SWALES AEROSPACE

FEMCI Workshop

at GSFC

18 May2000

Nonlinear FEA in the Design of a High Precision Opto-mechanical Instrument

by

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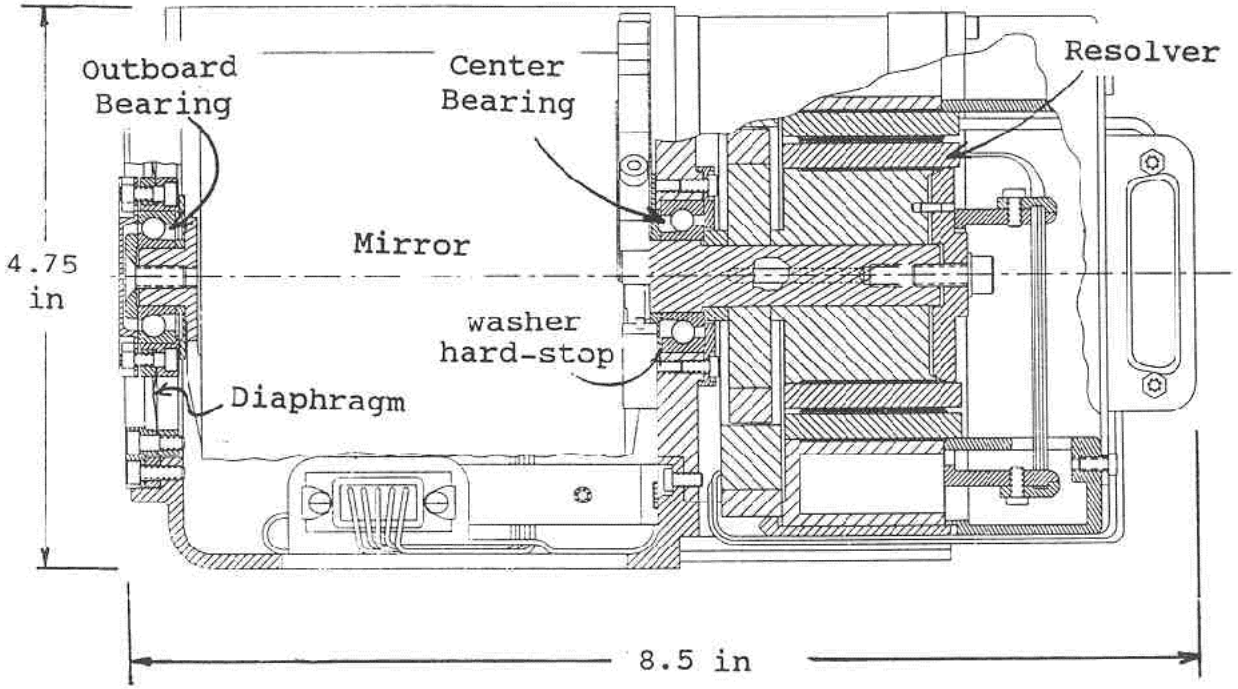
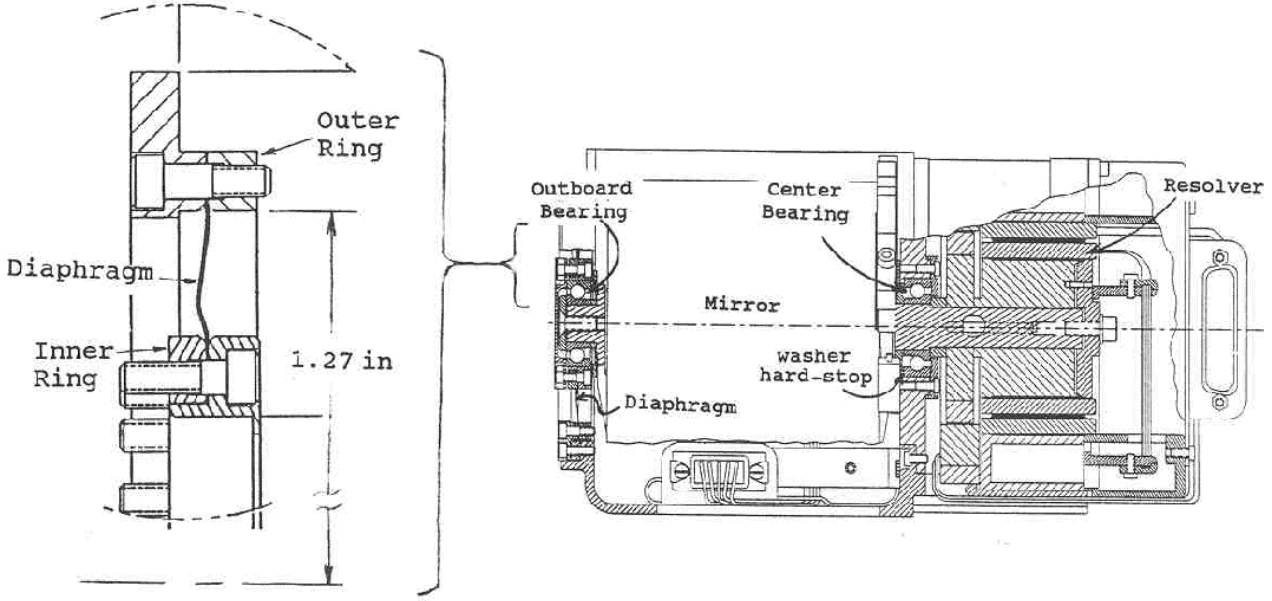
OVERVIEW AND DESCRIPTION

- DESIGN AND ANALYSIS RELATED TO SCAN MIRROR ASSEMBLY (SMA) OF THE “SPECIAL SENSOR ULTRAVIOLET LIMB IMAGER” (SSULI) INSTRUMENT
- WILL FLY ON AN EARTH ORBITING SPACECRAFT TO MEASURE THE DENSITY OF AIR AT ALTITUDES FROM 48KM TO 750KM
- SMA USED TO SWEEP THE FIELD OF VIEW OF A DETECTOR BY ROTATING A SILICON CARBIDE MIRROR, DESIGN LIFE = 3 YEARS



DESIGN ISSUES / DIFFICULTIES

- ANNULAR DIAPHRAGM USED TO APPLY AND MAINTAIN A “LIGHT” AXIAL PRELOAD ON THE BEARING SET
- SURVIVING AXIAL LAUNCH LOADS DESPITE LIGHT PRELOAD AND FLEXIBLE DIAPHRAGM
- TRAVEL STOP INCORPORATED TO LIMIT LAUNCH VIBRATION LOADS
- AMOUNT OF FREE TRAVEL: A COMPROMISE BETWEEN HIGHER MECHANICAL LOADS DURING LAUNCH AND AN INCREASED RISK OF CONTACT DURING OPERATION



- PRELIMINARY SIZING OF DIAPHRAGM, BEARINGS, INTERFACES
- DETAILED ANALYSES: DIAPHRAGM STIFFNESS & STRUCTURAL INTEGRITY
  DIAPHRAGM SUPPORTED SYSTEM DYNAMICS
- VERIFICATION: STRUCTURAL TESTING

APPLIED LOADING

- ESTIMATE OF STATIC ACCELERATION DUE TO RANDOM VIBRATION LOADS:

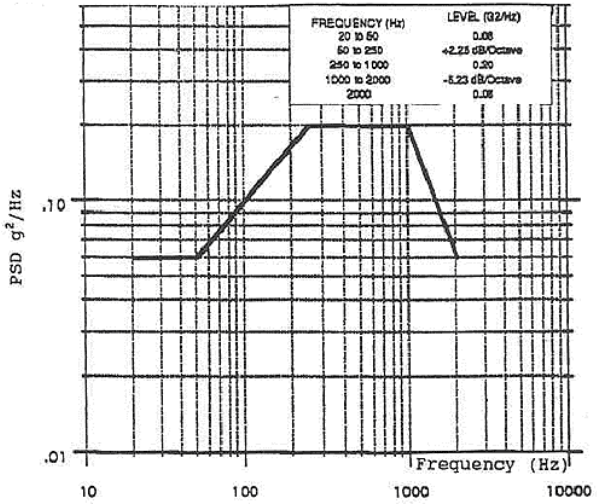
$$a_{3s} = 3\left(\Pi f_1 PSD\, Q/2\right)^{1/2} = 3\left(\Pi(170)(0.14)(10)/2\right)^{1/2} = 58G's$$

- LAUNCH QUASI-STATIC LOADS:
  TITAN-III, THRUST: 6 G's, LATERAL: 2.6 G's

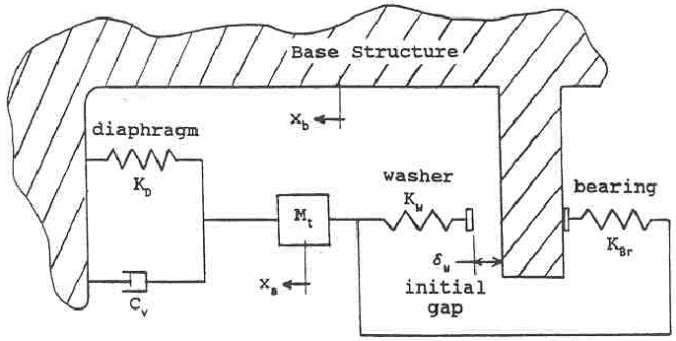
$$a_{QS} = \left(6^2 + 2.6^2\right)^{1/2} = 6.5G's$$

- SIMPLIFIED WORST CASE LOADING:
  APPLIED PRELOAD (6.5 lb) + ENFORCED DISPLACEMENT (0.010 in)

RANDOM VIBRATION LOADS:



MECHANICAL SYSTEM SCHEMATIC:



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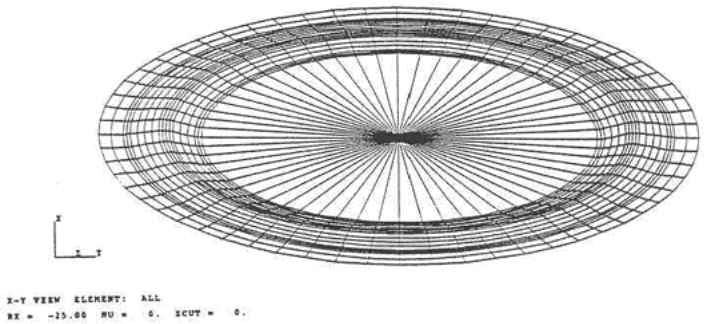
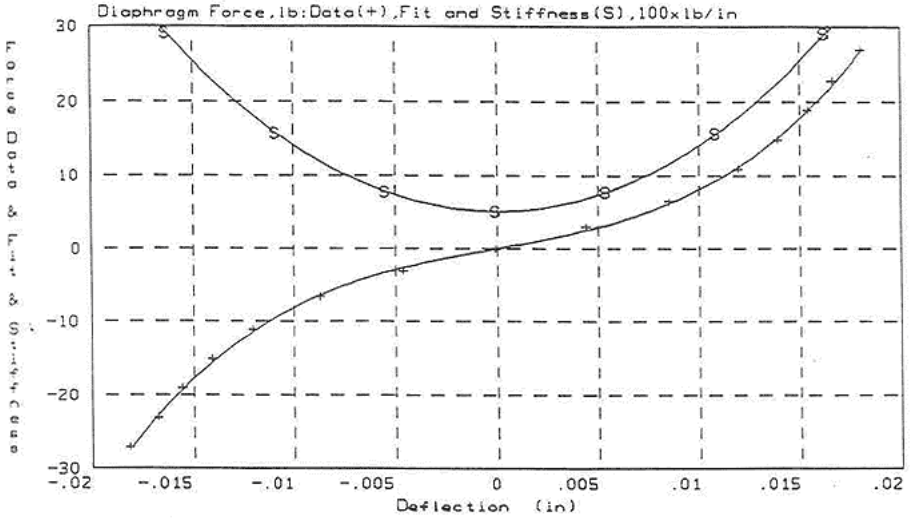
FORCE - DEFLECTION RESPONSE

- NONLINEAR FEA OF DIAPHRAGM USING NASTRAN

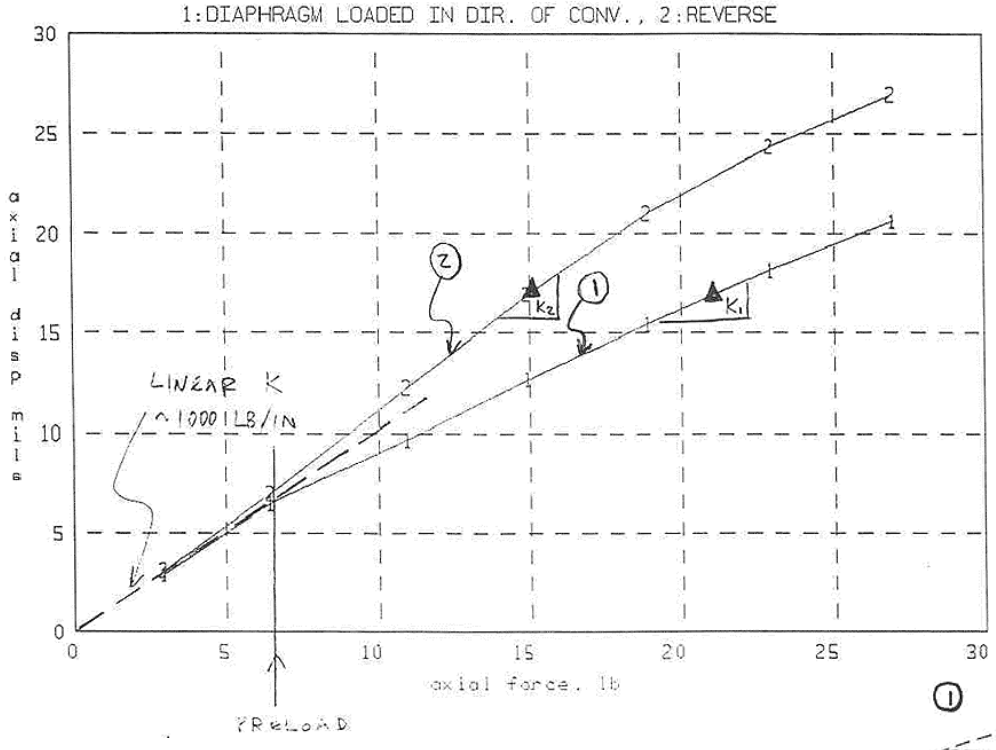


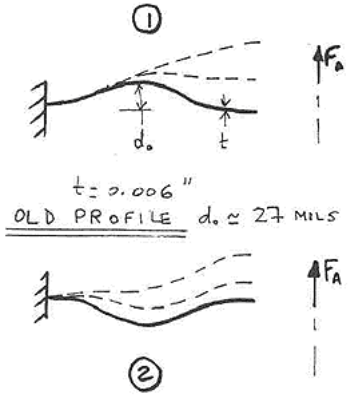
- FORCE-DISPLACEMENT RESPONSE



- NONLINEARITY DUE TO FLATTENING OF THE DIAPHRAGM CONVOLUTION
- TEST SHOWED 1000 lb/in AT APPLIED FORCE = 7lb
- ANALYTICAL SOLUTION GIVES 540 lb/in AT 0 APPLIED FORCE

EFFECT OF NONLINEARITY ON INDUCED AXIAL FORCE UNDER APPLIED DISPLACEMENT



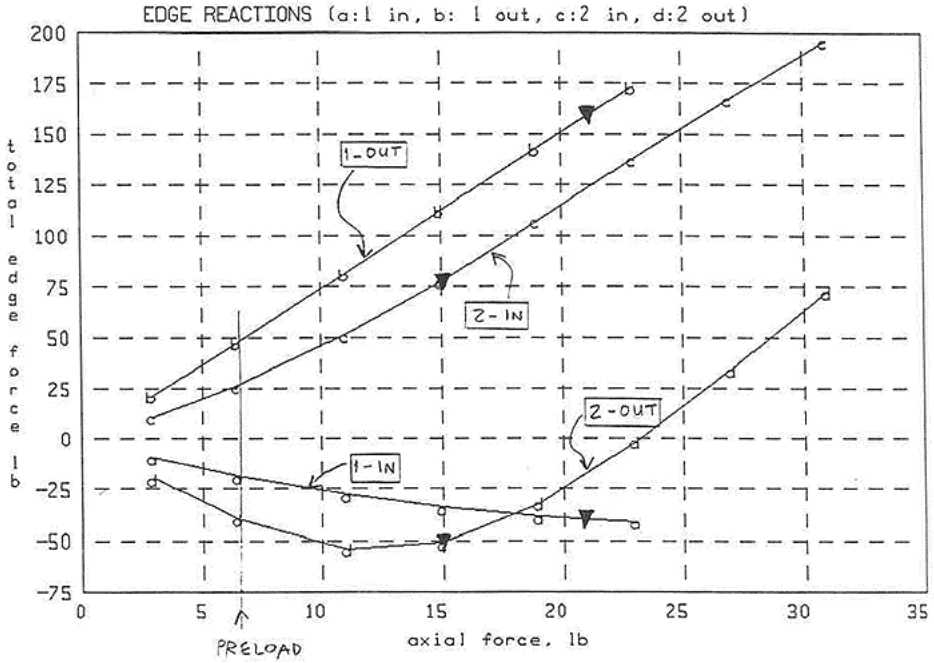


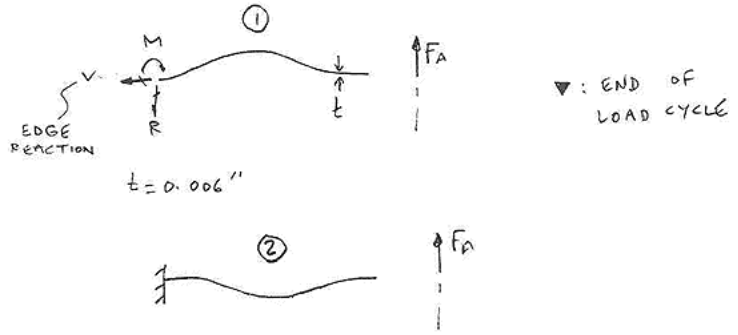
▼ : END OF LOAD CYCLE (6.5 LB PRELOAD + 0.01" DISP)

$K_2 \simeq 890$ LB/IN

$K_1 \simeq 1430$ LB/IN

EFFECT OF NONLINEARITY ON INDUCED EDGE FORCE UNDER AXIAL FORCE





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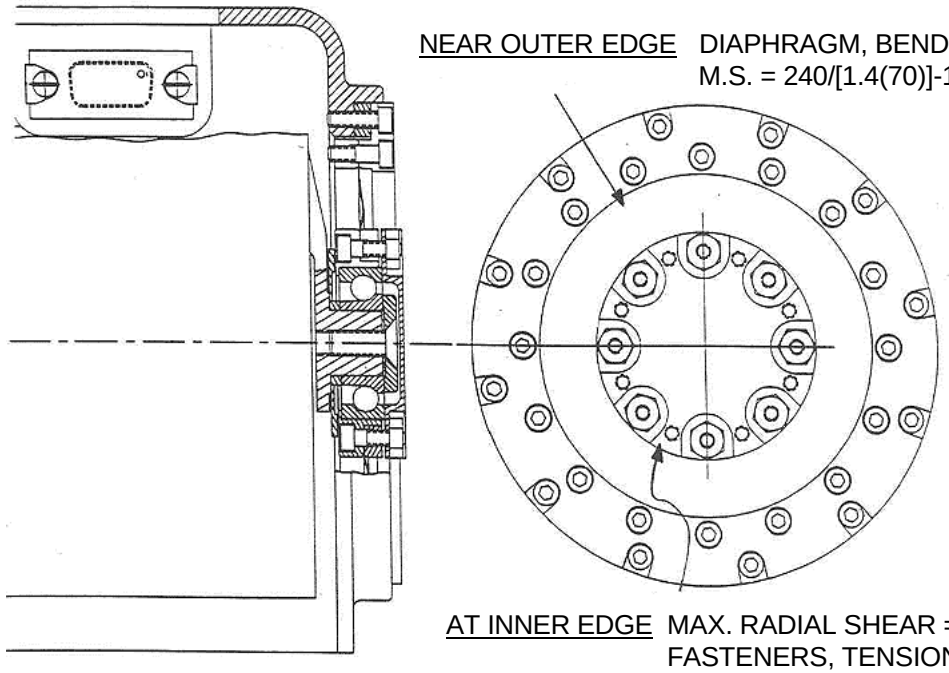
CONVOLUTED DIAPHRAGM STRUCTURAL INTEGRITY

- DIAPHRAGM AND INTERFACES STRENGTH ASSESSMENT:



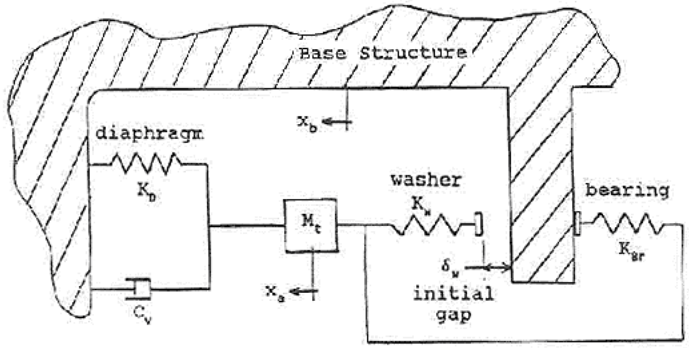
NEAR OUTER EDGE DIAPHRAGM, BENDING + TENSION, σ_{max}= 70KSI
M.S. = 240/[1.4(70)]-1 = +1.45

AT INNER EDGE MAX. RADIAL SHEAR = 62 LB/IN
FASTENERS, TENSION + SHEAR, M.S.=+LARGE
DIAPHRAGM, SHEAR BEARING, M.S.=+0.25

- CYCLIC LIFE VERIFICATION
  - A THROUGH-THE-THICKNESS CRACK WAS ASSUMED
  - IT WAS PROPAGATED IN THE CIRCUMFERENTIAL DIRECTION
  - PROPAGATED UNDER FULLY REVERSED CYCLING AT THE MAX. STRESS LEVEL
  - USING THE FRACTURE ANALYSIS ALGORITHM “FLAGRO”
  - BASED ON A SCATTER FACTOR OF 4, A LIFE OF 18.400 CYCLES WAS ESTIMATED
  - ACTUAL NO. OF CYCLES THE PART WILL SEE ESTIMATED TO BE 11,800 CYCLES

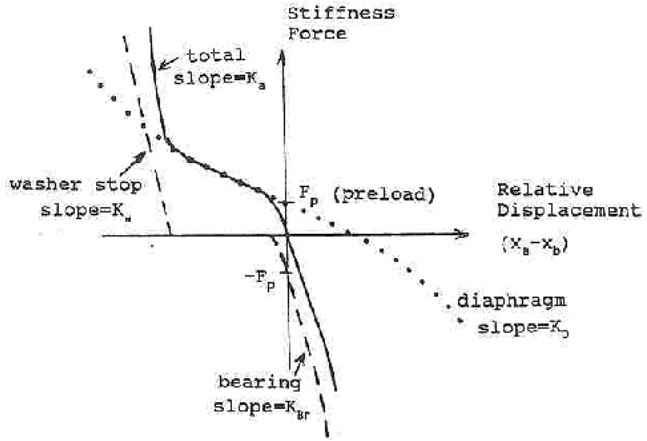
AXIAL DYNAMIC RESPONSE

- MECHANICAL SYSTEM SCHEMATIC:



- EQN. OF MOTION: $M_t\, d^2x_a\, /\, dt + C_v\, dx_a\, /\, dt + K_a\, x_a = G_a\, M_t + K_a\, x_b$

- SYSTEM STIFFNESS FORCE - DEFLECTION:



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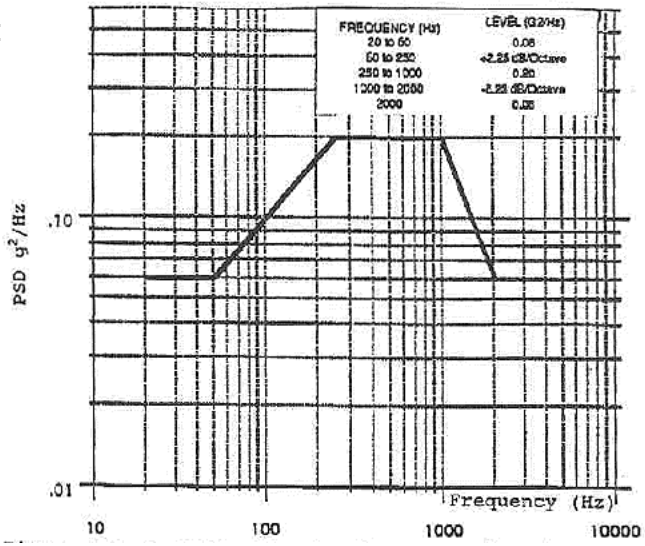
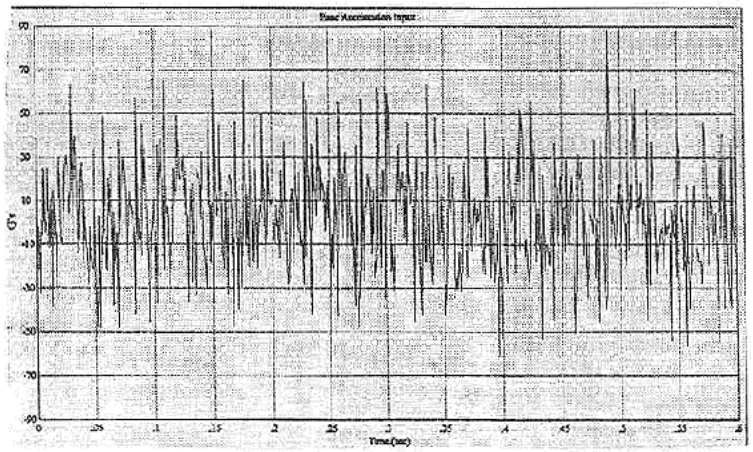
AXIAL RESPONSE SIMULATION

- PSD OF TEST RANDOM BASE SHAKE:

  QUALIFICATION LEVEL
  RANDOM VIBRATION
  TEST PSD



- BASE ACCELERATION INPUT:
  (G's vs. TIME)



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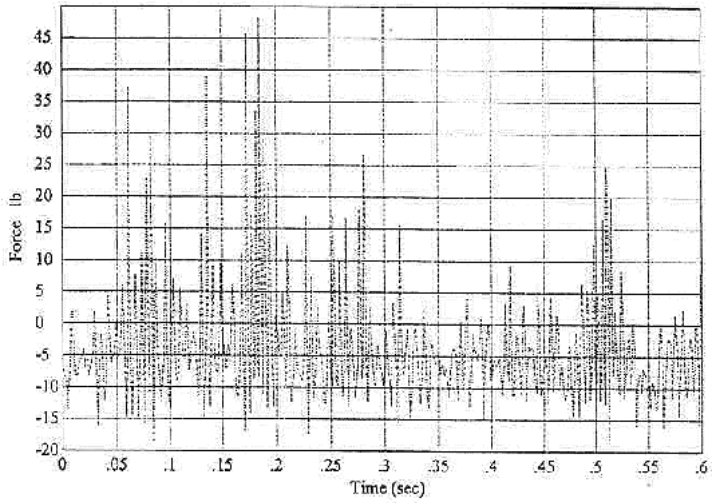
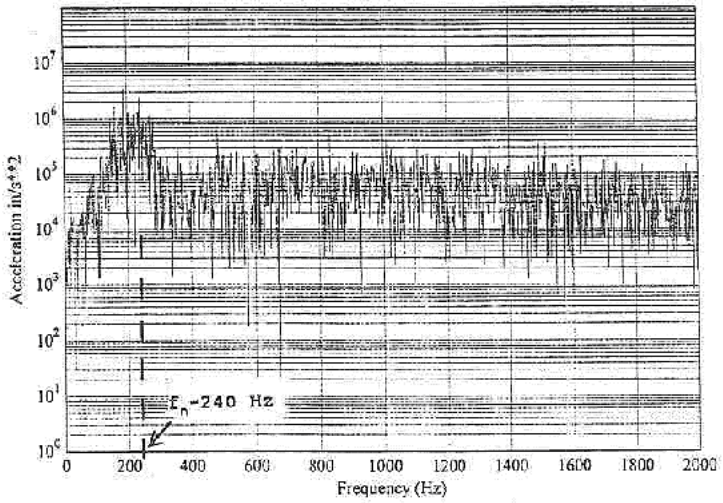
AXIAL RESPONSE SIMULATION

- SIMULATION RESULTS FOR DIAPHRAGM FORCE:



- ACCELERATION RESPONSE FREQUENCY CONTENT:



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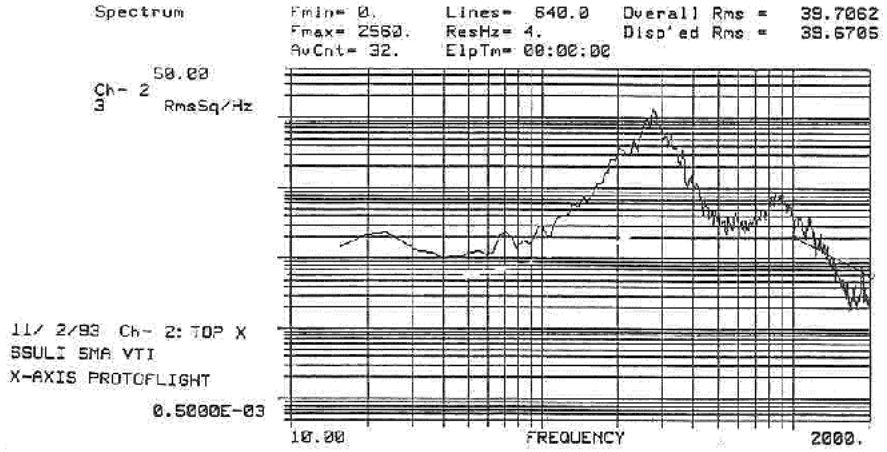
STRUCTURAL VERIFICATION TESTING

- RANDOM VIBRATION TESTS ON SMA MASS MODEL
- IN THE AXIAL AND THE TWO RADIAL DIRECTIONS

AXIAL ACCELERATION UNDER AXIAL BASE SHAKE:



RADIAL ACCELERATION UNDER RADIAL BASE SHAKE: