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LIGHTNING PROTECTION SYSTEM
FOR
SPACE SHUTTLE

PREPARED BY
PLANNING RESEARCH CORPORATION
Systems Services Company
for
DESIGN ENGINEERING
JOHN F. KENNEDY SPACE CENTER, NASA

August 1977

DESIGN ENGINEERING DIRECTORATE

National Aeronautics and
Space Administration
John F. Kennedy Space Center

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Lightning Protection System
For
Space Shuttle

May 17, 1976

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SECTION I

INTRODUCTION

1.1 PURPOSE

The purpose of this study is to evaluate the suitability and cost effectiveness of using a lightning mast for the Shuttle Service and Access Tower (SSAT) similar to the type used for the Apollo Soyuz Test Project (ASTP) Mobile Launcher (ML).

1.2 SCOPE

The study presents evaluations in five areas:

a. ASTP launch damage to mast, mast supports. grounded overhead wires, and the instrumentation system

b. Modifications required to permit reusing the ASTP mast on the SSAT

c. Comparative costing factors per launch over a 10-year period in repetitive maintenance and refurbishment of the existing and modified masts, mast supports. grounded overhead wires, and ground instrumentation required to sustain mechanical and electrical integrity of the masts

d. Effects of blast testing samples of the ASTP ML-type mast (corrosion and electrical flashover)

e. Comparison of damages from ASTP launch (item a) and from blast testing (item d)

The areas of evaluation are covered in the following sections of this study.

SECTION II

ASTP LAUNCH DAMAGE

2.1 MAST

The lower portion of the mast and environment were inspected at 1000 hours EDT on 16 July 1975, 18 hours after the ASTP launch. Although the mast was subjected to a certain amount of heating, it appeared undamaged. The outer coating of the mast was still uniformly shiny and solid on all sides, and a coin-tapping test indicated no delamination or voids within the fiberglass body (figure 2-1). During launch, the visible portion of the rocket plume apparently passed the mast without contacting it.

The top of the mast was inspected on 12 November 1975 after removal of the mast assembly from the Launch Umbilical Tower (LUT). Both mast and sheave assembly appeared unaffected by the heat and vibration of the ASTP launch.

2.2 MAST SUPPORTS

The metal at the base of the mast and the platform below appeared undamaged during the 16 July inspection. Paint on the support members was not burned or scorched. The sides of the crane housing showed no effects from the launch. Even the black vinyl tape used on cables and some plastic tubing was unaffected (figure 2-2).

However, black-and-yellow safety tape used on lower portions of the mast platform supports was affected (figure 2-3). This tape was used to fasten sponge rubber bumpers in place. The sponge rubber, not heat resistant, was burned or heated until it was pulverized and chunks blown off. The tape itself was extensively melted and virtually destroyed. Since these materials are not heat resistant, this damage proved that the area had indeed been subjected to at least a minor degree of heating. The safety tape did not support combustion and showed no evidence of fire; it was melted, but not scorched or burned.

The damaged bumper pads on all four platform supports were low enough so that the crane housing shielded some of them from the horizontal blast of the rocket. The pads at all four locations received about the same amount of damage, indicating that most heat impulse probably came from above.

The glass lens was cracked on one of the floodlights used to illuminate the mast. This damage may have been incurred prior to launch; breakage from lamp heating has been a problem.

2.3 GROUNDED OVERHEAD CABLE

On 16 July 1975 the grounded overhead (catenary) cable was inspected from mast support platform and ground levels during a post-launch damage inspection. Initial evidence indicated no damage; apparently the rocket's visible plume

Figure 2-1. Lightning Mast After the ASTP Launch

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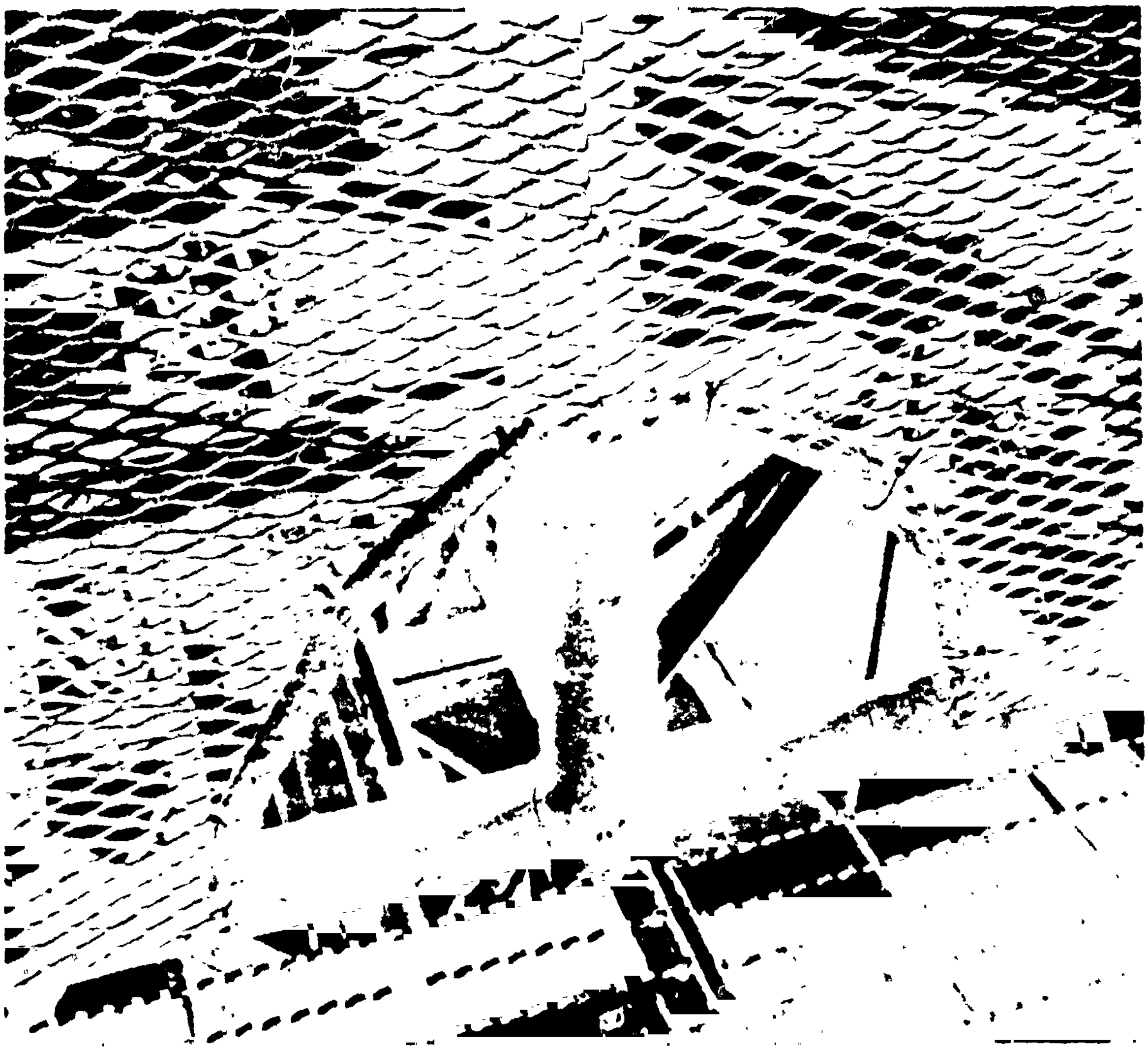

Figure 2-2. Plastic Tubing After Exposure to ASTP Launch Radiation

Figure 2-3. Safety Tape and Sponge Rubber Bumper Damage Caused by Heat Radiation During the ASTP Launch

did not contact the cable so that the degree of heating was similar to that near the crane and the mast. The cable appeared to have withstood the vibration of launch without damage.

On 7 October 1975 approximately 1500 feet of the grounded catenary cable was removed from the ASTP LUT at Launch Pad 39B. Cable was removed from the east and west sides of the LUT in two equal section , each extending from ground level to a point approximately 103 feet from the top of the lightning mast. Both sections of the cable were closely inspected by three engineers for physical evidence of lightning stroke attach, particularly the stroke that hit the east cable at 1713:07 hours EDT, 9 June 1975. No pit marks were found in either cable section. All marks found could be attributed to handling, although surface rust would have obscured any minor pitting. Rust appeared uniformly distributed along the east and west cables.

On 12 November 1975 the center section of the catenary cable was inspected after removal of the lightning mast assembly from the LUT. This cable section, which is approximately 206 feet long and retained by the sheave assembly, hangs in equal lengths from the top of the mast assembly. Rust was present on the cable and no pitting was observed. The only evidence of lightning attach was found on the sheave-mounted lightning rod. Melted metal at the tip of the rod indicated lightning attach by one or more low coulomb discharges.

2.4 INSTRUMENTATION SYSTEM

The ASTP lightning detection system is comprised of two types of prototype instrumentation equipment installed by the KSC Information Systems Directorate (IN). Redundant systems, designed by the Measurement Systems Division (IN-MSD) and the Telemetric Systems Division (IN-TEL), are installed at each end of the overhead catenary wire. The IN-MSD equipment is designed to record the entire stroke, while the IN-TEL equipment records only the first 35 microseconds. Both systems were operating satisfactorily prior to the ASTP launch.

While no damage to either instrumentation system was reported during or immediately after the launch, the IN-MSD equipment failed to operate when lightning struck the catenary 5 days later.

At 1444:30 hours EDT, 20 July 1975, lightning struck the catenary cable and the IN-TEL equipment recorded a peak current of 80 kA during the first 35 microseconds. Magnetic links and a peak-reading voltmeter indicated a current of almost 100 kA, possibly due to a later peak. No waveform recordings were obtained by IN-MSD instrumentation at either end of the catenary wire, even though the current magnitude was well within the triggering capabilities of this equipment.

An examination of the IN-MSD equipment revealed that a fuse was blown in the equipment at the east end of the catenary and that connections were loose on a circuit board at the west terminus.

2.5 COMPARISON OF ASTP AND SHUTTLE PLUME EFFECTS

The MSFC Structures and Propulsion Office has calculated that the thermal energy radiated by the Saturn IB Launch Vehicle on the ASTP lightning mast and support structure was 20 to 30 Btu/ft^2-s. Since the radiating portion of the S-IB exhaust plume passed each point along these vertical structures in approximately 1 second, it follows that the average thermal energy radiated on any given point was 25 Btu/ft^2.

Plume data for the 205,000 (205K) pound thrust H-1 Rocket Engine used on the ASTP Saturn IB Launch Vehicle were not available from KSC and MSFC sources. Therefore, the envelope of the 205K-pound thrust exhaust plume 500°F isotherm was approximated from available data on 80K- and 150K-pound thrust H-1 engines.* Using these data, the 500°F isotherm of a single 205K-pound thrust engine was calculated to be 350 feet long and 44 feet in diameter. The maximum diameter is attained 216 feet aft of the nozzle exit plane. As shown in figure 2-4, the S-IB engines are configured in a cross-type arrangement. The outboard engines are located approximately 8 feet from the vehicle centerline and have a 6° outward cant in the null position. Assuming the 6° cant, and that the exhaust plumes do not change shape by interaction, envelopes of the outboard engine 500°F isotherms will extend 58 feet outward from vehicle centerline (the combined diameter equals 116 feet). During a no-wind, full-thrust launch, the vehicle centerline is about 76 feet from the mast centerline so that with the above assumptions, the 500°F isotherm envelope would pass approximately 15.5 feet from the 5-foot-diameter mast (76-58-2.5 = 15.5).

Comparison of the thermal energy experienced by the ASTP lightning mast and anticipated radiation on the Shuttle mast is difficult, as no Shuttle data have yet been developed for this specific purpose. An instrumented ground test of a Shuttle Solid Rocket Booster (SRB) motor will be conducted by the Thiokol Chemical Corporation in October 1975, and a KSC-funded study of the radiating effects of all Shuttle propulsion system exhaust plumes on the launch complex facilities will be initiated by MSFC before the end of 1975.

Until more accurate data are available, the MSFC Structures and Propulsion Office is estimating that the radiated thermal energy of the SRB on nearby structures will be from 10 to 40 Btu/ft^2-s, except for areas of direct

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* References

R. L. Evans and O. L. Sparks, "Launch Deflector Design Criteria and Their Application to the Saturn C-1 Deflector," April 12, 1962.

C. R. Mullen, et. al., "Saturn Base Heating Handbook," NASA CR-61390, MSFC, May 1, 1972.

"Skylab Saturn 1-B Flight Manual," MSFC-MAN-206, Sept. 30, 1972.

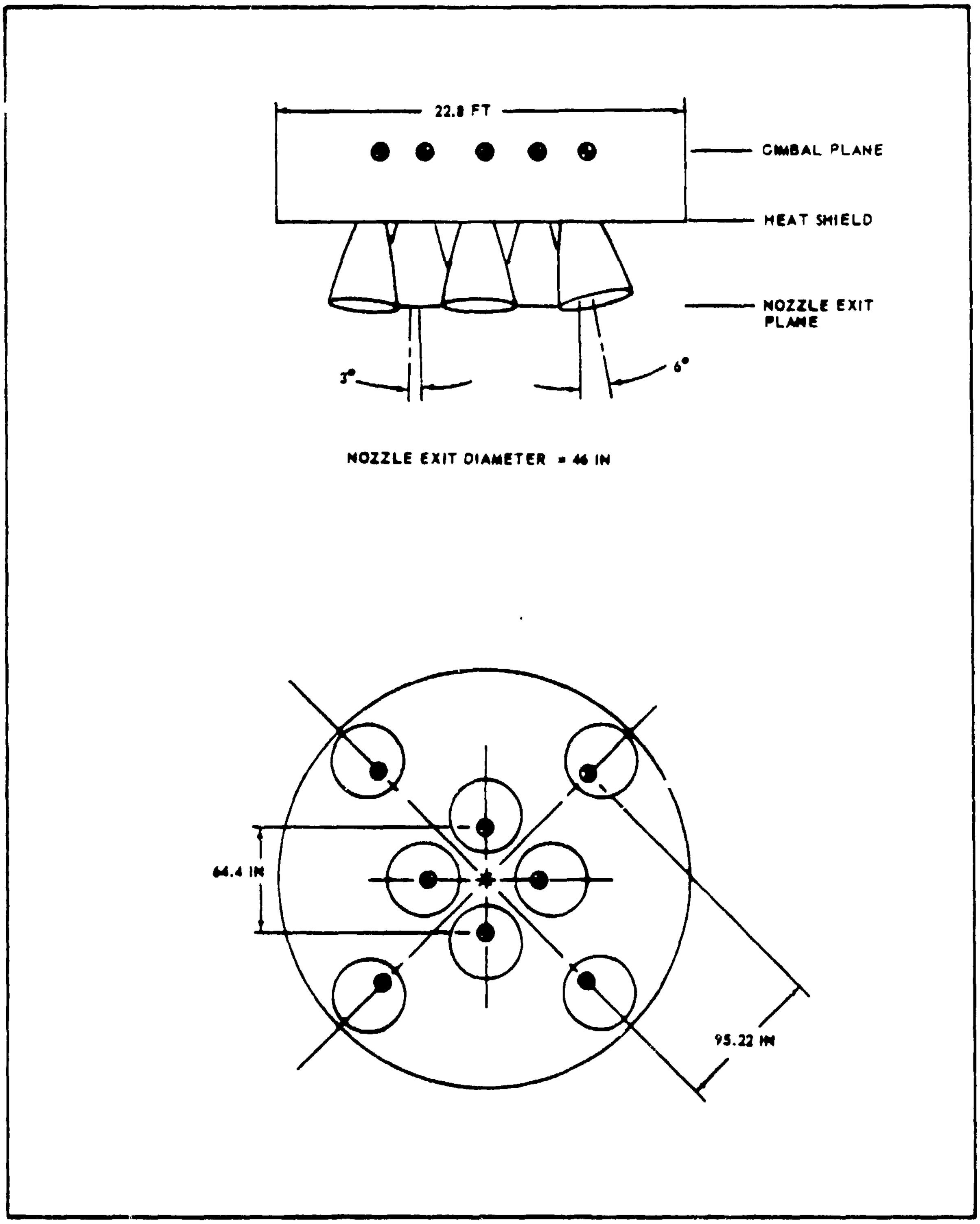


Figure 2-4. S-IB Cross-Type Engine Arrangement

impingement by the visible plume (≥500°F). Where direct plume impingement occurs, the Btu level is assumed to be directionally proportional to the plume temperature in degrees Fahrenheit. MSFC personnel also acknowledge that a level of 10 to 20 Btu/ft^2-s would probably be sensed by the SSAT and mast from a single SRB plume. This report uses 15 Btu/ft^2-s as the average thermal energy flux along the entire length of the SRB plume to end of the 500°F isotherm.

Figure 2-5 shows two plots of Space Shuttle altitude versus time: one, X, with normal engine operation and the other, Y, with the Orbiter no. 2 main engine failing at liftoff. The isothermic profile of a single SRB exhaust plume is shown in figure 2-6 relative to axial distance from the engine and mast transit time. The positions of the east edge of the lightning mast with no drift and with a 1.5 ft/s westward drift are plotted as lines A and B respectively at the left of figure 2-6. The radial distances in the left plume drawing are accentuated by a factor of 10 to show the proximity of the isotherms to the mast. The normal 1:1 plume 500°F isotherm shape is shown at the right.

Some other factors that must be considered when making a comparison of the thermal energy flux radiations of different propulsions systems are: the chemical and geometric dissimilarities of the exhaust plumes, differences in the acceleration rates between vehicles, and the proximity of the near side of each exhaust plume to the structure(s) under consideration. Listed in table 2-1 are the major differences in the plume of the S-IB and the projected performance of the Shuttle SRB plume nearest the SSAT; acceleration times and plume proximities are compared to the respective umbilical/access tower. Rise time of the Shuttle is based on NAR Dwg VC72-000015, dated 4 March 1974.

Table 2-1. Comparison of S-IB and Shuttle SRB Single Engine/Motor Plumes

Factor	S-IB	Shuttle SRB
Diameter of 500°F isotherm envelope	44 feet	125 feet
Length of 500°F isotherm envelope	350 feet	1850 feet
Vehicle transit time - liftoff to top of hammerhead crane	10 s	5.2 s
Plume transit time at lightning mast (perpendicular radiation time)	≈1 s	5.8 s
Plume-to-mast minimum distance (No-wind) (Maximum allowable drift)	 15.5 feet unknown	 10.75 feet -2.0 feet

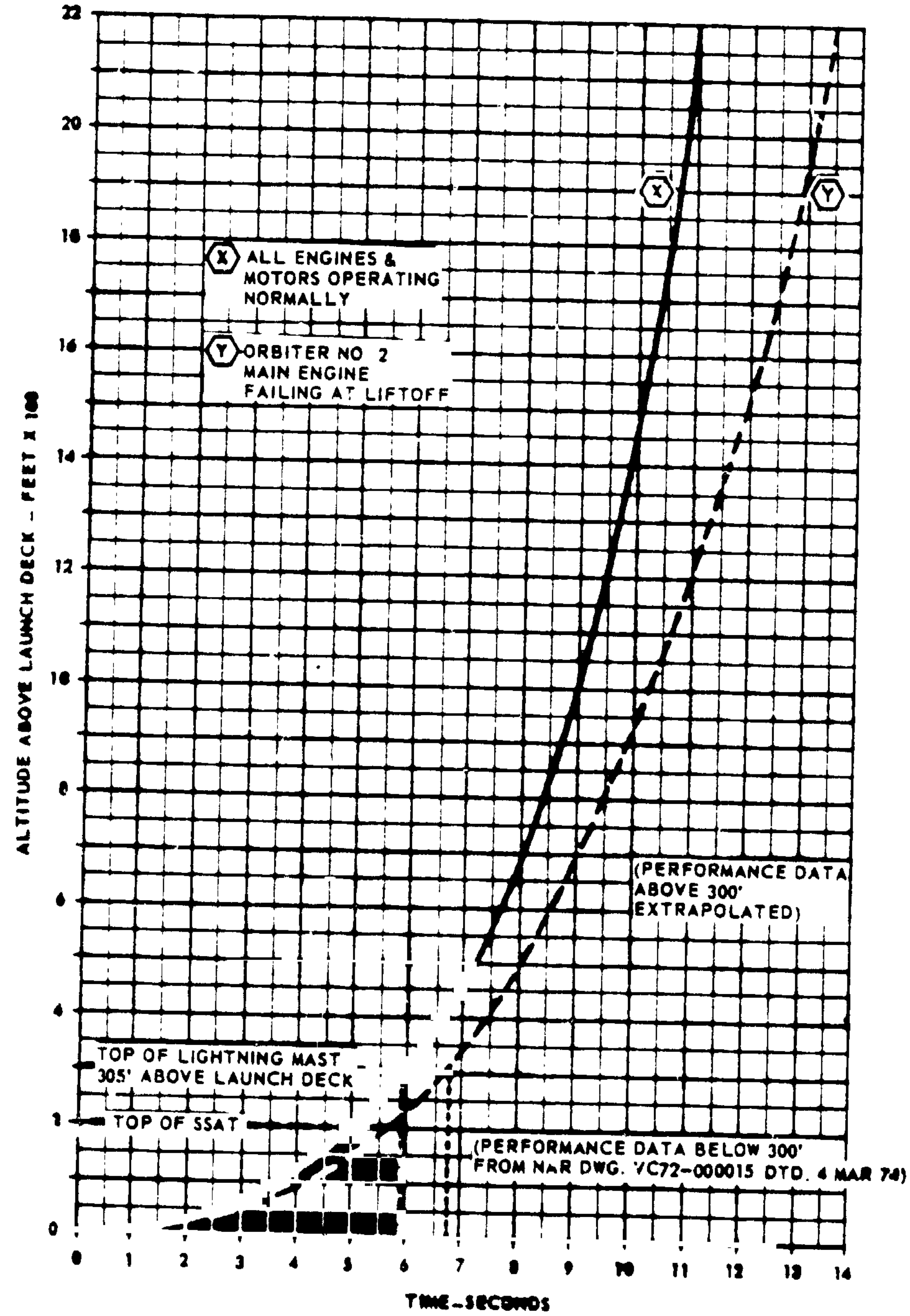
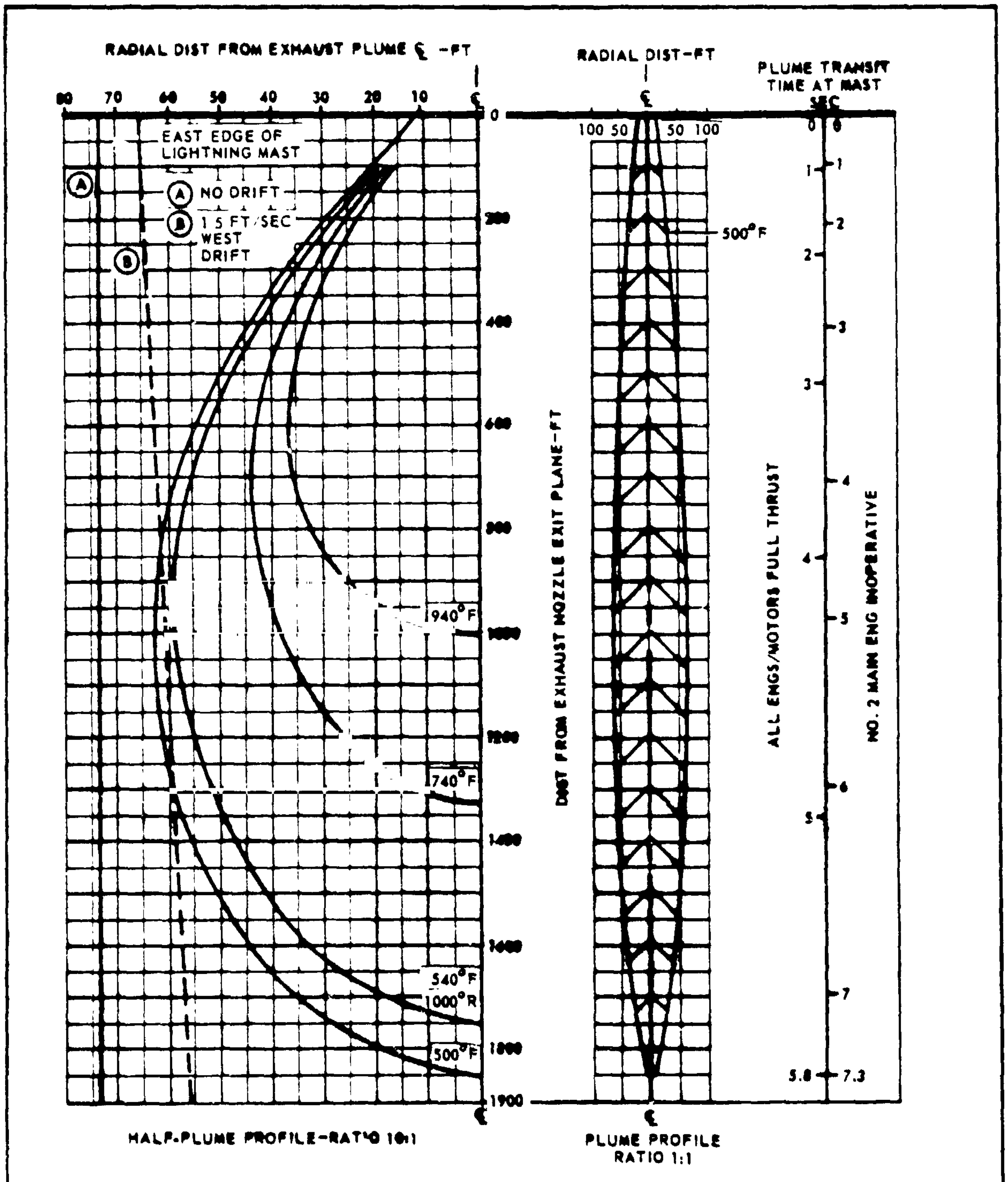


Figure 2-5. Altitude Versus Time of Space Shuttle During Liftoff - Sea Level Conditions



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- LOCKHEED TECH NOTE LMSC HREC TN D[illegible]19
- NORTH AMERICAN ROCKWELL DRAWING VC7[illegible], DTD. 4 MAR 74

Figure 2-6. Isothermic Profile of a Single Shuttle Solid Rocket Booster Exhaust Plume Showing Projected Flame Impingement on Lightning Mast

Using the aforementioned factors and nominal launch conditions, it is calculated that the Shuttle lightning mast and support structure will experience a minimum of 87 Btu/ft^2 total radiated heat from the single SRB exhaust plume nearest the SSAT (15 Btu/ft^2-s x 5.8 s). Nominal launch conditions are defined as a no-wind, sea-level standard day, with all Space Shuttle propulsion units operating at full thrust. Note that this calculation does not consider the total radiated heat of the combined SRB and main engine plumes, nor the probable increased cross section of the combined plume caused by interaction of gases within the five individual plumes.

Other factors that will significantly increase the level of radiated heat on the lightning mast are: an easterly wind, causing the vehicle to drift towards the mast; the loss of a main engine after liftoff, which would increase mast exposure time to the exhaust plume; and any outward cant to the SRB exhaust plume trajectory, a condition that could envelop the SSAT and lightning mast in flame.

2.6 CONCLUSIONS AND RECOMMENDATIONS

The ASTP lightning mast appeared undamaged by the thermal energy and shock vibrations from the Saturn IB Launch Vehicle.

However, Shuttle lightning detection equipment must have far greater reliability than the ASTP instrumentation system. It must be capable of withstanding all environmental threats induced by launch operations, lightning strokes, and hurricane-force winds, including the problems of acoustic vibration and power-voltage fluctuations described in 2.4. Criteria for Shuttle lightning detection equipment are discussed in sections III and IV.

Although the ASTP grounded overhead (catenary) cable survived direct lightning strokes, high winds, and the heat and vibration of launch, it did deteriorate due to rust. The cable used for long-term lightning protection of the Space Shuttle launch environment must have a high tolerance to salt fog and require an absolute minimum of maintenance. It is recommended that this cable be manufactured of a corrosion-resistant metal such as stainless steel, or be otherwise treated to resist rust for the projected life span of the Space Shuttle program.

An accurate model of the total Shuttle plume is not currently available. However, for a lightning mast located on the SSAT crane in a position similar to the ASTP mast, a conservative study of the thermal energy impinging on the mast from only the nearest SRB indicates a total radiated heat of 87 Btu/ft^2, as compared with 25 Btu/ft^2 during the ASTP launch. The plumes of the Orbiter main engines and the other SRB can only increase this energy. Radiations from the total Shuttle plume are scheduled for further study. These study results will be compared with the radiation test results from the propulsion blast tests on the ASTP mast material reported in section V.

2.7 ADDENDUM: LARGE SOLID ROCKET MOTOR EXHAUST RESIDUE INVESTIGATION

In conjunction with the ASTP launch damage study, an investigation was performed in October, 1975, to determine the magnitude and effects of large solid rocket motor (SRM) exhaust residuals on a Titan III launcher-transporter. The transporter that was examined had been used to launch the Titan IIIC/ Viking II space vehicle from Launch Complex 41 (LC-41) on August 20, 1975.

No exhaust residuals were found. The complete absence of these materials, in particular the aluminum oxides, can only be attributed to the 1-hour water deluge and heavy rains that cleansed the transporter immediately after launch.

Sample scrapings were taken from six locations on the transporter by personnel of the Microchemical Analysis Section, SO-LAB-32, along with reference samples of pneumatic concrete (Martyte) ablative material (Ref: Laboratory Request No. MAS-6725). X-ray diffraction data were generated for the individual samples and compared; these data were then compared with those from a computerized American Society for Testing Materials (ASTM) data search-and-match system covering more than 25,000 individual elements and compounds.

No SRM exhaust residues were identified. The comparison of scrapings and reference samples showed general similarities in X-ray diffraction patterns except for the No. 4 sample, which exhibited a tackiness attributed to contact with a rubbery substance used to fill transporter cracks and crevices. Minor pattern differences were presumed to have resulted from crystallographic changes induced by intense heat from the firings.

The carbonaceous appearance of surfaces sampled was considered likely to have resulted from thermal decomposition of polymeric fuel binder or rubber cable insulator covers; the surface coating appeared to be amorphous or noncrystalline in nature and produced no measurable X-ray data.

The general arrangement of the Titan IIIC/Viking II launch support equipment is shown in figure 2-7. Figures 2-8 and 2-9 indicate the sequence and locations in which the sample scrapings were made.

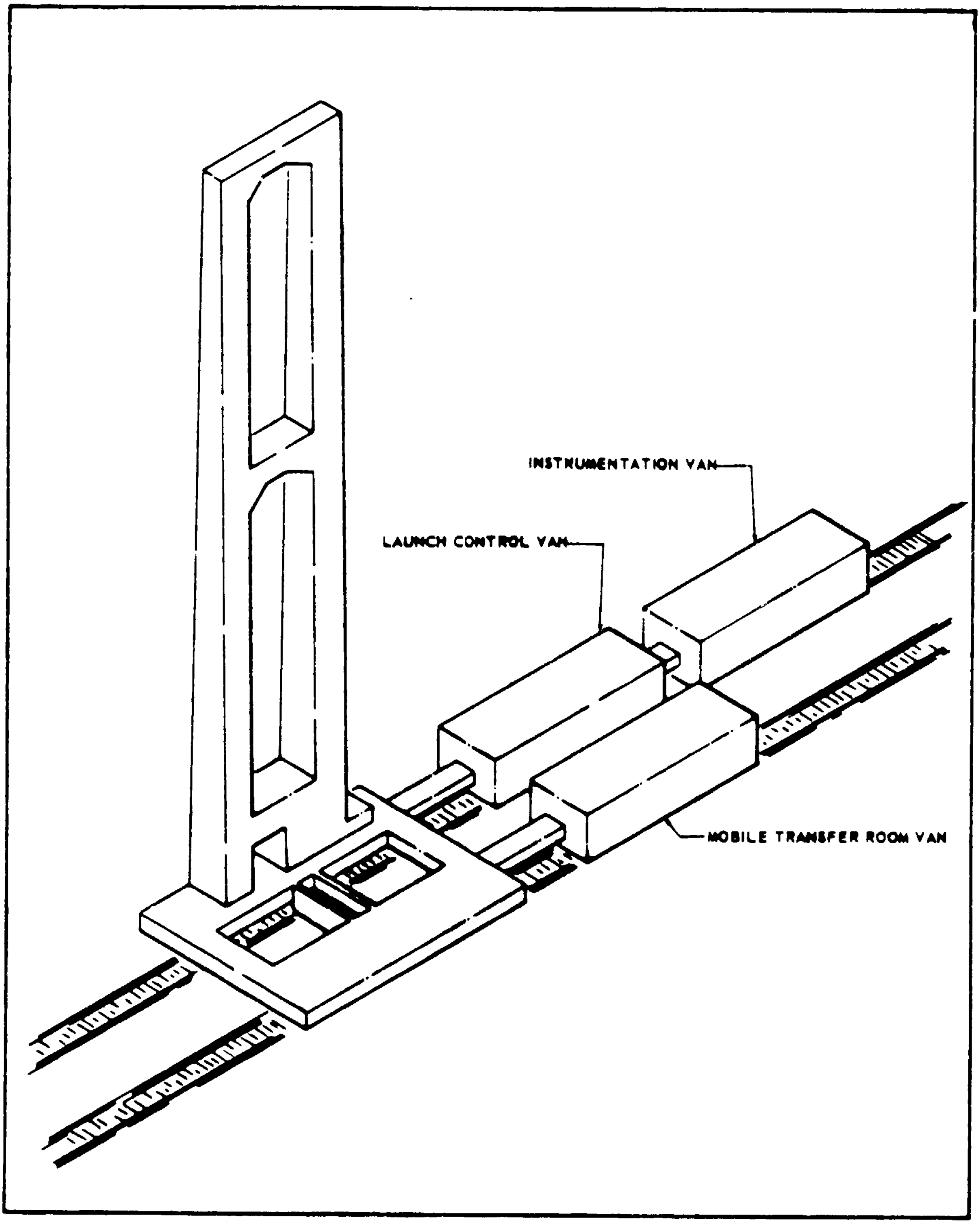
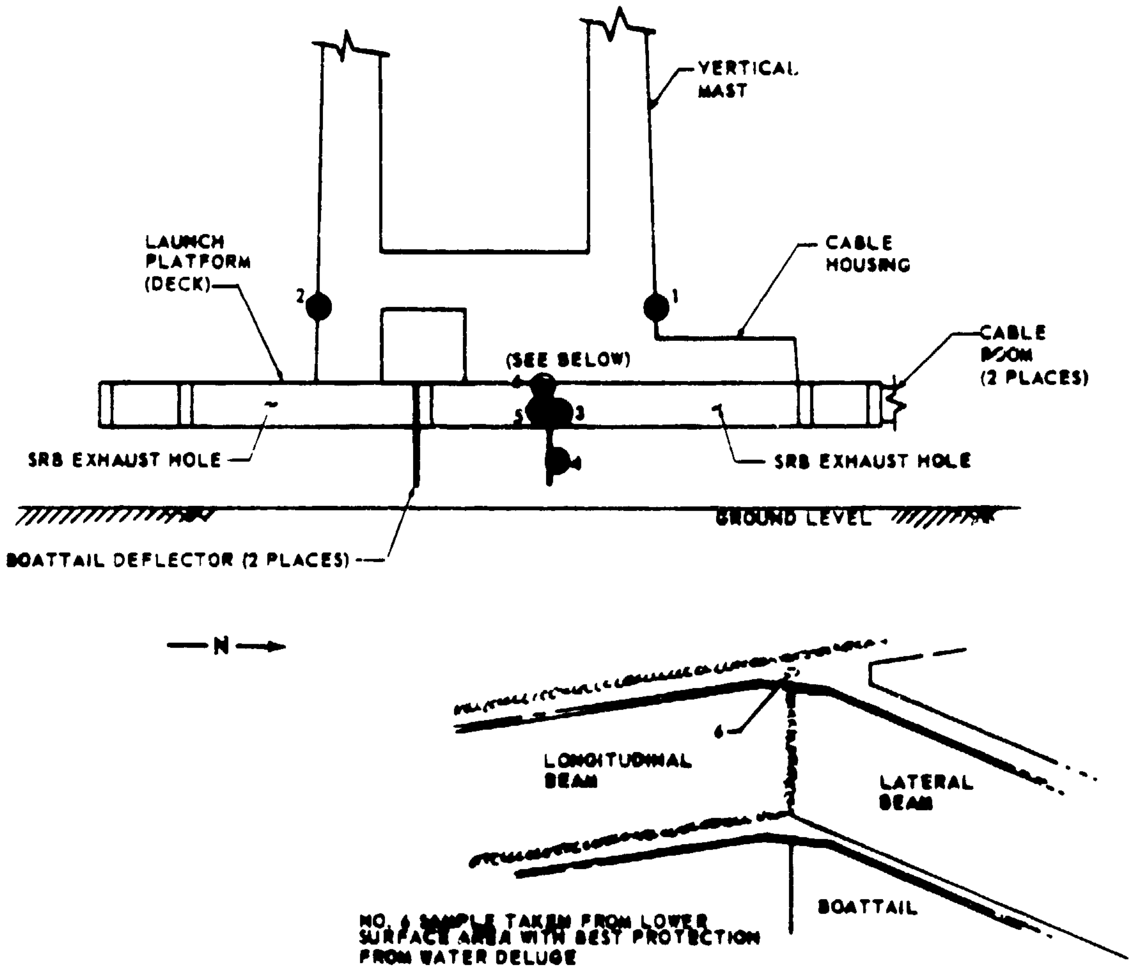


Figure 2-7. Titan Transporter No. 2 With Railroad Vans at LC-41



NO. 6 SAMPLE TAKEN FROM LOWER SURFACE AREA WITH BEST PROTECTION FROM WATER DELUGE

Figure 2-8. Vertical View/Cross Section of Titan Transporter No. 2

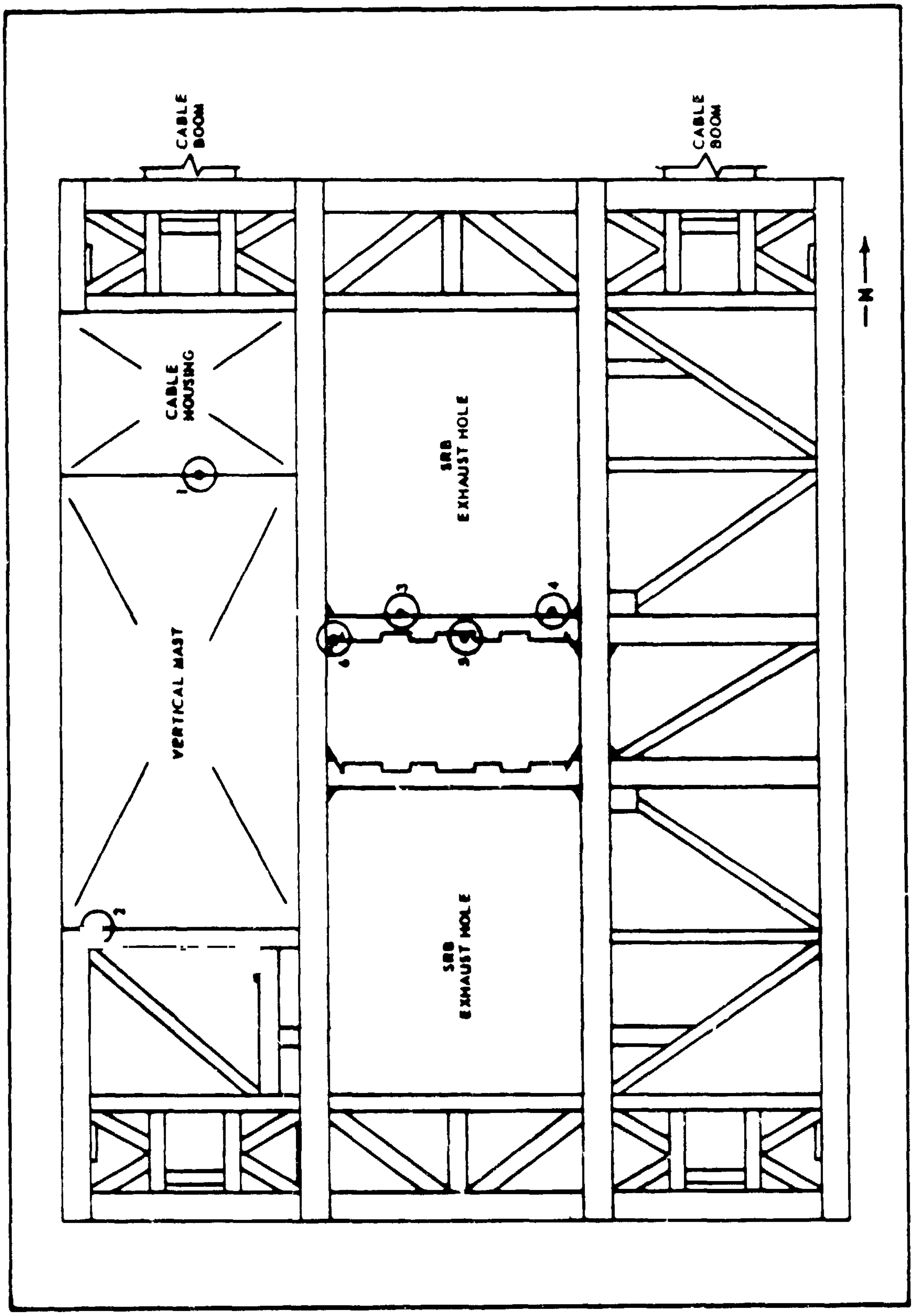


Figure 2-9. Plan View/Launch Platform - Titan Transporter No. 2

SECTION III

REQUIREMENTS STUDIES

This section presents the results of separate studies conducted to evaluate structural, instrumentation, and lighting and marking requirements of the Space Shuttle lightning protection system.

3.1 APOLLO-SOYUZ TEST PROJECT (ASTP) LIGHTNING MAST MODIFICATIONS

This study was conducted to evaluate and define the structural modifications required for use of the ASTP lightning protection system with the Space Shuttle. Consideration was given to the design of the fiberglass mast, the mast support structure, provisions for access, and system installation. Included with this study is a rough order of magnitude (ROM) engineering estimate of installation and maintenance costs for a 10-year design period. A concept is presented for maximum use of the existing hardware; however, some new construction will be necessary to satisfy the Shuttle installation design requirements.

3.1.1 STRUCTURAL FEATURES.

3.1.1.1 ASTP Lightning Protection System. The ASTP lightning protection system was designed to protect the Saturn/Apollo launch vehicle while it was prepared for launch on Complex 39, Pad B. Structurally, the ASTP lightning protection system consists of a 75-ft fiberglass tube with a steel cap/sheave assembly about 5 ft in height attached to its top. The base of the pole incorporates a steel chair assembly in which the pole is bonded and secured. The bottom of the chair assembly is anchored to a structural steel space frame which supports the mast above the hammerhead crane atop the Launch Umbilical Tower (LUT) and ties into the base of the crane itself. A steel wire rope is stretched over the sheave at the top of the mast and anchored at ground level about 1,000 ft both east and west from the centerline of the LUT. The cable hangs with a catenary shape that is required to clear all grounded structures by at least 50 ft. The grounded steel cable affords a three-dimensional cone of protection against lightning strikes within the protected area below the catenary cable. A sketch of the system is shown in figure 3-1. During operations of the crane when it is rotated about the top of the LUT, the lightning mast also rotates with the crane; however, the catenary cable does not rotate and is maintained in an east-west plane as a result of a vertical pivot on the sheave assembly at the top of the mast. This allows the mast to rotate with the crane under the stationary catenary cable.

3.1.1.2 SSAT Lightning Protection System. For the Space Shuttle program, the mast will be supported atop the Shuttle Service and Access Tower (SSAT) on the launch pad. The ASTP lightning protection system can be conceptually adapted for use on the SSAT; however, several new structural design requirements must be met. In order to preclude the grounding cable from being struck by the Shuttle vehicle during launch or from being immersed in engine exhaust plume, the plane of the catenary shaped grounding cable should be oriented north-south

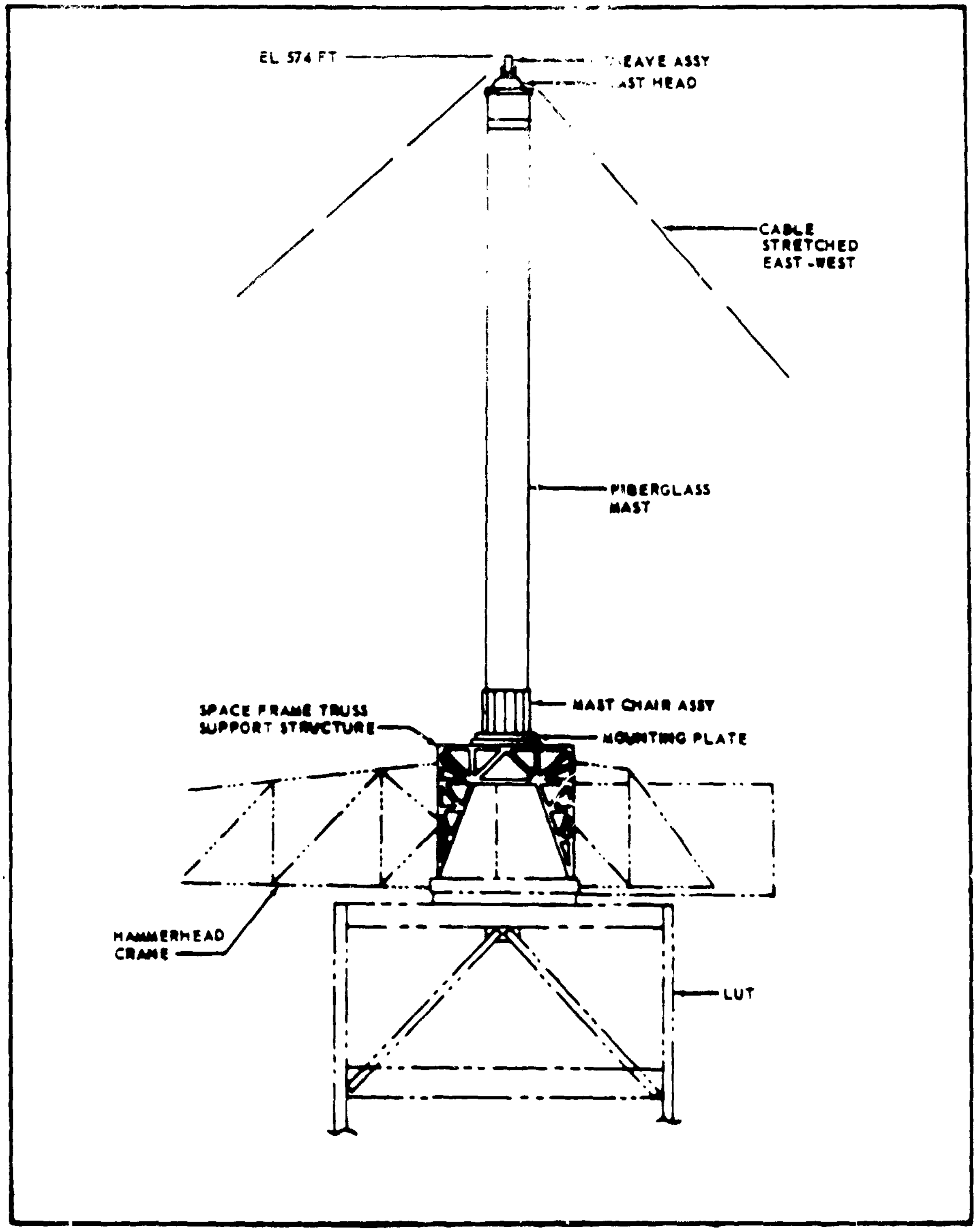


Figure 3-1. ASTP Lightning Protection System

instead of east-west. The ASTP fiberglass mast and supporting steel structure were designed for only one Saturn launch with no requirement for the effects of repeated exposure to launch-induced loads. The structural components were designed for only operational wind conditions and minimum protection from the natural environment because the ASTP mast could be moved with the mobile launcher umbilical tower to the VAB for protection from more severe environments and for periodic inspection and maintenance.

Since the SSAT is a permanent installation, it must be designed for a service life of at least 10 years, and the fiberglass mast and its structural steel supporting system must be able to withstand the most severe hurricane and natural environmental conditions as well as repeated exposure to the Shuttle launch environments. Provisions are also required for allowing inspection and maintenance of the mast and grounding cable on a timely basis.

In order to satisfy the operational and environmental requirements associated with the Shuttle lightning protection system installation, several design constraints not provided by the ASTP lightning mast structure must be imposed. These include:

a. Design service life of at least 10 years

b. Permanent and fixed installation on the SSAT on the launch pad

c. Access and/or maintainability provisions for the fiberglass mast

d. Repeated exposure to Shuttle launch environment

e. Long-time exposure to the natural environmental elements

f. Hurricane and storm survivability

Additional structural provisions and strength will be required for the SSAT fiberglass mast and its steel truss space frame support structure.

3.1.2 STRUCTURAL DESIGN LOADS. The ASTP lightning mast and support structure were designed to withstand only operational wind loads with velocities well below hurricane strength. The structural system for SSAT must withstand hurricane wind forces. For a nominal mast elevation of 400 ft above ground where the hurricane design wind velocity becomes 181 mi/h (125 mi/h at ground level), the design loading on the SSAT mast installation is 83.3 lb/ft^2. This hurricane wind load, the critical design load for the SSAT installation, is 4.5 times the ASTP design load.

The operational wind of 74 kn at 600 ft elevation was used to design the ASTP lightning mast structures. This equates to a wind of 46.4 mi/h at ground level. The operational wind loading for the SSAT installation at 400 ft elevation will be 68 kn or 15.5 lb/ft^2. This also corresponds to 46.4 mi/h at the ground. Operational wind velocities on the lightning mast system and on the hammerhead crane are combined with the maximum crane hook loads to produce the maximum moment reacted through the crane/lightning mast interface with the top of the SSAT. Because of the lower elevation of the lightning mast and crane, these combined operational loads will be less for the SSAT installation than that for the ASTP design; therefore, operational loads are not critical for the SSAT installation.

The design loads on the SSAT mast installation due to a Shuttle launch have not yet been defined; however, unless the exhaust plume comes very close to the mast structure, the loads due to launch should be less critical than the hurricane wind loads.

3.1.3 FIBERGLASS MAST DESIGN FOR SSAT. The design of the fiberglass mast for the SSAT must also be integrated with its structural steel space frame support and with the geometry of the lightning grounding cable that the mast supports. Conceptually, the structural configuration of the lightning mast for Shuttle lightning protection can remain the same as that used for ASTP (see figure 3-1).

3.1.3.1 Mast Strength Properties. The factor of safety used for the ASTP mast was greater than 10.0 on ultimate bending stress because of unknowns in loads resulting from wind gusts and in the fiberglass material properties. If the same factor were used for the SSAT installation, the existing pole could not be used and a fiberglass mast wall thickness of about 6 in would be required by the hurricane wind-design conditions. Based on ASTP experience and accepted industry standards, a factor of safety of 3.0 on minimum ultimate tensile strength can be safely assumed for the SSAT installation design. This indicates an allowable tensile stress of 5,000 lb/in^2 for design to peak loads. For the existing ASTP mast with a tube wall thickness of approximately 7/8 in, this translates into an allowable bending amount of 1,030 kip-ft at its base.

3.1.3.2 Mast Design Modifications. The ASTP mast rises 80 ft above its support structure. When applying the design wind pressure loading of 83.5 lb/ft^2, the reaction moment at the base is of the order of 1,340 kip-ft and exceeds the allowable moment for the fiberglass material. Figure 3-2 shows a comparison of reaction moment at the mast base versus the mast height where the reaction moment is a function of mast height squared. To remain within an allowable bending stress, the maximum mast height is 70 ft; therefore, the SSAT mast must be shortened by at least 10 feet by removing a section of the fiberglass tube. Because the top portion of the mast has a thinner wall, a portion should be taken from it here in order to maintain the maximum strength at the bottom of the mast where the greatest moment is carried. A steel ring is provided at the top of the tube to facilitate fastening the mast head and sheave assembly; therefore, the cutting and splicing should be done at a convenient distance below the top of the fiberglass tube and between the top two stiffening diaphragms. The splicing procedure would be that used for the original construction of the mast.

Because of the increased design loads for the SSAT lightning mast, the anchor connection used to secure the mast to its support structure must be strengthened. The ASTP installation utilized 7/8-in Ø high-strength bolts through the

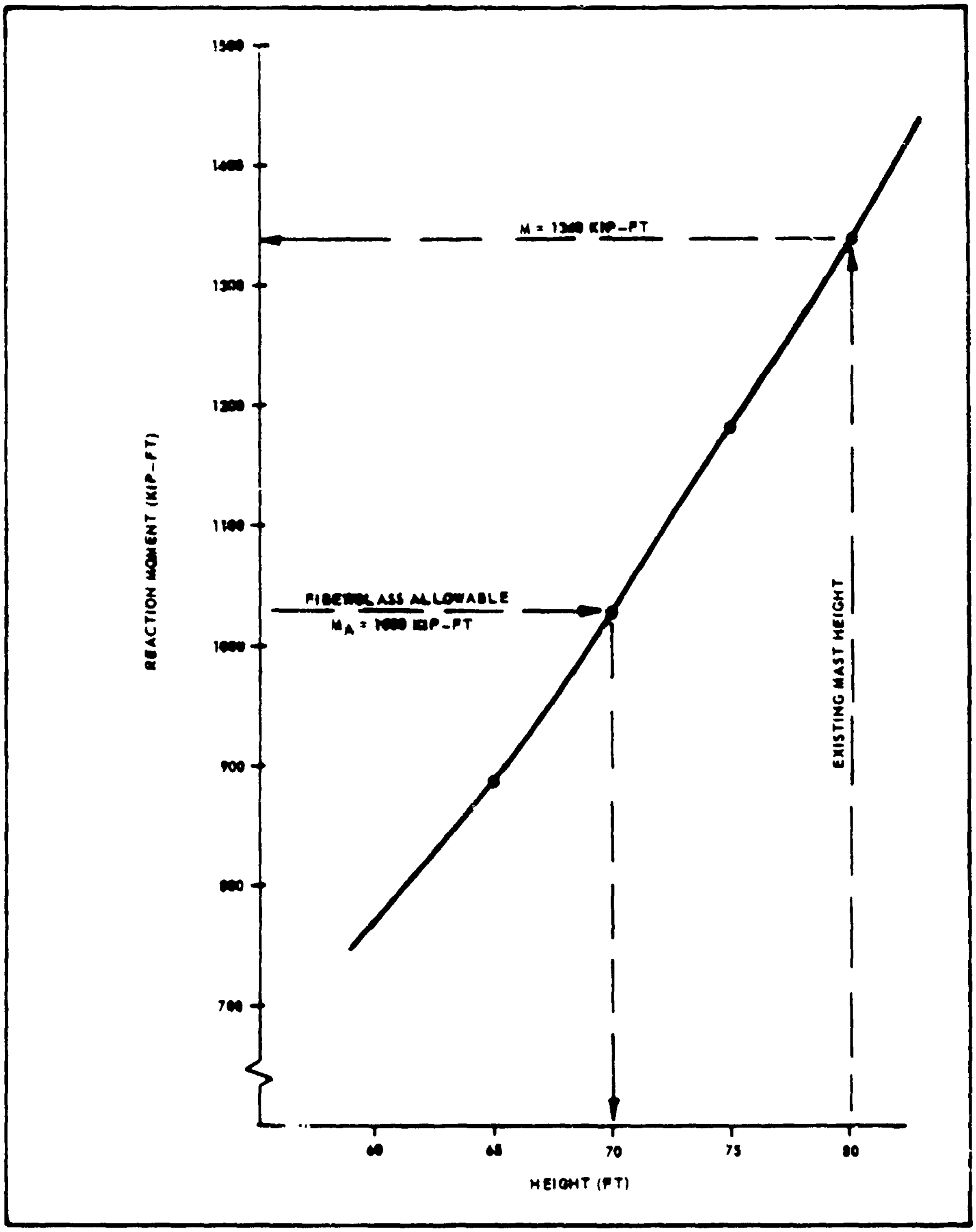


Figure 3-2. Moment Reaction at Mast Base Versus Height of Mast

1-in bottom plate of the steel chair at the mast base. For the SSAT installation, 1-1/4-in 0 high-strength bolts and a 1-in backing plate could be used to obtain the greater required strength.

3.1.3.3 Mast Access Provisions. The SSAT is a permanent and fixed installation; therefore, provisions must be made to allow access to the mast top for periodic inspection and maintenance of the mast, the lightning grounding cable, and the sheave mechanism. The simplest means to provide access would be to install a ladder of nonconducting material such as fiberglass inside the mast. This concept requires access to the inside of the mast at its base and larger openings in the mast cap for access through the top (see figure 3-3). The fiberglass tube has stiffening diaphragms spaced inside the mast. In the ASTP configuration, there is a 2-ft-diameter hole in the center of each of the diaphragms. To accommodate the access ladder, these holes must be enlarged to 3 ft.

Access to the inside of the lightning mast is not available in the ASTP configuration. A workable concept for allowing access at the base of the SSAT mast is to support the mast on an open structural steel pedestal that would transfer the design loads from the mast base down to the space frame support structure. By using a 10-ft pedestal, as shown in figure 3-4, the fiberglass portion of the mast could be shortened 10 ft. This would reduce the bending moment in the fiberglass tube to values that are within the allowable limits of the material.

Inside the tube, a work platform could be provided which will allow a workman to stand erect with his head and arms outside of the mast. This concept is shown in figure 3-3. The platform could be constructed as an integral part of the top stiffening diaphragm inside the tube. A hatch in the floor of the platform would allow access up the ladder and serve when closed as a small work platform.

The sheave that supports the lightning grounding cable should be adequate for SSAT use without modifications. The steel mast head just below the sheave will have to be modified to allow access through the top of the mast. The mast head can be modified by removing some of the radial stiffeners; however, the remaining stiffeners will have to be strengthened to adequately transfer the cable loads into the fiberglass mast. A concept for the reconfigured mast head is illustrated in figure 3-5.

3.1.3.4 Mast Environmental Protection. The lightning mast system will be continuously exposed to the natural elements for a long period of time. To protect the structural integrity of the mast from the natural elements (particularly sunlight which degrades the elastic and strength properties of fiberglass), the structural components must be painted with a suitable protective covering. In addition to protection from the natural elements, the fiberglass and steel components must be protected from abrasive materials and heat from the exhaust of the Shuttle booster engines. The launch environment on the lightning mast has not yet been defined; however, the need for a good protective coating is apparent.

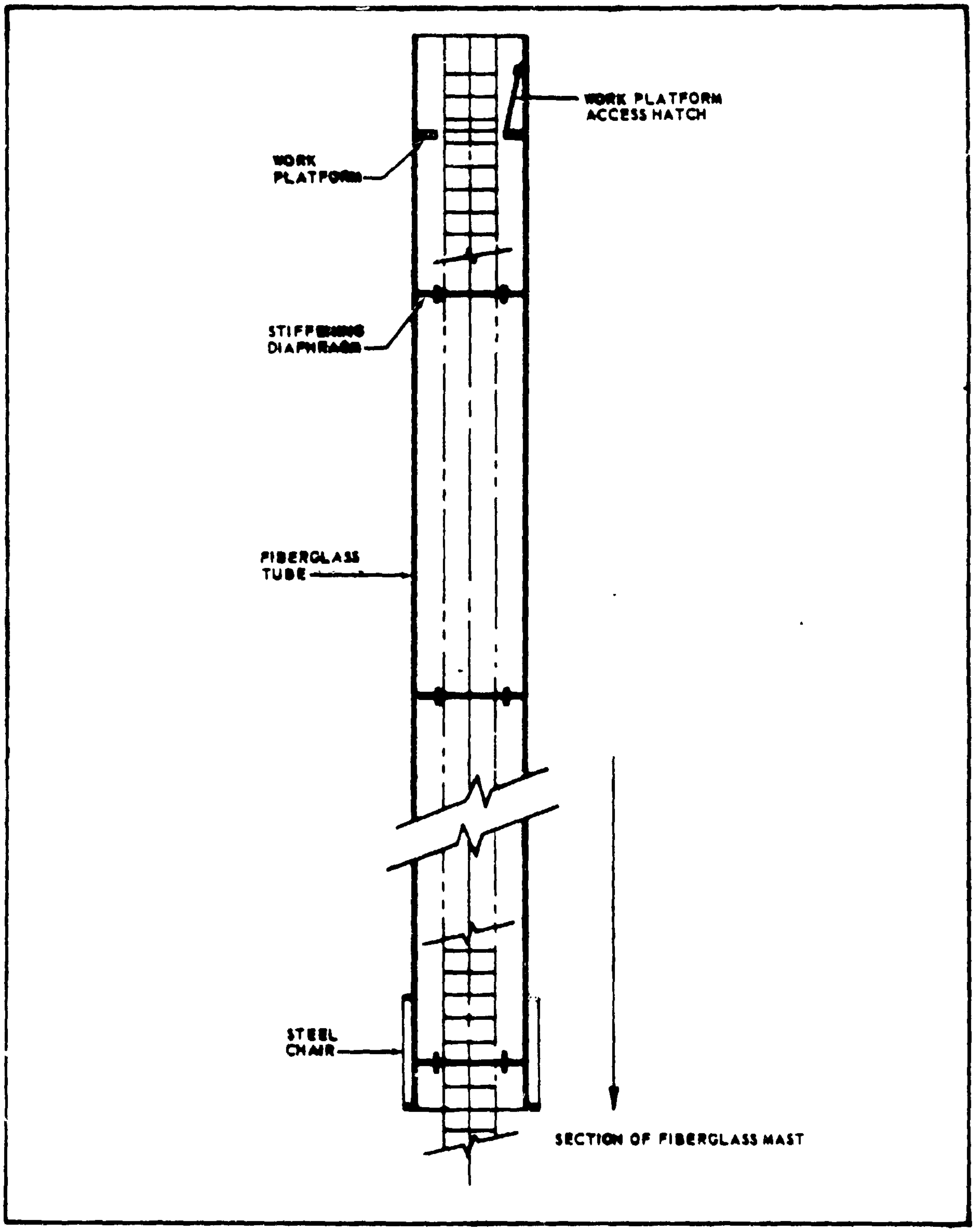


Figure 3-3. Mast Access Provisions

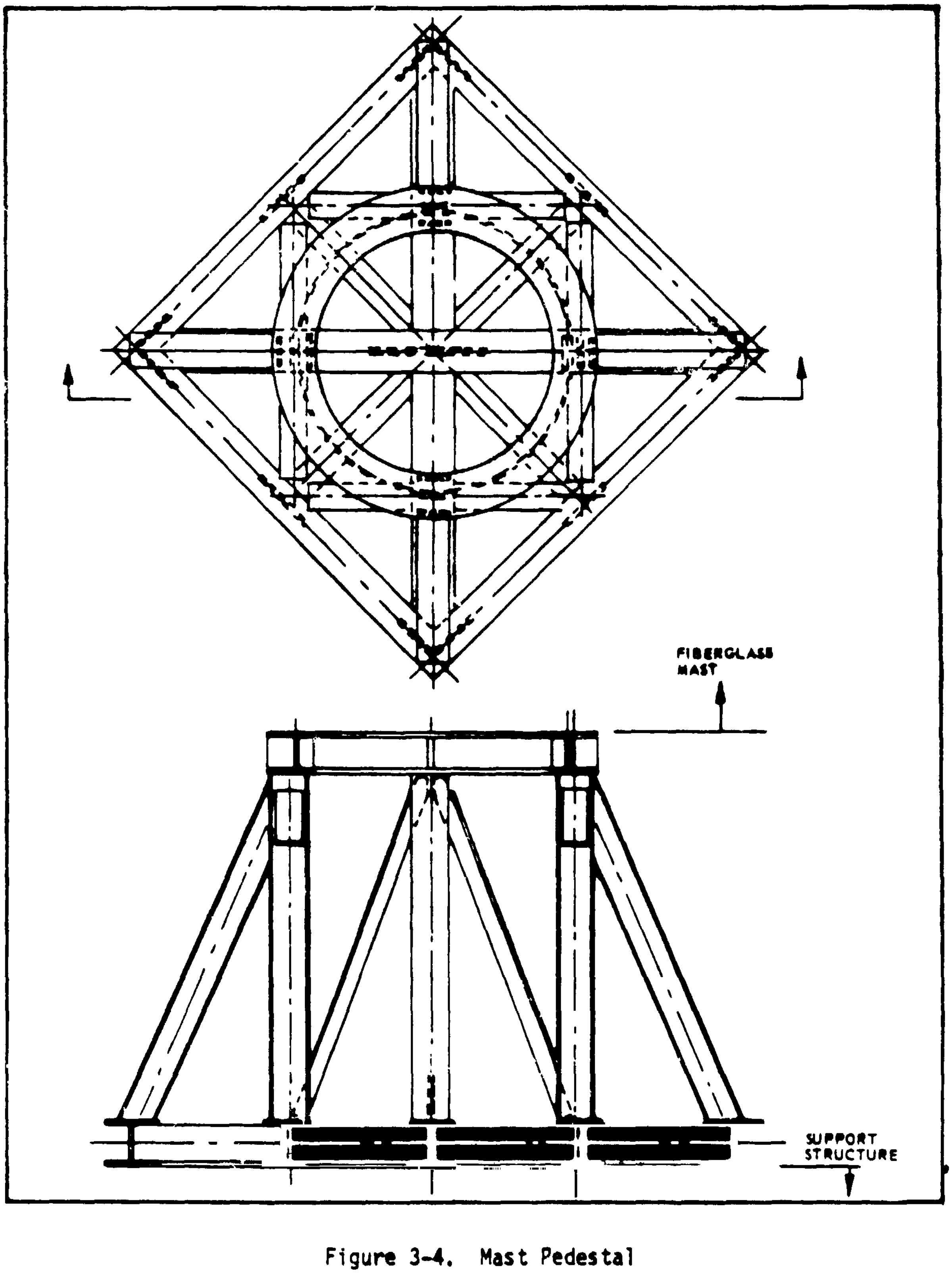
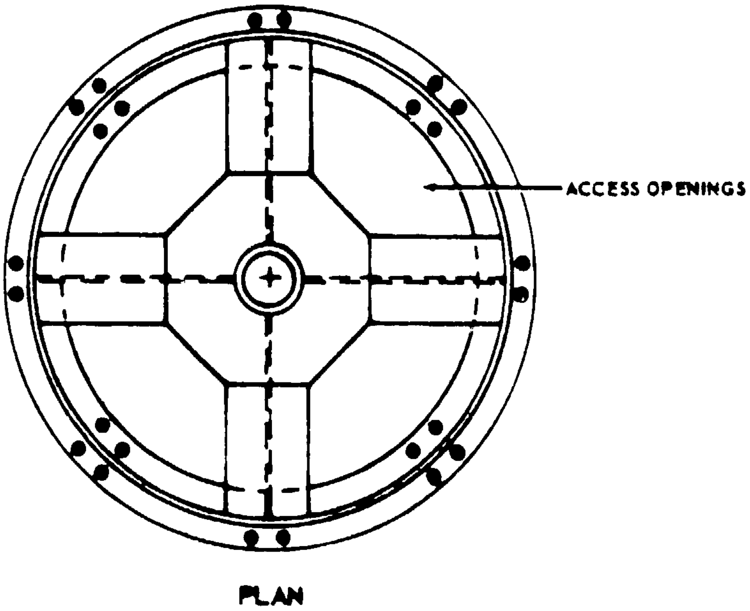


Figure 3-4. Mast Pedestal



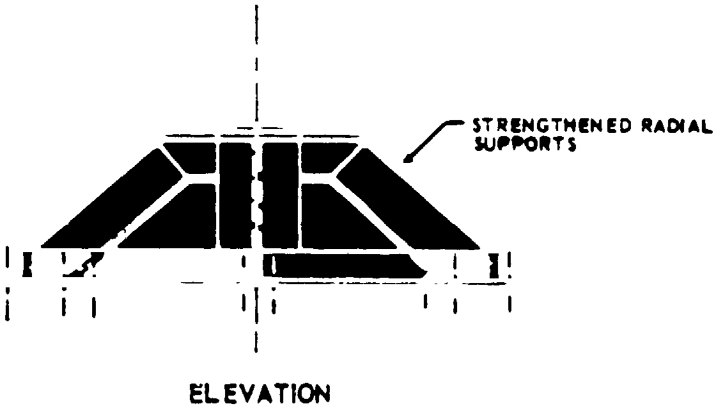


Figure 3-5. 'Mast Head Cap

A coating for the fiberglass lightning mast must shield the fiberglass from sunlight, provide thermal protection from extreme high temperatures, act as sealant to protect against intrusion of moisture and salt spray, and maintain an elastic surface that will not chip or crack. A coating that fits these requirements is Dow Corning 20-103 Sealant, used by NASA for various applications for over 10 years. The properties of this sealant are shown in appendix A.

The protective coating should be sprayed on the outside of the mast to ensure good penetration of any small cracks or seams on the surface and provide good adhesion of the sealant. Since the inside of the fiberglass mast is open at both ends, the coating should also be applied to the inside to protect it from the natural and launch-induced environments. An analysis of the coating weight for various thicknesses of sealant is included in appendix A. A minimum thickness of 1/8 in is recommended for the outside of the mast and for the inside at the top. The remaining interior surface mast can be less thickly coated.

To help protect the inside of the mast from the intrusion of flame and hot corrosive gases during launch, hinged or removable doors can be provided at the top and bottom of the mast. The openings would be closed during a launch but opened before and after launch to reduce the chance of the condensation of moisture on the inside surfaces. Moisture could short-circuit the electrical insulating properties of the fiberglass.

3.1.4 MAST SUPPORT STRUCTURE DESIGN FOR SSAT. The ASTP lightning mast support structure supported the mast above the hammerhead crane atop the LUT. The structure was designed to react operational winds of 46.4 mi/h at ground level. Because of the increased loads on the lightning mast for the SSAT installation, the steel truss support structure must have the capability to react greater loads. The support structure consists of a space frame truss that bridges the hammerhead crane. At the four corners of the space frame are steel leg trusses that support the frame and the lightning mast. They react the loads into the base of the hammerhead crane. With strengthening for the greater loads, the existing support structure can be used for the SSAT installation.

3.1.4.1 <u>Support Structure Strength Properties</u>. The space frame truss and its legs are made from standard shapes of A36 structural steel. The factors of safety and design-allowable loads for the structural steel members are based on accepted steel industry standards and defined by KSC-STD-Z-0004, Standard for the Design of Structural Steel Buildings and Framework, and by the American Institute of Steel Construction.

3.1.4.2 <u>Support Structure Modifications</u>. The steel truss space frame that bridges the hammerhead crane is made from standard steel shapes with bolted connections. About 50 percent of these steel members will require strengthening to support the greater design loads. The strengthening would be accomplished by replacing the critical members with heavier members with greater cross-sectional area and less critical buckling properties. On some members, the cross-sectional area is adequate to support the compressive stresses; however, additional lateral bracing is required to prevent buckling. The base of the fiberglass mast would be supported by a new structural steel pedestal attached to the top of the steel support structure. The pedestal could be designed to help strengthen the top chord of the space frame and to help distribute the loads throughout the support structure. A schematic of the support structure for the SSAT installation is shown in figure 3-6.

The support structure leg trusses are constructed from standard steel shapes utilizing welded connections. The top of the leg weldments are bolted into the space frame truss, and the bottoms are pinned to the hammerhead crane base structure. Figure 3-7 shows how the leg weldments can be strengthened simply by welding steel plate to the chord at the leg trusses.

A steel box frame at the base of the ASTP support structure tied the truss support structure to the bottom of the hammerhead crane. This structure was designed to provide maximum stiffness between the bottom of the support structure legs and the base of the crane for the operational loads on the system. The frame was over-designed in terms of strength. It is anticipated that the existing tie-in frame will have adequate strength for the SSAT installation under the more critical hurricane loads and still have sufficient stiffness to permit operations under the lower operational loads. The structure should be checked again during the detailed engineering design of the SSAT lightning protection system to ensure the adequacy of the frame.

3.1.4.3 Steel Structure Protective Paint. All carbon steel structures in the SSAT lightning protection system must be coated and sealed with inorganic zinc paint per KSC-SPEC-F-0020. This requirement is applicable for all carbon steel at KSC.

3.1.5 GROUNDING CABLE CLEARANCES AND DESIGN. A design requirement for the ASTP lightning protection system was that the grounding cable must clear all grounded structures by at least 50 ft. This requirement can also be met with the SSAT installation even with the shortened fiberglass mast height; however, greater tension must be applied to the catenary cable to pull it up and away from the pad structures. The clearance study shown in figure 3-8 for a 70-ft mast (10 ft shorter than ASTP) on a 10-ft steel pedestal indicates that all grounded structures, including the hammerhead crane boom rotated in any direction, will meet the 50-ft clearance requirement if a tension of about 4,500 lb is maintained in the cable at the top.

If a 65-ft mast on a 10-ft pedestal is used to reduce the bending moment applied to the steel truss space frame, the elevation of the top of the mast would be reduced 5 ft. The cable clearance study shown in figure 3-9 indicates the cable will clear all grounding structures by 50 ft except for the end of the hammerhead crane boom when it is rotated directly under the cable. By rotating the crane about 20 degrees to either side of the north-south cable, the 50-ft clearance is obtained and all structures are within the cone of protection of the cable.

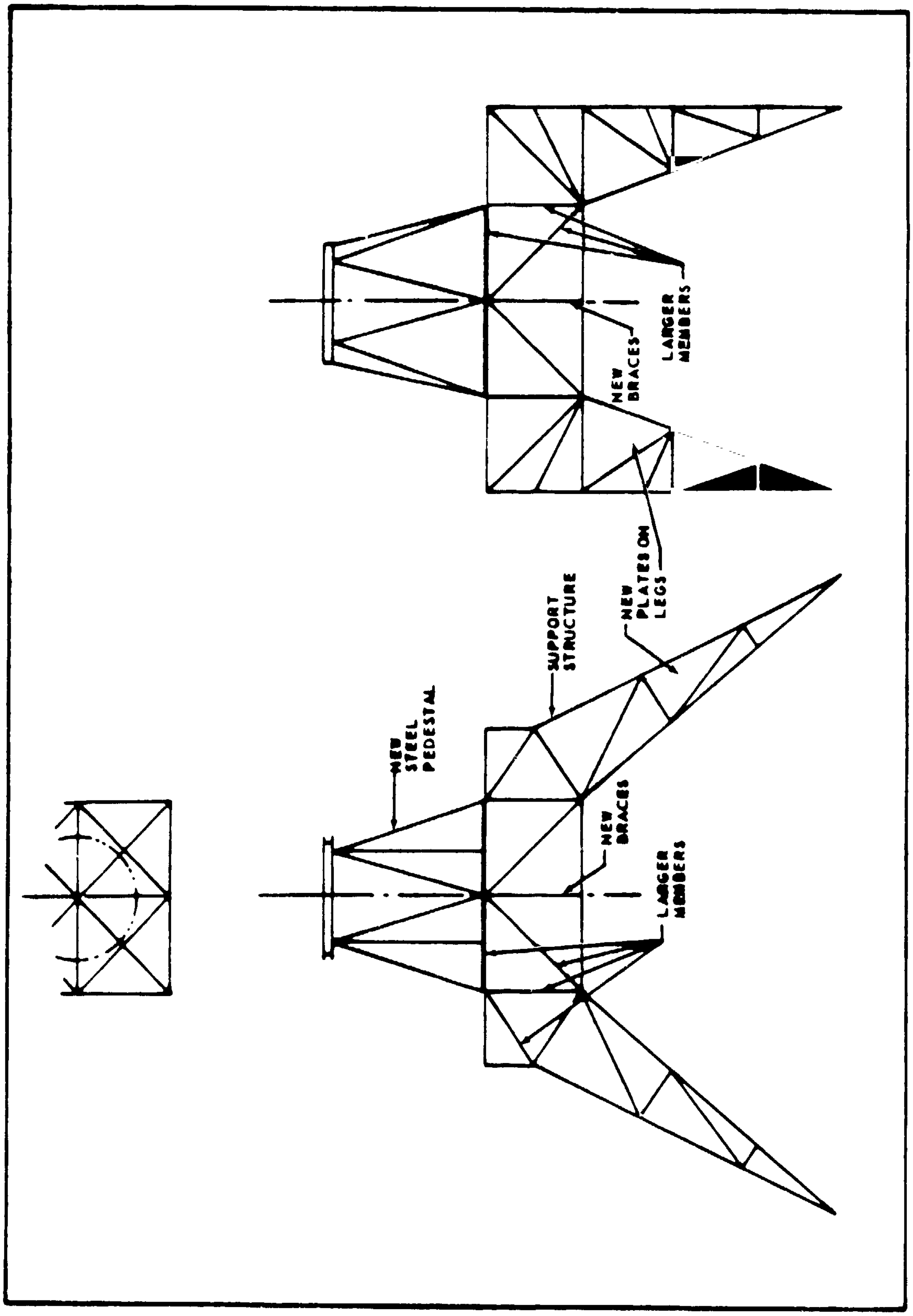


Figure 3-6. Space Frame Truss Support Structure

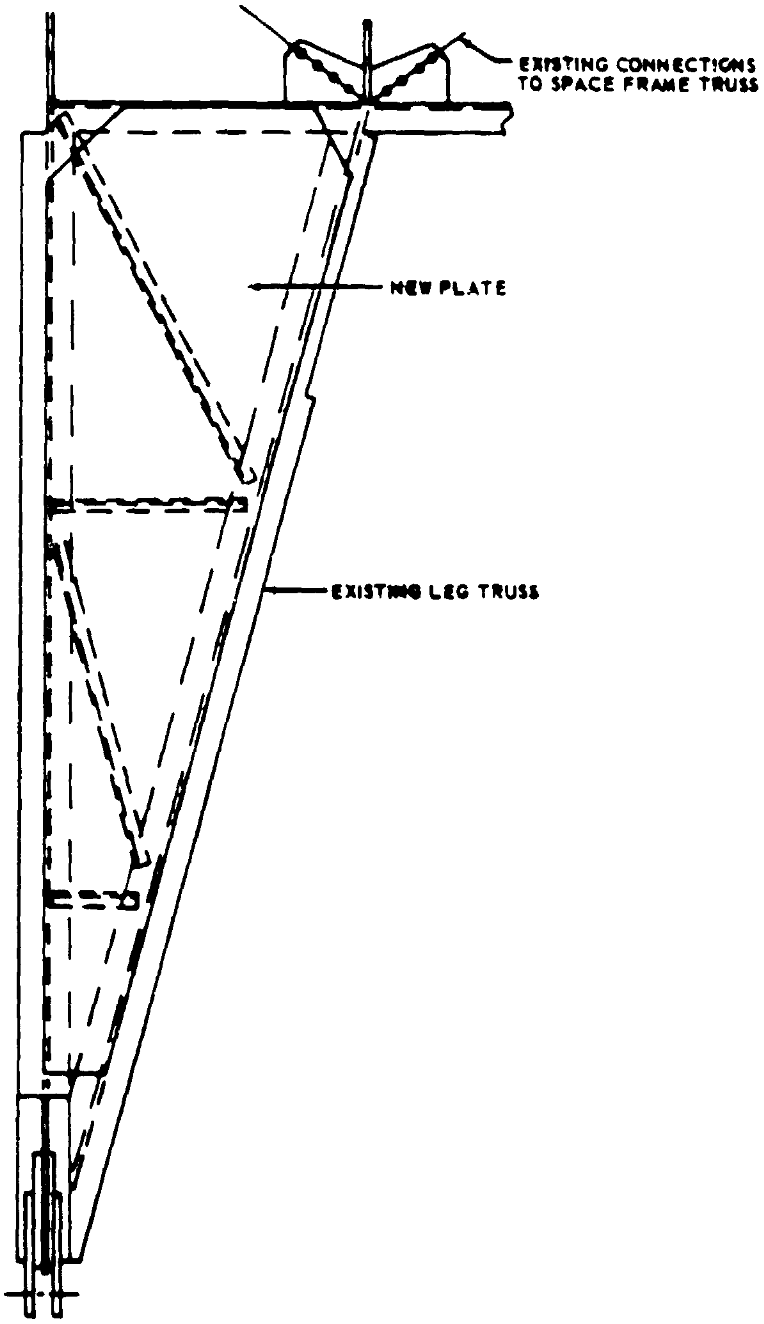


Figure 3-7. Typical Space Frame Leg Modification

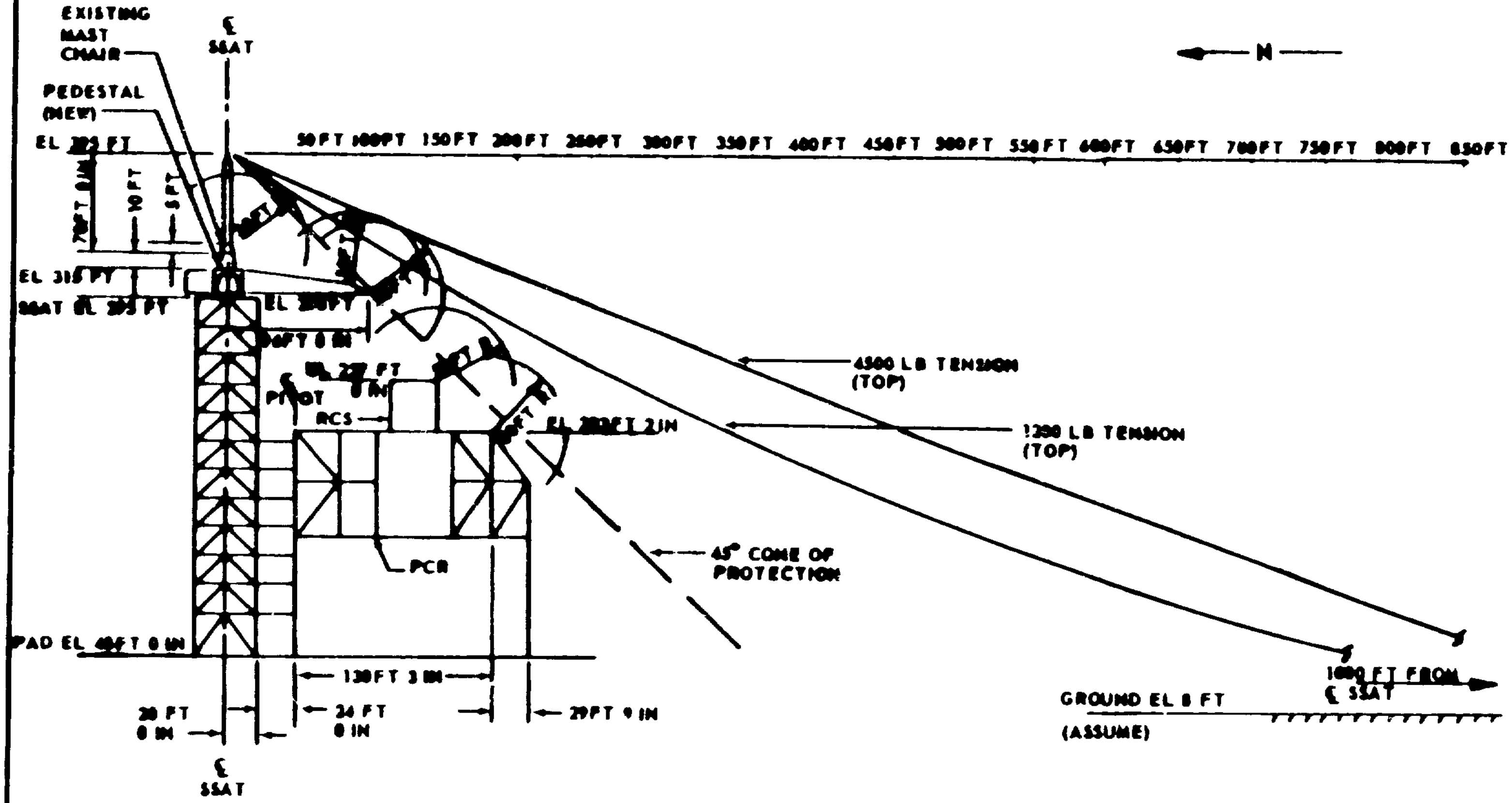


Figure 3-8. Catenary Grounding Cable Clearance Study (70-Ft Mast Pole)

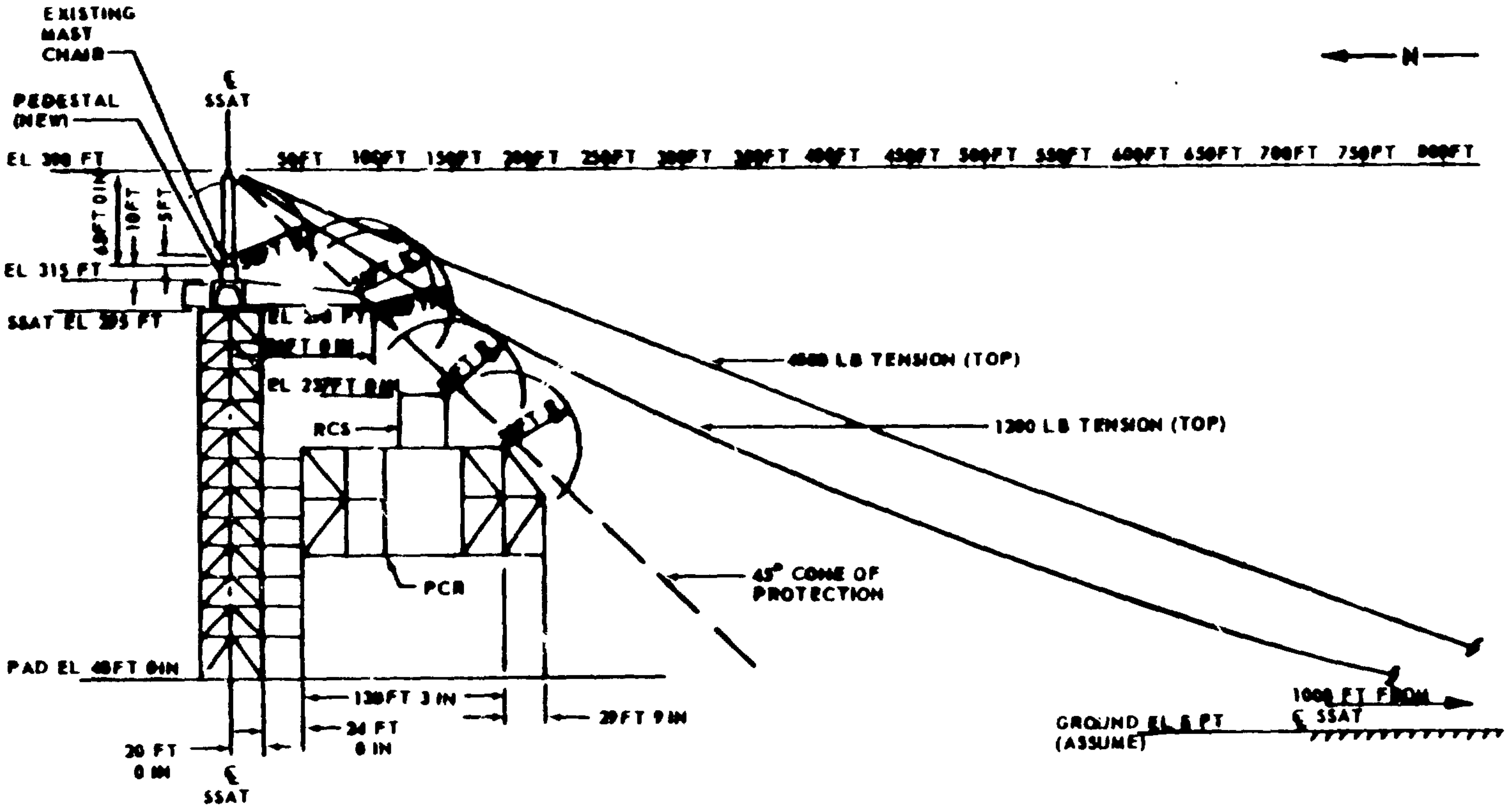


Figure 3-9. Catenary Grounding Cable Clearance Study (65-Ft Fiberglass Pole)

The grounding cable used for the SSAT lightning protection system should be made of high-quality stainless steel with a standard steel core or a high-quality galvanized steel such as monitor AA. The minimum breaking strength for a typical 1/2-in, 6 by 19 IWRC stainless wire rope is on the order of 21,000 lb. With a maximum tension in the SSAT application of 4,500 lb, the factor of safety for the cable is at least 4.5 on minimum breaking strength. This is within acceptable limits of industry standard practice.

For the SSAT installation, the catenary grounding cable must be oriented in a north-south direction as compared to an east-west orientation for ASTP. This results from the fact that the SSAT is permanently installed at the pad and immediately to the west of the Shuttle vehicle, and an east-west cable would interfere with the Shuttle during launch.

Because of the new orientation of the grounding cable, new ground deadman anchors at each end of the cable must be constructed. The existing hardware used for ASTP can be used for the SSAT installation; however, new concrete pads must be placed at the new locations.

3.1.6 ESTIMATE OF COSTS. The rough-order engineering estimate of material and labor costs in table 3-1 was made for the modification concepts presented herein. The cost data reflect only the modification work on the ASTP system to allow it to meet the design requirements of a Shuttle protection system. These data do not include the removal of the ASTP system from the LUT nor the erection of the system on the SSAT.

3.1.7 CONCLUSION AND RECOMMENDATIONS. The final conceptual configuration of the lightning protection system for installation on the SSAT is shown in figure 3-10. The modifications required to meet the design goals include:

a. Shortening the fiberglass mast by at least 10 ft (15 ft preferred to minimize modifications to the steel support structure)

b. Redesigning the steel mast head at the top to allow access

c. Providing a fixed work platform inside the mast to allow working at the top

d. Installing a ladder inside the mast to allow access for inspection

e. Providing a steel support pedestal between the support structure and the mast base to allow access inside the mast

f. Strengthening the steel support structure to withstand hurricane winds

The only recurring cost anticipated for the lightning mast system is the recoating of the fiberglass with its ablative sealant. Assuming a maximum ablation or removal of 0.005 in per launch, this maintenance cost would be incurred every 2 to 3 years. The amount of wear will depend on the exact thermal and

Table 3-1. Rough Order Cost Estimate

Item	Cost	
Fiberglass Mast Modification		
Shorten mast	$ 5,500	
Fabricate and install ladder	3,600	
Fabricate and install platform	2,400	
Steel mast head	800	
Prepare surface and spray on protective coating	3,600	
		$15,900
Support Structure Modification		
Disassemble and reassemble	$12,000	
Fabricate new truss members	4,200	
Fabricate new pedestal	9,600	
		$25,800
Cable System		
New stainless steel wire rope	$ 4,000	
New anchor pads	2,400	
		$ 6,400
Subtotal		48,100
Miscellaneous, profit, taxes (15%)		7,200
Total		$55,300

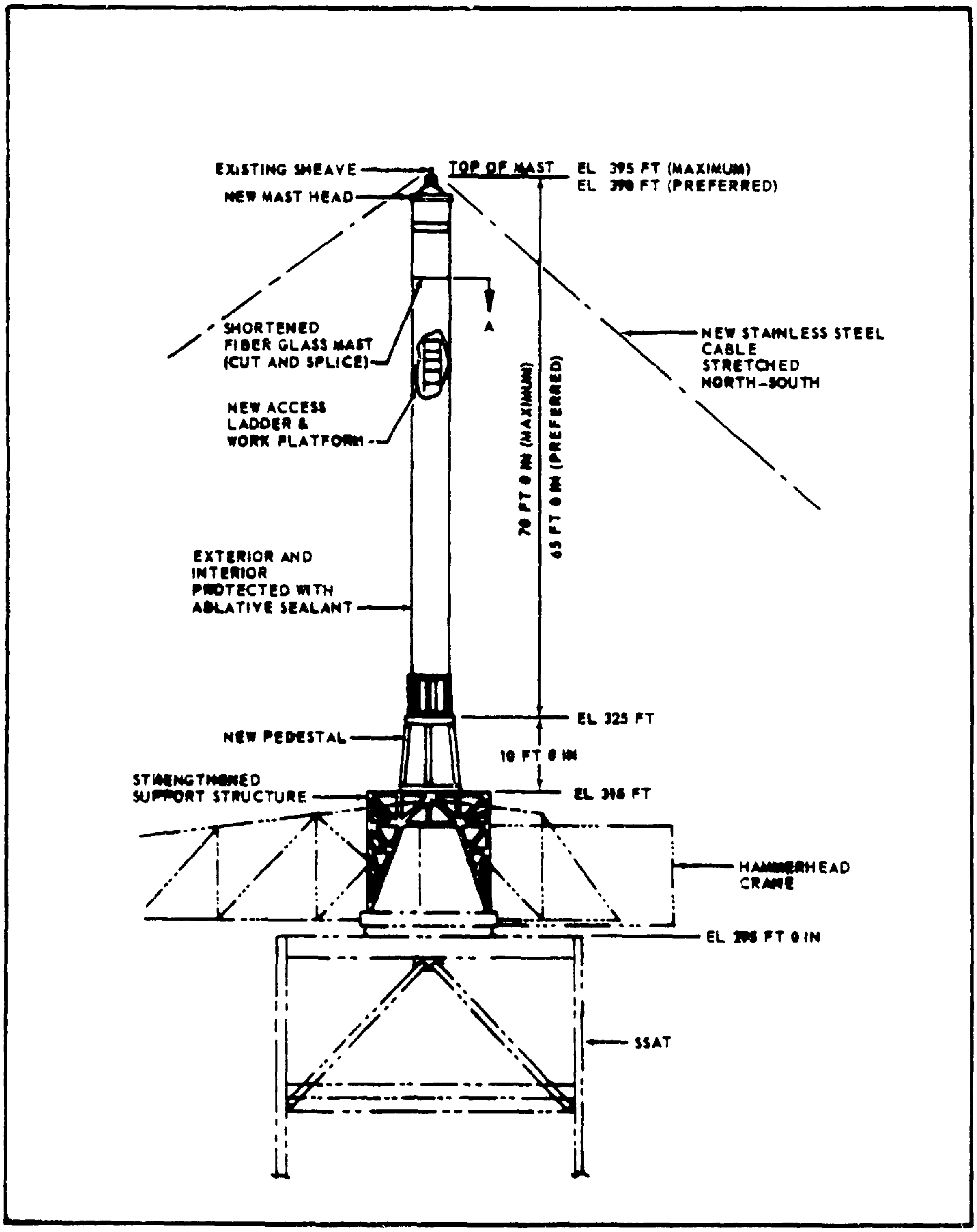


Figure 3-10. SSAT Lightning Protection System

corrosive environment imposed on the mast; this has not yet been fully defined. The maintenance painting and corrosion protection of the steel support structure is assumed to be included in normal maintenance of the SSAT.

These conclusions are based on the design criteria assumed for this study. No firm launch environment data were available. If these criteria change, the extent and costs of the modifications will change. The only significant recurring costs will be the periodic recoating of the inside and outside of the fiberglass mast with an ablative sealant.

3.2 GROUND INSTRUMENTATION

The ASTP ground instrumentation for measuring lightning stroke current waveforms at each end of the lightning intercepting catenary cable can also be used for the Shuttle lightning protection system. The Shuttle protective cable should be oriented north-south and supported by a fiberglass mast on the SSAT. The ASTP instrumentation will be reviewed in the next section before discussing possible modifications for Shuttle.

3.2.1 ASTP LIGHTNING WAVEFORM INSTRUMENTATION. For ASTP two shielded enclosures were provided at each end of the protective catenary cable to house separate sets of instrumentation. The east end of the cable is shown in figure 3-11. The cable is isolated from the anchor point by insulators and grounded by a down lead and ground rod (figure 3-12). Two current sensors, one a Pearson coil to obtain the current waveform and the other a Kirtland coil to obtain the rate of change of current, are coupled to the ground rod. The Pearson coil is used with a compactor digital recorder and the Kirtland coil with a biomation digital recorder, each housed in separate shielded enclosures (figure 3-13). Peak reading voltmeters (PVM's) are also used to obtain the sensor peak voltages. The compactor instrumentation is shown in figure 3-14 and the biomation instrumentation in figure 3-15. A complete block diagram of the two sets of instrumentation is shown in figure 3-15.

Details of the sensor installations are shown in figure 3-17. The upper coil is a Pearson current sensor. Its output is optically coupled to the compactor (figure 3-18). The compactor records only preset steps of voltage change, ranging from 1 to 50 percent. When set at 5 percent, 40 data points per stroke are recorded, giving the compactor a capacity of 51 strokes. At an average of 3 strokes per flash, the flash capacity is 17. The scan rate is 2 MHz, giving a sample interval of 0.5 μs. The nominal current range is 2 to 100 kA. The data are transmitted to the LCC where a printout and waveform are provided (figure 3-19). The data can also be analyzed by a computer to provide peak current, rise time to peak, rise time (10 to 90 percent), and time to 50 percent of peak.

This instrumentation was tested with exponential and oscillatory current waveforms. Typical waveform recordings are shown in figures 3-20 and 3-21. The interval increase during the slowly varying portion of the waveform is shown in figure 3-20. The waveform at the top of figure 3-21 was obtained with the

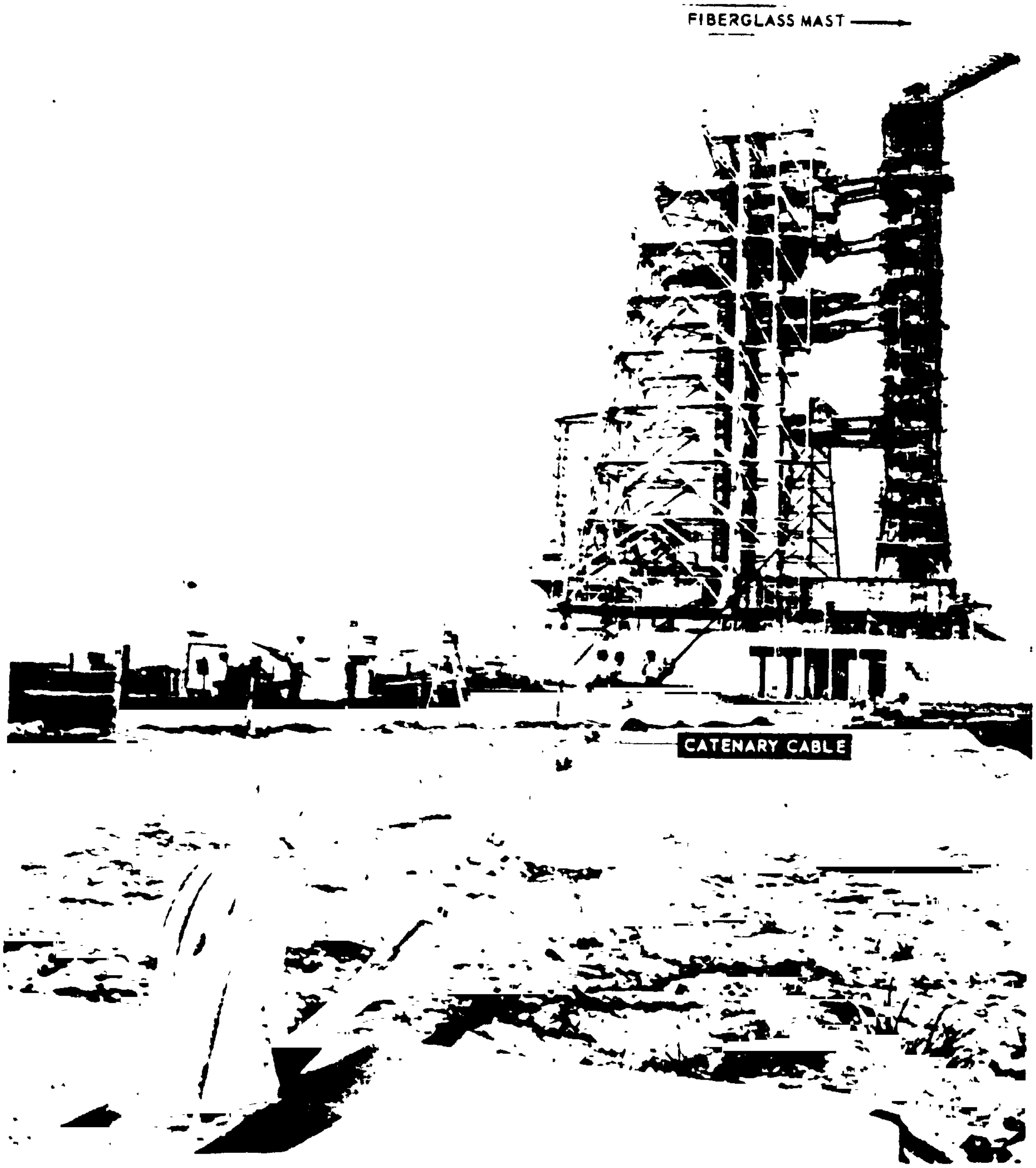


Figure 3-11. Grounded Catenary Cable Viewed From East Anchor Point to Top of Fiberglass Mast. A Similar Anchor Point Is on the West Side.

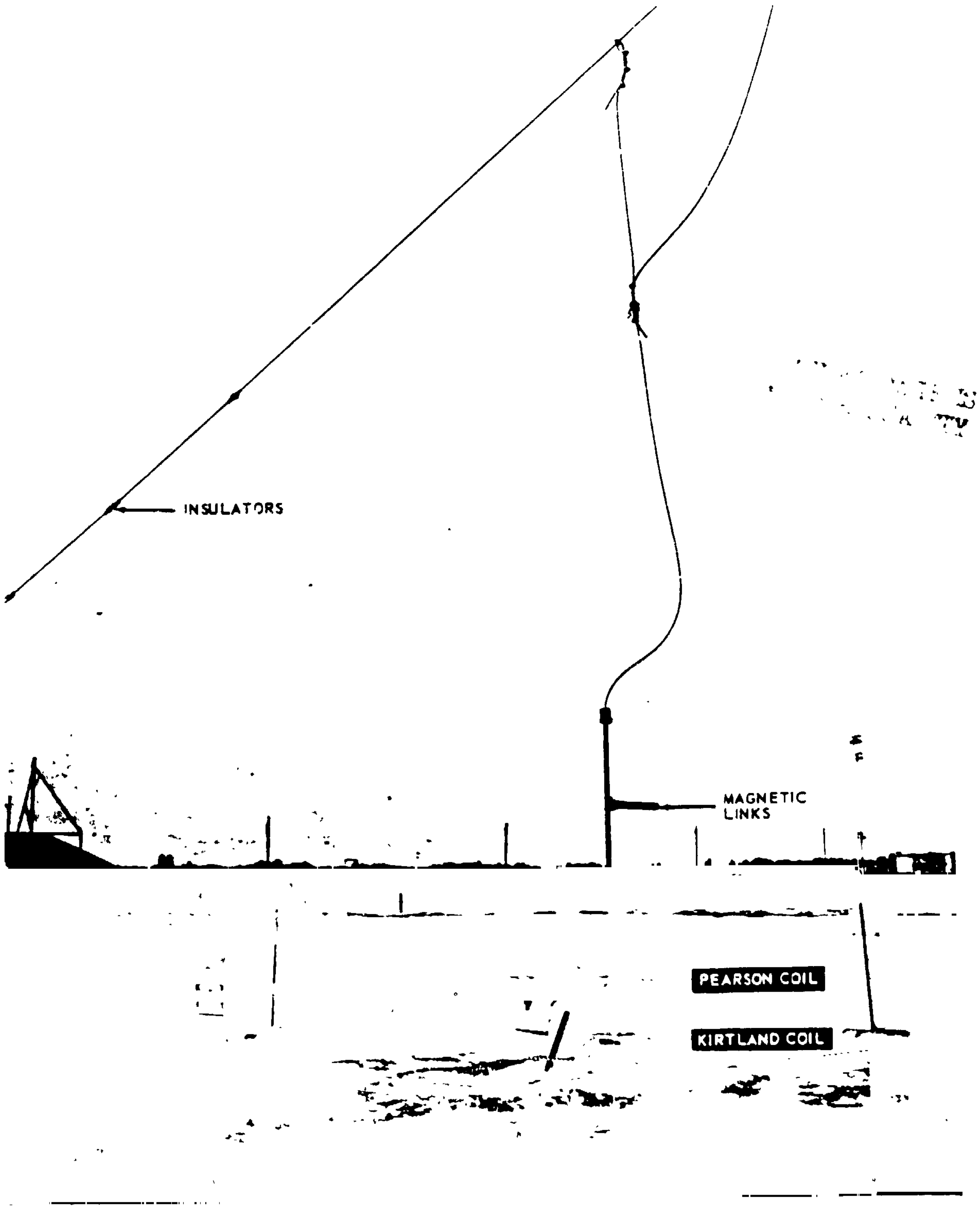


Figure 3-12. Current Waveform Sensors on Grounded Down Lead From Catenary Cable. Cable Insulators at Left.

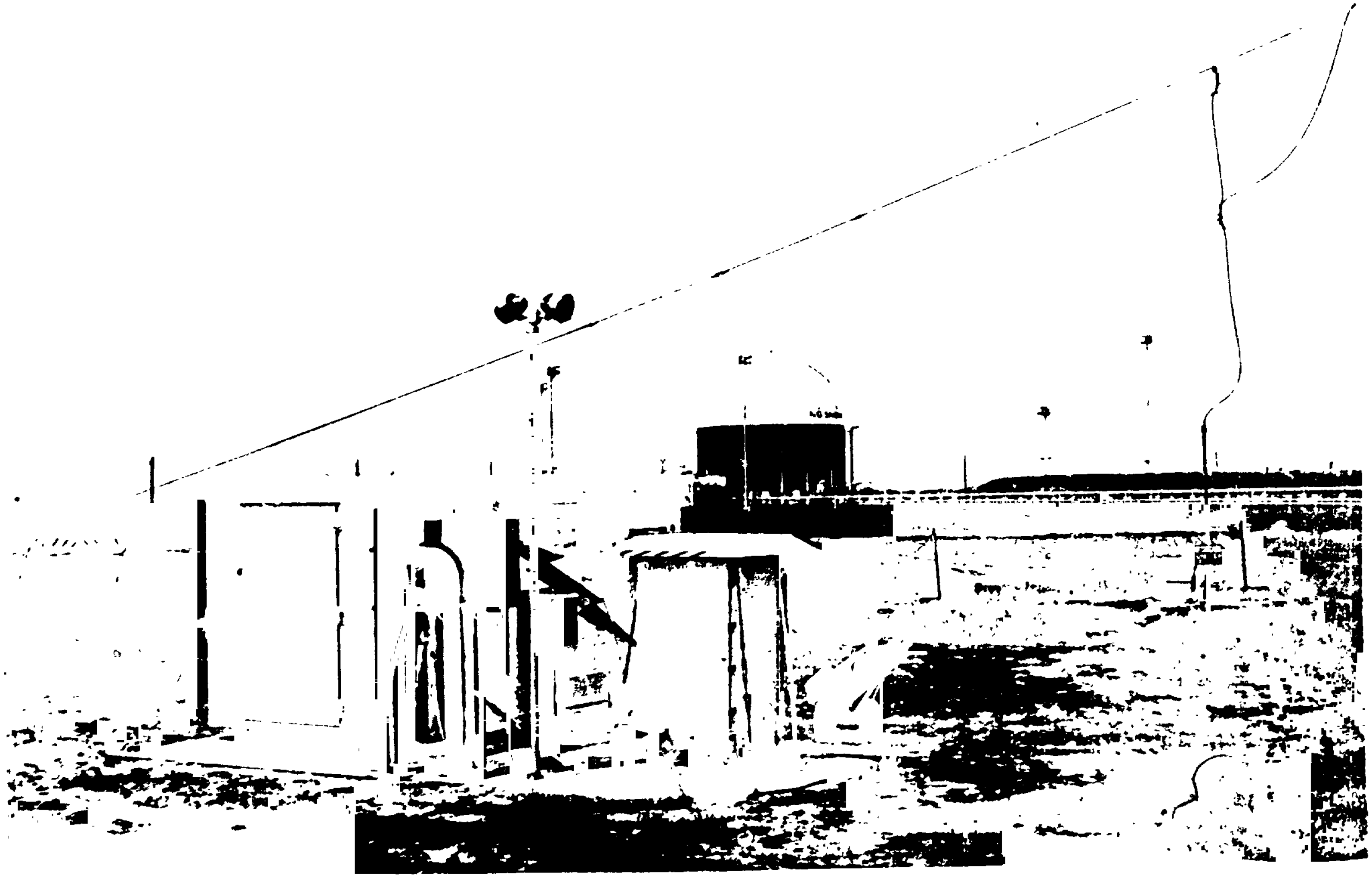


Figure 3-13. Shielded Enclosures for Compactor on Left and Biomation on Right

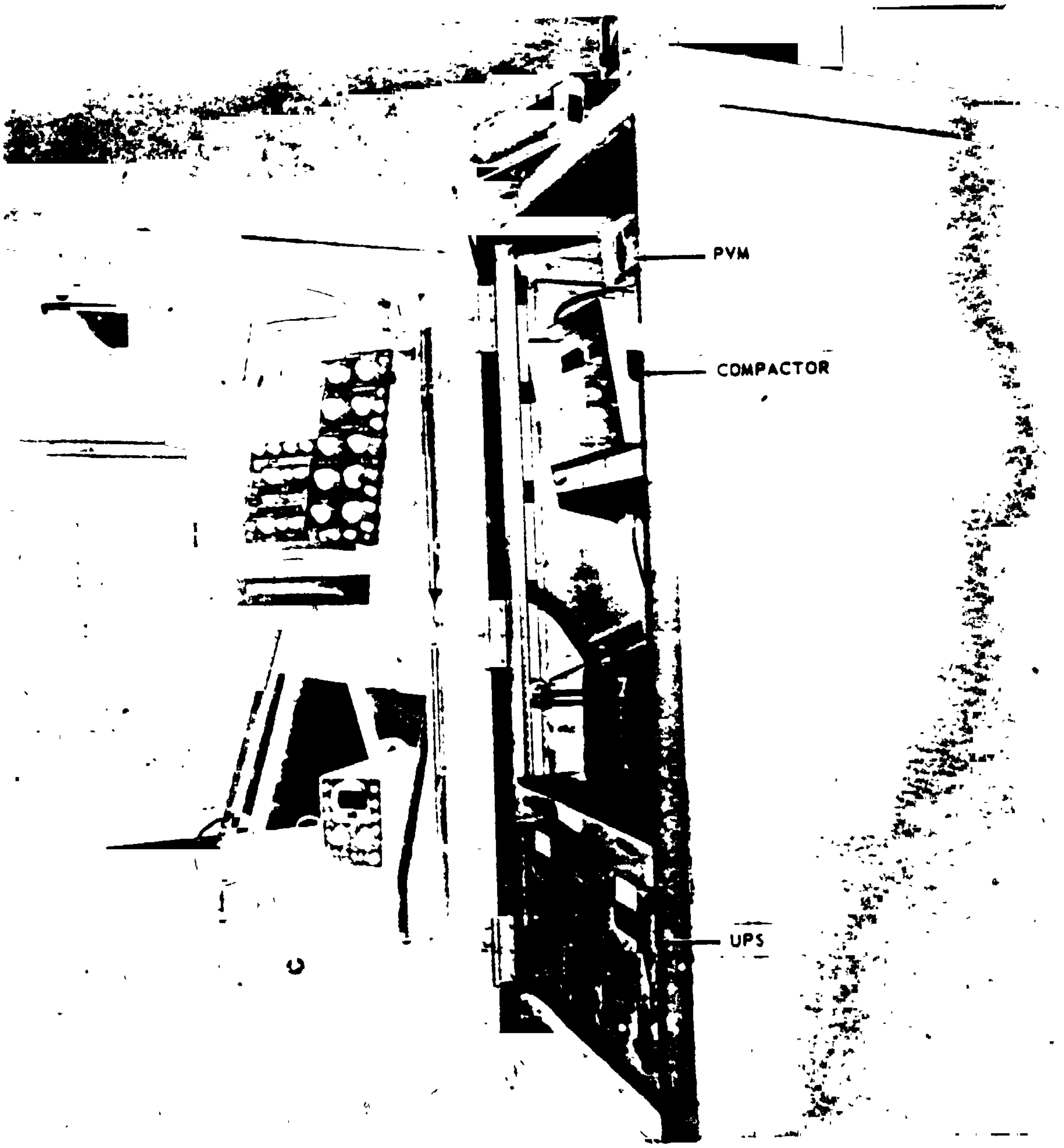


Figure 3-14. PVM and Compactor Used With Pearson Coil Current Waveform Sensor

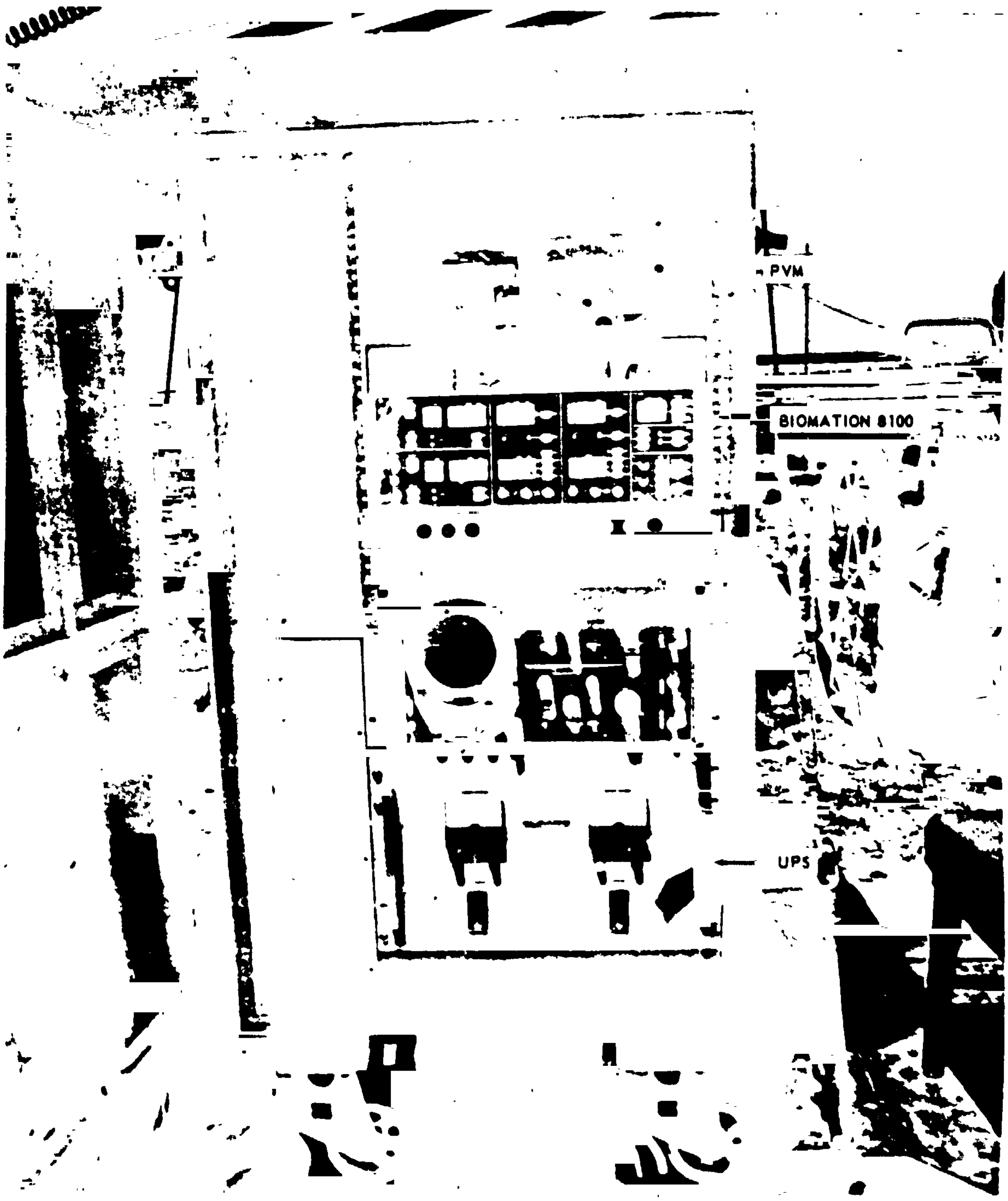


Figure 3-15. PVM and Biomation Used With Kirtland dI/dT Sensor

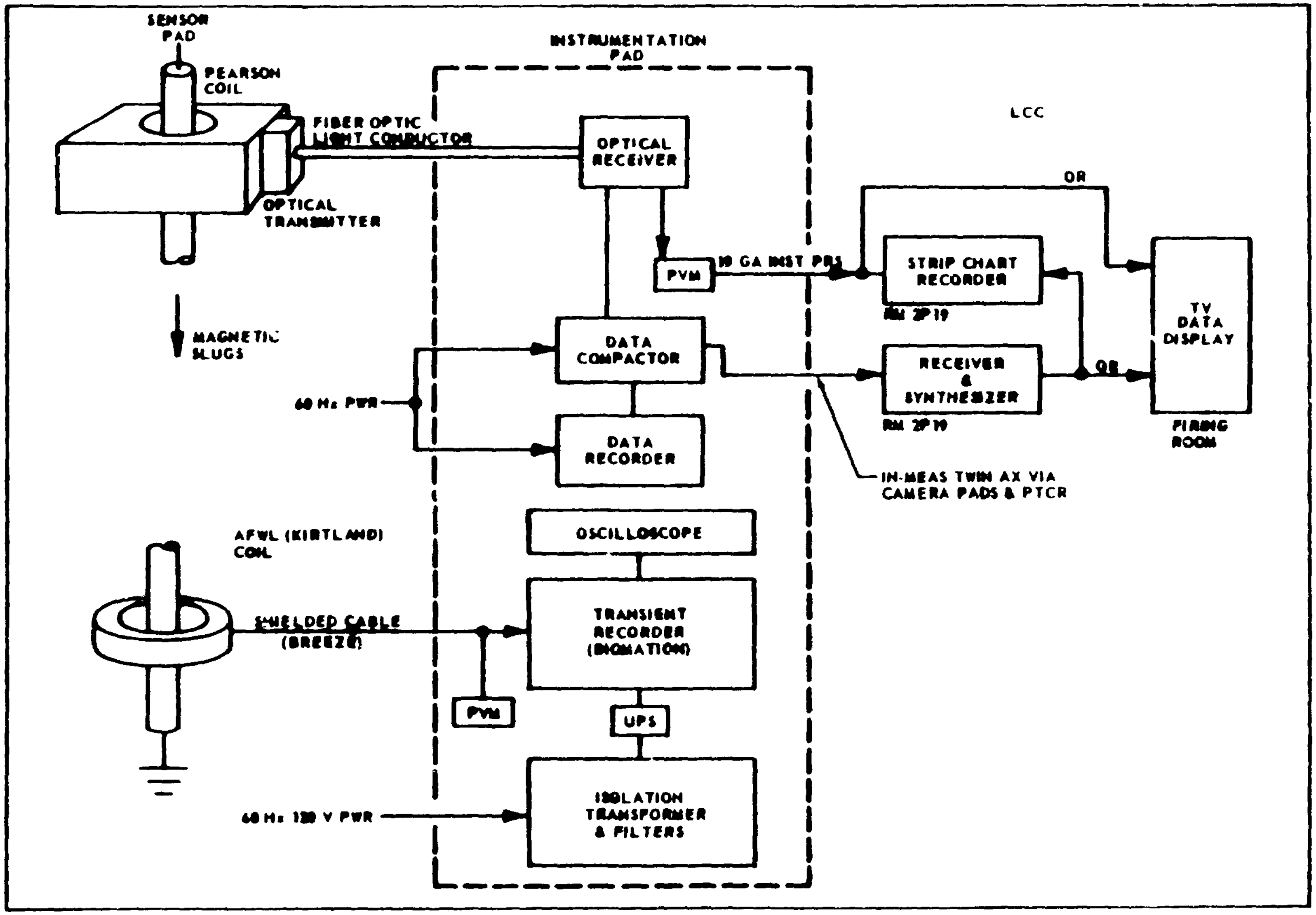
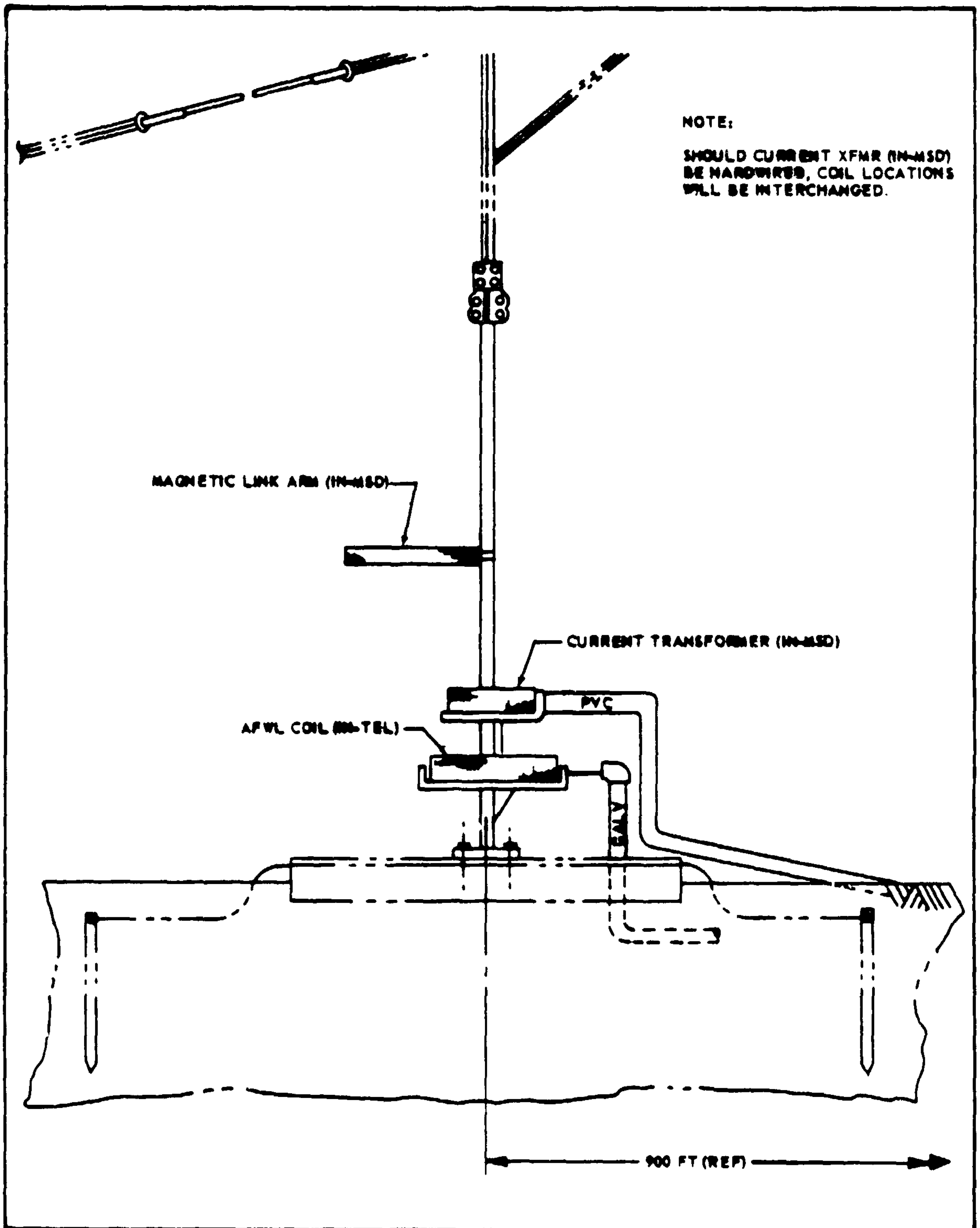


Figure 3-16. Static Cable Lightning Measurement Instrumentation



NOTE:

SHOULD CURRENT XFMR (IN-MSD) BE HARDWIRED, COIL LOCATIONS WILL BE INTERCHANGED.

Figure 3-17. Typical Installation - Sensor Pad. ASTP Catenary Wire Lightning Instrumentation LC-39B

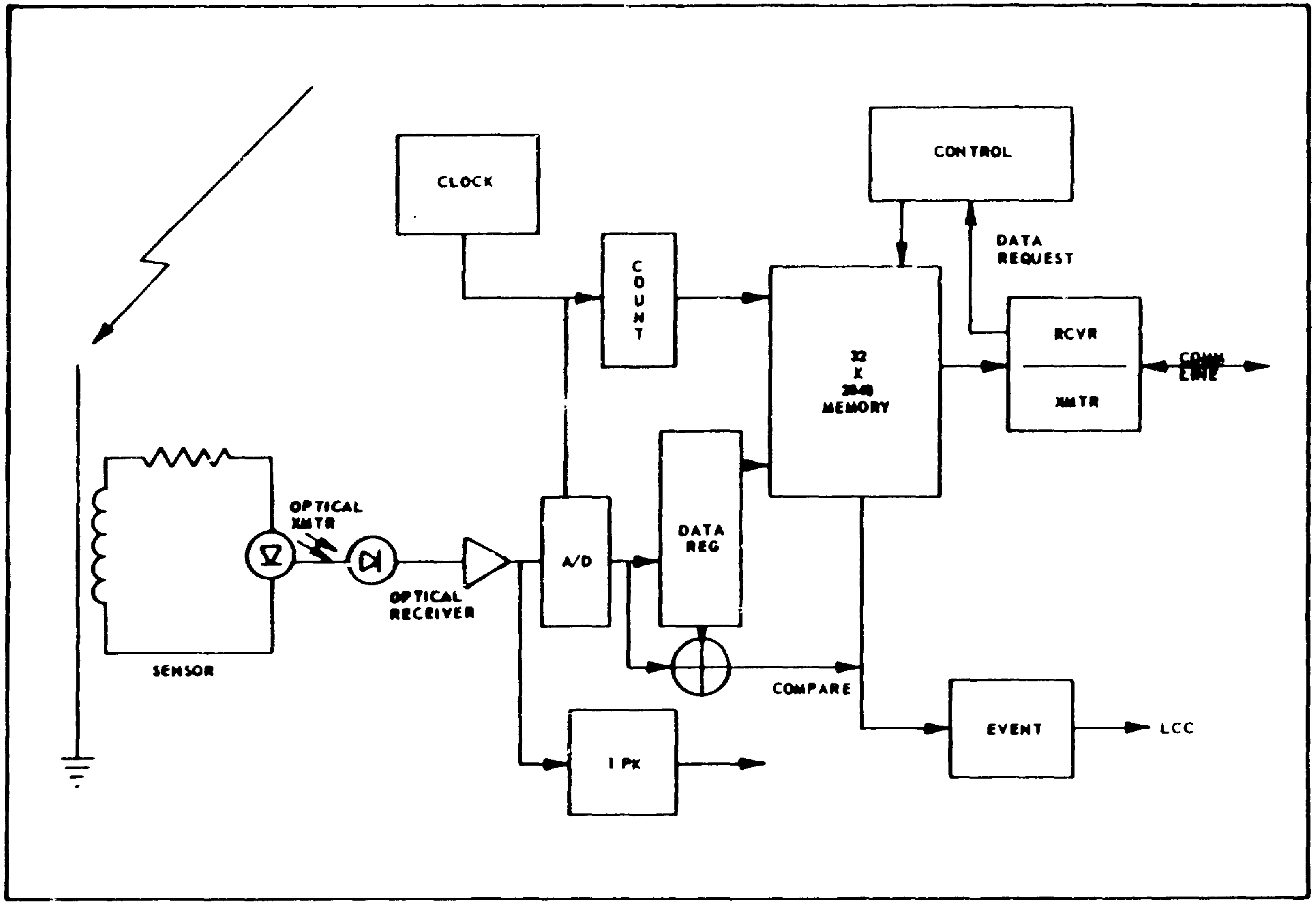


Figure 3-18. Data Acquisition Lightning Waveform Measurement

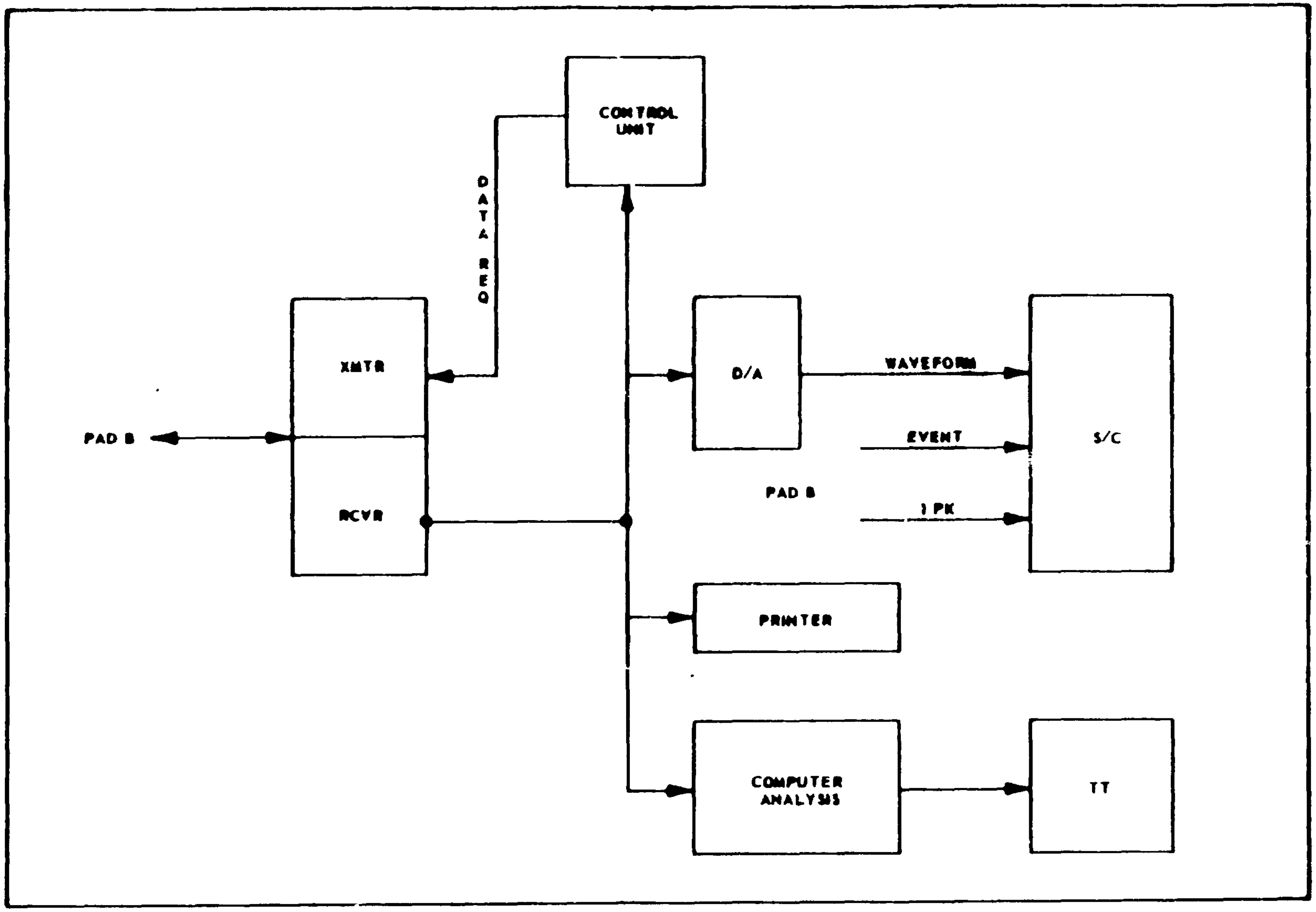


Figure 3-19. LCC Data Reduction Lightning Waveform Measurement

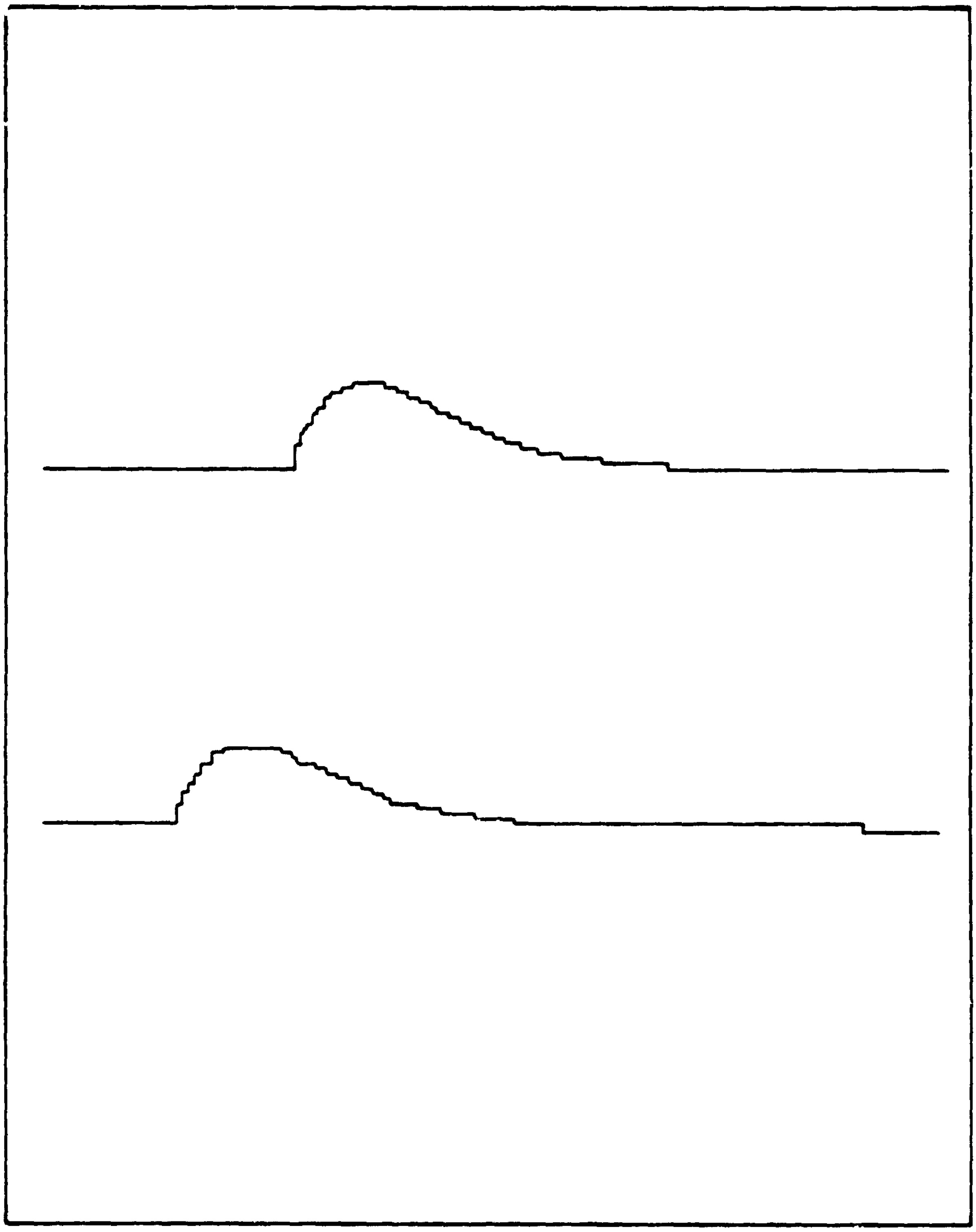


Figure 3-20. Exponential Waveforms Reproduced After Acquisition by Compactor

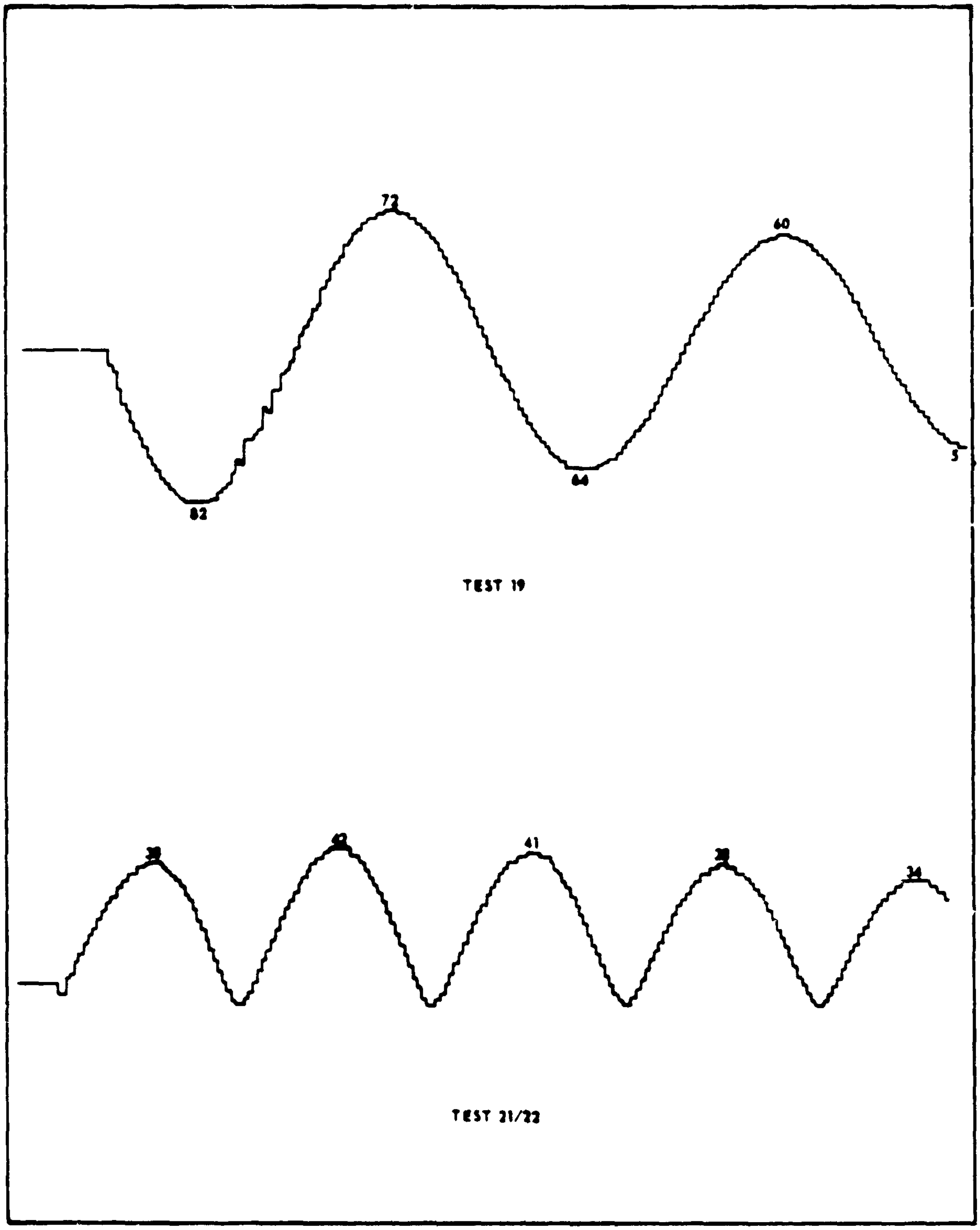


Figure 3-21. Compactor-Acquired Oscillatory Waveforms. Waveform at Top Was Hard-Wired to the Compactor. Bottom Waveform Shows Amplitude Distortion Introduced by Fiber-Optic Coupling.

sensor hard-wired to the compactor. Fiber-optic coupling, used for the waveform shown at the bottom of figure 3-21, introduced an amplitude distortion and polarity was also lost.

The lower coil shown in figure 3-17 is a dI/dT sensor obtained from Kirtland Air Force Base, New Mexico. Its output is hard-wired to a biomation transient recorder (figure 3-22) which stores 2,080 samples of data at scan rates up to 100 MHz giving a minimum sampling interval of 0.01 µs. A time base of 40 µs with 0.02-µs intervals and a full-scale dI/dT of 50 kA per µs were selected for most of the ASTP recordings. The digital waveform is optically coupled from the shielded enclosure at the pad to phone pairs and then transmitted to the CIF antenna site. The instrumentation is remotely controlled as shown in figures 3-23 and 3-24. The dI/dT waveform is integrated by computer, and both the dI/dT and current waveforms are plotted. The nominal rate of change of current range was 1 to 50 kA per µs for ASTP. Typical waveforms of the July 20, 1975, post-ASTP stroke to the protection system are shown in figures 3-25 and 3-26.

3.2.2 ASTP INSTRUMENTATION MODIFICATIONS. The ASTP instrumentation can be used on the Shuttle SSAT lightning protection system cable with some modifications for improved performance and reliability and for consolidation of equipment. Simplification and the application of new techniques should also be considered, but such techniques may not be cost effective compared to the instrumentation and sensors already purchased except for installations on a possible second launch pad.

The following modifications should be considered:

a. The fiber-optic circuitry associated with the Pearson coil sensor and compactor should be improved to correct waveform distortion so that the lightning waveform can be accurately recorded. Consideration should be given to the alternate hard wire shielded pair coupling.

b. Shielding of the compactor and associated equipment should be improved as necessary. The equipment should be examined for susceptibility to vibration. Any vibration sensitivity should be reduced by antishock techniques. The compactor equipment was not reliable enough to record the 80-kA post-ASTP lightning stroke to the catenary cable.

c. All the current waveform data recording equipment at the pad should be consolidated in one shielded enclosure at each end of the cable or in one central location, such as in the PTCR. Coupling between the sensors and the enclosures is facilitated by high signal levels. Either fiber-optics or twin conductor coax cable may be used.

d. The performance of the instrumentation should be verified and calibrated periodically and on demand using insulated minizappers permanently installed at each end of the catenary cable. The minizappers would apply low-level exponential and oscillatory waveforms to the system ground rods.

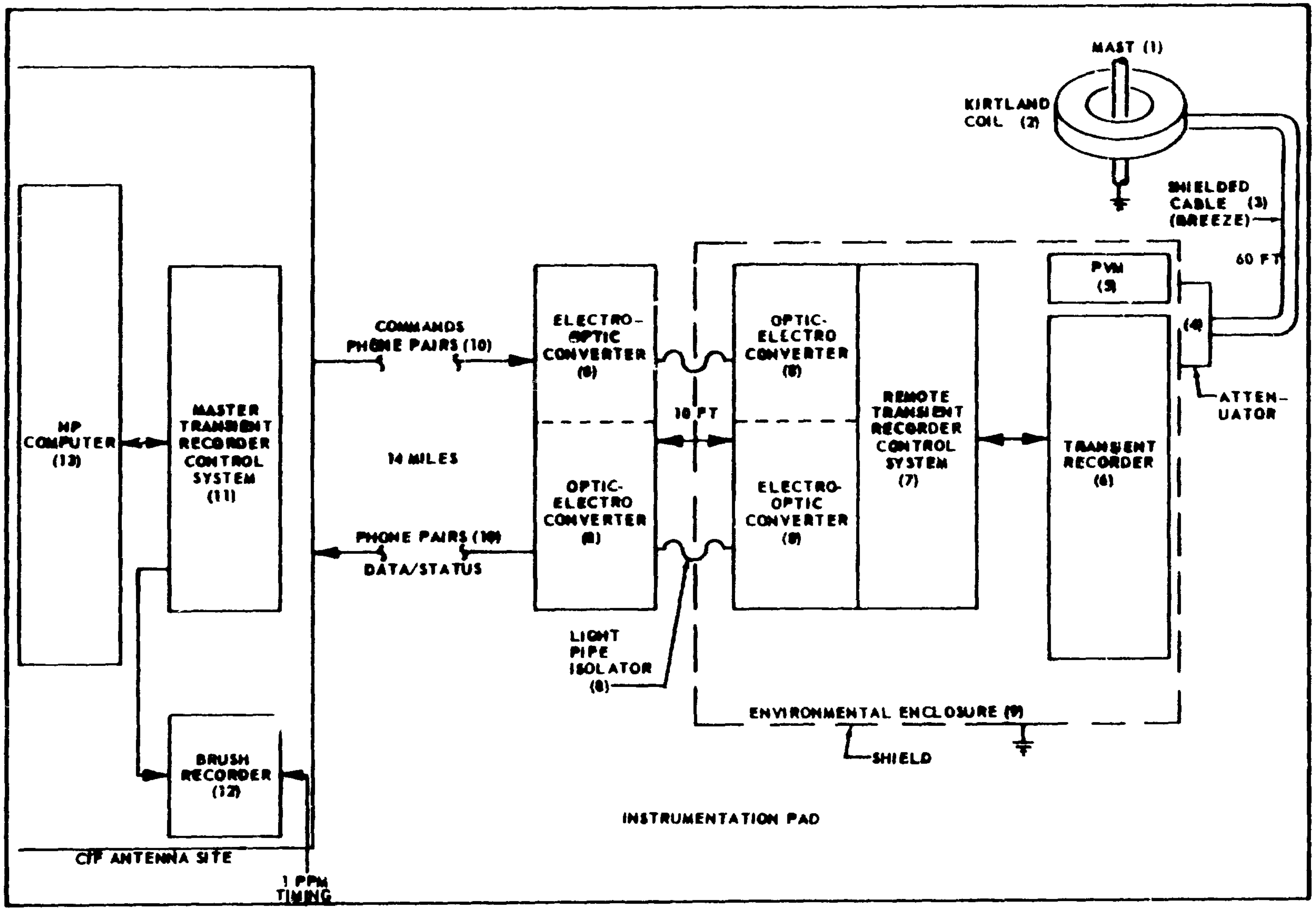


Figure 3-22. Data Transmission Path, RLMT

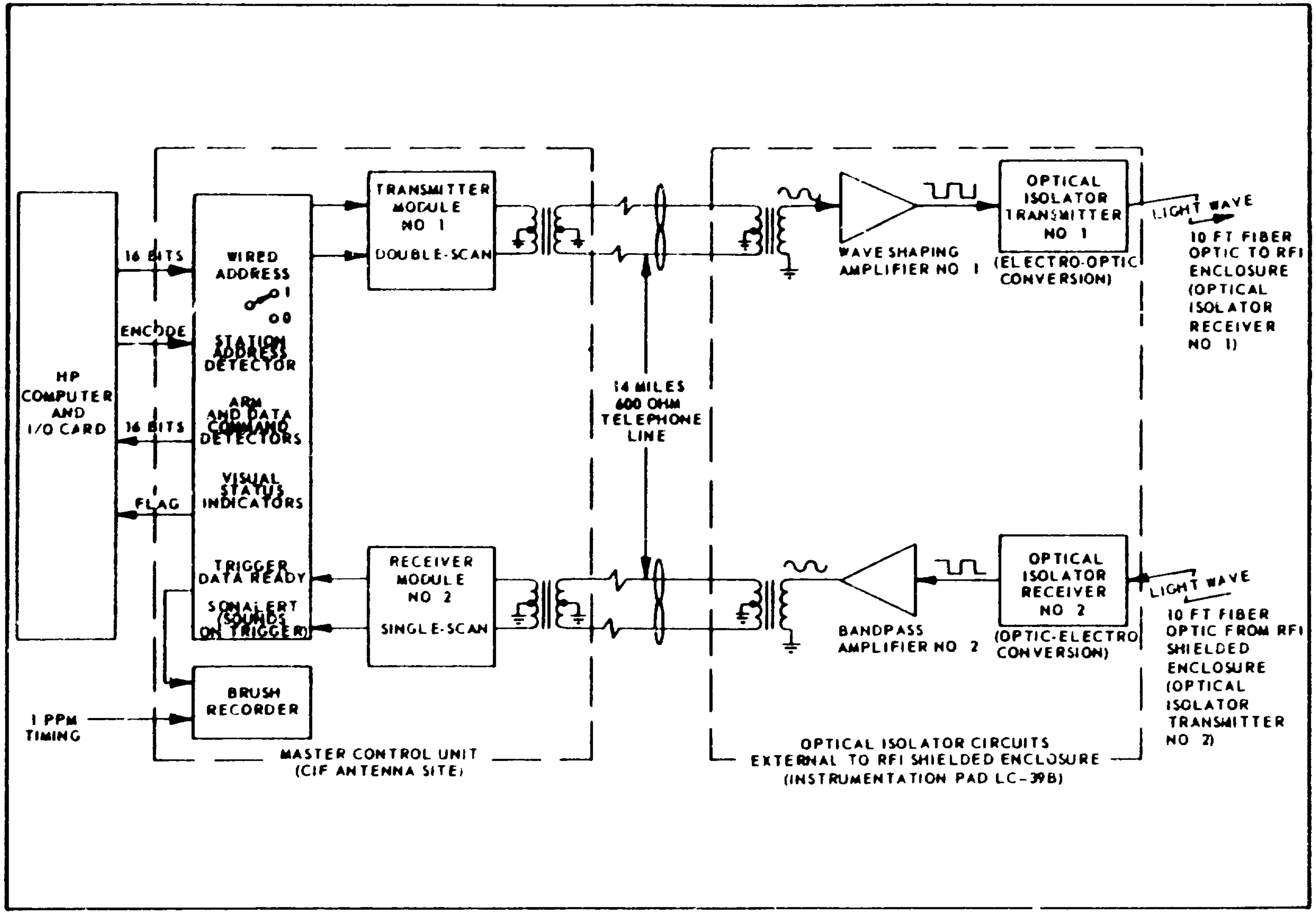


Figure 3-23. Remote Control System for Remote Lightning Monitor (RLMT)

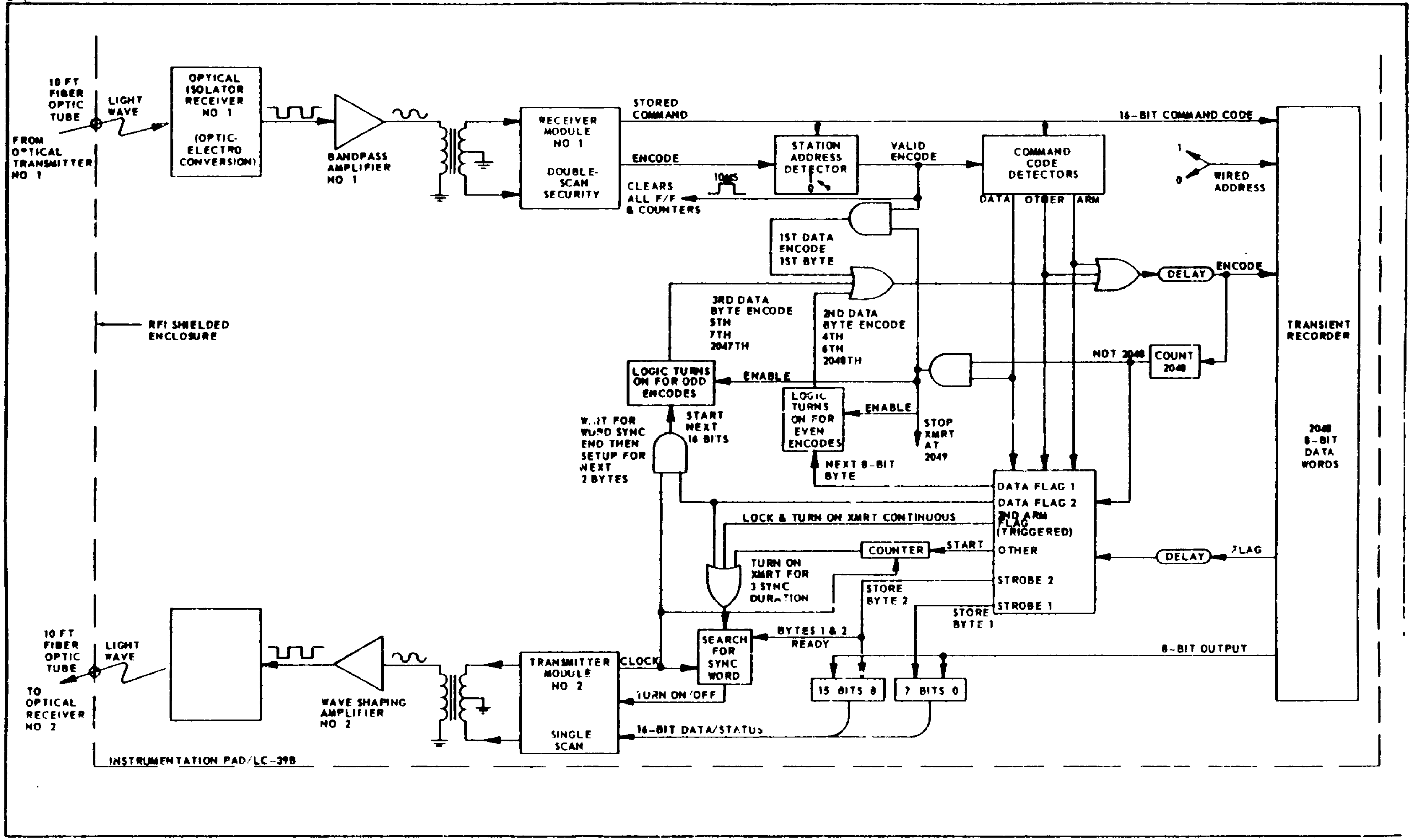


Figure 3-24. Remote Control System for Remote Lightning Monitor (RLMT)

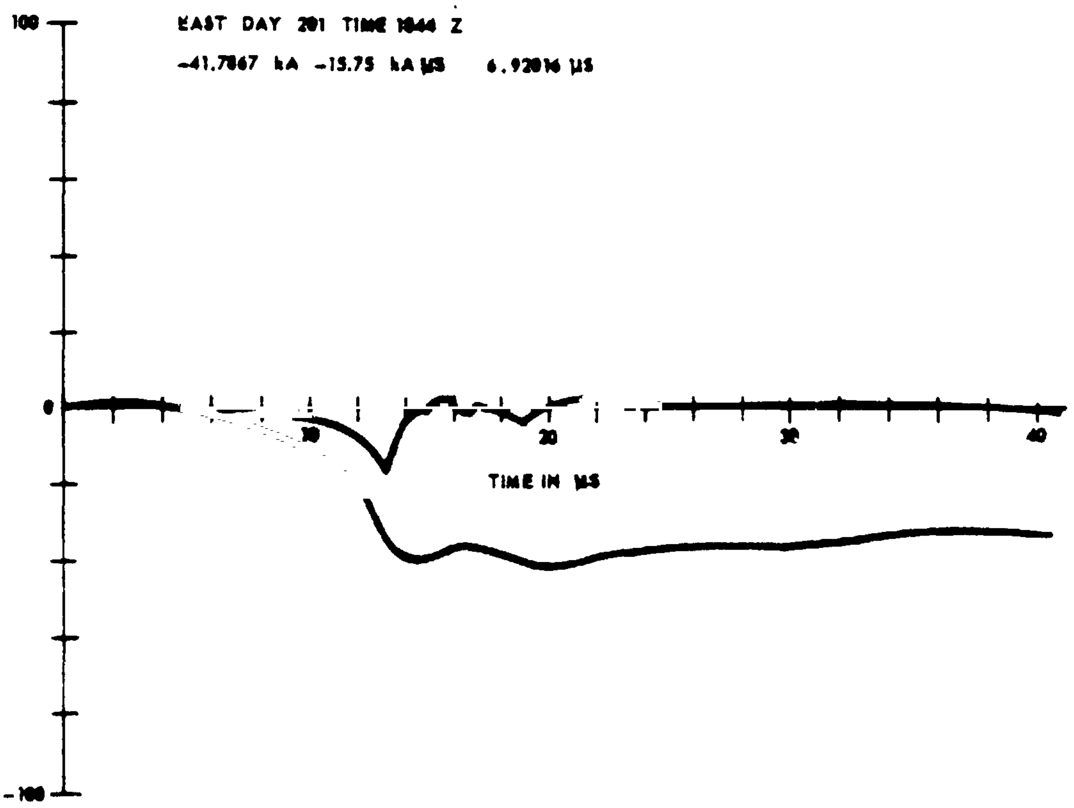


Figure 3-25. Lightning Waveforms From East Side of Catenary Reproduced After dI/dT Acquisition by Biomation 8100 From Kirtland Coil. Both dI/dT and I Waveforms Are Shown.

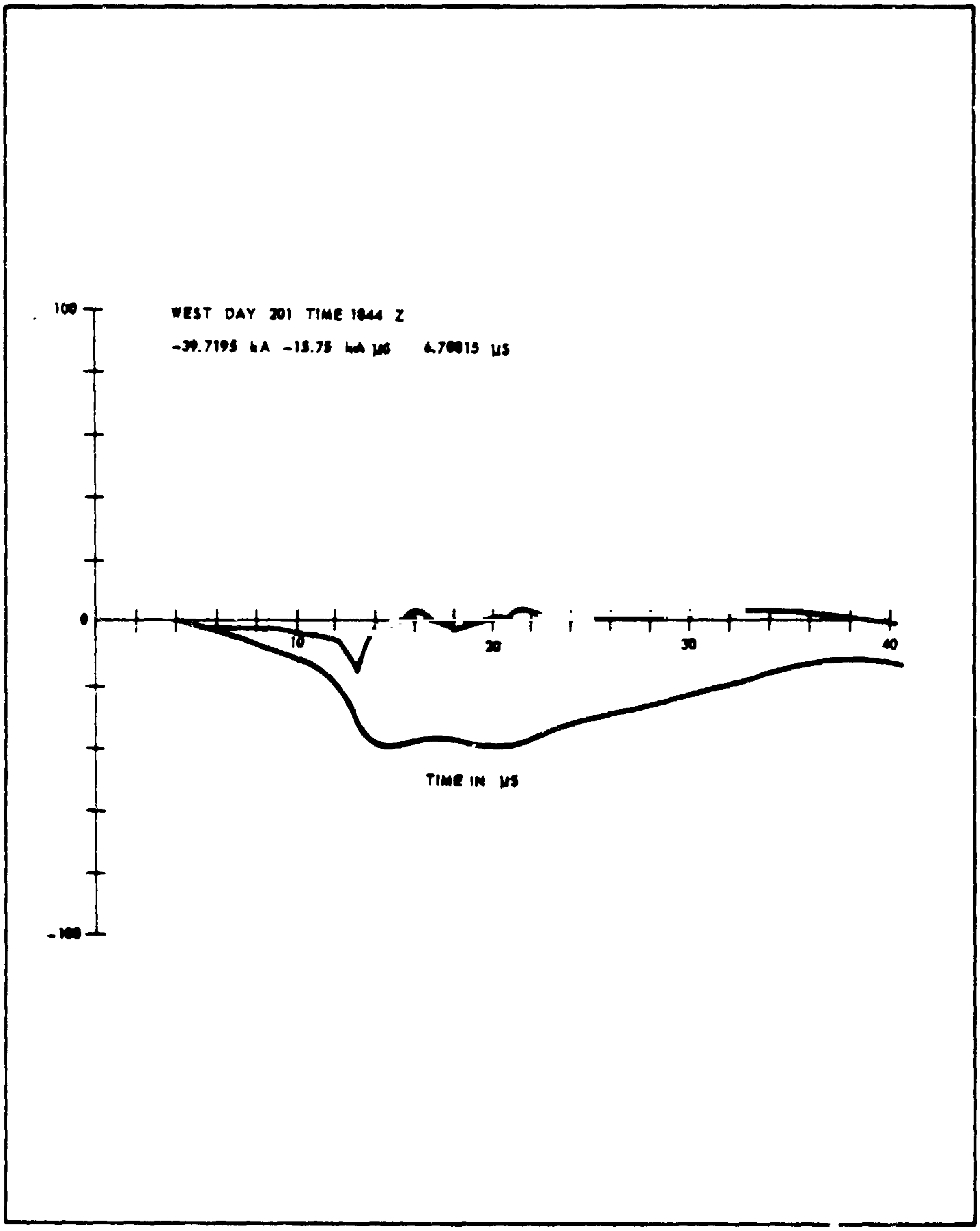


Figure 3-26. Lightning Waveforms From West Side of Catenary Reproduced After dI/dT Acquisition by Biomation 8100 From Kirtland Coil. Both dI/dT and I Waveforms Are Shown.

e. The biomation recorder should be adjusted to record the first 100 μs of each stroke. This setting will record 95 percent of all strokes to their 50-percent decay point. The 5 μs ahead of the triggering pulse and the first 10 μs after triggering could be sampled with a sampling interval of 0.02 μs. The rise time of 98 percent of all strokes is less than 10 μs. The minimum time to 50-percent peak is also 10 μs. Using the dual time base capability of the biomation the next 90 μs, during which the waveform is usually slowly varying, could have a sampling interval of 0.5 μs.

f. The biomation has two independent channels which can be used to record both the current and dI/dT waveforms direct from the appropriate sensors rather than integrating dI/dT to obtain the current waveform.

g. The biomation output can be recorded on tape approximately every 3 ms. Since the minimum time between strokes is 3 ms, all strokes can be recorded at high sampling rates using the biomation.

h. While the Pearson and Kirtland coils were satisfactory sensors for ASTP and could be used for Shuttle, the sensing may be simplified and improved by the use of a resistive tubular shunt to measure the current and a simple concentric mutual inductor to measure rates of change of current.

Two advantages of the current measuring shunt are:

(1) A high signal level (approximately 1 V/kA) appears across a low resistance (approximately 1 mΩ), so that the interference from stray signals is negligible and signal transmission is simplified.

(2) Calibration is easily accomplished using a bridge or battery, ammeter, and millivoltmeter. The resistance can be made constant over a wide frequency range.

Two forms of the current shunt are shown in figures 3-27 and 3-28. The low inductance reentrant type shown in figure 3-27 can be made integral with the ground rod to screw into a small hole in the ground plate. The impedance of these shunts can be made almost linear to about 3 MHz and down 3 dB at 12 MHz. The response time can be of the order of 0.03 μs which can be reduced to 0.01 μs by using compensation techniques. These shunts can measure currents up to 500 kA.

The mutual inductor is essentially a concentric cylindrical skirt on the lower portion of the ground rod (figure 3-29). The cylinder is about twice the diameter of the ground rod and has a length of about 7 in. It can be located just above the ground plane. This concentric tube mutual inductor can be made accurate to within 10 percent for all frequencies up to about 65 MHz.

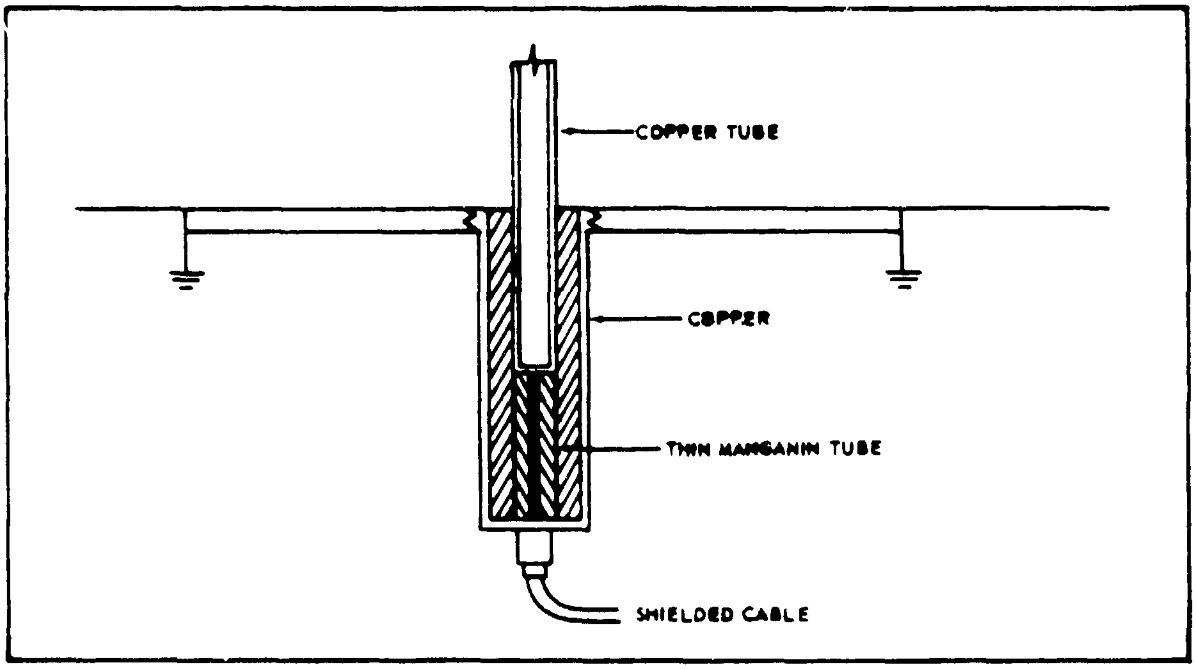


Figure 3-27. Reentrant-Type Resistance Shunt for High-Current Measurement

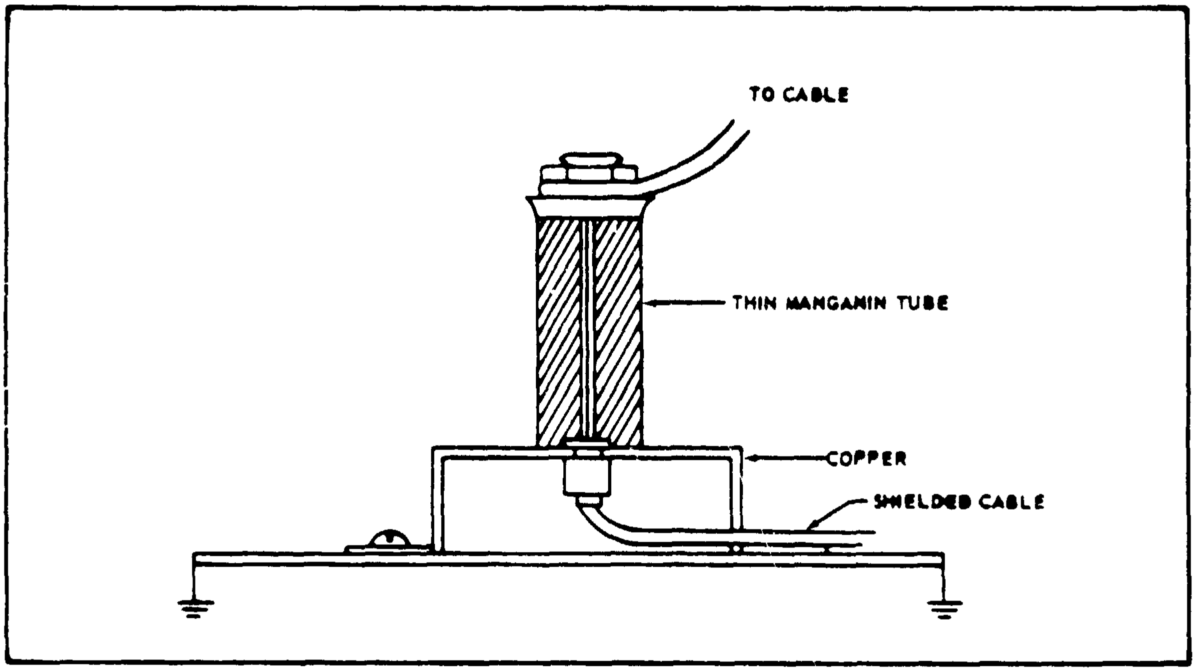


Figure 3-28. LTRI Resistance Shunt for High-Current Measurement

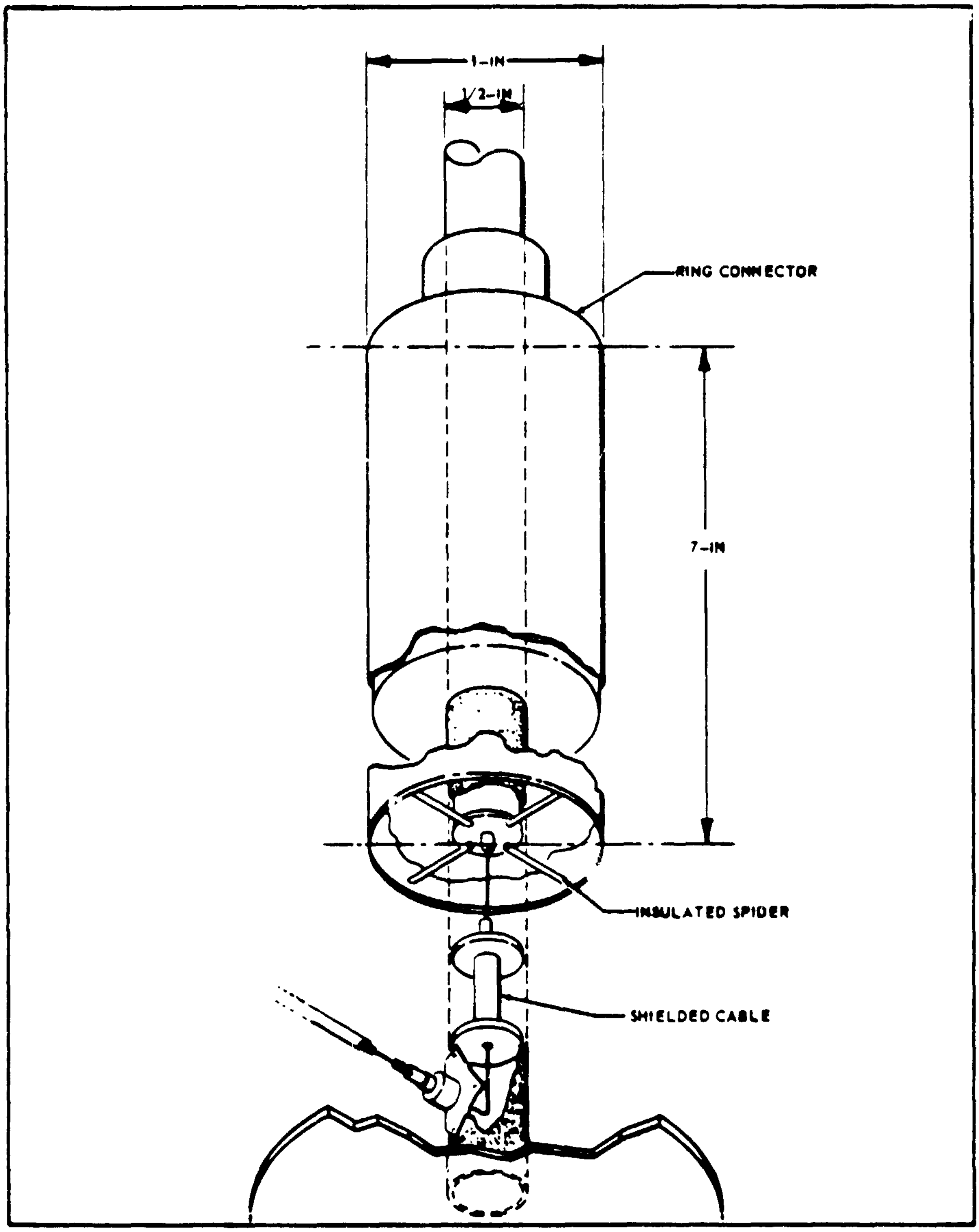


Figure 3-29. Coaxial Mutual Inductor for Measuring Rates of Change Current

i. Analog shift registers are available which can store a limited number of samples (64 to 128) with a 0.15-μs sampling interval followed by an analog readout at a slow rate for about 3.2 ms. A lightning current waveform could be recorded at a high sampling rate and essentially stretched out in time for permanent recording on inexpensive slower equipment. Two analog shift registers are currently available, the General Electric SCT-26 and the Reticon SAM-64. At present these are limited in capacity and somewhat slower than desired, but they will be further developed and may find application for inexpensive data acquisition in later Shuttle installations.

j. Waveform parameters, such as rise time, peak current, and time to 50-percent peak, should continue to be measured. Waveforms should also always be identified by automatic time recording with the waveform.

3.2.3 INSTRUMENTATION COSTS. The instrumentation developed and used for ASTP can be transferred to the Shuttle lightning protection system. With normal maintenance the equipment can be used over a 10-year period if required; however, sufficient lightning experience may be obtained in a shorter period. Some of the instrumentation, such as the biomation waveform recorders, was borrowed for ASTP and may not be available to be dedicated to Shuttle waveform recording.

It is assumed that an A2A wideband circuit will be available for multiplex data transmission and that appropriate data processing and recording equipment will be available. As an alternative, about five biomation recorded strokes could be stored at the pad instrumentation site using auxiliary memories. Their capacity would be sufficient to store 90 percent of the flashes. Any additional strokes before readout could be stored in the compactors. The improvements outlined in paragraph 3.2.2 should be considered and implemented if feasible.

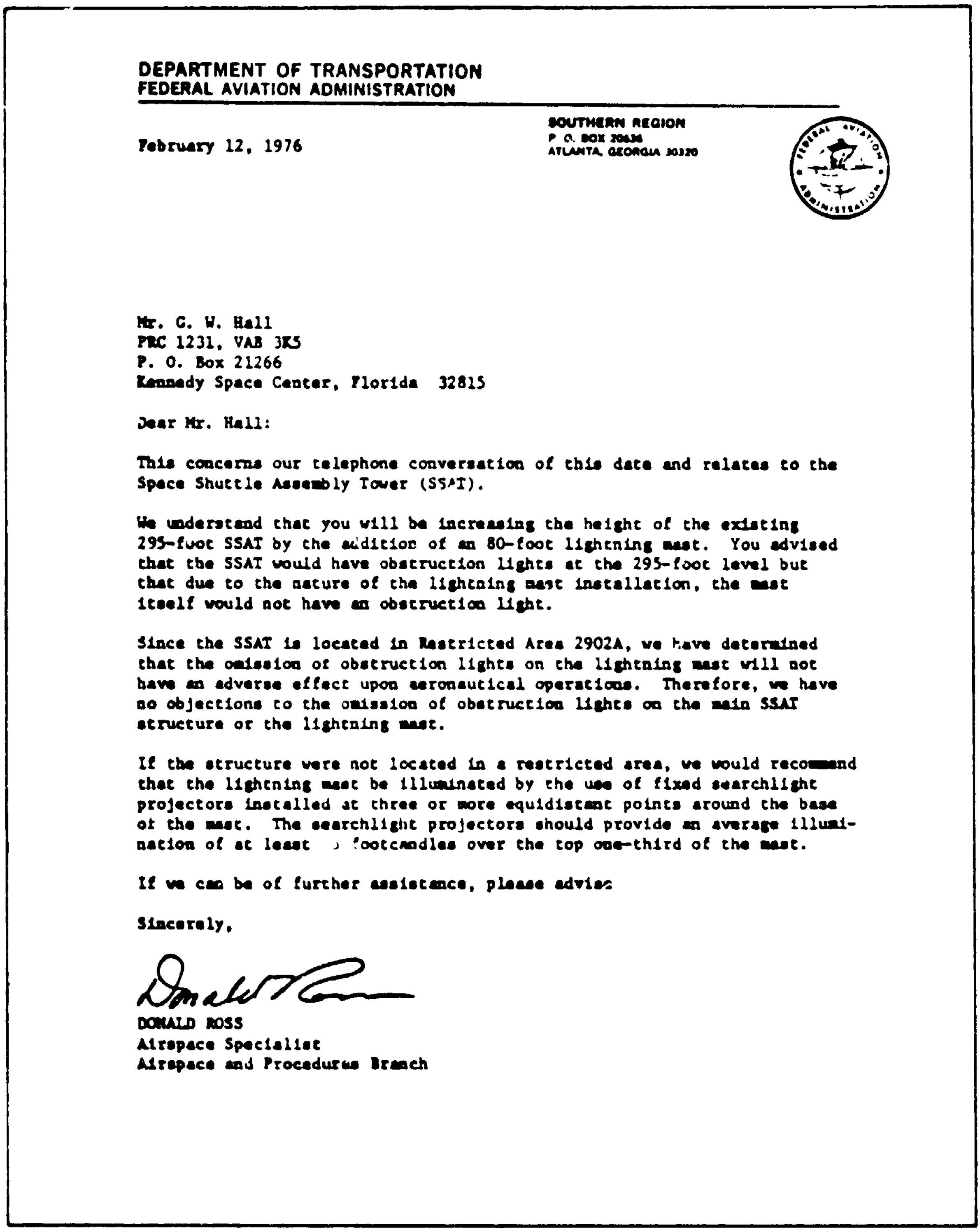
Costs involved in the transfer of ASTP instrumentation to Shuttle are shown in table 3-2.

3.3 LIGHTNING MAST LIGHTING AND MARKING REQUIREMENTS

3.3.1 GENERAL. This subsection reports on a study of various methods of marking and lighting the Shuttle lightning mast to ensure its visibility at all times, principally as protection against inadvertent incursions by low-flying aircraft. The mast, to be erected atop the SSAT, is not subject to the usual Federal Aviation Administration (FAA) requirements for obstruction marking and lighting, because its proposed site is within an area designated as Restricted Area 2902A by the FAA. (Figure 3-30 documents the FAA position with respect to obstruction lighting of the mast. This letter was received in connection with a separate study sponsored by DD-EDD-11 to provide a concept design for mast lighting.)

Table 3-2. Instrumentation Costs

Item	Estimated Cost
Installation and consolidation in the Shuttle configuration	
Materials	$10,000
Labor (5 man-months)	10,000
Shock mounting and antivibration measures	1,000
Correct waveform distortion	Accomplished
Minizappers for operational verification tests	
Materials	1,000
Labor (1 man-month)	2,000
Two Model 8100 biomations (if KSC units are not available)	20,000
Auxiliary memories for biomations (optional)	
Materials	2,000
Labor (1 man-month)	2,000
Current and rate-of-rise shunts (optional)	
Materials	2,000
Labor (1 man-month)	2,000
SAMS for experimental purposes (optional)	500
Subtotal	$52,500
Less optional equipment	-8,500
	44,000
Less borrowed biomations	-20,000
Total	$24,000



DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SOUTHERN REGION
P. O. BOX 20636
ATLANTA, GEORGIA 30320

February 12, 1976

Mr. G. W. Hall
PRC 1231, VAB 3K5
P. O. Box 21266
Kennedy Space Center, Florida 32815

Dear Mr. Hall:

This concerns our telephone conversation of this date and relates to the Space Shuttle Assembly Tower (SSAT).

We understand that you will be increasing the height of the existing 295-foot SSAT by the addition of an 80-foot lightning mast. You advised that the SSAT would have obstruction lights at the 295-foot level but that due to the nature of the lightning mast installation, the mast itself would not have an obstruction light.

Since the SSAT is located in Restricted Area 2902A, we have determined that the omission of obstruction lights on the lightning mast will not have an adverse effect upon aeronautical operations. Therefore, we have no objections to the omission of obstruction lights on the main SSAT structure or the lightning mast.

If the structure were not located in a restricted area, we would recommend that the lightning mast be illuminated by the use of fixed searchlight projectors installed at three or more equidistant points around the base of the mast. The searchlight projectors should provide an average illumination of at least [illegible] footcandles over the top one-third of the mast.

If we can be of further assistance, please advise

Sincerely,

Donald Ross

DONALD ROSS
Airspace Specialist
Airspace and Procedures Branch

Figure 3-30. FAA Letter Concerning Shuttle Lightning Mast Obstruction Lighting

Nevertheless, the methods and materials proposed in the various candidate systems studied conform to FAA guidelines (reference FAA Advisory Circular No. 70/7460-1C, dated 11 December 1973).

3.3.2 BASIC REQUIREMENTS. Ground rules established for this study are as follows:

a. Electrically conductive materials will not be used on the mast. This precludes the use of electrical conductors within the mast or conductive paint on the exterior surface.

b. Major emphasis will be placed on cost effectiveness of the system.

c. Maintenance requirements will be minimal.

d. Redundancy will be provided where required.

e. The system life expectancy will be a minimum of 10 years. It must be capable of surviving within the Shuttle launch environment and of withstanding repeated lightning strokes.

3.3.3 MAST LIGHTING SYSTEMS STUDIED. Ten systems for providing obstruction lighting for the lightning mast were considered. Five of these were rejected after preliminary studies showed them to be impractical because of high cost, fragility, or maintenance difficulty, or a combination of these reasons. These were:

a. High-Intensity Flashing White Strobe Lights. Use of the FAA type L-856 lights would require a typical expenditure of $18,150 for a three-light system. The lights alone would weigh approximately 550 lb, and a 3.6-kVA power source would be required.

b. Flashing White Beacon Light. Use of a 300-mm omnidirectional beacon system would involve approximately $5,000 in material costs and require 1 kVA of electrical power. Two high-voltage cables and a power cable would have to be routed along the catenary. The beacon alone would weigh about 100 lb.

c. Solar Cell-Battery Combination. This method of powering obstruction lights would require excessive maintenance and would not survive the down-blast of the engines during Shuttle liftoff.

d. Windmill-Battery Combination. This type of power system would have the same disadvantages as the solar cell-battery combination, in addition to installation difficulties.

e. Gaslight Installation. While a gaslight fixture using propane and a thorium oxide Welsbach mantle could provide sufficient light, it would be unacceptable because of fire and explosion hazards.

The five candidate systems discussed below were found to be within the guidelines set by the study ground rules.

3.3.3.1 Hazard Light With Power Leads Routed Along Catenary. An obstruction light mounted on top of the catenary pulley sheave assembly could be energized by shielded 115-V ac power leads routed along or embedded in one leg of the catenary (see figure 3-31). The power leads would follow the catenary to its ground terminal where they would be tied into the critical power circuit. The leads would be protected further by lightning arresters to bleed off any charges induced by direct lightning strokes to the catenary. The obstruction light could be a flashing red light for nighttime obstruction marking. Table 3-3 lists the material requirements and estimated cost for this system.

3.3.3.2 Fiber-Optics Bundle (Light Pipes). This approach would use three fiber-optics bundles to remotely illuminate three hazard lights mounted on top of the mast (see figure 3-32). Each light pipe would be 80 ft long and 3 to 4 in thick. A high-intensity strobe lamp and associated optical gear, located beneath the base of the mast, would be required for each light pipe. The top of each pipe would terminate in an FAA-approved, type L-810 obstruction light with a Fresnel globe. The light beacons could be pulsed either by switching gear or by a shutter interrupting the light source 20 to 30 times a minute. The inherent 70-percent light loss of the fiber-optics bundles would be compensated for by high-intensity strobe lamps. Table 3-4 shows the material requirements for this system.

3.3.3.3 Six-In Mirror System. In this system, rays from three 500-W quartz-iodine high-intensity lamps would be reflected upward by a parabolic collimating front surface mirror through fiberglass tubes of like diameter. The tubes would be suspended within the mast, with the tops protruding through a hole at the top of the mast (see figure 3-33). Here, the parallel light rays would impinge on the interior surface of a Fresnel-lens globe and be refracted in a 360-degree pattern. While even moderate wind loading would cause bending of the mast, the optical tube could be mechanically isolated from the mast by gimballing the tube and light source from the sheave support assembly. Material requirements of this system are shown in table 3-5.

3.3.3.4 Airmotor-Alternator Combination. In this system an airmotor driven by compressed air (90 lb/in^2) would be used to generate power for three obstruction lights (see figure 3-34). An air compressor at the base of the mast would supply air to the motor through a polyvinyl chloride (PVC) tube. The motor would drive an electrical alternator; one of 500-W rating would be sufficient to drive a three-light array using 116-W lamps. Double lamp fittings could be used to reduce maintenance requirements, with a capability of switching from one lamp to the other in case of a failure. Table 3-6 shows the material requirements for this system.

3.3.3.5 Base-Mounted Floodlights. This system would use an arrangement of four floodlights similar to that employed for obstruction lighting of the ASTP lightning mast during periods of darkness (see figure 3-35). The ASTP

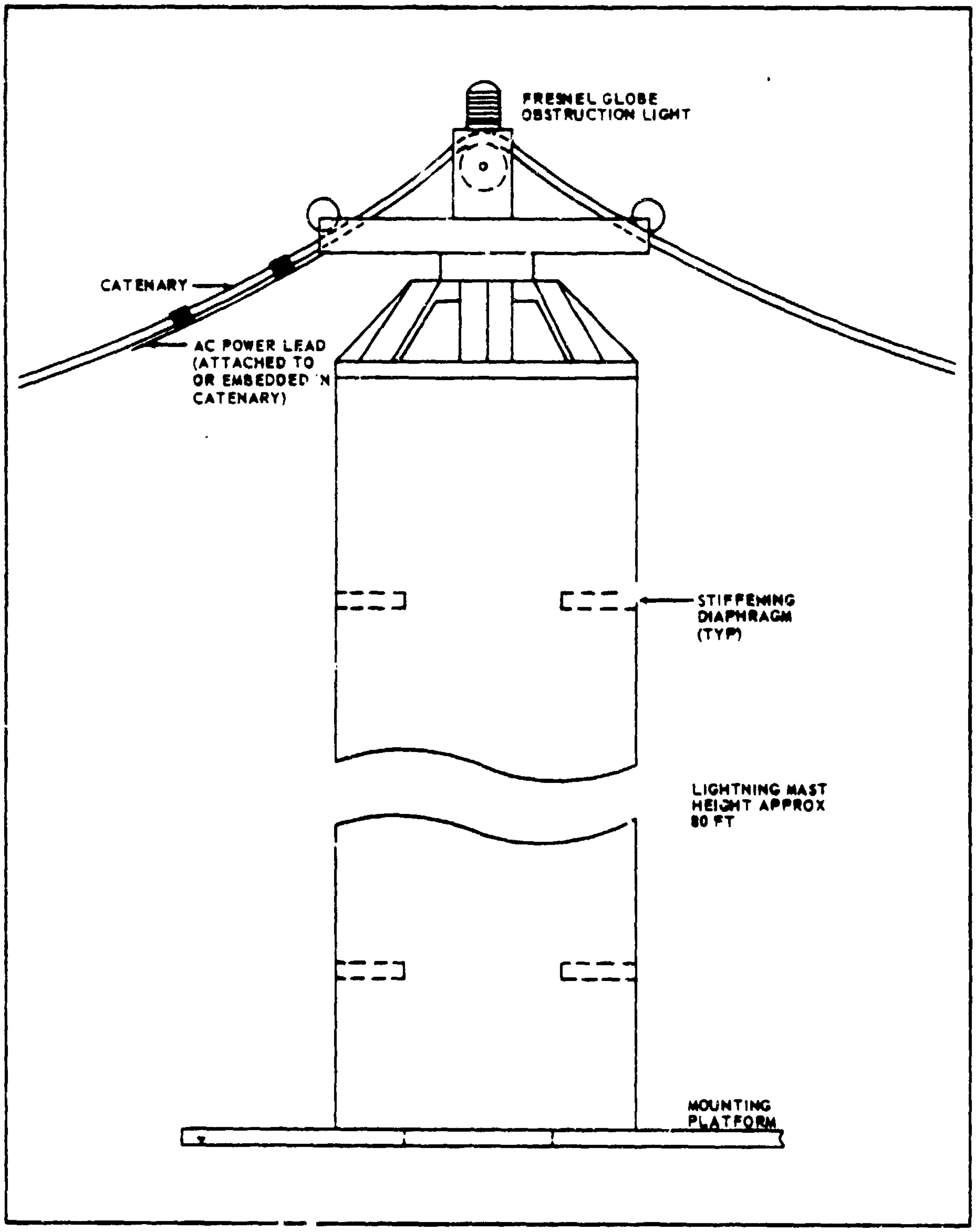


Figure 3-31. Obstruction Light Energized by Power Lead Along Catenary

Table 3-3. Top-Mounted Obstruction Light Material Requirements

Part Name	Manufacturer	Mfg P/N	Quantity	List Price
300-mm hazard beacon	Crouse & Hinds	FCB-12	1 ea	$ 482.00
Beacon lamp	G.E.	620PS40/1P	1 ea	4.66
Failure alarm relay assembly	Crouse & Hinds	TLR	1 ea	59.00
Beacon flasher	Crouse & Hinds	TSS-24	1 ea	130.00
Photoelectric control	Crouse & Hinds	PEC-4	1 ea	91.00
Mineral insulated shielded cable	General Cable	449/2	1,000 ft	945.00
Mounting hardware	-	-	-	100.00
Cable connectors, seals, and glands	General Cable	-	-	50.00
			Total	$1,861.66

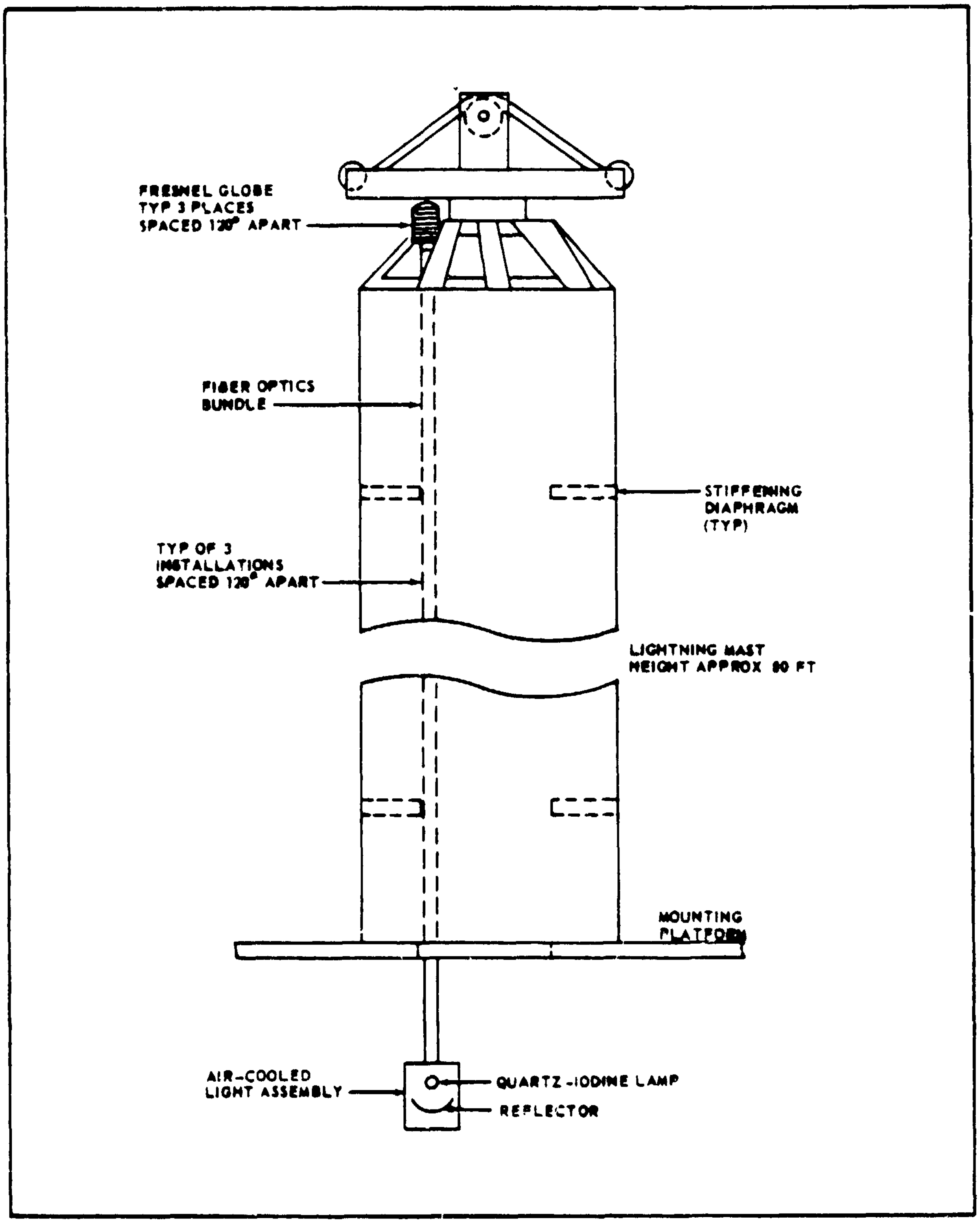


Figure 3-32. Fiber Optics Light Pipe Mast Lighting System

Table 3-4. Fiber Optics Material Requirements

Part Name	Manufacturer	Mfg P/N	Quantity	List Price
Strobe lamps	Dielectric Communications	NPN	3 ea	$ 300.00
Power Supply	Dielectric Communications	200K70-3	1 ea	1,750.00
Control and monitor panel	Dielectric Communications	200K70-4	1 ea	200.00
Master timer	Dielectric Communications	200K70-5	1 ea	300.00
Photocell	Dielectric Communications	200K70-600	1 ea	25.00
Fiber-optic bundle 5 in dia, 80 ft long	American-Optical	NPN	3 ea	1,500.00
Red globe	Crouse & Hinds	EOL	3 ea	45.00
6-in reflector	Ealing-Optical	23-5440	3 ea	105.00
Lamp housing	GFE	Local mfg	3 ea	150.00
Miscellaneous hardware	GFE	Local mfg	-	150.00
			Total	$4,525.00

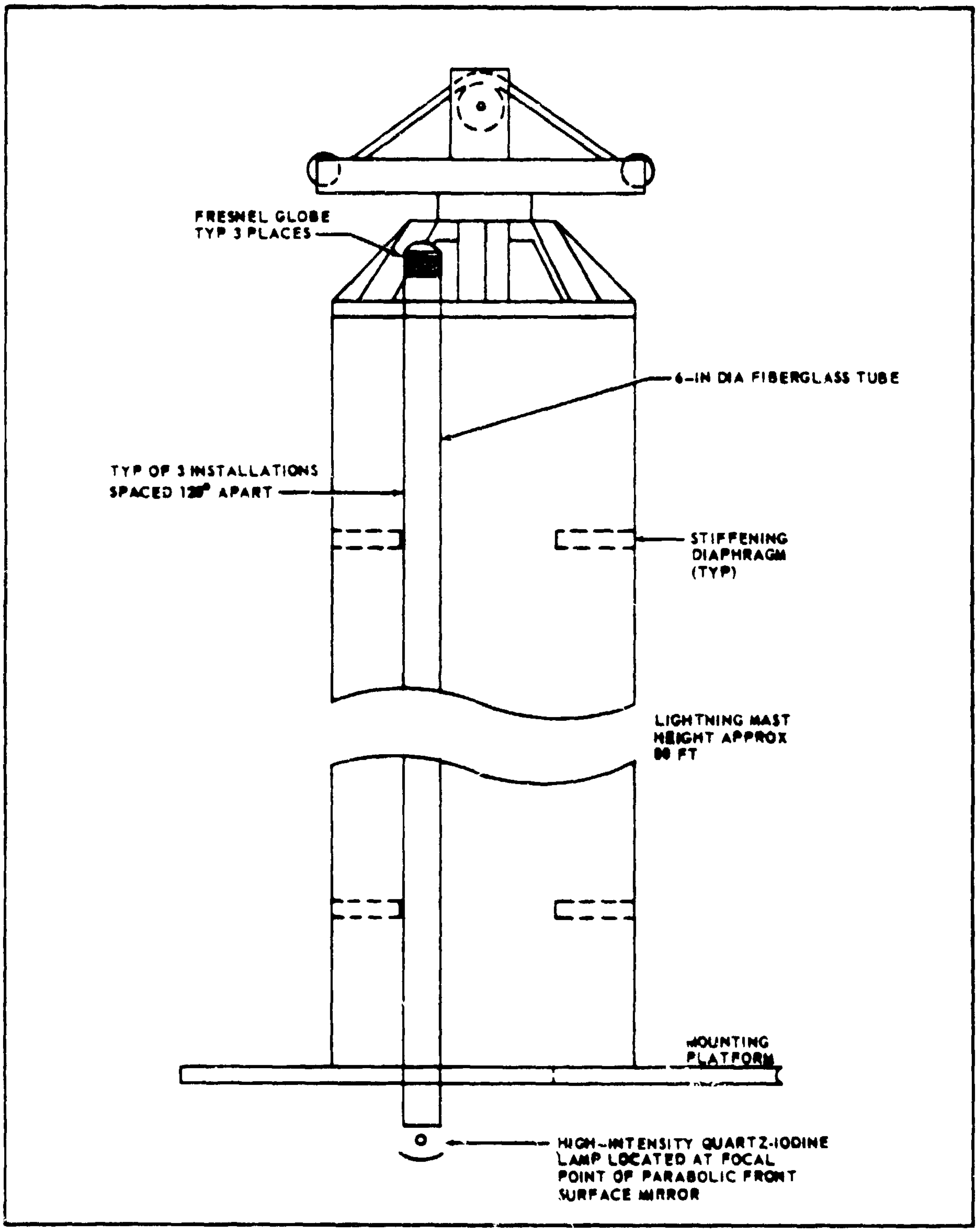


Figure 3-33. Mirror Optical Lighting System

Table 3-5. Mirror System Material Requirements

Part Name	Manufacturer	Mfg P/N	Quantity	List Price
Strobe lamps	Dielectric Communications	NPN	3 ea	$ 300.00
Power supply	Dielectric Communications	200K70-3	1 ea	1,750.00
Control and monitor panel	Dielectric Communications	200K70-4	1 ea	200.00
Master timer	Dielectric Communications	200K70-5	1 ea	300.00
Photocell	Dielectric Communications	200K70-600	1 ea	25.00
Red globe	Crouse & Hinds	EOL	3 ea	45.00
6-in reflector	Ealing-Optical	23-5440	3 ea	105.00
Lamp housing	GFE	Local mfg	3 ea	150.00
Miscellaneous hardware	GFE	Local mfg	-	150.00
			Total	$3,025.00

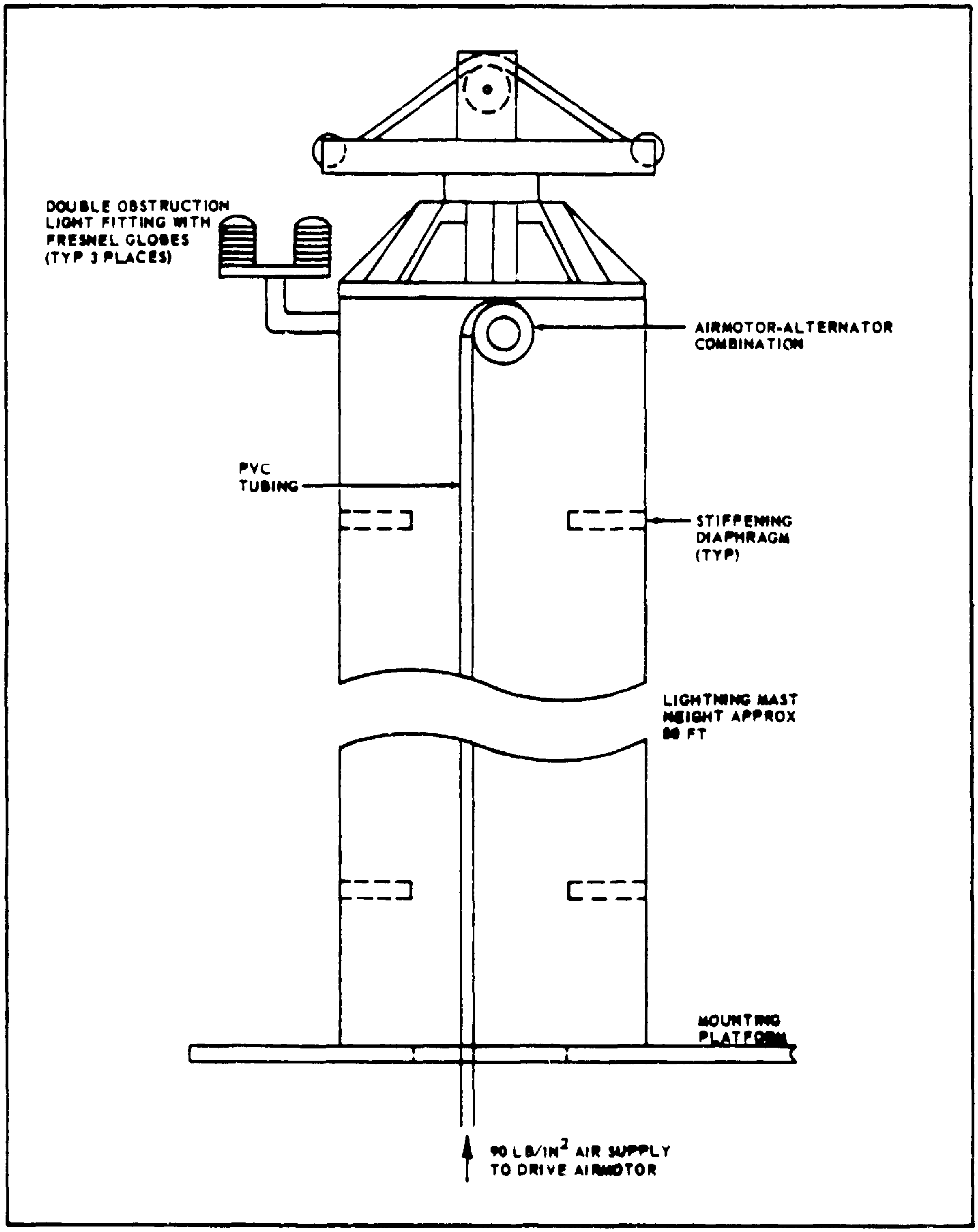


Figure 3-34. Airmotor-Alternator Combination

Table 3-6. Air-Driven Alternator System Material Requirements

Part Name	Manufacturer	Mfg P/N	Quantity	List Price
1-hp airmotor	Gardner-Denver	MA-2	1 ea	$ 700.00
0.5-kVA alternator	Georator Corp.	36-003	1 ea	590.00
Air compressor	Hill Bros.	02255	1 ea	2,337.00
PVC tube 1.0 in dia, 0.10 in wall	Commercial Plastics	NPN	100 ft	20.00
Double obstruction light	Crouse & Hinds	EOL	74 ea	167.00
Lamp	Crouse & Hinds	116A21/TS	6 ea	23.40
Failure alarm and transfer relay	Crouse & Hinds	TLR	3 ea	178.00
Photoelectric control	Crouse & Hinds	PEC-4	2 ea	180.00
Miscellaneous hardware	GFE	Local mfg	-	1,250.00
			Total	$5,445.40

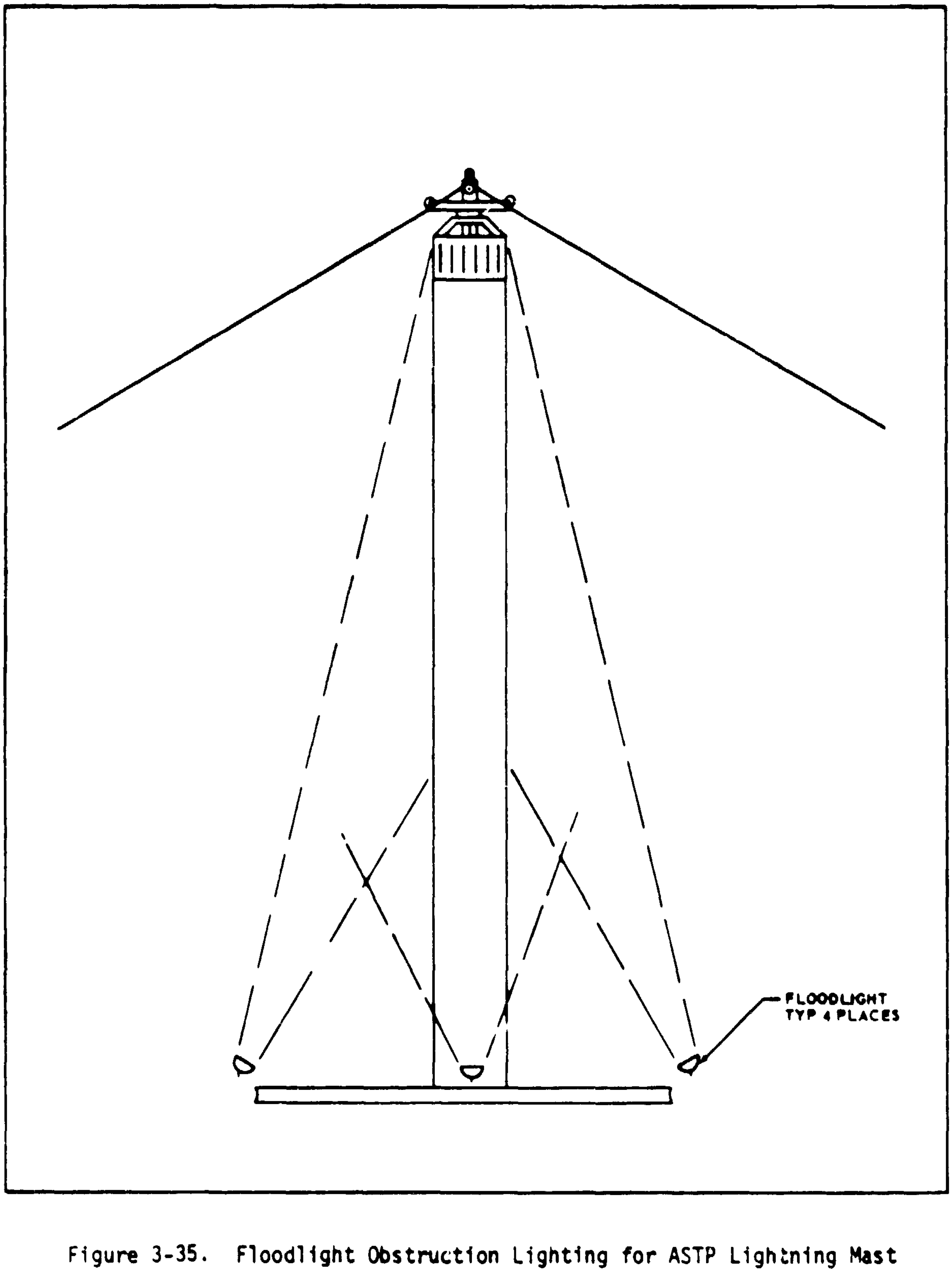


Figure 3-35. Floodlight Obstruction Lighting for ASTP Lightning Mast

system proved satisfactory for the short-term program and, except for occasional replacement of cracked lenses, maintenance requirements were minimal. Two of the floodlights were used for illumination of the lower portion of the mast while two lighted the top portion. The lights were equidistantly placed around the base and met the general requirements of FAA AC 70/7460-1C for nonstandard obstruction lighting (except that paragraph 15.f of the FAA circular recommends an average illumination of 15 footcandles over the top one-third of the installation). The proposed system for the Shuttle lightning mast would use four explosion-proof searchlight projectors with dual auto-switching lamp bulbs and would be actuated by redundant sky-viewing light sensors. A remote malfunction monitoring system, as prescribed in paragraph 15.h of AC 70/7460-1C, would be incorporated.

While the cost of this system cannot be estimated without knowing the exact configuration of the Shuttle lightning mast and support platform, it would appear to be among the least expensive systems considered. All materials would be standard commercial or Government-furnished equipment (GFE).

The floodlights used to ASTP obstruction lighting were manufactured by Pyle-National under catalog number FEQ-11112. The bulbs were quartz-iodine, type T3 clear, with single-contact recessed bases and were rated at 500 W.

3.3.4 COMPARISON OF CANDIDATE SYSTEMS. Table 3-7 provides a comparison of the five candidate systems based on engineering analyses of pertinent characteristics including visibility, survivability, ease of installation and maintenance, technical feasibility, and others. The letters E, G, F, and P respectively represent ratings of excellent, good, fair, and poor. All of the systems studied received high ratings in visibility, survivability, safety, and redundancy (where applicable). Poor ratings, however, were given to three of the systems in other areas based on the following considerations:

a. The hazard light with power leads routed along the catenary would be difficult to maintain. Access to the obstruction light would be possible only by such means as a scaffold or a helicopter with a bosun's chair. Cable faults would be difficult to correct.

b. The mirror optical system is considered poor in the area of technical feasibility because of implementation difficulties. Complete loss of light would result from deviation in the direct optical path of the light beam.

c. The airmotor-alternator combination would present installation difficuities involving the modification of the upper mast to receive the components. Cost of the system would reflect this problem.

Comparison of the remaining candidate systems (floodlighting and fiber optics) tended to favor the choice of floodlighting on the basis of probable cost. The floodlight system would also have installation and maintenance advantages, design simplicity, and a precedence of performance acceptability established by FAA and the ASTP floodlighting systems.

Table 3-7. Comparison of Candidate Systems

Candidate System	Nighttime Visibility	Ease of Maintenence	Ease of Installation	Hurricane Survivability	SRB Liftoff Survivability	Technical Feasibility	Safety Considerations	Obstruction Lights (No.)	Redundancy	Cost and Material Requirements
Hazard light with power leads routed along catenary	E	P	*	E	**	E	E	1	N/A	$1,861.66 (see table 3-3)
Light pipes (fiber optics)	G	G	E	E	E	G	E	3	E	$4,525.00 (see table 3-4)
Six-in mirror optical system	G	G	F	E	E	P	E	3	E	$3,025.00 (see table 3-5)
Airmotor-alternator combination	G	G	P	E	E	G	G	3	E	$5,445.40 (see table 3-6)
Floodlighting system	G	E	E	E	G	E	E	4	E	**

E = Excellent; G = Good; F = Fair; P = Poor
*Good to poor depending upon the location of the mast at installation
**To be determined

3.3.5 MAST MARKING. Alternate orange and white markings are commonly used on tail structures to ensure their visibility from the air during daylight hours. Such visibility would be desirable for the Shuttle lightning mast as a protection against possible encroachment by stray aircraft although the structure will be located in flight-restricted airspace.

While the FAA-approved protective markings are normally applied by painting, this method is not compatible with Shuttle lightning mast requirements. The fiberglass mast surface is classified "critical" because of the necessity of coating it with an ablative thermal protective material to protect it from the heat of rocket exhaust (see FAA AC 70/7460-1C, paragraph 9.b). Therefore, to provide good daytime visibility, as well as high reflectivity for floodlighting during periods of darkness, the coating applied to the mast surface should be white or as nearly white as possible. The metal sheave assembly should be painted orange (FAA Orange No. 12197) to give the structure maximum definition against a cloud background during daytime. Figure 3-36 illustrates the recommended marking concept.

3.3.6 CONCLUSION AND RECOMMENDATIONS. The information developed in this study supports the following recommendations as the most practical methods for marking and lighting the Shuttle lightning mast:

a. Coat the mast with a thermally protective material having high light reflectivity.

b. Paint the mast sheave assembly orange for cloud-mast definition.

c. Illuminate the mast with base-mounted floodlights during periods of darkness.

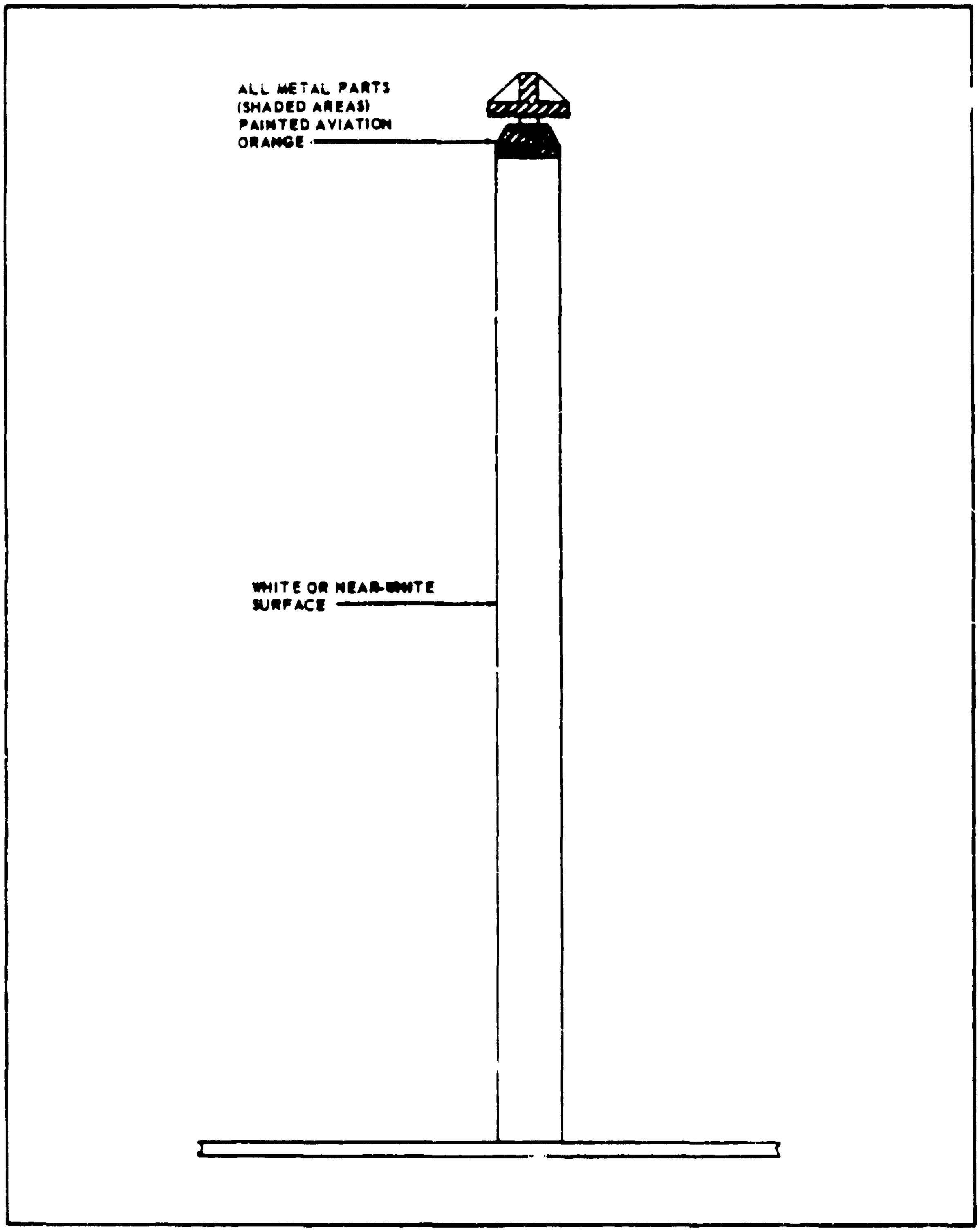


Figure 3-36. Shuttle Lightning Mast Marking

SECTION IV

BLAST TESTS OF ASTP MAST SAMPLES

4.1 DESCRIPTION AND LOCATION OF SAMPLES

Six samples of the ASTP Mobile Launcher lightning mast were exposed to the propulsion blasts of Delta rockets 116 through 121 on pads 17B and 17A. Samples 1, 2, and 3 were 8 in wide, 18 in long, and 0.5 in thick mounted on a metal plate. Each of these samples was instrumented with two calorimeters and one thermocouple. Sample 4 was deleted from the sequence and used for making samples 6A and 6B. Samples 6, 6A, and 6B were mounted on a single plate which was placed at the top of the umbilical tower and oriented toward the rocket blast. Sample 6 was 1.5 in wide, 24 in long, and 0.5 in thick. Samples 6A and 6B were 1.45 in wide, 5.95 in long, and 0.5 in thick. Sample 5 was 1.5 in wide, 24 in long, and 0.5 in thick and was strapped to the north railing of the pads.

Some of the samples were relocated during the tests to increase the blast intensity. On pad 17B, samples 1, 2, and 3 were relocated for tests 3 and 4. On pad 17A, test 2A involved sample 5 only, and test 5 utilized all samples except sample 1. Samples 2 and 3 were again relocated for test 5. The locations of the various samples for all the tests are summarized in figure 4-1. The sample locations were reviewed and approved by the Delta propulsion chief.

For the first test, samples 1, 2, and 3 were coated one half with orange gel coat and the other half with white gel coat similar to that used on the ASTP mast. The gel coat thickness used on ASTP was about 20 mils, so the coating thickness used for the gel coat tests was from 10 to 46 mils. The thickness was measured before and after launch. The orange was used because of the possibility that orange markings might be used on the mast. It was decided that such markings were not needed, and this coating was generally later replaced with Dow Corning (DC) 20-103 aerospace sealant, an ablative material. Samples 5, 6, and 6A were also coated with white gel coat having thicknesses varying from 3 to 14 mils. Sample 6B was coated with DC 20-103 having thicknesses varying from 72 to 92 mils.

4.2 TEST RESULTS

Examination after the first test showed little or no erosion except on sample 5, located on the launch pad railing, which had an erosion of 5 to 20 mils, essentially removing the coating. The highest mean temperature measured was 581°F for 4 s on sample 1. The highest mean heating rate was 6.8 Btu/ft^2-s for 4 s on the orange side of sample 1.

A more detailed summary of the test results, based on SO-LAB-4 examinations of erosion and tempilabels, is presented in appendix A. The microchemical analyses of the sample surfaces by SO-LAB-32 are also included in appendix A along with pretest photographs and photographs of the samples after each test. A typical Delta before and during launch is shown in figures 4-2 and 4-3.

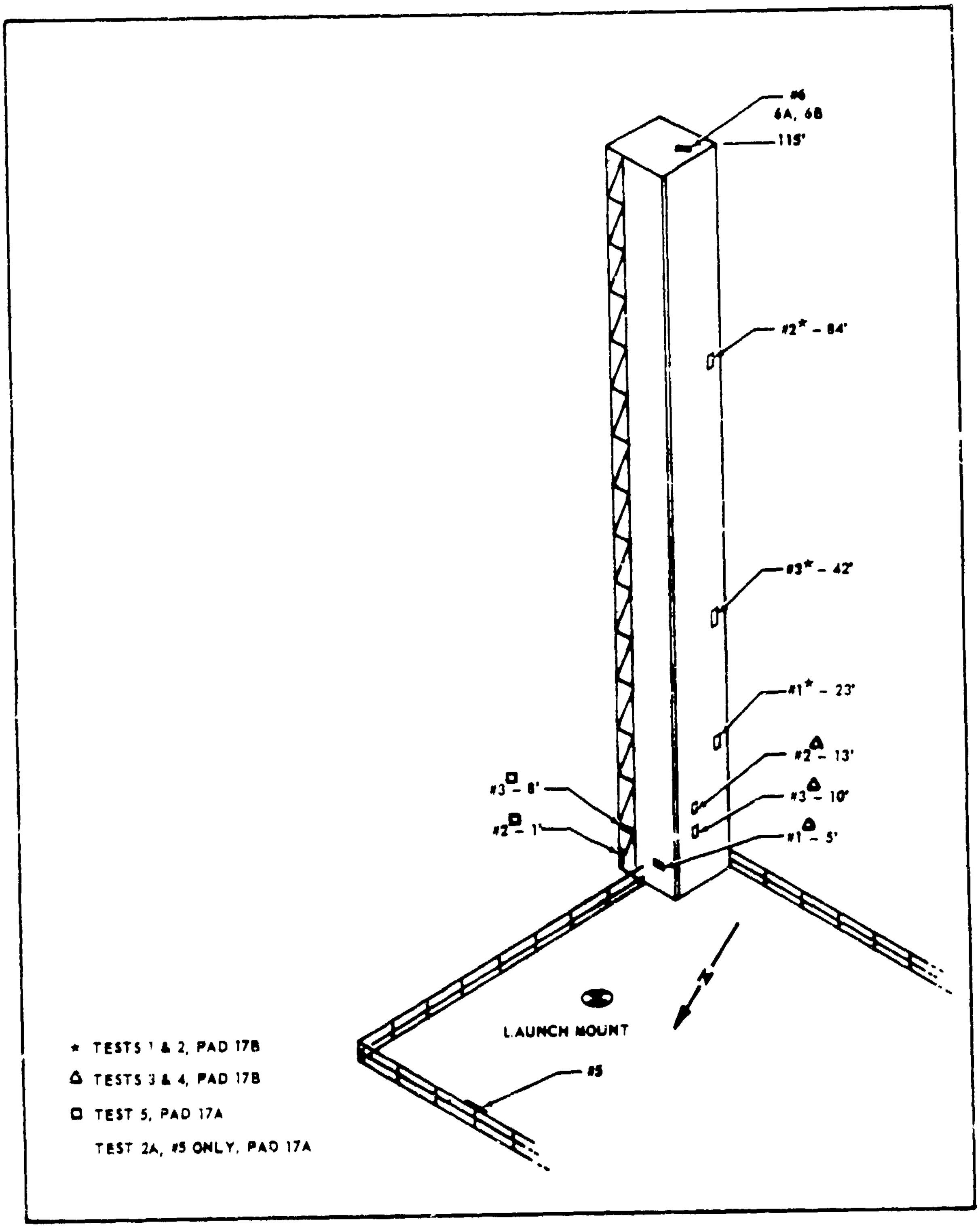


Figure 4-1. Location of Shuttle Lightning Mast Samples on Pads 17A and 17B

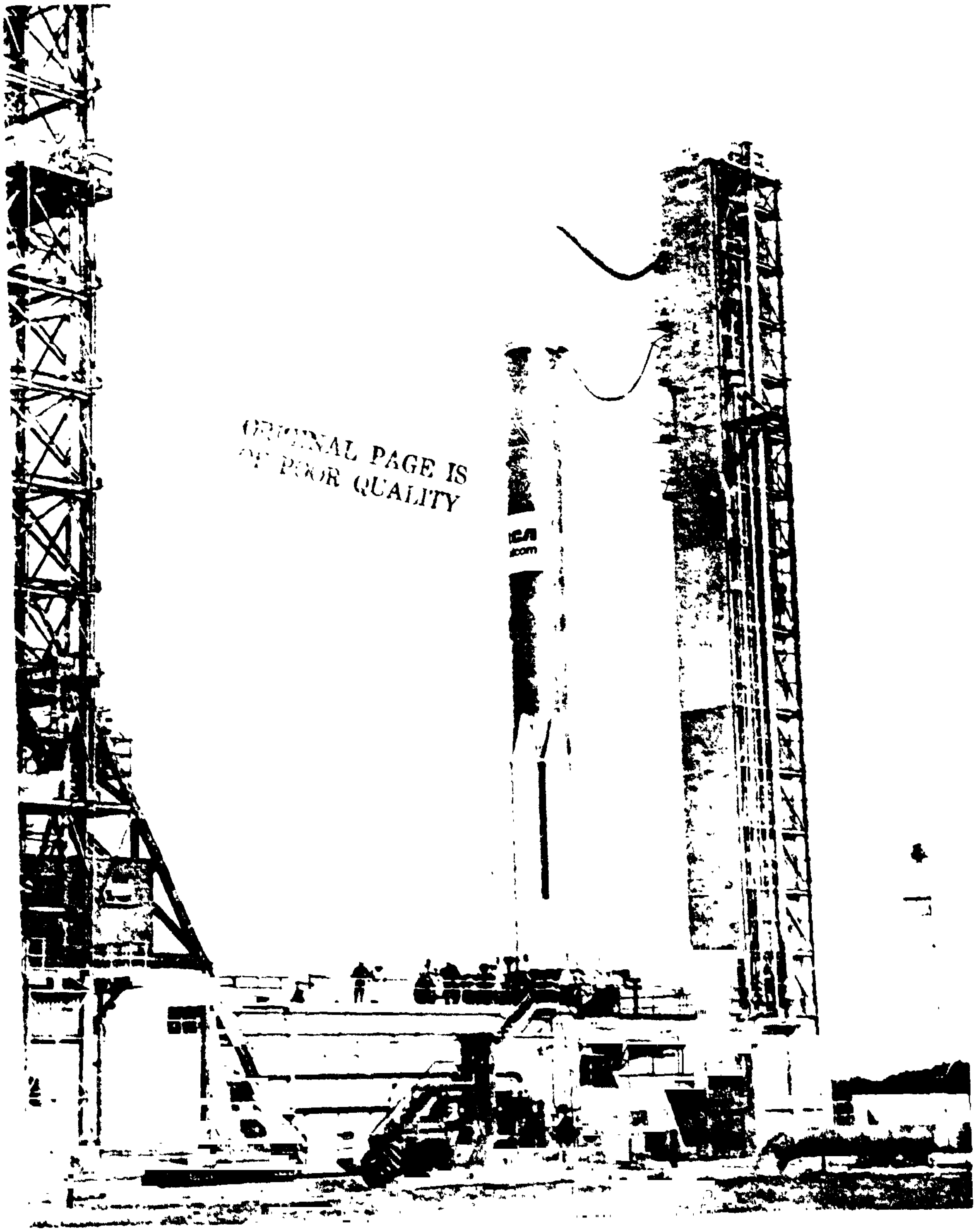


Figure 4-2. Prelaunch of Satcom-A, Delta 118

Figure 4-3. Liftoff of Satcom-A, Delta 118

Blast test liftoff conditions are summarized in figures 4-4, 4-5, 4-6, 4-7, and 4-8 for tests 1 through 5, respectively. The heat from SRM No. 9 was expected to impinge on most of the samples, and the heat from SRM No. 5 primarily affected sample 5. Wind caused the actual footprint track to vary from that predicted as shown in the figures.

Before the second test, the orange gel coat on samples 1 and 3 and the white gel coat on sample 5 were replaced with DC 20-103 about 0.1 in thick. Measurements after the second test showed that sample 5 was the only one that showed significant erosion, from 1 to 29 mils. The highest mean temperature was 262°F for 4 s on sample 1. The highest mean heating rate was 5.6 Btu/ft^2-s for 4 s on the DC 20-103 side of sample 3.

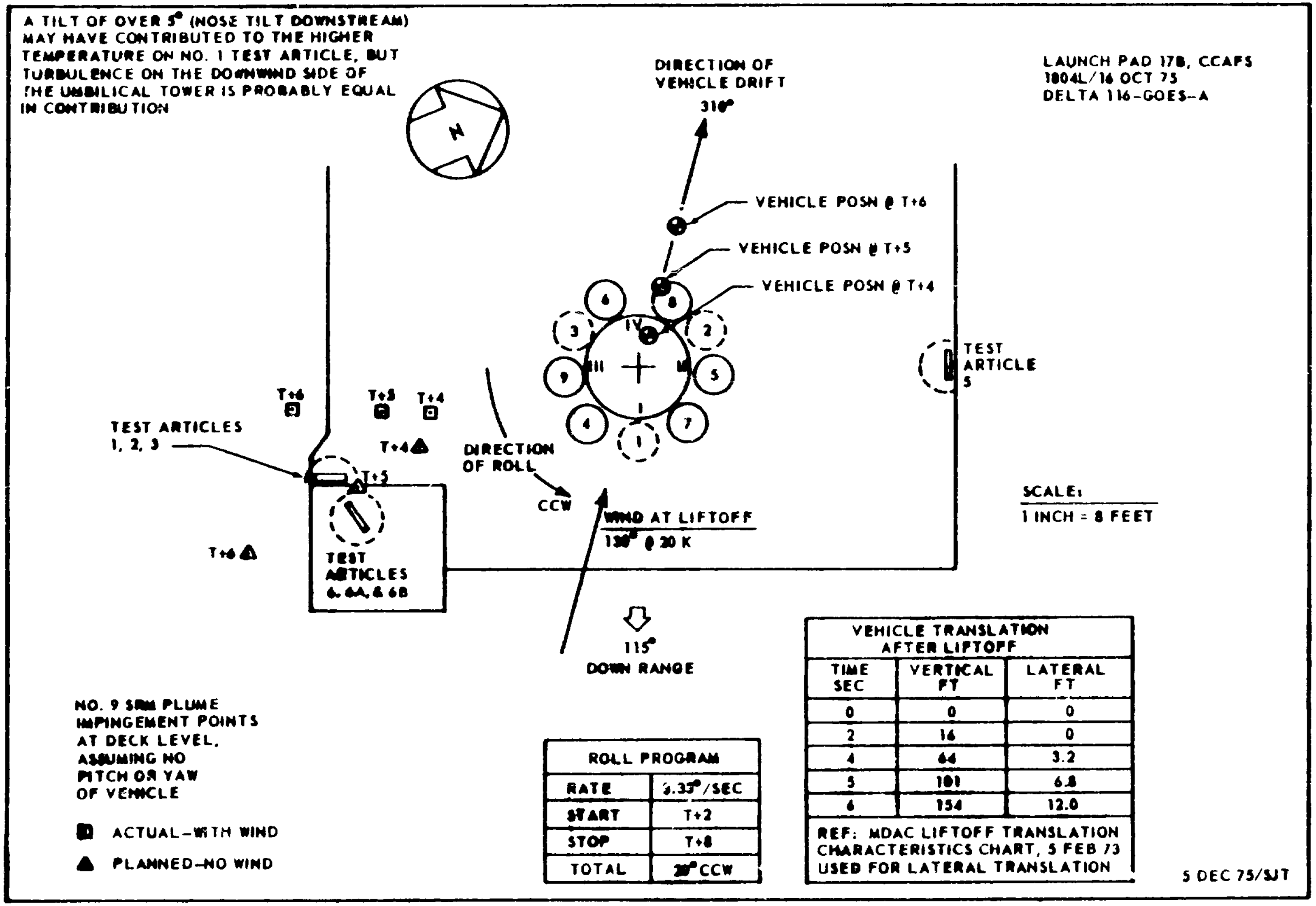
To increase the exposure of the samples to heat, samples 1, 2, and 3 were repositioned as shown in figure 4-1 for the third and fourth tests. After the third test, examination of sample 1 showed a maximum erosion of 15 mils on the gel coat side, almost removing the coating. Sample 5 lost up to 30 mils of DC 20-103. The samples also showed some buildup in places due to impinging material. The highest mean temperature measured was 461°F for 4 s on sample 1. The highest mean heating rate was 7.0 Btu/ft^2-s for 4 s on the DC 20-103 side of sample 3.

After the fourth test, sample 1 lost virtually all of its remaining gel coat up to 30 mils. There was also significant erosion and buildup of the other samples. The highest measured mean temperature was 1030°F for 4 s on sample 1. Sample 2 had the highest mean heating rate of 8.1 Btu/ft^2-s for 4 s with a mean temperature of 527°F for 4 s.

Samples 2 and 3 were again repositioned for increased blast effects during test 5. One half of each sample was freshly coated with DC 20-103. After the test, sample 3 had a maximum gel coat erosion of about 31 mils, and the DC 20-103 maximum erosion was 7 mils. Sample 2 lost its remaining gel coat with a small amount of erosion of the fiberglass, and the maximum erosion of the DC 20-103 was 41 mils. The DC 20-103 was also pitted, probably due to the method of application. Spray painting should correct this difficulty. The maximum erosion on sample 5 was 31 mils.

Samples 5 and 6 were duplicated initially so that lightning flashover tests could be made to determine the effects of the embedded blast materials on the flashover characteristics of the coated surfaces. Sample 6 on the top of the umbilical tower was also subjected to the environmental effects such as ultraviolet and salt spray.

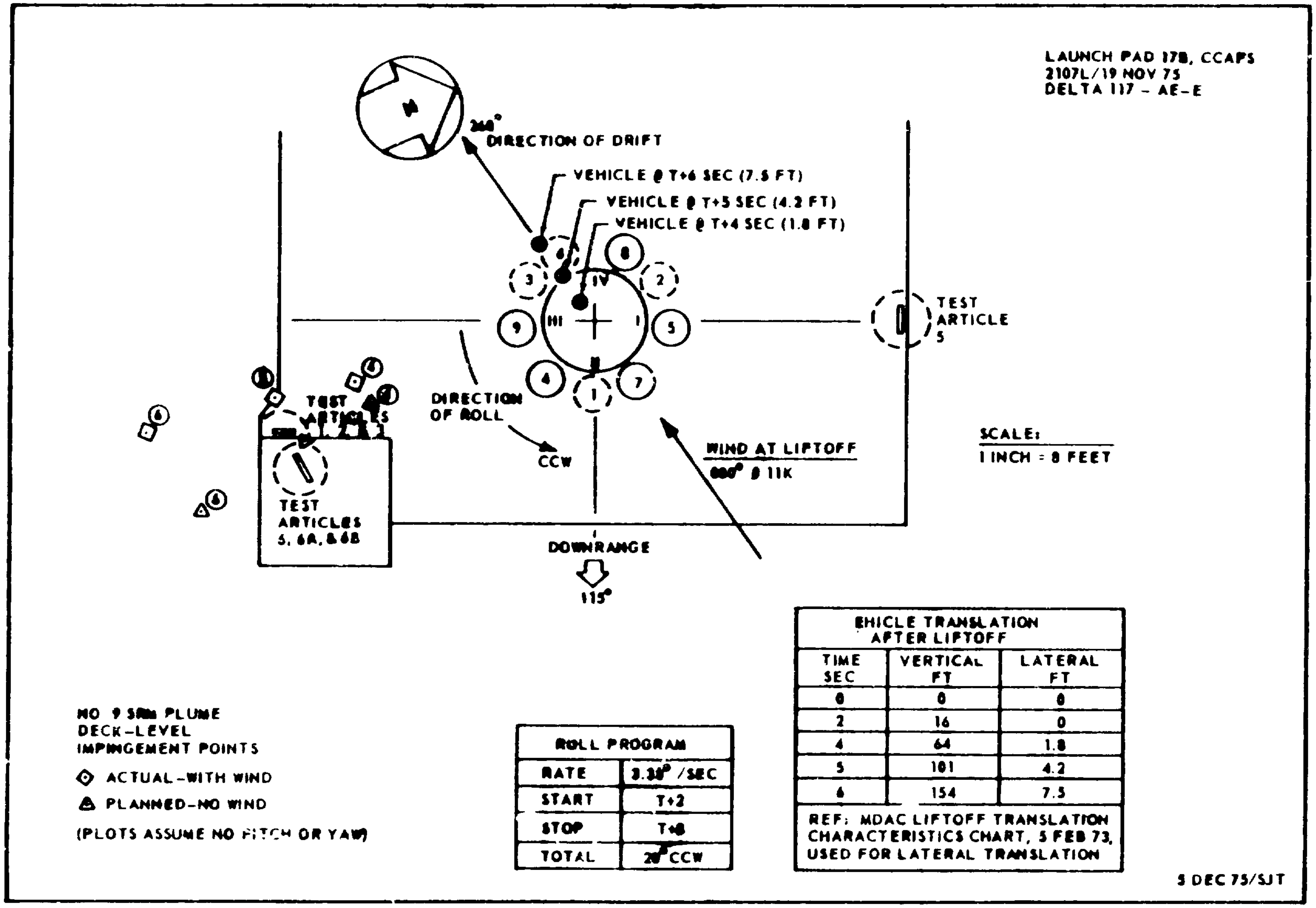
While the heat radiation to be expected from the Shuttle plume has not been completely defined, preliminary information on mast heating at liftoff (figure 4-9) indicates a peak heating rate of 10.6 Btu/ft^2-s and an average rate of about 5 Btu/ft^2-s for 4 s. The measurements made on the test samples during the Delta launches compared favorably with these levels. The maximum rate was 10.2 Btu/ft^2-s, and the maximum average rate was 8.1 Btu/ft^2-s for 4 s.



ROLL PROGRAM	
RATE	3.33°/SEC
START	T+2
STOP	T+8
TOTAL	20° CCW

VEHICLE TRANSLATION AFTER LIFTOFF		
TIME SEC	VERTICAL FT	LATERAL FT
0	0	0
2	16	0
4	64	3.2
5	101	6.8
6	154	12.0
REF: MDAC LIFTOFF TRANSLATION CHARACTERISTICS CHART, 5 FEB 73 USED FOR LATERAL TRANSLATION		

Figure 4-4. First Blast Test Liftoff Conditions

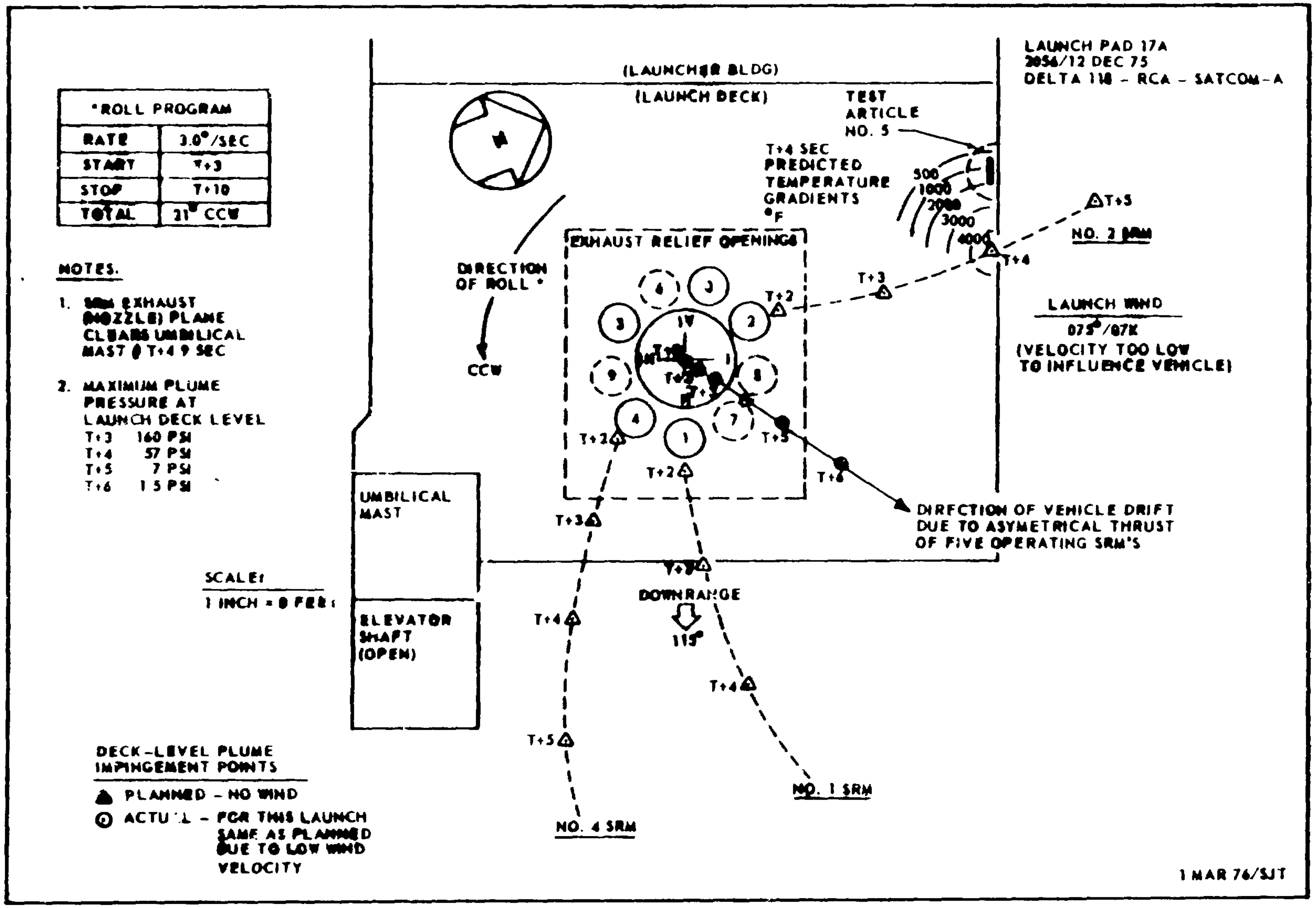


ROLL PROGRAM	
RATE	3.33° /SEC
START	T+2
STOP	T+8
TOTAL	20° CCW

VEHICLE TRANSLATION AFTER LIFTOFF		
TIME SEC	VERTICAL FT	LATERAL FT
0	0	0
2	16	0
4	64	1.8
5	101	4.2
6	154	7.5

REF: MDAC LIFTOFF TRANSLATION CHARACTERISTICS CHART, 5 FEB 73, USED FOR LATERAL TRANSLATION

Figure 4-5. Second Blast Test Liftoff Conditions



*ROLL PROGRAM	
RATE	3.0°/SEC
START	T+3
STOP	T+10
TOTAL	21° CCW

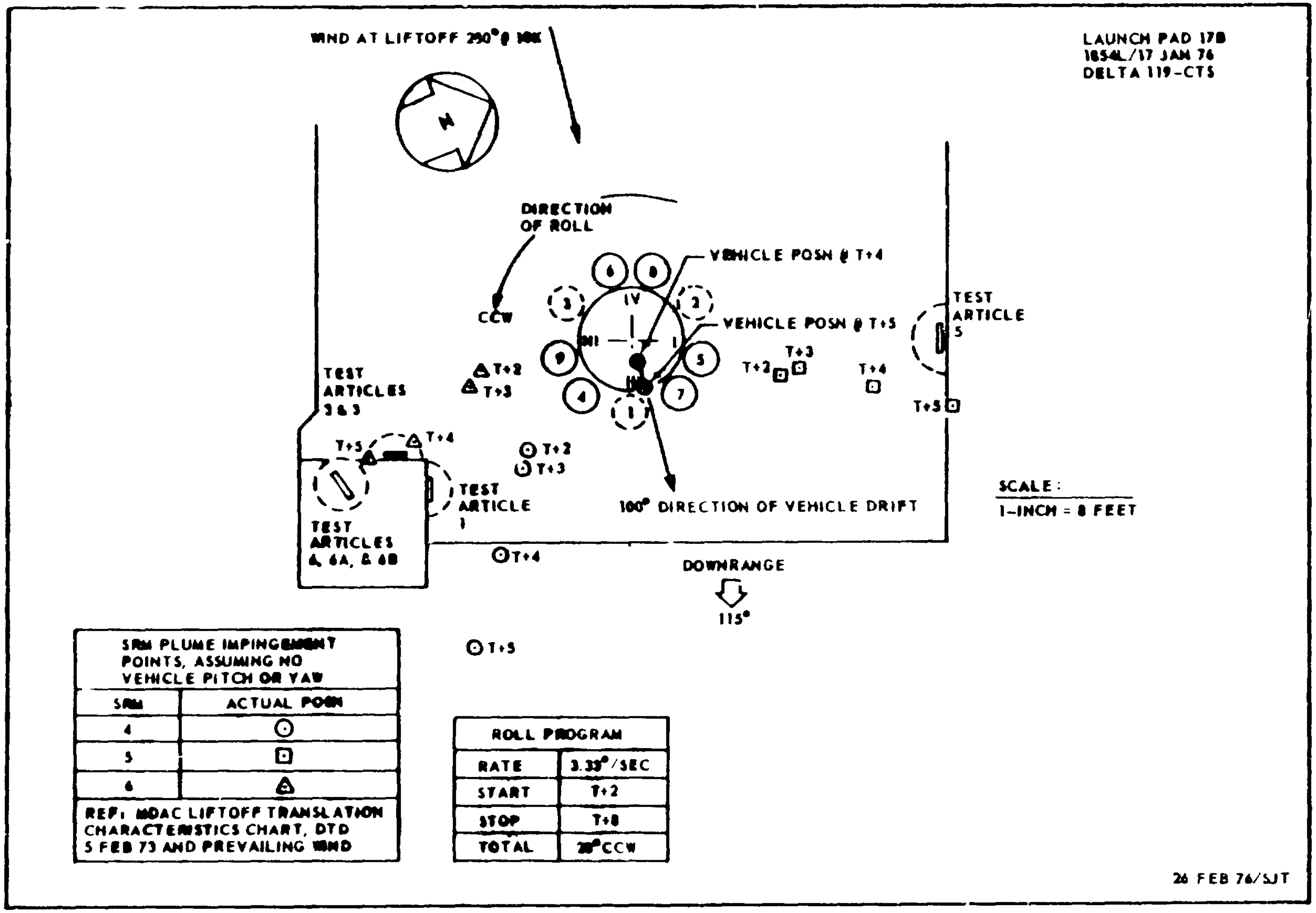
NOTES.

1. SRM EXHAUST (NOZZLE) PLANE CLEARS UMBILICAL MAST @ T+4.9 SEC
2. MAXIMUM PLUME PRESSURE AT LAUNCH DECK LEVEL
   T+3 160 PSI
   T+4 57 PSI
   T+5 7 PSI
   T+6 1.5 PSI

DECK-LEVEL PLUME IMPINGEMENT POINTS

▲ PLANNED - NO WIND
⊙ ACTUAL - FOR THIS LAUNCH SAME AS PLANNED DUE TO LOW WIND VELOCITY

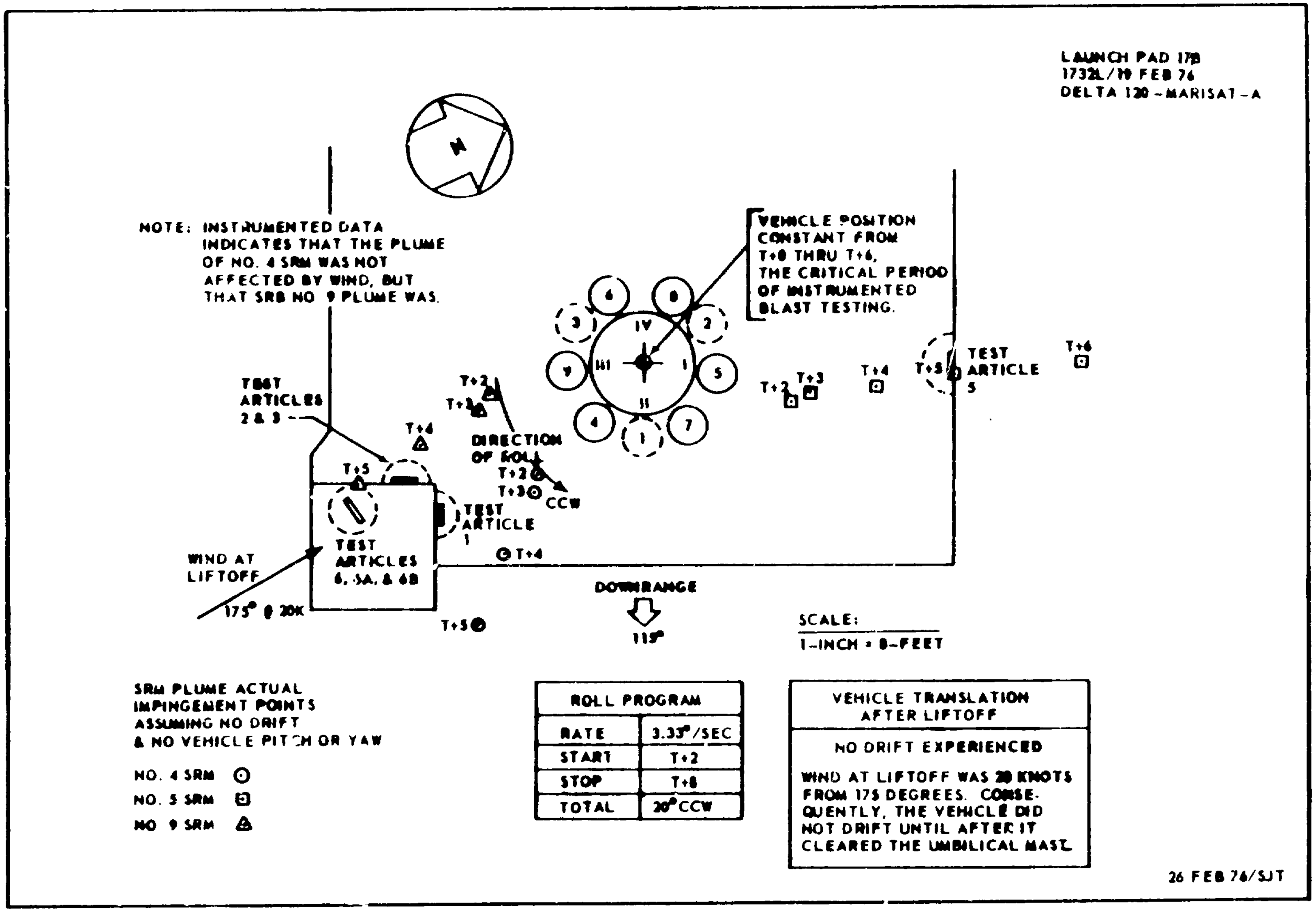
Figure 4-5A. Blast Test No. 2 Liftoff Conditions



SRM PLUME IMPINGEMENT POINTS, ASSUMING NO VEHICLE PITCH OR YAW	
SRM	ACTUAL POSN
4	⊙
5	⊡
6	△
REF: MDAC LIFTOFF TRANSLATION CHARACTERISTICS CHART, DTD 5 FEB 73 AND PREVAILING WIND	

ROLL PROGRAM	
RATE	3.33°/SEC
START	T+2
STOP	T+8
TOTAL	20°CCW

Figure 4-6. Third Blast Test Liftoff Conditions



NOTE: INSTRUMENTED DATA INDICATES THAT THE PLUME OF NO. 4 SRM WAS NOT AFFECTED BY WIND, BUT THAT SRB NO 9 PLUME WAS.

VEHICLE POSITION CONSTANT FROM T+0 THRU T+6, THE CRITICAL PERIOD OF INSTRUMENTED BLAST TESTING.

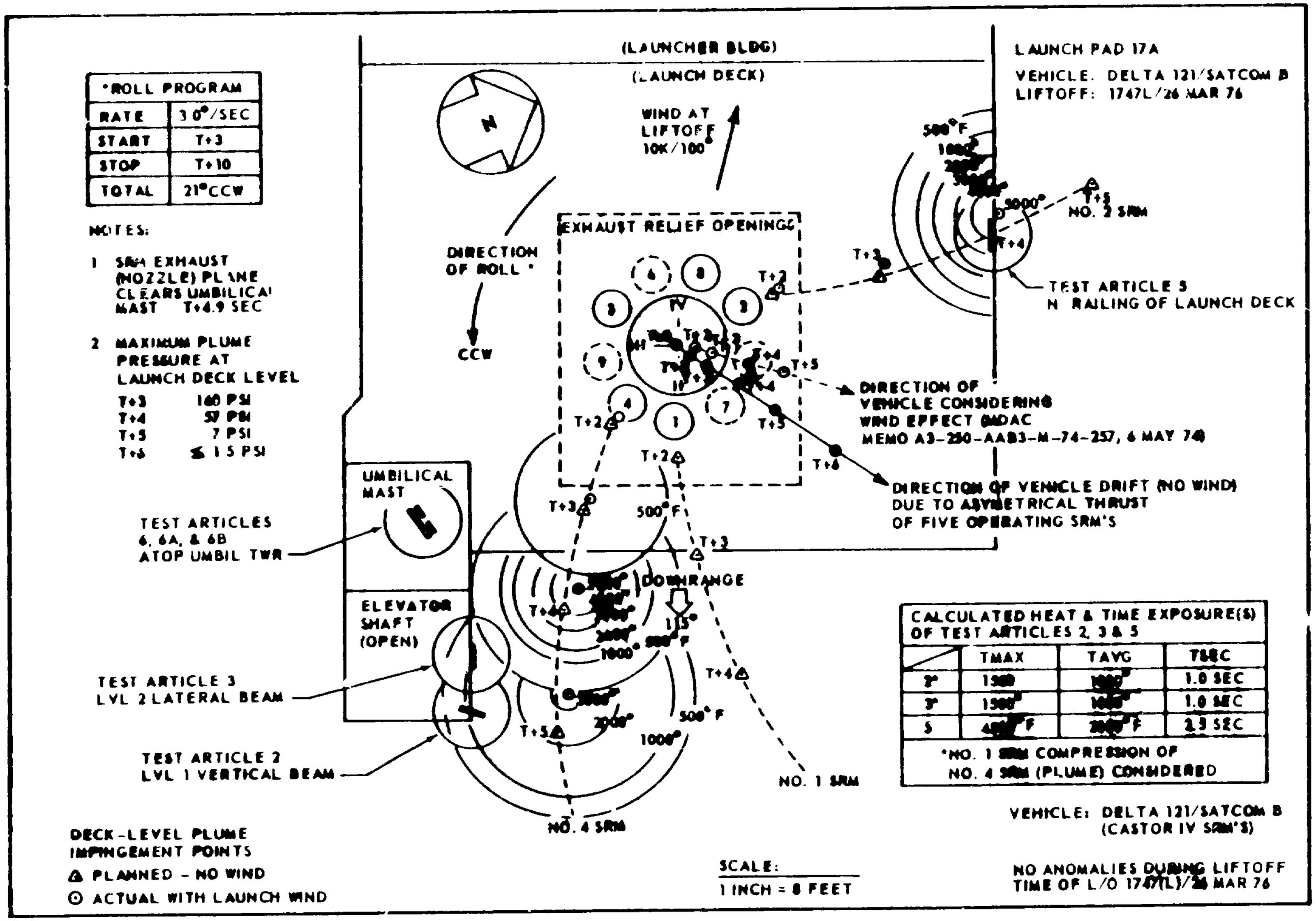
SRM PLUME ACTUAL IMPINGEMENT POINTS ASSUMING NO DRIFT & NO VEHICLE PITCH OR YAW

NO. 4 SRM ○
NO. 5 SRM ⊡
NO 9 SRM △

ROLL PROGRAM	
RATE	3.33°/SEC
START	T+2
STOP	T+8
TOTAL	20° CCW

VEHICLE TRANSLATION AFTER LIFTOFF
NO DRIFT EXPERIENCED WIND AT LIFTOFF WAS 20 KNOTS FROM 175 DEGREES. CONSEQUENTLY, THE VEHICLE DID NOT DRIFT UNTIL AFTER IT CLEARED THE UMBILICAL MAST.

Figure 4-7. Fourth Blast Test Liftoff Conditions



*ROLL PROGRAM	
RATE	3.0°/SEC
START	T+3
STOP	T+10
TOTAL	21°CCW

NOTES:

1. SRM EXHAUST (NOZZLE) PLANE CLEARS UMBILICAL MAST T+4.9 SEC
2. MAXIMUM PLUME PRESSURE AT LAUNCH DECK LEVEL

T+3	160 PSI
T+4	57 PSI
T+5	7 PSI
T+6	≤ 1.5 PSI

CALCULATED HEAT & TIME EXPOSURE(S) OF TEST ARTICLES 2, 3 & 5

	TMAX	TAVG	TSEC
2*	1500°	1000°	1.0 SEC
3*	1500°	1000°	1.0 SEC
5	4500°F	2000°F	2.5 SEC

*NO. 1 SRM COMPRESSION OF NO. 4 SRM (PLUME) CONSIDERED

VEHICLE: DELTA 121/SATCOM B (CASTOR IV SRM'S)

NO ANOMALIES DURING LIFTOFF TIME OF L/O 1747(L)/26 MAR 76

Figure 4-8. Fifth Blast Test Liftoff Conditions

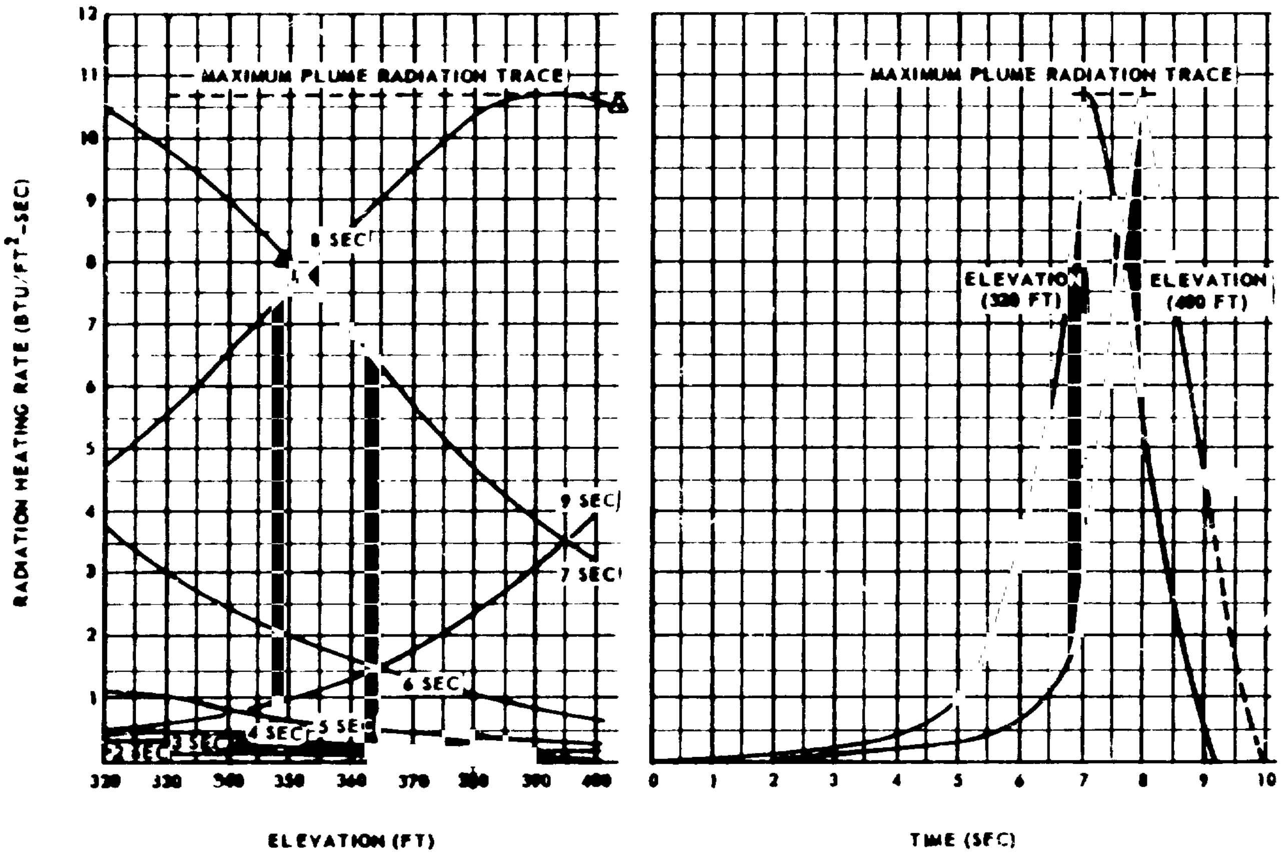


Figure 4-9. Total Plume Radiation Heating Rate to SSAT Vertical Lightning Mast

Lockheed report LMSC-HKEC-TN390419, dated October 1974, indicates a Shuttle main engine sea level plume 1000°F temperature envelope extending over 5,000 ft from the engine. Guidance corrections and/or wind effects may cause the plume to impinge on the lightning mast after liftoff. This possibility should be investigated further when more data are available. In a recent telecon, Lockheed indicated that their earlier results on plume lengths would not change significantly in current reports.

The sample tests indicated the DC 20-103 is the preferred mast coating material. A properly applied 1/8-in-thick coating should be satisfactory but may have to be reapplied periodically, depending on launch frequency; however, the material tested is no longer available, since asbestos was used in its manufacture. A new material in which glass spheres replace the asbestos should be available soon and should be both blast tested and checked for possible electrical flash-over effects to verify that its properties are satisfactory.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

Some of the conclusions in this section are necessarily tentative, reflecting early task completion before complete information on the Shuttle plume heating effects and the properties of the new substitute DC 20-103 proposed mast coating is available. In addition, the electrical surface flashover voltages of coated samples, before and after blast tests, have not been measured.

Based on the expected Shuttle plume heating rate at the SSAT vertical lightning mast of 10.6 Btu/ft^2-s maximum with a mean of 5.3 Btu/ft^2-s for 4 s on liftoff only, the total heat impinging on the Shuttle mast of about 4 by 5.3 = 21.2 Btu/ft^2 is almost the same as the 25 Btu/ft^2 estimated for the ASTP mast. The ASTP lightning mast appeared undamaged by the thermal energy and shock vibrations from the Saturn 1B launch vehicle; however, for Shuttle there is some possibility of direct main engine plume impingement on the mast after liftoff due to wind effects and guidance corrections because of the long length of the plume, exceeding 5,000 ft.

Structurally, the modifications required to meet design goals include:

a. Shorten the ASTP mast by a minimum of 10 ft to minimize modifications to the steel support structure. In doing this, however, the integrity of the mast as an insulator must be maintained; any shortening reduces its insulating safety factor. It should be recognized that the lightning experience with the ASTP mast was limited to one large stroke (100 kA). For this reason, electrically, the full-length ASTP mast is preferred.

b. Redesign the steel mast head to permit access.

c. Provide a fixed work platform inside the mast to allow working at the top.

d. Install ladder inside the mast to allow access for inspection.

e. Provide a steel support pedestal between the support structure and the mast base to allow access inside the mast.

f. Strengthen the steel support structure to withstand hurricane winds.

The proposed work platform inside the mast should be designed as an insulating dielectric barrier to prevent electrical flashover on the inside of the mast.

For Shuttle the lightning protection cable must be oriented north-south. U.S. Steel has recommended that extra improved galvanized plow steel be used for the catenary cable rather than stainless steel for use over a 10-year period because of corrosion difficulties experienced with stainless steel cables. The cable size should be 1/2 in. as it was for ASTP. A 50-ft clearance should be maintained between the cable and all grounded metal structures. The insulating length of the mast should be at least 20 percent greater than the air clearance (50 by 1.2 = 60 ft minimum) to ensure that the mast, its surface contaminated to some degree by exposure to the elements, will not become a preferred arcover path. If practical, the catenary cable ground points should be moved toward the mast by 100 to 150 ft to reduce the voltage wave propagation time and therefore minimize the effect of the reduced mast insulation length. During thunderstorm warning periods, the SSAT crane should be parked as close to the cable as possible, maintaining the 50-ft clearance.

After selection of the final configuration, the new Shuttle system and structures should be modeled to determine the lightning-induced effects to be expected, as was done for ASTP. As an alternative, the electromagnetic fields could later be measured full scale using the proposed lightning simulator.

The lightning current waveforms and the rates of rise of current should be measured at each end of the cable as for ASTP, but the instrumentation, except for the current sensors, should be relocated at a central point such as the PTCR. The instrumentation should be basically the same as used for ASTP except for modifications to improve recording and reliability. The biomation transient recorder should be used to record all strokes instead of just the first 40 μs of the first stroke of a flash. The waveforms should continue to be analyzed and to read out the significant parameters of rise time, peak current, maximum rate of rise, and time to one-half peak. The instrumentation should be operationally verified periodically by using insulated minizappers permanently installed at each end of the catenary cable. Optionally, the sensors may be replaced by built-in shunts and concentric mutual inductors.

The most practical methods for marking and lighting the Shuttle lightning mast are:

a. Coat the mast with a thermally protective material having high light reflectivity.

b. Paint the mast sheave assembly orange for cloud-mast definition.

c. Illuminate the mast with base-mounted floodlights during periods of darkness.

Samples of the ASTP mast fiberglass material were subjected to heating rates up to a maximum of 10.2 Btu/ft^2-s with a mean of 8.1 Btu/ft^2-s for 4 s during six Delta rocket launches on pads 17B and 17A. These rates were about the same as the expected Shuttle lightning mast maximum plume radiation on lift-off. The blast tests indicated that DC 20-103 aerospace sealant, properly applied, was a preferred coating to the gel coat used for ASTP. Assuming an ablation of 0.005 in per launch on the average, a 0.1-in coating would need to be replaced about every 15 launches, possibly yearly. This is the only recurring cost anticipated for the lightning mast system on the SSAT. Gel coat tended to bake and crack and uncoated fiberglass lost resin due to volatilization in repeated blast tests. Data on mast heating during the initial ascent period are not yet available. The possibility of direct impingement of the Shuttle main engine plume on the lightning mast should be investigated further when the launch environment is fully defined.

The new substitute DC 20-103, using glass spheres in place of asbestos, should be subjected to blast tests to verify that its essential properties are at least equivalent to those of the discontinued material. Untested and blast-tested coated samples are available for additional tests to determine the possible effects of the coatings on electrical flashover potentials. The new DC 20-103 substitute material should be used as a coating and subjected to similar tests.

APPENDIX A

SUPPORTING DATA

This appendix contains various supporting data in the form of attachments to this document. These attachments are identified below in order of sequence.

a. Properties of Typical Mast Coating, Dow Corning 20-103 Aerospace Sealant

b. Shuttle Lightning Study Thermal Coating Calculations

c. Test Article Evaluations

d. Blast Test Samples Analyses

e. Photographs of Tests

ATTACHMENT 1

PROPERTIES OF TYPICAL MAST COATING

DOW CORNING 20-103 AEROSPACE SEALANT

TYPICAL PROPERTIES

These values are not intended for use in preparing specifications

Before Catalyst Addition

Viscosity at 77 F (25 C), poises	15,000

After Catalyst Addition

Nonvolatile Content 24 hours at 158 F (70 C), percent	97
Extrusion Rate at 90 psi with ⅛-inch orifice, grams per minute	100
Flow 1½-inch disc, ⅛-inch thick, inches	0.5
Working Time, hours	2
Tack-Free Time, hours at 77 F (25 C)	6

After Curing

	Specific Gravity at 77 F (25 C)	1.45
ASTM D 412	Tensile Strength psi	480
ASTM D 412	Elongation, percent	150
	Low Temperature Flexibility, degrees F	-85
	Humidity Resistance, 10 days at 120 F (49 C), condensing conditions	Good
	Reparability	Good
	Peel Strength cohesive, ppi	9
	Shear Strength cohesive failure, psi	
	Aluminum, ALCLAD 2024	300
	Aluminum, per Mil-C-5541	300

Electrical Properties

ASTM D 149	Electric Strength, volts per mil	450
ASTM D 150	Dielectric Constant	
	60 Hz	4.8
	10^5 Hz	3.6
ASTM D 150	Dissipation Factor	
	60 Hz	0.057
	10^5 Hz	0.065

Thermal Properties

Specific Heat at 77 F (25 C), BTU per (lb) (°F)	0.26
Thermal Conductivity at 77 F (25 C), BTU per (hr) (ft) (°F)	0.17

Ablative Properties, Chemical Torch Testing

	Test Condition No 1	*Test Condition No 2*
Fuel	oxygen-acetylene	oxygen-acetylene
Heat Flux, cold wall BTU per (ft^2) (second)	40	260
Flame Direction to Surface, degrees	20	90
Penetration Rate, 60 second test duration, mils per second	1.01	1.66
Char Characteristics	Granular, fair adhesion to subsurface, subsurface dry, powdery	Granular, fair adhesion to subsurface, subsurface dry, powdery
Backside Temperature Increase, ¼-inch thick sample degrees C	*(No backing panel)*	*(40-mil aluminum backing panel)*
at 30 seconds	16	17
at 60 seconds	45	50

Ablative Properties, Plasma Torch Testing (simulated air)

	Test Condition No 3	*Test Condition No 4*
Cold Wall Heat Flux, BTU per (ft^2) (second)	100	300
Enthalpy, BTU per pound	4,500	5,500
Test Duration seconds	60	60
Surface Temperature degrees F (C)	2,750 (1,510)	3,250 (1,786.7)
Apparent Gross Heat of Ablation and Radiation Cold Wall Heat Flux and mass loss, residual char left intact BTU per pound	47,000	9,000
Net Effective Heat of Ablation, Hot Wall Heat Flux and mass loss, residual char left intact, BTU per pound	15,000	5,000

ATTACHMENT 2

SHUTTLE LIGHTNING STUDY

THERMAL COATING CALCULATIONS

SHUTTLE LIGHTNING STUDY - THERMAL COATING CALCULATIONS SJT/20 October 1975

ASTP LIGHTNING MAST, UNCOATED

DIMENSIONS: (ASTP Mast Configuration)

Length (L)	- Fiberglass Mast	75 ft 1 in		
	- Top Splice Plate Extension	0 ft 8 in		
	Overall Length	75 ft 9 in		
	- Adjust effective length for splice plate thickness; 2 x 0.5 = 1 in	0 ft 1 in		
Total Effective Length (L_T)		75 ft 10 in	=	75.833 ft
Outside Diameter (D) - Average for Mast		5 ft 2 in	=	5.167 ft
Circumference (C) - Average for Mast (πD)		194.779 in	=	16.232 ft
Spoilers	- Four 1/2" Sq Spoilers, 68 ft + 5 in long			
	- Length each Spoiler (L_S)	821.0 in	=	68.416 ft
	- Width each Spoiler (W_S) (2 sides @ 0.5 in ea)	1.0 in	=	0.083 ft

SURFACE AREA:

Mast and Splice Plate $A = CL$	177,248.89 in^2	=	1230.895 ft^2
Spoilers (4) $A_S = 4 (L_S W_S)$	3,284.00 in^2	=	22.806 ft^2
Total Surface Area $A_T = A + A_S$	180,532.89 in^2	=	1253.700 ft^2

THERMAL INSULATING MATERIAL

Dow Corning 20-103 Aerospace Sealant (an ablative)

Specific Gravity = 1.45 @ 77°F (after curing)

Weight = (1.45 x 62.4 lb) = 90.48160 lb-ft^3

= (90.4816 1728 lb) = 0.05236 lb-in^3

WEIGHT OF COATING AT VARIOUS DEPTHS

7 November 1975

NOTE: Mast diameter (D) adjusted to mean value of coating in each calculation of circumference (C) by adding one-half total coating depth to D; i.e.

$D_{mean} = D_{mast} + 1/2\ (2\ \text{coatings})$

CONSTANTS: Length of mast (L_T) = 75.833 ft (ASTP Configuration)

Surface area of four Spoilers (A_S) = 22.806 sq. ft

Diameter of uncoated mast (D) = 62.000 in

COATING			MAST			
				Mean Values		
Depth in	DC 20-103 lb-ft^2	Weight lb	D in	C in/ft	A ft^2	A_T ft^2
0.100	0.754	946.78	62.100	195.091 16.258	1232.87	1255.679
0.125	0.942	1183.32	62.125	195.171 16.264	1233.37	1256.176
0.150	1.131	1421.29	62.150	195.249 16.271	1233.87	1256.672
0.200	1.508	1896.56	62.200	195.407 16.284	1234.86	1257.664
0.250	1.884	2371.31	62.250	195.564 16.297	1235.85	1258.657
0.300	2.262	2849.32	62.300	195.721 16.310	1236.84	1259.648
0.350	2.639	3326.83	62.350	195.878 16.323	1237.84	1260.642
0.375	2.827	3565.24	62.375	195.957 16.330	1238.33	1261.138
0.400	3.016	3805.09	62.400	196.035 16.336	1238.83	1261.635
0.450	3.393	4284.09	62.450	196.192 16.349	1239.82	1262.628
0.500	3.770	4763.85	62.500	196.349 16.362	1240.81	1263.620
0.600	4.524	5725.38	62.600	196.664 16.388	1242.75	1265.560
0.700	5.278	6690.42	62.700	196.978 16.415	1244.78	1267.600
0.750	5.655	7173.84	62.750	197.135 16.428	1245.78	1268.580
1.000	7.540	9602.54	63.000	197.920 16.493	1250.74	1273.550

ATTACHMENT 3

TEST ARTICLE EVALUATIONS

Test Article Evaluation

1.0 TEST ARTICLE NO. 1

The approximate size of the test panel was 8 in by 18 in (two sides). The orange side (gel coat) had an average panel thickness of 922 mils. The white side (gel coat) had an average panel thickness of 904 mils.

1.1 TEST NO. 1

Test date: 16 October 1975

Erosion: None

Temperature labels: Not reported

Temperature: 720°F peak
581°F mean average (4 s)

Heat flux rate: Btu/ft^2-s orange side: 9.0 peak
6.8 mean average (4 s)
Btu/ft^2-s white side: 6.6 peak
4.9 mean average (4 s)

Visual appearance: The photographs indicated a very slight discoloration of the test article.

Refurbishment: Temperature labels were installed on each side. The orange side was coated with DC 20-103 to a thickness of 100 to 125 mils. The average panel thickness was 1,057 mils. The white side was recoated (gel coat) only in the temperature label area.

1.2 TEST NO. 2

Test date: 19 November 1975

Erosion: Little or none

Temperature labels: Unchanged

Temperature 330°F peak
262°F mean average (4 s)

Heat flux rate: Btu/ft^2-s orange side: 8.2 peak
7.3 mean average (4 s)
Btu/ft^2-s white side: 6.8 peak
5.3 mean average (4 s)

Visual appearance: The photographs indicated a total discoloration of the orange side (DC 20-103) and erosion plus discoloration of the white side (gel coat).

Refurbishment: The old temperature labels were removed, and new ones were installed. The orange side (DC 20-103) was recoated to an average panel thickness of 1,044 mils. The white side (gel coat) was recoated to the original panel thickness.

1.3 TEST NO. 3

Test date: 17 January 1976

Erosion:
Orange side (DC 20-103): minimum 3 mils
maximum 11 mils
White side (gel coat): minimum 41 mils (buildup)
maximum 15 mils

Temperature labels: No change

Temperature:
625°F peak
461°F mean average (4 s)

Heat flux rate: No report

Visual appearance: The photographs indicated discoloration and some pitting of the orange side (DC 20-103) and discoloration, erosion, and severe pitting of the white side (gel coat).

Refurbishment: The orange side (DC 20-103) was recoated to an average panel thickness of 1,037 mils. The white side (gel coat) was recoated to an average panel thickness of 893 mils.

1.4 TEST NO. 4

Test date: 19 February 1976

Erosion:
Orange side (DC 20-103): minimum 1 mil
maximum 9 mils
White side (gel coat): minimum 7 mils
maximum 30 mils

Temperature labels: No change

Temperature:
1700°F peak
1030°F mean average (4 s)

Heat flux rate: Btu/ft^2-s orange side: 1.7 peak
1.6 mean average (4 s)
Btu/ft^2-s white side: no report

Visual appearance: The photographs indicated more discoloration, some erosion, and a few pits on the orange side (DC 20-103) and complete discoloration and severe erosion of the white side (gel coat).

Refurbishment: The test article was not refurbished.

Test Article Evaluation

2.0 TEST ARTICLE NO. 2

The approximate size of the test panel was 8 in by 18 in (two sides). The orange side (gel coat) had an average panel thickness of 920 mils. The white side (gel coat) had an average panel thickness of 911 mils.

2.1 TEST NO. 1

Test date: 16 October 1975

Erosion: None

Temperature labels: Not reported

Temperature: 250°F peak
210°F mean average (4 s)

Heat flux rate: Btu/ft^2-s orange side: 4.6 peak
4.0 mean average (4 s)
Btu/ft^2-s white side: 2.9 peak
2.3 mean average (4 s)

Visual appearance: No visible change

Refurbishment: The test article was not refurbished.

2.2 TEST NO. 2

Test date: 19 November 1975

Erosion: None

Temperature labels: Not reported

Temperature: 335°F peak
242°F mean average (4 s)

Heat flux rate: Btu/ft^2-s orange side: 6.6 peak
4.7 mean average (4 s)
Btu/ft^2-s white side: 4.2 peak
3.5 mean average (4 s)

Visual appearance. The photographs indicated a slight discoloration of the orange side (gel coat) and no visible change to the white side (gel coat).

Refurbishment: The test article was not refurbished.

2.3 TEST NO. 3

Test date: 17 January 1976

Erosion: Orange side (gel coat): minimum 7 mils (buildup)
maximum 3 mils
White side (gel coat): minimum 3 mils (buildup)
maximum 2 mils

Temperature labels: Not reported

Temperature: 470°F peak
356°F mean average (4 s)

Heat flux rate: Btu/ft²-s orange side: 8.9 peak
7.0 mean average (4 s)
Btu/ft²-s white side: 5.2 peak
4.5 mean average (4 s)

Visual appearance: The photographs indicated a considerable amount of discoloration of both sides, orange and white.

Refurbishment: Both sides were recoated with gel coat, the orange side to an average panel thickness of 923 mils and the white side to an average panel thickness of 912 mils.

2.4 TEST NO. 4

Test date: 19 February 1976

Erosion: Orange side: minimum 7 mils (buildup)
maximum 3 mils
White side: minimum 3 mils (buildup)
maximum 2 mils

Temperature labels: Not reported

Temperature: 750°F peak
527°F mean average (4 s)

Heat flux rate: Btu/ft²-s orange side: 10.2 peak
8.1 mean average (4 s)
Btu/ft²-s white side: 7.6 peak
3.1 mean average (4 s)

Resiliency test (shore "A" hardness): 54 average

Visual appearance: The photographs indicated considerable discoloration of both sides with some erosion and pitting.

Refurbishment: The orange side was refurbished with DC 20-103 to an average panel thickness of 1,053 mils. The white side was recoated with gel coat to an average panel thickness of 911 mils.

2.5 TEST NO. 5

Test date: 26 March 1976

Erosion: Orange side (DC 20-103): minimum 17 mils
maximum 41 mils
White side (gel coat): minimum 17 mils
maximum 46 mils

Temperature labels: 150°F

Temperature: Instrumentation failed

Heat flux rate: Instrumentation failed

Resiliency test (shore "A" hardness): 49 average

Visual appearance: The photographs indicated discoloration, some erosion, and considerable pitting of the orange side (DC 20-103). There was complete erosion of the white side (gel coat) with some damage to the fiberglass.

Refurbishment: The test article was not refurbished.

Test Article Evaluation

3.0 TEST ARTICLE NO. 3

The approximate size of the test panel was 8 in by 18 in (two sides). The orange side (gel coat) had an average panel thickness of 915 mils. The white side (gel coat) had an average panel thickness of 919 mils.

3.1 TEST NO. 1

Test date: 16 October 1975

Erosion: None

Temperature labels: Not reported

Temperature: 335°F peak
267°F mean average (4 s)

Heat flux rate: Btu/ft^2-s orange side: 8.3 peak
5.1 mean average (4 s)
Btu/ft^2-s white side: 5.2 peak
5.0 mean average (4 s)

Visual appearance: The photographs indicated a very slight discoloration of both sides.

Refurbishment: The test article was not refurbished.

3.2 TEST NO. 2

Test date: 19 November 1975

Erosion: None

Temperature labels: No change

Temperature: 355°F peak
252°F mean average (4 s)

Heat flux rate: Btu/ft^2-s orange side: 8.6 peak
5.6 mean average (4 s)
Btu/ft^2-s white side: 6.0 peak
5.6 mean average (4 s)

Visual appearance: The photographs indicated little or no change.

Refurbishment: The temperature labels were replaced. The orange side was refurbished with DC 20-103 to an average panel thickness of 1,131 mils. The white side (gel coat) was repatched as required, and new measurements were not recorded.

3.3 TEST NO. 3

Test date: 17 January 1976

Erosion: Orange side: minimum 1 mil (buildup)
maximum 6 mils
White side: minimum 12 mils (buildup)
maximum 2 mils (buildup)

Temperature labels: No change

Temperature: 330°F peak
234°F mean average (4 s)

Heat flux rate: Btu/ft^2-s orange side: 1.2 peak
1.1 mean average (4 s)
Btu/ft^2-s white side: not recorded

Visual appearance: The photographs indicated complete discoloration, some erosion, and pitting of both sides.

Refurbishment: The temperature labels were replaced. The orange side (DC 20-103) was recoated to an average panel thickness of 1,027 mils. The white side (gel coat) was recoated to an average panel thickness of 918 mils.

3.4 TEST NO. 4

Test date: 19 February 1976

Erosion: Orange side: minimum 11 mils (buildup)
maximum 5 mils
White side: minimum 12 mils (buildup)
maximum 2 mils

Temperature labels: Not reported

Temperature: 450°F peak
369°F mean average (4 s)

Heat flux rate: Btu/ft^2-s orange side: 1.4 peak
1.2 mean average (4 s)
Btu/ft^2-s white side: not recorded

Resiliency test (shore "A" hardness):	53 average
Visual appearance:	The photographs indicated that the white side was discolored, charred in appearance, with severe erosion and pitting. The orange side had some discoloration, some erosion, and slight pitting.
Refurbishment:	The temperature labels were replaced. The orange side (DC 20-103) was recoated to an average panel thickness of 1,030 mils. The white side was recoated to an average panel thickness of 918 mils.

3.5 TEST NO. 5

Test date:	26 March 1976	
Erosion:	Orange side:	minimum 6 mils (buildup) maximum 4 mils
	White side:	minimum 7 mils maximum 31 mils
Temperature labels:	150°F	
Temperature:	Instrumentation failed	
Heat flux rate:	Instrumentation failed	
Visual appearance:	The photographs indicated discoloration, slight erosion, and some pitting of the orange side (DC 20-103). There was complete erosion of the white side (gel coat) with some damage to the fiberglass.	
Refurbishment:	The test article was not refurbished.	

Test Article Evaluation

5.0 TEST ARTICLE NO. 5

The approximate size of the test panel was 1.5 in by 24 in, accommodating two temperature labels. The panel was coated with gel coat. The average recoated panel thickness was 543 mils. The average coated panel thickness was 551 mils.

5.1 TEST NO. 1

Test date: 16 October 1975

Erosion: Minimum 5 mils
Maximum 20 mils

Temperature labels: 350°F

Visual appearance: The photographs indicated complete discoloration and complete erosion of the coating.

Refurbishment: The temperature labels were removed, and the gel coat was removed by sanding. New temperature labels were installed, and the face and sides of the panel were coated with DC 20-103 to a thickness of 100 to 125 mils. The average panel thickness was 648 mils.

5.2 TEST NO. 2

Test date: 19 November 1975

Erosion: Minimum 1 mil
Maximum 29 mils

Temperature labels: Unchanged

Visual appearance: The photographs indicated little or no discoloration and very little pitting.

Refurbishment: The temperature labels were removed and new ones installed. The coating material was patched and measurements made in the temperature label area.

5.3 TEST NO. 3

Test date: 17 January 1976

Erosion: Mininum 8 mils (buildup)
Maximum 30 mils

Temperature labels: No readings obtained

Visual appearance: The photographs indicated some discoloration, some erosion, and slight pitting.

Refurbishment: The panel was measured and new temperature labels installed. The average panel thickness was 627 mils.

5.4 TEST NO. 4

Test date: 19 February 1976

Erosion: Minimum 4 mils (buildup)
Maximum 6 mils

Temperature labels: No reading obtained

Resiliency test (shore "A" hardness): 66 average

Visual appearance: The photographs indicated very little discoloration or erosion.

Refurbishment: New temperature labels were installed, and the material was repaired around the label area. There were no prelaunch measurements made.

5.5 TEST NO. 5

Test date: 26 March 1976

Erosion: Minimum 13 mils
Maximum 29 mils

Temperature labels: 150°F

Visual appearance: The photographs indicated some discoloration, some erosion, and considerable pitting.

Refurbishment: The test article was not refurbished.

Test Article Evaluation

6.0 TEST ARTICLE NO. 6

The approximate size of the test panel was 2 in by 24 in. The panel was coated with gel coat to an average panel thickness of 352 mils. There were no temperature labels installed.

6.1 TEST NO. 1

Test date:	16 October 1975
Erosion:	None
Refurbishment:	The panel did not require refurbishment.

6.2 TEST NO. 2

Test date:	19 November 1975
Erosion:	None
Refurbishment:	The panel did not require refurbishment.

6.3 TEST NO. 3

Test date:	17 January 1976
Erosion:	None
Refurbishment:	The panel was recoated (gel coat) to an average panel thickness of 364 mils.

6.4 TEST NO. 4

Test date:	19 February 1976
Erosion:	1 mil (buildup)
Refurbishment:	The panel was not refurbished.

6.5 TEST NO. 5

Test date:	26 March 1976
Erosion:	Minimum 1 mil (buildup) Maximum 0
Visual appearance:	The photographs indicated only a slight discoloration.
Refurbishment:	The test article was not refurbished.

Test Article Evaluation

6A.0 TEST ARTICLE NO. 6A

The approximate size of the test panel was 1.5 in by 6 in with temperature labels installed. The panel was coated with gel coat to an average panel thickness of 553 mils.

6A.1 TEST NO. 1

Test date 16 October 1975

Erosion: None

Temperature labels: 200°F

Refurbishment: The temperature labels were removed, and the panel surface was sanded. New labels were installed, and the surface was recoated (gel coat) to an average panel thickness of 565 mils.

6A.2 TEST NO. 2

Test date: 19 November 1975

Erosion: None

Temperature labels: Poor response due to insufficient exposure time

Refurbishment: The exposed temperature labels were removed and new ones installed. The surface was patched (gel coat) to an average panel thickness of 567 mils.

6A.3 TEST NO. 3

Test date: 17 January 1976

Erosion: 1 mil (buildup)

Temperature labels: No report

Refurbishment: New temperature labels were installed, and the area around the labels was patched.

6A.4 TEST NO. 4

Test date: 19 February 1976

Erosion: Minimum 13 mils (buildup)
Maximum 9 mils

Temperature labels: Labels did not respond.

Refurbishment: New temperature labels were installed, and the area around the labels was patched.

6A.5 TEST NO. 5

Test date: 26 March 1976

Erosion: 2 mils

Temperature labels: No report

Visual appearance: The photographs indicated very little change in appearance

Refurbishment: The test article was not refurbished.

Test Article Evaluation

6B.0 TEST ARTICLE NO. 6B

The approximate size of the test panel was 1.5 in by 6 in with temperature labels installed. The panel was coated with DC 20-103 to a thickness of 100 mils. The average panel thickness was 635 mils.

6B.1 TEST NO. 1

Test date:	16 October 1975
Erosion:	None
Temperature labels:	Less than 150°F
Refurbishment:	The temperature labels were replaced, and the coating (DC 20-103) was patched around the label area. The average panel thickness was 632 mils.

6B.2 TEST NO. 2

Test date:	19 November 1975
Erosion:	None
Temperature labels:	Poor response due to insufficient exposure time
Refurbishment:	The temperature labels were replaced, and the coating (DC 20-103) was patched around the label area. The average panel thickness was 633 mils.

6B.3 TEST NO. 3

Test date:	17 January 1976
Erosion:	None
Temperature labels:	No change
Refurbishment:	The temperature labels were replaced, and the coating (DC 20-103) was patched around the label area. The average panel thickness was 632 mils.

6B.4 TEST NO. 4

Test date:	19 February 1976
Erosion:	Minimum 0 Maximum 11 mils

Temperature labels:	No change
Resiliency test (shore "A" hardness):	60 average
Refurbishment:	The panel was not refurbished.

6B.5 TEST NO. 5

Test date:	26 March 1976
Erosion:	1 mil (buildup)
Temperature labels:	No change
Resiliency test (shore "A" hardness):	64 average
Visual appearance:	The photographs indicated very little change in appearance.
Refurbishment:	The test article was not refurbished.

ATTACHMENT 4

BLAST TEST SAMPLES ANALYSES

MICROCHEMICAL ANALYSIS SECTION
SO-LAB-32, Room 1274, O&C Building
NASA/KSC
Nov. 7, 1975

SUBJECT: Analysis of Samples Removed From Five Test Articles Located at Various Levels on the Umbilical Tower [illegible], Upper Camera Mount Platform and Railing at Pedestal [illegible]. Samples Obtained Pre- and Post GOES-A Launch, Complex 17B

LABORATORY REQUEST NO: MAS-6758

1.0 Foreword

1.1 Requester: S. J. Thomson/PRC/PRC-1240/X7-3562

1.2 Requester's Sample Description: Five test articles - seven samples are mounted on Complex 17B per attached drawing.

1.3 Requested: Remove surface materials (loosely bound) by transfer methods and analyze material removed. Post launch sampling and analysis for SRB combustion products per attached listing and motor description. Task to be performed on 10-14-75 and 10-17-75.

2.0 Analytical Tests and Results

2.1 An optical microscope was used to partially identify material removed from the five test articles.

2.2 X-Ray diffraction analysis was used to aid in the identification of some of the bulk powder samples removed from a camera lens and paint residue on a camera mount located at the upper most level of the umbilical tower.

2.3 An electron microprobe X-ray analyzer was employed to provide elemental data of particulates and metallic specimens from test articles and bulk powder samples from camera lens and paint residue from top unit camera mount.

2.4 Infrared spectrophotometric methods were used to attempt to determine the type of organic material used as a binder in the paint from top unit camera mount.

2.5 A scanning electron microscope and its auxiliary attachments were found useful in the study of particle morphology and as well chemical composition based on elemental determinations (EDAX Unit).

2.6 Figure 1, attached, indicates the location and test article number identification. The data contained in this report uses the location numbers for sample identity.

2.7 Table 1 lists the samples obtained for both pre - and post launch conditions.

2.8 Tables 2 and 3 summarizes the data obtained on both pre - and post launch samples and gives methods of sampling.

2.9 Table 4 presents other pertinent data relative to both pre - and post launch samples.

2.10 Figure 2 shows a gray particle (spherical), one of many taken off a Kimwipe to verify zinc-base paint contaminant.

Figure 3 gives an EDAX X-ray spectrum of a copper colored particle that was primarily copper.

Figure 4 shows two X-ray spectra of the rusty underside of a paint (GEL Coat) particle. The presence of iron verifies rust.

3.0 Discussion

3.1 Some of the test article surfaces did not appear to have been contaminated from SRM exhausts. For example No. 1, No. 2, and No. 3 (according to location) were essentially unchanged. No. 4 ASTP GEL Coat and No. 5 ASTP GEL Coat were damaged by the SRM engine exhausts.

3.2 The overwhelming evidence for SRM residue was found on the camera lens and test article No. 5. Both locations contained residues composed of major Al and major/minor Ti and Cl which are known SRM exhaust residue components.

3.3 Since Al and Cl are known SRM exhaust residue components and possibly Ti, these elements were given priority for SRM exhaust contaminant determination. Some confusion did exist where several particles contained all of these elements at pre launch conditions. Therefore, only the residue on the camera lens produced reliable evidence of SRM exhaust residue.

Chemist: L. Bostwick
L. Bostwick

Approved:
D. P. Jones

TABLE 1

	DELTA Complex 17B Pre Launch Samples Oct. 14, 1975 Scotch Tape		DELTA Complex 17B Post Launch Samples Oct. 16, 1975 Scotch Tape
No. 1	Red Paint Surface White Paint Surface	No. 1	Red Paint Surface White Paint Surface
No. 2	Red Paint Surface White Paint Surface	No. 2	Red Paint Surface White Paint Surface
No. 3	Red Paint Surface White Paint Surface	No. 3	Red Paint Surface
No. ~~4~~ 6	ASTP White GEL Coat Long Test Article ASTP White GEL Coat Short Test Article DC Test Strip	No. ~~4~~ 6	ASTP White GEL Coat Long Test Article ASTP White GEL Coat Short Test Article DC Test Strip Camera Mount Paint Residue
No. 5	ASTP White GEL Coat Two Areas Sampled	No. 5	ASTP GEL Coat - Tan Loose Particles Scraped Into Petri Dish ASTP GEL Coat - Tan Residue Remove With Scotch Tape - Test Article Removed For Refurbishing Gray/White Film on Camera Lens Cover Glass.

TABLE 2

CHEMICAL AND OPTICAL MICROSCOPIC DATA
PRE LAUNCH SAMPLES

	WHITE PAINT SURFACE	RED PAINT SURFACE	KIMWIPE
No. 1	Scotch tape removed only a few particles that appeared to be inorganic and a number of fibers probably from a Kimwipe used to clean the surface prior to sampling.	Same as white paint surface findings.	Particles from both red and white paint surfaces appeared to be sand, rust, metallic chips, gray paint particles, colored fibers, red particles and some nondescript particles.
No. 2	Scotch tape removed only a few nondescript particles and some fibers.	Same as white paint surface plus a few particles that were dark gray resembling paint chips.	Found were metallic chips, fibrous particles such as "wood" fibers, sand, red paint, green and blue particles, some rust and other nondescript particles.
No. 3	Scotch tape removed some fibers and black particles. A large number of very tiny opaque particles were noted.	Same as for white paint surface.	Several gray (paint?) particles sand, green particles, tan "wood-like" fibers, rust, blue and tiny black spherical particles observed.
No. 6	No scotch tape sample taken.	No scotch tape sample obtained.	DC 20-130 coating-orange and brown rust particles, gray spherical (paint?) particles, various colored fibers and metallic chips. White paint surface - orange and brown rust particles (brown were magnetic), various colored fibers, a few light green particles and metallic chips.

TABLE 2 (CON'T)

CHEMICAL AND OPTICAL MICROSCOPIC DATA
PRE LAUNCH SAMPLES

	WHITE PAINT SURFACE	RED PAINT SURFACE	KIMWIPE
No. 5	Scotch tape removed sand, fibers, rust, gray spherical particles (paint?). Q-Tip was used to sample and black particles and a small copper-colored chip were picked up for analysis.	No red paint on this test article.	No Kimwipe samples obtained.

TABLE 3

CHEMICAL AND OPTICAL MICROSCOPIC DATA POST LAUNCH

	WHITE PAINT SURFACE	RED PAINT SURFACE	KIMWIPE
No. 1	Scotch tape removed very few particles. Those observed were small off-white flakes and one tan particle.	Scotch tape removed a few short segments of various colored fibers, a tan particle, rust, one or two small metallic chips and two black particles.	No Kimwipe sample obtained.
No. 2	No sample obtained.	Scotch tape removed tan particles (sand?), sand, rust, clear glassy particles (not sand-like) and not much else.	No Kimwipe sample obtained.
No. 3	Scotch tape removed a few very tiny black particles. Also an occassional tan particle. Surface would appear to be quite clean.	Scotch tape removed sand particles, short segments of tan fibers, rust, red (paint?) particles and a few small white opaque particles.	No Kimwipe sample obtained.
No. 6	Scotch tape removed a number of loose paint particles from side and corner that was exposed to extreme heat from SRM. Paint particles appeared as blisters. Under side of some, rust appeared. EDAX identified iron as a major element. This on the small test article. Similar type samples were removed from large test article.	No red paint surface.	No Kimwipe sample obtained.

TABLE 3 (CON'T)

CHEMICAL AND OPTICAL MICROSCOPIC DATA
POST LAUNCH

	WHITE PAINT SURFACE	RED PAINT SURFACE	KIMWIPE
No. 6	DC 20-103 surface. Scotch tape removed a number of small white particles, fibers, rust, red and an occassional large white flakey particle. Some tan particles (paint?) also found on tape.	No red paint surface.	No Kimwipe sample obtained.
No. 4	Camera mount white paint residue removed with Scotch tape. Material also very white and fluffy.	No red paint surface.	No Kimwipe sample obtained.
No. 5	Scotch tape removed large flakes of residual paint from test article. Some material also collected in a petri dish. Paint was tan to brown and badly eroded away. Metallic particles were found in the petri dish and imbedded in the test article.	No red paint surface.	No Kimwipe sample obtained.

TABLE 4

OTHER PERTINENT PARTICLE DATA

PRE LAUNCH	
No. 2	Paint Chip-Gray *EDAX DATA: Major: Zinc
No. 3	Four Particles-EDAX a) Metallic Major: Al Minor: Si Trace: Ca, Cl, Ti, Fe b) Tan Major: Al Minor: Si, Cl Trace: Ca, Ti, Fe c) Tan Major: Al Minor: Si Trace: Ca, Cl, Ti, Fe d) Tan Same as "b"
No. 5	Copper Colored Chip Major: Cu *EDAX UNIT: Permits X-ray spectra to be obtained whereby principal emission lines from elements are used to identify the elements.

POST LAUNCH	
No. 4	Infrared spectral data did not reveal an organic content for paint residue from camera mount.
No. 4	X-Ray diffraction data showed the paint residue to be principally aluminum oxides with zinc oxide as a minor component.
No. 4	Electron microprobe data indicated particles are composed of major Al.
No. 5	Petri Dish Particles-EDAX) Metallic - Magnetic Major: Fe Minor: Al Trace: Ti, Cl b) Light Tan-Fluffy Major: Al, Ti c) Dark, Dark Gray Major: Al Minor: Cl, Ti Trace: Zn d) Tan With Glass Fiber Impression Major: Al, Si Minor: Ti Trace: Ca
No. 5	Camera Lens Film - X-Ray Diffraction of Composite: Principally - Al oxides Minor: Fe oxide, Zn oxide, Ti oxide and possibly Si oxides

TABLE 4 (CON'T)

OTHER PERTINENT PARTICLE DATA

PRE LAUNCH		POST LAUNCH
	No. 5	Test Article - Electron Microprobe Data on Particles. a) Metallics Major: Al b) Non-Metallics Ca-rich Fe-rich Cl-rich
	No. 5	SEM - EDAX - Camera Lens Composite: Major: Al, Si, Cl Trace: Ca, Ti, Fe

MICROCHEMICAL ANALYSIS SECTION
SO-LAB-32, Room 1274, O&C Building
NASA/KSC
Dec. 29, 1975

SUBJECT: Analysis of Samples Removed From Five Test Articles Located at Various Levels on the Launch Tower and Platform, Cx 17B. Post Atmosphere E Launch

LABORATORY REQUEST NO: MAS-6807

RELATED DOCUMENTATION: MAS-6758

1.0 Foreword

1.1 Requester: S. J. Thomson/PRC/PRC-1240/7-3914

1.2 Requester's Sample Description: 5 Test articles, with 7 samples mounted on Complex 17.

1.3 Requested: Post launch sampling and analysis of SRM combustion products.

Remove loosely bound surface materials by transfer method for analysis and identification.

2.0 Analytical Tests and Results

2.1 A scanning electron microscope and its auxiliary attachments were used to produce SEM-EDAX data on some of the particles collected from the test articles.

2.2 An optical microscope was also used to identify some of the particles collected from the various test articles.

2.3 X-Ray diffraction methods were employed to determine compound identification of material removed from camera lens covers.

2.4 The particles collected after launch were very similar to those gathered after the previous launch. The one area where SRM combustion products were plentiful was on the camera lens covers.

The areas on the Scotch tape that appeared to contain gross numbers of finely divided particles were apparently only an optical illusion and was believed to have been tiny air bubbles. EDAX elemental analysis was performed on some of the Scotch tape areas and these areas yielded no elemental information. If these finely divided particles were real then EDAX would have shown the presence of at least aluminum.

2.5 Table 1 gives the sample location and identification and Table 2 summarizes the analytical data of the individual samples collected.

Chemist: L. Bostwick
L. Bostwick

Approved: J H Jones
J. H. Jones

TABLE 1

SAMPLE LOCATION AND IDENTIFICATION

TEST ARTICLE PLACEMENT

LOCATIONS	TEST ARTICLE I.D. NUMBER	SO-LAB SAMPLE NO.
1	1	1
2	3	2
3	2	3
4	6	4
5	5	5

TABLE 2

CHEMICAL AND OPTICAL MICROSCOPIC DATA

No. 1 D.C.: Scotch tape removed several large, flat, grainy white paint (?) particles, various colored fibers, sand, rust, tan particles and clusters of very finely divided particulates.

WHITE: Scotch tape removed a large nunber of white paint particles that resemble blisters. The under surface of the particles showed black and rusty spots. A few fibers were observed.

X-Ray fluorescence (EDAX) data show the following results:

a. White particles contain major Silicon and Titanium.

b. Metallic particle - major aluminum.

No. 2 WHITE: Scotch tape removed white/tan paint particles, green particles, short fiber segments, rust, sand and small black particles.

No. 3 RED: Scotch tape removed red paint particles, white crystals, rust, fibers, sand and gray (paint ?) particles.

WHITE: Scotch tape removed identical materials identified for No. 1 white above.

No. 6 D.C.: Scotch tape removed a few tan paint particles, sand, some fibers and numerous tiny particulates.

X-Ray fluorescence (EDAX) analysis did not detect any elements for the tiny particulates and in fact they may just be surface irregularities on the Scotch tape and not SRM exhaust particles as was first suspected.

TABLE 2 (Continued)

No. 5 D.C.: Scotch tape removed black porous particles, rust, sand fibers, glassy spherical particle, small black particles and a large number of very tiny particulates.

X-Ray fluorescence (EDAX) data show the following results:

a. Sand - Major Silicon

b. Metallic particle - Major Aluminum

c. Glassy Sphere - Major Aluminum and Calcium

Minor/Trace - Silicon, Chlorine and Iron

Gray Power: Camera: Material removed from protective lens cover at Launch pedistal level was analyzed by X-ray powder camera methods. The results were:

Composition: Mixture of Al oxides

MICROCHEMICAL ANALYSIS SECTION
SO-LAB-32, Room 1274, O&C Building
NASA/KSC
Feb. 19, 1976

SUBJECT: Analysis of Samples From Five Test Articles, Cx 17B, Post CTS Launch

LABORATORY REQUEST NO: MAS-6807B

RELATED DOCUMENTATION: MAS-6758
MAS-6807
MAS-6807A

1.0 Foreword

1.1 Requester: S. Thomson/PRC/PRC-1240/7-3914

1.2 Requester's Sample Description: Five test articles with seven samples mounted on LC 17. Base material of each sample is fiberglass.

1.3 Requested: Remove loosely bound surface materials by transfer methods and analyze for SRB combustion products.

2.0 Analytical Tests And Results

2.1 An optical microscope was used to partially identify material removed from the five test articles.

2.2 X-Ray diffraction methods were used to help identify the residue removed from the camera lens cover at zero level.

2.3 An electron microprobe X-ray analyzer was used to produce elemental data on both metallic and non-metallic particulates.

2.4 The sample numbers correspond with the test article designation assigned by the requester except for the camera lens cover sample.

2.5 Table I summarizes the analytical data obtained by the various methods described in paragraphs 2.1, 2.2 and 2.3.

3.0 Discussion

3.1 A number of samples contained metallic aluminum particles which are believed to be SRB exhaust residue.

Chemist: L Bostwick
L. Bostwick

Approved:
J. [illegible]. Jones

TABLE I

CHEMICAL AND OPTICAL MICROSCOPIC DATA

Sample	Optical Microscope	Chemical
No. 1	GEL Coat: Tan/white large paint particles, much finely divided material. Gray/black metallic luster particles. Dark brown rust-like particles	Metal Particles - Major Al, tan/white paint particles are Ti-rich, with and/or without minor/trace S and Cl. Random scattered Fe-rich and Si-rich particles.
	Dow Corning: White paint particles, metallic aluminum particle clusters, sand, black particles and rust.	Paint - Major Si. Numerous small Fe-rich and a small number of Ca-rich particles. Metallic Particles - Major Al
No. 2	GEL Coat: Spherical metallic aluminum particles, paint particles, sand, rust and black particles.	Tan/white paint particles are Ti-rich with minor/trace S and Cl. Few Fe-rich and Si-rich particles. Trace of Zn also detected (paint ?).
	Red Coat: Same as Gel Coat.	Reddish/tan particles contain major Al, strong minor to trace Zn with and/or without associated minor/trace Cl, Si, S and traces of Ca and K. Randomly scattered Fe-rich particles.
No. 3	GEL Coat: Occassional aluminum particle aggregate, white/tan paint particles, rust particles imbedded in paint particles.	Tan/white particles contain major Ti, Al, Fe plus minor/trace Cl and Si.
	Dow Corning: Black particles (charred paint) aluminum particles, paint particles, rust and a few fiber fragments.	Composite of dark particles. Major Fe plus scattered traces of Ti, Ca Si, Cl and S.
No. 6	GEL Coat: Long and short test article. Rare aluminum particle, tan/white paint particles, black particles, rust-colored particles, very large number of tiny, various colored particles.	Heterogeneous mixture of Fe-rich, Al-rich, Ca-rich, K-rich and Si-rich. Also observed was minor/trace Cl, S and P randomly distributed throughout the sample.

TABLE I (CON'T)

CHEMICAL AND OPTICAL MICROSCOPIC DATA

Sample	Optical Microscope	Chemical
	Dow Corning: An occassional aluminum particle aggregate. Paint particles, black, tan, rust-colored particles and a great number of small various colored individual particles.	Tan/white particles not analyzed for elemental composition.
No. 5	GEL Coat: Metallic aluminum particles, sand, paint particles, reddish and black particles	Particles: Major Si with heterogeneous associated major Al, Fe; low minor/trace Ca plus possible traces of Zn, Cl, S and K.
Lens Cover	White to dark gray particulates collected on cotton swabs.	Predominantly major Al with major/minor Si, Zn, Ca, K, Cl, S, Fe, Ni plus possible trace of P. X-Ray diffraction data found a mixture of * α- and * δ - Al_2O_3 plus minor/trace quantity of unidentified crystalline compound(s).

* α- = alpha phase

* δ - = delta phase

TR-1530

MICROCHEMICAL ANALYSIS SECTION
SO-LAB-32, Room 1274, O&C Building
NASA/KSC
Mar. 25, 1976

SUBJECT: Analysis Of Samples Removed From Five Test Articles Located At Various Points On Cx 17B. Post Marisat A Launch

LABORATORY REQUEST NO: MAS-6807C

RELATED DOCUMENTATION: MAS-6758, MAS-6807, MAS-6807A, MAS-6807B

1.0 Foreword

1.1 Requester: S. J. Thomson/PRC/PRC-1240/7-3562

1.2 Requester's Sample Description: Five test articles were mounted at various locations on Complex 17B.

1.3 Requested: Remove loosely bound surface materials by transfer methods for analysis. Analyze for SRB combustion products.

2.0 Analytical Tests And Results

2.1 An optical microscope was used to partially identify the material removed from each test article.

2.2 X-Ray diffraction methods were used to identify some of the material removed from a camera lens cover.

2.3 An electron microprobe X-ray analyzer provided elemental data of particulates removed from each test article.

2.4 Table I lists the test articles and the optical microscopic analysis of the loose particles removed using Scotch tape.

2.5 X-Ray diffraction data indicated that the material on the camera lens cover was a mixture of aluminum oxides, i.e., alpha, eta, epsilon and gamma phases.

2.6 The electron microprobe data are included in Table I.

3.0 Conclusions

3.1 Aluminum was found in a number of the samples removed from the test articles. The implication is that SRB exhaust residue was the source of the aluminum.

Chemist: L Bostwick
L. Bostwick

Approved: J Jones
J. F. Jones

TABLE I

OPTICAL MICROSCOPIC DATA
ELECTRON MICROPROBE X-RAY DATA

Test Article	Particle Identification - X-Ray Microprobe Data		
No. 1 A Gel Coat	1. Sand Particles	4. Black Particles	7. Large Paint Particles
	2. Glass Fibers	5. White Particles	8. Tan (Finely divided paint particles)
	3. Amber Particles	6. Light Blue Particles	
	A. Heterogeneous major/minor Ca, Si, Ti, Al; Ti, Si predominate		
	B. Weak minor/trace Zn, S		
	C. Traces Cl, Fe		
B Dow Corning	1. Sand Particles	4. White Paint Particles (Large)	
	2. Rust Particles	5. White Paint Particles (Finely divided)	
	3. Black Particles		
	A. Heterogeneous major Si, Al; Si predominates		
	B. Major/minor Ca		
	C. Minor/trace Zn, S		
	D. Traces Cl, Fe		

TABLE (CON'T)

Test Article	Particle Identification - X-Ray Microprobe Data
No. 2 A Gel Coat (Red)	1. Red Particles 2. Brown Particles 3. Blue Particles 4. Black Particles 5. White Particles 6. Off-White Particles 7. Copper Colored Particles 8. Al Metallic Aggregates 9. Fibers (man-made)
	A. Heterogeneous major Si, Al, Zn, Cl; Si predominates B. Minor/trace S, K, Ca C. Traces Fe, Cu D. Randomly scattered small Fe-rich, Ca-rich particles
B Gel Coat (White)	1. Sand Particles 2. Tan Particles 3. Brown Particles 4. Black Particles 5. Fibers (man-made)
	A. Heterogeneous major Ti, Al; Ti Al predominate B. Minor/trace Si, Cl C. Traces Zn, Ca, K D. Randomly scattered Fe-rich, Ca-rich, K-rich, Cu-rich particles

TABLE I (CON'T)

Test Article	Particle Identification - X-Ray Microprobe Data
No. 3 A Gel Coat	1. Large White Paint Particles 2. Large Tan Paint Particles 3. Small Black Particles 4. Small Paint Particle Fragments 5. Sand Particles A. Heterogeneous major/minor Ti, Al, Si, and these predominate B. Minor/trace Zn C. Traces Ca, Al D. Randomly scattered small Fe-rich particles
B Dow Corning	1. Few White Paint Particles 2. One or Two Black Particles (Rust ?) 3. Short Fiber Fragments A. Heterogeneous major Si, Al, Ti, Cl, Ca, K; Ca predominates B. Traces S, Zn, Fe C. Randomly scattered small Zn-rich and Fe-rich particles

TABLE (CON'T)

Test Article	Particle Identification - X-Ray Microprobe Data
No. 5 Hand Rail	1. Metallic Al Clusters 2. Finely Divided White Paint Particles 3. Few Tan Particles 4. Short Glass Fiber Fragments A. Heterogeneous major Al, Si and these predominate B. Weak minor/trace Cl, Ca C. Randomly scattered small Fe-rich and Zn-rich particles
No. 6 A Gel Coat	1. Large Tan Particles 2. Small Tan Particles 3. Gray Paint (?) Particles A. Heterogenous major Al, Si, Cl, Ti, Zn, Fe, Ca B. Minor/trace S C. Trace K Small Al-rich particles dominate
No. 6 B Dow Corning	1. Black, Finely Divided Particles 2. Tan, Finely Divided Particles 3. Large Gray Particles 4. Fiber Fragments 5. White, Finely Divided Particles

TABLE I (CON'T)

Test Article	Particle Identification - X-Ray Microprobe Data	
	A. Heterogeneous major Al, Ca, Si, Zn, Cl, Fe, Ti	
	B. Traces S, K	
	Al predominates	
Long Strip Gel Coat	1. Large White Paint Particles (Blisters)	4. Few Brown/Tan Particles (Rust)
	2. Finely Divided Paint Particles	5. Few Black Particles
	3. Few Fibers	
	A. Heterogeneous major Al, Ti and these dominate	
	B. Minor/trace Zn, Cl, Ca, Si	
	C. Traces S, Fe, K	
	D. Randomly scattered small Fe-rich particles	
Left Camera Lens	A. Major Al	
	B. Traces Fe, Zn, Cl throughout	
	C. Randomly scattered Ca-rich, Si-rich, S-rich particles	

MICROCHEMICAL ANALYSIS SECTION
SO-LAB-32, Room 1274, O&C Building
NASA/KSC
Apr. 22, 1976

SUBJECT: Analysis of Samples Removed From Four Test Articles Located on Cx 17A Plus a Sample From a Camera Lens. Post Comsat B Launch

LABORATORY REQUEST NO: MAS-6807D

RELATED DOCUMENTATION: MAS-6758, MAS-6807, MAS-6807A, B, C

1.0 Foreword

1.1 Requester: S. Thomson/PRC/PRC-1240/7-3562

1.2 Requester's Sample Description: Four test articles with 6 samples mounted on Cx 17A. Base material is fiberglass. Protective finishes are Gel Coat and DC 20-103.

1.3 Requested: Remove loosely bound material from each test article and analyze for SRB combustion material.

2.0 Analytical Tests and Results

2.1 An optical microscope was used to partially identify material removed using Scotch tape.

2.2 X-Ray diffraction analysis was used to aid in the identification of solids removed from the camera lens.

2.3 An electron microprobe X-ray analyzer was used to provide elemental data of particulates from each of the test articles.

2.4 The data collected on the particles from the test panels can be found in Table I.

2.5 X-Ray diffraction data indicated that the material on the camera lens cover was a mixture of aluminum oxides, i.e., alpha, eta, epsilon and gamma phases.

2.6 Elemental data obtained using an electron microprobe X-ray analyzer are also included in Table I.

3.0 Conclusions

3.1 Aluminum was found in a number of the samples removed from the test articles. It is believed that the SRB exhaust residue was the source of the aluminum.

3.2 The data for the particles collected after the Comsat B Launch were found to be similar to those for previous post launch samples.

Chemist: L. Bostwick
L. Bostwick

Approved:
J. F. Jones

TABLE I

OPTICAL MICROSCOPE, X-RAY DIFFRACTION AND ELECTRON MICROPROBE DATA

Test Article	Particle Identification + X-Ray Diffraction + Microprobe (Elemental)	
No. 5 Handrail	1. Transparent spherical particles 2. White irregularily - shaped clusters and individual particles 3. Tan, black and sand particles 4. Individual irregularily - shaped transparent particles 5. Fibers, probably man-made	A. Heterogeneous Major: Si, Al plus random scattering of small Fe-rich particles (Rust).
No. 2 Dow Corning	1. Transparent spherical particles 2. Black, sand, rust and paint particles 3. Paint particle residues 4. Fibers, probably man-made	A. Heterogeneous Major: Si, Al B. Minor/Trace: Ca, Zn
No. 2 Gel Coat	1. Tan paint particles 2. Rust 3. Glass fibers 4. Fused metallic particles	A. Overall Major Ti B. Heterogeneous Major: Al, Si, Ca C. Minor/Trace: Cl, Zn, S D. Random scattering of small Fe-rich particles (Rust).
No. 3 Dow Corning	1. Transparent spherical particles 2. White irregularily - shaped clusters and individual particles 3. Tan, black and sand particles 4. Individual irregularily - shaped transparent particles 5. Fibers, probably man-made	A. Overall Major: Si B. Heterogeneous Major: Al C. Minor/Trace: Ca, Zn

TABLE I (CONTINUED)

Test Article	Particle Identification + X-Ray Diffraction + Microprobe (Elemental)	
No. 3 Gel Coat	1. Transparent spherical particles 2. White irregularily - shaped clusters and individual particles 3. Tan, black and sand particles 4. Individual irregularily - shaped transparent particles 5. Fibers, probably man-made. 6. Rust particles	A. Overall Major: Ti B. Heterogeneous Major/Minor: Si, Al C. Minor/Trace: Zn, Cl, Ca D. Random scattering of small Fe-rich particles
No. 6 Gel Coat Long Test Article	1. Bubble fragments of paint 2. Tan and black particles 3. Brown, orange and sand particles 4. Tan and white paint particles 5. Transparent spherical particles 6. Light blue particles	A. Heterogeneous Major: Ti, Fe, Al, Ca B. Minor/Trace: Si, Zn, Cl C. Trace: S
No. 6A Dow Corning	1. Sand, rust and black particles 2. Transparent and opaque spherical particles 3. Orange and green particles 4. Numerous finely divided particles 5. Short man-made fibers 6. White paint particles	A. Heterogeneous Major: Si, Ca Zn, Cl B. Minor/Trace: Fe, Al, K, S
No. 6B Gel Coat	1. Sand, rust and black particles 2. Transparent and opaque spherical particles 3. Orange and green particles 4. Numerous finely divided particles 5. Short man-made fibers 6. White paint particles 7. White paint particles similar to blister residue	A. Heterogeneous Major: Ti, Al, Ca, P B. Minor/Trace: Fe, Si, Zn C. Traces: Cl, S, K

TABLE I (CONTINUED)

Test Article	Particle Identification + X-Ray Diffraction + Microprobe (Elemental)		
Camera Lens Cover	Optical Microscopic Data N/A	Microprobe Data: Heterogeneous Major: Al Si, Ca Minor/Trace: Fe, Cl, S, Zn	X-Ray Data: Mixed aluminum oxides eta, alpha, epsilon and gamma phases

ATTACHMENT 5

PHOTOGRAPHS OF TESTS

Color

Photographs of Blast

Tests are Available

At DD-EDD For

Observation