Effective Mass of Fluid in Tank Vibration Testing

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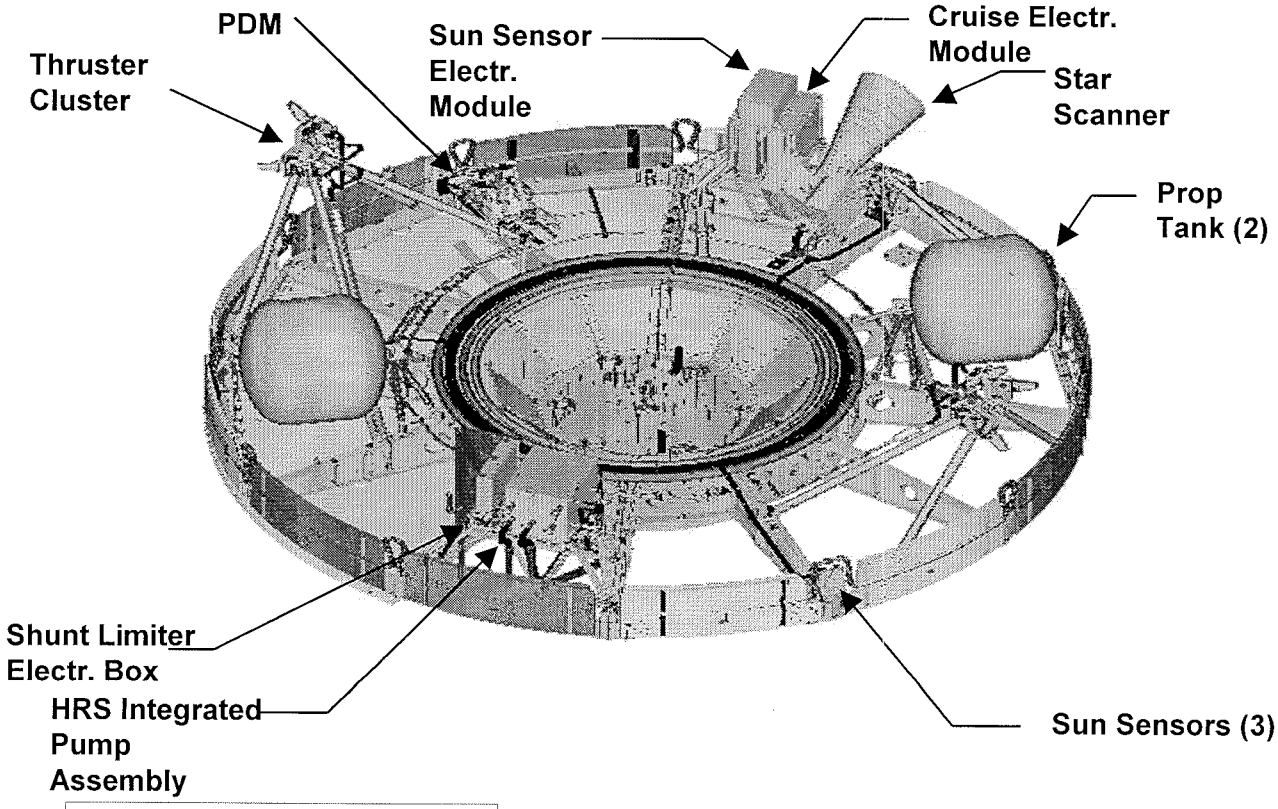
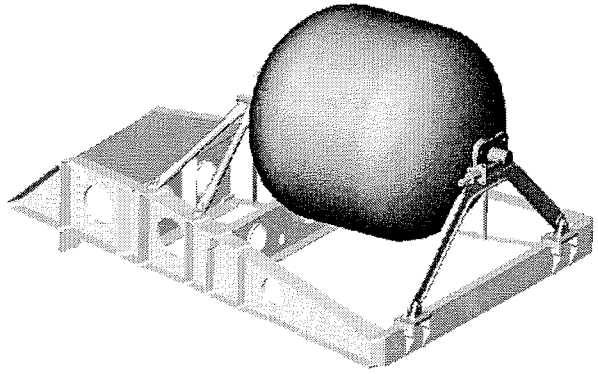
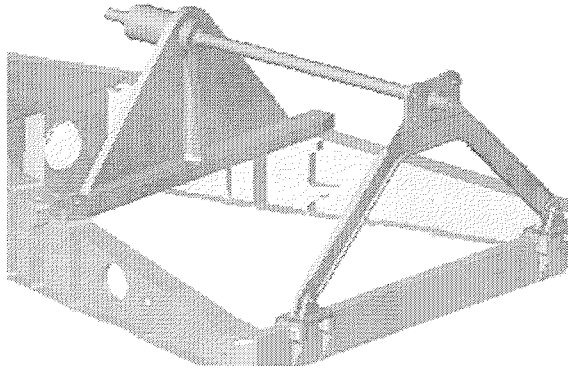
Background

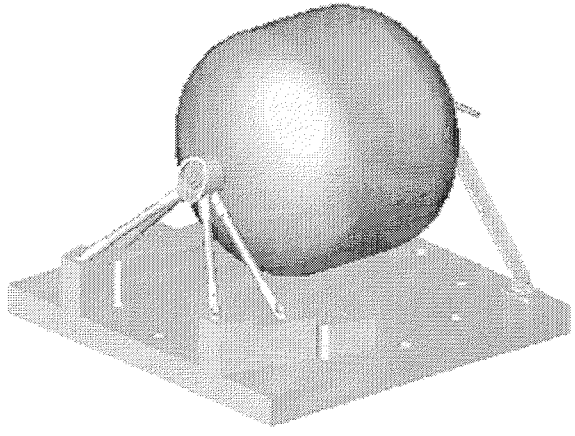
- Ultralight composite propellant tanks proposed for the Mars Exploration Rover (MER) Spacecraft
  - 16 in. dia. near sphere configuration
  - 5 mil Al liner with a composite overwrap, boss mounting, & internal propellant management device (PMD)
- Tank structural analysis w/flight mounts showed minimal design margin
- Vibration tests conducted on a 14 in. dia. unpressurized composite development tank with primary objective to evaluate effective mass of the fluid under vibration

Cruise Stage Layout



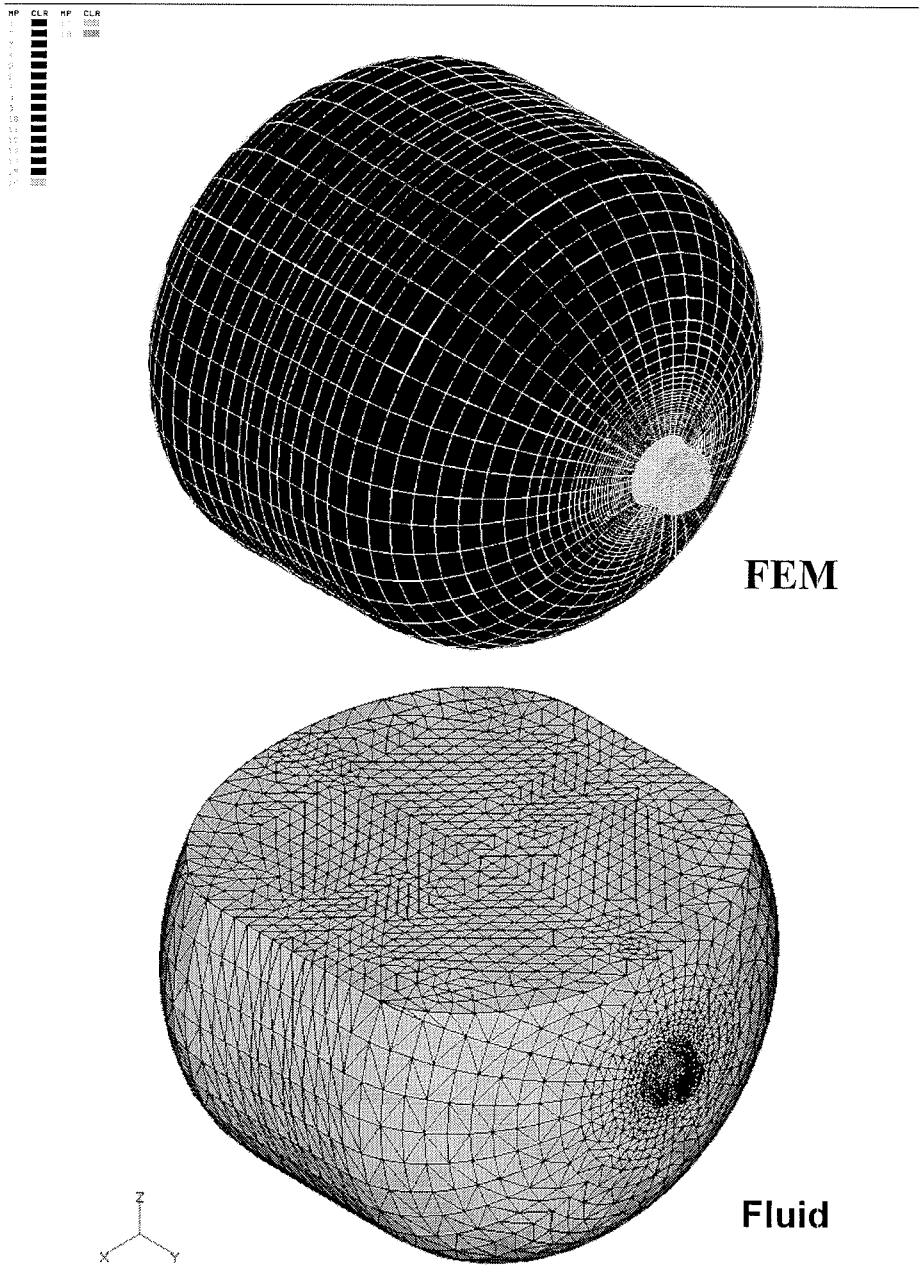


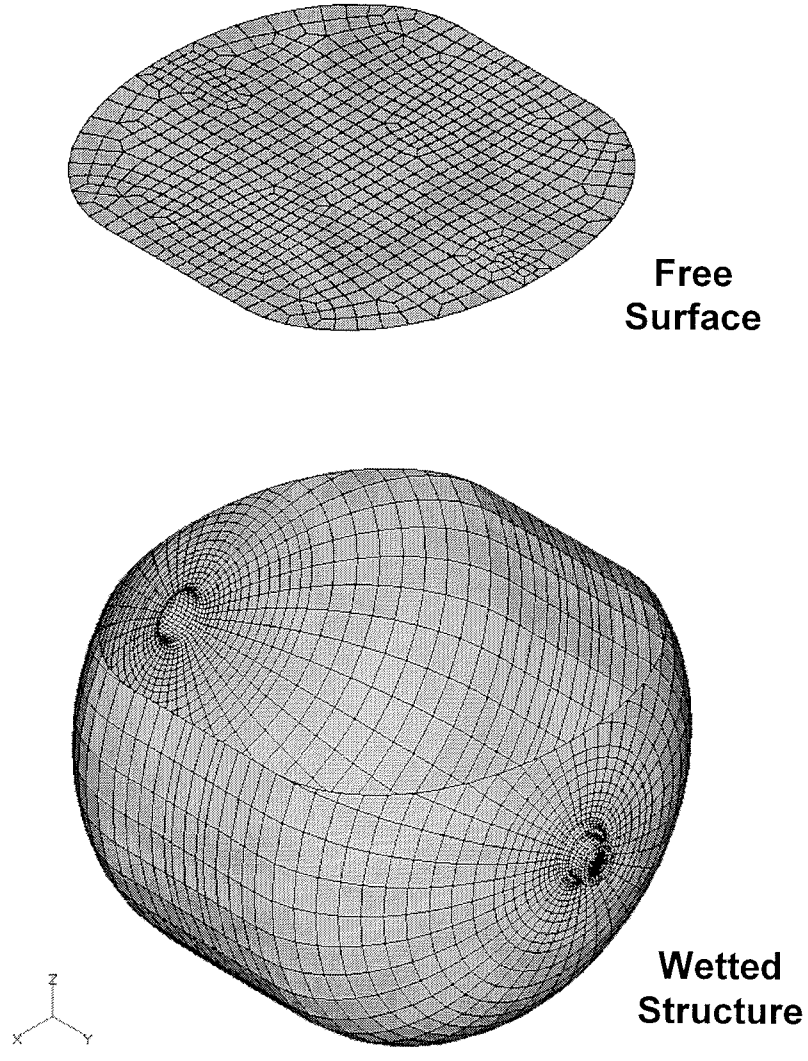




FEM

(QUARTUS ENGINEERING/CARLETON)





FREQUENCIES AND EFFECTIVE MASS
(Tank Installed on Flight Mounts)
(QUARTUS ENGINEERING/CARLETON)

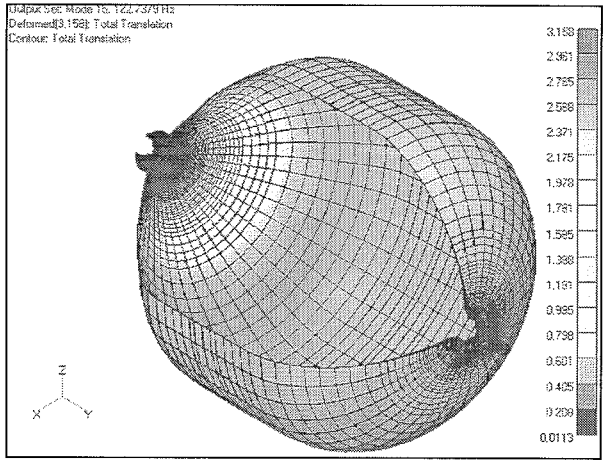
Mode No.	Frequency (Hz)	Effective Mass (%)						Mode Shape Description
		TX	TY	TZ	RX	RY	RZ	
1	1.55	0.0	33.1	0.0	0.0	0.0	0.0	1st Longitudinal Slosh
2	1.59	32.1	0.0	0.0	0.0	0.0	30.9	1st Lateral Slosh
3	2.01	0.0	0.0	0.0	0.0	0.0	0.0	
4	2.12	0.0	0.0	0.0	0.0	0.0	0.0	
5	2.26	0.0	0.0	0.0	0.0	0.0	0.0	1st Vertical Slosh (sym-sym)
6	2.43	0.0	0.0	0.0	0.0	0.0	0.0	
7	2.46	0.0	0.0	0.0	0.0	0.0	0.0	
8	2.67	0.0	1.7	0.0	0.0	0.0	0.0	2nd Longitudinal Slosh
9	2.73	1.9	0.0	0.0	0.0	0.0	1.8	2nd Lateral Slosh
10	3.47	0.0	0.5	0.0	0.0	0.0	0.0	3rd Longitudinal Slosh
11	3.59	0.5	0.0	0.0	0.0	0.0	0.5	3rd Lateral Slosh
12	113.84	0.0	60.8	0.0	0.0	0.0	0.0	1st Longitudinal Bending
13	166.92	0.0	0.0	97.0	97.0	0.0	0.0	1st Vertical Bending
14	197.10	60.6	0.0	0.0	0.0	0.0	61.6	1st Lateral Bending
Total		95.1	96.1	97.0	97.1	0.0	94.8	

Rotational effective mass WRT origin of global (basic) coordinate system

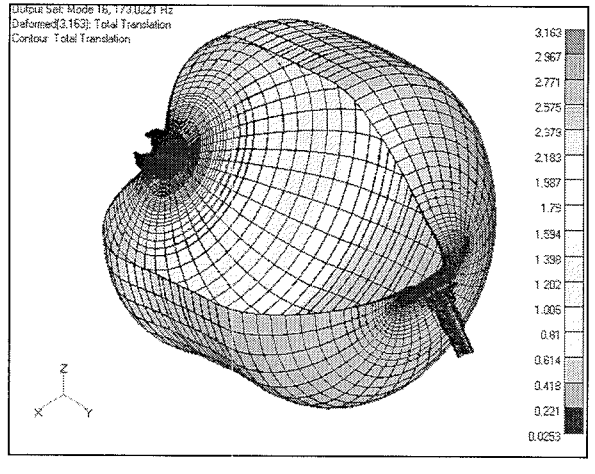
ULTRALIGHT COMPOSITE TANK

- Tank 2.2 Kg + Propellant 25 to 35 Kg
- Fuel Slosh (Lateral) Frequency = 1.59 Hz
- Tank Natural Frequencies:

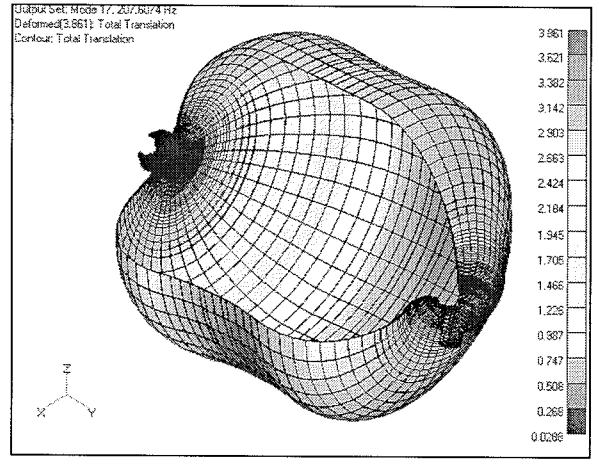
1st Longitudinal - 127.7 Hz - 60.8% Y



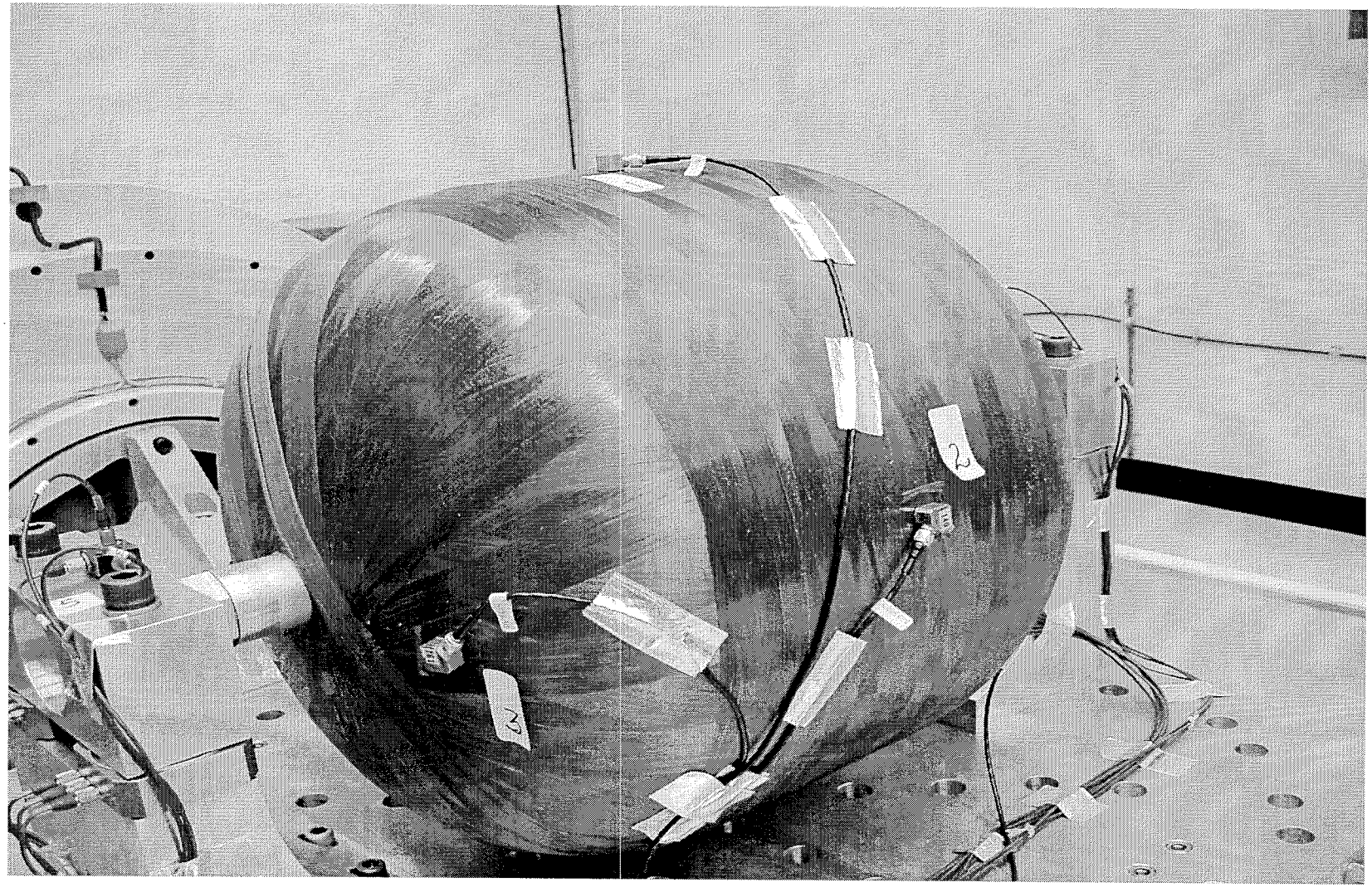
1st Vertical - 173.0 Hz - 97.0% Z



1st Lateral - 197.1 Hz - 60.6% X



TEST SET-UP



JPL B144 Test Lab

Sine Spectrum

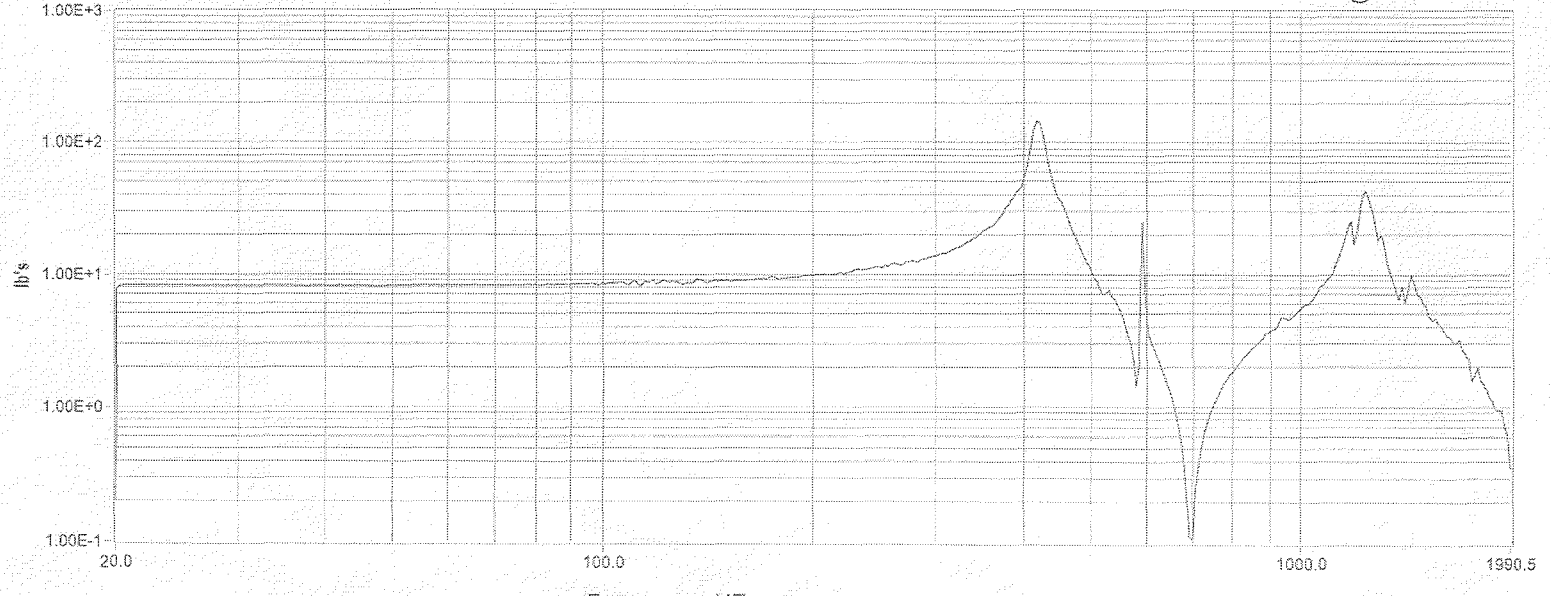
Test Date/Time: 1-Mar-2002 14:35:26

Test Title: Mars Exploration Rover
Specimen Name: 14" Porpellant Tank
Test File Number: Run
Part Number/ID: EM
Channel #: 14 Node Number: 0014
Channel Description: na

Test Description
Y-Axis 1/2g Pre-Sine Survey

Log Analysis Sweep dF= 0.01 x Frequency, Proportional Bandwidth dF= 20.00% of Freq

Max = 146.2356 lb's @ 417.36 Hz



Analysis Date/Time: 01-Mar-2002 14:46:29

Force; Y

FREQUENCY OF THE TANK

- Frequency

- dry tank	417.36 Hz.
- 43.0 # propellant	218.00 Hz. Y axis
- 51.6 # propellant	195.00 Hz. Y axis
	197.88 Hz. X axis
	149.77 Hz. Z axis

FLUID EFFECTIVE MASS

- Fluid Effective mass
  - 51.6 # propellant
    - 26.0 # in X &Y axis (lateral)
      - 50 % of Fluid
    - 51.6 # in Z axis (vertical)
      - 100 % of Fluid
  - _ 43.0 # propellant
    - 20.0 # in X & Y axis (lateral)
      - 47 % of Fluid

Summary

- Effective mass of fluid in axes perpendicular to the gravitational force is about 1/2 of actual mass.
  - Independent of acceleration level up to at least 10 g's
  - Small dependence on volume of fluid (two measurements)
  - Differences in tank fundamental frequencies are fairly consistent with measured fluid effective mass
  - Effects of different tank sizes and configurations unknown
- Effective mass of fluid in axis parallel to the gravitational force is the same as the actual mass.