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MULTIPURPOSE HARDENED SPACECRAFT INSULATION

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ABSTRACT

TRW has successfully developed and implemented a Multipurpose Hardened Spacecraft Multilayer Insulation (MLI) system which meets diverse survivability and performance requirements.

Within the definition and confines of a MLI assembly (blanket), the design:

- a. Provides environmental protection from natural and induced nuclear, thermal, and electromagnetic radiation
- b. Provides adequate electrostatic discharge protection for a geosynchronous satellite
- c. Provides adequate shielding to meet radiated emissions requirements
- d. Will survive ascent differential pressure loads between enclosed volume and space.

This paper describes the MLI design which meets these requirements and discusses design evolution and verification.

The application is for MLI blankets which closeout the area between the laser crosslink subsystem (LCS) equipment and the DSP spacecraft compartment. Ancillary requirements were implemented to ease installation at launch facility and to survive ascent acoustic and vibration loads. Directional venting accommodations were also incorporated to avoid contamination of LCS telescope, spacecraft sensors, and second surface mirrors (SSMs).

As the MLI design matured, requirements were changed or better defined, resulting in a long and tedious conceptualization and testing phase. The challenges to the insulation personnel to accommodate these diverse and dynamic requirements were significant, if not at times painful.

SCOPE

The process undertaken by TRW to develop, verify, and test a MLI configuration that met all requirements was a long and tedious one taking over four years to complete. Several design iterations were required to incorporate ancillary requirements.

The narrative form was used to capture the evolution of the design. The intent of this paper is two-fold:

1. To describe the new MLI configuration that meets diverse performance requirements by documenting its construction and assembly/fabrication methodology

2. To reinforce the need for concurrent engineering (CE) as a major part in any hardware development phase. Lessons learned during this process do well in bolstering this argument.

The appendix presents design criteria as edicted toward the end of the hardware development phase. As sometimes happens in research and development, the actual "requirements definition" package was written after the start of the design phase. An example of the 'tiger team' instead of 'concurrent engineering' mentality.

BACKGROUND

A decision was made at the inception of the program to provide radiation protection to sensitive LCS equipment using hardened MLI closeouts for the open (to space) areas between the DSP spacecraft bay and the LCS radiators. The LCS design, by a separate contractor, was too mature and the weight penalty too large to harden the electronics boxes themselves.

The author believes (hindsight, of course) that this decision might have been different if it was tempered by emphasis on CE activity rather than cost trade-offs.

SUBSYSTEM DESCRIPTION

Figure 1 describes LCS hardware configuration, DSP spacecraft structure (bay), and MLI closeouts. Electronic equipment (mounted to the equipment frame) and the telescope comprise the LCS subsystem. All LCS equipment, with the exception of the gimbaled telescope, is supported by the frame which is mounted vertically in the spacecraft bay. The equipment frame and the telescope are independently supported at the same three points in the bay by essentially separate truss systems.

Second surface mirror radiators are mounted on the front (spacecraft +X) of the electronic equipment to radiate heat outward. These radiators are beryllium and are fairly stiff and light. Detectors and lasers support the two lower radiators and are in turn supported by the optics assembly which is attached by a three point mount to the lower part of the equipment frame. The radiators are attached at their edges to the DSP bay by the LCS MLI closeouts.

REQUIREMENTS DEFINITION AND IMPLEMENTATION

PHASE 1. THERMAL INSULATION BLANKETS HARDENED FOR RADIATION PROTECTION

Initial requirements established the utilization of a tantalum metal foil (0.001 in. thick) within the MLI construction to provide the hardening. This 1 mil thick tantalum foil would provide the radiation hardening equivalent of 0.090 in. thick aluminum. The thin foil was malleable and could be readily formed into the polyimide and polyester MLI shapes. At this point, cognizant engineering groups decided that this would be the optimum and most cost effective method of implementing the hardening requirement. Figure 2A shows the typical construction (Phase I) of the MLI closeouts. The tantalum foil is encapsulated by 1 mil polyimide tape to provide protection from abrasion during forming and assembly into the MLI.

Due to the hardening requirement, the design of the closeouts was predicated on 100% line-of-sight protection from any potential natural or induced nuclear

radiation source in space. Insulation development personnel attacked the problem by assuming that the closeouts, which closed out the spaces between LCS electronic radiators and spacecraft structure, had to "hold water." This analogy served well to implement the "line-of-sight" design requirements.

The three-dimensional shape of the thermal MLI closeout designs required forming of the tantalum to duplicate the thermal MLI shape. This required a significant amount of new fabrication and assembly methodology development. Stress relief holes at corners, normally required in sheet metal or MLI fabrication, could not be incorporated. In this case, any aperture, no matter how small, negated the radiation protection. Workarounds for thin foil forming methods were developed to alleviate this problem.

During the configuration development phase, tantalum barriers were necessary at certain interfaces to support the "line-of-sight" protection requirement. This is shown typically in figure 2B.

A closeup of a typical blanket is shown in figure 3. The blankets shown in the figure are flight-like with the exception of the use of nonperforated plastic films.

After completion of the development and subsequent preliminary blanket drawings, the MLI closeouts were incorporated into a CAD mechanical ICD drawing of the LCS hardware and the spacecraft structure. Line-of-sight analyses were then conducted to determine if the closeout configuration met the radiation protection criteria.

OTHER DESIGN REQUIREMENTS ESTABLISHED DURING PHASE 1

Nylon velcro (hook and pile) interfaces were established as the interface between the LCS hardware and the DSP spacecraft bay. This was driven by (1) LCS contractor hardware was to be integrated into the DSP spacecraft at the launch site facility, and (2) TRW closeouts were to be integrated for several qualification and acceptance tests at both the LCS contractor facility and at TRW. Interface requirements were established as a part of the applicable mechanical ICD.

At this time, standard geosynchronous electrostatic discharge grounding accommodations were incorporated. These included, at that time, outer (space facing) and inner layer VDA grounding with redundant ground tabs.

At the end of this phase, TRW personnel supported thermal-vacuum testing of the LCS at the contractor facility. The LCS thermal-vacuum support fixture somewhat duplicated the configuration of the DSP spacecraft bay into which the LCS was to be integrated for flight. This provided TRW personnel with an excellent opportunity to verify the form and fit of the closeouts and their installability. Various design (shape) changes were incorporated into the closeout design as a result of these "fit-checks" and subsequently incorporated to the ICD.

During this activity, a strawman procedure was cowritten by the LCS contractor and TRW to define mechanical activities and schedule requirements for the activity at the launch site. Integration of the LCS occurs late in the launch preparation sequence, with complex parallel and serial mechanical activities required.

PHASE 2. MLI CONFIGURATION DESIGN MODIFIED DUE TO RADIATED EMISSIONS SHIELDING REQUIREMENTS (EMC ENHANCEMENTS)

Later in the program, requirements were formalized to the insulation group based on the electromagnetic shielding effectiveness characteristics of the closeouts. Electromagnetic compatibility (EMC) became an issue after the LCS electrical interface requirements were well defined.

Tailored requirements were established for the closeouts after samples of the current closeout design were tested for EMC effectiveness. The closeouts would provide the LCS equipment with a degree of shielding effectiveness equivalent to at least 20 dB of attenuation between 14 kHz and 18 kHz with the following exceptions:

- a. Between 10 MHz and 20 MHz, the closeouts shall provide at least 10 dB of attenuation
- b. Between 1 GHz and 2.4 GHz, the closeouts shall provide at least 35 dB of attenuation.

These criteria significantly impacted the closeout configuration design insofar as their assembly. Enhancements to the design included primarily:

- a. A change to conductive stainless steel velcro interfaces (MLI to spacecraft and MLI to LCS radiators)
- b. The use of conductive epoxy (Ecco-Bond 57C) for all metal-to-metal interfaces (i.e., metalized velcro to tantalum).

The MLI construction incorporating these requirements is shown in figure 4. Solutions were more complex than just changing to metalized velcro. All metal-to-metal surfaces and interfaces had to be contiguous. Implementation necessitated some structural changes to the DSP spacecraft bay. Adding secondary support brackets, to simplify the complicated geometry of the spacecraft at the velcro faying surfaces, was required. The locations in question are shown in figure 5. The "as-is" interfaces were altered to facilitate velcro installation and bonding. The modifications incorporated into the spacecraft bay design are depicted in figure 6.

Figure 7 shows a typical grounding tab implemented into the MLI to meet EMC requirements. Ground-to-structure is through the metalized velcro interface.

At this point, project management decided that the thermal insulation closeouts were now taking on significantly more performance characteristics and were multi-purpose in their function. It became necessary to capture all requirements with a "specification" identifying all design criteria. Germane excerpts from this specification are included in the appendix. Paragraph 3.3.2 of the appendix delineates, in detail, the design criteria incorporated for the closeouts as a result of the EMC effectiveness testing.

Writing this specification required that all players (engineering disciplines) gathered together to identify interdependencies and impacts. Concurrent engineering activity at last.

PHASE 3. MLI CONFIGURATION DESIGN MODIFIED DUE TO CONTAMINATION REQUIREMENTS/CONCERNS

A concern that surfaced during the writing of this specification, was the effects of contamination on the LCS telescope. Contamination of the LCS SSM radiators and another TRW sensor installed on the +Z surface of the spacecraft were secondary concerns.

The MLI closeout design included stainless steel velcro interfaces around the periphery of the individual closeouts to attach them to the TRW spacecraft structure and to the LCS radiators. The concern was that during ascent, particulate contamination entrapped in the bay would vent through the velcro interfaces and deposit on telescope, sensors, and SSMs. Contamination analysis validated these concerns resulting in a requirement to seal the velcro interface by overtaping with polyimide tape. Overtaping negated the purpose of the velcro interfaces since now the closeouts would not be easily removed and reinstalled. Calmer heads prevailed as schedule time for this activity was included as part of the final integration activities at the launch facility.

This change also forced a change in base aluminized plastic materials comprising the multilayer construction of the blankets. In the original design, blanket venting itself occurred through the edges of the assembly. With edges now sealed, a change to perforated aluminized plastic filler and outer layer materials was made. Analysis of the particulate contamination available within the MLI itself was also made. Results were acceptable and the change approved.

The contamination issue resulted in a major design change to incorporate a vent in one of the closeouts. Vent design and size was driven by differential pressure requirements during ascent (0.1 psid). Its location and direction of discharge was critical as was EMC shielding requirements. The vent design is described in figure 8. Vent EMC design criteria is described in the appendix, paragraph 3.3.2.2.

ACOUSTIC DEVELOPMENT TEST

The MLI closeout designs were frozen. A flight-like set of the closeouts was fabricated and were installed into a structural test configuration (see figure 9) of the LCS and the DSP spacecraft. Open areas between LCS SDM radiators and spacecraft bay are shown in figures 10A and 10B. These same areas with MLI closeouts installed are shown in figures 11A and 11B. A closeup of the insulated assembly is shown in figure 12. The purpose of the test was to verify their capability to withstand the predicted acoustic environment to be imposed during ascent. Test requirements for this acoustic test are presented in the appendix, paragraph 4.1.2.1.

The test was successful and TRW breathed a sigh of "its over and we made it." A closeout design that meet all (it was believed) requirements was finally on paper.

PHASE 4. MLI CONFIGURATION DESIGN MODIFIED DUE TO LAUNCH ACOUSTIC/VIBRATION ENVIRONMENTS (RADIATOR DEFLECTIONS)

As it turned out it was not true. Data was published reporting the results of static analysis using an analytical model of the LCS and spacecraft. The impact of this data on the closeout design needed to be understood.

Relative movements between the radiator edges and DSP will result from both the high frequency acoustic and structure-borne vibration and from the low frequency flight loads vibrations. At any point in flight there will be vibrations from both frequency ranges. Test or analysis cannot normally treat both effects simultaneously, so they are commonly treated separately as was done for the MLI closeouts.

The closeout performance during high frequency acoustic and structure-borne vibration was verified during the aforementioned acoustic test.

To understand the impact of the closeouts on the radiators during flight load events in the low frequency region, the only type of analysis available at this time was static analysis using peak accelerations. Load factors for this analysis were determined from "final design load cycle" results for the Titan and the shuttle. Since redesign of the closeouts was in process, waiting for more comprehensive deflection data, from coupled loads or base shake analysis efforts planned in the future, was not an option.

From the structural dynamics point of view, equipment (mounted to the equipment frame) and the telescope are primary mass components. Detectors, lasers, lower radiators, and optics assembly account for about 116 lb of the approximately 300 lb subsystem.

The radiators, which are attached to the spacecraft bay by the closeouts, must be able to accommodate any relative movement between radiators and structure since the only load path intended is through the three point mount.

Static analysis data indicated that worst-case relative displacements across the LCS/DSP interface were:

MAXIMUM RELATIVE DISPLACEMENT IN EACH DIRECTION (in.)*

dX	dY	dZ	Z Level
0.112	0.067	0.031	LR lower edge
0.099	0.067	0.031	LR upper edge
0.077	0.067	0.028	DR upper edge
0.063	0.051	0.023	ER lower edge
0.063	0.053	0.023	ER upper edge

* TRW document, IOC L122.2.90-103, "LCS/DSP Closeout Compliance Requirements," from E. A. Verner and A. J. Dunn, dated 11 May 1990.

These values include 10 mil (3σ) for the acoustic response in the X direction normal to the radiators (see figure 13) to account for the acoustic (high frequency) vibrations. A factor of 1.4 was recommended to show adequate margin for qualification, considering the inconsistencies in installation.

The impact on the current design had to be evaluated. Could compliance of the closeouts accommodate the expected relative displacements as defined by the data presented above?

COMPLIANCE TEST

Compliance testing was in order. A simplified test was designed to verify whether the current design could withstand expected deflections. Fabrication of a test article that duplicated the worst case configuration as defined by the data was needed.

The test article was approximately a 1 ft² assembly duplicating the two lower edge (+Z) laser radiator corners (at + and -Y). Full size representations of the 211-1, -2, and the -209 closeouts were fabricated. Since the test article was approximately 1/3 as wide (Y axis) as the flight article, a proportionally sized vent box was incorporated to duplicate its effect on the compliance of the MLI corner assembly (test article is shown in figure 14).

Upon initial installation of the test article in the fixture, a nominal (flight integrated) separation between laser radiator edge and spacecraft structure was established. The test encompassed: first compressing (-dX) the test fixture attachment plate (laser radiator simulator) by 50% of the maximum (dX = 0.157; worst-case = LR, lower edge + margin) required per the data in the above table; and then tensioning (+dX) the same distance.

The first test (one cycle) resulted in failure of the bond line at the corners, between velcro and simulated radiator. After two weeks of "intensive" brainstorming (the tiger-team mentality), involving design reviews of alternate concepts to make the MLI corner assembly more compliant, a candidate was selected. A test article incorporating this "flexible" design was fabricated. Basically this design incorporated a joint/corner (between the -209 and -211 closeouts) with a built-in convex curvature. This curvature would act like a "spring". Setting it at nominal distance (dX) upon installation would essentially precompress this "spring," allowing it to be further compressed when loaded in the -dX direction and expand when tensioned in the +dX direction.

Another test was performed using the same setup as before, but subjecting the assembly to 100 cycles. The result, failure at the velcro hook and pile interfaces themselves. Failure meant that separation of the hook from the pile exceeded the maximum allowed gap of 0.050 in.

LET US "DO IT RIGHT" APPROACH

Never has the saying "...back to the drawing board" been more appropriate. At this time a total redesign of the MLI closeout laser radiator joint/corner configuration was undertaken. Supporting the MLI design group were members of the stress, structures, and material engineering groups ("It is never too late for CE"). The knowledge base acquired to date served well in identifying and eliminating design concepts that would adversely affect the EMC enhancements, the radiation protection criteria, and the installability concerns. Acceptance of the design was also predicated on proving that the closeouts would survive acoustic and vibration loads during ascent without any loss in performance. By this time, the "closeout design problem" had manifested itself as a 'show stopper' to project, company, and customer. Extreme interest in "solutions" was the byline from all interested persons.

Previous compliance testing, as described above, only subjected the closeouts to deflections in one axis (X). In flight, loads would be applied simultaneously in all three axes causing deflections in all three directions.

It was obvious that a test program to simultaneously load a full size test article (radiator) in all three axes was not practical or cost effective.

FULL SIZE MOCKUP

The next best thing was to design and fabricate a full scale, high fidelity and dynamic mockup of the LCS/spacecraft bay assembly. The design will incorporate a worm gear assembly attached to the simulated radiators. This assembly will allow the radiators to traverse in the X and Y axes (Z axis deflections negligible) from any point within the envelope created by the required deflections (+ margin).

A flight-like set of the closeouts will be installed on the mockup for demonstration purposes. Actuation through all axes will be possible. Interim visual inspections and photographic documentation will reveal any failures at the velcro interfaces or at the Ecco-Bond lines.

SUCCESS (IS IMMINENT)

The design is "not on paper" as of this writing. Assembly of the mockup and integration of the closeouts will occur in September 1990. We fully expect to demonstrate acceptable compliance using the dynamic mockup. It is five years since the design and verification process started. We did our "real" concurrent engineering work in the fourth year.

CONCLUSION

Sometimes implementing requirements into the hardware design goes well, sometimes it does not. This narrative provides a good example of when it does not. When I first wrote this paper, it was not as a narrative but was written in the classical "technical paper" form. The latter form, I thought, did not lend itself in meeting my two objectives.

"Cost and schedule" is what we all live by in this industry. Hindsight shows that implementing radiation protection within the MLI was probably the wrong decision when incurred costs are used as the measuring tool. Five years ago, hardening the LCS equipment electronic boxes would probably have cost less even with the weight penalty. Five years ago, understanding the importance of concurrent engineering would probably have facilitated the design and verification process of hardening through the use of MLI. Performance requirements/criteria could have been implemented as shown in figure 15. That is the significance of the lessons learned during this process.

Technically, we at TRW gained a lot of valuable experience.

a. The technology of hardening spacecraft structure and/or hardware through the multilayer insulation is valuable and will certainly be used again.

b. The assembly and fabrication methods to enhance the EMC shielding effectiveness of MLI will also be beneficial to other applications.

Insofar as schedule, "luck" played a big part in schedule considerations. The need date for the hardened MLI flight hardware somehow kept slipping due to other reasons not associated with the MLI design problem. Five sets of very expensive closeouts are not required until late next year.

APPENDIX

HARDENED MLI CLOSEOUT SPECIFICATION

Today's design for the MLI closeouts encompass a diverse and complex set of requirements which have successfully been implemented for flight application.

Germane excerpts from the governing specification are presented here. (Extracted from TRW Document IOC L125.2.90-005, "EQ Spec for LCS Closeouts Revised per 1-4-90 Meeting," from J. Lloyd Petty, dated 22 Jan 1990.)

3. CHARACTERISTICS

3.1 Functional Description. The closeouts function as follows:

- a. Complete the thermal enclosure of the sensor components when mounted to the spacecraft body.
- b. Provide line-of-sight protection of sensor electronic equipment (boxes) from prompt radiation through the use of a tantalum layer in the MLI blanket.
- c. Provide easy access to sensor equipment by being removable using velcro fastener systems.
- d. Provide vent of ambient pressure from the sensor compartment during launch. Vent will not allow a line-of-sight path to contamination-sensitive surfaces.

3.1.1 Functional. The closeouts help to maintain thermal balance while protecting the sensor equipment from natural and induced radiation. The closeouts will be electromagnetically compatible with other spacecraft subsystems and will be grounded for protection against electrostatic discharges.

3.1.2 Pressure/Altitude, Venting. The vent design shall ensure that the maximum delta pressure from inside to outside the sensor compartment is less than 0.1 psi.

The ambient pressure characteristics during STS ascent/descent are defined in EV1-48, and for Titan IV ascent in figure A-1.

3.1.2.1 Natural and Induced Radiation. The sensor shall be protected from the natural and induced radiation environment as defined in (applicable TRW document). There shall be no line-of-sight radiation permitted to strike the sensor electronic components (boxes).

3.1.2.2 Weight. The weight of a set of closeouts shall not exceed 4 lb.

3.2 Environmental Conditions. The closeouts shall be designed to withstand or shall be protected against the worst probable combination of environments as specified below, and shall operate as specified herein without performance degradation.

3.2.1 Operating Environments

3.2.1.2 Pressure/Altitude. The closeouts will be capable of operating at atmospheric pressure between sea level and $10E-10$ torr (verifiable to $5 \times 10E-5$ torr).

3.2.1.3 Acoustic Field. The closeouts shall be designed to withstand the acoustic environment imposed by the launch vehicle during launch and ascent as defined in 3.3.6 of EV1-48.

3.3 Design and Construction. The closeouts design shall be in accordance with the requirements herein.

3.3.1 Parts, Materials, and Processes

3.3.1.1 Materials and Processes. Only materials and processes conforming to all requirements (applicable TRW document) shall be considered standard and shall be used. The approved materials and processes shall be as specified in (applicable TRW document).

3.3.1.2 Dissimilar Metals. Protection of dissimilar metal combinations shall be in accordance with MIL-STD-889. The worst-case environment, including storage, shall be considered.

3.3.1.3 Magnetic Materials. Magnetic materials shall be used only if necessary for equipment operation. Those magnetic materials used shall cause minimum permanent, induced, and transient external magnetic fields.

3.3.1.4 Fungus-inert Materials. Materials that are nutrients for fungus shall not be used when their use can be avoided. Materials shall be treated in accordance with MIL-T-152 if not hermetically sealed. If materials are used in a hermetically sealed enclosure, fungicidal treatment will not be necessary.

3.3.1.5 Finish. All surface finishes shall meet the environmental, bonding, and thermal property requirements as specified in DOD-E-8983.

3.3.1.6 Outgassing. Low outgassing polymeric materials shall be used where sensitive thermal control and other surfaces are in direct line-of-sight and where temperature differences can exist between such surfaces. Materials shall be selected for low outgassing per (applicable TRW document).

3.3.1.7 Insulating and Dielectric Materials. Not applicable.

3.3.1.8 Thermophysical Properties. The thermophysical properties of the thermal materials used in the closeout design are the same as summarized in (applicable TRW document).

3.3.1.9 Contamination Control

3.3.1.9.1 Contamination Path. The vent design shall allow no contaminants a line-of-sight path to the optical sensor, radiator mirrors, or surfaces of sensors and detectors.

3.3.1.9.2 Closeout Surface Cleanliness. At scheduled general cleanings and prior to final closeout installation, the exterior and interior surfaces of the closeouts shall be free from such visible contamination as scale, particles, corrosion, dirt, grease, oil, or other foreign materials when examined under white light (to 150 fc) from a distance of 1 to 2 ft as specified in (applicable TRW document).

3.3.1.9.3 Allowable Molecular Levels. Prior to final closeout installation the allowable molecular deposition levels on the internal and external surfaces shall be $<0.001 \text{ g/ft}^2$ as specified in (applicable TRW document).

3.3.2 Electromagnetic Compatibility. The sensor closeout will provide the sensor equipment compartment with a degree of shielding effectiveness. The closeouts shall provide at least 20 dB of attenuation between 14 kHz and 18 MHz with the following exceptions:

a. Between 10 MHz and 20 MHz, the closeouts shall provide at least 10 dB of attenuation.

b. Between 1 GHz and 2.4 GHz, the closeouts shall provide at least 35 dB of attenuation for the sensor not to interfere with or be interfered by (applicable satellite) communication links.

3.3.2.2 Vent Openings Shielding. All vent openings shall be designed to provide shielding effectiveness which is not less than 35 dB of attenuation between 1 GHz and 2.4 GHz.

3.3.2.3 Mating Joints. Conductive hook and pile fastener tape (velcro or equivalent) shall be used on all closeout/spacecraft, closeout/radiator, closeout/radiator cover, and closeout/closeout mating joints. The fastener tape shall be replaced after 11 cycles of attachment/detachment.

3.3.2.4 Fastener Tape Attachment. The fastener tape shall be bonded to the closeout tantalum layer with ECCO-Bond 57C. The fastener tape shall be continuous along the circumference of the individual closeouts and the sensor's spacecraft equipment bay except at corners where the fastener tape is cut and butt joined. The maximum gap between pieces of tape at the corners and butt joints shall be 0.05 in.

3.3.2.5 Fastener Tape Resistance. The dc electrical resistance, measured through the thickness of the fastener tape prior to bonding, shall be 2 ohms maximum.

3.3.2.6 Sealing of Fastener Tape With RTV. The primary around the edge of the fastener tape shall be filled with a bead of RTV, to entrap the ECCO-Bond within the bonding area of the fastener tape.

3.3.2.7 Sealing of Fastener Tape Interfaces. Clear kapton tape shall be applied, continuous or overlapped, to cover edges of mated hook to pile fastener tape.

3.3.2.8 Apertures

3.3.2.8.1 Fastener Tape Mating Surfaces. Using magnification, there shall be no clear aperture with a linear dimension greater than 0.05 in along any of the fastener tape mating surfaces.

3.3.2.8.2 Tantalum Layer. Using magnification, there shall be no clear aperture with a linear dimension greater than 0.05 in. in the tantalum layer.

3.3.2.9 Staples for Added Strength. Corrosion resistant steel staples, which may be used to provide additional strength to the bond of fastener tape to the MLI closeouts, shall not be removed from the blanket once installed.

3.3.2.10 Tantalum Sheet Lap Joints. All bonding of the closeouts tantalum sheet lap joints shall be done with ECCO-Bond 57C, and shall extend along the entire length of the bond joint.

3.3.3 Grounding of Closeouts

3.3.3.1 Ground Design. The closeouts shall be grounded to the spacecraft structure by means of conductive fastener tape. The ground shall include the outer layer of MLI, the tantalum foil layer used for radiation shield, and the inner layer of MLI.

3.3.3.2 Grounding Levels. The dc electrical resistance measured from any point on the closeout surface through the fastener tape to the adjacent spacecraft structure shall be 35 ohms maximum for EMC for electrostatic discharge (ESD).

3.3.4 Mechanical Compliance

3.3.4.1 Induced Loads. The induced load levels shall result in a positive margin of safety in the sensor.

3.3.5 Interchangeability. Each closeout shall be directly interchangeable in form, fit, and function with other closeouts of the same part number.

3.3.6 Safety. The closeouts shall be designed to meet the requirements of NHB 1700.7, paragraph 209-3 (flammable material).

3.3.7 Human Performance/Human Engineering. TRW will follow the applicable human engineering standards established in MIL-STD-1472.

4. QUALITY ASSURANCE PROVISIONS

4.1 General. Quality assurance controls for fabrication, inspection, and testing of the closeouts shall be in accordance with (applicable TRW document).

4.1.1 Failure Criteria. The closeouts shall exhibit no failure, malfunction, or out-of-tolerance performance or degradation as a result of examinations and tests specified herein. Any such failure, malfunction, out-of-tolerance performance, or degradation shall be cause for Material Review Board action. Retest requirements shall be in accordance with MIL-STD-1540.

4.1.1.2 Government Inspection. The procuring agency, or its designated representative, shall have the option to witness all formal tests, all environmental exposures, pre- and post-exposure examinations of tested items, and to verify all test equipment and calibration data.

4.1.2 Development Tests

4.1.2.1 Acoustic Test. An acoustic test shall be performed on a test of representative flight-like closeouts when installed between the structural development model of test sensor and the spacecraft test model. The test shall verify their capability to withstand the predicted acoustic environment to be imposed on the closeouts in flight.

Test Requirements

a. The closeout test articles shall be subjected to a broadband random incidence sound field with an overall pressure level of 145.2 dB (re: 0.0002 dyne/cm²).

b. The octave band sound pressure levels shall be as specified in Table II, column 3 of EV1-48A.

c. The acoustic environment shall be applied to the test article for a period of three minutes.

4.1.2.2 Shielding Effectiveness Test. The closeouts' shielding effectiveness shall be demonstrated by conducting a laboratory test using an EMC engineering approved test sample.

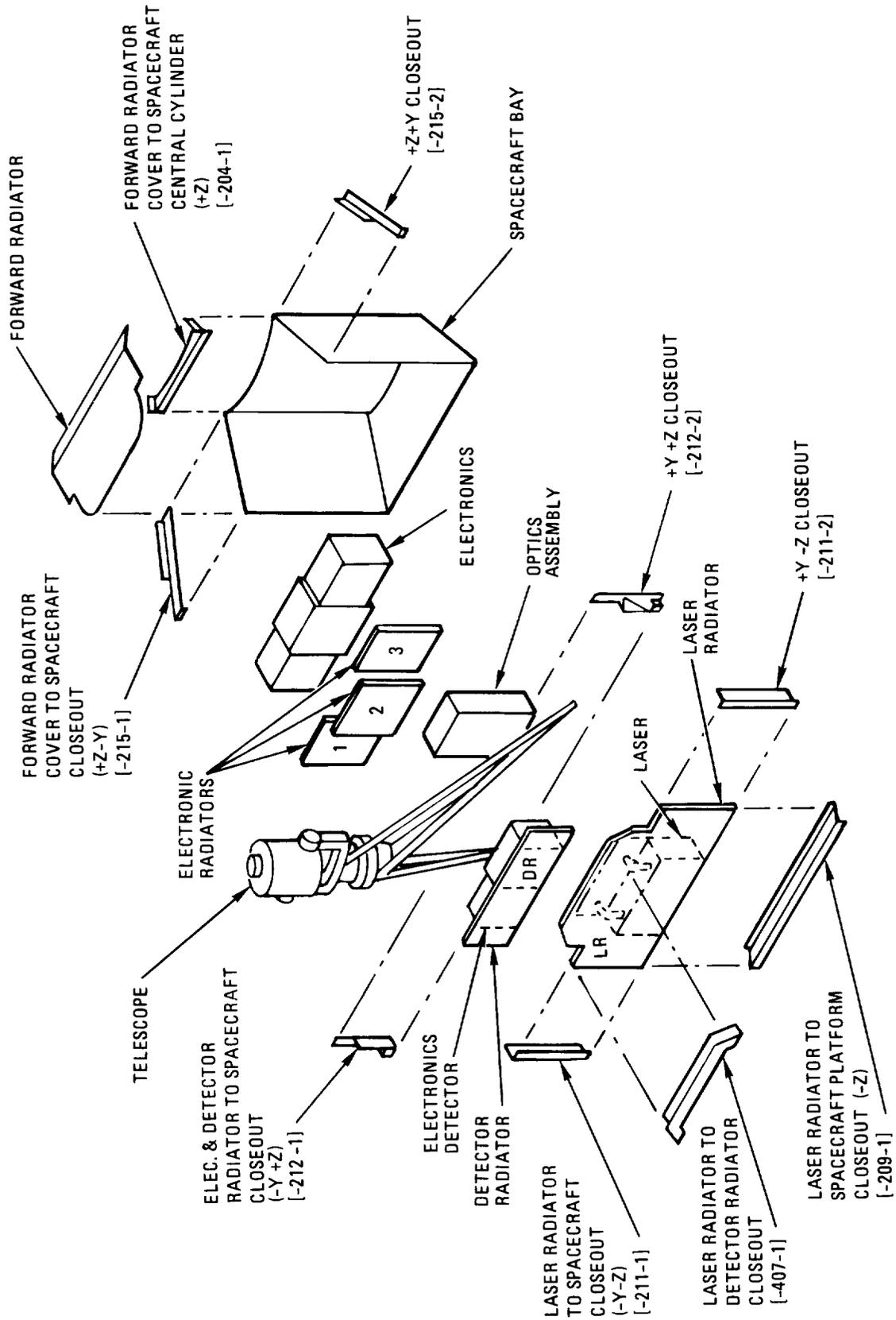
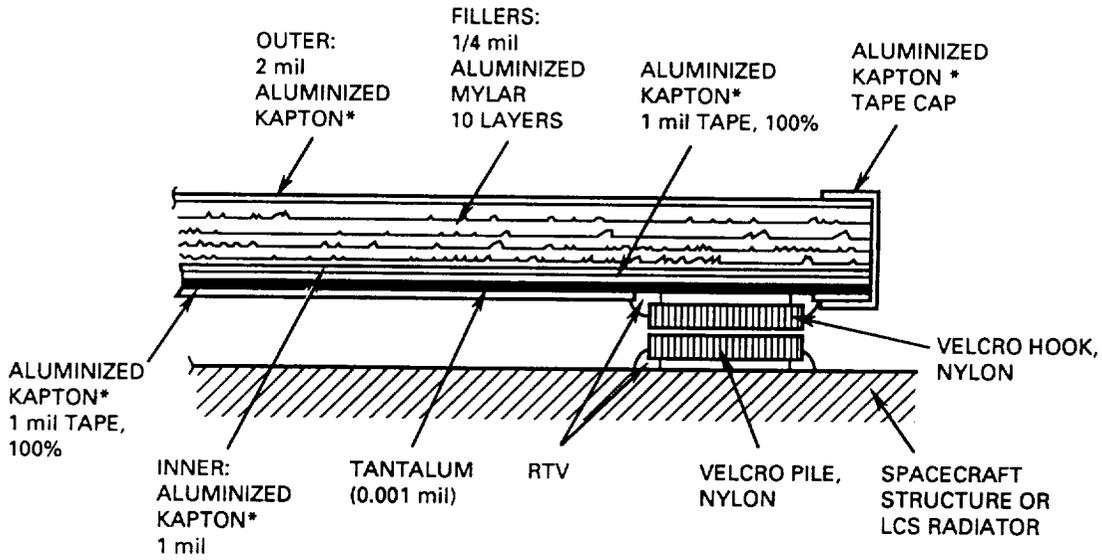


Figure 1. Laser Crosslink Subsystem (LCS) Closeouts - Overview



* ® KAPTON IS A REGISTERED TRADEMARK OF THE DUPONT CORPORATION

Figure 2A. MLI Closeout Cross-Section, Typical Construction (with tantalum)

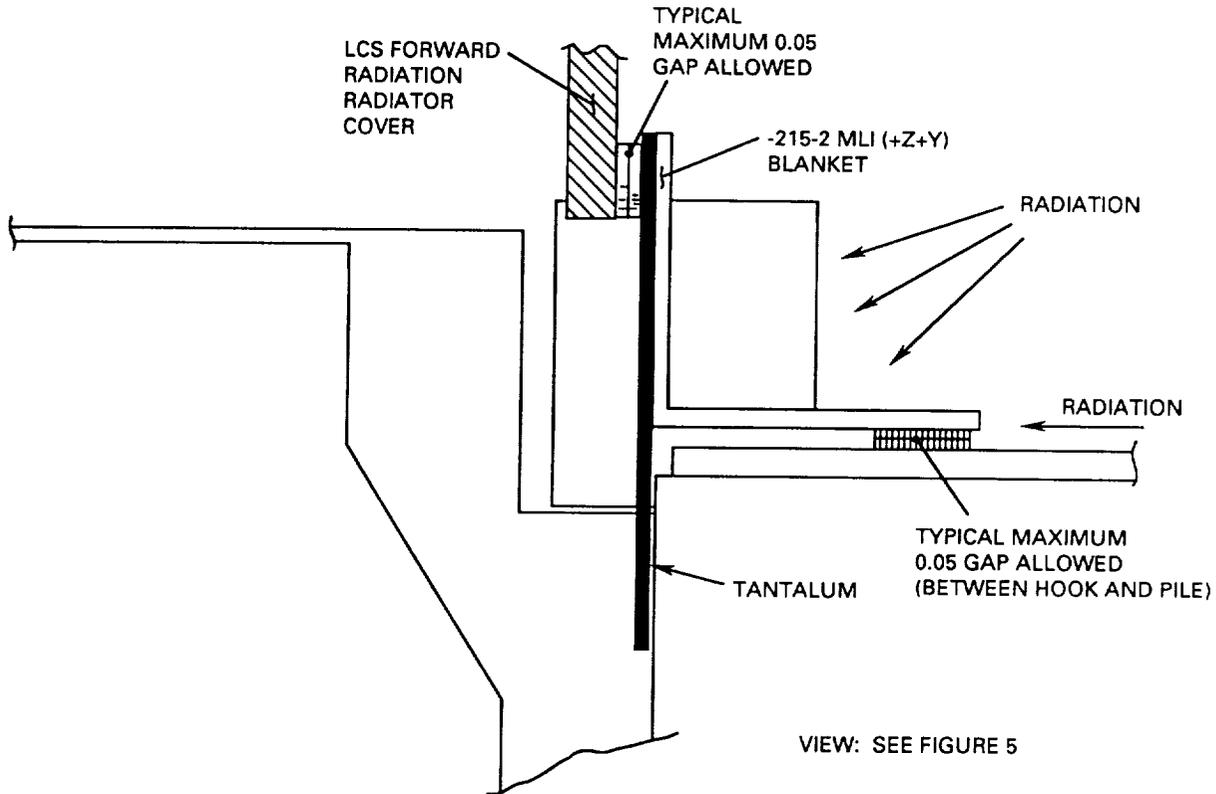


Figure 2B. Typical Tantalum Barrier Closeout Design Radiation Protection Method; Typical for 100% Line-of-Sight

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

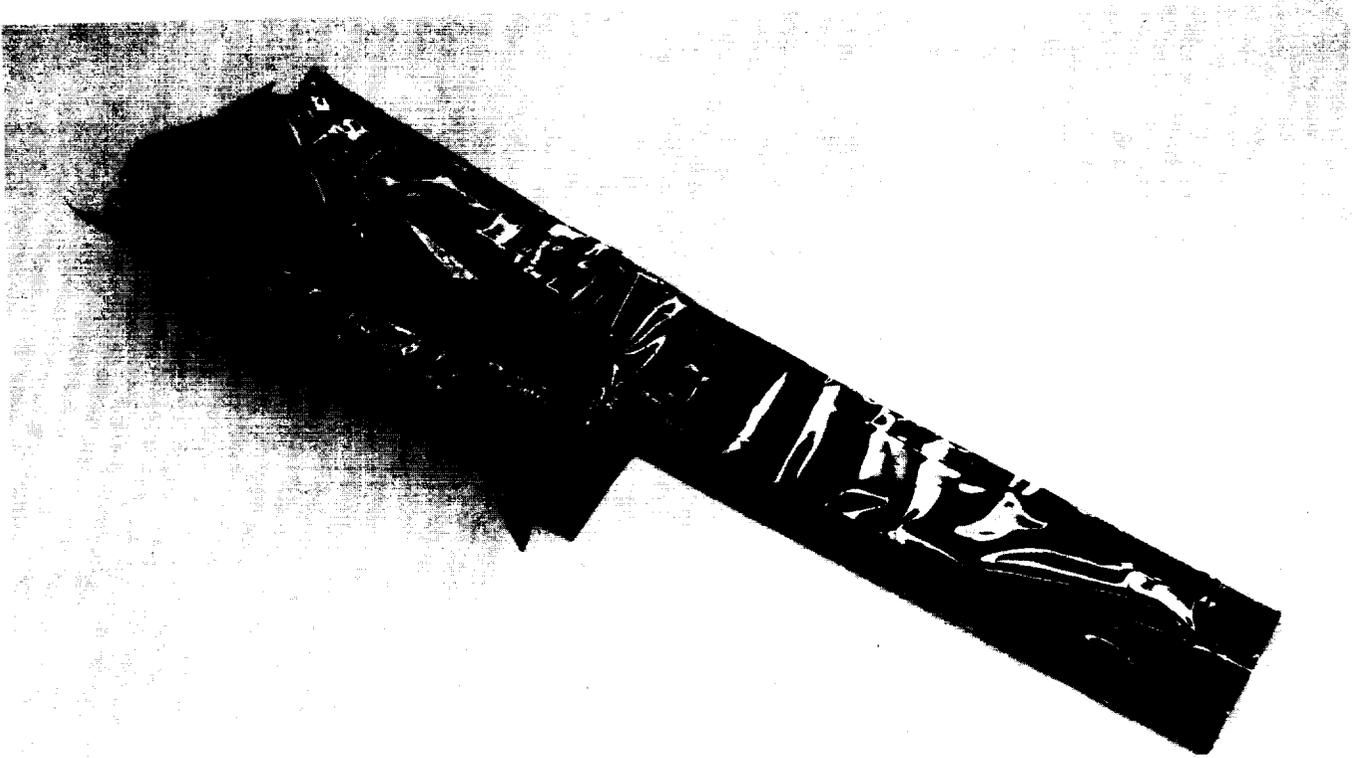


Figure 3A. LCS MLI Closeout (-212)

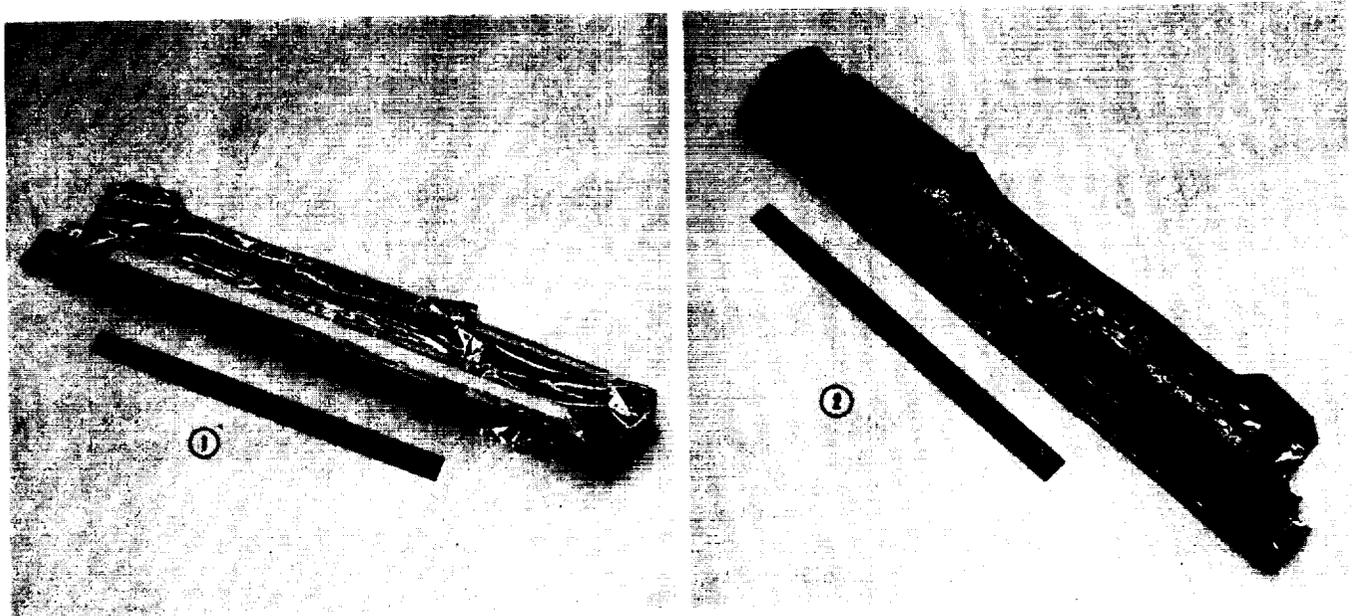
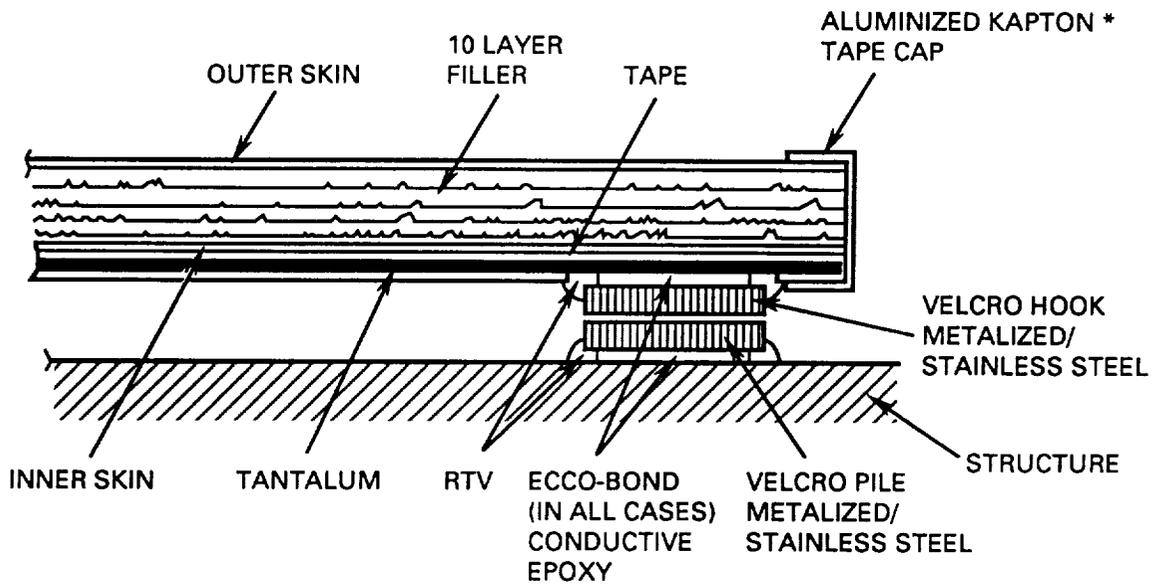


Figure 3B. LCS MLI Closeout
[(1) -215 space side; (2) -215 structure side]



* ® KAPTON IS A REGISTERED TRADEMARK OF THE DUPONT CORPORATION

Figure 4. Typical MLI Closeout Construction with EMC Enhancements

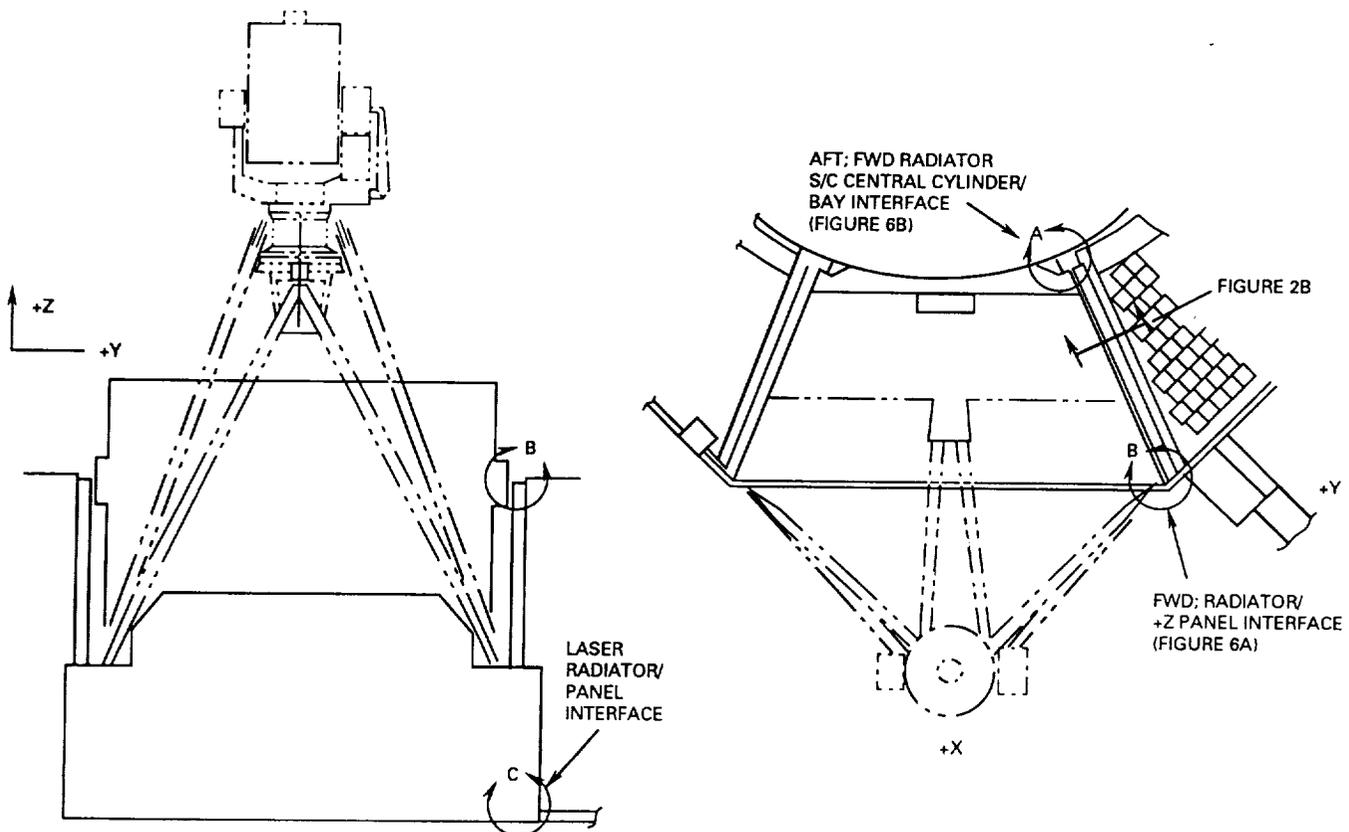
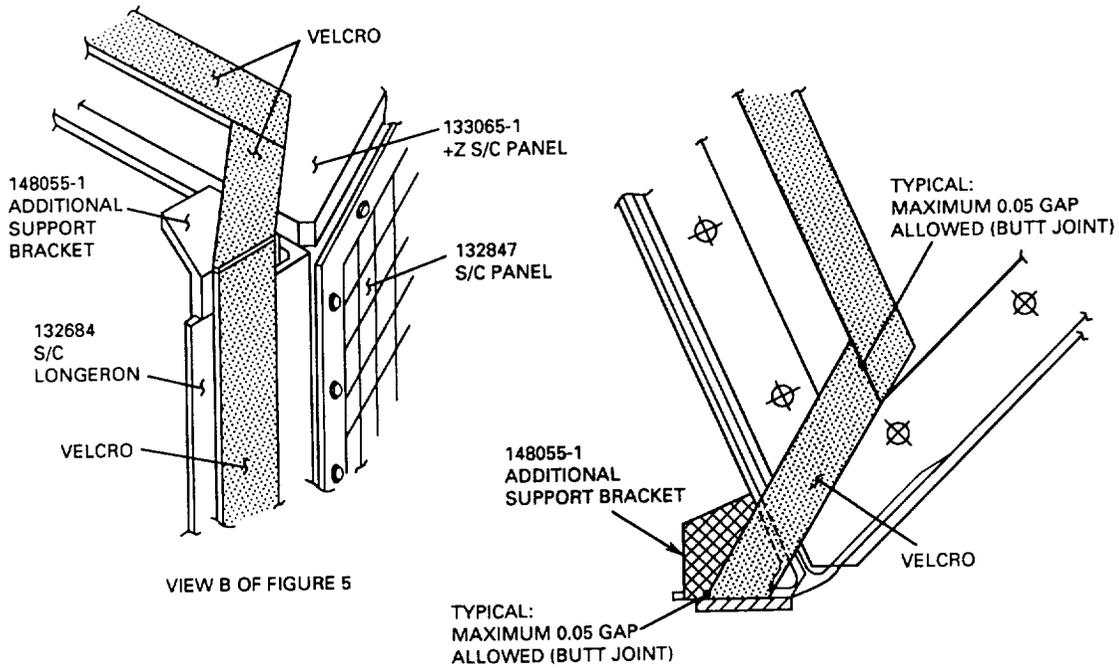
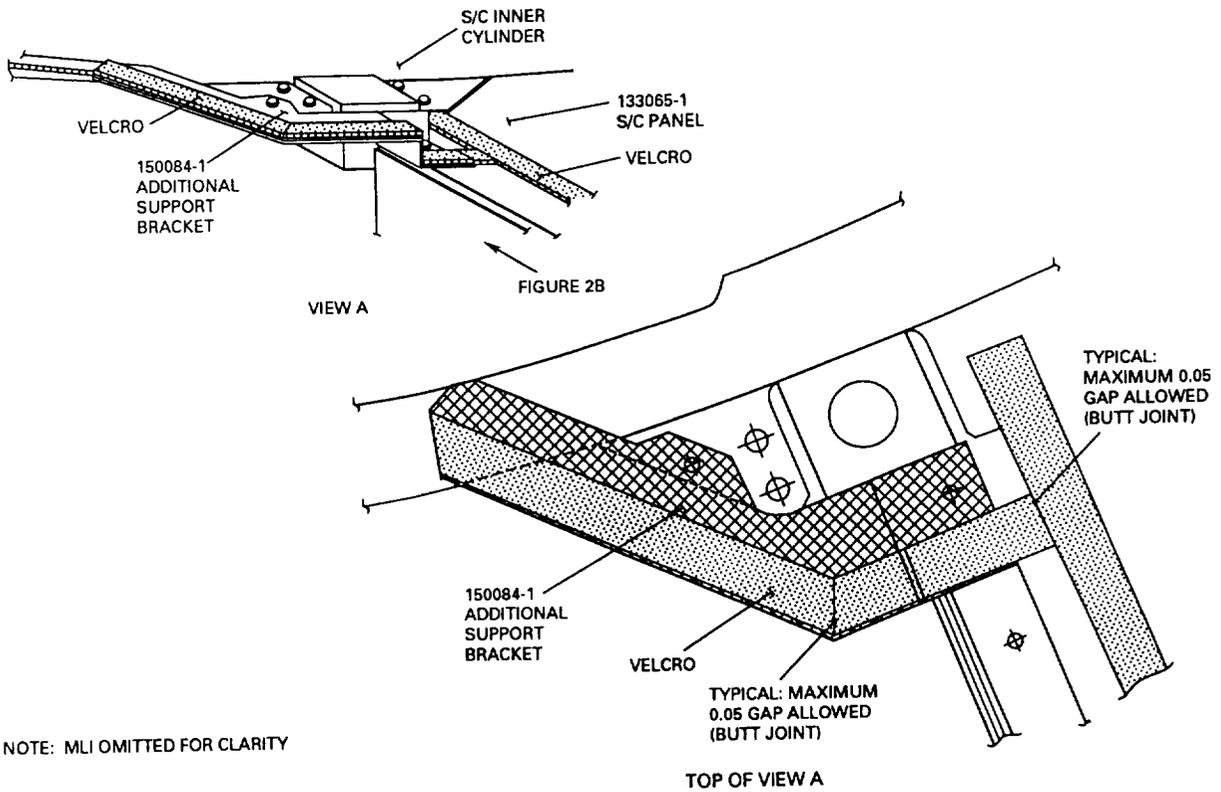


Figure 5. LCS/Spacecraft Bay Assembly - Overview



NOTE: MLI OMITTED FOR CLARITY

Figure 6A. +Z FWD Spacecraft Bay Interface; Continuous Stainless Steel Velcro/Bond Method; Modifications for EMC Enhancements Implementation



NOTE: MLI OMITTED FOR CLARITY

Figure 6B. +Z Aft Spacecraft Bay Interface; Continuous Velcro/Bond Method; Modifications for EMC Enhancements Implementation

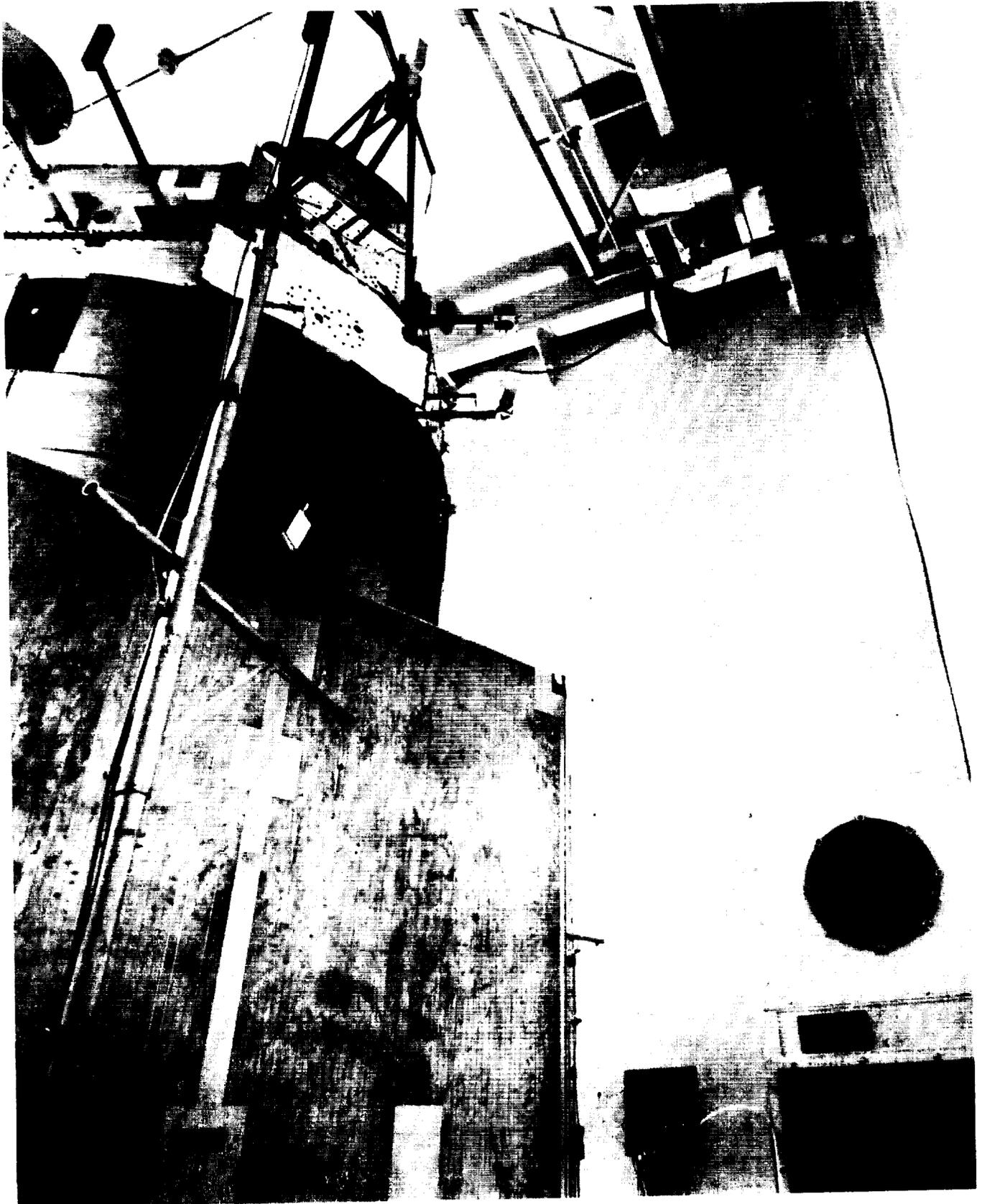


Figure 9. LCS Structural Development Model and DSP Structural Test Model
(preparation for acoustic test)

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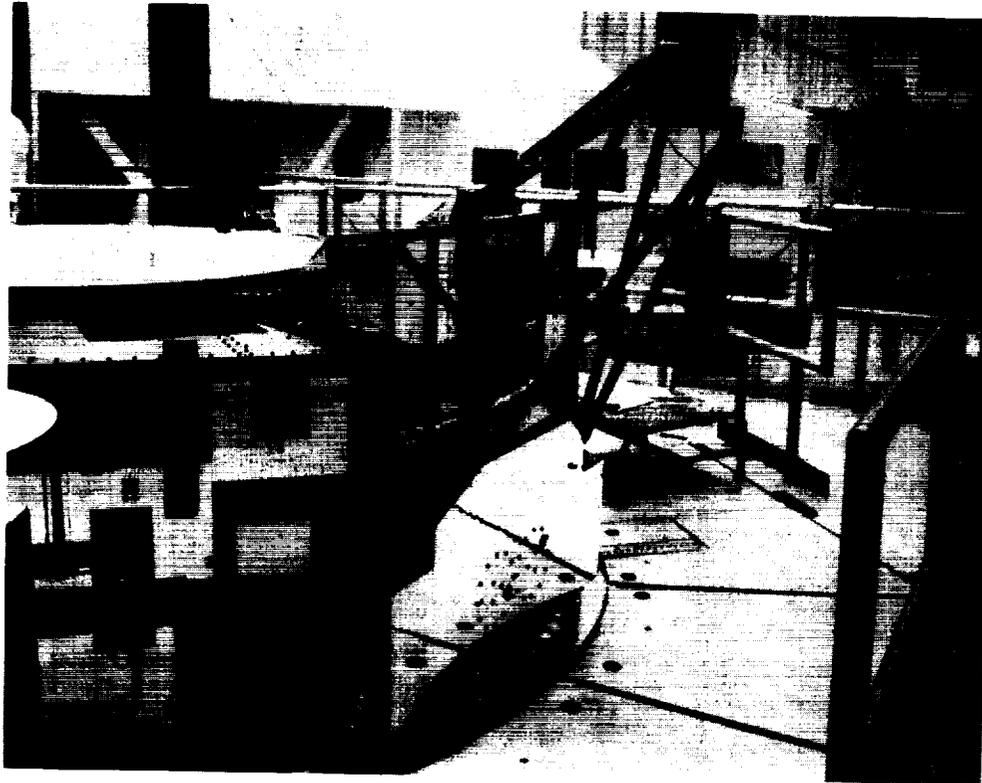


Figure 10A. LCS SDM/STM Acoustic Test Article (-Y View)



Figure 10B. LCS SDM/STM Acoustic Test Article (+Y View)

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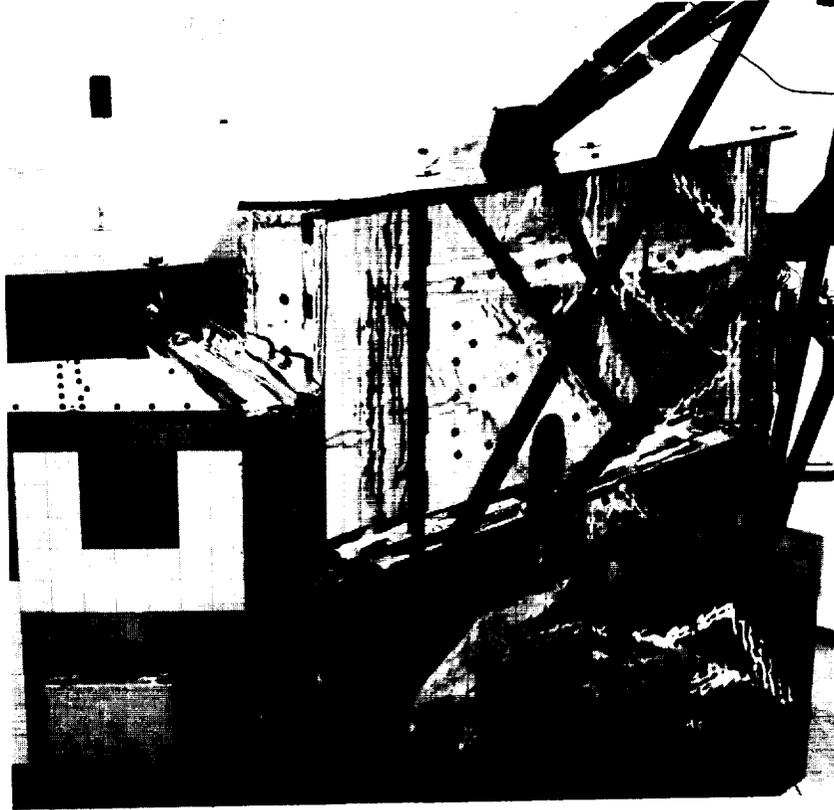


Figure 11A. LCS SDM/STM Acoustic Test Article With MLI Closeouts (-Y View)

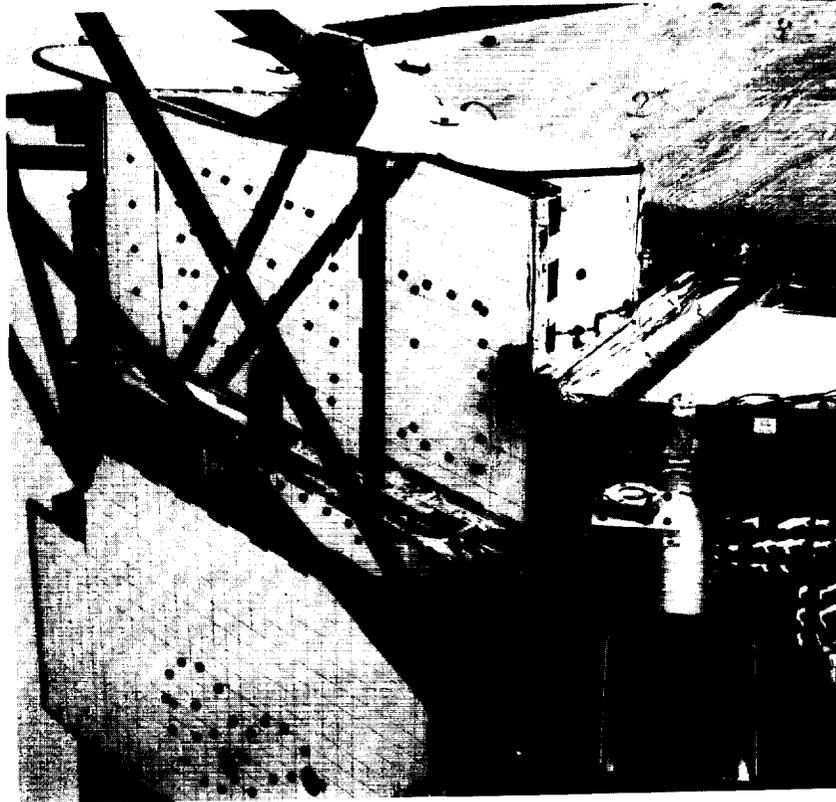


Figure 11B. LCS SDM/STM Acoustic Test Article With MLI Closeouts (+Y View)

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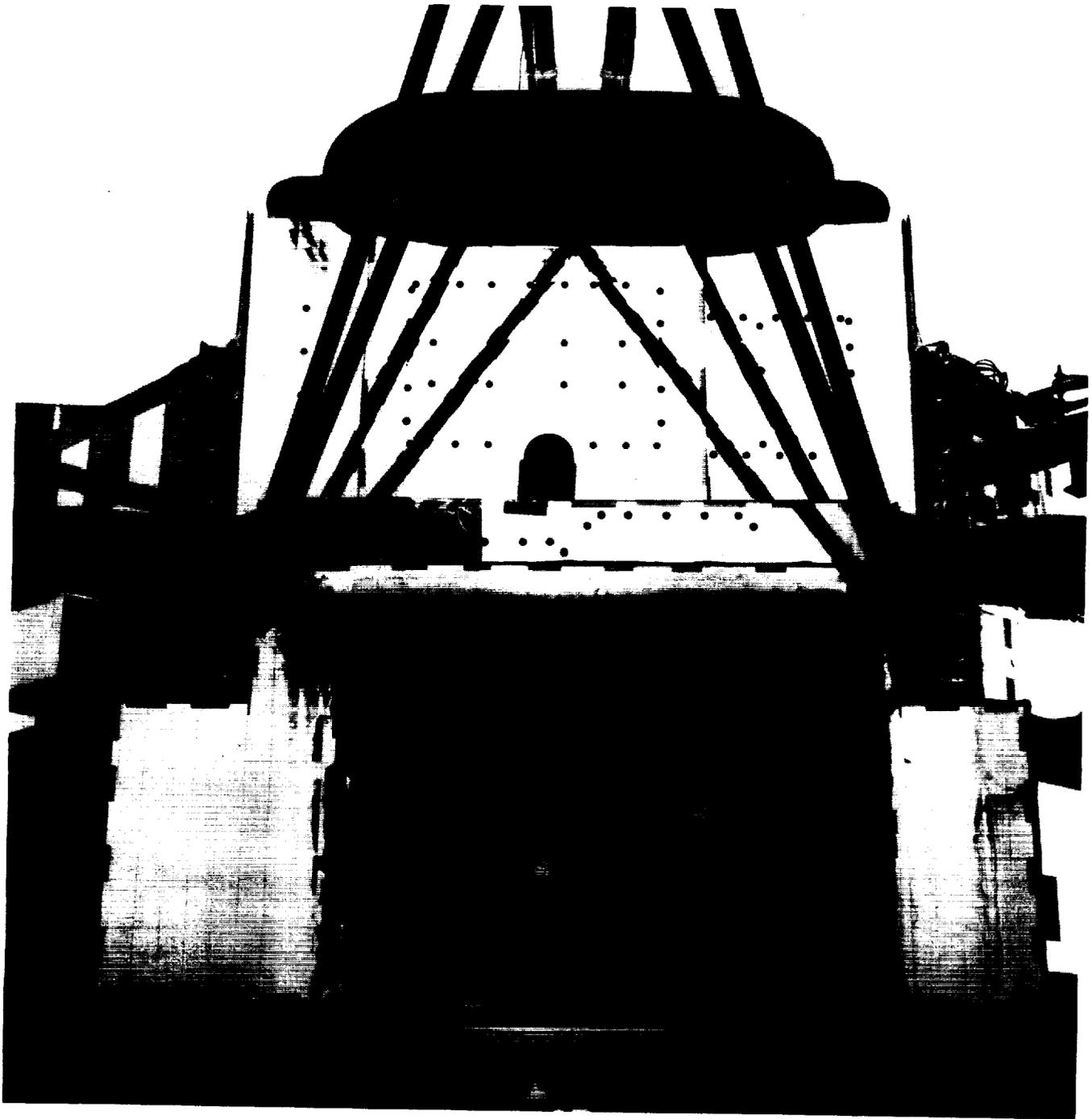


Figure 12. LCS SDM/STM Acoustic Test Article (Front View)

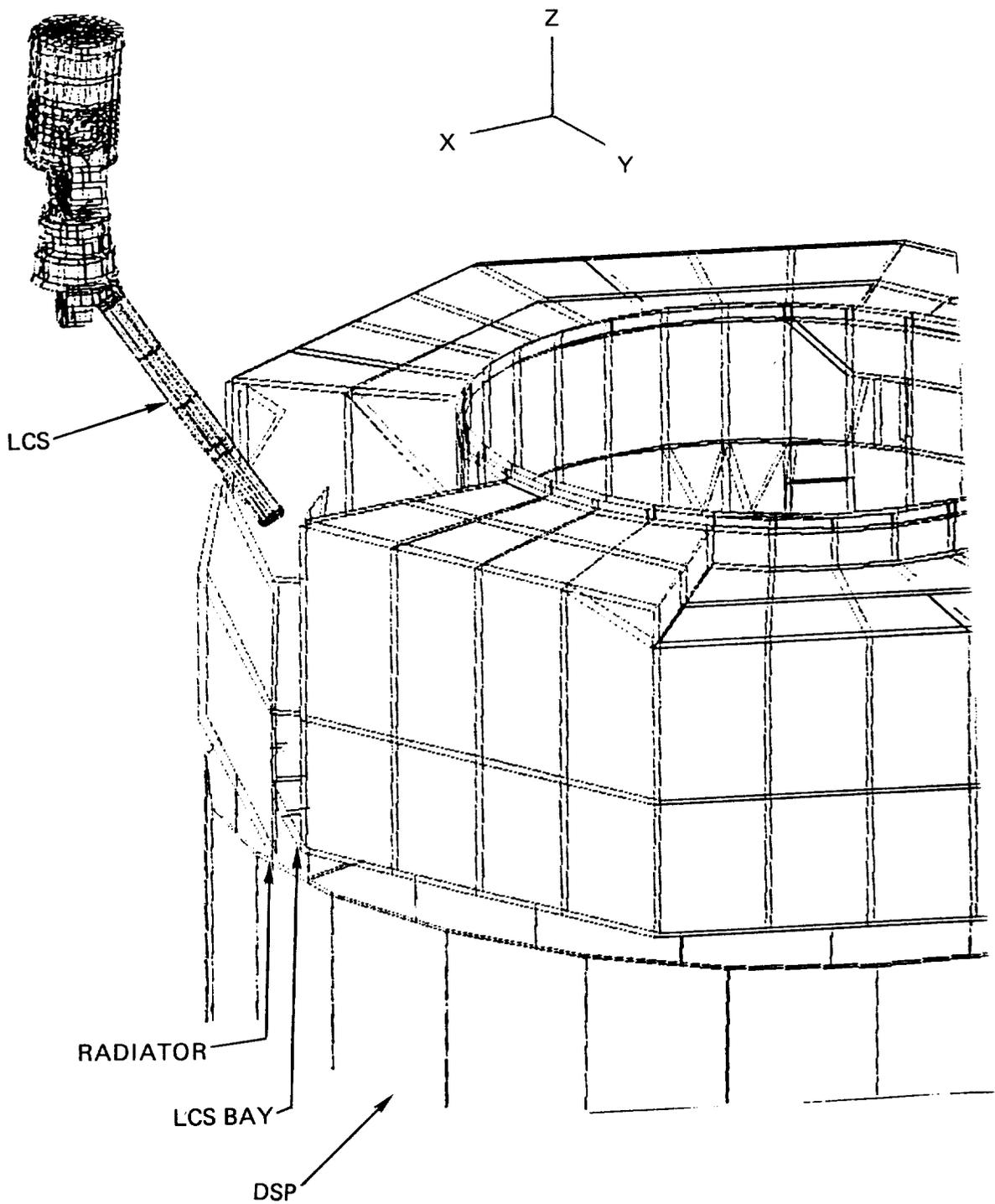


Figure 13. Static Displacement Plot of DSP/LCS Coupled Model
(one load case)

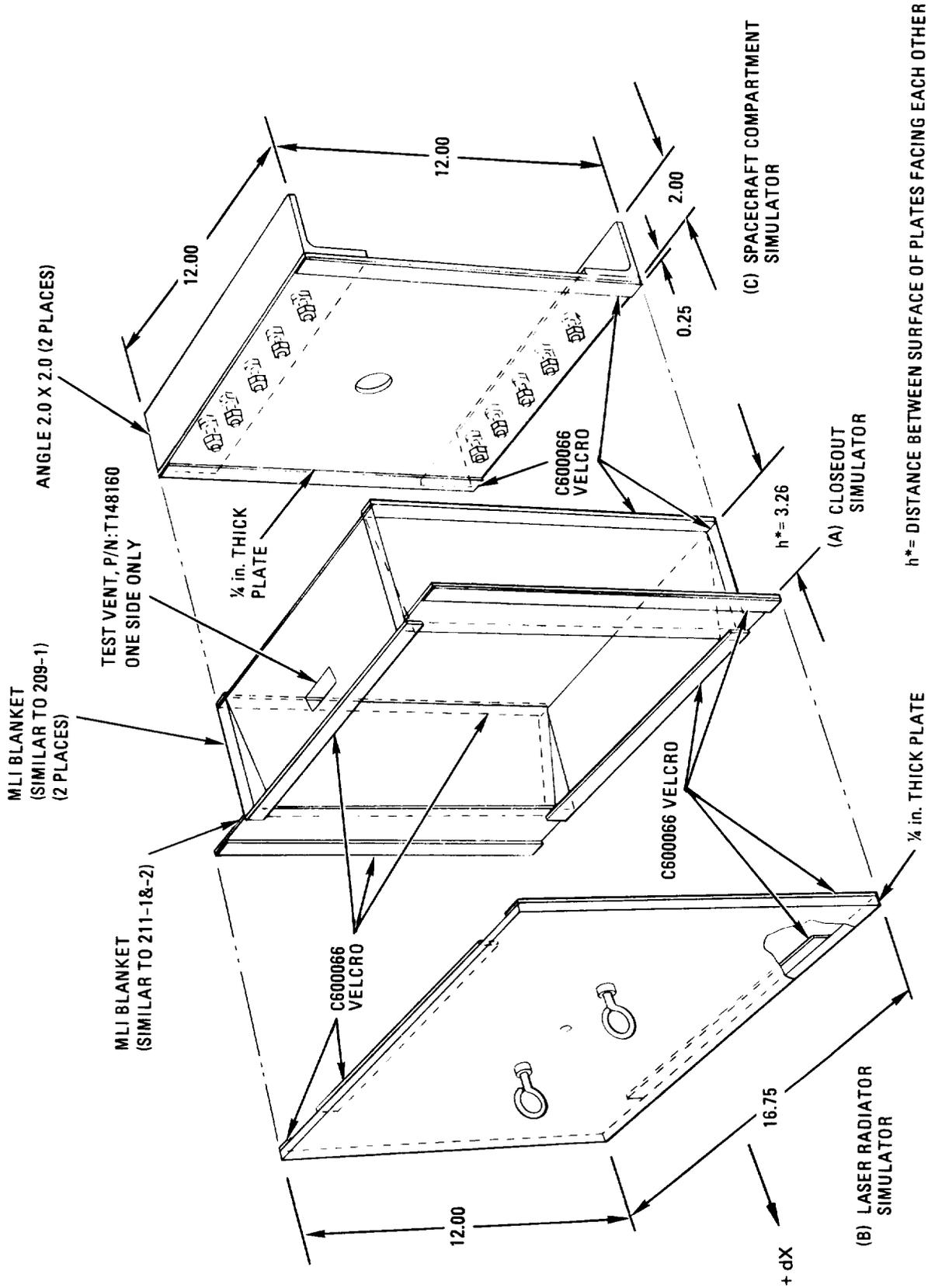
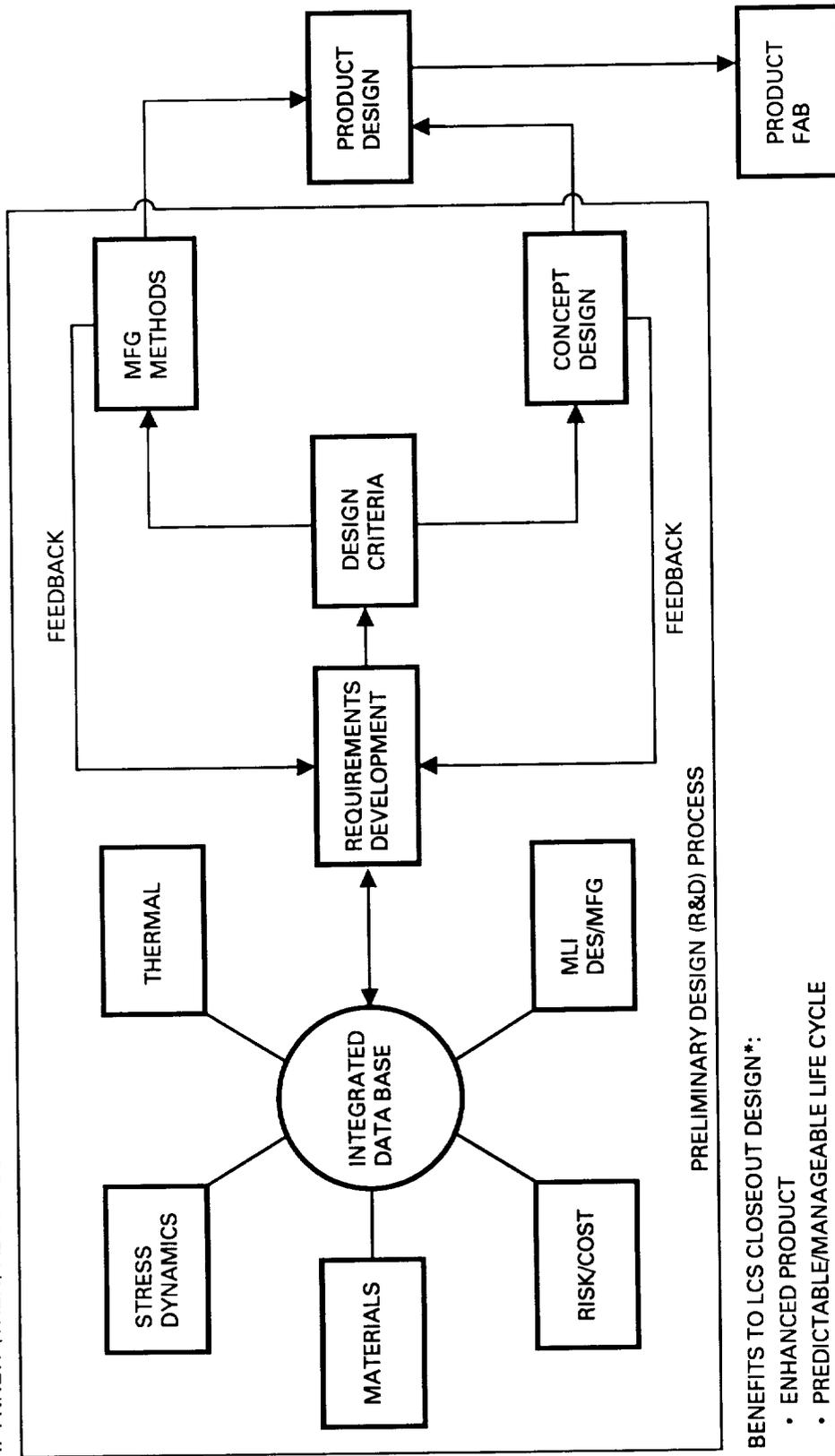


Figure 14. MLI Closeout Compliance Test Article/Test Setup

IF I KNEW (THEN) ABOUT CONCURRENT ENGINEERING



PRELIMINARY DESIGN (R&D) PROCESS

BENEFITS TO LCS CLOSEOUT DESIGN*:

- ENHANCED PRODUCT
- PREDICTABLE/MANAGEABLE LIFE CYCLE
- COMPRESSED DESIGN CYCLE
- REDUCED COSTS (EOs, SCRAP, REWORK, NONVALUED ADDED TASKS)
- SHORTER MANUFACTURING CYCLE

* TO ANY PRODUCT DESIGN

Figure 15. Concurrent Engineering Applied

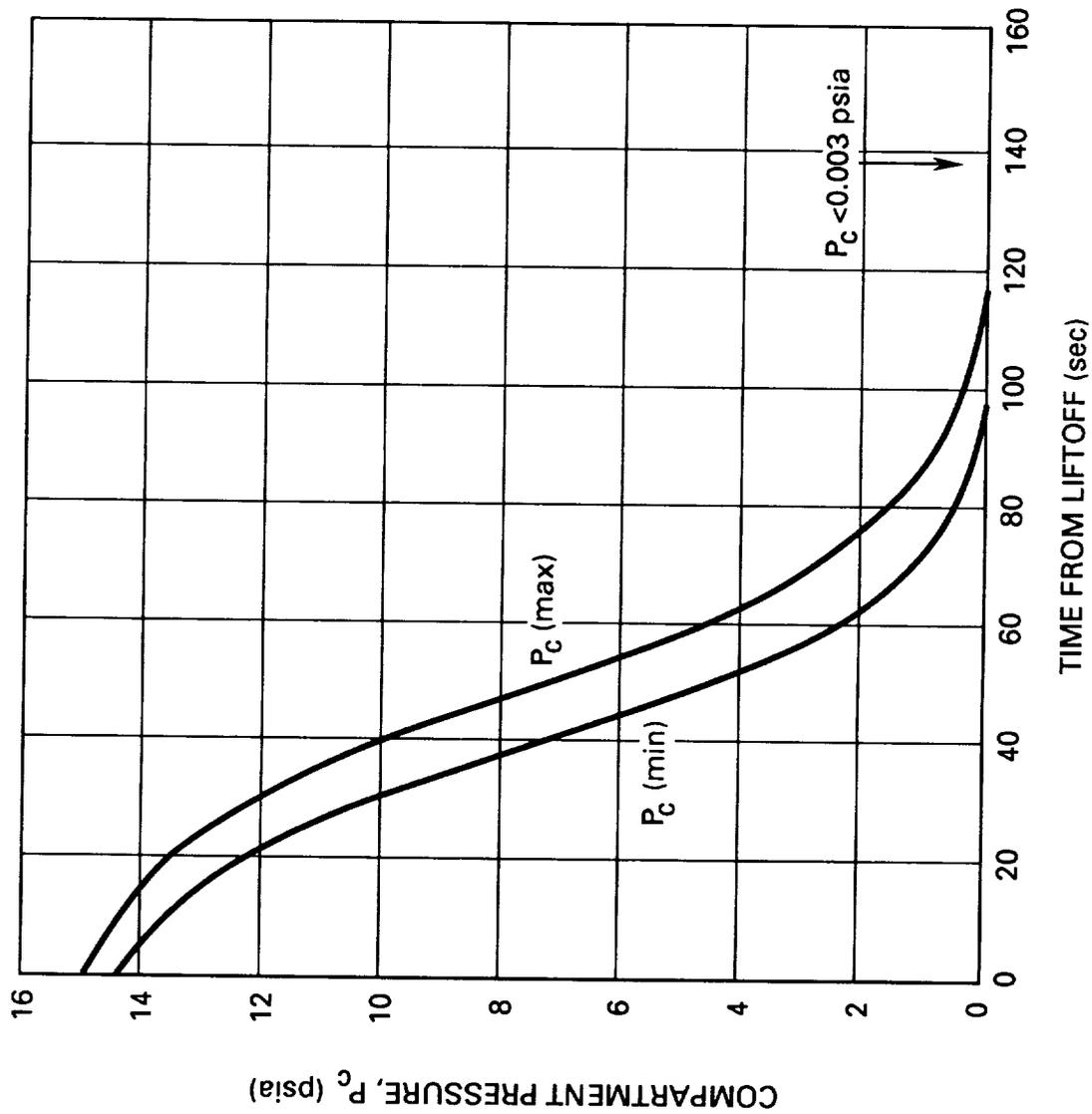


Figure A-1. Titan IV Pressure History During Ascent