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LAUNCH VEHICLE RECOVERY SYSTEM REQUIREMENTS

ABSTRACT

The primary considerations in the design and development of a recovery system applicable to present expendable first stage launch vehicles are discussed. The general requirements that define the essential characteristics of a feasible recovery system are derived from three critical phases during flight. The degree of criticalness is primarily influenced by the conditions at stage cutoff and separation. The three critical phases of flight are broken down into the following: (1) conditions and requirements between stage separation to re-entry; (2) re-entry; and (3) terminal descent and landing.

This paper presents vehicle considerations that must be investigated in establishing the requirements of a recovery system applicable to first stage expendable launch vehicles in the SATURN class. In addition, two programs initiated at the George C. Marshall Space Flight Center (MSFC), National Aeronautics and Space Administration (NASA), Huntsville, Alabama, to substantiate a recovery program for launch vehicles are reviewed. The two programs are the H-1 engine salt water immersion tests and the booster retrieval exercises at sea.

LAUNCH VEHICLE RECOVERY SYSTEM REQUIREMENTS

I. GENERAL

Before discussing the recovery system requirements, some of the problems that are inherent to booster recovery should be stated. Expendable launch vehicles are primarily designed to obtain a minimum structural weight to propellant weight ratio to provide for greater payload capability. In taking such an approach, it is of utmost importance for the vehicle design engineer to investigate all conceivable means for reducing the weight of the vehicle structure. As a result, the deceleration loads and re-entry heating imposed on the vehicle structure will place a major requirement in the design and application of recovery techniques. This means that after separation the recovery system must provide for the following: (1) proper vehicle stabilization and orientation; (2) means to reduce vehicle velocity to alleviate re-entry loads and aerodynamic heating; and (3) terminal descent and landing (figure 1).

Figure 1. Recovery System Requirements at Phases of First Stage Flight.

The vehicle structure limitations must not be exceeded regardless of the orientation maneuvers or functions that the recovery system must perform.

II. STAGE SEPARATION TO RE-ENTRY

Vehicle Stabilization and Orientation

The requirement for launch vehicle stabilization and orientation results from three basic considerations: (1) maximum deceleration during re-entry; (2) deployment of deceleration devices; and (3) impact.

Studies must first be made to determine whether the launch vehicle's natural stability characteristics will suffice, or if it will require use of kick rockets, stabilization fins, inflatable drag devices, or other means for proper attitude alignment during re-entry. In most SATURN vehicle configurations investigated to date, the results indicated that the vehicle became unstable after separation of the upper stages.

If at separation the unstable vehicle develops a tumbling and/or flat spin rotational motion during free flight, it must be eliminated and controlled for the remainder of the flight. Tumbling and/or spinning motions, once they are developed, could cause the vehicle structure to fail and break up. In the event the vehicle structure withstood these motions during free flight, stabilization and orientation of the vehicle during re-entry would require a complex and costly reaction jet attitude control system with a high total impulse.

In addition to the natural aerodynamic instability of expended vehicles, consideration must be given to the separation requirements. In separation of the upper stages, an initial interstage disconnect must take place. The interstage disconnect is then followed by either of two separation events: (1) firing of retro-rockets attached to the first stage; or (2) ignition of second stage and firing into the top of the first stage. Either of the two methods will give an initial impulse on the stage, at which time may also start the residual propellants sloshing inside the tanks. Sloshing, along with the undesirable dynamic characteristics, leads to another consideration - dumping of residuals. Dumping of propellants appears quite feasible, but trade-off studies must be made between requirements imposed on the stabilization and orientation systems (if residuals stay on board) versus the added complexity in incorporating propellant dumping capabilities and possible reduction of overall mission reliability.

With the fuel sloshing and the rise of temperatures at re-entry, consideration must also be given to the propellant tanks pressure relief valves which may become operative and work for or against the stabilization system. Tank pressures <u>must</u> be maintained, since capability of the vehicle structure to withstand re-entry and landing loads is greatly dependent on these internal tank pressures.

After investigating typical expended vehicle structural capabilities, aerodynamic characteristics, and considering typical trajectories giving cutoff velocities between 5,000 - 10,000 ft/sec, the most desirable vehicle attitude at re-entry, recovery system deployment, and impact must be selected. For most recovery techniques, the re-entry attitude would be the same. The most desirable attitude is engine first, since the vehicles are best capable to withstand longitudinal loads and better maintain their stability with the engines first.

The engine first attitude will require the minimum maneuvers and provide the vehicle's center-of-gravity/center-of-pressure relationship that will give minimum aerodynamic instability. The stability requirements of different launch vehicles may vary, but the allowable deviation will be small.

During the orientation phase, if the requirement for dumping propellants is desired, control or prediction of propellant location must be monitored. The resultant forces from venting must be considered and the selected recovery system must provide for means to overcome these forces during free flight and re-entry.

In reviewing the trajectories for most present day launch vehicles, cutoff velocities range between 7,000 - 10,000 ft/sec. These velocities will definitely give deceleration forces that far exceed most vehicle structural normal load capabilities, and in some cases may even exceed the axial compressive load capabilities. These high cutoff velocities should not be taken lightly. In many cases proposals and/or investigations of recovery techniques tend to take the basic vehicle structure capabilities stated, but fail to consider the effect deceleration loads have on the shrouding, propellant lines, engines, and other accessories. Some damage can possibly be tolerated in these areas; but depending on the recovery technique, consideration must be given to components breaking loose and damaging and/or affecting either the stabilization or deceleration system. With the previously mentioned considerations, the conditions that have to be satisfied in this phase are: (1) maintaining continuous booster stability; (2) orienting the booster to re-entry attitude most compatible with the booster structure; and (3) a means of reducing vehicle velocity to alleviate re-entry loads and temperatures.

III. RE-ENTRY

Investigations show that present vehicle designs and/or configurations offer very little hope of alleviating the present inherent structural weaknesses in terms of being compatible with re-entry deceleration loads. Therefore, controlling the energy of a vehicle during re-entry so that it will not prove disastrous to the structure is an important problem. Deceleration during re-entry is due to aerodynamic drag which varies with the ambient air density and the square of the vehicle velocity. The gas dynamic heating rate varies approximately with the air density and the cube of the velocity. Deceleration, as well as heating rates, depends strongly on the vehicle shape and trajectory. Therefore, both parameters have to be studied carefully before selecting the recovery system concept. Stability and drag could be augmented by the addition of stabilization fins and/or drag devices to the vehicle (figure 2).

Figure 2. Several Methods for Stability and Drag Augmentation.

Detail trade-off studies must be made considering heat protection techniques on the vehicle versus aerodynamic drag devices to reduce vehicle velocity prior to maximum dynamic pressure during re-entry. A compromise or combination of these two methods may be most effective. Careful consideration must be given to additional components since the weight of every component aiding the overall recovery mission is charged against the recovery system. The recovery mission may at times be eliminated solely on the weight penalty effect on the vehicle payload.

IV. TERMINAL DESCENT AND LANDING

After the vehicle has been through re-entry (controlled or uncontrolled, depending on the requirement), a means for the most favorable method of decelerating the vehicle to impact must be investigated. The terminal descent and landing requirements for launch vehicles are determined by considerations of allowable vehicle structure loads during recovery system functions and the anticipated retrieval methods.

There are basically two types of recovery approaches (wet or dry) to consider: (1) dry - Landing on a dry surface, whether at launch site, a downrange island, or a floating platform; and (2) wet - Landing on water. Either approach can probably be satisfied by several recovery techniques.

Table 1. Recovery Methods Considered

DECELERATION

DRAG	LIFTING
Ballistic body	Fixed wings
Drag brakes	Flexible wings
Parachute	Rotary wings
Balloon	

MANUEVER AND LANDING

Vertical descent	Horizontal landing
Baloon floatation	Fixed wings
Retro-rockets	Flexible wings
Turbojets	
Rotary wings	

In some cases, one recovery technique may satisfy the requirements for either wet or day type recovery. The recovery technique considerations must also include evaluation of retrieval requirements. Here again, depending on the landing or final deceleration system, consideration must be made of shrouding, engines, propellant lines, etc. If impacting on water, the vehicle must remain watertight after impact. Buoyancy forces and tip-over loads must also be considered.

Furthermore, the cost, weight, development and qualification time for the system, particularly if it requires an advancement of the state-of-the-art, and vehicle modifications required to adapt recovery system must all be evaluated.

In addition to all the effort spent in investigating feasible recovery techniques by both government agencies and private concerns, there has been much effort expended on retrieval studies and refurbishment cost estimates applicable to expended vehicles. The results on these studies varied widely. The George C. Marshall Space Flight Center, a strong proponent for recovery, felt that much could be gained by using actual vehicle hardware to better define and support recovery of launch vehicles.

Two programs of interest to the overall recovery program were initiated at the MSFC. The two programs conducted were: (1) retrieval exercises under actual sea conditions with a full-scale MERCUTY-REDSTONE booster with the proposed LSD (Landing Ship Dock); and (2) salt water immersion tests on an H-1 engine. These two programs were initiated primarily to better understand the problems associated with wet type recovery, and to help evaluate wet versus dry recovery techniques and cost analysis.

V. RETRIEVAL EXERCISE

A program to acquaint and solve some of the problems associated with wet recovery was conducted at the MSFC in 1960. The program consisted of some preliminary tests conducted at MSFC, followed by full scale exercises at sea. A development program for a parachute recovery system for the

MERCURY-REDSTONE booster was in effect at this time, so it was only logical that a REDSTONE booster was used as the test vehicle.

The tests at the MSFC got underway after a troop training REDSTONE booster was obtained and modified to simulate a MERCURY-REDSTONE booster in weight and configuration. These preliminary investigations were primarily to determine possible damage at water impact, flotation angle, and depth of submersion (figures 3 and 4).

Figure 3. Measuring Angle of Floatation, using Carpenter's Level and Protractor.

Figure 4. Booster Nearing Maximum Depth of Penetration.

The solution to these problems was of great interest since they would determine the handling methods for safing and retrieval employed in floating the booster into the recovery vessel.

Results obtained from the preliminary tests at the MSFC indicated that the use of an LSD as a recovery vessel was the most practical method of recovering a MERCURY-REDSTONE booster. In coordination with U.S. Naval forces, a 2-day training exercise was conducted approximately 50 miles at sea from Norfolk, Virginia. This was to ascertain the capabilities of the LSD and to provide training for the underwater demolition team and LSD crew.

Special recovery equipment was used by the UDT in preparing the booster for towing aboard ship and for receiving and securing the booster to the saddles.

Four retrieval exercises were conducted. Figures 5 through 8 illustrate the position of the saddles in the well of the LSD, and the operational procedure in towing the booster into the well of the LSD and placement on the saddles (figures 5, 6, 7 and 8).

Figure 5. Saddles Positioned on LSD Well Deck.

Figure 6. Towing Booster to LSD.

Figure 7. Placement on Saddles in LSD Well.

Figure 8. Preparing Booster for Towing Aboard Ship.

The primary objective of this first retrieval attempt was to check out the proposed handling procedures. As the first step, the booster, swimmers and their rubber boat, and the towing crew aboard the LCVP were launched. The LSD drained the well and moved away several thousand yards. The swimmers then approached the booster and went through the safing procedures without any difficulty, and also installed the handling connections.

After the safing operation was completed the booster was taken in tow by the LCVP and positioned astern the LSD, which was maintaining a constant heading into the waves. The LSD was ballasted so as to have 8 feet of water in the well at the stern gate sill. The LCVP continued towing until its bow was over the LSD stern gate. The LCVP then reversed, disconnected its tow line, and moved off to the port side and stood by. Swimmers with lines from the LSD attached lines to prescribed connections on the booster, and the booster was positioned over saddles. Once the booster was positioned, deballasting of the well proceeded until booster rested firmly on saddles. After the well was drained, the booster and recovery equipment were checked for damage.

The second operation omitted the safing procedure, but went through with towing booster out and back into LSD with the LSD maintaining a heading of 2 to 3 knots into the waves. The third operation was very similar to the second. A change on the tiedown location of the nylon restraining slings was made.

The final operation was a complete simulated recovery. The booster was set free and all personnel stayed aboard the LSD. The LSD deballasted and steamed off 10 miles from booster. At 10 miles the booster was held on surface radar while the aircraft tracked it 50 miles from 1500 feet.

Once the tracking exercises were over, the LSD started toward the booster. Ballasting of LSD and preloading of LCVP were performed while enroute. When the LSD was approximately 1000 yards from the booster, the LCVP was launched and proceeded to the booster. Upon arriving at the booster, the swimmers went through the safing operation; the booster was taken in tow, and brought into the well of LSD and positioned as before.

VI. H-1 ENGINE SALT WATER IMMERSION PROGRAM

Sea water immersion tests were conducted on a Rocketdyne H-1 engine in order to evaluate the corrosive effects of sea-water recovery on the engine and to define the procedures necessary to restore the engine for flight service. The H-1 engine is the one presently used, in a cluster of eight, to power the SATURN C-1, S-I stage. The water immersion program involved a series of tests in which the H-1 engine was immersed in sea water for given periods of time, followed by various post treatments designed to minimize the corrosive effect of sea water. The engine was then disassembled, evaluated for corrosion damage, reassembled, and test fired (figures 9 and 10).

Figure 9. H-1 Engine, Half-Submerged.

Figure 10. Spraying H-1 Engine after Recovery.

The purpose of this test program was to better define the effects of salt water immersion on the H-1 engine. Because of the various recovery schemes proposed for SATURN booster recovery, it was essential that hardware such as an H-1 engine be immersed in salt water and the results investigated to better evaluate the economics of booster recovery (wet versus dry recovery systems). The salt water immersion tests, reconditioning, and subsequent full duration static firings of the H-1 engine provided valuable information reflecting the feasibility of re-using large boosters after exposure to salt water.

The test program scheduled a series of three immersion tests with subsequent hot firing in the test stand. The first test was performed with all known preservative measures, the second with less preservation, and the third and final test with no preservation methods applied. The salt water immersion was performed at Port Canaveral, Florida, and the dismantling, checking of components, assembly, and hot firing at the MSFC, Huntsville, Alabama.

The general test procedures were as follows:

1. First test - March, 1961. H-1 engine was:

    a. Prepared and static fired.

    b. Immersed in salt water to a depth of 10 feet for 2 hours, and half-submerged for 2 hours.

    c. Purged. Preservations were applied.

    d. Stored for 2 weeks.

    e. Dismantled, inspected, cleaned, damaged parts were replaced, and engine was assembled.

    f. Hot fired for short duration and full duration (150 seconds).

2. Second test - June, 1961:

    a. Immersed H-1 engine to a depth of 10 feet for 1 hour, half-submerged for 3 hours, and on the surface for 3 hours.

    b. Waited 12 hours before purging, and applying minimum preservatives.

    c. Upon arrival at the MSFC, engine was dismantled, inspected, cleaned, damaged parts were replaced, and engine was assembled.

    d. Hot-fired for short duration and full duration.

3. Third test immersion in August, 1961; hot fired in March, 1962.

a. Dropped H-1 engine into water to simulate water entry conditions, immersed it, held it half-submerged, and on the surface for a total of 9 hours.

b. Engine washed with fresh water; no preservative compounds were used.

c. Upon arrival at the MSFC, engine was dismantled, inspected, partially cleaned, and left in storage.

d. Six months later the engine was assembled and hot-fired for short duration and full duration.

In order to establish an approximate cost factor, a log was kept of the procedures, reconditioning manhours, materials, and an itemized list of replaced engine parts. The cost to recover and recondition the H-1 engine was approximately 5 per cent of the cost of a new one.

VII. SUMMARY

Recovery of expended first stages on present vehicle designs and/or configurations will definitely impose many problems on the recovery system. The problems are not insurmountable, but careful consideration must be given to each and every one. There are presently a few techniques that appear applicable and feasible. The penalty (corrosion and refurbishment costs) for wet-type recovery techniques does not seem to be as high as previously anticipated. The selection of a system to satisfy all requirements is open at the present time. The potential benefits from recovery of presently expended launch vehicles are listed in Table 2.

Table 2. Benefits of Recovery

Post flight examinations

Re-use of flight proven hardware

Cost reduction

Avoidance of expended booster fallout

ABORT CAPABILITY

- Key to Booster Life
- Minimization of Range Safety Problems

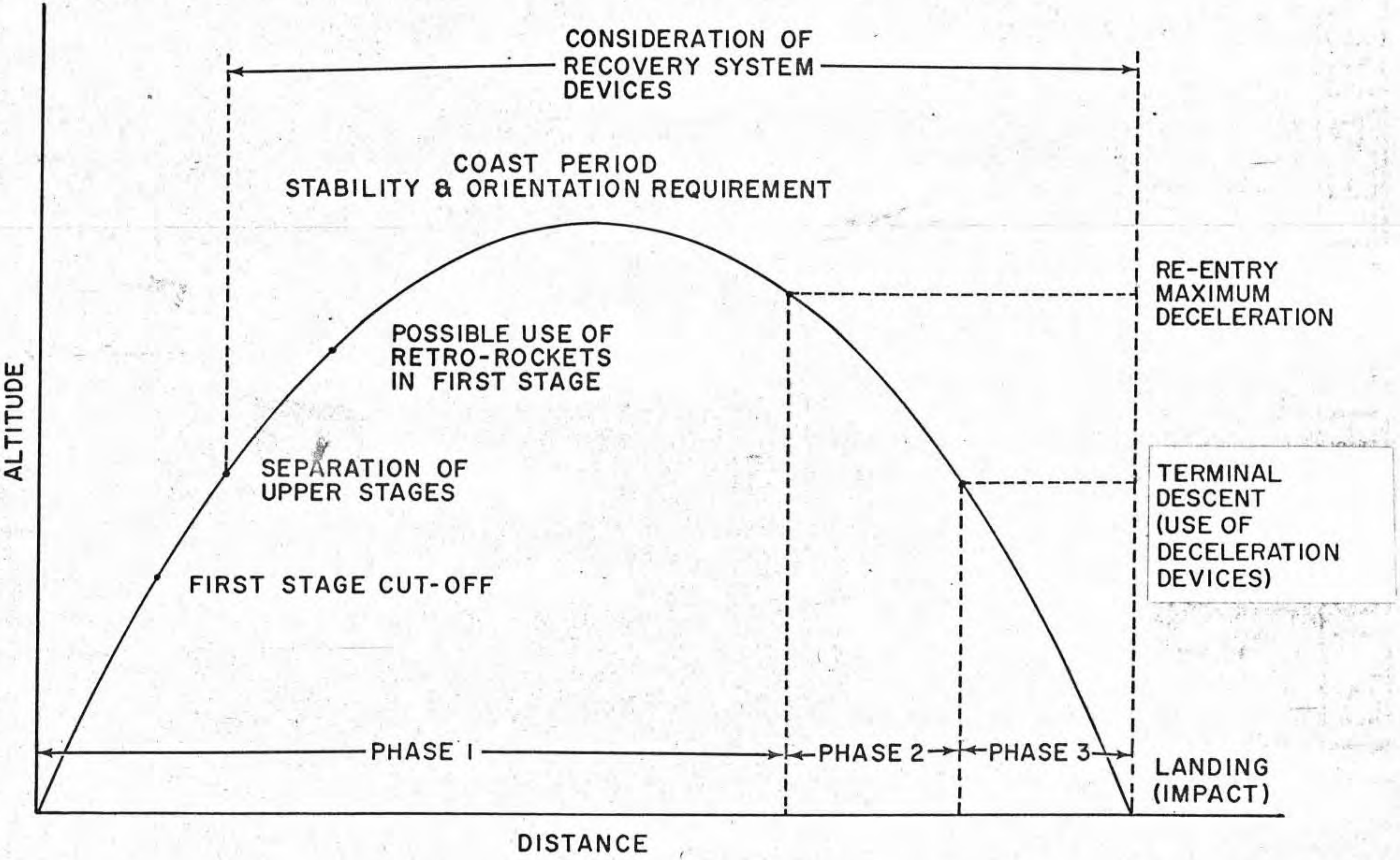

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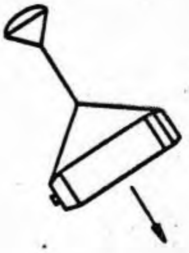
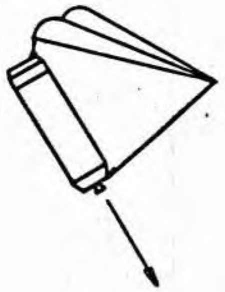
Figure 1. Recovery System Requirements at Phases of First Stage Flight.

ATTACHED STABILIZING FINS ONLY

BROADSIDE TRIMMING

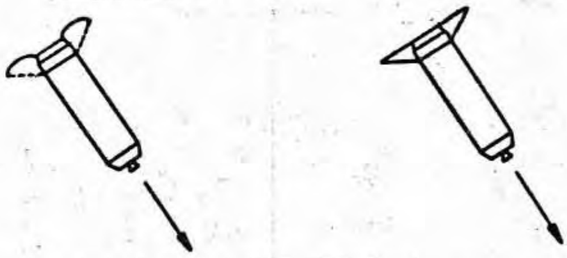


ATTITUDE STABILIZATION FLEXIKITE PROGRAMMED LIFT



TRAILING HIGH MACH DRAG DEVICE ONLY

ATTACHED HIGH MACH DRAG DEVICE ONLY



TRIMMING TO MAX BODY L/D

Fig 2 Several methods of stability and Drag Augmentation

FIGURE 3 - ANGLE OF FLOTATION MEASURED USING CARPENTERS' LEVEL AND PROTRACTOR

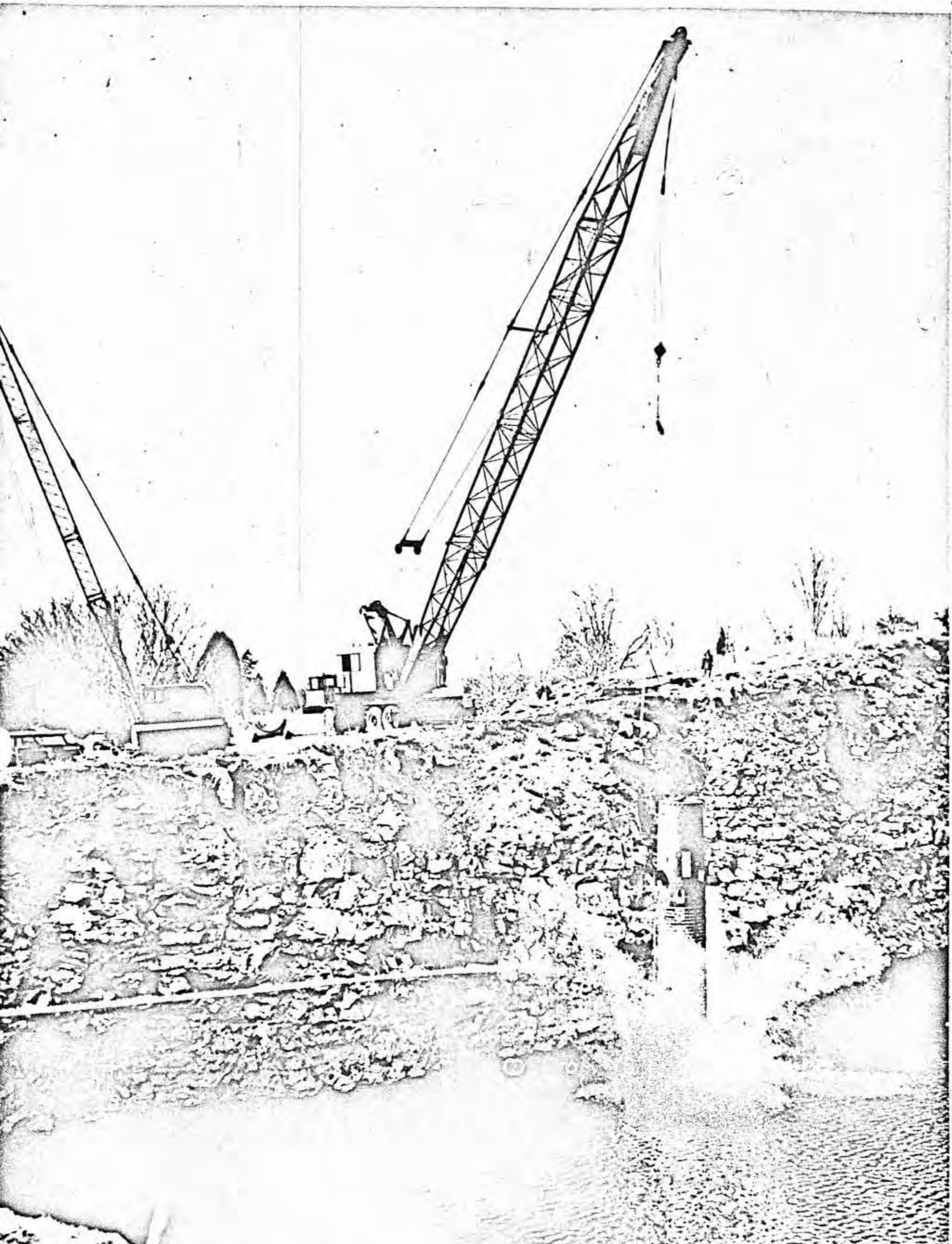


FIGURE 4 - BOOSTER NEARING MAXIMUM DEPTH OF PENETRATION

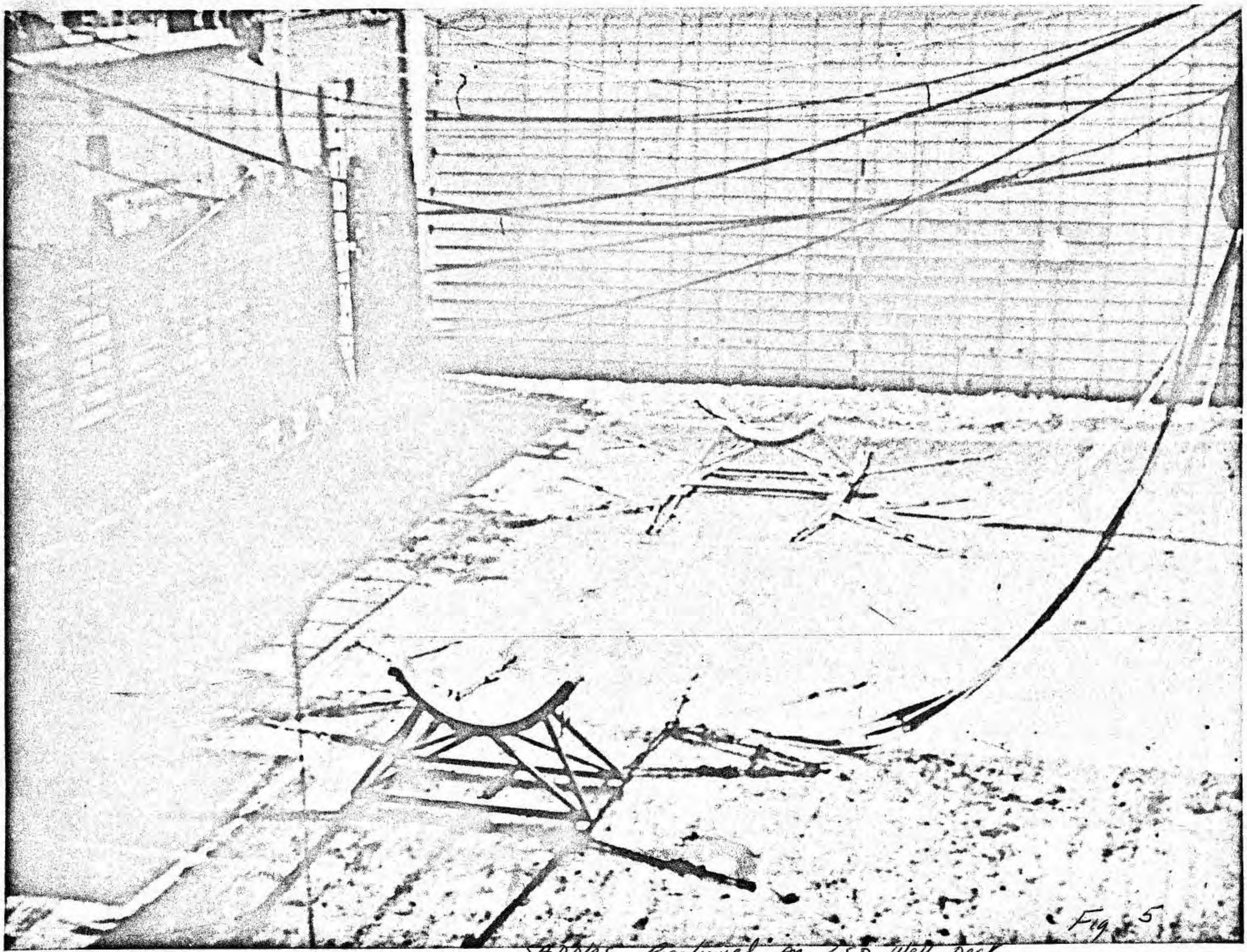


Fig 5

SADDles Positioned on LSD Well Deck

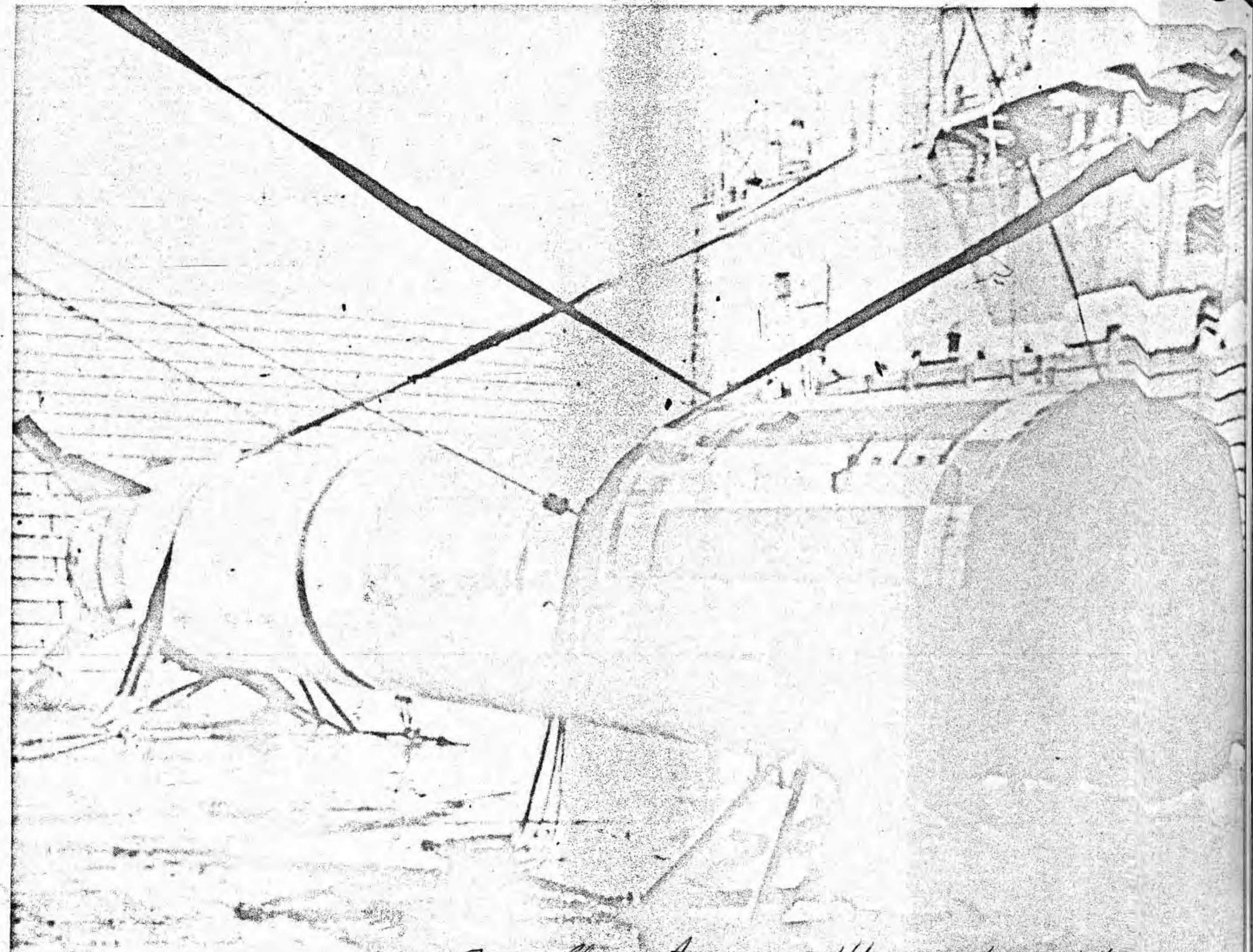


Fig 7 Placement on saddles in LSD well

Fig. 6 Towing Booster to LSD

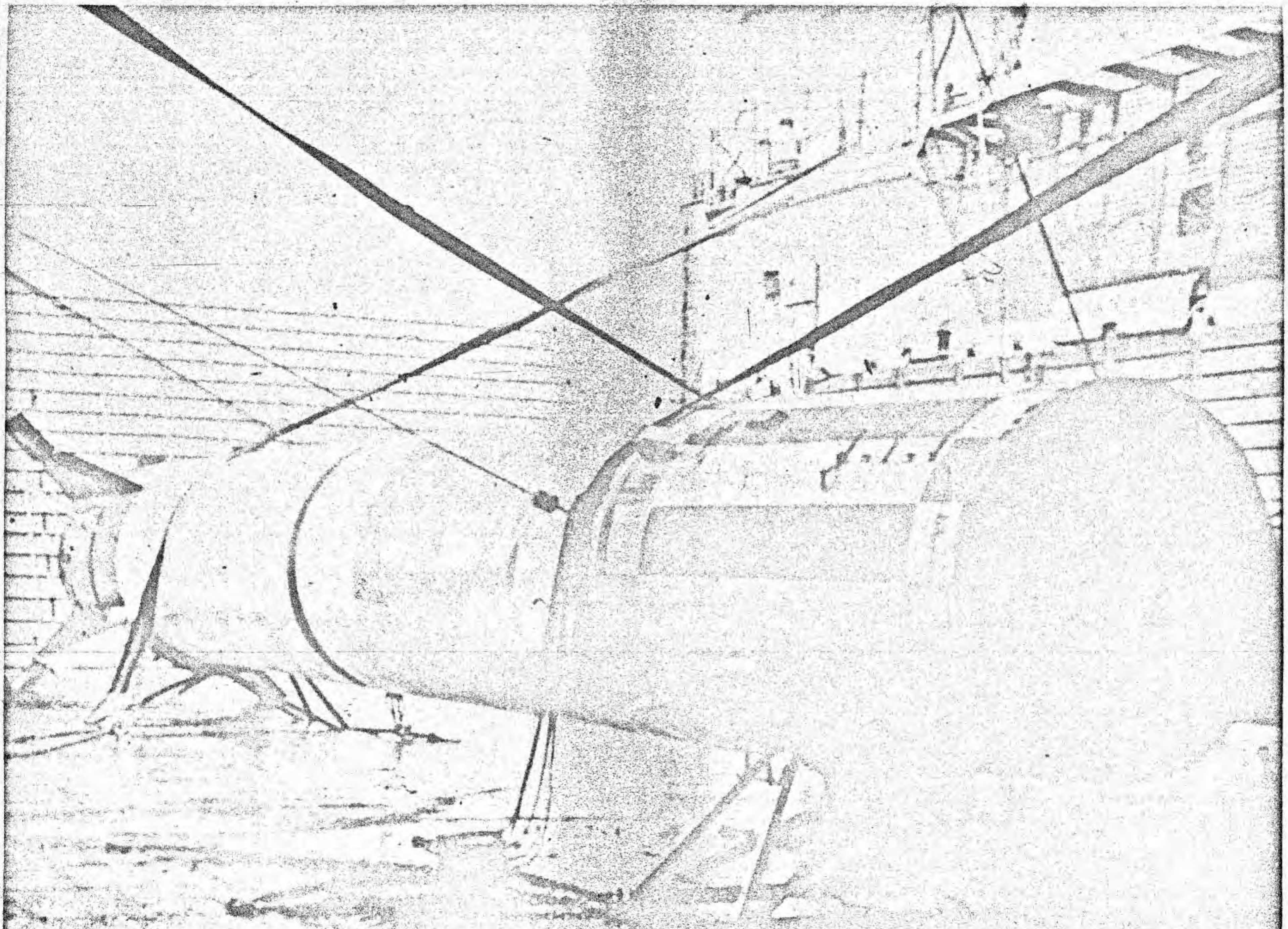


Fig. 7 Placement on saddles in LSD well

Fig 8 Preparing Boosters For Towing aboard LSD

(Fig. 9 H-1 Engine Half-submerged

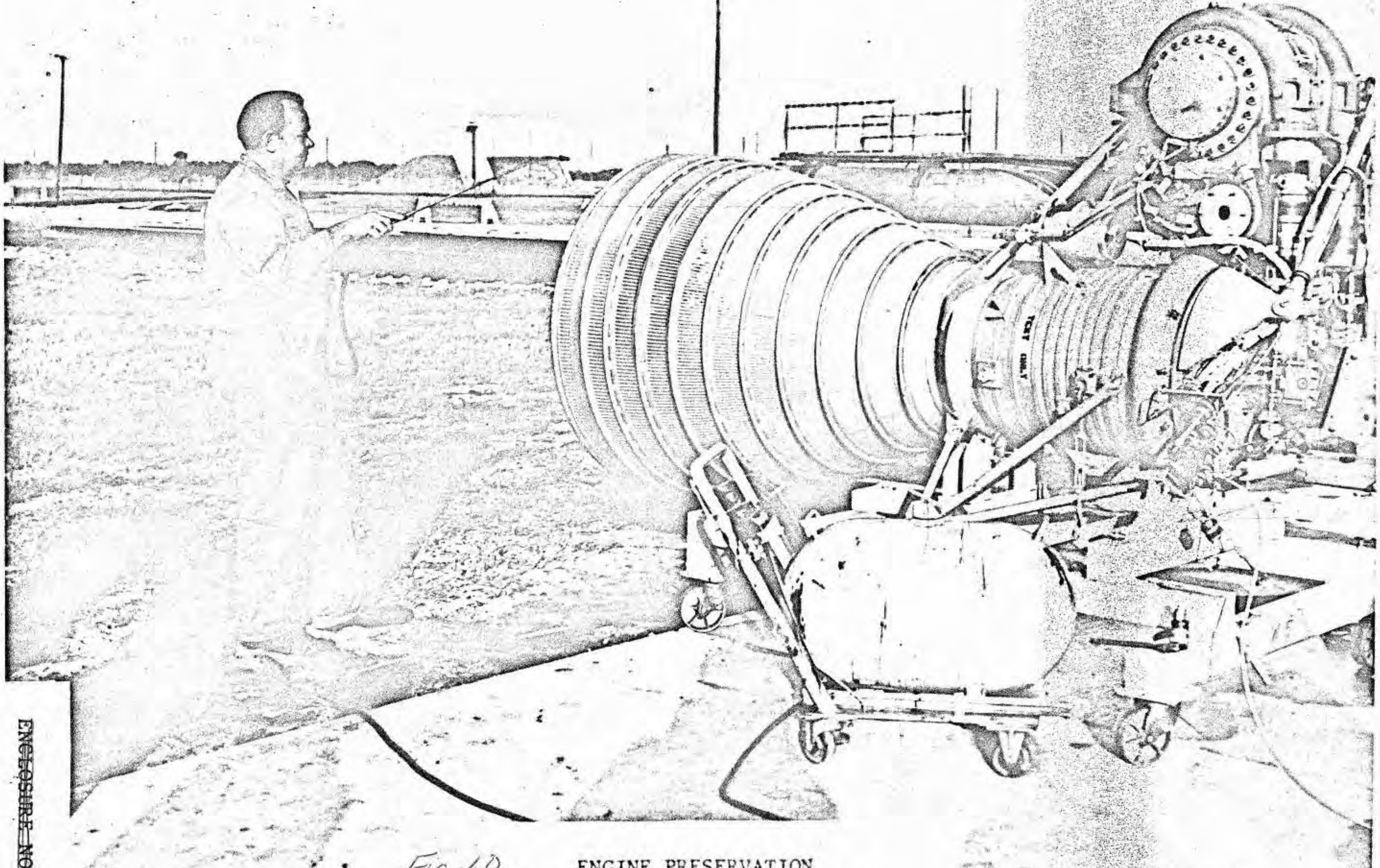


Fig 10 ENGINE PRESERVATION
EXTERNAL SURFACE-P-9-OIL SPRAY

~~ENCLOSURE NO.~~ 4