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Alpha LAMP Integration Facility

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Abstract

This paper describes the activity recently completed to meet the simulated space environment requirements for the ground-based testing of an integrated Space Based Laser (SBL) system experiment. The need to maintain optical alignment in the challenging dynamic environment of the pressure recovery system required to simulate space dominated the design requirements. A robust system design was established which minimized the total program costs, most notably by reducing the cost of integrating the components of the experiment. The components of the experiment are integrated on an optical bench in a clean area adjacent to the vacuum chamber and moved on air bearings into the chamber for testing.

Introduction

The Space Based Laser system experiment consists of the megawatt class Alpha hydrogen-fluoride chemical laser, the four meter (13 foot) diameter Large Aperture Mirror Program (LAMP) beam director, and an outgoing wavefront sensor based beam control system containing adaptive optical elements, as illustrated in Figure 1. The Alpha laser must be maintained at less than 5-10 torr pressure while generating approximately 90 Kg/sec (200 lb/sec) of Free Dry Air Equivalent (FDAE) exhaust gasses. The experiment also contains a diagnostic system incorporating a 1.5 meter (4.9 foot) telescope.

Although ground testing is much less expensive and more flexible than testing in space, the fidelity of space environment simulation is limited by physical constraints and the experiment budget. Management methods similar to the "Integrated Product Team" concept, Design-to-Cost, and "Concurrent Engineering" techniques were used to complete this project on-time and within budget. The design activity through acquisition of the building permit required 12 months. Construction was completed in approximately 24 additional months.

The requirement to pump the laser exhaust gasses up to atmospheric pressure in ground testing and to maintain precise optical bench positioning dominated the design of the space simulation facility. The seismic and acoustic environment produced by the laser pressure recovery system during testing required optical bench isolation from both the ground as well as the vacuum vessel. Integrated components of the space based laser system were mounted on an optical bench surrounded by a vacuum chamber. Isolators tailored to attenuate the seismic disturbance supported the optical bench from a seismic mass with supporting pilings below the vacuum vessel. Tuned mass dampeners and other passive techniques were also used to further attenuate frequencies near the resonate frequencies of the bench and the components on the bench. Damping of transmission of vibrations from the chamber to the bench was further improved by incorporating use of flex sections in fluid lines, "angel-hairing" of wiring bundles, and rubber seals where the isolators pass through the vacuum chamber floor.

The integration and checkout of precision optical hardware requires personnel to wear cleanroom apparel. This activity, performed in a confined area, can require excessive efforts in time and energy. The lessons-learned during the previous integration of the Alpha Laser in its vacuum vessel was the basis for the requirement for a Class 100,000 "Pre-Integration Area" outside the testing vessel for integration of the experiment components. Once the integration is sufficiently completed, the optical bench with the installed experiment hardware can be transported on air bearings into the minimum size vacuum vessel for testing.

Configuration

The experiment, as shown in Figure 1, is housed in two separate vacuum chambers joined by a 19.5 m (64 foot) long, 60 cm (two foot) diameter vacuum beam duct for the transmission of the high power laser beam. One chamber houses the Alpha laser, first tested in 1991. The second chamber, the Alpha/LAMP Integration (ALI) Test Chamber Assembly (TCA), is a 1206 cubic meter (42,600 cubic foot) "D" shaped, flat bottom chamber containing the experiment optical components mounted on a dynamically isolated 90,700 Kg (100 ton) steel optical bench. Adjacent to the TCA is a 3850 cubic meter (136,000 cubic foot) Class 100,000 clean room used for pre-integration of the experiment prior to its installation in the vacuum chamber. Air bearings are used to move the optical bench from the pre-integration area into the vacuum chamber as shown in Figure 2. Once inside the vacuum chamber, the optical bench

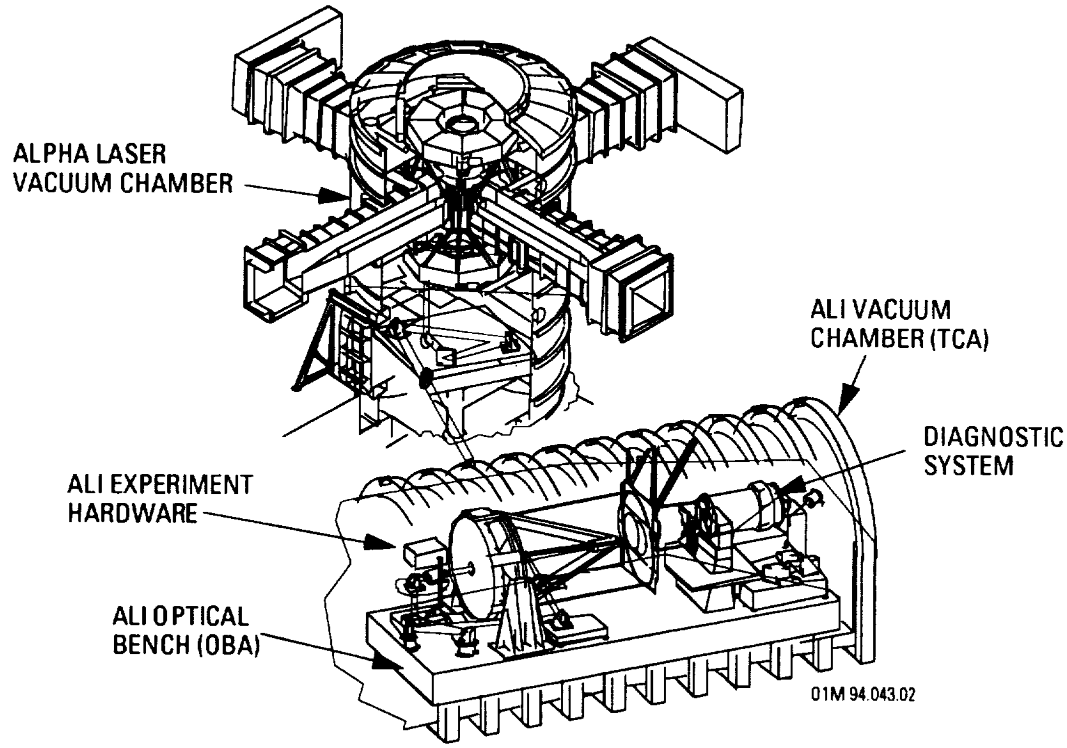


Figure 1. Space Based Laser Experiment Configuration

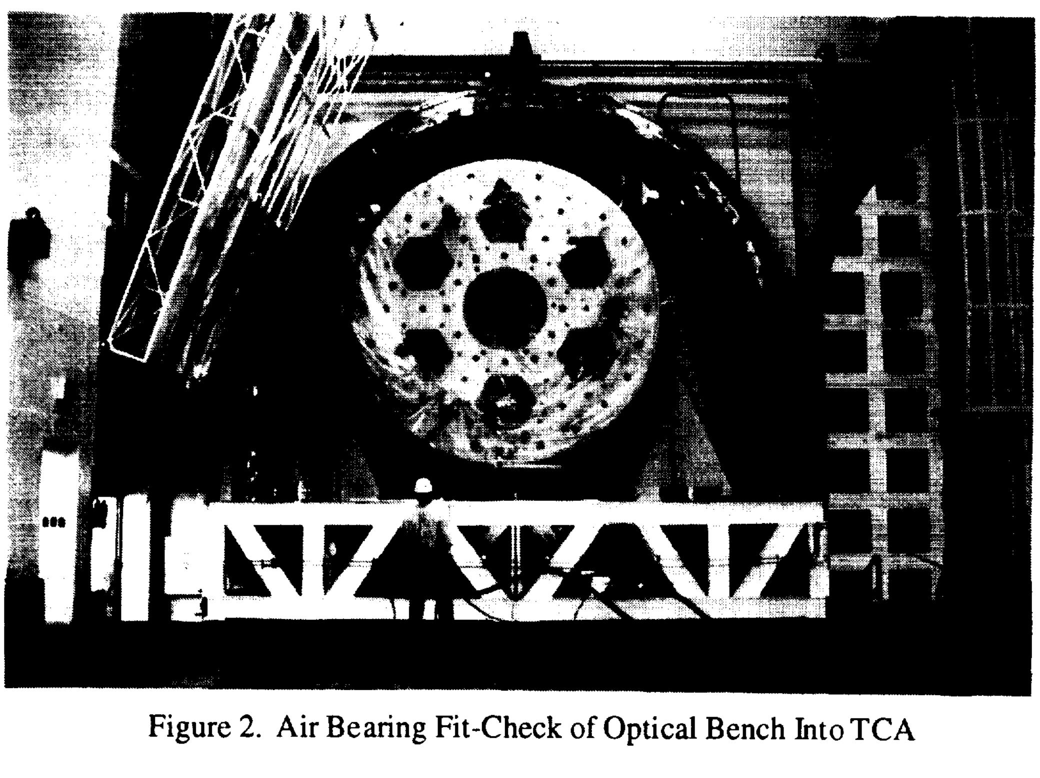


Figure 2. Air Bearing Fit-Check of Optical Bench Into TCA

and experiment components weighing a total of 136,100 Kg (150 tons) are supported on isolators to provide vibration isolation from the surrounding pressure recovery system and maintain precise optical bench positioning during the experiment.

Gate valves and expansion bellows at each end of the vacuum beam duct are used to provide the capability for testing in each chamber independently and to decouple them dynamically. When the laser is operating and the gate valves are open on the vacuum beam duct, the pressure is always maintained higher in the TCA than in the MSA with a positive flow of helium to insure no combustion products from the laser enter from the laser vacuum chamber. This approach saved the cost and complexity of explosion proofing the contents of the TCA.

Support pallets for the TCA vacuum pumps, liquid nitrogen, pneumatics, dry air, and deionized water were fabricated from existing Alpha designs wherever possible to save overall costs. Changes to the designs based on test site experience with Alpha were incorporated to reduce operational and maintenance costs.

Vacuum Chamber

In general, the space simulating environment required for this experiment is not particularly difficult to achieve by conventional space simulation standards. No extremely hard vacuum, solar simulation, or cold plates were needed. However, the level of cleanliness, control of the water vapor and contaminant outgassing, and isolation from the seismic environment, were stressing requirements on the chamber design. Design loads for the vessel are full vacuum (external), 5.6 mm of mercury (3 inch water) (internal), seismic conditions, and testing hardware loads associated with the moving of the OBA from the integration area into the vessel.

The basic dimensions of the TCA are 8m (26 ft.) wide at the bottom, 4 m (13 ft.) high vertical walls, and a 4m (13 ft.) radius cylindrical top cap section. Overall length of the chamber is 21.3 m (70 ft.) A patented flex seal design allowed for inclusion of an extremely large closure (8 m x 8 m or 26 ft x 26 ft) without costly field machining and acceptable life cycle costs.

Temperature control and Class 100,000 level cleanliness inside the vacuum vessel is maintained during nontesting periods by a Heating, Ventilation and Air Conditioning (HVAC) system with HEPA filters and a continuous cleaning design. Vacuum cleaner ports are also provided at the level of the optical bench surface inside the vacuum vessel with a central HEPA filter system to facilitate cleaning prior to test. Booty/garment rooms typical of clean room facilities were located as required to transition personnel and equipment into the cleanliness controlled areas.

Chamber environment requirements for water and other contaminants had a major effect on material selection and cost tradeoffs. Stainless steel was selected for the 1.6 cm (5/8 inch) shell and 2.5 cm (1 inch) sidewalls of the vacuum chamber which are exposed to the test environment. However, epoxy painted carbon steel was used for the outside stiffeners, supports, and other ancillary parts to reduce costs. Similarly, stainless steel was used for the top of the optical bench near the optical components, while an epoxy painted carbon steel structure was used below the bench surface which is isolated from the test environment by a designed purge flow/vacuum pump arrangement. Since the vacuum pumps draw the air from below the bench surface (diagonally at two corners), the outgassing of the epoxy painted carbon steel surfaces below the top of the bench is controllable. Careful material selection combined with long periods of soak-out prior to testing were required to control outgassing to meet the requirement for a water content of less than 1000 ppm for the experiment environment. Any polymeric materials including coatings, lubricants and sealants are vacuum stable, low outgassing and non-shedding. The TCA enclosure, including all vacuum seals, are designed so that total leakage of the TCA shall not exceed 100 millitorr per hour when the start-test pressure is 500 millitorr or less.

Three general configurations were considered for the shape of the vacuum vessel: spherical, cylindrical, and "D" shaped. The spherical shape for example had the thinnest wall (lowest weight) but the poorest volumetric efficiency and was not adaptable to the existing site constraints. The cylindrical shape also has similar limitations. The "D" shape was selected for its combined benefits of volumetric efficiency, lifecycle costs, compatibility with the seismic isolation, adaptability with the existing site and the planned hardware integration approach. The flat bottom chamber design with operable end closure was very compatible with the air bearing system for moving the optical bench between the integration area and the vacuum vessel. A large seismic mass with supporting pilings was conveniently positioned below the isolators of the optical bench. The weight of the vacuum vessel was independently supported around the periphery with its own foundation and supporting pilings. This concept proved to be quite effective in providing vibration isolation between the optical bench and the vacuum vessel, and was compatible with the available space adjacent to the existing Alpha laser facility. The existing building was also modified to provide thermal as well as acoustical protection for the vacuum vessel.

Three levels of electro-optical support rooms with computer floors, conditioned power and fire suppression systems were constructed adjacent to the TCA. Judicious location of mandoors into the vacuum chamber, an emergency shutdown system and combustible gas detection system were included in the chamber design to insure a non-confined work space. This significantly reduced the cost of operation by improving integration efficiency.

Equipment Handling Provisions

A 18,000 Kg (20-ton) bridge crane is provided to assemble the parts of the vacuum chamber during construction and also to integrate components in the Pre-Integration Area, as shown in Figure 3. A monorail enabled the hoist of the overhead crane to pick components from the roadway below the PIA, pass through the 4.9 m x 12.2 m (16 foot x 40 foot) bifold doors, and precisely position it within the support boundaries as shown in Figure 4. The crane requirements were driven by the optical bench sections to be delivered. A continuous 1,000 Kg (1-ton) monorail/bridge system is also provided inside the vacuum chamber as illustrated in Figure 5. The system provides for safe installation of smaller components and optics after the optical bench has been inserted into the chamber.

Figure 3a. Bridge Crane - Assembly of TCA

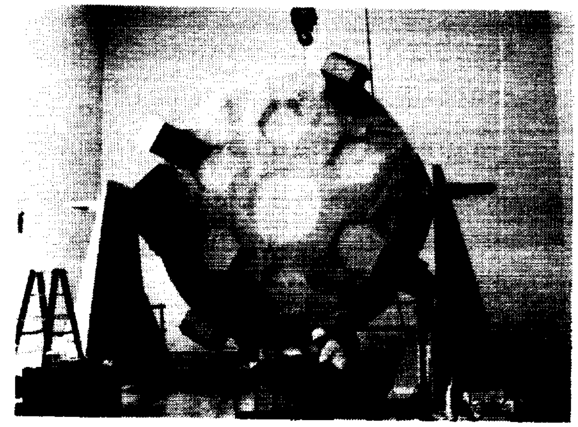


Figure 3B. Bridge Crane - Components Integration In PIA

Figure 4. Optical Bench Segment Lifted Into PIA

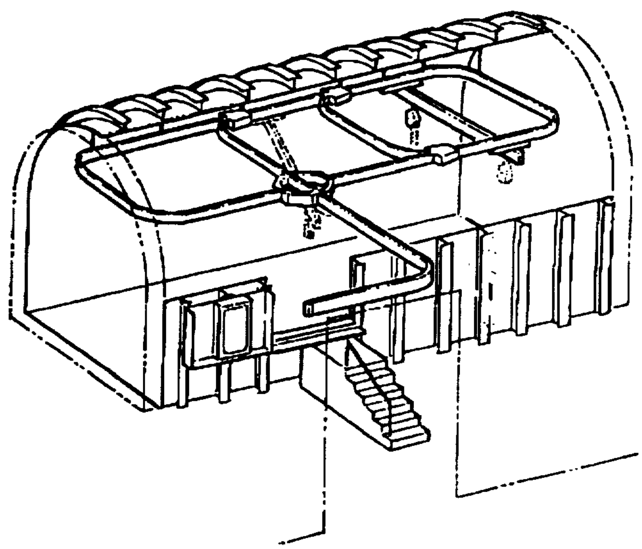


Figure 5. Equipment Handling System inside TCA

A stowable cleanroom was provided to support cleanliness control for hardware transition in and out of the Pre-Integration Area. Each time a component is processed into the clean environment of the PIA for integration, the transition enclosure must be cleaned, the entrapped air cleaned, the component unbagged, and the component transported from the transition area onto the optical bench. Numerous large cleaned and bagged components will be required to complete the integration of the subsystems so the transition enclosure was made as small as possible since the inside surfaces had to be cleaned each time.

The integration sequence plan also requires a barrier between the PIA and the TCA when the end door of the TCA is opened. A remotely operated roller mechanism was designed to deploy a soft polished vinyl curtain (clean screen) between the sealing surfaces before the door was moved to the stowed position. The stowable clean room and clean screen are depicted in Figure 6.

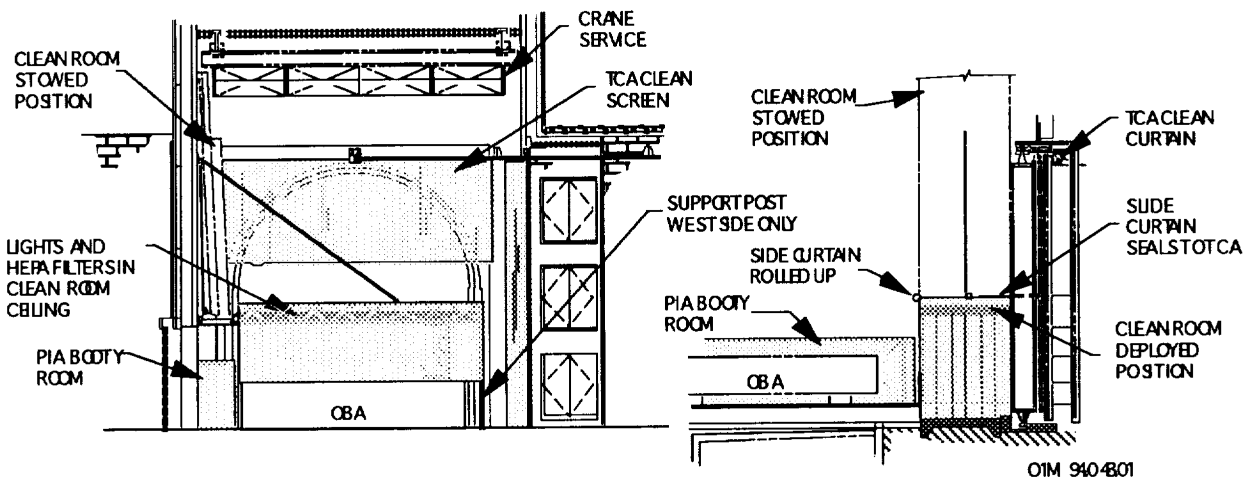


Figure 6. Stowable Clean Room and Clean Screen

Optical Bench Configuration

The Optical Bench Assembly (OBA) consists of the 7.3 m wide by 19.5 m long by 137 cm high (24-ft x 64-ft x 54-inch) optical bench and its isolation system which provides a stable, level, non-deflecting platform for the ALI experiment. The optical bench was constructed from structural steel shapes and plates welded into a truss or space frame configuration and was fabricated in six separate subassemblies to facilitate manufacturing and transportation limits. Final assembly of the OBA is shown in Figure 7. The four end segments are 3.6 m wide by 6.2 m long (12-ft x 20-ft 4-in) and weigh 9525 Kg (21,000-lbs) each. The two center bench segments are 3.6 m wide by 7.1 m long (12-ft x 23-ft-4-in) and weigh 19,050 Kg (42,000-lbs) each. The weight difference is a result of optimization of the bench masses to provide an efficient structure at the lowest possible total weight.

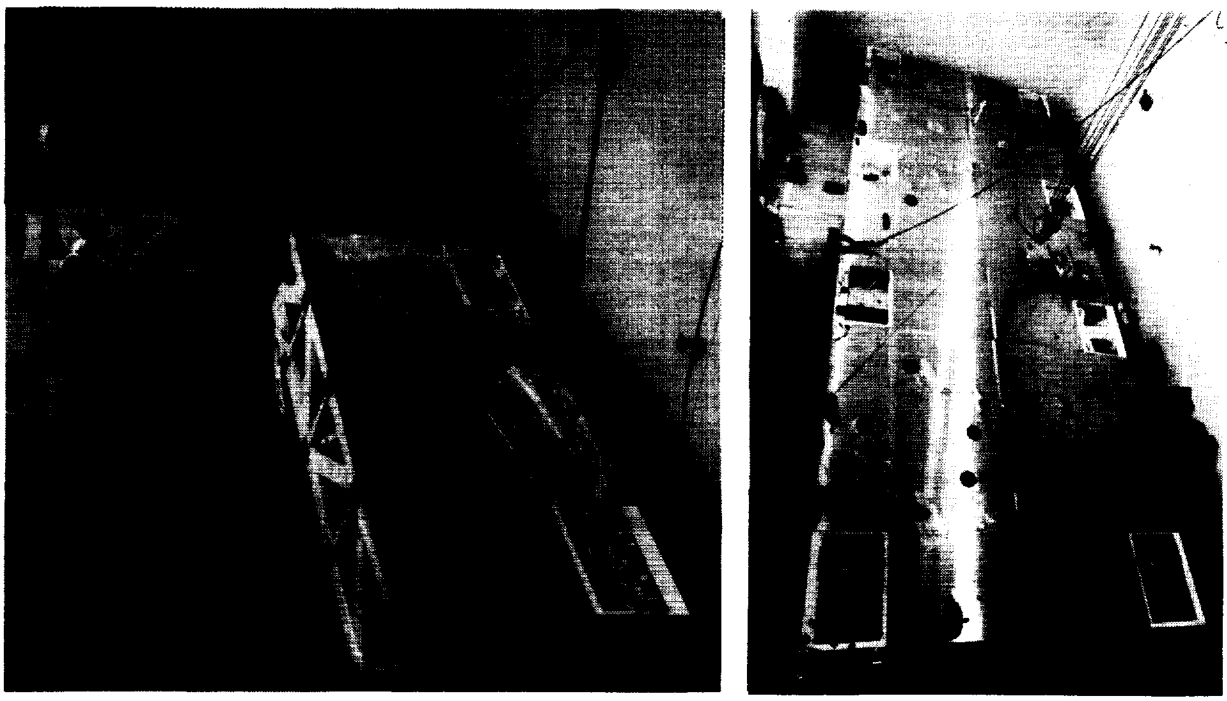


Figure 7. Optical Bench Assembly in PIA

To prevent rusting and a contamination problem within the TCA clean room environment, a white epoxy paint was applied. A spacecraft qualified paint system was utilized with low outgassing properties; i.e., the Collected Volatile Condensable Material (CVCM) is not greater than 0.1% and the Total Mass Loss (TML) is not greater than 1.0%. The top plates were a nominal 1.6 cm (0.625-inch) thick 304L stainless steel plate. These bench segments were bolted at primary beam intersections to maximize local bench stiffness; in addition, tapered pins were installed for joint stiffness and accurate assembly of the optical bench within the PIA prior to final installation into the TCA.

The most challenging requirement for the OBA was to isolate the experiment from the seismic environment created by the rocket driven steam ejection system required to simulate a space environment for the laser system operation. The isolation of the LAMP was critical since its primary mirror modes are in the 2.5 through 9 Hz range. Therefore, the isolators were required to be ≤ 1 Hz with the goal for the lowest possible isolation frequency without developing new isolation technology.

A design goal was to minimize the weight of OBA while maintaining a minimum of 16 Hz frequency for the fundamental bending mode. Considerations for manufacturing, assembly and installation were included in the design process. The 16 Hz minimum frequency chosen met the requirement of being an order of magnitude above the natural frequency of the OBA/LAMP combination. Other design goals were to provide structural damping 2% (Q=50%) in the fundamental mode and minimizing the end-to-end deflection under 10 urad peak-to-peak between 5 to 300 Hz. The structural model of the optical bench was performed on NASTRAN and optimized on a proprietary optimization code which uses design variable sensitivities to minimize the mathematical objective function and satisfy constraint functions. Each truss member was optimized to a minimum cross section which produced the minimum weight.

OBA Isolation System

Pneumatic isolators provide one of the best methods for vibration isolation since they are able to accommodate large loads, varying center-of-gravity, and provide fast roll off of the vibration frequencies above the resonance frequency. The OBA is isolated and supported by pneumatic isolators which form a three-point determining system. Eight isolators are interconnected to form three master/slave sets with each master containing the movement sensing servo-valve hardware. The isolator selected uses a laminar flow damping orifice which contains thousands of tiny orifices instead of the single conventional damping orifice. In addition, a hybrid-chamber design enhances the damping efficiency by minimizing the air volume between the piston and damper. This new orifice design is responsible for the lower natural frequency, faster settling time, better high center of mass stability due to a smaller volume in the spring chamber, and less amplification at resonance due to the smaller volume.

The OBA isolators are designed to perform under 0.8-Hz for the given load of 145,000 Kg (320,000-lbs) for the disturbance PSD shown on Figure 8. Each isolator has a maximum load carrying capacity of 18,000 Kg (40,000-lbs.) The isolators are 91 cm (36-in) high by 91 cm (36-in) diameter supported by a similar sized pedestal. This compact isolator height simplified both the integration task and the vacuum seal design with the TCA floor, as shown in Figure 9. Therefore, the pedestal required only to be a structural base with adjustment capabilities and a vacuum seal interface with the TCA.

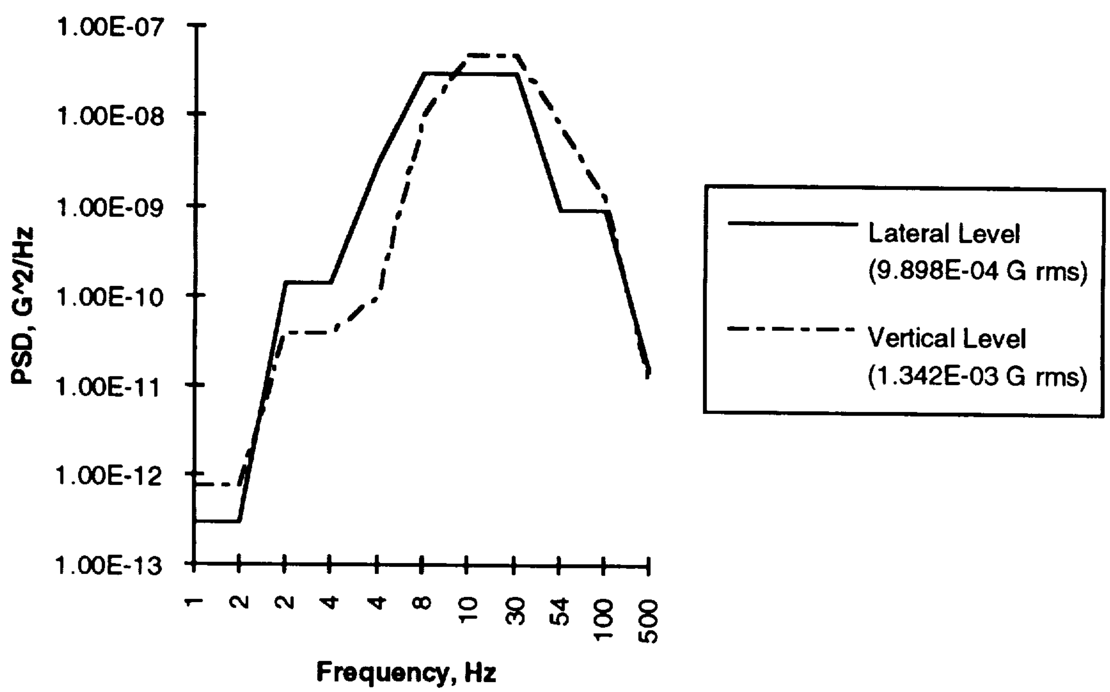
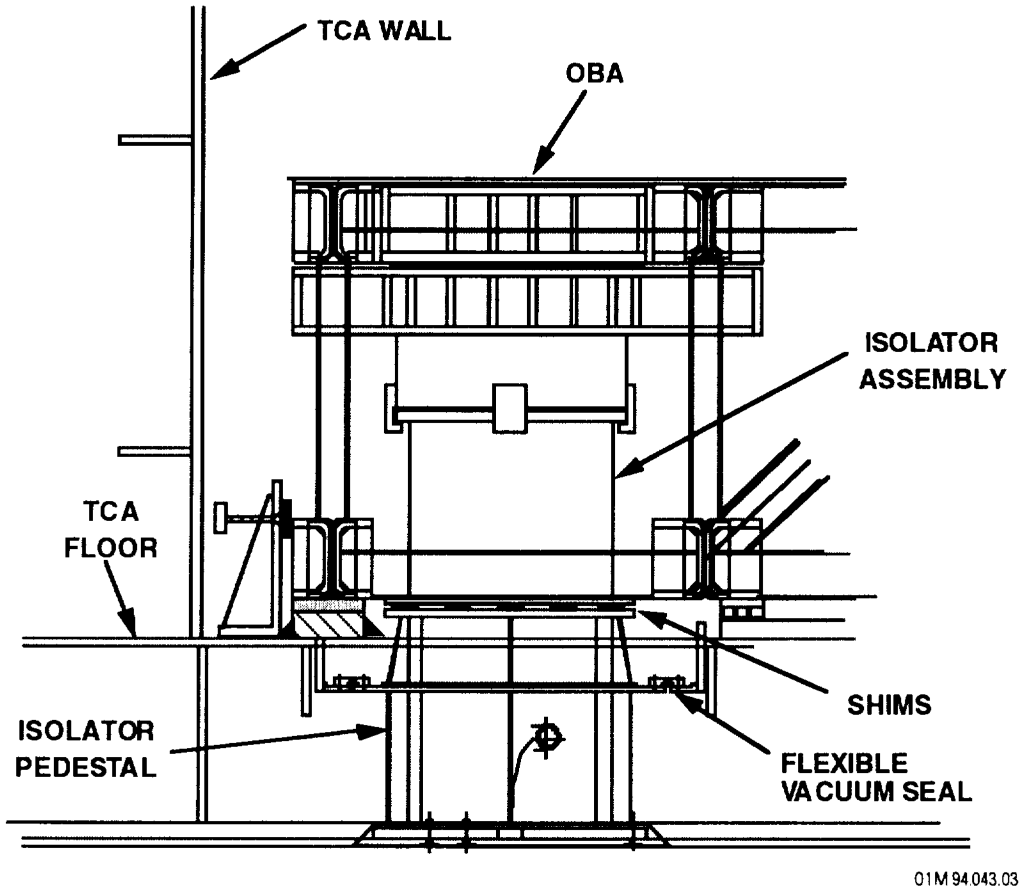


Figure 8. Seismic Disturbance Input



END VIEW LOOKING INTO THE TCA

Figure 9. OBA Isolator Assembly Final Installation

The pneumatic isolators/servo-valve system can be bleeding or non-bleeding. The pneumatic supply gasses are vented external to the TCA. When disturbed, the OBA returns to its nominal position +/- the steady state error in less than 0.5 seconds. Leakage into the TCA as measured by a helium leak detector is less than 10^{-5} atm/cc/sec. The OBA is capable of movement in six degrees of freedom and is limited to ± 1.0 cm (± 0.38 inches) maximum translational movement in each direction. In addition, the OBA rotation is limited to a maximum of 1.0 milliradian rotation about each axis.

Optical Bench Damping

The structural passive damping was accomplished with a tuned mass damper. A tuned-mass damper (TMD), also known as an auxiliary mass damper, is a vibration damping device consisting of a mass and a damped "spring" attached to a structure at or near an antinode of a troublesome mode of vibration. The basic theory is that by adding an oscillator whose own natural frequency is close to that of a troublesome mode, it can impart a force (due to its own resonance) back on the base structure that counteracts the base structure's motion. Since another degree of freedom has been added, another system mode is added, and it is very near the frequency of the target mode. The TMD essentially splits the target mode into two coupled modes of the TMD and base structure, each with high damping. This effect and a schematic spring-mass TMD are shown in Figure 10.

The TMD physical mass was determined from an empirical relationship to be 35.6 Kg (78.5 lbs.). Knowing the mass of the TMD, the spring stiffness was determined by calculating the desired tuning ratio. The TMD frequency at 16.65 Hz results in a lower mode of 16.48 Hz with a damping coefficient of 2.23 and an upper mode of 16.96 Hz with a damping coefficient of 2.37.

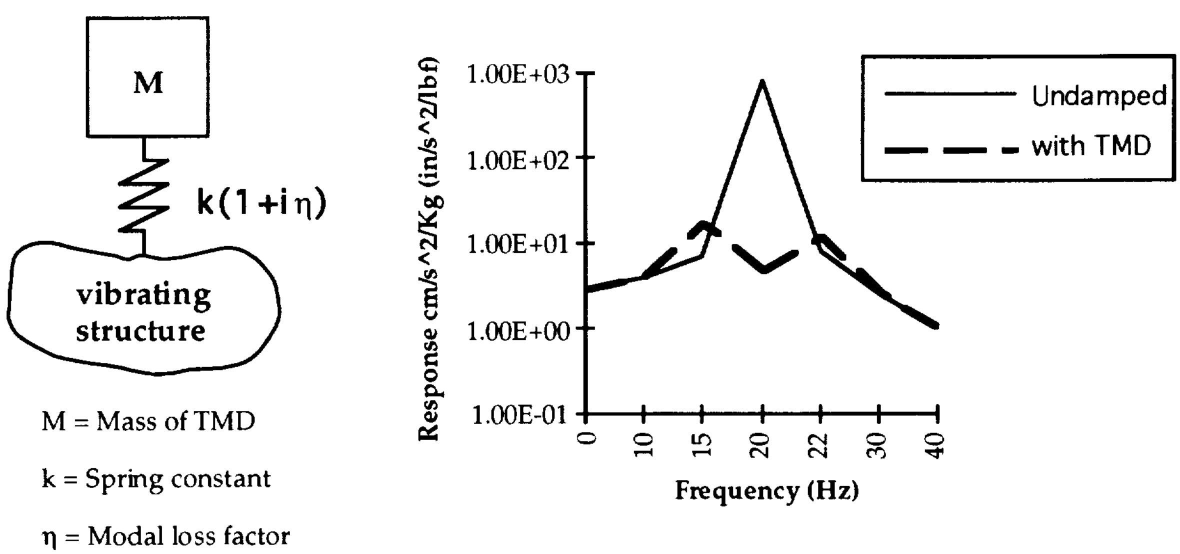


Figure 10. TMD Effects

Conclusion

This space simulation facility provides a cost effective, practical means to demonstrate a Space Based Laser in a realistic ground test environment. It significantly reduces overall program cost as well as minimizes the technical risk before conducting a flight experiment. The facility design provides for upgrades to the experiment hardware configuration and enables the facility to act as a test bed for future developments. Embodied in the space simulation facility design is a mixture of existing facility engineering practices with innovation in certain areas to meet unique requirements, all implemented in a cost and schedule conscious environment.