SIMULATION TESTING OF LAUNCH CRITICAL SHUTTLE GROUND SUPPORT EQUIPMENT AT THE LAUNCH EQUIPMENT TEST FACILITY, KENNEDY SPACE CENTER

R.T. UDA, S.R. DANDAGE, and D.C. MacDONALD
Planning Research Corporation

ABSTRACT

The National Aeronautics and Space Administration (NASA) is currently developing an economical space transportation system known as the Space Shuttle. Various ground support equipment (GSE) has to perform critical functions to assure a successful launch of the Shuttle vehicle. In order to test this equipment under simulated launch conditions, NASA is activating a Launch Equipment Test Facility (LETF). This facility will simulate effects such as vehicle deflections and oscillations at the pad, rain, cryogenic shrinkage, vehicle lift-off, and solar heating. A physical description of the LETF and its cost-effective utilization is provided in this paper. Test articles, test categories, and test descriptions are detailed. Particular emphasis is placed on simulation equipment and conditions.

INTRODUCTION

Following the successful completion of the Apollo Program, construction efforts on the Space Shuttle launch and landing project started in 1974. The intended purpose of the Space Shuttle Program is to provide an economical space transportation system to carry men, equipment, laboratories, satellites, and propulsion stages to and from Earth orbit. This program is expected to reduce the cost of space transportation to a fraction of the cost of present expendable booster vehicles. Figure 1 shows the Shuttle processing-launch-landing cycle.

Launching a Space Shuttle Vehicle (SSV) involves synchronized operation of launch critical GSE and highly trained launch personnel. The Space Shuttle Program requires testing of launch critical GSE under every possible condition. To provide a testing environment for the equipment, NASA has designed and developed the LETF at John F. Kennedy Space Center (KSC), Florida, which will be used to test GSE under various simulated launch conditions.

The ability of the GSE to react properly under various conditions must be verified prior to committing the equipment to a manned launch. The LETF will be used to test GSE which could cause failure to the vehicle if it did not function properly. Various launch vehicle conditions such as vehicle deflections and oscillations at the pad, rain, solar heating, cryogenic shrinkage, and vehicle lift-off will be simulated by the facility.

FACILITY OBJECTIVES

The primary objective of the LETF is to provide a capability for qualifying and certifying operability, reliability, and maintainability of launch critical GSE prior to installation at the launch complex or between launches when recertification is required. A secondary objective is to provide a capability for development testing of conceptual GSE designs.

JUSTIFICATION

Previous investigations indicated the SSV schedule could be affected by needlessly shipping the GSE back and forth to George C. Marshall Space Flight Center (MSFC) at Huntsville, Alabama, for testing. Using the salvaged Saturn V test equipment from MSFC and erecting this same equipment, modified to Shuttle requirements, at KSC was determined to be advantageous to the Space Shuttle Program in terms of time, cost, and proximity to the launch complex. Hence, it was decided to design and develop the LETF to support tests on access arms, umbilicals, and associated GSE at KSC.

CRITICAL GSE TEST ARTICLES

The LETF will provide the capability for testing, qualifying, and certifying the operation and reliability of the Orbiter access arm (OAA), tail service masts (TSMs), external tank (ET) gaseous hydrogen (GH_2) vent umbilical and access arm, and solid rocket booster (SRB) support/holddown posts. Such equipment is considered launch critical because their malfunction can cause damage to the SSV as well as a mission failure.

OAA. The Shuttle OAA is a modified Apollo swing arm #9. It provides access and egress between the Space Shuttle access tower and the Orbiter vehicle. An environmental chamber is located at the end which interfaces with the Orbiter.

TSMs. The TSMs provide the capability for loading/offloading liquid oxygen (LOX) and liquid hydrogen (LH_2) into the SSV. During lift-off, the TSMs disconnect and retract the T-0 umbilicals from the aft end of the Orbiter and store/protect them within the TSM blast housings from the high temperature exhaust plume and blast loads of the SSV.

ET GH_2 Vent Umbilical and Access Arm. This system allows venting of GH_2 from the ET and achieves umbilical disconnect, withdrawal, and line management as the SSV ET ascends at launch.

SRB Support/Holddown Posts. Eight support/holddown posts will be used for supporting, restraining, and releasing the SSV SRBs during launch. These posts also provide jacking and leveling capability for stacking the SRBs.

TEST CATEGORIES

At KSC, three test categories have been established to separate the testing of Space Shuttle launch critical GSE.

Concept Verification Tests. Concept verification tests consist of a series of tests performed to verify basic theoretical or experimental design principles and concepts. The tests are designed to evaluate the design concepts of critical parts under simulated conditions of operation; confirm adequacy of selection of components and parts; and determine capabilities of equipment under test. Concept verification tests have already been accomplished and successfully completed on TSM and ET GH_2 vent umbilical test articles.

Prototype Tests. Prototype tests consist of a series of tests performed on certain test articles to demonstrate physically its dynamic function, suitability, and reliability. Data is developed from these tests which provide the means to estimate the confidence level of the system to perform its intended function. If acceptable, these prototype test articles may become flight items. A prototype model of the TSM has been designed, fabricated, and assembled and will be tested in the fall of 1976.

Qualification Tests. Qualification tests consist of a series of tests performed on actual flight configured hardware to demonstrate that the design criteria have been satisfied and that the items, as produced, will perform the required functions reliably in accordance with the test criteria.

IMPLEMENTATION PHASES

The LETF project is being accomplished under three phases (Ref. 1).

Phase I Implementation. Phase I implementation includes planning, development, facility design, construction, installation of basic facility equipment, and checkout (Figure 2).

Phase II Implementation. Phase II implementation (Figure 3) is being accomplished under a combined phase IIA and IIB effort. Phase IIA implementation entails planning, development, support systems design, construction, installation of simulation systems and other GSE, and checkout. Phase IIB implementation is a parallel effort to phase IIA which includes refurbishing and modifying the OAA random motion simulator (RMS), TSM and ET GH_2 vent line RMS and lift-off simulator (LOS), and SRB support/holddown posttest fixture. Upon conducting a successful checkout of the test facility under phase II, the LETF will be ready for launch critical GSE testing.

Phase III (Operational). Phase III (Figure 4) includes installation, checkout, and test of the four launch critical GSE test articles, i.e., OAA, TSMs, ET GH_2 vent umbilical and access arm, and SRB support/holddown posts. These test articles are presently being designed, fabricated, and assembled at KSC.

LETF DESCRIPTION

Significant items that comprise the LETF are briefly discussed in the following paragraphs (Ref. 2). Refer to Figures 2 and 3 for relative locations in the LETF of each of the items discussed.

SRB Support/Holddown Posttest Fixture Pad. This pad will support the SRB support/holddown posttest fixture.

OAA RMS Pad. This pad will accommodate

the test equipment which consists of an RMS and an Orbiter skin section. The OAA test will be performed on this pad.

TSM and ET GH_2 Vent Line and Access Arm RMS Pad. This pad will be used for the TSM test and the ET GH_2 vent umbilical and access arm test. A platform is provided to support the simulator for simultaneously testing the umbilical and access arm and the TSM. Figure 5 shows the platform on the pad. The tower simulator is shown in the background.

Tower Simulator. The tower simulator (a three-level section of existing launch umbilical tower #3 approximately 60 ft in height) is supported on four footings. The area immediately under the tower houses the hydraulic pumps for the RMSs and other related GSE. Figure 6 shows the tower simulator, hydraulic pump house, and transformers.

General Pads. Eighteen small general purpose pads measuring approximately 2 ft by 2 ft have been placed as required for electrical cabling, hydraulic, and pneumatic line support.

Pump House. The pump house (Figure 6), located at the base of the tower simulator, includes four 100-gpm motors/pumps, hydraulic oil reservoir, hydraulic charging unit, an exhaust fan, and other ancillary equipment.

LH_2 System. Liquid H_2, supplied from LH_2 tankers, will be used to chill down to cryogenic temperatures the TSM LH_2 umbilical and lines. Hydrogen gas will be vented through the GH_2 vent umbilical and also to the atmosphere. All LH_2 lines are vacuum jacketed.

LN_2 System. Liquid N_2, supplied from LN_2 tankers, will be used to simulate LOX flowing through the LOX umbilical for pressurization.

GN_2 System. Gaseous N_2, supplied from 10,000 psi GN_2 tube trailers, will be used for purging umbilicals, operational intercommunication system communication boxes, ac power distributors, and as a media for system pressurization.

GHe System. Gaseous He, supplied from GHe tube trailers, will be used for purging GH_2 vent umbilical and LH_2 TSM umbilical.

AC Power Distribution System. This system is supplied by a 13.2 kV/480 V - 750 kVA transformer and primary switch. Secondary voltages of 480 V and 277/115 V will be distributed to the pump house, service tower, and test simulators to satisfy ac power and lighting requirements within the test area. AC power is provided to the test control room from existing power panels in Building M7-505.

Control and Monitor System. The control and monitor system is capable of remote control from the test control room (Figure 7) during the ET GH_2 vent umbilical and TSM tests (H_2 flowing). Local control will be provided at the simulator areas (H_2 not flowing).

Cabling. Cabling is routed in trenches covered with steel grating (Figure 8) from the pump house to the control room and simulators. All ac power cabling within the trenches is sealed in high voltage conduit.

Instrumentation. Approximately 350 measurements will be needed to acquire data for functional, qualification, and final verification of GSE/flight hardware interfaces during simulated tests. Instrumentation test equipment will include recorders, transducers, strain gages, load cells, optical instrumentation, flow meters, and other necessary sensors to fulfill all specified conditions of usage. Readings will be analog, digital, and/or actual gage readouts. These outputs will be recorded for complete evaluation of all tests required to support this phase of the Shuttle Program.

Operational Intercommunication System. An operational intercommunication system will be provided at the LETF. The system will be connected into the main system already installed in the Operations and Checkout Building and to the test stands.

TEST SIMULATORS AND FIXTURES

The simulation test equipment was previously located at MSFC, where it was used in the Apollo Program for GSE testing. The equipment was brought by barge in March 1975 to KSC, where the simulators were cost-effectively refurbished and modified for the Space Shuttle configuration.

From calculations based on previous launch experience, the motion of the Orbiter before launch due to various effects such as wind deflections, solar heating, cryogenics, and engine serious hardware damage.

Upon successful completion of manual testing, the ability of the umbilical carrier to track the simulated Orbiter vehicle motions will be verified. This series of tests will be conducted with the umbilical carrier mated to the Orbiter vehicle RMS. All relative motions between the Orbiter vehicle and the TSMs will be simulated, including the full range of Orbiter vehicle oscillation frequencies and simulated "vehicle fueled" and "vehicle unfueled" conditions. The TSM system will be monitored throughout these tests for binding, chafing, and loosening of components.

The next series of tests will verify proper operation of the TSM system during lift-off simulation. The TSM system will be placed in actual launch configuration and operated automatically during each test cycle. Early tests in this series (with no vehicle random motion) will be conducted with the Orbiter vehicle LOS placed in a nominal, "vehicle fueled" position relative to the TSM. Maximum and minimum vehicle lift-off accelerations will be simulated. Tests will be conducted with the Orbiter vehicle LOS placed in anticipated "extreme" positions with respect to the TSM. Following these tests, random motion of the Orbiter vehicle simulator, at both "nominal" and "extreme" positions, will be introduced with lift-off occurring in conjunction with random motion. As this phase of testing progresses, cryogenic lines will be chilled (using LH_2 and LN_2) prior to lift-off simulation. This series of tests will be completed using chilled lines and simulated rain conditions.

The final series of tests will be similar to those described in the previous paragraph but with the added condition of simulated system failures. Selected portions of the umbilicals and mast disconnect/retract systems will be disabled prior to vehicle lift-off simulation.

ET GH_2 Vent Umbilical and Access Arm Test. Testing of the ET GH_2 vent umbilical and access arm system will commence with proof load tests of the arm structure and measurement of arm deflections. Concurrent with these tests, loads imposed on the fixed-arm platform and tower simulator structure will be determined.

Manual operation of the arm will be performed to verify interfaces and mechanical integrity of the arm components. A series of tests consisting of alignment and adjustment of arm components and arm positioning stops will be performed. Extension and retraction of the arm to verify clearances and interfaces, freedom from binding, as well as locking and latchback verification will be accomplished. The ET skin panel with its umbilical on the LOS structure coupled with the umbilical system (ground side) attached to arm cradles will be cycled throughout its expected motion envelope and monitored for satisfactory operation. Umbilical system operation (under required motion, including launch abort) with all systems functioning, including GH_2 chilldown and simulated rain, will be conducted to verify satisfactory operation. Dynamic operation of the system normal disconnect and disconnect in the back-up mode will be accomplished in the same manner as previously described.

SRB Support/Holddown Posttest. These tests will be conducted to verify the capability of the SRB support/holddown posts to support, restrain, and release safely and reliably the SSV during prelaunch and launch operations.

The SRB support/holddown posttests will be basically structural in nature. Testing under down-loading, up-loading, side-loading, and combined-loading will be accomplished. Stress readings and post-deflections will be monitored and recorded. Torque and preload tests of nut and bolt will be accomplished to determine optimization.

Explosive release synchronization tests will be conducted to verify firing of release nuts within the prescribed time prior to simulated SRB ignition and release command. Timing of release will be verified. Certain component failures will be simulated to test the reliability of the system.

CONCLUSIONS

The Launch Equipment Test Facility at KSC provides a cost-effective means for qualification testing of launch critical GSE for the Space Shuttle Program. Use of refurbished and modified simulation test equipment from the Apollo Program has provided considerable cost savings.

System countdown and test procedures will be prepared for LETF testing scheduled to commence in the Spring of ignition will have been predicted. The TSMs, OAA, and ET vent line will be tested in the LETF to ascertain the capability of these equipments to survive such motion. The simulators used for this function consist mainly of two basic functions, i.e., random motion simulation and lift-off simulation. Random motion simulation is required for testing the TSM, OAA, and ET vent line. Testing the SRB support/holddown posts will be accomplished using a special test fixture designed for that purpose.

Random Motion and Lift-off Simulators. A typical RMS and LOS (Figure 9) consist of a servo-controlled hydraulic/pneumatic resonant drive system, lubrication and cooling systems, and a control system. Random motion in two orthogonal directions in the horizontal plane is simulated by two carriages capable of generating Lissajous figures ranging from a straight line to a circle. Vertical motion is simulated by the LOS. Friction is minimized by using a rail and roller design.

The LOS consists of a tower structure in which two elevator panels ride vertically up and down to simulate the lift-off conditions. Each panel can be controlled independently with its hydraulic drive system. The panels are used for the two TSMs. The OAA flight skin panel is rigidly mounted on the modified tower structure which is attached to the RMS. It has no vertical motion capabilities.

SRB Support/Holddown Posttest Fixture. This is a structural fixture which simulates SRB loads. It uses two hydraulic cylinders to apply test loads to the SRB support/holddown post in two orthogonal directions. These cylinders will be used separately and in combination to test the loading capacity of the holddown post.

TEST CONDITIONS

As required by the Shuttle Master Verification Plan (Ref. 3), testing will be performed under conditions simulating vehicle motion before launch, fueling and purging, system power-up/power-down, emergency, hold, and other situations.

Launch environment is affected considerably by rain, solar heating, cryogenic effects, Orbiter deflections and oscillations, and vehicle lift-off. Satisfactory operation of the launch critical GSE has to be insured under such a wide range of conditions. The LETF will simulate these effects and will be used to investigate the response of GSE under these simulated launch conditions.

DESCRIPTION OF TESTS

OAA Test. Testing the OAA system will commence with proof load tests of the arm structure and measurement of arm deflections. Concurrent with these tests, loads imposed on the tower simulator structure will be determined.

A series of tests consisting of alignment and adjustment of the OAA components will follow the load tests. The interface between the environmental chamber on the arm and the Orbiter skin panel attached to the RMS will be checked, and the arm positioning stops will be adjusted accordingly. The operation and adjustment of the latchback mechanism equipment on the OAA and tower simulator will be verified. Furthermore, all components will be checked for free movement and interference during arm rotation.

The OAA will be extended toward the Orbiter skin panel which is attached to the RMS, and the loads imposed on the Orbiter will be determined. The seal between the environmental chamber and the Orbiter skin panel will be monitored for satisfactory operation.

The operation of the OAA rotation system will be verified in a series of manually and automatically controlled tests. Moving the OAA to the extend and retract positions will be tested with the Orbiter skin panel in various positions. Certain component failures will be simulated to test the reliability of backup systems.

Testing will include verification of the systems serving the environmental chamber, i.e., environmental controls and electrical/communications equipment. In addition, rain conditions will be simulated with and without vehicle motion simulation.

TSM Test. Testing of the TSM system will commence with manually controlled operation of the umbilical disconnect and retract mechanisms. Proper operation of the retract mechanism will be verified. These tests will validate the operation of the various mechanisms. Since they are conducted manually, tests can be quickly terminated in event of malfunction to preclude

1977. These procedures will be used by technicians and launch operations personnel to perform the qualification tests. Testing and subsequent required changes/modifications will "debug" the systems and qualify them for manned launches of the SSV. The training and experience acquired by technicians and launch personnel on the LETF operation will qualify them for launch complex operations during an actual manned launch.

REFERENCES

1. KSC Launch Equipment Test Facility Design Engineering Implementation Plan, GP-1051, John F. Kennedy Space Center, KSC, Florida, October 17, 1975.

2. Launch Equipment Test Facility - *Space Shuttle - Preliminary Engineering Report*, TR-1301, Revised, John F. Kennedy Space Center, KSC, Florida, January 24, 1975.

3. Shuttle Master Verification Plan, JSC-07700-10-MVP-01, Lyndon B. Johnson Space Center, Houston, Texas, May 15, 1973.

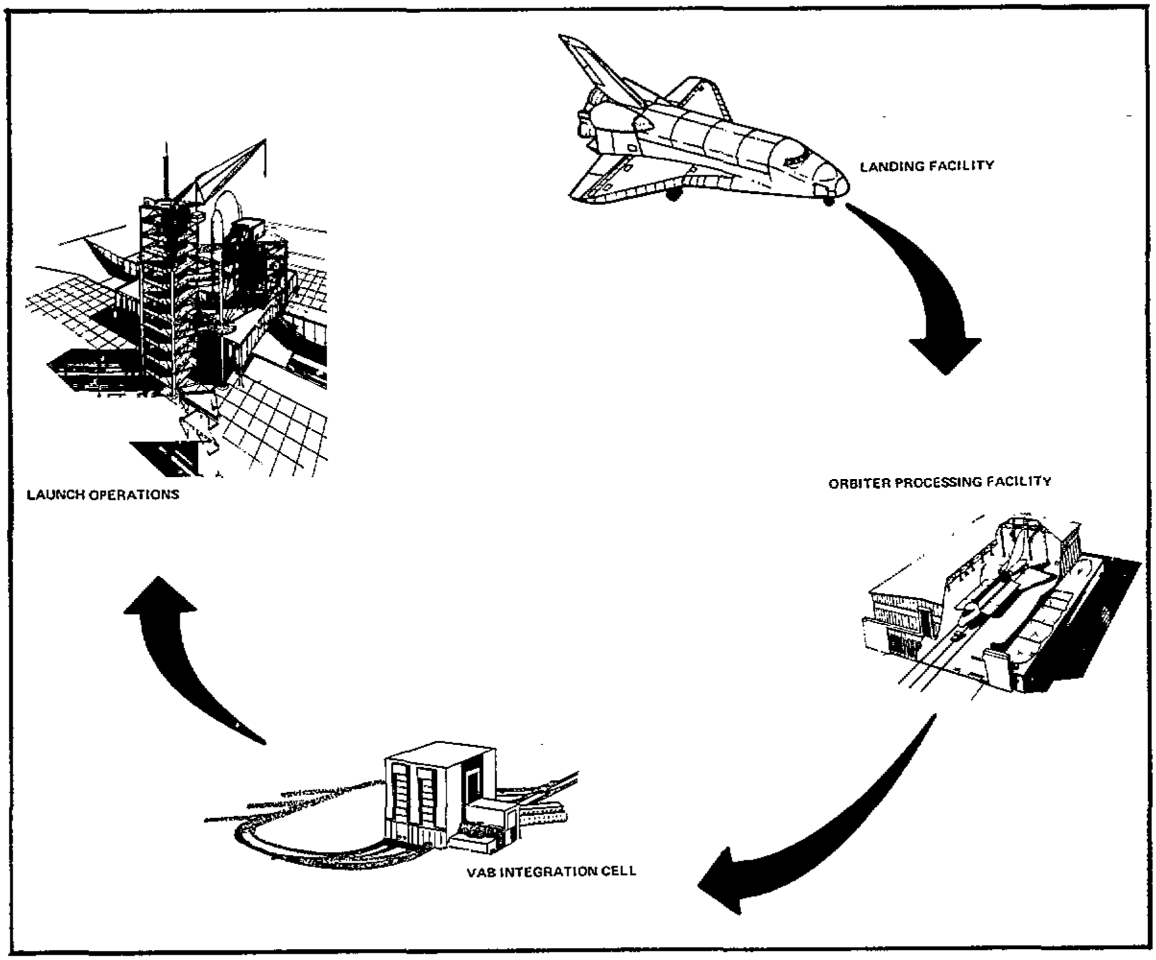

Figure 1. Shuttle Processing-Launch-Landing Cycle

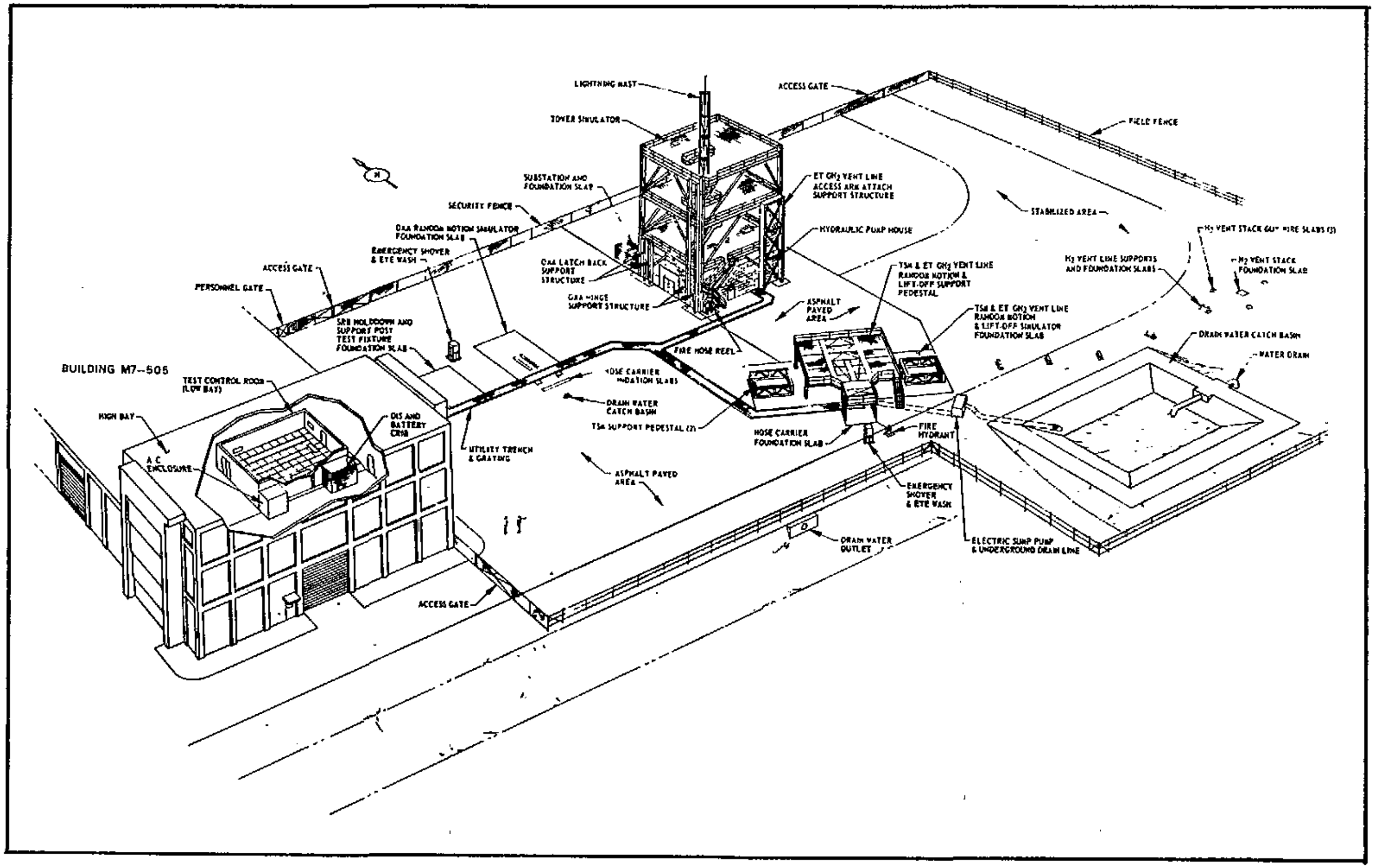

Figure 2. Shuttle Launch Equipment Test Facility at KSC - Phase I

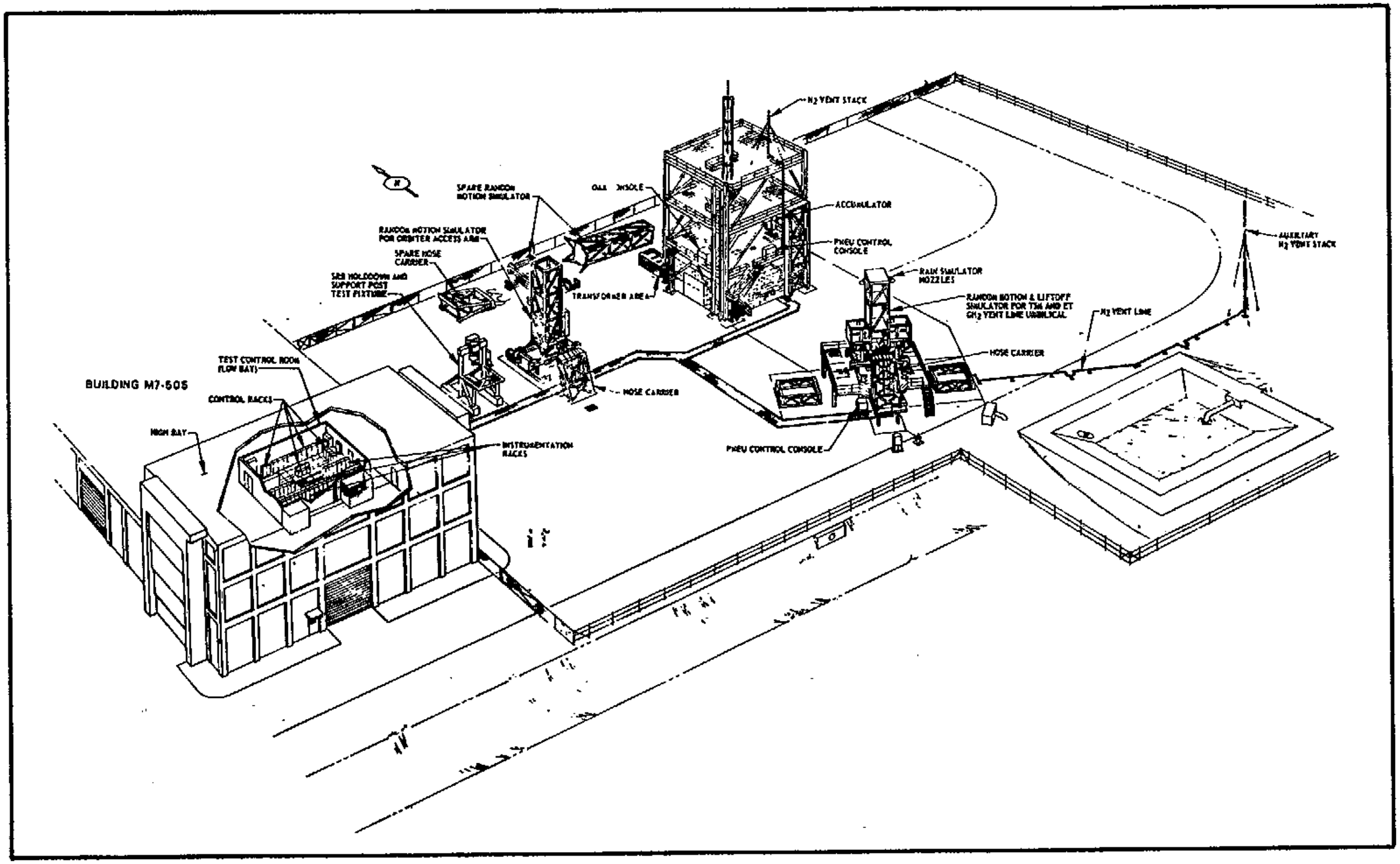

Figure 3. Shuttle Launch Equipment Test Facility at KSC - Phase II

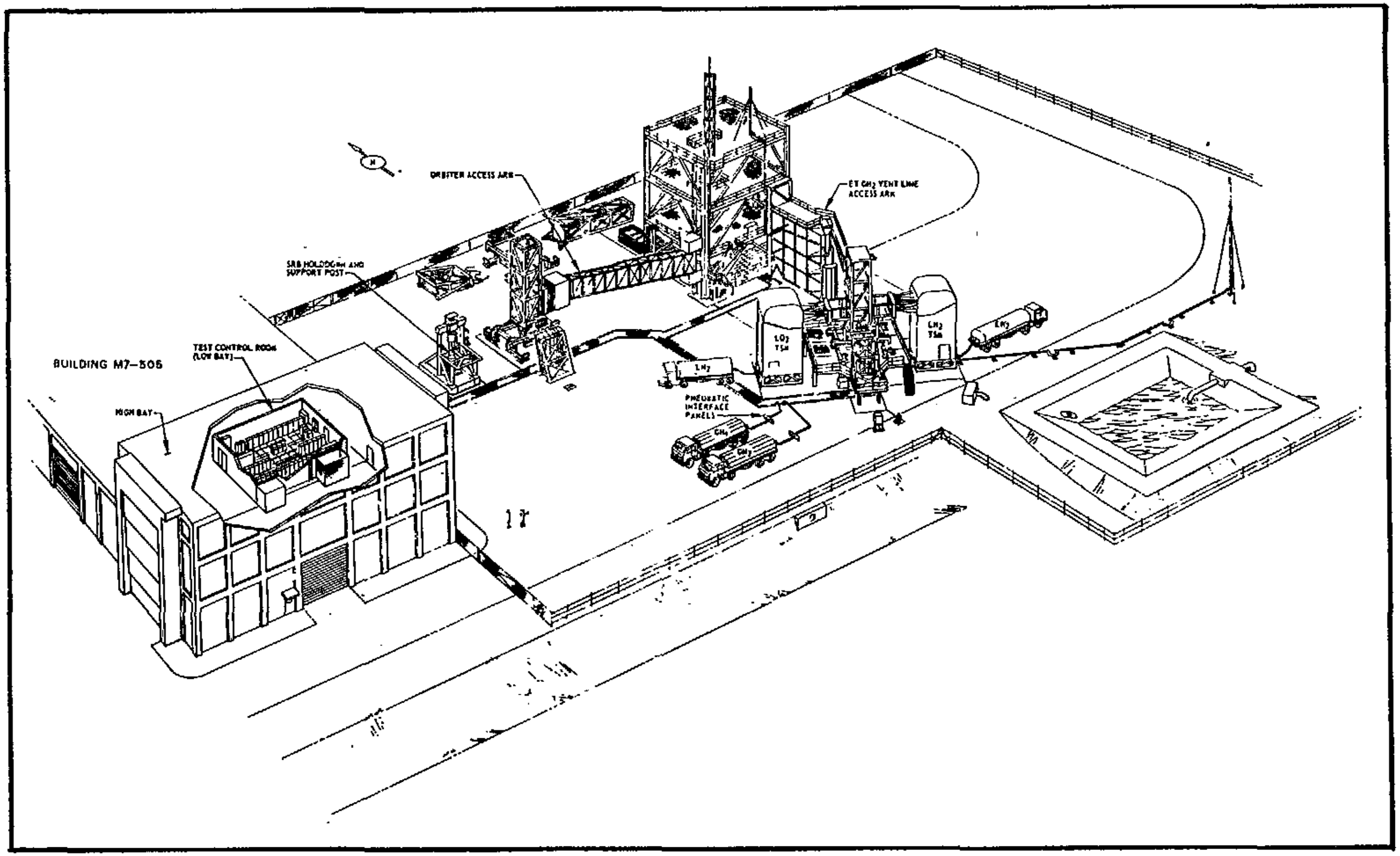

Figure 4. Shuttle Launch Equipment Test Facility at KSC - Phase III (Operational)

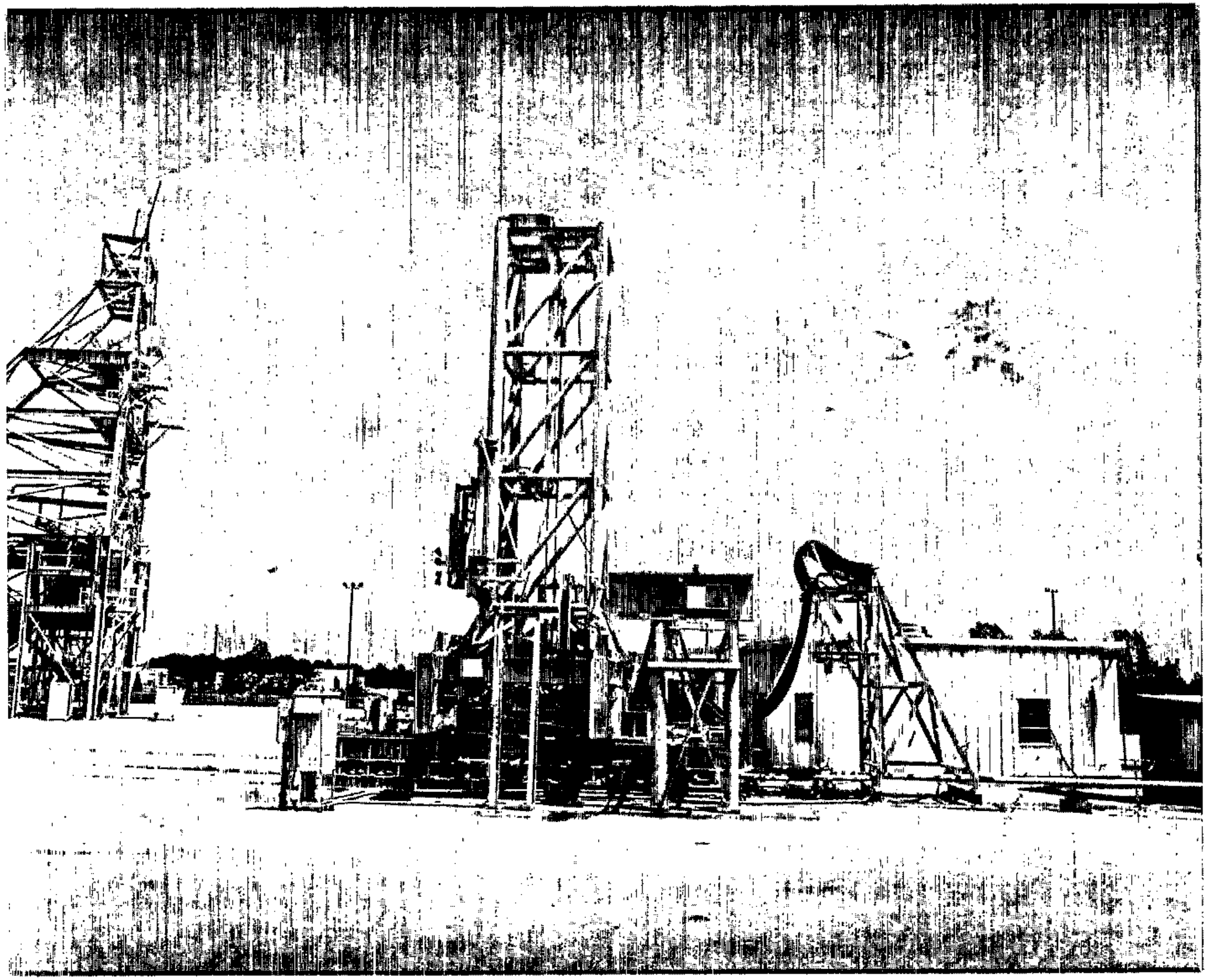

Figure 5. TSM and ET GH_2 Vent Line Access Arm - RMS Pad with Pedestals (TSM and RMS) and Tower Simulator in Background

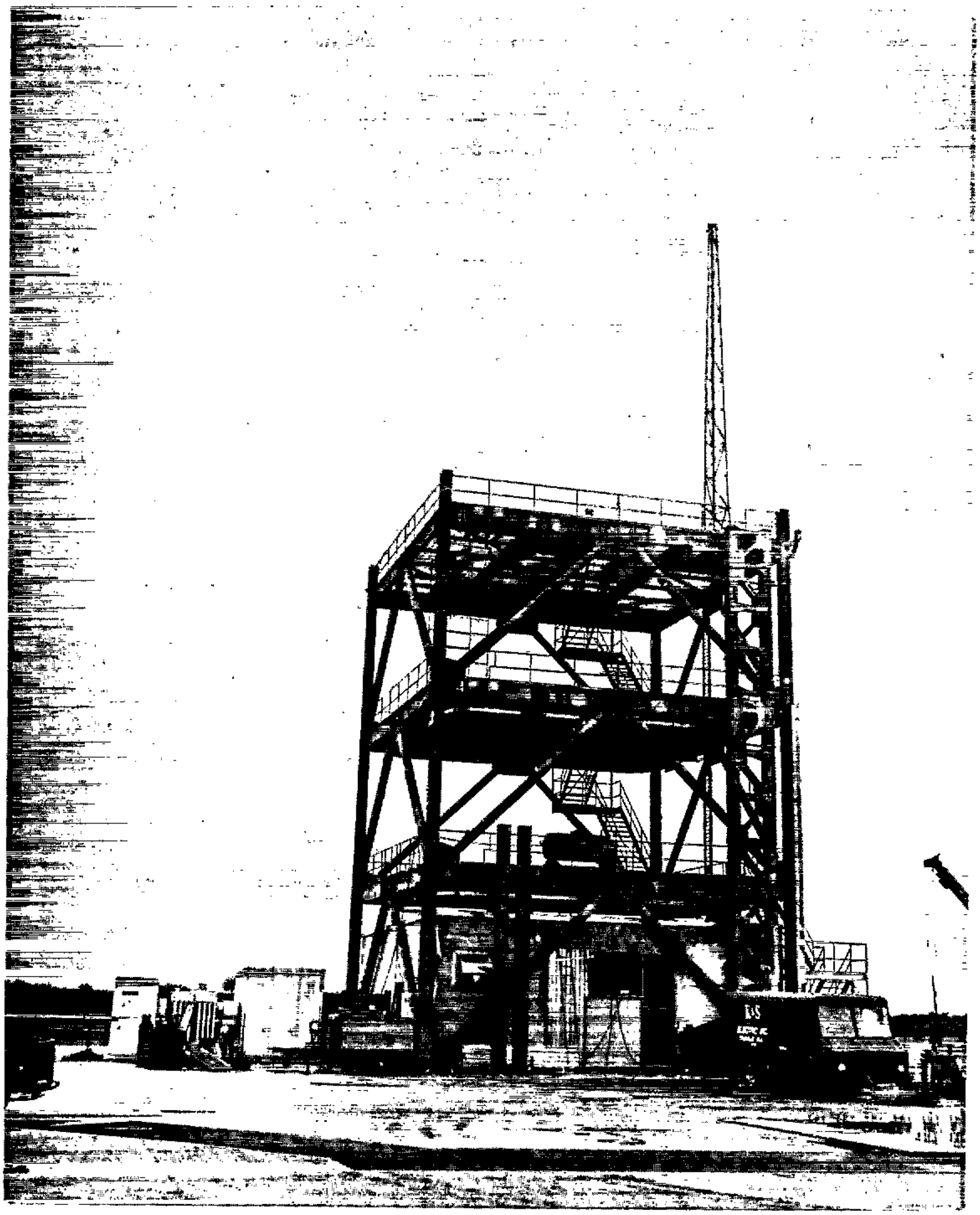
Figure 6. Tower Simulator, Hydraulic Pump House, and Transformers

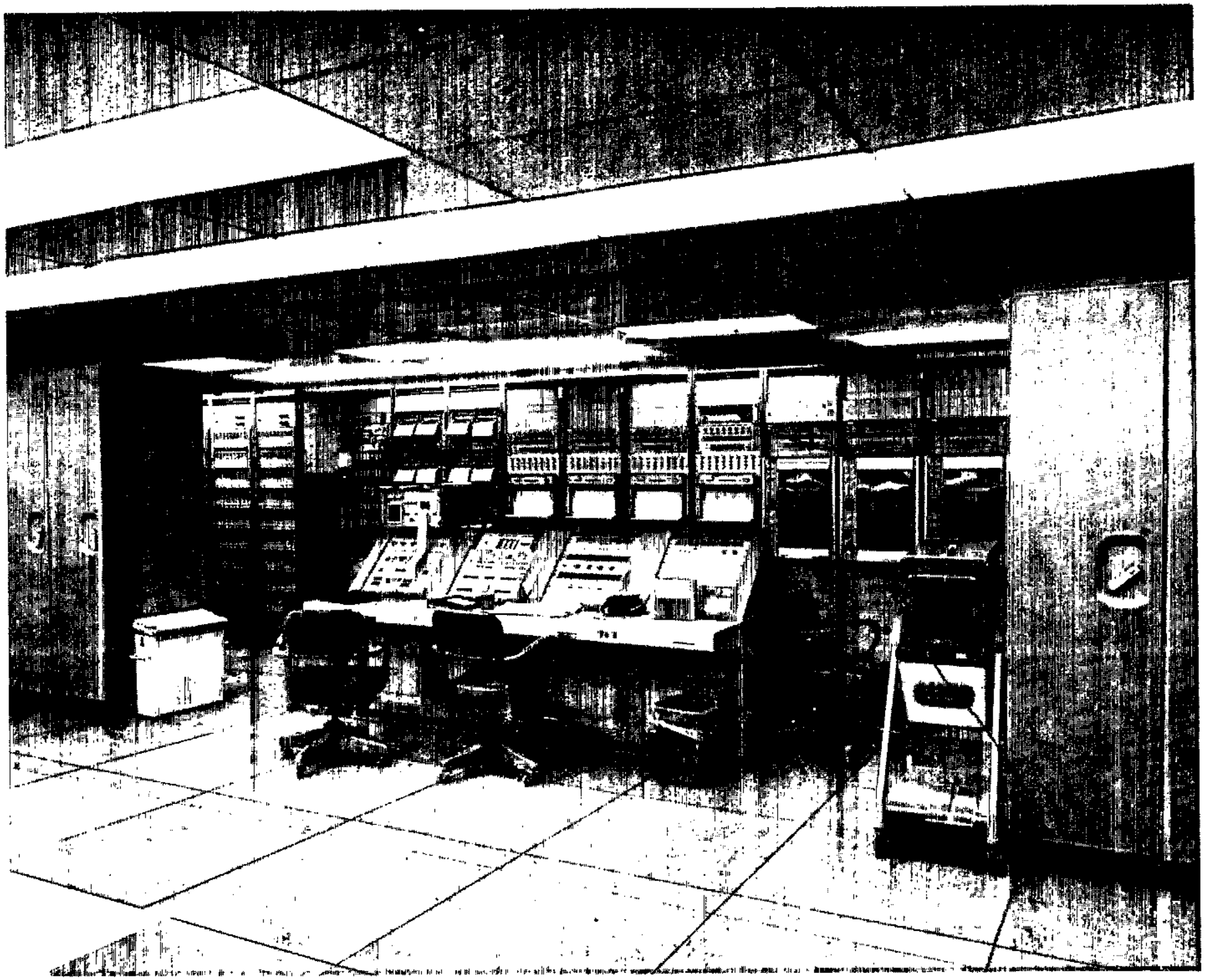

Figure 7. Test Control Room

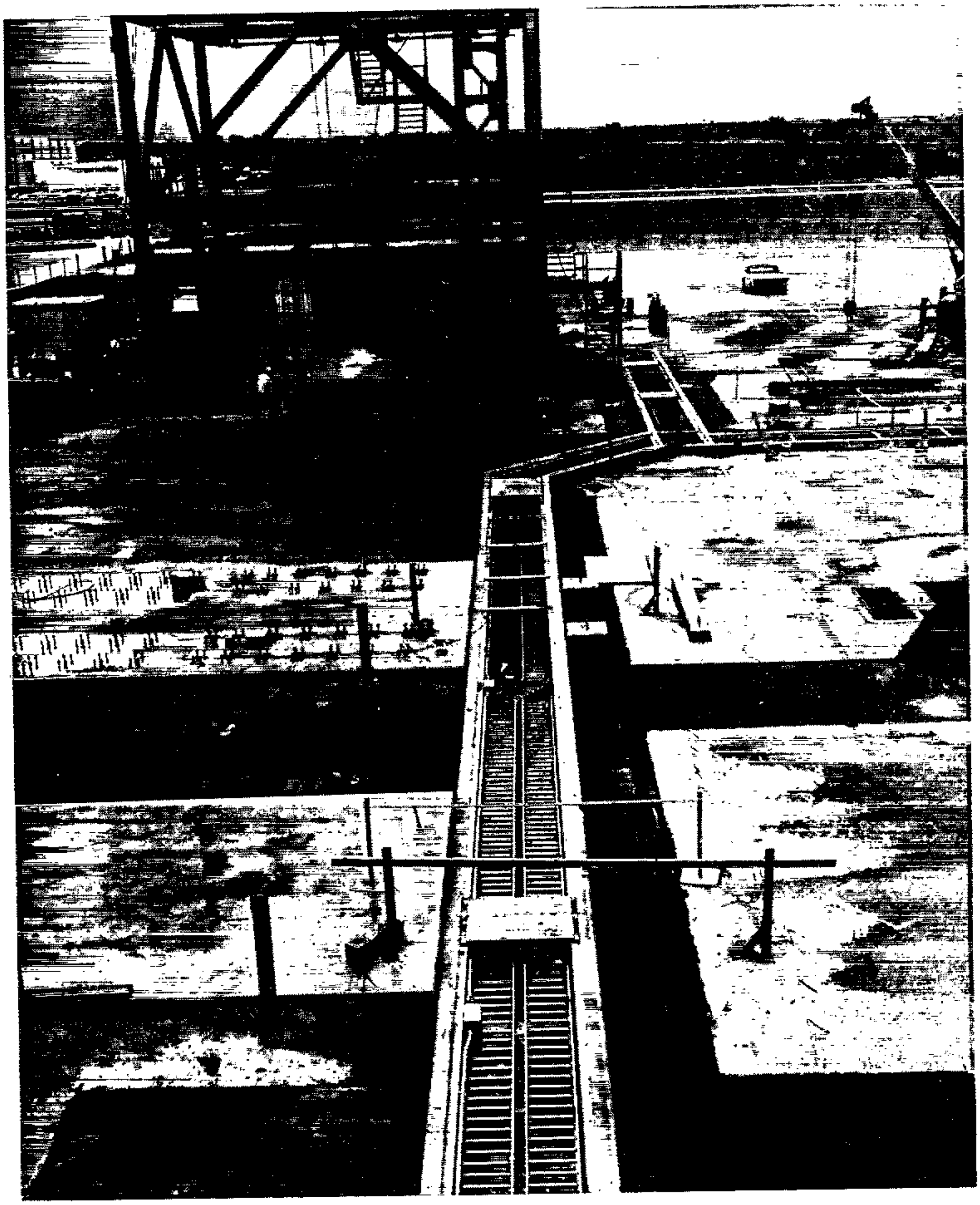

Figure 8. Cable Trenches with Steel Grating

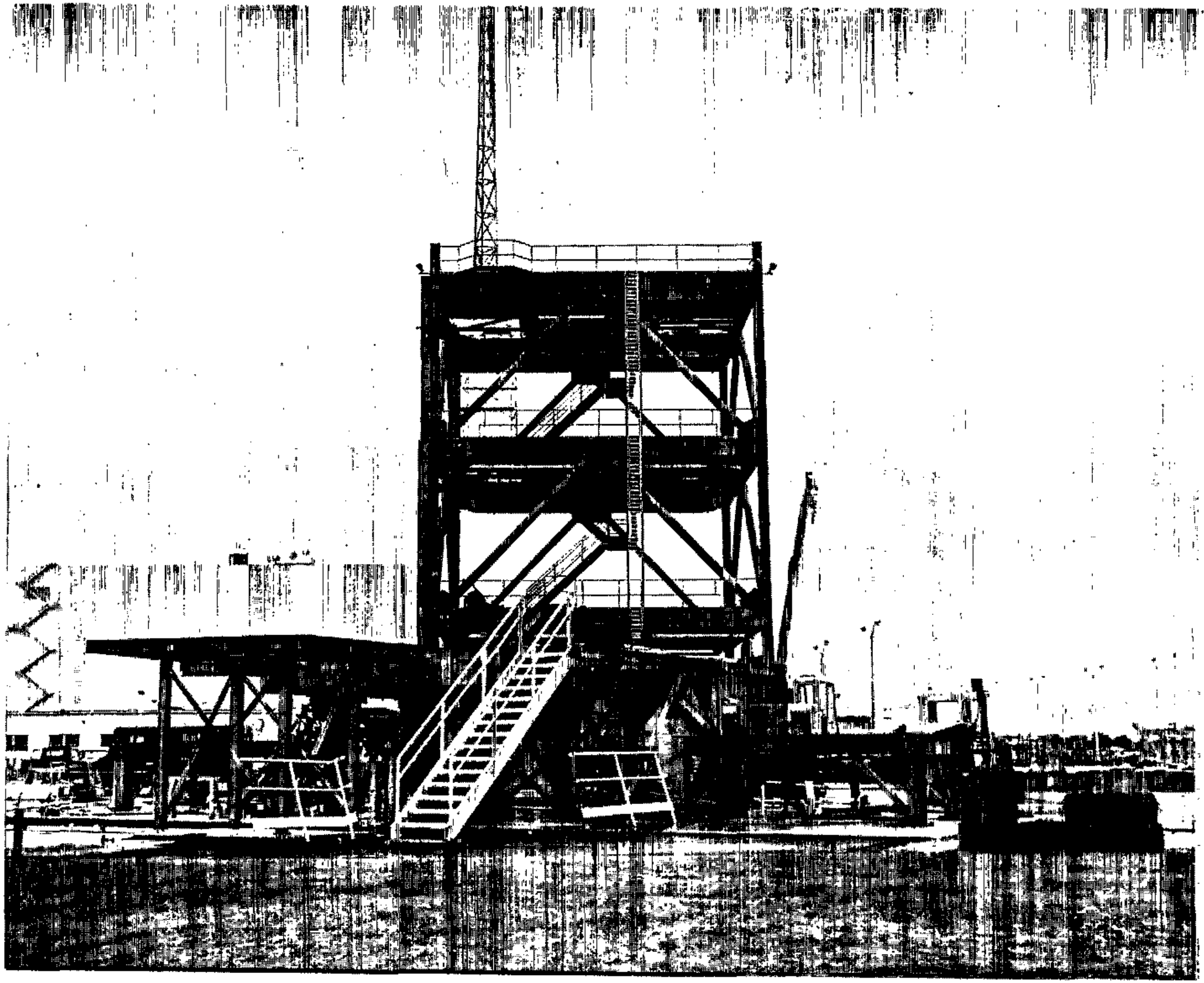

Figure 9. A Typical Random Motion and Lift-off Simulator

ABOUT THE AUTHORS

MR. ROBERT T. UDA is a Principal Lead Engineer at Planning Research Corporation, Kennedy Space Center, Florida. He worked on design, development, test, and evaluation of the Space Shuttle tail service mast concept. He also served as Lead Engineer on the design of the LOX and LH_2 umbilical plate installation fixture on the Orbiter access stand in the Orbiter processing facility. Past experience includes: Astronautical Engineer with the Air Force, AFPRO, MDAC, Huntington Beach, California; Launch Operations Manager with the Air Force, SAMSO, TIII, SPO, Los Angeles. He holds the B.S. degree in aerospace engineering from the University of Oklahoma and the M.S. degree in astronautics from the Air Force Institute of Technology.

DR. SUBHASH RAJARAM DANDAGE is a Senior Engineer at Planning Research Corporation, Kennedy Space Center, Florida. He has primary responsibility for the dynamic and kinematic design of the ground support equipment for the Space Shuttle Program through computer simulation, special design projects and trade studies. Past experience includes: Supervisor at Maharashtra Engineering Society in India; Research Associate at University of Wisconsin; and Consulting Engineer at Universal Engineering, Inc. He holds the Ph.D. in mechanical engineering from the University of Wisconsin.

MR. DONALD C. MACDONALD is a Senior Engineer at Planning Research Corporation, Kennedy Space Center. He is responsible for overall administration, coordination, and technical effort of assigned work orders, including efforts of other department personnel. Past experience includes: Senior Product Engineer at Chrysler, Senior Test Control Supervisor and Engineering Scientific Specialist at LTV Missiles and Space Division, and Program Coordinator at General Dynamics/Astronautics Division. He holds the B.S.M.E. and B.B.A. degrees from Northeastern University.