A DESIGN TEMPLATE FOR GAS SATELLITE PAYLOADS

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The Naval Postgraduate School has designed a small, low cost, general purpose satellite bus, ORION. An investigation of the structural requirements has been done for ORION as an extended Get Away Special (GAS) canister payload. The structure must be able to withstand the design limit load of 6.0 g's acceleration in ± X and ± Y, and a limit load of 10.0 g's in the ± Z. The structure must also have modal vibration greater than 35 Hz. A finite element analysis in linear bending considers an aluminum stiffened cylinder with two equipment plates and a top plate. Considerable weight reduction from the original design results. The structure configured for ORION may be helpful to other GAS payload users as a design template for similar satellites.

INTRODUCTION

The Naval Postgraduate School (NPS) has designed ORION--a small, general purpose satellite bus in an effort to provide hands-on experience of engineering principles to NPS students. The satellite weighs approximately 270 lbs, has a diameter of 19 inches and height 35 inches. ORION is an autonomous satellite bus capable of 800 nm circular orbit up to 2200 nm elliptical orbits from an initial shuttle altitude of 135 nm. ORION has its own attitude control, station keeping, telemetry, data storage, processor and power supply for a payload up to 50 lbs.[1]

ORION will afford the opportunity of space based research to a larger number of researchers and with greater flexibility than is available by present means. This can be done at a cost on the order of 1.5 million dollars. Payloads of 2 cubic feet and 50 pounds can receive 15 watts of continuous power to support experiments. Discrimination of orbit parameters is also available to experimenters by means of ORION's propulsion subsystem. Presently, small experiments must adopt the orbital requirements of larger payloads while flying as secondary payloads. Launch capabilities for ORION range from the Shuttle extended GAS canister to expendable launch vehicles. Structural requirements of ORION as an extended GAS canister payload are studied here.

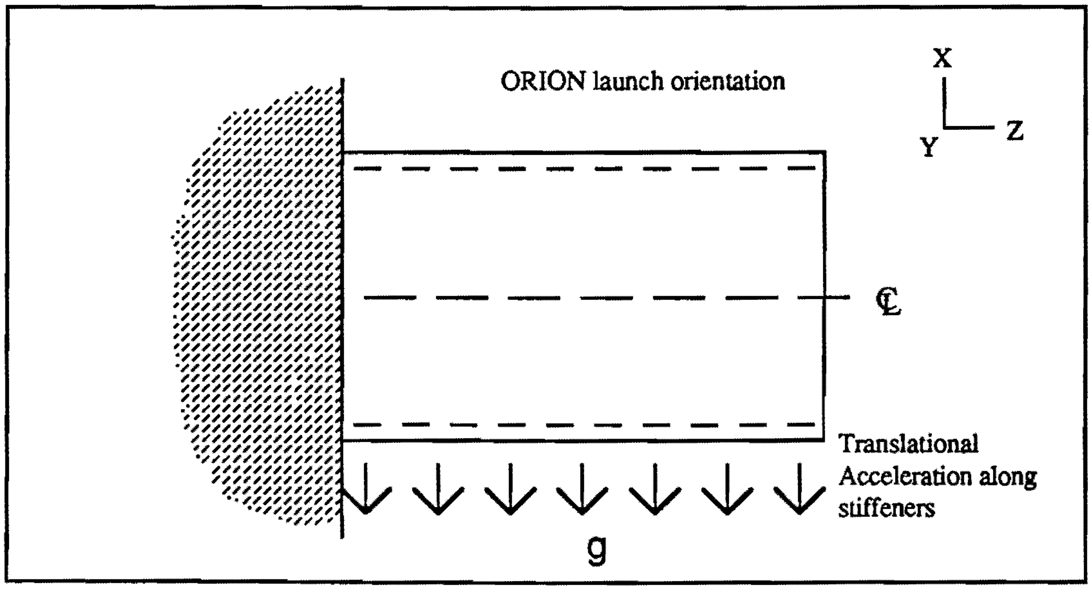

Fig. 1 Launch Orientation

Table 1
SAMPLE OF PROPOSED LAUNCH VEHICLES

Vehicle Name	Company	Nos. of ORIONS	Altitude	
		(350 lbs)	Equatorial (KSC)	Polar (VAFB)
Super Starbird				
(Castor 4A)	SDC	1	360 nm	125 nm
(Algol 3A)	SDC	1	470 nm	220 nm
SDC Scout (Star 20)	SDC	1	620 nm	340 nm
C-3A (Star 20)	SDC	1	630 nm	350 nm
(Star 20)		1 (2)	300 nm	960 nm
Pioneer (31)	SDC	1	740 nm	470 nm
LEO	ECR	1	800+ nm	460+ nm
		2	280+ nm	--
Liberty 1	PAL	1	750 nm	155+ nm

SDC = Space Data Corporation, (602) 966-1440
ECR = Eagle Canyon Research, (916) 644-1171
PAL = Pacific American Launch Systems, (415) 595-6500

LOAD REQUIREMENTS

Table 2 shows the load vectors for use in analysis if testing will be done for verification, as will be the case for ORION. The load vectors for analysis only use higher factors of safety, namely 1.5 for Yield F.S. and 2.0 for Ultimate F.S. This is taken from the "Get

Table 2
LOAD VECTORS FOR ANALYSIS VERIFIED BY TEST
Yield F.S. = 1.25
Ultimate F.S. = 1.5

Dir.	Limit Load (g's)	Yield Load (g's)	Ultimate Load (g's)
±X	6.0	7.5	9.0
±Y	6.0	7.5	9.0
±Z	10.0	12.5	15.0

Away Special Payloads Safety Manual." This study considers only the limit loads within the linear regime. Analysis using ultimate strength of materials requires non-linear methods. Adhering to linearity in bending ensures a more conservative design.

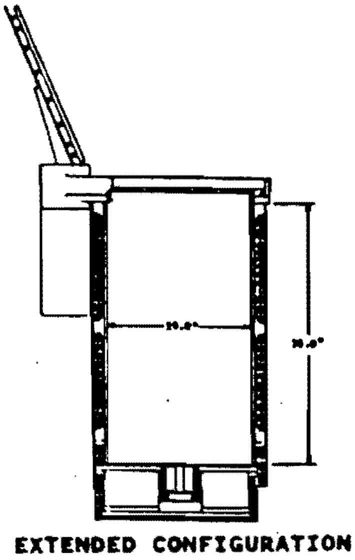

Fig. 2 Extended GAS canister

MODEL CONFIGURATIONS

Different configurations were analyzed for static loading. The material used in this analysis is aluminum 6061-T6. Models consisted of structures with four, three and two stiffeners. The stiffener cross-sections were taken from stock list. It was found that two stiffeners are all that is needed to ensure structural integrity for loads of 12 g's in the transverse axis. Skin thickness was 0.0625 in. thick with a radius of 9.4375 in. This gives 1/16 in. allowance for the solar panels. Plate thickness varied from 0.100 in. thick to 0.25 in. thick. A thickness of 0.125 in. was found to be adequate to support ORION component masses. Three plates were used for this analysis located at 6.875 in., 22.375 in. and 35 in. from the bottom. The lower plate has a 6.0 in. radius hole to accommodate a hydrazine fuel tank.

Addition of ORION component masses was done by means of adding mass points to the computer model or by distributed masses on model grids. Table 3 shows the component masses added with g as 386.4 in/sec2.

Table 3

ORION COMPONENT MASS PLACEMENT

Component Masses		
Component	Mass, slugs (lbm)	Location (description)
Propellant tank & Propellant	2.177e-01 (84.12)	Distributed on points at height 12.0" on skin (9.0708e-03 slugs per point; 24 points)
Sun Sensor	7.410e-04 (0.286)	Single point at (0.17.1875,9.4375)
Telemetry Antenna	6.280e-04 (0.243)	Single point at (0, 35,0)
Spin Thruster (4)	1.880e-03 (0.728)	Four points: (± 9.3844.17.1875,± 1.0)
Precession Motor (2)	1.880e-03 (0.728)	Points: (- 8.4375,3.4375,1.0); (8.4375,3.4375,-1.0)
Pressurant Tank	2.280e-03 (0.881)	Points: (± 2.863,6.875,7.263) (± 3.379,6.875,-8.812)
GaAs Solar Cell Array, Cover Glass, Substrate Adhesive, Thermal Blankets, Thermal Sensors	1.642e-02 (6.344)	Distributed mass on the satellite skin with mass value = 8.4812e-06 slugs/in.^{2}
Main Computer, Data Storage Unit, Status Sensors, Solar Shunt Regulator, Power Supply, Battery Packs (2), Valves and Pipe & Fittings	9.827e-02 (37.97)	Mass Distributed on Equipment Plate at height 22.375 in. with mass value of 3.5629e-04 slugs/ in.^{2} on each grid of the plate.
Payload and Payload Components	6.866e-02 (26.53)	Distributed on the top plate with mass value = 2.4895 slugs/in.^{2}

RESULTS

Table 3 shows the results of static analysis for the elements with largest deflections for the prescribed load. Although a load of 5 g's was used in Y as opposed to 6.0, the deflections are small enough that this is of little concern. A doubling of the load will result in doubling of the deflections since the structure is undergoing linear bending. Therefore, an increase in load to 6.0 g's would mean a factor of 1.2 increase in deflections. The stresses resulting would be quite small as well since the Von Mises failure criterion is 2.63 % at 5.0 g's. For those loads in Z where the deflections are considerable, (bending of the plates), stiffeners can be added to the plates for more rigidity. The deflections analyzed for a 0.125 in. thick plate with a single angle stiffener (1.0 in. X 1.0 in. X 0.125 in.) attached along the center line decreased by 81 %. The addition of stiffeners to the equipment plates would also have the desirable effect of increasing the modal vibrations.

Table 4
RESULTS FOR STATIC ANALYSIS

	Component Masses added			Structure Alone		
Loading	10 g's in X	10 g's in Z	5 g's in Y	10 g's in X	10 g's in Z	10 g's in Y
Max. Deflection (in.)	-0.009853	-0.160	-0.005546	-0.001421	-0.01461	-0.0008203
Von Mises Failure Criteria	5.66%	21.38%	2.63%	0.65%	1.87%	0.38%

VIBRATIONS

The first two modal frequencies from the vibrations analysis do not give favorable results. This is due mainly to the addition of the component masses. The addition of the component masses, although decreasing the modal frequency, would in reality also add some stiffness to the structure. As an example, the computer and data recorder would essentially be an aluminum box attached to an equipment plate, (as opposed to 'mathematical' mass added to the computer generated model). Looking at the modal shapes, it is evident that the plates cause the lowering of the modal frequencies. Again, stiffness can be added to the plates by means of stiffeners. Testing of the actual structure will disclose the magnitude of this problem.

Table 5
MODAL VIBRATION FREQUENCIES

Mode	Component Masses Added Frequency (cycles per second)	Structure Alone Frequency (cycles per second)
Mode # 1	3.101E+01	1.026E+02
Mode # 2	3.388E+01	1.084E+02
Mode # 3	6.259E+01	2.077E+02

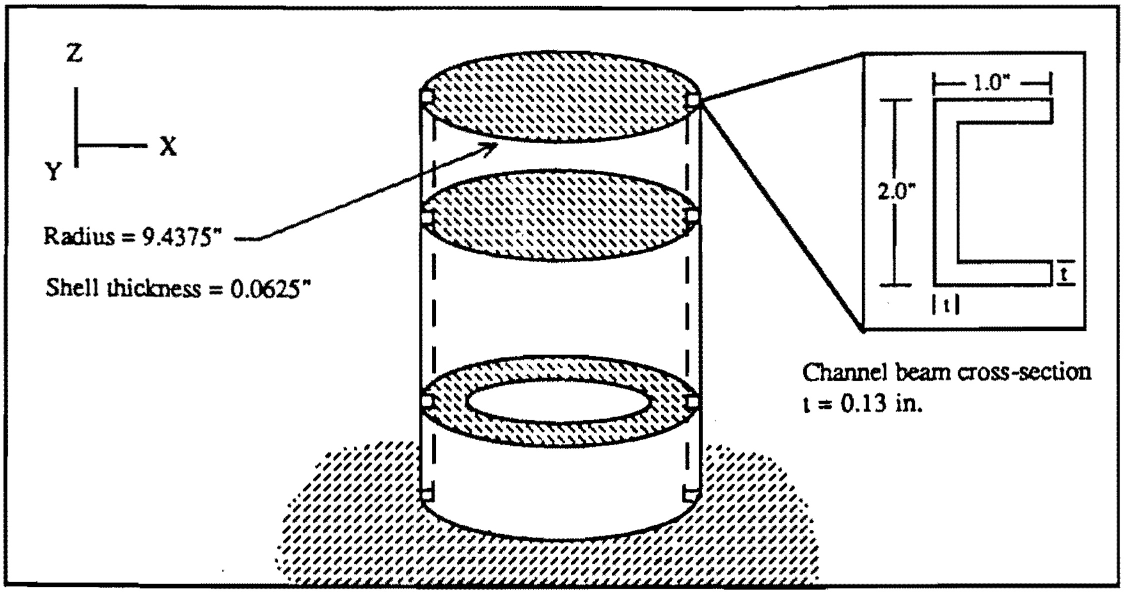

Fig. 3 ORION Configuration

CONLUSION

The ORION structure has reached a milestone of an initial configuration by analysis. The results of a finite element analysis show that the structure will withstand the static load limits prescribed for a GAS payload. Testing will be needed to verify the results and acquire actual modal frequencies. Although specific to ORION, the structural configuration reached could be used for similar small satellites whether launched from an extended GAS canister or expendable launch vehicles.

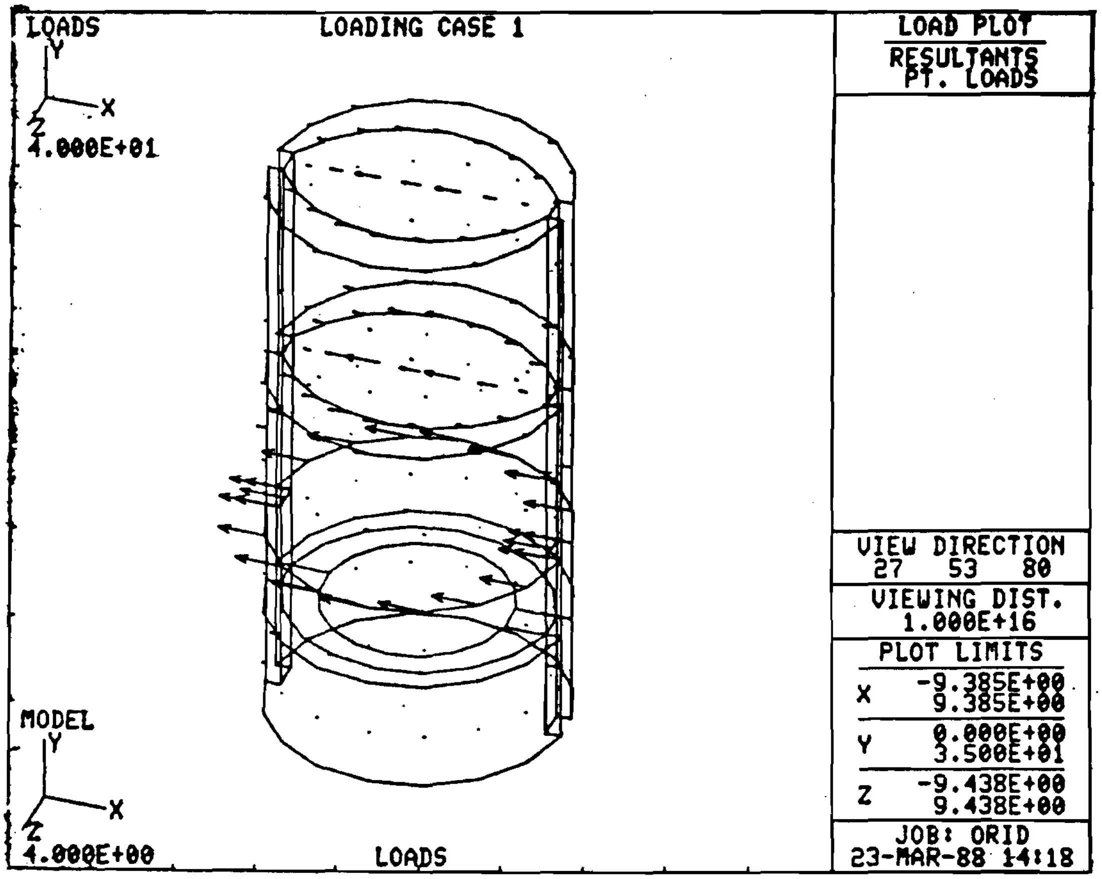

Fig. 4 Loading in the Stiffener Plane

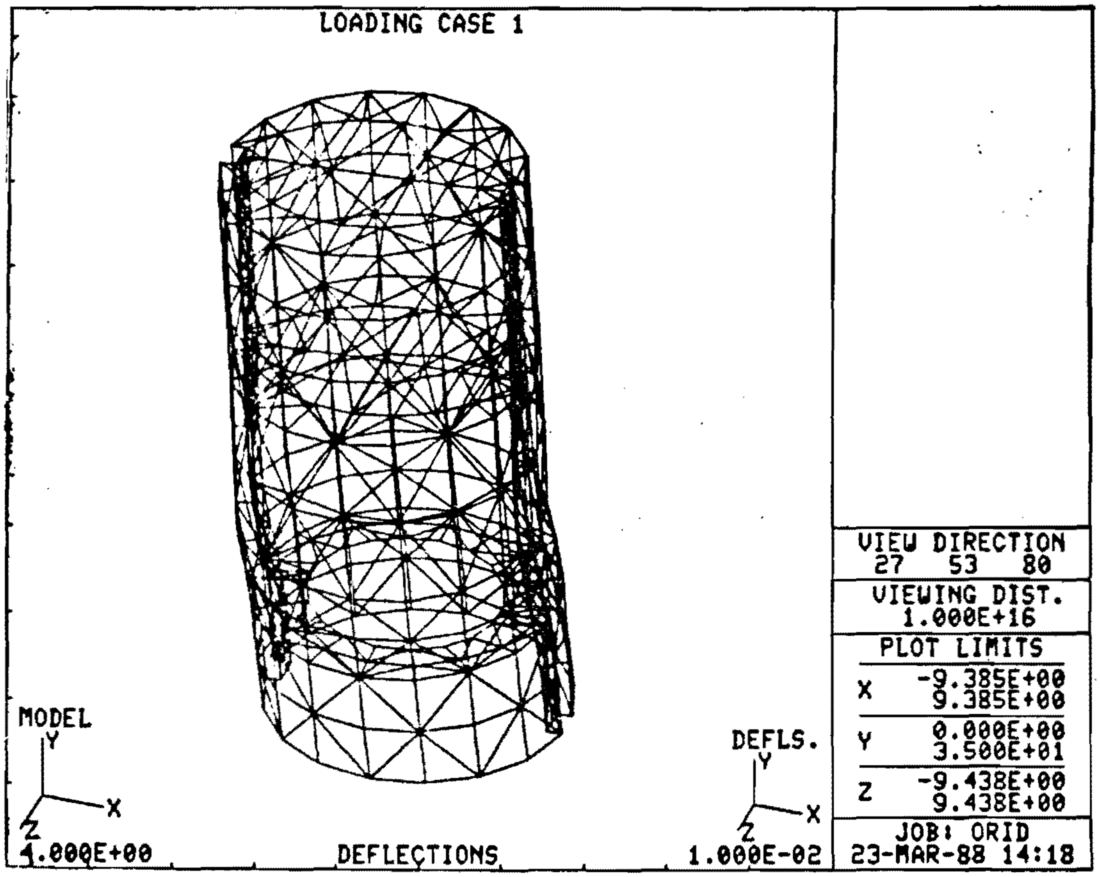

Fig. 5 Deflections for Loading in Stiffener Plane

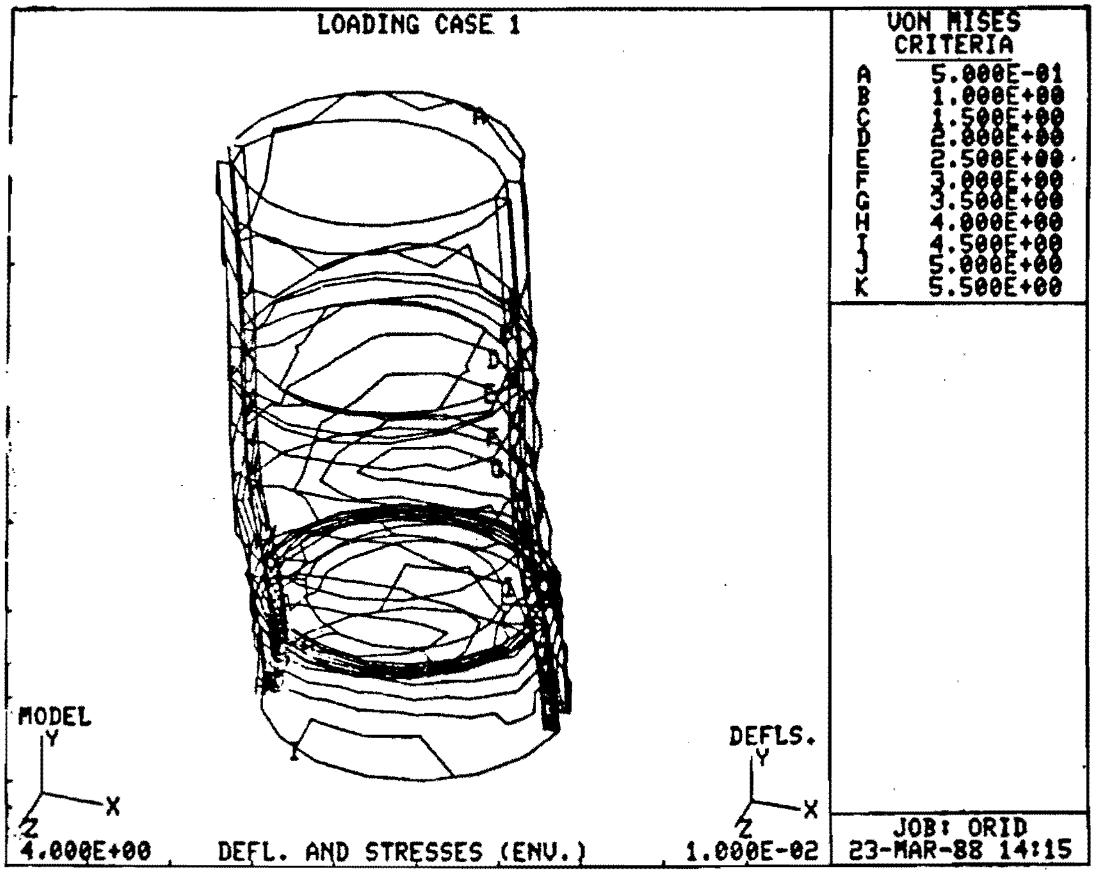

Fig. 6 Stress Contours for Loading in Stiffener Plane

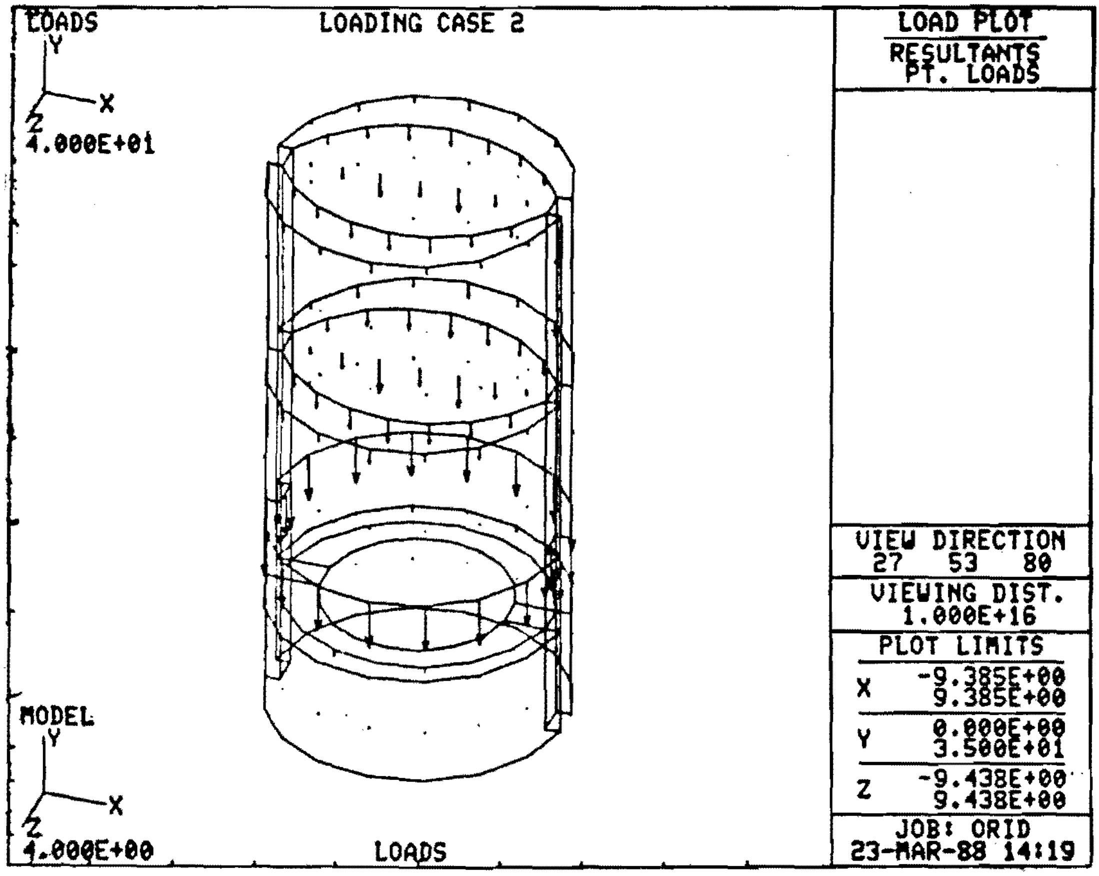

Fig 7 Loading along Longitudinal

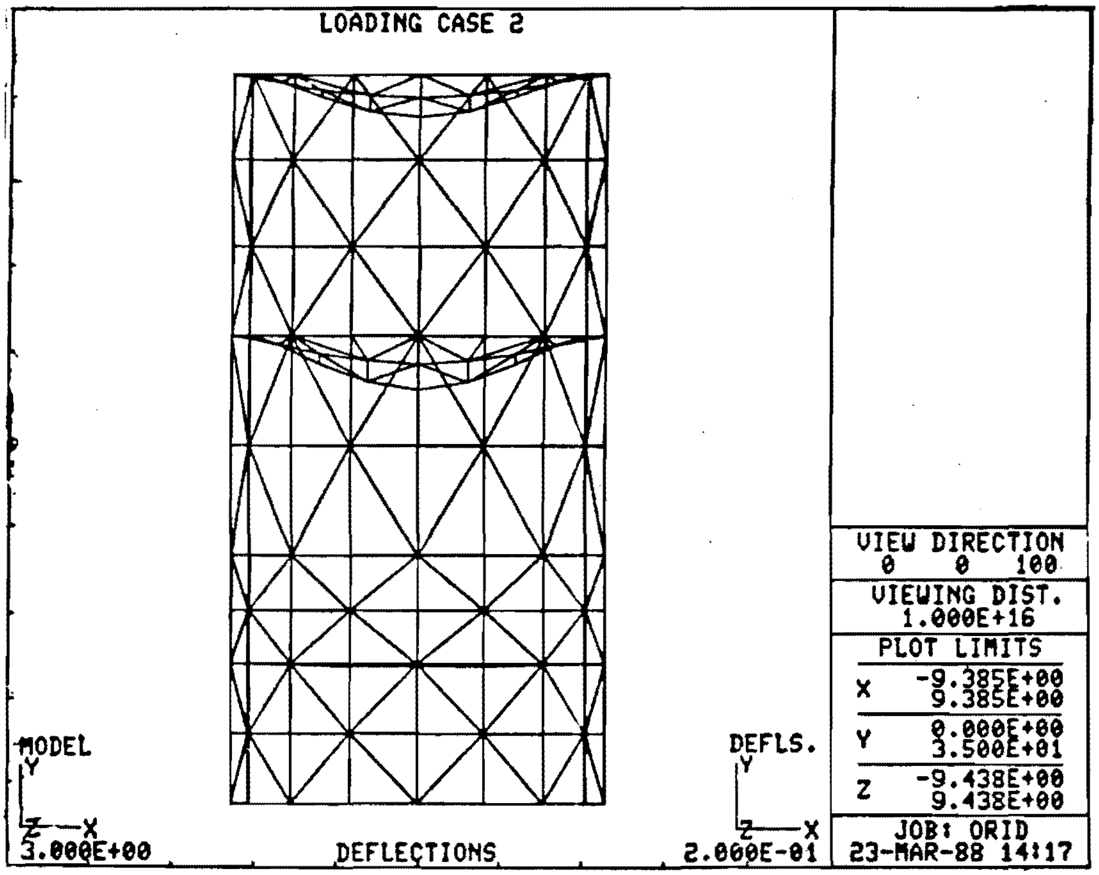

Fig. 8 Deflections for Loading along Longitudinal

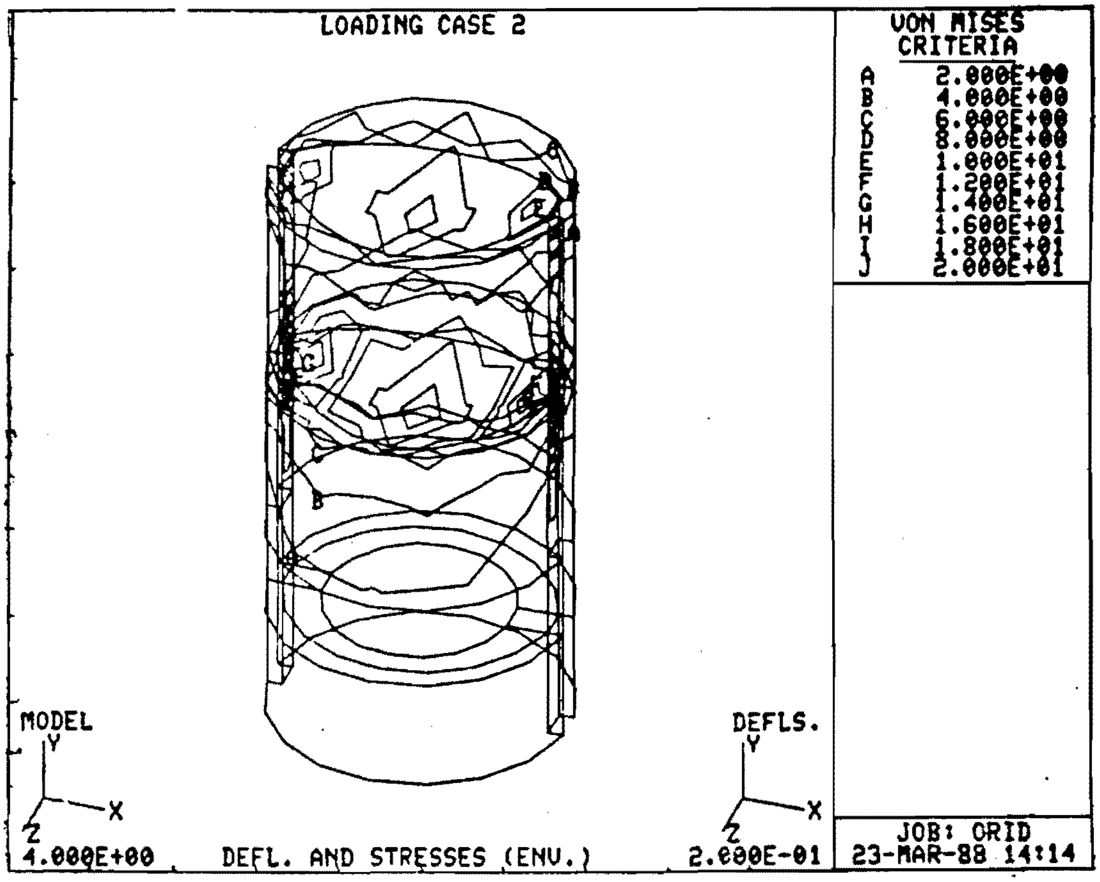

Fig. 9 Stress Contours for Loading along Longitudinal

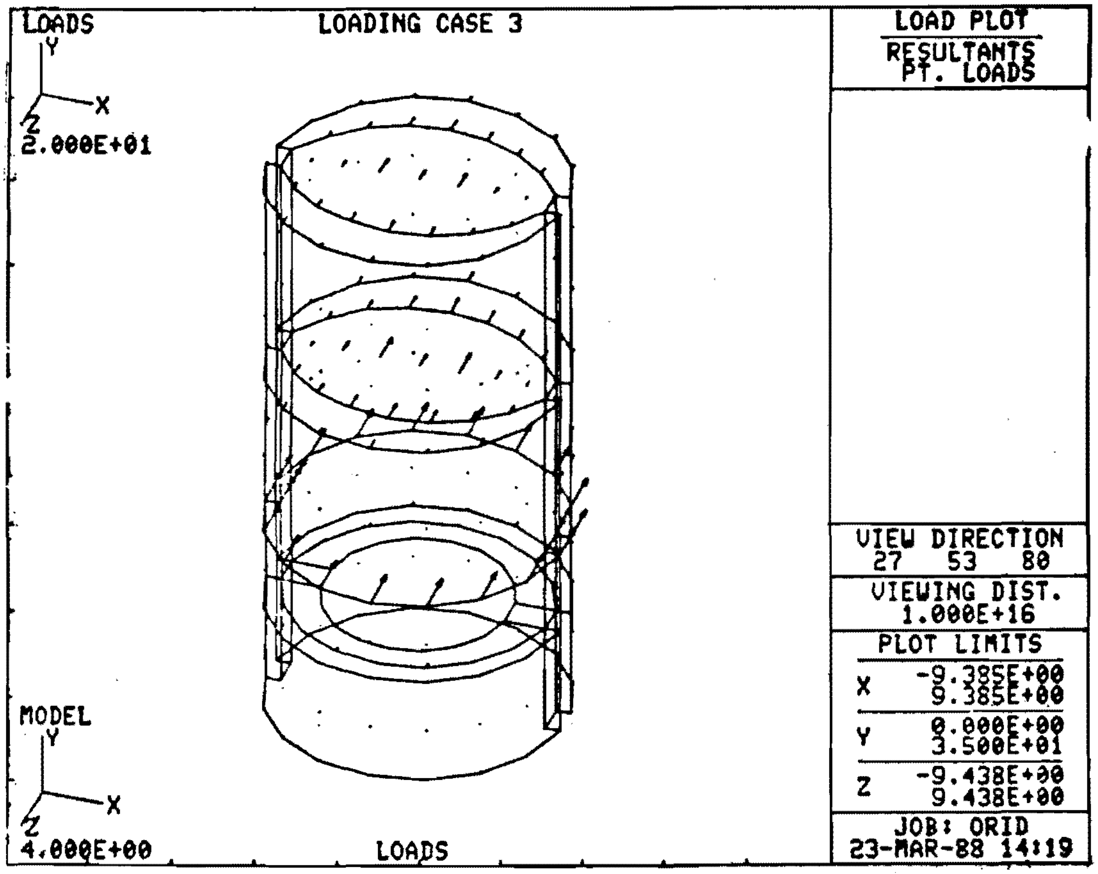

Fig 10 Loading in Transverse

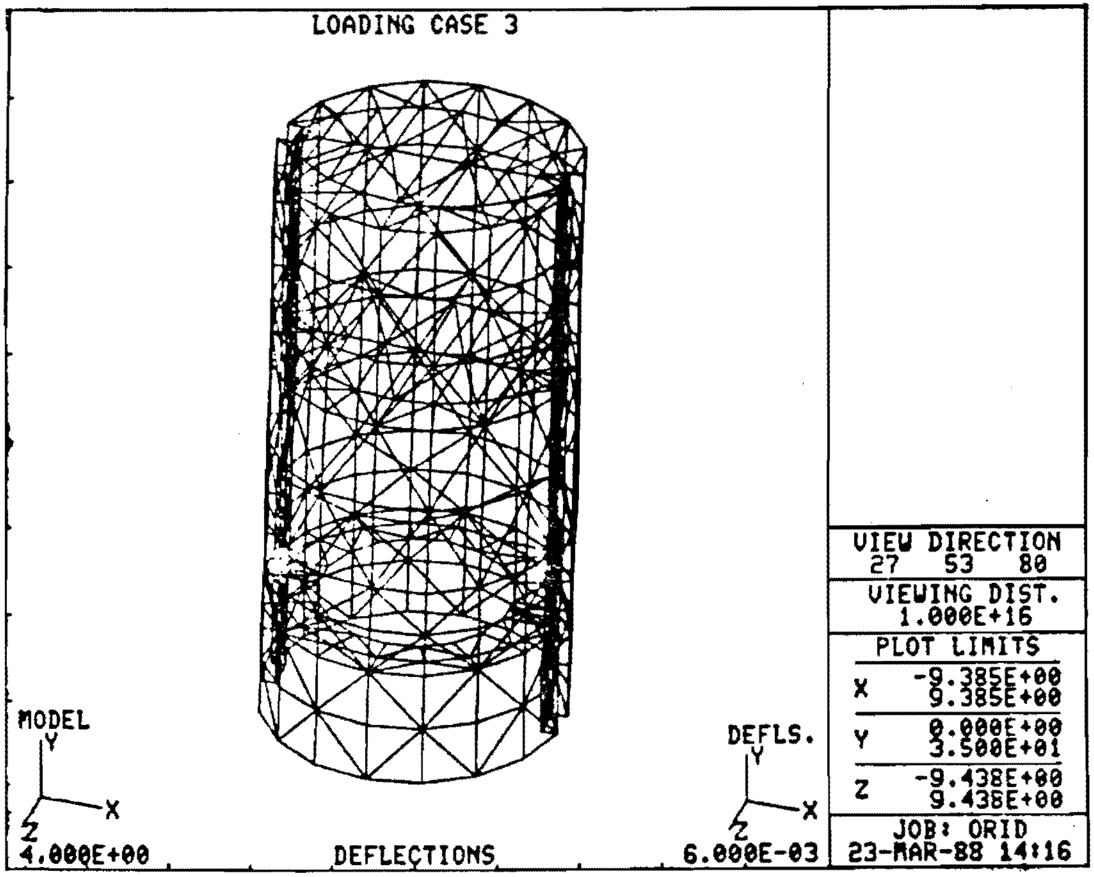

Fig. 11 Deflections for Transverse Loads

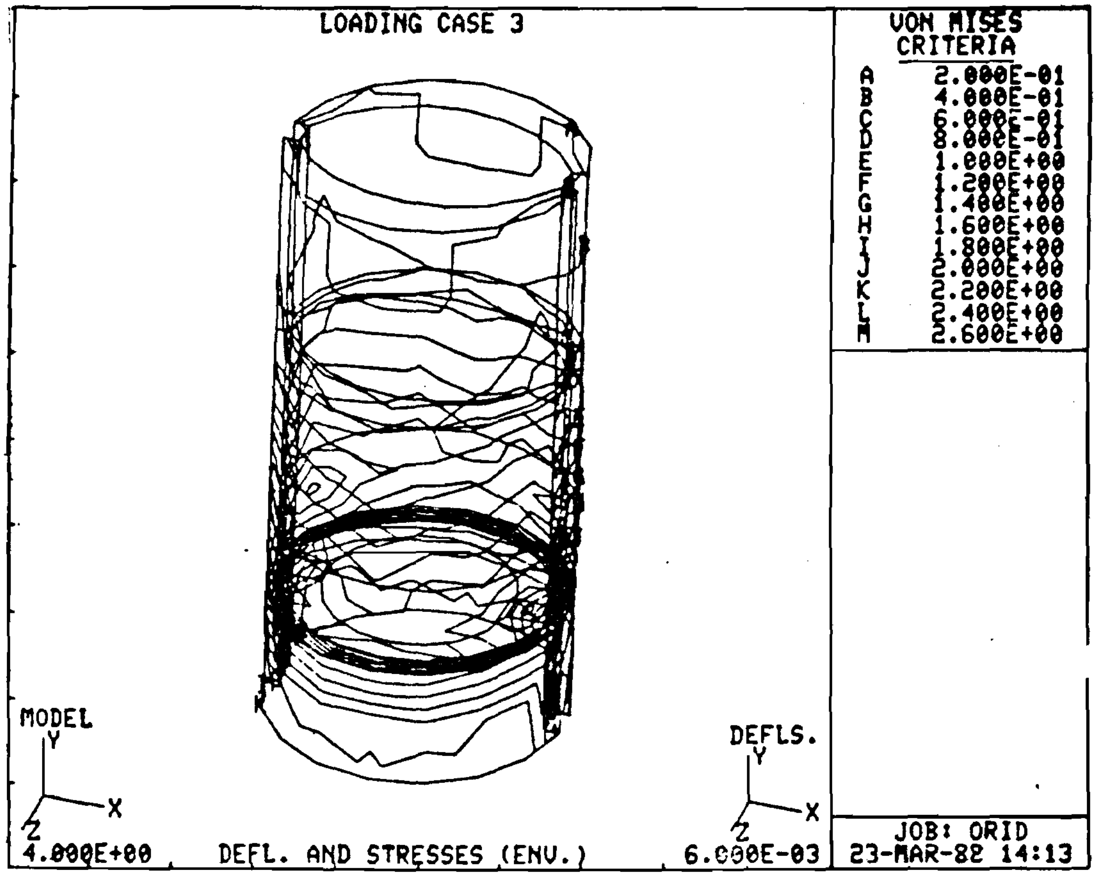

Fig. 12 Stress Contours for Transverse Loads

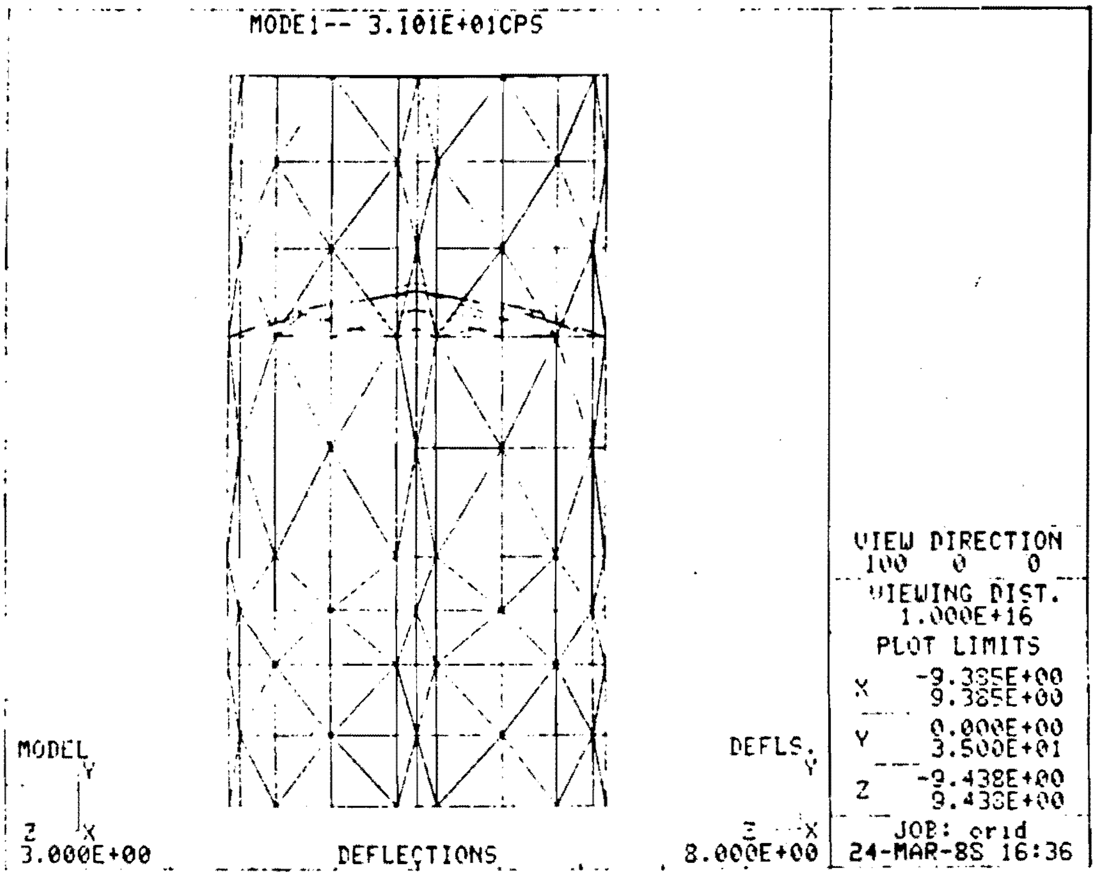

Fig. 13 First Modal Frequency of ORION

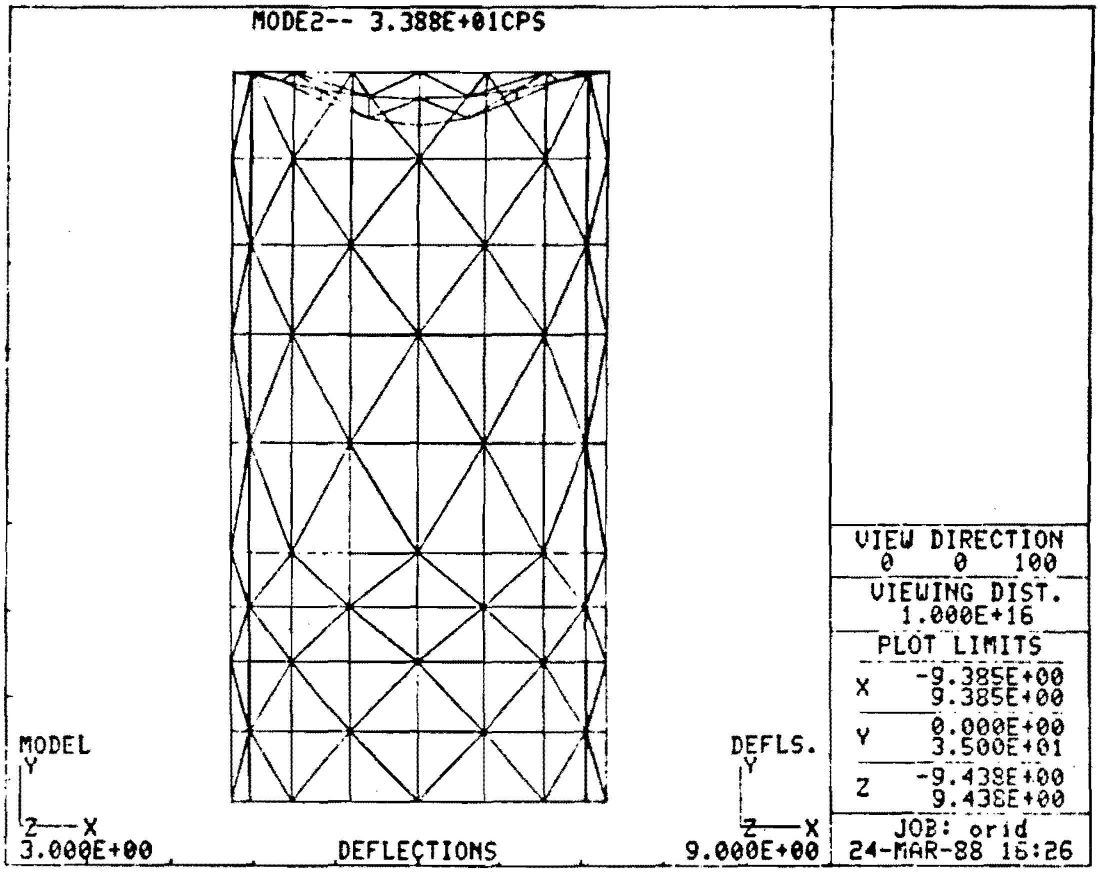

Fig. 14 Second Modal Frequency

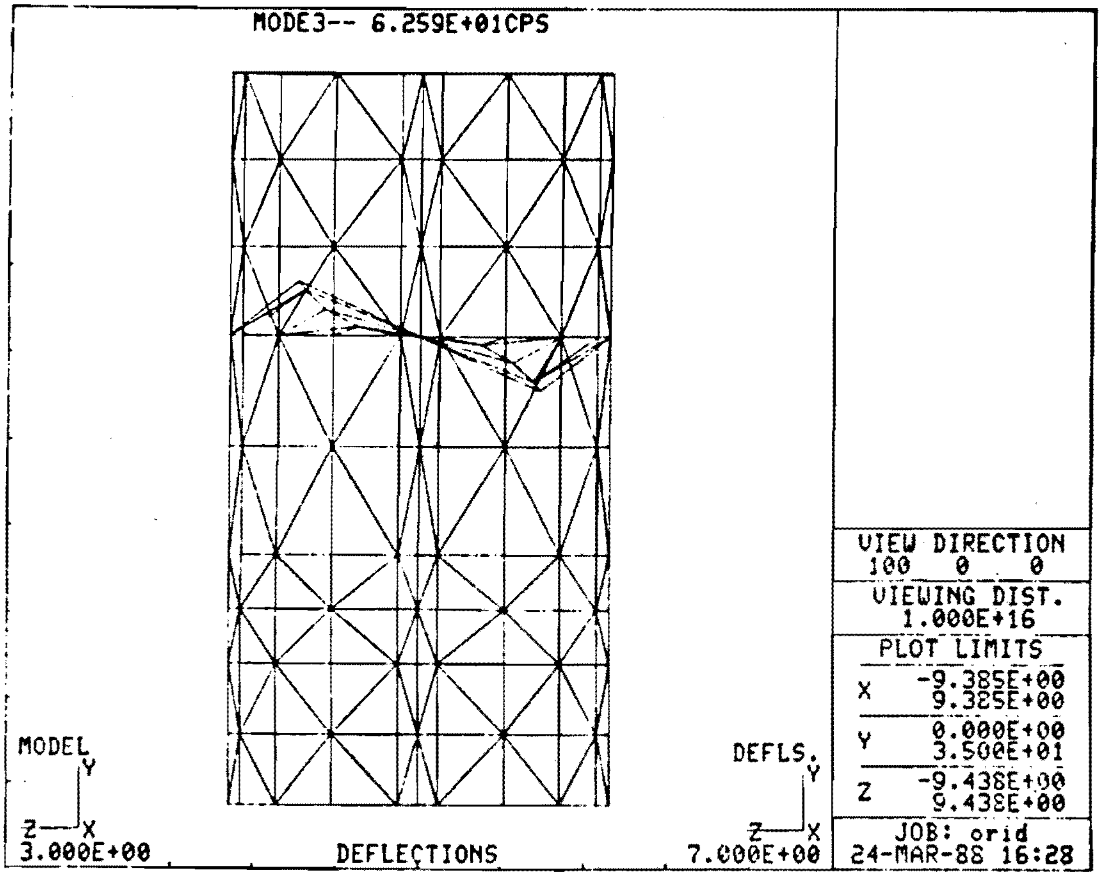

Fig. 15 Third Modal Frequency

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