

DESIGN AND DEVELOPMENT OF THE
SPACE SHUTTLE TAIL SERVICE MASTS

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ABSTRACT

The successful launch of a Space Shuttle vehicle depends on the proper operation of two tail service masts (TSMs). Reliable TSM operation is assured through a comprehensive design, development, and testing program. In a previous paper (ref. 1), the TSM concept verification test (CVT) was described. This paper presents the results of the CVT and the resulting impact on prototype TSM design. The design criteria are outlined, and the proposed prototype TSM tests are described.

INTRODUCTION

Major requirements of the TSM mechanism are to:

- o Provide physical support for the lines and cables connected to the Orbiter T-0 umbilicals.
- o Support Orbiter checkout and launch preparations in an environment of salt air, sand, wind, and rain as defined in reference 2.
- o Provide the capability for a test ("plugs out") umbilical disconnect and retract.
- o Allow the carrier and supporting lines to remain connected to the Orbiter during payload exchange, external tank (ET) pressurization and tanking, solar and wind deflections, and Space Shuttle main engine (SSME) ignition, thrust buildup vibration, and acoustics.
- o Rotate the 2250-pound carrier 11-15 degrees to detach it from the Orbiter and retract it (on command) into the TSM housing in approximately 1500 milliseconds.
- o Be ready to reconnect a new Orbiter within 100 hours after launch.
- o Provide the capability to pre-position the carrier with quick disconnects (Q/Ds) and lines installed, to support installation of the carrier on the Orbiter.

Two TSMs, identified as LOX TSM and LH₂ TSM, are located separately on two sides of the Orbiter. Figure 1 shows the concept of the TSM and its major components. Telescopic links are used to avoid excessive vibration traveling to and from the Orbiter. Power for disconnecting and retracting the umbilical carrier is supplied by a dropweight. Tension latches in the upper links and compression shock absorbers in the lower links effectively secure the carrier to the mast during the retract process. Belleville springs are used to minimize the instantaneous tensile force peaks in the upper links which also contain shock absorbers for compression.

TSM DEVELOPMENT PROGRAM

A comprehensive TSM design and development program (figure 2) is in progress at John F. Kennedy Space Center, Florida. The design is performed with the help of a kinematic study (a detailed stress analysis and an acoustic analysis of the blast structure) performed on the PDP-11 computer graphic system (a dynamic analysis program using the GE-635 computer).

Two test facilities (figure 3) are utilized in the TSM test program. The concept verification test facility (CVTF) consists of a liftoff simulator erected inside a building. The launch equipment test facility (LETF) includes a random motion simulator, cryogenic supplies, and a test control room (ref. 3).

CONCEPT VERIFICATION TESTING

The CVT provided early confidence in the feasibility of the TSM concept before a full scale prototype was fabricated. Only critical TSM concepts, those involving the disconnect process using lanyards and telescoping links, were tested. In effect, only the top portion of the mast was modeled. The dropweight power system, bonnet operation, blast structure, and retract phase of the TSM operation were not included in the CVT model. Figure 4 shows an overall view of the CVT rig. Further details of the rig and its design are included in reference 1.

CVT RESULTS

The concept verification testing included a number of component tests as well as seven dynamic system tests. A full account of these tests is available in the Test Report, TR-1443 (ref. 4). The following is a brief summary of the results.

The first dynamic test was conducted at about half the maximum anticipated operating speed (at 0.6 g nominal masthead acceleration) in order to avoid structural damage due to any unexpected problems.

The test was highly successful, and the disconnect operation took place without any problems. Therefore, the second test was performed at the maximum anticipated operating speed (1.2 g nominal masthead acceleration). The test indicated the feasibility of the TSM concept. However, two minor problems were discovered during the test which were resolved before the next test. Tests 3 to 7 obtained proper chronological sequence of operations and effects of various modifications. These tests were performed at the minimum anticipated nominal acceleration (0.8 g). It was determined during initial tests that the flexhose was not as stiff as anticipated, and the motion of the masthead was a result of the bottoming out of the lower links (which did not have shock absorbers). The link lengths, lanyard lengths, and initial masthead position had to be adjusted to achieve the desired sequence and to compensate for the flexhose effect. One disconnect (test 4) was conducted from a 2-inch higher initial position of the umbilical carrier. The link forces in this test were high due to the carrier descending through a larger distance under gravity. Disconnects from any higher carrier position were postponed until prototype testing due to the absence of shock absorbers in the links. The desired chronological sequence was obtained in test 7.

The force levels in the lanyards, links, and other components of the rig generally were as anticipated. Forces exerted on the liftoff simulator were acceptable. During independent side loading tests, the link-masthead assembly was found to be considerably stiffer than anticipated. This, however, was still within the expected side motion requirements of the TSM.

Useful data on the vacuum jacketed (VJ) flexhose were unavailable prior to CVT. Independent investigation of the hose characteristics and its effect on masthead dynamics were undertaken. A hysteresis type behavior of the hose and a significantly large dead band were observed. However, the TSM operation did not seem to be significantly affected by the VJ flexhose properties.

During deceleration of the masthead, both upper and lower links experienced compression which consequently raised the umbilical carrier. As anticipated, carrier rise was too low to cause any problems during the CVT. However, in the prototype, the masthead-carrier assembly traces an arc. Therefore, carrier inertia, together with some carrier rise, conceivably could have caused the carrier to overturn. This potentially hazardous situation was corrected in the prototype design by raising the upper link attachment point on the mast, thus making the upper link angle more acceptable.

PROTOTYPE TSM DESCRIPTION

The prototype TSM is a full-scale model of the production design with only minor differences. The basic components are briefly described in the following paragraphs (refer to figure 1).

T-0 Umbilical Carrier. The time-zero (T-0) umbilical carrier interfaces with the airborne Orbiter skin panel. It includes the fluid couplings and electrical connectors required to service the Orbiter vehicle at or near T-0 in the countdown. It also provides the capability for simultaneously disconnecting these couplings and connectors at liftoff.

Links. Two sets of telescopic links support the carrier to the mast. Each set consists of an upper and lower link. The prototype upper links contain two latches and Belleville springs for tension. All prototype links are equipped with compression shock absorbers to reduce impact forces at the end of the telescoping action. A new, improved design of links has been made for the production TSM. This new design contains ratchet type latches. Figure 5 shows the carrier and the prototype links as assembled to the mast.

Mast. The mast supports the flexhoses and lines going from the mobile launcher platform (MLP) to the umbilical carrier interface. During carrier retract, the mast rotates about a pivot located near the base of the TSM structure until the action is stopped by mast shock absorbers. Figure 6 shows the completely fabricated mast being transported to the CVTF for assembly and testing.

Bonnet. The bonnet, along with the blast structure, provides blast protection for the TSM assembly. It is held in the "up" position until the carrier is safely inside the blast structure. At this point, the bonnet is "kicked" down by the bonnet thruster to completely enclose the assembly.

Dropweight. The dropweight provides power for TSM retraction. When the separation bolt is pyrotechnically released, energy is transferred using a lanyard system from the dropweight through the carrier to the mast.

Separation Bolt. For prototype TSM testing, the separation bolt will be replaced with a pneumatically released separation nut designed to operate at 2000 psig of GN₂.

Lanyard System. This system consists of a pair of identical lanyard assemblies. Each assembly has two lanyards connecting the upper and lower sides of the carrier to a common lanyard tiepoint. The main lanyards run from this tiepoint over the mast sheaves to the dropweight through a mechanical advantage system.

Shock Absorbers. In addition to shock absorbers in the four links, one shock absorber is used to dissipate energy from the falling dropweight. Two shock absorbers are used for decelerating the rotating mast and two for the bonnet.

Blast Structure. The blast structure provides structural support and protection for the TSM subsystems. It is designed to withstand dynamic, blast, acoustic, and vibrational loads, and temperature gradients created by vehicle exhaust blast at liftoff. Figure

7 shows the blast structure after being completely fabricated.

OBJECTIVES OF PROTOTYPE TESTING

The main objective of prototype testing is to validate/verify that the test model will operate as intended under simulated launch conditions prior to fabrication of production units. If any anomalies or failures occur, necessary redesign and/or changes will be made to rectify the inadequacy. In addition to the above, the prototype testing will serve the following purposes:

- o A highly sophisticated computer model of the TSM has been developed (ref. 5). The system equations are obtained by Lagrange Formulation and are accurately solved by using a fourth order Runge-Kutta algorithm. By comparing prototype TSM results with the computer predictions, the model will be validated and improved if necessary. The model has previously been used in prototype design and will be used further for the production TSM.

- o The prototype tests will provide early familiarity of TSM to test crews and operations personnel. The tests will also help develop and refine operations concepts and criteria.

- o Tests will be conducted to verify hardware operation under nominal and off-nominal launch environments and umbilical release configurations.

- o The prototype tests will demonstrate reliability and maintainability of the TSMs.

PROTOTYPE TEST PHASES

Testing of the prototype TSM will be accomplished in three phases. These phases are described in the following paragraphs.

Phase I Testing. Phase I testing includes TSM system testing without using the upper housing (hood), bonnet, bonnet thruster, and bonnet decelerator. Testing will be accomplished in the CVTF. Dynamic tests will be performed with the liftoff simulator airborne skin panel at a fixed position at test initiation. No induced environmental dynamic simulations such as liftoff and random motion simulations will be applied.

Phase II Testing. Phase II testing includes testing of the complete TSM system which includes using the upper housing (hood), bonnet, bonnet thruster, and bonnet decelerator. Testing will be accomplished in the CVTF. Dynamic testing will be performed with the simulator panel at a fixed position at test initiation and also with liftoff simulation. No induced environmental dynamic simula-

tions will be applied other than liftoff simulation.

Phase III Testing. Phase III testing includes full dynamic testing of the TSM including liftoff and random motion simulations. Testing will be accomplished in the LETF. Induced environments such as cryogenic fluid flows, simulated blast temperatures and pressures, and acoustic effects will be excluded.

PROTOTYPE TEST REQUIREMENTS

General test and data requirements are published in the Test Plan (ref. 6). Detail test requirements and procedures are presented in the Test Requirements document (ref. 7).

Prior to dynamic testing, weights and inertial properties of major moving assemblies were measured. A test fixture was designed and fabricated to measure mass moments of inertia by the quadrifilar torsional pendulum method.

Sixty-three strain gages, 25 accelerometers, 6 linear potentiometers, 2 angular potentiometers, 4 microswitches, 4 load cells, 1 pressure transducer, and 1 event marker will record sufficient data to evaluate complete performance of the TSM. Nineteen critical dynamic measurements will be available for "quick look" within minutes after the test for test engineers to obtain adequate information to reconfigure the system for the next test. All recorded data will be computer-processed (digitized, filtered, integrated, and plotted) as required. A computer program for reducing and integrating accelerometer data on the Raytheon RDS 500 computer has been developed and tested. In addition, three cameras will take motion pictures of the TSM from different angles during each dynamic test. Still photographs will record pre- and post-test static observations.

Phase I tests consist of three parts. Part 1 includes component and subsystem tests such as lanyard spring rate test, mast and dropweight shock absorber tests, link shock absorber tests, mast torsion, carrier to blast structure clearance test, and various adjustments. Part 2 includes seven dynamic tests at the minimum nominal operating speed. The tests cover disconnects from various initial carrier heights. Four additional tests at maximum nominal operating speeds are proposed under Part 3 testing.

Phase II testing also consists of two parts. Part 1 consists of bonnet and bonnet system tests, and Part 2 includes six complete system tests.

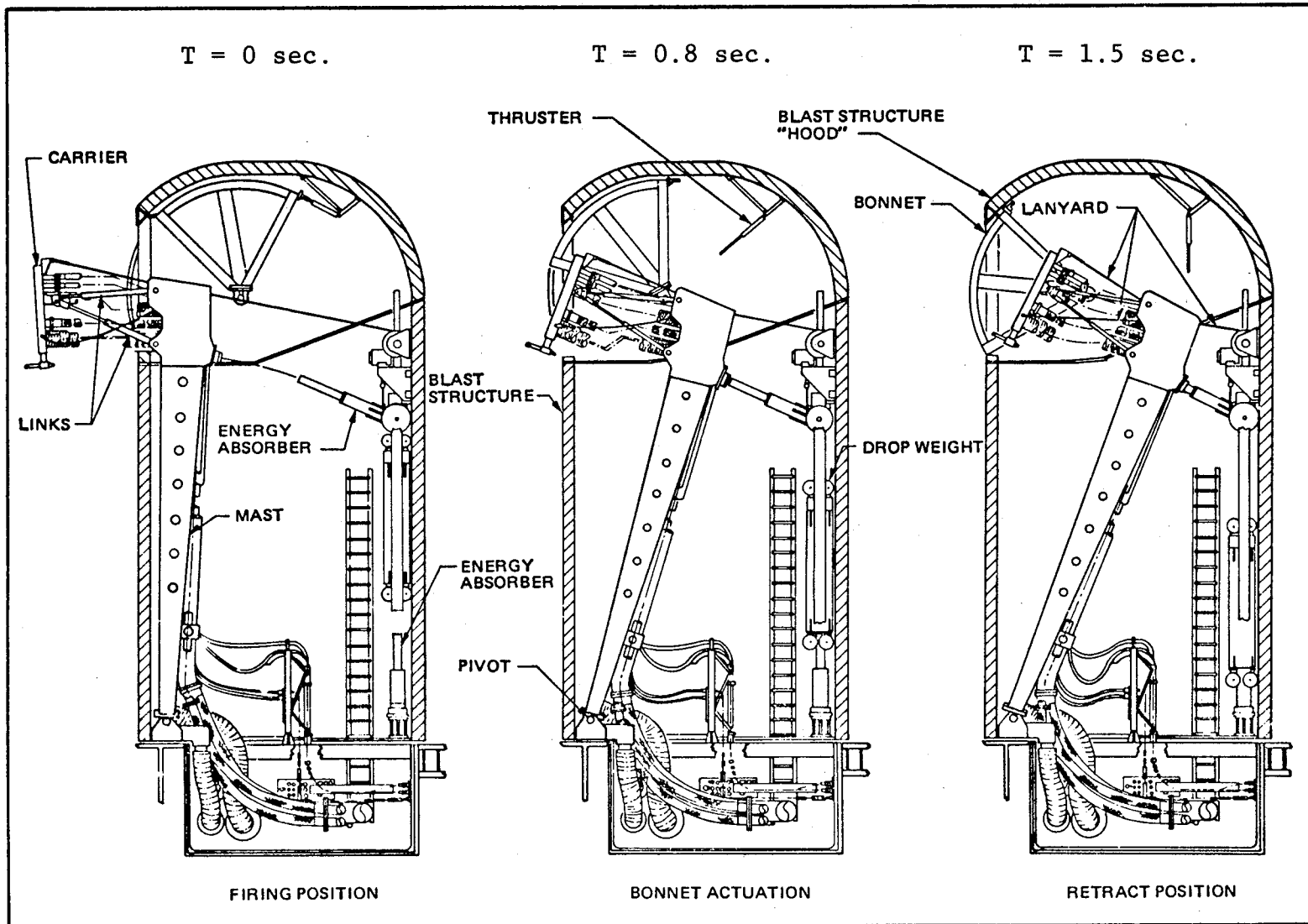
Requirements for Phase III testing have not been determined as of November 1976.

CONCLUSION

The concept of disconnecting and retracting the umbilical carrier by using lanyards, telescoping links, and a rotating mast is feasible. Forces in various components of the TSM as well as forces on the Orbiter can be controlled within reasonable limits.

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Figure 1. Conceptual Operation of the TSM

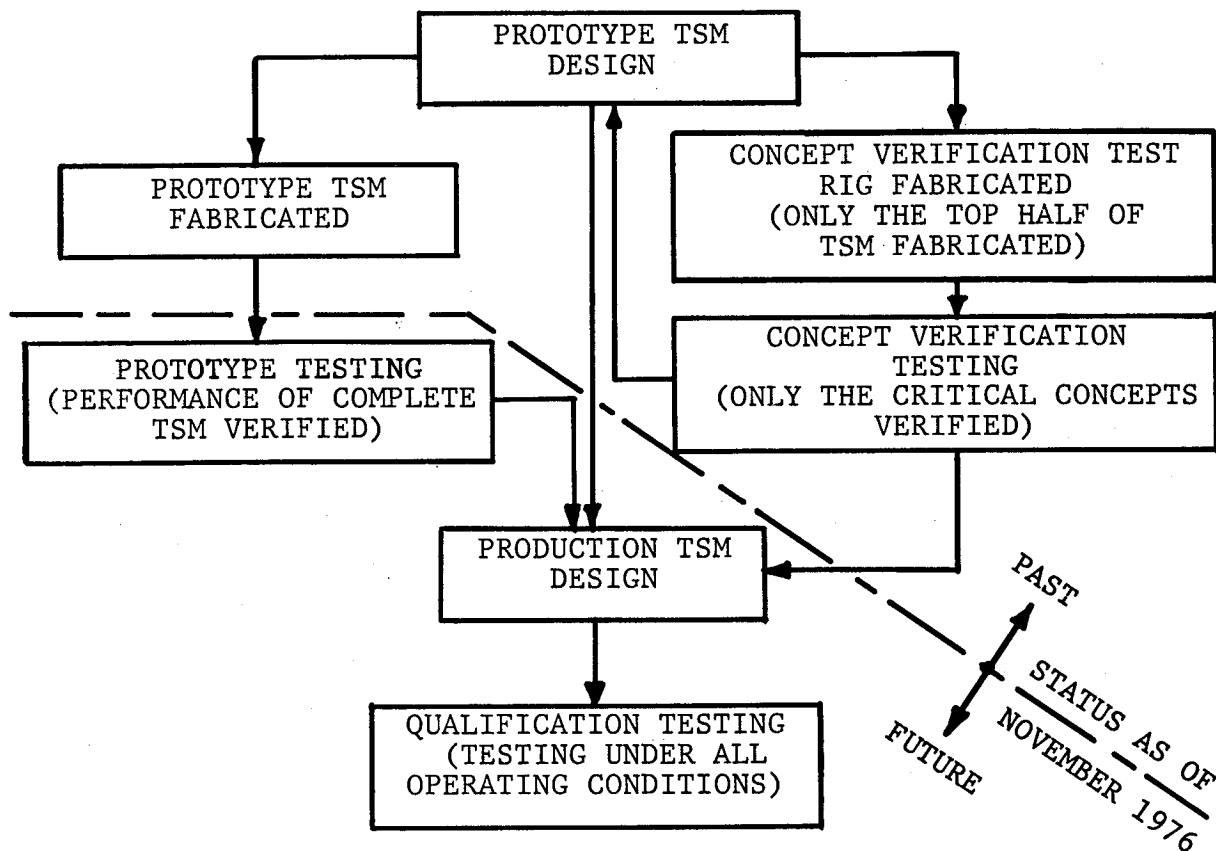


Figure 2. TSM Design and Development Program

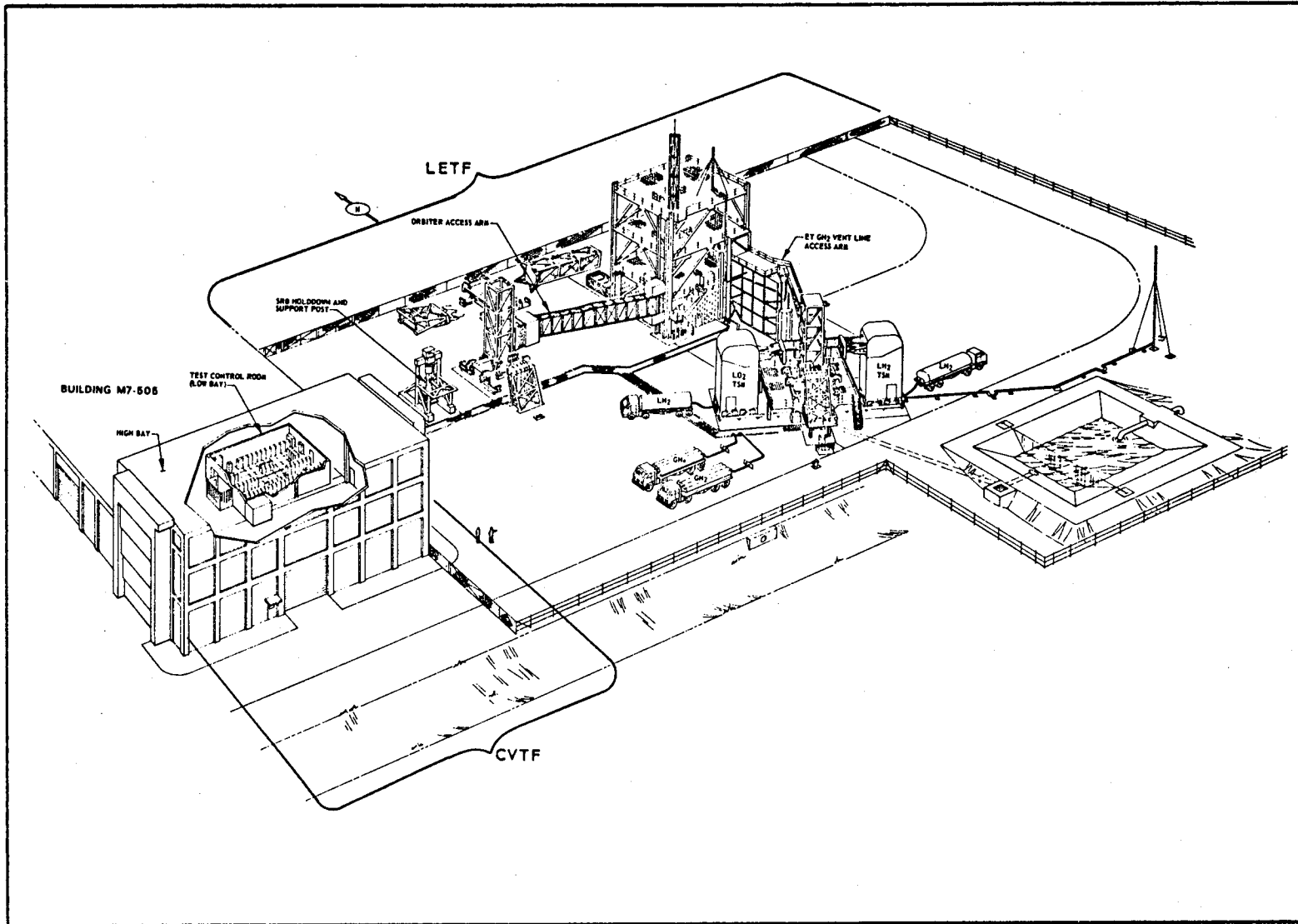


Figure 3. CVTF and LETF Isometric Diagram

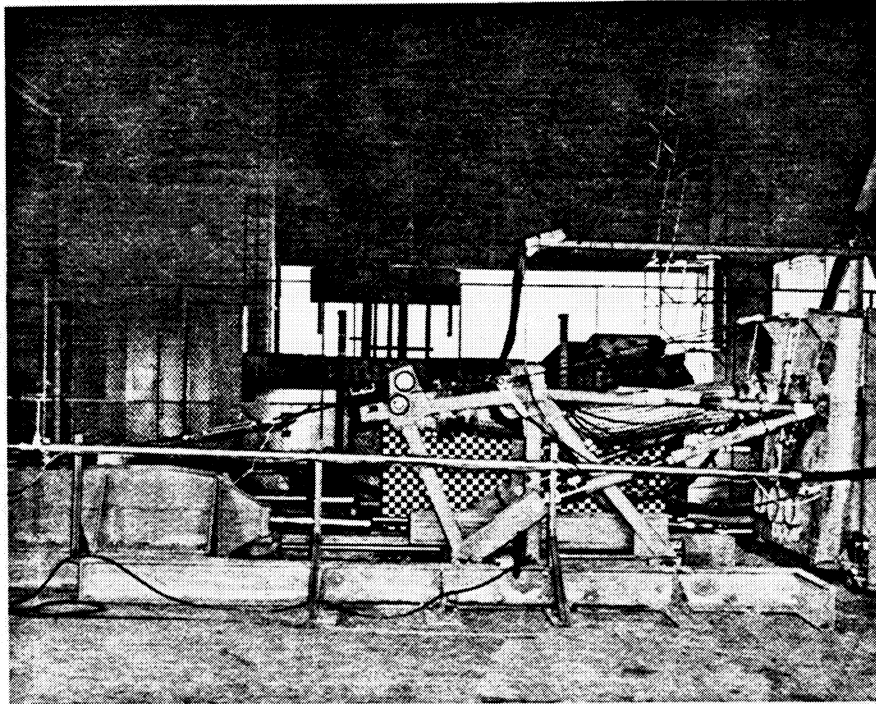


Figure 4. Overall View of the CVT Rig

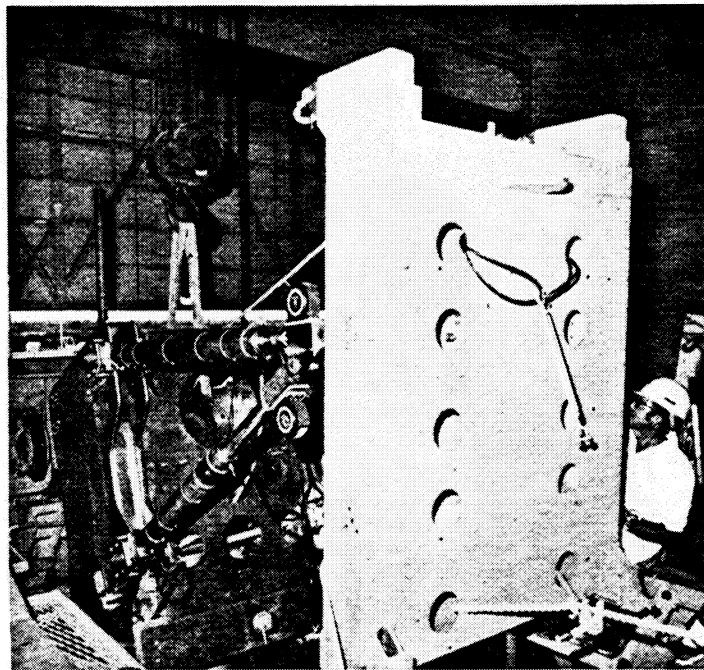


Figure 5. Umbilical Carrier and Links, TSM Prototype

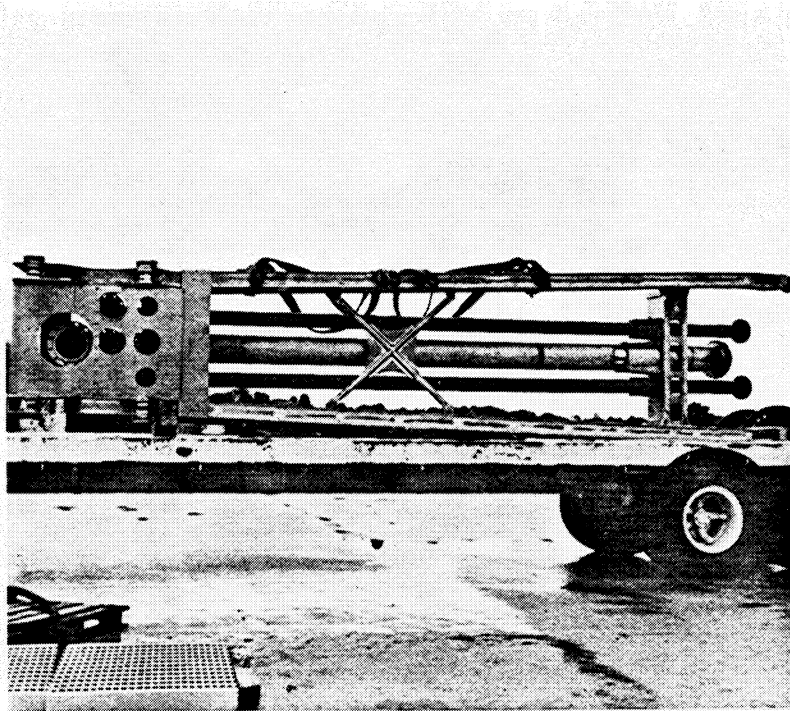


Figure 6. Completely Fabricated Prototype Mast

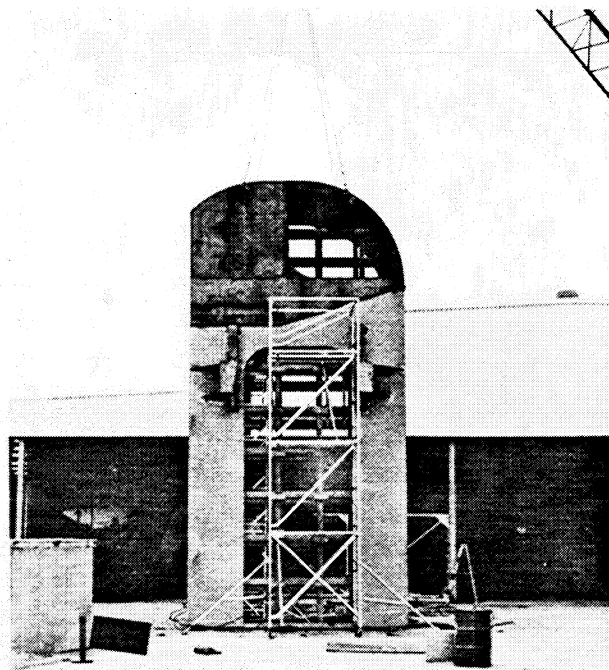


Figure 7. Completely Fabricated Blast Structure, TSM Prototype