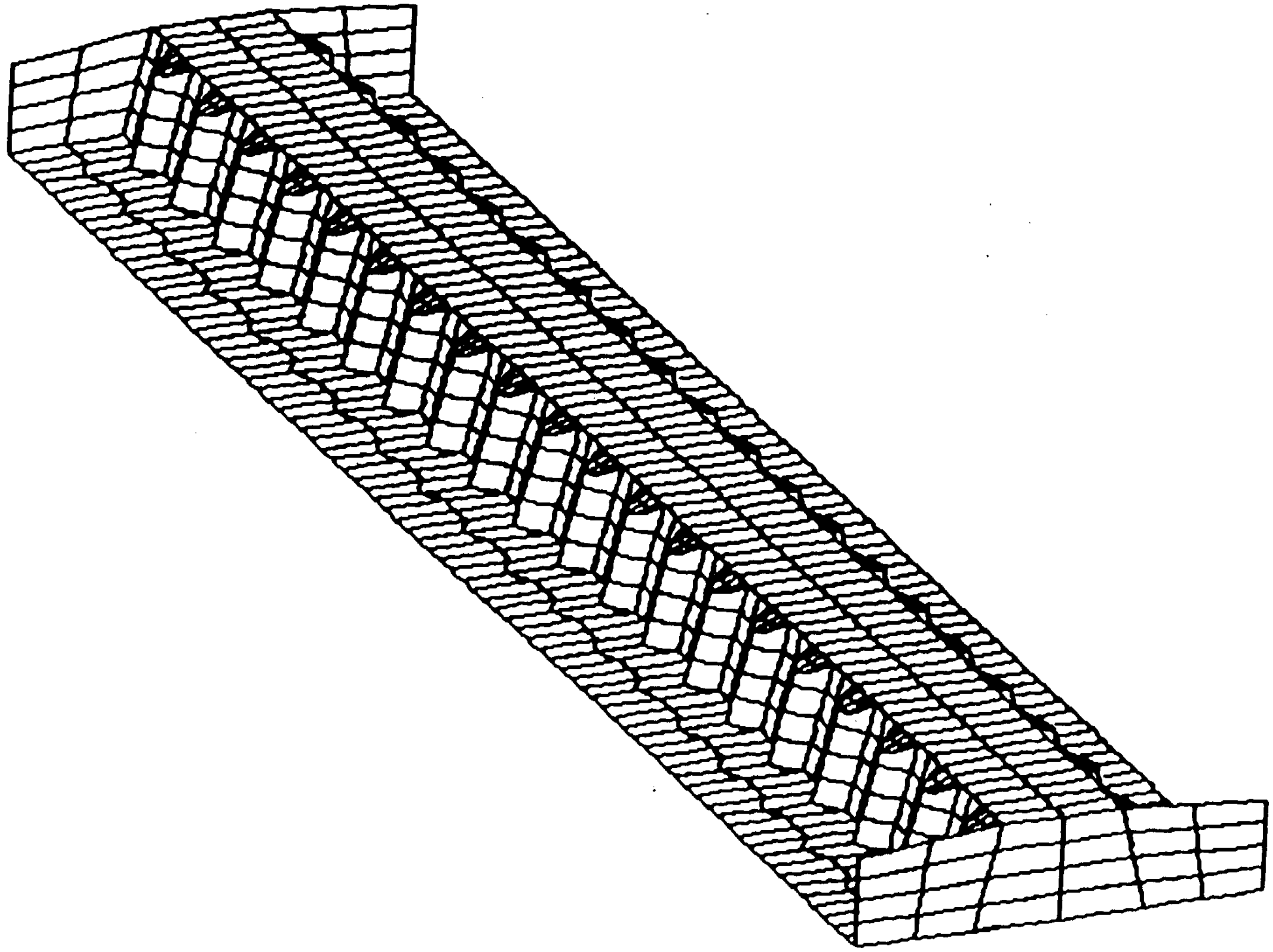
MACHINED-OUT I-BEAMS



SPF HAT STRINGER

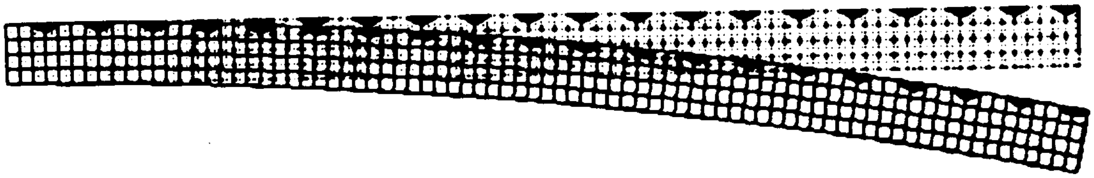


DETAIL MODEL OF SPF HAT STRINGER

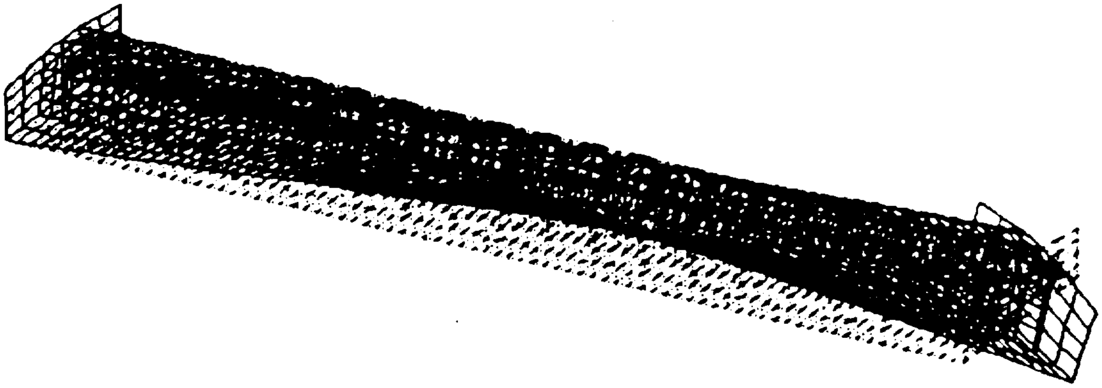


LOADED SPF HAT STRINGERS

COMPRESSION, $A_{eff} = 0.368$ in^2

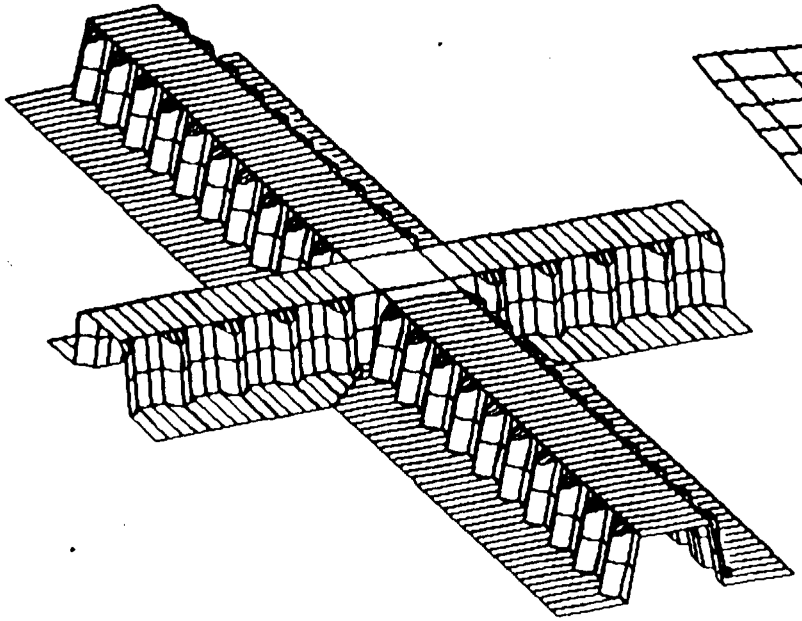


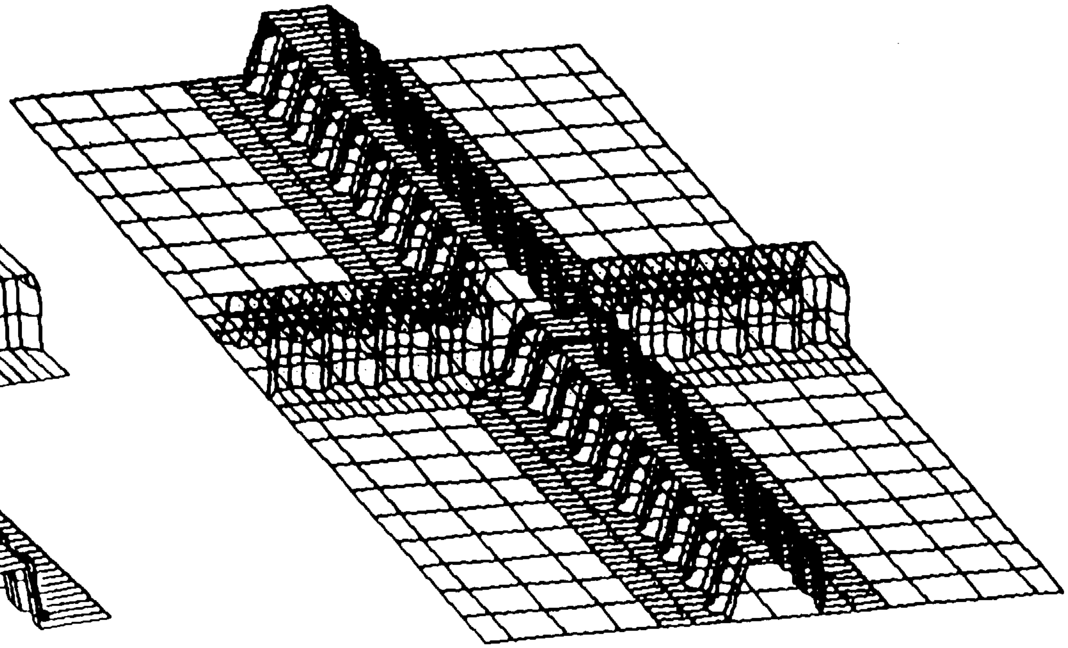
BENDING, $I_{eff} = 0.129$ in^4



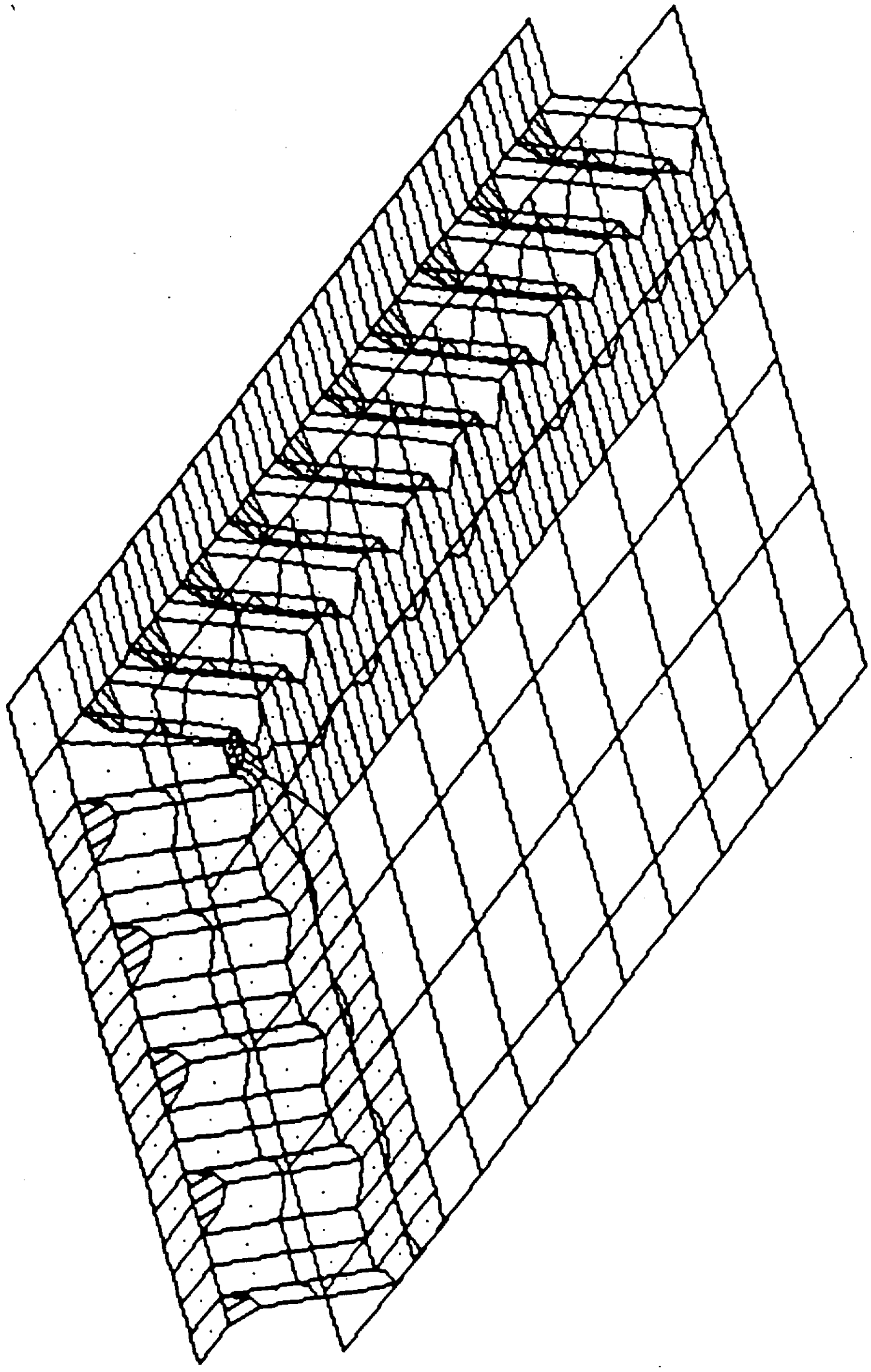
TORSION, $J_{eff} = 0.249$ in^4

SPF STRINGER/FRAME PANEL

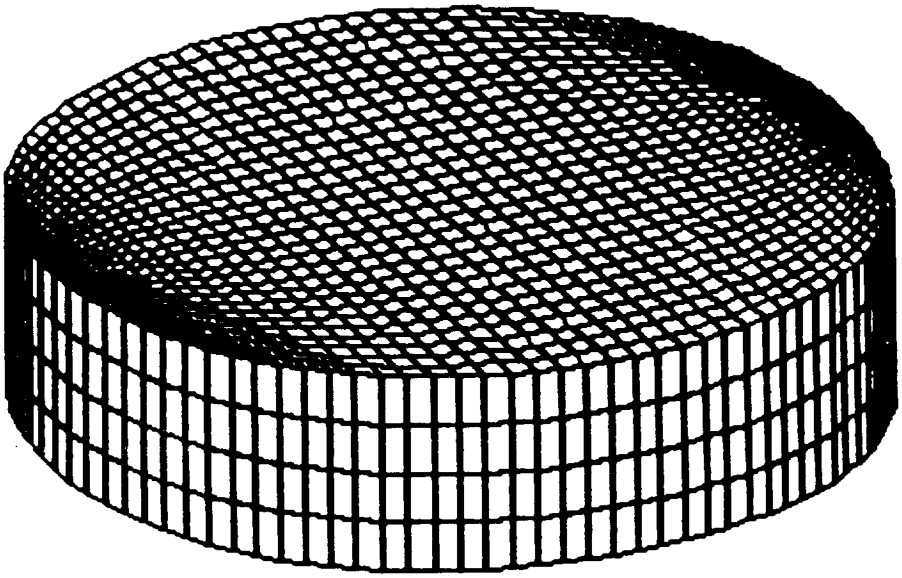


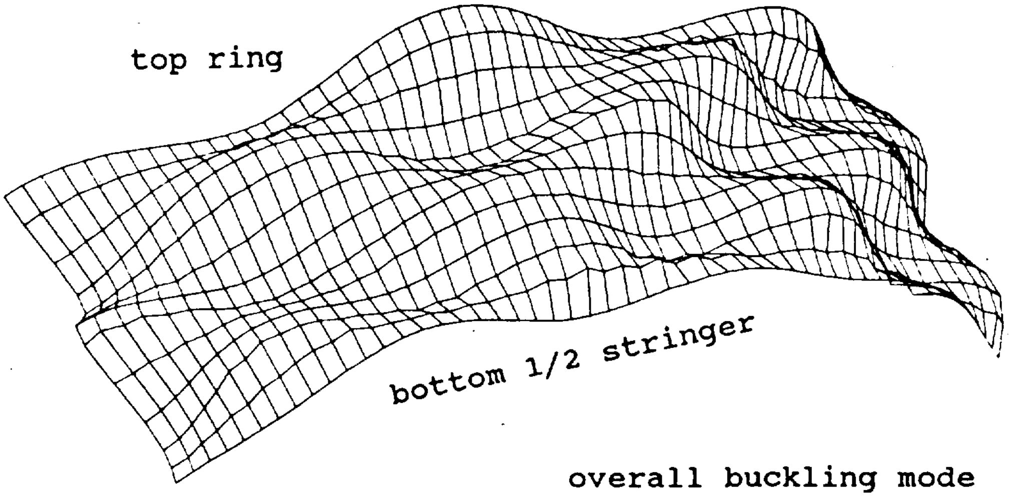


QUARTER SPF STRINGER/FRAME PANEL

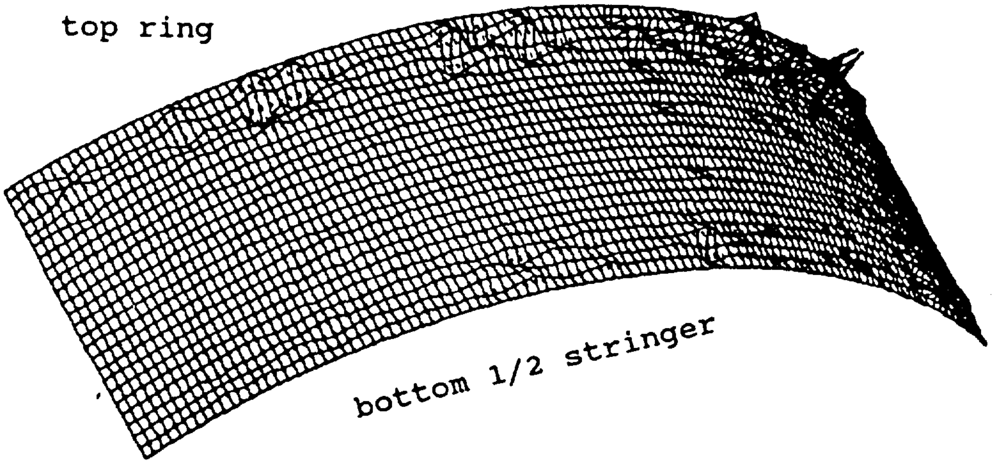


UPPER QUARTER OF TANK

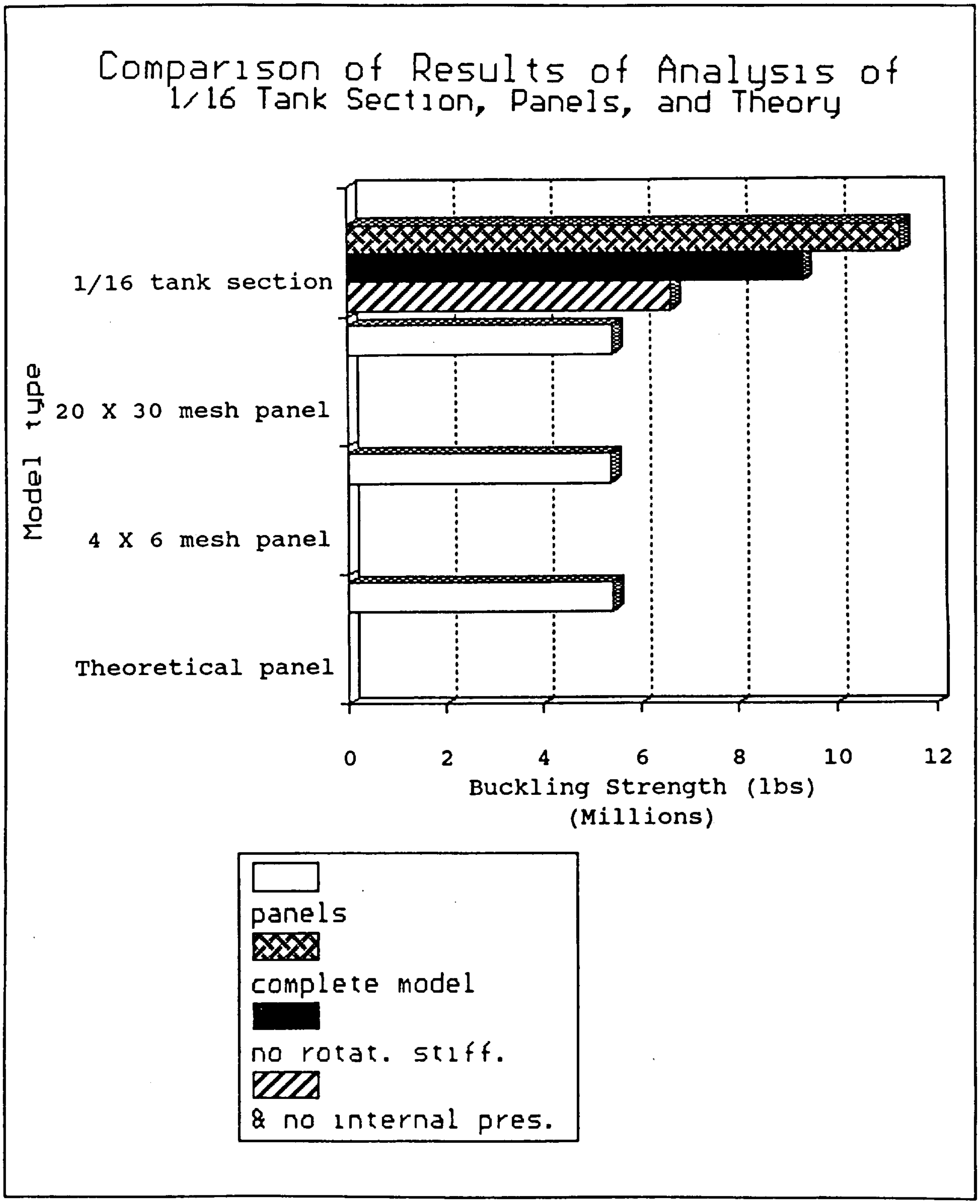




overall buckling mode



panel buckling mode


Comparison of Results of Analysis of
1/16 Tank Section, Panels, and Theory
Model type
1/16 tank section
20 X 30 mesh panel
4 X 6 mesh panel
Theoretical panel
0
2
4
6
8
10
12
Buckling Strength (lbs)
(Millions)
panels
complete model
no rotat. stiff.
& no internal pres.

MacNeal and Harder

4 Characteristics

- Element Geometry
  Taper, Skew, Aspect Ratio, Warp
- Problem Geometry
  Single and Double Curvature,
  Slenderness Ratio
- Material Properties
- Loading and Constraints
  Deform Elements in all posible
  directions

Ansys Element Test Results

Element	Percent Error Plane Stress (.0012864)	 Plane Strain (.00183645)
Stif63	5.1	
Stif93	0.02	
Stif42	13.3	5.5
Stif82	7.8	0.08
Stif45		5.2

The percent error calculated by comparing the displacement at the inner radius of the disk.