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JOINT OPTICS STRUCTURES EXPERIMENT (JOSE)*

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*Original figures not available at time of publication.

The objective of the JOSE program is to develop, demonstrate, and evaluate active vibration suppression techniques for Directed Energy Weapons (DEW). DEW system performance is highly influenced by the line-of-sight (LOS) stability and in some cases by the wave front quality. The missions envisioned for DEW systems by the Strategic Defense Initiative require LOS stability and wave front quality to be significantly improved over any currently demonstrated capability.

Earlier work sponsored by the Defense Advanced Research Project Agency (DARPA) in the Active Control of Space Structures (ACOSS) program led to the development of a number of promising structural control techniques. However, the ACOSS theory was developed for well characterized structures with narrow bandwidth disturbances. Further these techniques were applied to relatively simple beam, plate, and truss type structures. These techniques were able to, at best, demonstrate vibration suppression of a factor of 100. DEW structures are vastly more complex than any structures controlled to date. They will be subject to disturbances with significantly higher magnitudes and wider bandwidths, while holding higher tolerances on allowable motions and deformations.

Meeting the performance requirements of the JOSE program will require: upgrading the ACOSS technologies to meet new more stringent requirements, the development of requisite sensors and actuators, improved control processors, highly accurate system identification methods, and the integration of the above hardware and methodologies into a successful demonstration.

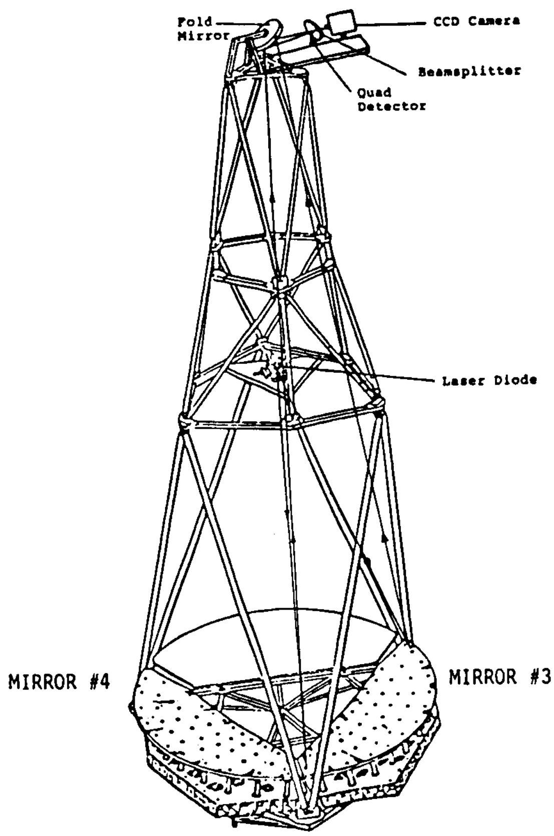
1. Demonstrate the effect of Disturbances on line of sight error

2. Demonstrate use of Active Structural control to correct LOS error caused by Disturbances

3. Compare simulation predictions to experimental results

JOSE OBJECTIVES

A realistic test article for the JOSE demonstration was provided by the High Altitude Large Optics (HALO) program. The HALO program run by the Rome Air Development Center (RADC) was to develop techniques for the manufacture of lightweight optics. In the final phase of the program, two HALO active mirror panels and a third mirror mass simulator were integrated into a large graphite-epoxy structure. This assembly was designed to have many of the characteristics of a large, lightweight, optical system. It utilizes lightweight, tubular graphite-epoxy structural members which may be typical of DEW type structures. The ends of the structural members are fit with Invar joints. The optics include large ultra-lightweight mirrors that are actively controlled by surface and alignment actuators to maintain optical performance. Each mirror is supported by three pairs of position actuators. Each pair forms a "V" shape with the vertex resting on the truss. The actuators are flexured at both ends to reduce the bending moments transmitted to the mirror surface. The dummy mirror is supported on three pairs of struts in place of the actuators. The struts are also fitted with flexures at the ends. In addition to its unique construction, the HALO truss was sized to fit inside a vacuum chamber at Itek. The JOSE program has taken advantage of the existing HALO structure to provide optical performance and structural vibration data.

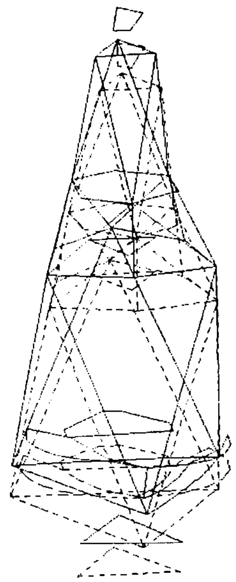


High Altitude Large Optics

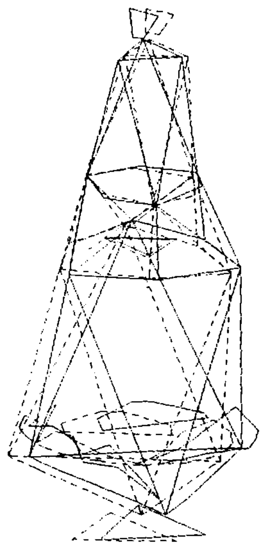
During the delay prior to the start of the JOSE program an opportunity to test the HALO truss occurred. The objectives of the test were:

1. Measure the important modes of vibration, i.e., those likely to contribute to line-of-sight error under in-service excitations. Modal data including natural frequencies, damping ratios, mode shapes, and associated modal masses were measured. These data were used to "tune" a finite-element model of the truss.
2. Measure the damping of selected modes in air and in the Itek vacuum chamber.
3. Measure selected frequency response functions between input force and LOS error. These were used to calculate the power spectral density (PSD) of the LOS motion for specified disturbance PSD's.
4. Characterize the local bending modes of one of the primary mirror panels. These modes are of particular interest for the tuning of the finite element of the mirror supports.

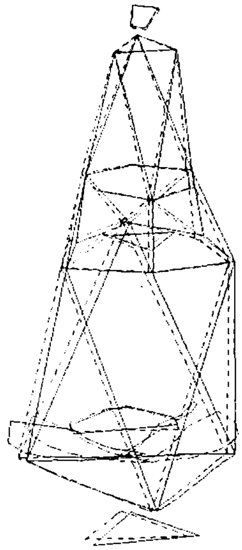
During the planning for the test it was decided to support the truss on soft, pneumatic springs at the corners of its triangular base. This simulates the isolation system that may be used in a DEW system. Approximately 650 frequency response functions were measured in determining the structural characteristics of the HALO truss. Determining which of the modes contributed significantly to the LOS error required the use of a three milliWatt laser diode and a quad cell detector. Frequency response functions were measured between the input force and the output of the quad cell detector. The importance of these measurements can be seen from the following plots. The frequency of the first structural mode is below 10 Hz, while there are no optically significant modes until 21 Hz.



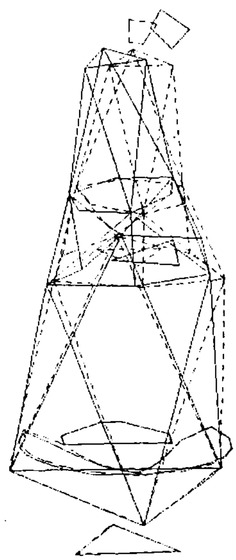
Shape of vibration mode at 3.51 Hz.



Shape of vibration mode at 4.63 Hz.

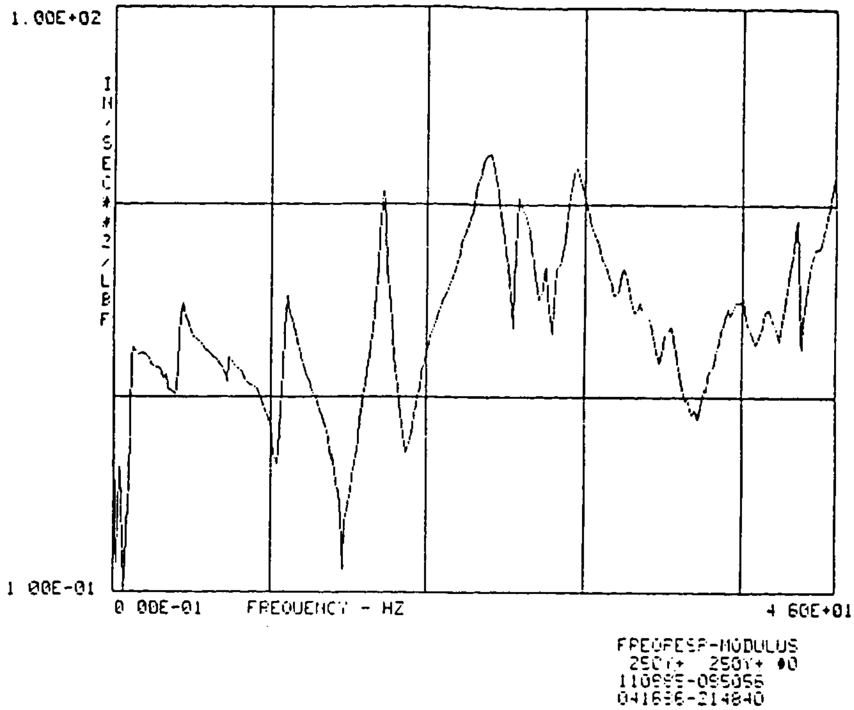


Shape of vibration mode at 20.80 Hz.

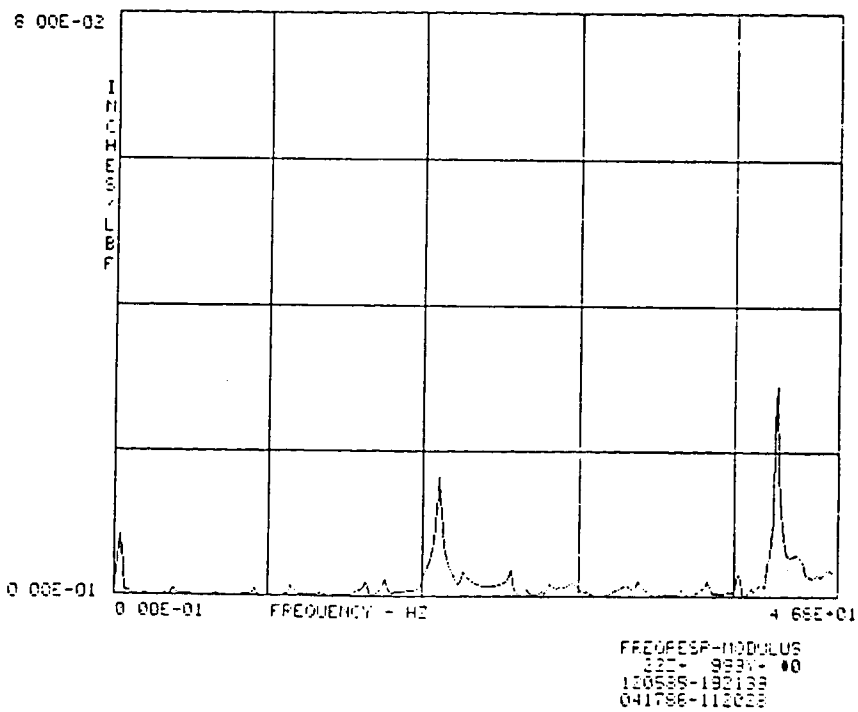


Shape of vibration mode at 23.98 Hz.

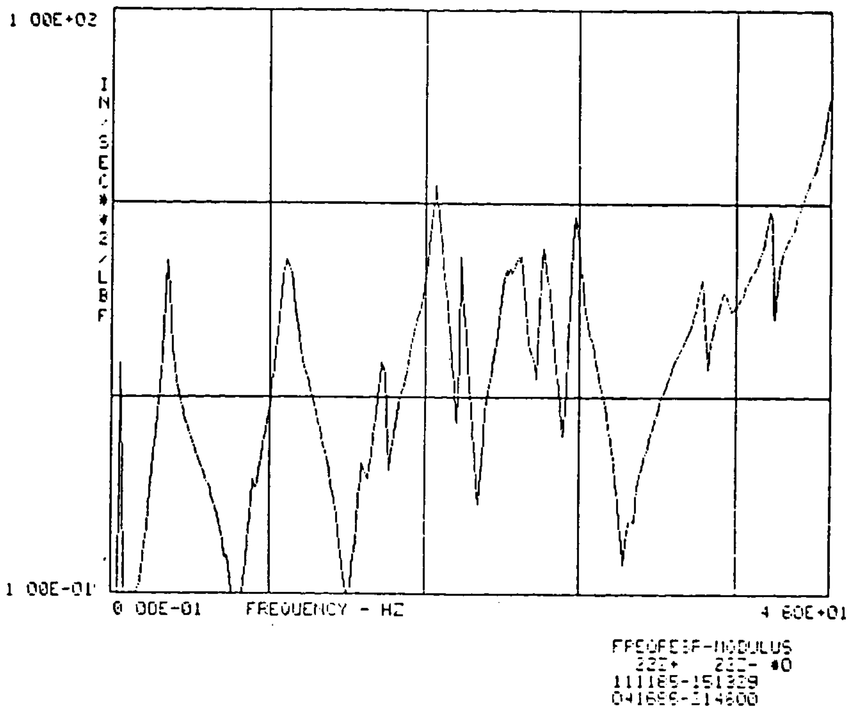
FREQUENCY RESPONSE FUNCTIONS



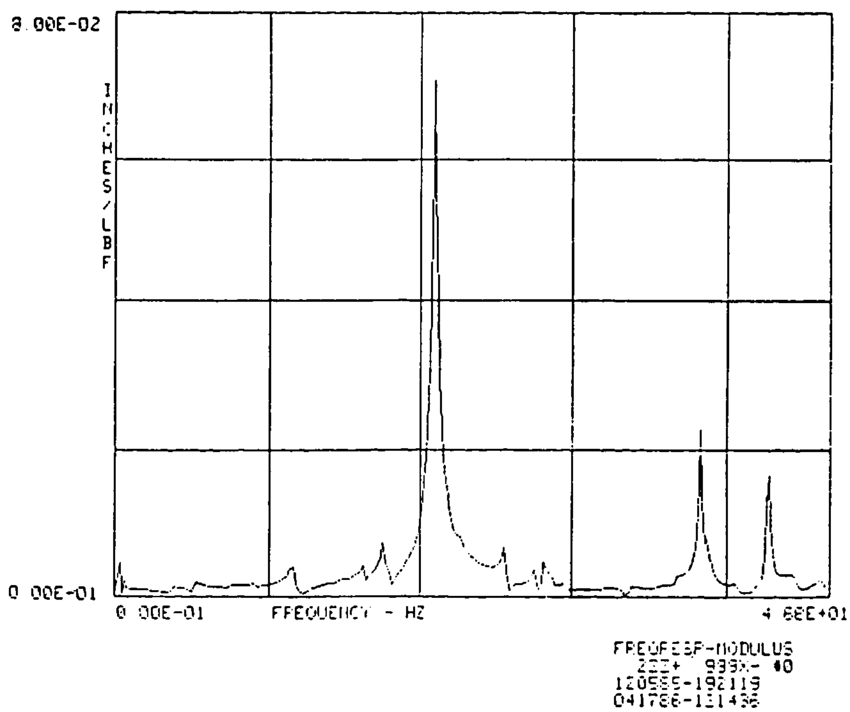
HALO truss with mirrors main sweep 1 burst random.



Line-of-sight motion FRF
burst random, in vacuum.

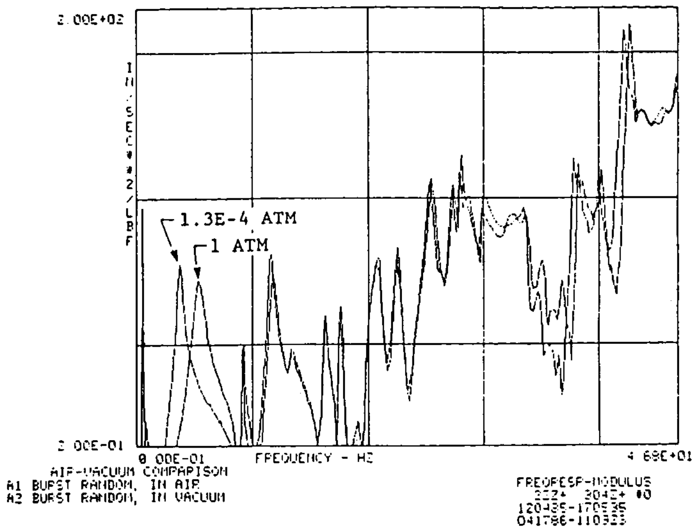


HALO truss with mirrors main sweep 2.



Line-of-sight motion FRF
burst random, in vacuum.

In order to determine the effect of vacuum on the structural damping the HALO truss was placed in a vacuum chamber and selected frequency response functions were remeasured. The following plot and table indicate that the effect of the vacuum was negligible and the changes that did occur are most likely related to the slight difference in the mounting of the pneumatic supports.

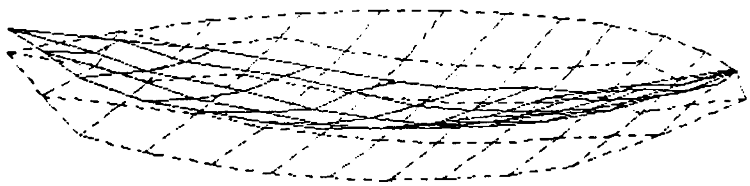


AIR-vacuum comparison,
A1 burst random, in air,
A2 burst random, in vacuum.

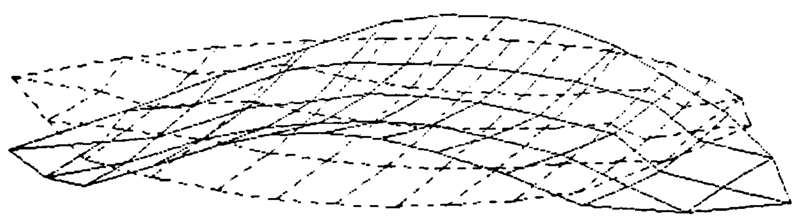
Response Coordinate	Natural frequency f_r,Hz		Viscous damping ratio ζ_r	
	Air	Vacuum	Air	Vacuum
351Y-	9.20	9.14	0.010	0.0085
22Z+	11.79	11.50	0.020	0.022
120Y-	13.42	13.28	0.033	0.023
351Y-	16.17	16.19	0.0096	0.0084
410Z-	17.46	17.48	0.0067	0.0078
22Z+	20.82	20.84	0.013	0.012
410Z-	22.46	22.57	0.0087	0.0069
351Y-	25.39	25.58	0.0077	0.0076
410Z-	27.28	27.48	0.0064	0.0064
351Y-	27.89	28.03	0.0056	0.0049
351Y-	29.39	29.53	0.0073	0.0066
410Z-	31.71	32.07	0.0043	0.0061
410Z-	33.53	33.92	0.0076	0.0058
410Z-	36.43	36.74	0.0048	0.0048
351Y-	37.89	38.26	0.0031	0.0036
304Z+	39.96	40.25	0.0029	0.0034
304Z+	42.10	42.65	0.0034	0.0018

Damping of the HALO Experimental Structure
In Air and In Vacuum.

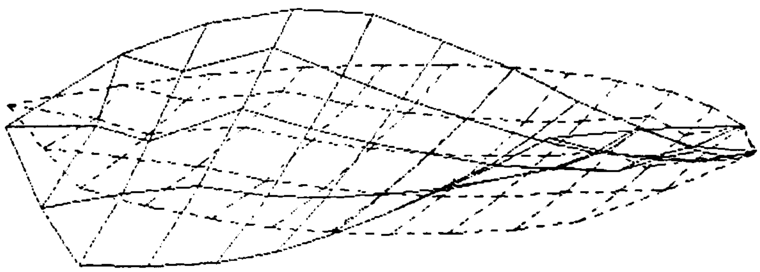
A specialized modal test was performed to examine the local modes of one of the mirrors on its fine figure actuators. The local mode test was performed using a roving impulse excitation and multiple fixed accelerometers. A total of 159 frequency response functions were measured on the mirror and used to determine the bending modes. The mirror exhibited modes corresponding to rigid body motion of the mirror on its supports and classical plate bending. Both may be important to LOS and wavefront error. The data were used to tune the finite-element model of the truss with respect to the stiffness of the coarse and fine figure actuators, and the mirrors themselves.



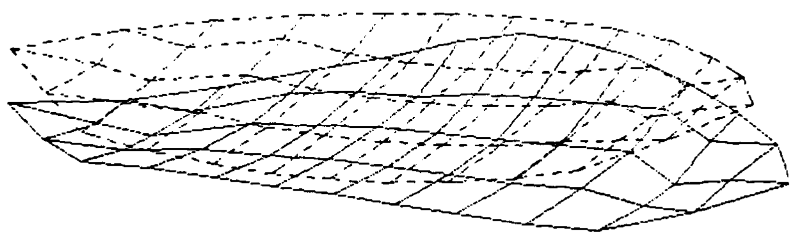
Shape of vibration mode at 36.44 Hz.



Shape of vibration mode at 37.96 Hz.

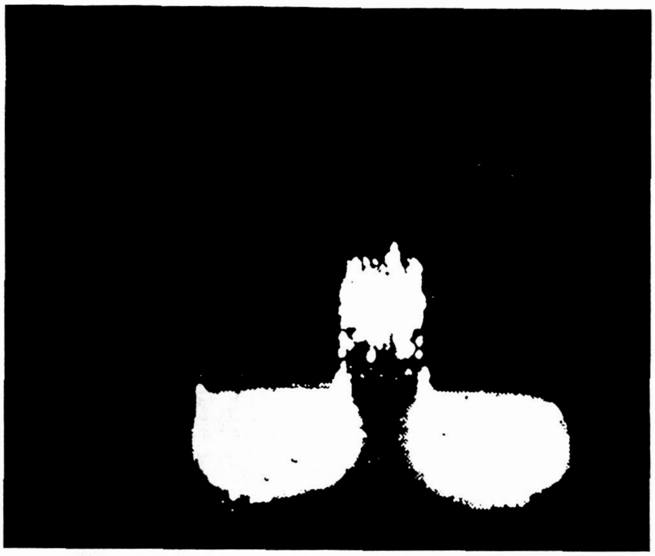


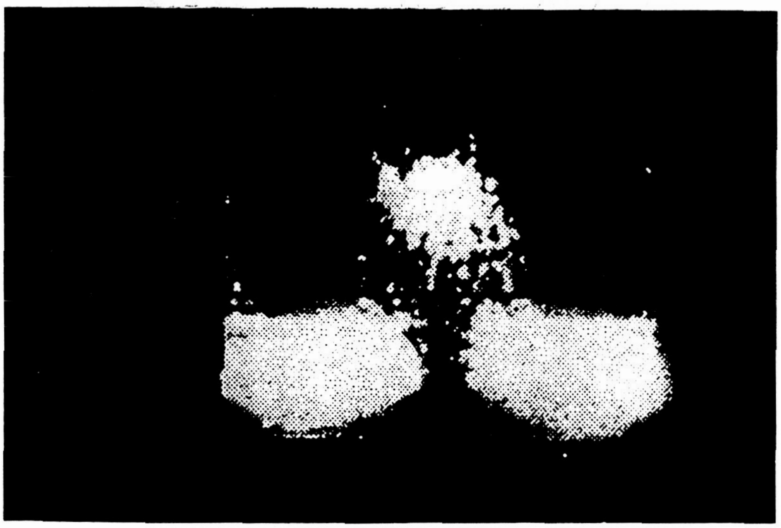
Shape of vibration mode at 39.22 Hz.



Shape of vibration mode at 44.87 Hz.

A 100 x 100 pixel array, 3mm x 4mm in size, was used to record the effect of the structural vibrations on the wavefront quality. The rms wavefront error was calculated from the peak spread function.





PIXEL ARRAY

The results of both the LOS and wavefront error were used to estimate the equivalent errors that could be expected from the vibrations that are likely in a DEW system.

Vibration Source	Frequency Range	Approx. WFE, m RMS
Coolant Lines (Bends)	0.1 - 10Hz	0.05 u m RMS
	10 - 100Hz	0.01 u m RMS
Resonator Forward End Cap	0.1 - 100Hz	7.7 u m RMS

Wavefront Error Predictions