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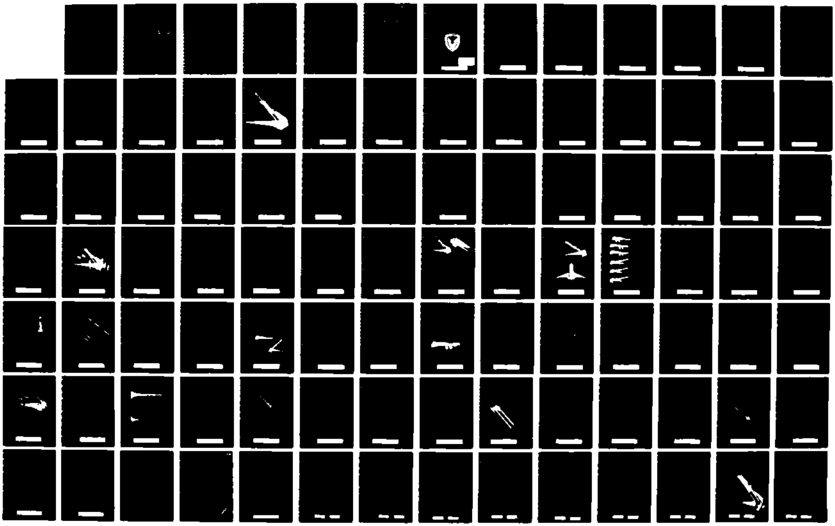

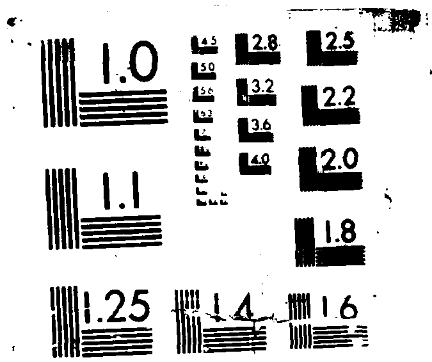


MICROCOPY RESOLUTION TEST CHART

(2)

# Lightweight Towed Howitzer Demonstrator

Final Report

Volume B

Technical Presentations - Part I





April 1987

Contract Number DAAA21-86-C-0047

FMC CORPORATION
Northern Ordnance Division
4800 East River Road
Minneapolis, Minnesota 55421



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The LTHD (Lightweight Towed Howitzer Demonstrator) was to be a 9,000 lb equivalent to the M198, transportable via Blackhawk helicopter, with reduced emplacement time using fewer personnel. The FMC design achieved weight reduction via a mortar-like configuration, composites structure, and hydraulic actuators. Recovery of power from the recoil system, in turn, facilitated crew reduction via hydraulic emplacement, four-way joystick tube lay, and power ramming. FMC completed Concept Development (Ph I) and two-thirds of Detailed Design (Ph II) prior to funds running out.

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04 JUNE 85

PROPOSAL

FMC

Proposal for:

# Lightweight Indirect Fire Weapon System

Prepared in response to U.S. Army
Armament Research and Development Center
Solicitation No. DAAK10-85-R-0254

U.S. ARMY
ARDC

## Volume 3A: Technical Approach (155mm Lightweight Towed Howitzer Demonstrator)

FMC Corporation
Northern Ordnance Division
Minneapolis, Minnesota

[redacted]

4 June 1985 [redacted]

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# Abbreviations

| | |
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| ACO | Administrative Contracting Officer |
| AMCCOM | Armament, Munitions, and Chemical Command |
| ARDC | Armament Research and Development Center |
| ARM | Artillery Recoil Mechanism |
| B&P | bid and proposal |
| BCF | Brooklyn Center Facility |
| BOM | Bill of Material |
| CAD | computer-aided design |
| CAS | cost accounting standard |
| CATFAE | Catapult-Launched Fuel-Air Explosive |
| CCV--L | Close Combat Vehicle--Light |
| CDR | Critical Design Review |
| CDRL | Contract Data Requirements List |
| CEL | Central Engineering Laboratories |
| CHC | Columbia Heights Center |
| CM | configuration management |
| COTR | Contracting Officer's Technical Representative |
| DCAA | Defense Contract Audit Agency |
| DCAS | Defense Contract Administration Services |
| DFC | direct fire control |
| DOF | degree-of-freedom |
| DSWS | Division Support Weapon System |
| DTIC | Defense Technical Information Center |
| EEO | Equal Employment Opportunity |
| EMP | electromagnetic pulse |
| ESPAWS | Enhanced Self-Propelled Artillery Weapon System |
| FOB | free on board |
| FOOB | fire out of battery |
| FRACAS | failure reporting, analysis, and corrective action system |
| G&A | general and administrative |
| GALS | Generic Autoloader System |
| GIDEP | Government Industry Data Exchange Program |
| HHS | hybrid hard/soft |
| HIP | Howitzer Improvement Program |
| HMMWV | High-Mobility Multipurpose Wheeled Vehicle |
| ICAS | Improved Conventional Armament System |
| IFC | indirect fire control |
| ILS | integrated logistics support |
| IR&D | independent research and development |
| LIFWS | Lightweight Indirect Fire Weapon System |
| LSA | logistics support analysis |
| LTHD | Lightweight Towed Howitzer Demonstrator |
| MRB | Material Review Board |
| NAVPRO Office | Naval Plant Representative |
| PAC | payroll added cost |
| PDR | Preliminary Design Review |
| PHA | preliminary hazard analysis |
| POPS | Pricing of Proposal Systems |
| QA | quality assurance |
| QC | quality control |
| QE | quadrant elevation |
| RAM-D | reliability, availability, maintainability, and durability |
| RDF | Rapid Deployment Force |
| RFP | request for proposal |
| RPM | rounds per minute |
| RRS | Robotic Resupply System |
| SF | standard form |
| SOW | statement of work |
| TPM | technical performance measurement |
| TTB | Tank Test Bed |
| UM | unit of measure |
| WBS | work breakdown structure |

# Compliance Matrix

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# Section 1
# Introduction

We have the experience and capabilities to conceptualize, design, and fabricate the Lightweight Towed Howitzer Demonstrator (LTHD). We can also produce and support those designs. Our design will provide the U.S. Army with a 155-mm lightweight howitzer that is airliftable by the modified Blackhawk helicopter.

Our understanding of the project objective and of the operational, functional, and physical requirements of the LTHD are summarized below. The description of our technical development plan and our approach to complete this project are consistent with a technology demonstration project.

We propose a unique combination of innovative design, state-of-the-art technology, off-the-shelf components, and composite materials for the LTHD. Using this approach, we have resolved the weight problem with low to moderate technical risk and within the required timeframe. The LTHD concept lends itself to the application of additional advanced technology features in the future, such as a composite barrel or an innovative recoil mechanism. However, these features were not proposed for this concept, because we consider them to add unnecessary technical risk.

Our proposed weapon system uses a unique approach to meet the weight and stability requirements. The system configuration consists of dual forward-spreading trails stabilizing a firing platform with a low-level trunnion and a single-elevation cylinder that supports the recoil and cannon assemblies on a dual-rail slide (figure 1-1). The concept was configured to perform similar to the M198 Towed Howitzer and to meet the 9,000-pound weight limitation. Environmental, noise, and blast overpressure requirements are included in the concept development to provide a reliable system that can be safely operated by the crew.

The weapon will be supported by a detachable wheel unit. This feature allows additional weight reduction (600 pounds) should airlifting under adverse conditions become necessary. The wheel unit has four wheels equipped with HMMWV tires. A four-wheel configuration will enhance travel stability of the weapon when towed behind a vehicle. The wheel unit could also be used to assist in loading of heavy projectiles (Copperhead), or to move ammunition in the firing position.

Our design approach will be a conservative one. Where possible, components already employed in U.S. Army systems will be used. We will use innovative configurations or materials only where necessary to meet the weight and stability requirements.

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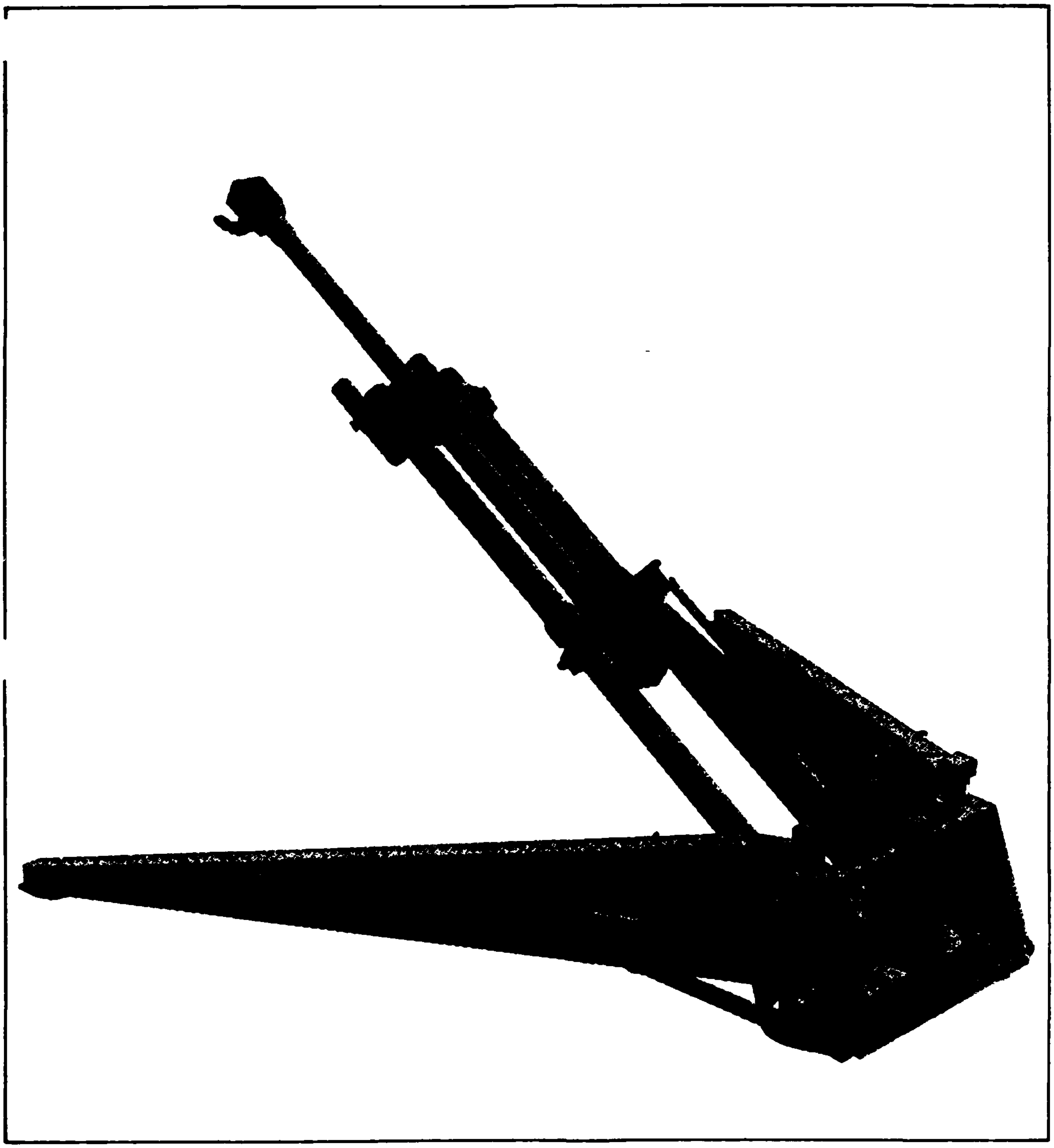

Figure 1-1. THE LTHD USES AN INNOVATIVE APPROACH to 155-mm howitzer configurations.

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Use of innovative techniques or materials will be determined by trade studies. Therefore, although the design will be innovative, the techniques or materials used will not be new and unproven. For example, although there will be many applications of composites, we will employ proven technology before considering the use of state-of-the-art or unproven materials.

Northern Ordnance will use a system engineering approach to address the interdisciplinary requirements for development of the 155-mm LTHD.

We realize that any development project carries with it inherent risk. We have reviewed the potential technical risks for this project and have identified risk control techniques to cope with and control any encountered risks. Because an urgent need exists for this weapon system, we have attempted to minimize all risks during concept exploration in our independent research and development (IR&D) efforts. This effort will continue throughout the project.

We offer a project team that is experienced in working with designs exposed to difficult working environments where ease of operation and maintenance is essential (figure 1-2). This team has been exploring the lightweight towed howitzer environment and weapon system requirements under the IR&D program since September 1984. This same team has evaluated recent howitzer designs to learn about complexities of howitzer weapon systems and the intricacies of lightweight design. We have visited with agencies involved in weapon system design and weapon system use, such as AMMRC, ARDC, and USFACS, to determine their needs and to listen to their concerns. To support our team, we have engaged Mr. John Simpson (a ballistics consultant), the FMC Central Engineering Laboratories (CEL), and the U.S. Army AMCCOM to join the effort.

CEL will conduct dynamic analyses on the entire weapon system as well as composite parts to minimize weight without impairing structural integrity. CEL's composite material fabrication shop will produce a significant portion of the piece parts for the LTHD demonstrator.

Watervliet Arsenal will provide detailed design of the cannon assembly and will fabricate, assemble, and test the cannon.

To summarize, we understand the requirements and have a sound approach to complete the project objective successfully. Our proposed LTHD concept meets all technical requirements, and we can design and fabricate the demonstrator system within the given schedule at reasonable cost.

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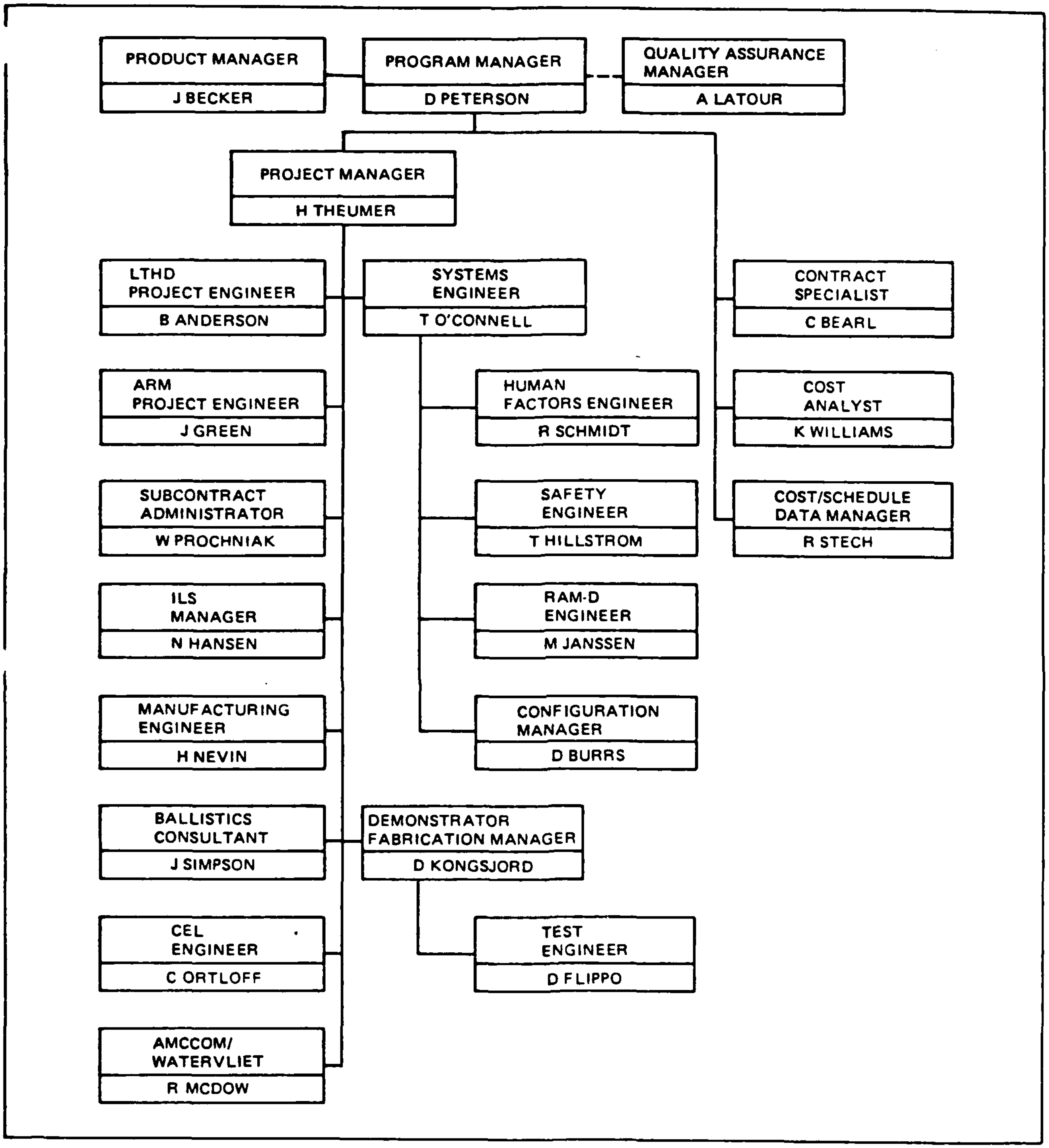


Figure 1-2. THE LIFWS PROJECT IS STAFFED with experienced design and development personnel.

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# Section 2
# Understanding the Requirements

> We understand the weight, stability, and operational requirements of the Lightweight Towed Howitzer Demonstrator (LTHD).

## 2.1 PROJECT OBJECTIVE

Our objective for the LTHD project is to develop and fabricate a 155-mm LTHD that can demonstrate the deployability and operability of a lightweight fire support system via airlift by upgraded Blackhawk (UH-60) helicopter and use of existing and developmental 155-mm ammunition. Performance and stability will meet or exceed that of the existing M198 Towed Howitzer. Appropriate advanced technology, as well as proven engineering concepts and components, will be combined to achieve the objective within the given timeframe and at the lowest possible risk.

Following concept definition, concept development, and detailed design, we will fabricate and deliver a demonstrator to ARDC for testing. We will develop a weapon with the following characteristics:

1. Weigh 9,000 pounds or less (to be transported by the modified Blackhawk helicopter)
2. Fire the 155-mm ammunition presently in U.S. Army stockpiles, as well as improved ammunition presently under development
3. Exhibit ballistic similitude to the M198 Towed Howitzer
4. Have a range of 30 km with rocket-assisted projectiles
5. Perform equal to or better than the M198 Towed Howitzer
6. Be emplaceable by a four-person crew in 3 minutes or less
7. Be shiftable by a four-person crew through 6,400 mils in 3 minutes or less
8. Provide stability equal to or better than the M198 howitzer system under both firing and cross-country touring conditions

As we address the project objective throughout this technical proposal, our discussions will reflect our understanding of both the objective and the issues that must be resolved in accomplishing it.

## 2.2 SYSTEM OPERATIONAL REQUIREMENTS

> Our experience as a designer and developer of gun systems ensures the LTHD will fully meet the operational requirements.

### 2.2.1 Performance Requirements

The purpose of the LTHD is to provide the Light Infantry Division with the range and firepower of a 155-mm fire support weapon

[redacted]

that can be airlifted for remote emplacement by a modified Blackhawk helicopter. Therefore, the following requirements must be met:

1. Meet or exceed the performance of the present M198 Towed Howitzer (which is too heavy to be airlifted by a UH-60 Blackhawk helicopter Blk 1 Mod), and exhibit the same or greater stability.
2. Fire all 155-mm ammunition presently in stock (i.e., projectiles, fuzes, and charges), and be capable of accepting modular charges presently under development.
3. Be towable by the family of tactical trucks presently in the U.S. Army inventory.
4. Operate with the same or smaller crew size as the M198 Towed Howitzer.

### 2.2.2 Physical Characteristics

The LTHD must meet the lift limitations of a modified Blackhawk helicopter. The system must also be capable of performing properly in the ambient situations specified for U.S. Army field equipment. The weapon must be able to withstand the rigorous treatment of off-the-road towing, and must possess these characteristics:

1. Weight of 9,000 pounds or less
2. Range of 24 km, unassisted; 30 km with rocket-assisted projectiles
3. Chamber pressure not in excess of 50,000 psi
4. Elevation range of -90 to 1,280 mils
5. Height and width not exceeding that of the M198 Towed Howitzer
6. Impulse to the recoil mechanism not exceeding 12,500 pound seconds
7. Crew protection from excessive noise or blast overpressure (MIL-STD-1474)
8. Operation within the requirements of MIL-STD-1472

Options such as extended range through higher chamber pressure, more powerful charges, longer gun tube, adaptation of future innovative recoil technology, and possible further weight reductions will be considered and applied whenever feasible or practicable within potential schedule or performance risks.

### 2.2.3 Operational Considerations

Developing a weapon system requires a detailed understanding of the environment in which, and the conditions under which, it is expected to perform. Because the weapon is planned for use with the Light Infantry Division, the assignment to a Rapid Deployment Force (RDF) mission is likely. As this assignment could take the weapon to any part of the world and would require the weapon to function reliably under any climatic conditions, special emphasis will be given to design for these encounters.

Designing a 155-mm weapon system with a weight far below anything presently in anyone's arsenal, yet capable of performing equal to or better than existing systems, will require innovative design efforts. Our proposed concept employs an unconventional configuration that takes advantage of new approaches. This unconventional-looking system will, however, provide the low-risk development demanded by the stringent schedule, and does consist of a judicial mix of innovative technology and conventional proven components. There will be room for further developments as the system progresses through advanced stages of design.

#### 2.2.3.1 Deployment

The system will conceivably be deployed within the RDF by airlifting the weapon, crew, and ammunition to the emplacement point. The unit will continue to depend on airlifted supplies until ground-based routes to the battery position can be established, and wheeled or tracked vehicles arrive. Under these conditions, the crew and

[redacted]

weapon could be exposed to hostile fire with very limited capability to displace to another position. Remote deployment under these conditions requires a reliable weapon system with "fail soft" capability (i.e., to be usable even with reduced performance). Maintenance will, to a certain extent, be conducted by the crew instead of a far-removed support unit. The crew would also have to move ammunition not directly deposited into the weapon firing position.

This emplacement scenario will, of course, substantially increase the risk of losing the weapon. The only assistance would be from those helicopters that are Light Infantry Division assets and are also used to fly combat missions and provide airlifted resupply. Another possibility would be a new type of towing vehicle that would be light enough (i.e., weigh less than 9,000 pounds and also tow 9,000 pounds) to be airlifted during a second wave deployment. However, the tradeoff remains the availability of fire support by 155-mm caliber howitzers with superior range and projectile payload capability requiring the UH-60 (Blk 1 Mod) or a towing vehicle to change position, or a much lighter 105-mm system which could possibly be moved by the crew unassisted by a towing vehicle.

The system could also be deployed in the conventional towed artillery method by being hauled into position by a vehicle which would also act as an ammunition support vehicle as needed. Therefore, the LTHD can be a replacement for heavier towed howitzer systems of identical caliber.

### 2.2.3.2 Operation and Maintenance Considerations

Operating and maintaining military equipment requires special consideration by the designer to allow the operator and maintainer to perform their tasks under adverse conditions.

Operation of equipment can be made easier by providing easy access to handles, wheels, controls, indicators, etc., and by ensuring tasks can be accomplished without excessive exertion. These human design criteria must fall within the range of human capabilities of the 5th to 95th percentile of the U.S. Army population. Equipment must be laid out to achieve efficient operation. Although this may be a function of task assignment, it has been and will continue to be considered during weapon design. Design of operational features will require the continued involvement of human factors engineering to optimize system effectiveness.

In a similar fashion, maintenance, at least that portion of it that is expected to be performed in the field away from maintenance facilities, must be easily accomplished. The use of common tools and simple procedures must be considered to allow a rapid return to the mission should maintenance become necessary.

These considerations may, in some cases, lead to simple and easy replacement of modular subsystems that require complicated maintenance at proper facilities (a tradeoff for ease of maintenance in the field, particularly in remote locations). Supply of replacements could be accomplished similar to, or in conjunction with, ammunition resupply.

[redacted]

# Section 3
# System Concept

> The FMC Lightweight Towed Howitzer Demonstrator (LTHD), providing M198 performance and stability in a 9,000-pound package with a conventional recoil mechanism, is also compatible with the FMC Artillery Recoil Mechanism (ARM) concept.

This section describes our design approach and concepts for the LTHD and is divided into these areas:

1. A summary of the evolution of the concept, problems, alternatives, and analyses employed to arrive at the solution (paragraph 3.1)

2. A brief overview followed by a description of the LTHD from the operational perspective (paragraph 3.2)

3. Detailed descriptions of the cannon, carriage, and fire control systems (paragraph 3.3)

This descriptive approach will provide adequate background for understanding our concept design decisions and will also provide sufficient detail for evaluating our concept design.

## 3.1 CONCEPT EVOLUTION

> The unique requirements of ultralight towed artillery are combined with composite technology through a concept evaluation framework to create the FMC LTHD.

Long-range large-caliber weapons tend to be heavy for good reasons (e.g., firing stability and reduced recoil forces). Therefore, the successful designer of a lightweight long-range large-caliber weapon will have to carefully consider all the ramifications of this ultralight requirement in all stages of the problem solution process: definition, generation, evaluation, and implementation.

### 3.1.1 The Problem

Defining the problem from the viewpoint of the procurement agency, vendors, and users will be vital to the success of the project. However, creating new concepts is pointless if the underlying problems are ill-defined or completely overlooked.

Our primary objectives for the LTHD program include:

1. Developing an LTHD that weighs 9,000 pounds
2. Providing M198 performance and stability

[redacted]

3. Being cost-effective and timely during the demonstrator phase
4. Using minimal sole sources during production
5. Not increasing blast overpressure or reducing operations effectiveness

Before detailing the primary objectives, we will describe these elements of the problem:

1. Weight reduction and stability
2. Stability and recoil force reduction
3. Stability, trunnion height, and trail length
4. Necessary weight reduction
5. Recoil mass reduction
6. Weight reduction and slide avoidance
7. Operations
8. Towing
9. Deployment
10. Environmental constraints

### 3.1.1.1 Weight Reduction and Stability

Two conditions must be considered if we assume that incorporating a few simple material changes could provide an M198 structure that weighs 9,000 pounds and that retains its current firing range of 155-mm conventional and improved munitions:

1. The M203 impulse should be valued at 12,500 pound seconds rather than the nominal figure of roughly 11,980 pound seconds generally used.
2. The minimum design quadrant elevation (QE) for this maximum charge should be 0 rather than the 270 mil limit currently in effect per the M198 Specification (Revision 1, April 1981, page 63).

However, incorporating the above conditions would inadvertently create an unsafe weapon. The weight of the howitzer is no longer sufficient to hold it down during firing. Figure 3-1 illustrates the firing stability problem.

To regain stability, we have three basic choices:

1. Reduce the recoil force.
2. Drop the trunnion height.
3. Lengthen the trails.

### 3.1.1.2 Stability and Recoil Force Reduction

Many recoil force reduction methods have been evaluated. They all have one characteristic in common—when something is gained, something else is lost. The four basic approaches are as follows:

1. Using recoilless artillery
2. Using muzzle brakes
3. Using soft recoil
4. Increasing conventional recoil stroke

#### 3.1.1.2.1 Using Recoilless Artillery

Recoilless artillery reduces the recoil to zero, while significantly reducing range for a given charge and projectile. However, because the M198 projectiles, charges, and ranges must be maintained, the relatively inefficient recoilless option can be immediately dismissed.

#### 3.1.1.2.2 Using Muzzle Brakes

Muzzle brakes significantly reduce recoil forces at the expense of overpressure exposure to the crew. Concern over the maximum allowable blast overpressure an M198 crew can tolerate has led FMC to view the M198 muzzle brake as the upper limit for U.S. towed artillery, at least in the LTHD timeframe.

#### 3.1.1.2.3 Using Soft Recoil

Soft recoil expands the time over which the recoil force can be applied, resulting in more effective use of the stroke but complicating the consequences of cookoff and misfire. These consequences result in the use of procedures that vary with charge and

[redacted]

sensitivity to ignition delay variances. If a NATO primer is used, we must use procedures which vary with temperature and country of origin.

Progress in the technologies that support soft recoil is encouraging but difficult to assess with respect to the overall probability of success. FMC views soft recoil as an important concept to continue evaluating, but feels it is too unpredictable to include in the LTHD portion of the Lightweight Indirect Fire Weapon System (LIFWS) Project at this time.

3.1.1.2.4 Increasing Conventional Recoil Stroke

Increasing conventional recoil stroke reduces the necessary retarding force (figure 3-2) and facilitates conventional handling of cookoff and misfire. However, increasing the conventional recoil stroke increases weight and the chance that sealing problems could occur.

Progress in the field of high-pressure high-velocity hydraulic seals has increased the upper limit on recoil stroke. Progress in the area of totally composite, high-pressure hydraulic cylinders for use in U.S. aircraft has paved the way to long recoil cylinders that weigh less.

FMC views increasing recoil stroke as the lowest risk method to regain stability through recoil force reduction.

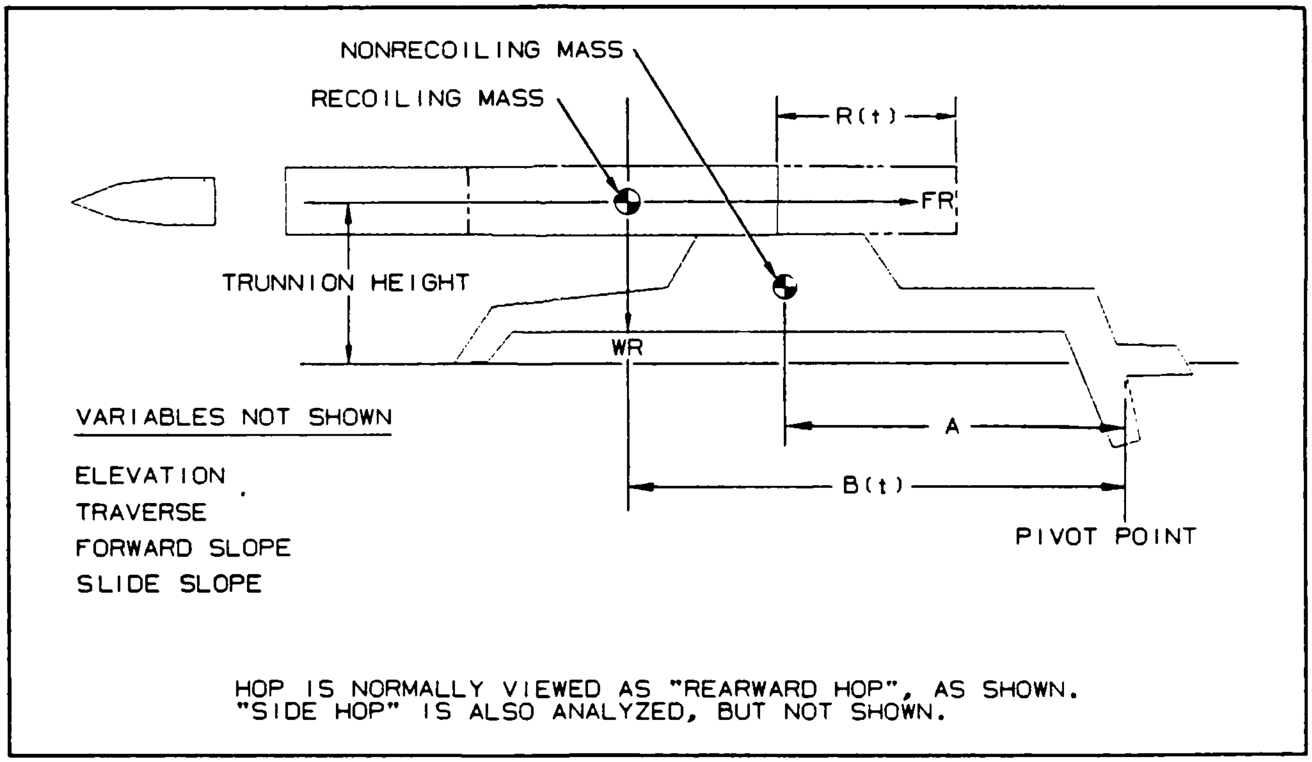


Figure 3-1. FIRING STABILITY MODEL accounts for moving CG, azimuth, ground slope, and QE.

[redacted]

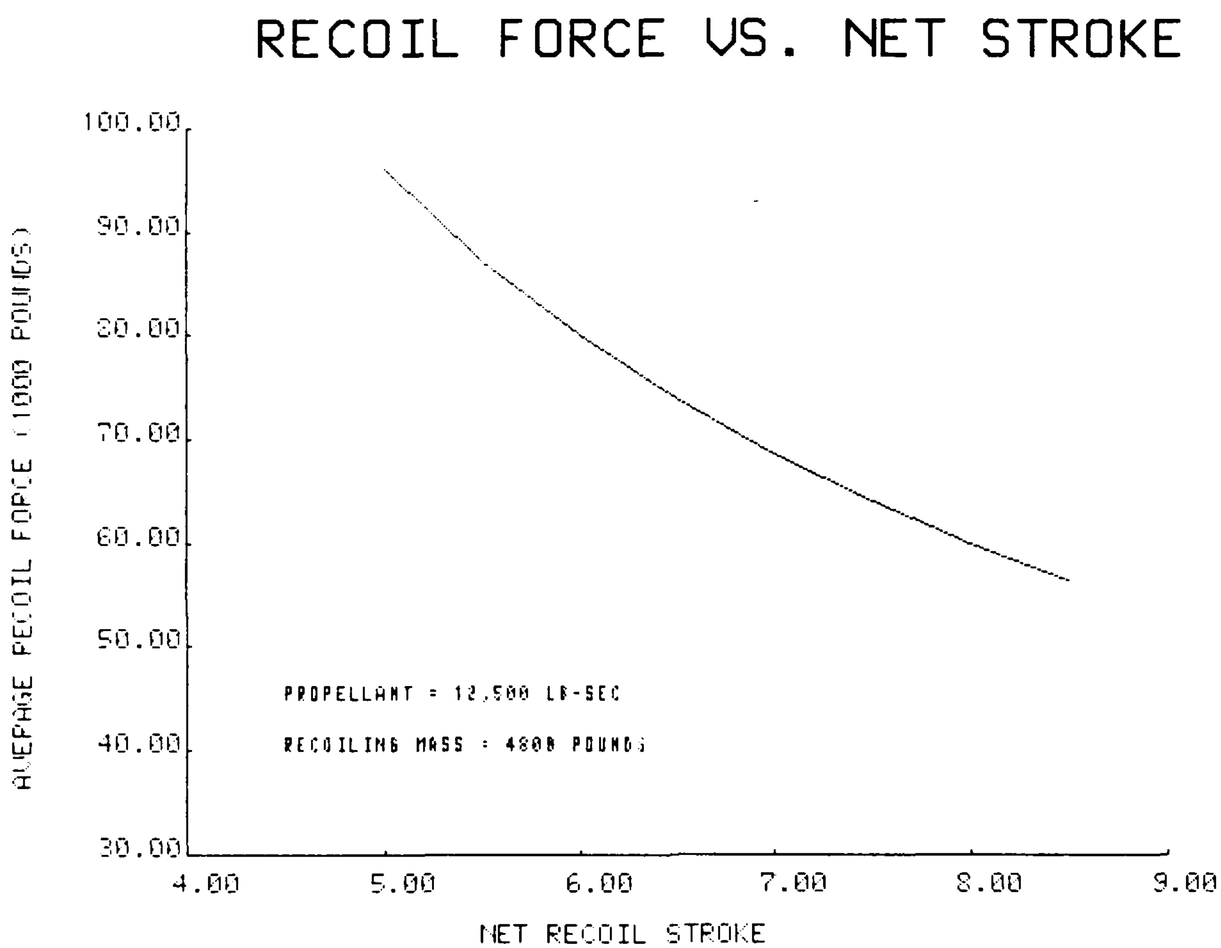


Figure 3-2. FIRING STABILITY CAN BE IMPROVED by increasing recoil stroke.

[redacted]

### 3.1.1.3 Stability, Trunnion Height, and Trail Length

Reducing the trunnion height has the most significant impact on stability and the least significant impact on weight. For example, reducing the M198 trunnion height from 4 to 2 feet is equivalent to increasing the recoil stroke from 70 to 140 inches or lengthening the trails from roughly 20 to 40 feet. Secondly, reducing the trunnion height serves to align the load path and reduce structure stresses, thereby reducing structure weight. However, reducing the trunnion height also makes loading more difficult and further limits the recoil stroke with a conventional configuration.

### 3.1.1.4 Necessary Weight Reduction

Assuming a 9,000-pound M198 can be made stable through a combination of recoil force reduction, reduced trunnion height, and lengthened trails, we must first determine if the necessary weight reduction (with a derivative of the M198 configuration) is achievable. The recoiling mass of the M198 is 7,000 pounds. The nonrecoiling mass of the M198 is 8,600 pounds; the nonrecoiling mass of the LTHD (assuming the same recoiling mass as the M198) is 2,000 pounds. Thus, the nonrecoiling mass must be reduced from 8,600 to 2,000 pounds to achieve a system weight of 9,000 pounds. This reduction would necessitate an average weight reduction in the nonrecoiling mass of 77 percent. Although not impossible, such a reduction would be prohibitively expensive.

Another solution would be the adoption of a modern, lightweight configuration such as the L119 howitzer. The L119 howitzer has a system-to-projectile weight ratio of 1,858 to 16 kg (or 116 to 1). Applying this ratio to the M198 (and using a 103-pound projectile), we arrive at 11,950 pounds (103 multiplied by 116), which is roughly halfway between the 15,760-pound M198 and the 9,000-pound requirement. (This comparison is a little misleading, because the L119 range is less than that of the M198, but it illustrates the fact that the M198 is already a fairly weight-efficient design, even by current standards.)

Both the M198 and the L119 were designed to be built with metal. Today's composite materials technology is promising and is starting to provide lightweight systems. However, reconfiguring conventional (metal-based) systems to capitalize on the properties unique to composites is frequently necessary.

FMC feels that an unconventional configuration, developed in harmony with composite materials and optimum recoil force, trunnion height, and trail length, will provide the most cost-effective LTHD.

### 3.1.1.5 Recoiling Mass Reduction

Reducing the weight of the cannon (the most massive item in the howitzer) seems logical. However, reducing the weight of the cannon increases the recoil force (figure 3-3), which worsens stability and enlarges the structure. Secondly, reducing the recoiling mass increases recoil velocity. This recoil velocity will necessitate a higher muzzle velocity relative to the barrel to maintain the muzzle velocity relative to the ground in order to maintain M198 range.

FMC feels a weight-reduced cannon will probably be necessary, but the weight reduction should be balanced against the increase in structural weight caused by higher recoil forces and resultant structural loads.

### 3.1.1.6 Weight Reduction and Slide Avoidance

A more subtle problem, sometimes referred to as horizontal displacement or slide, also exists. Reducing howitzer weight increases slide. The mechanism is similar to that of recoil.

[redacted]

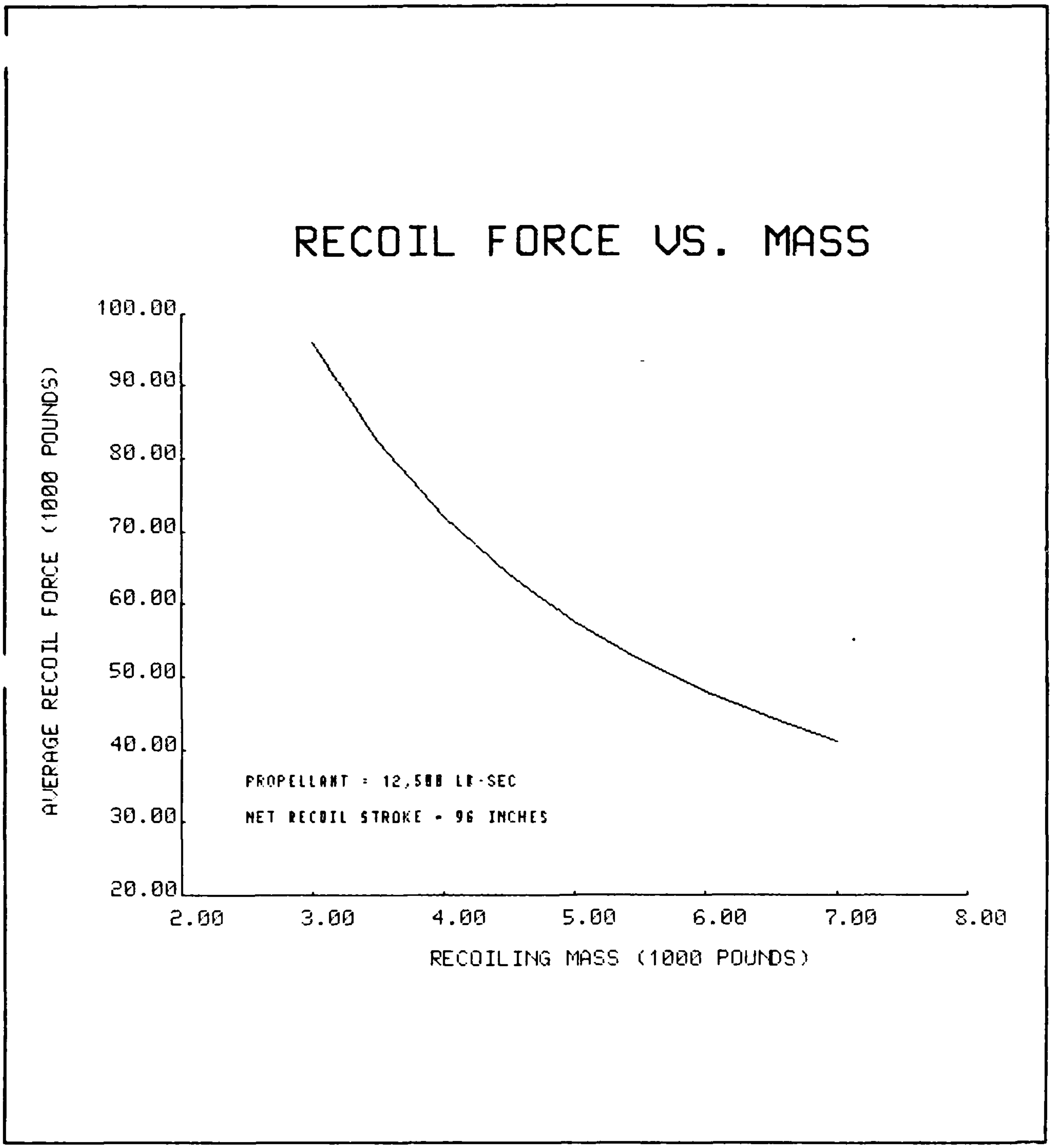


Figure 3-3. FIRING STABILITY IS REDUCED by reducing recoiling mass.

[redacted]

The recoiling mass is joined to the nonrecoiling mass with the recoil mechanism. (The nonrecoiling mass, in reality, also recoils.) This pseudo-nonrecoiling mass is joined to the true nonrecoiling mass (earth) by the spade-soil mechanism. Thus, just as reducing the recoiling mass increases the stroke necessary to hold the recoil force at the same level (figures 3-3 and 3-2, respectively), reducing the pseudo-nonrecoiling mass increases the stroke of the spade-ground mechanism (constant spade area, constant resisting force). This is slide. Thus, reducing howitzer weight increases slide.

To maintain the same slide as the M198 within the same ground conditions, the spade effectiveness must increase. The primary measure of spade effectiveness is spade area. FMC feels spade area will have to increase in such a manner that weight and emplacement/displacement times are reduced.

3.1.1.7 Operations

During the conceptual process of solving all mechanical problems, we must remember that a variety of people must be able to operate the LTHD at midnight, with no moon; in mud, with freezing rain driven by a high wind; and in subzero temperatures. Secondly, component failures and crew reductions must have a "soft" impact upon system operation, whenever possible, especially in functions critical to mission objectives.

3.1.1.8 Towing

Stability generally refers to firing stability. However, towing stability problems can also be as serious as firing stability problems. Unfortunately, weight reduction tends to worsen towing stability problems.

Both solid suspension systems and small tires save weight, but small tires require high-inflation pressures. These high-inflation pressures only serve to stiffen the ground engagement and aggravate the problems caused by a solid suspension. If small tires with high-inflation pressure are used, the contribution the LTHD can make to the rapid deployment force (RDF) could be nullified by an inability to survive towing.

FMC views towing stability equal in importance to firing stability. The suspension system or ground engagement will have to be softer than the M198.

3.1.1.9 Deployment

Weight is critical to tactical (helicopter) deployment. Tactical deployment by the UH-60 helicopter (modified to achieve 9,000-net lift capacity) is the driver of the weight reduction. Weight reduction is the driver of the LTHD. We have assumed that the slings are not included in the 9,000-pound howitzer specification; the actual hook load will be 9,000 pounds plus the weight of the slings and necessary rigging. Aerodynamic stability of the howitzer, while important, is viewed as a relatively minor consideration at this point.

Vertical shock loading, overall width, and height are critical to successful strategic deployment. Vertical shock loading due to ground impact from air-drop will produce 15 through 20 g's on the structure.

The C130 presents the greatest constraints upon overall stowed dimensions. Width and height are the most critical.

The 110-inch wide creates C130 loading problems. When narrow tires are put on, the width is reduced to 99 inches, but the inflation pressure must increase from 45 to 100 psi, thus creating a towing stability problem. The fact that these tires are not standard complicates the logistics aspect of the RDF mission.

The height of the howitzer is critical; the howitzer must clear the exit opening as the howitzer tips and slides down the ramp during extraction from the C130 by

[redacted]

parachute. This height constraint is more critical than that imposed by the 747's lower ceiling, because cargo is not extracted from the 747.

The C130 can handle an object that is 40-feet long. However, if the howitzer is winched on, the maximum length of the howitzer must be reduced by roughly 2 feet.

The combination of M198 lunette load and C130 ramp capacity creates a problem with loading: the 2.5-ton truck which must be used (to stay under the ramp limit) is being phased out. The elimination of this truck creates a logistics problem. This high lunette load should be avoided if possible.

FMC feels that the LTHD should meet these towing and transportation criteria:

1. The LTHD must be narrower than the M198.
2. The lunette load in the stowed configuration should be significantly reduced.
3. Standard tires and rims should be used if possible. High-Mobility Multipurpose Wheeled Vehicle (HMMWV) components should be used, if possible.

3.1.1.10 Environmental Constraints

Figure 3-4 summarizes the environmental constraints. Proper sealing joint design and careful selection of coating materials will provide the necessary waterproofness and resistance to humidity, fuel, hydraulic fluid, cleaning agents, and cleaning spray. Secondly, the configuration will eliminate those "hidden corners" that cannot be thoroughly cleaned in the event of contamination.

| ENVIRONMENTAL REQUIREMENTS | |
|---|---|
| REQUIREMENT | SPECIFICATION |
| OPERATING TEMPERATURE | -25 DEGREE F TO +160 DEGREE F |
| STORAGE TEMPERATURE | -70 DEGREE F TO +160 DEGREE F |
| HUMIDITY | 99 % PER MIL-STD-810D PROCEDURE II |
| SHOCK | MIL-STD-810D, METHOD 514.2 AS A GUIDE |
| VIBRATION | .4 INCH DOUBLE AMPLITUDE 1 TO 14 HZ, AND 4G 14 TO 500 HZ |
| FUEL | PER VV-F-800, MIL-T-5624, I MIL-G-3056, AND MIL-F-16884 |
| HYDRAULIC FLUID | PER STANDARD FIRE RETARDENT SPEC. MIL-STD-6083D |
| CLEANING AGENTS | PER P-C-437 |
| CLEANING SPRAY | WATER JET SPRAY 12 INCHES AWAY AND 90 DEGREES TO SURFACE |
| DUST | PER MIL-STD-810D, METHOD 510, PROCEDURE I |
| TEMPERATURE SHOCK | PER MIL-STD-810D, METHOD 503 |
| WATERPROOFNESS | PER MIL-STD-810D, METHOD 512.2 |

Figure 3-4. ENVIRONMENTAL REQUIREMENTS SHOULD BE EXPANDED to include fire retardancy--a necessary consideration when composite materials are involved.

[redacted]

Finite element analysis at the system level, in conjunction with material selection at the component level, will address temperature, shock, and vibration requirements. Composites have an advantage over metals in vibration and shock; composites can vary their damping capability.

Particular attention to oil reservoir breathers will achieve the necessary resistance to dust.

Use of composites will also require consideration of fire-retardant properties.

### 3.1.2 Generation of Alternatives

The generation of a broad range of alternatives is critical to the success of any unique opportunity that demands an unconventional solution. The LTHD presents such an opportunity.

Our initial approach produced a number of basic concepts. Concerned about the possibility that the optimum was not in the set of alternatives, we broke down the howitzer configuration into fundamental functional elements (figure 3-5). These elements were ground engagement, elevation, and traverse. Viewing the LTHD in this manner greatly expands the number of alternatives to 144. Figure 3-6 lists these alternatives.

### 3.1.3 Evaluation of Alternatives

Evaluation of alternatives requires skillful application of a broad range of analytical tools. Excessive attention to detail will "miss the forest for the trees," while too little will "spot you in the wrong forest."

The initial layers of evaluation were primarily qualitative. Previous discussions with Army, Navy, and international howitzer designers; users; and vendors provided us with an understanding for areas to avoid and areas to pursue and an understanding for the difference between nice and needed.

Figure 3-7 shows a few of the basic configurations considered. The unconventional configurations, compared to the conventional configurations (e.g., M114, M198, and M204), tended to be:

1. More compatible with composite construction
2. Capable of increased recoil strokes
3. Equipped with more weight efficient structures
4. Harder to load
5. Harder to equilibrate

The most relentless issue was that the most promising concepts aligned the firing load path with a low trunnion height. Both hamper manual breech access and trunnion accessibility, making the weapon harder to load and lay. Drawing on our mechanical breech access and electronic tube laying experience, we began to focus on the possibility of a manually operated, mechanically assisted breech and an electronic laying aid to address these issues.

### 3.1.4 Solution

A summary of the characteristics that led to our choice of the configuration for the FMC LTHD is shown in figure 3-8.

The FMC LTHD, relative to the other unconventional configurations, leads to:

1. Improved load path at both high and low QE's
2. Compatibility with the FMC ARM
3. An allowance for minimum trunnion height
4. A balanced weight distribution that results in one-third of the system weight holding the spade in the ground

[redacted]

NOTE: A model, fabricated to 1/12 scale to provide a hands-on demonstration, is available by request.

3.1.4.1 Analytical Approach

Our evaluation became increasingly quantitative. Sketches became shapes within Digital's VAX computer, via GEOMOD (software particularly well suited to geometric analysis). The most weight-strength critical parts were further analyzed using ANSYS, a software capable of determining stresses within complex shapes made of materials with properties that vary with orientation (composites).

Specific performance items (e.g., interior ballistics, recoil force profiles, firing stability, and elevation/depression rates) were handled on the Control Data Corporation Cyber, IBM 3270, and IBM personal computers. Custom programs have, when advantageous, been written to provide as much flexibility as practical.

A number of iterations at the system and component levels, in the areas outlined below, sized this preliminary concept of the FMC LTHD. The three primary inputs to this process were:

1. The optimal recoiling mass (paragraph 3.3.1)
2. The optimal retarding force (paragraph 3.3.2.3)
3. The optimal configuration providing for an optimal overall solution (covered in each paragraph as the parameters considered are covered)

The primary output was firing stability. Figure 3-9 shows a summary of the solution elements that regained M198 stability and their relative impact. A more detailed description of these elements and their relationship to the primary objectives, as defined in paragraph 3.1.1, is shown in figure 3-10.

3.1.4.2 Stability Analysis

A digital model was developed to analyze firing stability. This model takes these variables into account:

1. Moving CG of recoiling mass
2. Stationary CG of nonrecoiling mass
3. Resultant changing moment of inertia
4. QE
5. Traverse
6. Emplacement on an upgrade
7. Emplacement on a side slope

Figure 3-11 shows the LTHD stability for the case of zero QE, level ground, and centered traverse for both the nominal M203 (with M198 muzzle brake beta set at 0.70) and the 12,500 pound seconds input. The stabilizing moment (weight holding the howitzer down) is greater than the overturning moment (trunnion forces trying to tip the howitzer over) at all points of the recoil stroke.

We refer to the difference between the stabilizing moment and the overturning moment as the safety moment. Figure 3-12 illustrates how the safety moment is affected by side slope, upgrade, elevation, and traverse variations.

The stability model is currently being upgraded to account for system elasticity and joint clearances. Analysis to this point has assumed the components are rigid and component joints have zero clearance.

[redacted]

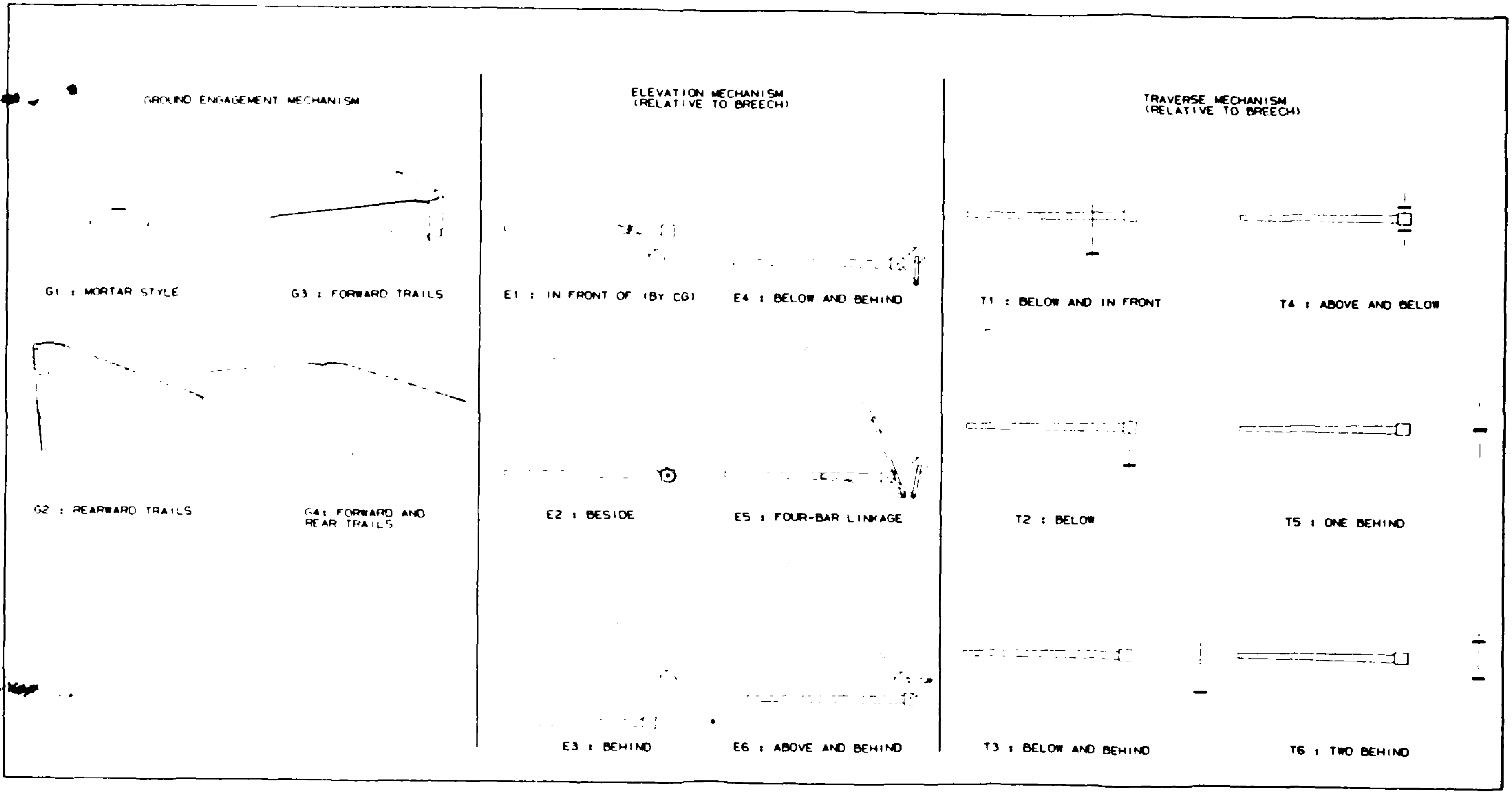


Figure 3-5. CLASSIFYING CONFIGURATION CONCEPTS provides a framework useful to the evolution of the FMC LTHD concept.

## Classification Scheme for Howitzer Configurations (Abstracted From Figure 3-5)

**Ground Engagement Mechanism**

G1 = Mortar-style
G2 = Rearward trails
G3 = Forward trails
G4 = Forward and rearward trails

**Elevation Mechanism (Relative to Breech)**

E1 = In front of (by C6)
E2 = Beside
E3 = Behind
E4 = Below and behind
E5 = Four-Bar linkage
E6 = Above and behind

**Traverse Mechanism (Relative to Breech)**

T1 = Below and in front
T2 = Below
T3 = Below and behind
T4 = Above and below
T5 = One behind
T6 = Two behind

## Examples of Howitzer Configurations Using Classification Scheme

| Combo | Get No. | Example | Combo | Get No. | Example | Combo | Get No. | Example | Combo | Get No. | Example |
|---|---|---|---|---|---|---|---|---|---|---|---|
| G1 E1 T1 | 1 | | G2 E1 T1 | 37 | M114 | G3 E1 T1 | 73 | | G4 E1 T1 | 109 | |
| G1 E1 T1 | 2 | | G2 E1 T2 | 38 | | G3 E1 T2 | 74 | | G4 E1 T2 | 110 | |
| G1 E1 T3 | 3 | | G2 E1 T3 | 39 | | G3 E1 T3 | 75 | | G4 E1 T3 | 111 | |
| G1 E1 T4 | 4 | | G2 E1 T4 | 40 | | G3 E1 T4 | 76 | | G4 E1 T4 | 112 | |
| G1 E1 T5 | 5 | | G2 E1 T5 | 41 | | G3 E1 T5 | 77 | | G4 E1 T5 | 113 | |
| G1 E1 T6 | 6 | | G2 E1 T6 | 42 | | G3 E1 T6 | 78 | | G4 E1 T6 | 114 | |
| G1 E2 T1 | 7 | | G2 E2 T1 | 43 | | G3 E2 T1 | 79 | | G4 E2 T1 | 115 | |
| G1 E2 T2 | 8 | | G2 E2 T2 | 44 | M198 | G3 E2 T2 | 80 | | G4 E2 T2 | 116 | |
| G1 E2 T3 | 9 | | G2 E2 T3 | 45 | | G3 E2 T3 | 81 | | G4 E2 T3 | 117 | |
| G1 E2 T4 | 10 | | G2 E2 T4 | 46 | | G3 E2 T4 | 82 | | G4 E2 T4 | 118 | |
| G1 E2 T5 | 11 | | G2 E2 T5 | 47 | | G3 E2 T5 | 83 | | G4 E2 T5 | 119 | |
| G1 E2 T6 | 12 | | G2 E2 T6 | 48 | | G3 E2 T6 | 84 | | G4 E2 T6 | 120 | |
| G1 E3 T1 | 13 | | G2 E3 T1 | 49 | | G3 E3 T1 | 85 | | G4 E3 T1 | 121 | |
| G1 E3 T2 | 14 | | G2 E3 T2 | 50 | | G3 E3 T2 | 86 | | G4 E3 T2 | 122 | |
| G1 E3 T3 | 15 | | G2 E3 T3 | 51 | | G3 E3 T3 | 87 | M204 | G4 E3 T3 | 123 | |
| G1 E3 T4 | 16 | | G2 E3 T4 | 52 | FMC Wedge | G3 E3 T4 | 88 | | G4 E3 T4 | 124 | |
| G1 E3 T5 | 17 | FMC Mortar | G2 E3 T5 | 53 | | G3 E3 T5 | 89 | | G4 E3 T5 | 125 | |
| G1 E3 T6 | 18 | | G2 E3 T6 | 54 | | G3 E3 T6 | 90 | FMC LTHD | G4 E3 T6 | 126 | FMC turret |
| G1 E4 T1 | 19 | | G2 E4 T1 | 55 | | G3 E4 T1 | 91 | | G4 E4 T1 | 127 | |
| G1 E4 T2 | 20 | | G2 E4 T2 | 56 | | G3 E4 T2 | 92 | | G4 E4 T2 | 128 | |
| G1 E4 T3 | 21 | | G2 E4 T3 | 57 | | G3 E4 T3 | 93 | | G4 E4 T3 | 129 | |
| G1 E4 T4 | 22 | | G2 E4 T4 | 58 | FMC Pistol | G3 E4 T4 | 94 | | G4 E4 T4 | 130 | |
| G1 E4 T5 | 23 | | G2 E4 T5 | 59 | | G3 E4 T5 | 95 | | G4 E4 T5 | 131 | |
| G1 E4 T6 | 24 | | G2 E4 T6 | 60 | | G3 E4 T6 | 96 | | G4 E4 T6 | 132 | |
| G1 E5 T1 | 25 | | G2 E5 T1 | 61 | | G3 E5 T1 | 97 | | G4 E5 T1 | 133 | |
| G1 E5 T2 | 26 | | G2 E5 T2 | 62 | | G3 E5 T2 | 98 | | G4 E5 T2 | 134 | |
| G1 E5 T3 | 27 | | G2 E5 T3 | 63 | | G3 E5 T3 | 99 | FMC Four Bar | G4 E5 T3 | 135 | |
| G1 E5 T4 | 28 | | G2 E5 T4 | 64 | | G3 E5 T4 | 100 | | G4 E5 T4 | 136 | |
| G1 E5 T5 | 29 | | G2 E5 T5 | 65 | | G3 E5 T5 | 101 | | G4 E5 T5 | 137 | |
| G1 E5 T6 | 30 | | G2 E5 T6 | 66 | | G3 E5 T6 | 102 | | G4 E5 T6 | 138 | |
| G1 E6 T1 | 31 | | G2 E6 T1 | 67 | | G3 E6 T1 | 103 | | G4 E6 T1 | 139 | |
| G1 E6 T2 | 32 | | G2 E6 T2 | 68 | | G3 E6 T2 | 104 | | G4 E6 T2 | 140 | |
| G1 E6 T3 | 33 | | G2 E6 T3 | 69 | | G3 E6 T3 | 105 | | G4 E6 T3 | 141 | |
| G1 E6 T4 | 34 | | G2 E6 T4 | 70 | | G3 E6 T4 | 106 | | G4 E6 T4 | 142 | |
| G1 E6 T5 | 35 | | G2 E6 T5 | 71 | | G3 E6 T5 | 107 | | G4 E6 T5 | 143 | |
| G1 E6 T6 | 36 | | G2 E6 T6 | 72 | FMC Space Frame | G3 E6 T6 | 108 | | G4 E6 T6 | 144 | |

Figure 3-6. THIS FRAMEWORK results in 144 conceptual configurations.

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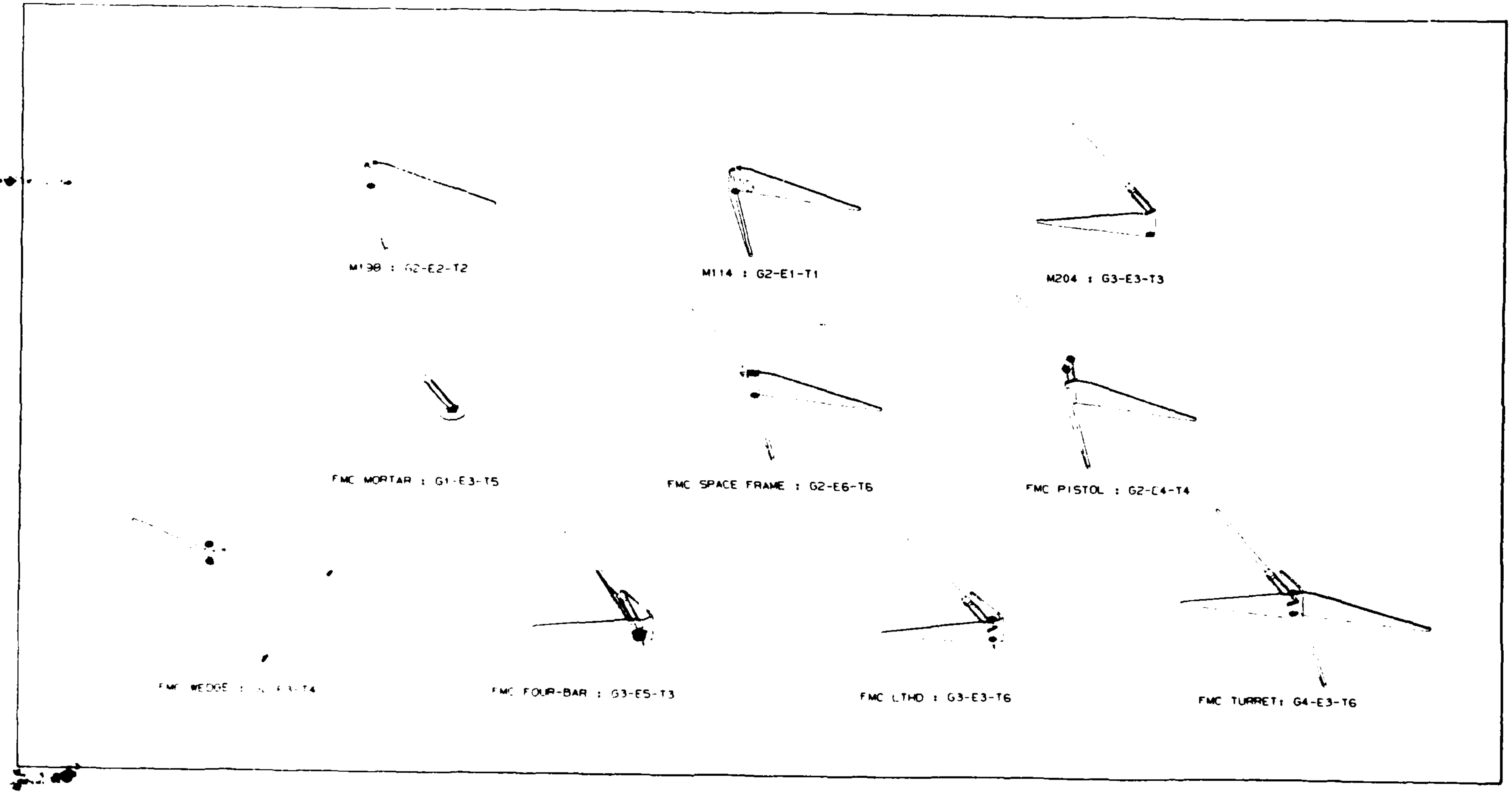


Figure 3-7. TEN of the 144 conceptual configurations are considered.

| Characteristics Critical to LTHD Objectives | Points | M114 | M198 | M204 | FMC Mortar | FMC Wedge | FMC Pistol | FMC Space Frame | FMC LTHD | FMC Four Bar | FMC Turret |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Weight of Howitzer: | | | | | | | | | | | |
| Structure compatibility with composites | 15 | 8 | 10 | 9 | 15 | 15 | 15 | 15 | 15 | 15 | 12 |
| Weight efficiency of structure | 10 | 4 | 5 | 5 | 10 | 5 | 5 | 5 | 8 | 5 | 5 |
| Low QE load path | 5 | 3 | 3 | 5 | 0 | 2 | 5 | 3 | 3 | 3 | 2 |
| High QE load path | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 5 |
| (Subtotal) | (35) | (20) | (23) | (24) | (30) | (27) | (30) | (28) | (31) | (26) | (24) |
| Firing Stability With Light Structure: | | | | | | | | | | | |
| Minimum trunnion height | 15 | 5 | 5 | 5 | 15 | 15 | 10 | 10 | 15 | 12 | 10 |
| Longer recoil compatibility | 15 | 4 | 5 | 7 | 15 | 15 | 10 | 10 | 15 | 10 | 15 |
| Compatibility with soft recoil | 5 | 3 | 3 | 5 | 5 | 5 | 0 | 0 | 5 | 5 | 5 |
| (Subtotal) | (35) | (12) | (13) | (17) | (35) | (35) | (20) | (20) | (35) | (27) | (30) |
| Operations Effectiveness: | | | | | | | | | | | |
| Attainability of zero QE | 10 | 10 | 10 | 10 | 0 | 10 | 10 | 10 | 10 | 10 | 10 |
| Traverse on carriage | 5 | 5 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 5 | 5 |
| Precision of barrel at projectile exit | 5 | 4 | 5 | 4 | 5 | 5 | 0 | 4 | 5 | 0 | 5 |
| Crew placement for blast overpressure | 5 | 4 | 4 | 4 | 5 | 4 | 4 | 4 | 5 | 3 | 5 |
| Manual access to breech | 3 | 3 | 3 | 3 | 0 | 2 | 2 | 2 | 0 | 2 | 0 |
| (or mechanical access if manual = 0) | 3 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 0 | 2 |
| Equilibration requirement | 2 | 2 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| (Subtotal) | (30) | (28) | (28) | (22) | (13) | (22) | (23) | (27) | (28) | (21) | (27) |
| Total | 100 | 60 | 64 | (63) | 78 | 84 | 73 | 75 | 94 | 74 | 81 |

Figure 3-8. A WEIGHTED COMPARISON of the conceptual configurations resulted in the FMC LTHD.

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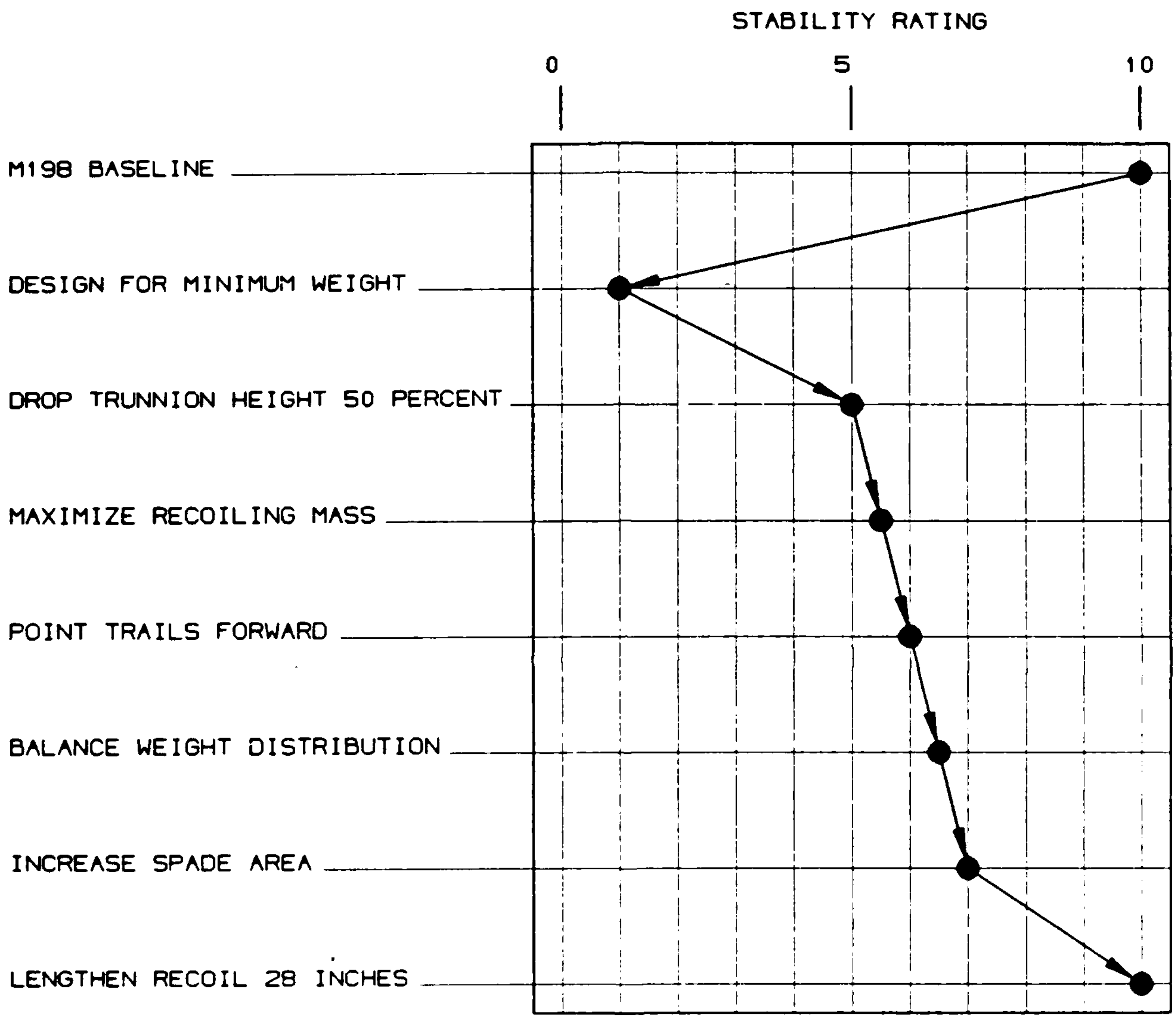



Figure 3-9. SEVEN STEPS provide the FMC LTHD with firing stability.

[redacted]

| Solution Element | Secondary Objective | Primary Objective |
|---|---|---|
| 0. Use M198 baseline | a. 30-km range | PERFORMANCE |
| 1. Design for minimum weight | a. Concept compatible with composites | WEIGHT REDUCTION |
| | b. Use composites to optimum degree | LOW RISK |
| 2. Drop trunnion height 50 percent | a. Reduce overturning moment during low QE firing | FIRING STABILITY |
| 3. Maximize recoiling mass | a. Hold recoil forces to minimum level possible for stability | FIRING STABILITY |
| | b. Facilitate use of conventional barrel to minimize barrel risk | LOW RISK |
| 4. Point trails forward | a. Facilitate balanced weight distribution | FIRING STABILITY |
| | b. Soft recoil is option | FIRING STABILITY |
| | c. Forward pointing trails provide anti-hop firing suspension | FIRING STABILITY |
| 5. Balance weight distribution | a. Increasing weight over spade improves holding power and stability | FIRING STABILITY |
| | b. Increasing weight on forward trails improves anti-hop effectiveness | FIRING STABILITY |
| 6. Increase spade area | a. Central spade reduces slide | FIRING STABILITY |
| | b. Three claws enhance spade in soft soil; replace spade in hard soil | |
| 7. Lengthen recoil 28 inches | a. Further reduce recoil force to level necessary for zero hop at less risk than altering muzzle brake | FIRING STABILITY |

Figure 3-10. THE SEVEN STEPS TOWARD FIRING STABILITY provide performance, weight reduction, and low risk.

[redacted]

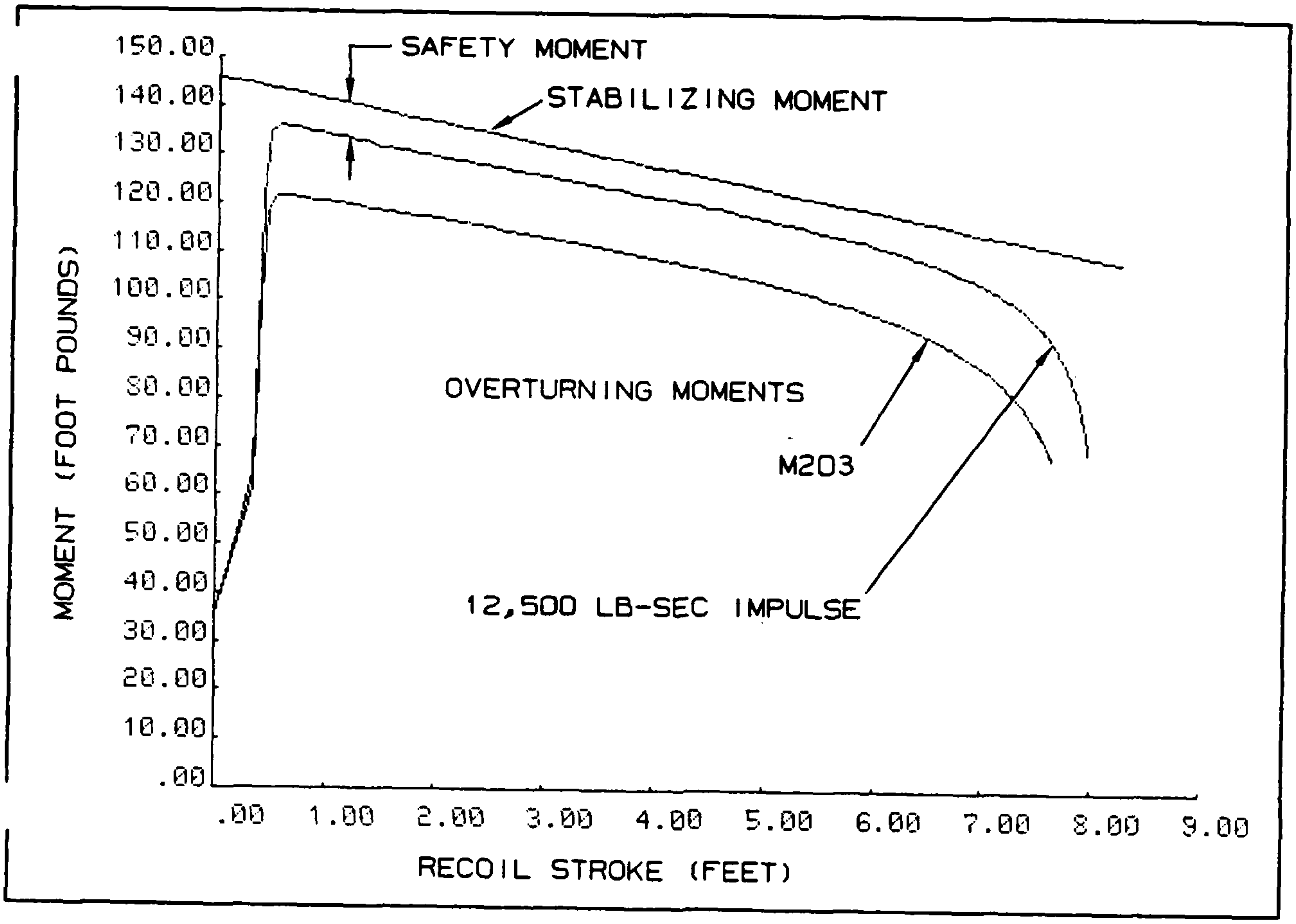



Figure 3-11. THE FMC LTHD provides a good margin of firing stability.

[redacted]

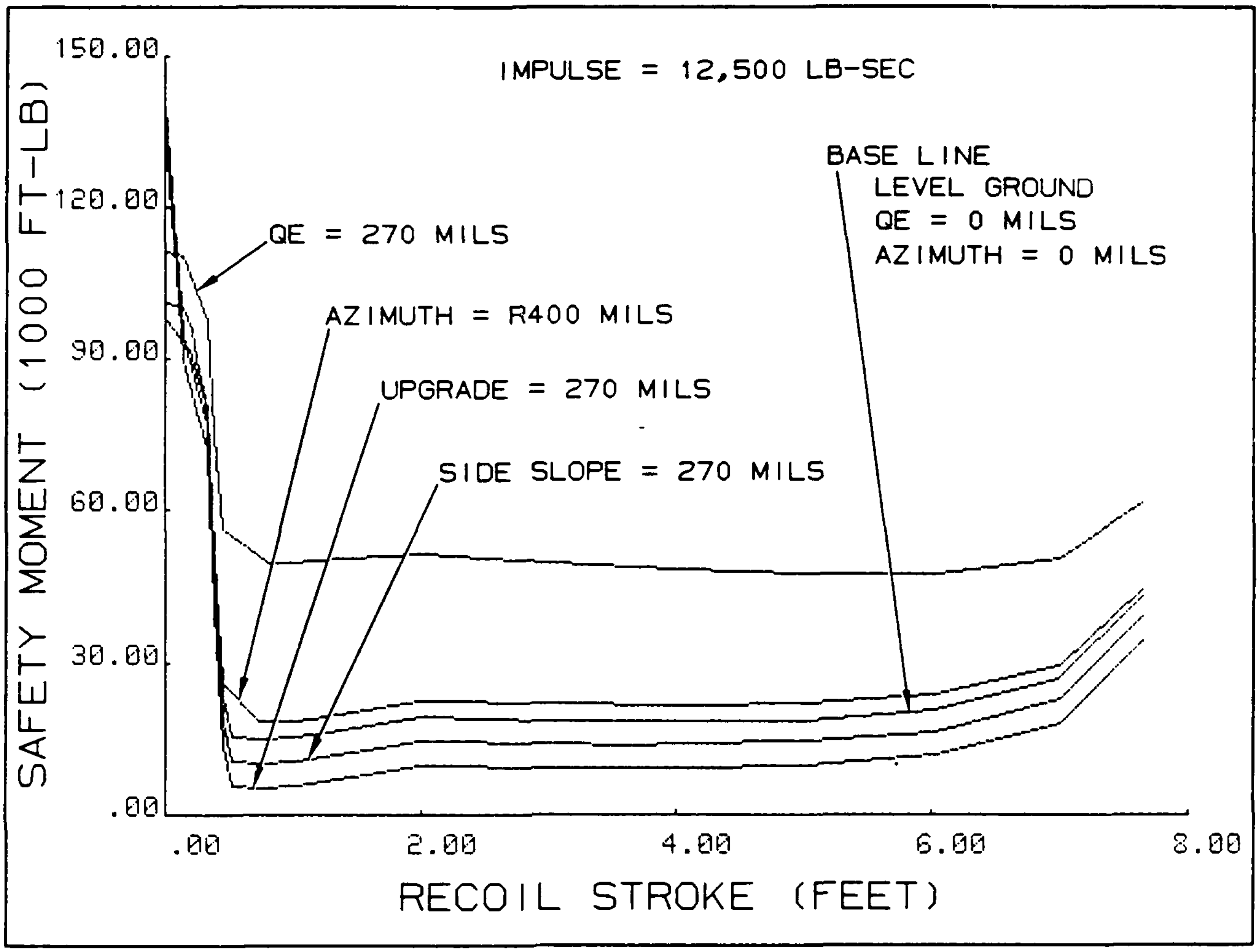



Figure 3-12. FIRING STABILITY is retained with traverse and on sloping terrain.

[redacted]

## 3.2 SYSTEM DESCRIPTION

> The FMC LTHD goes beyond M198 specifications in critical operational areas, while providing an 8,500-pound howitzer for helicopter-only movement.

The following subparagraphs provide a working understanding of the FMC LTHD. More detailed discussions at the component level are reserved for paragraph 3.3, Description of Subsystems. The thumbnail sketch of the LTHD (paragraph 3.2.1) provides sufficient understanding of the concept to embark on the operational description (paragraph 3.2.2).

### 3.2.1 Overview

The emplaced FMC LTHD is shown in figure 3-13. The configuration can be likened to an engine hoist. Elevation is achieved by raising and lowering the boom. The boom is composed of two slide tubes on the LTHD. The load is the cannon. The path of the cannon during recoil is defined by the slide tubes. The cannon and the slide tubes are joined by two recoiling yokes. Traverse is accomplished by mounting the boom on a swivel.

Projectile loading is accomplished with the load-tray mounted above the right slide tube. Projectiles are manually pushed up the load-tray with the permanently attached load-staff through the "right window" of the platform. When ready to ram, cannoneer 1 swivels the load-tray counterclockwise, and the projectile rolls into the ram-tube. The ram-staff is inserted through the "left window" of the platform, engages a "slider" (positioned at the base of the projectile), and the projectile is rammed. Loading is limited to 525 mils QE; ramming is limited to 800 mils QE. The resultant rates of fire are 4 rounds per minute to 525 mils, 2 rounds per minute to 800 mils, and 1 round per minute at 1,275 mils.

Howitzer lay is maintained with the M198 indirect fire control. The FMC LTHD platform is stationary, whereas the M198 upper carriage moves in azimuth. Tube lay relative to this stationary platform is done electronically and is displayed on the electronic laying aids. Elevation and traverse of the tube are accomplished with manually operated hydraulic pumps (one for the gunner and one for the assistant gunner).

Firing forces are focused into an integral firing platform, which is anchored to the ground through a central (hydraulically retractable) spade. This layout allows us to drop the trunnion by a full 2 feet, thus cutting the overturning moment in half. The forward pointing trails place one-third of the LTHD weight on the spade's integral platform to improve holddown and to provide the capability to convert to the FMC ARM without major redesign.

For towing, the cannon is depressed onto a dolly and secured by dolly mounts. These dolly mounts are an integral part of the recoiling yokes.

For more detail in a particular area, the Bill of Material (figure 3-14) also provides an index to additional views of specific components.

### 3.2.2 Operational Description

This paragraph describes these areas of operational description:

1. Deployment
2. Emplacement
3. Firing
4. Speed shift
5. Vulnerability to aerial bursts
6. Displacement



[redacted]

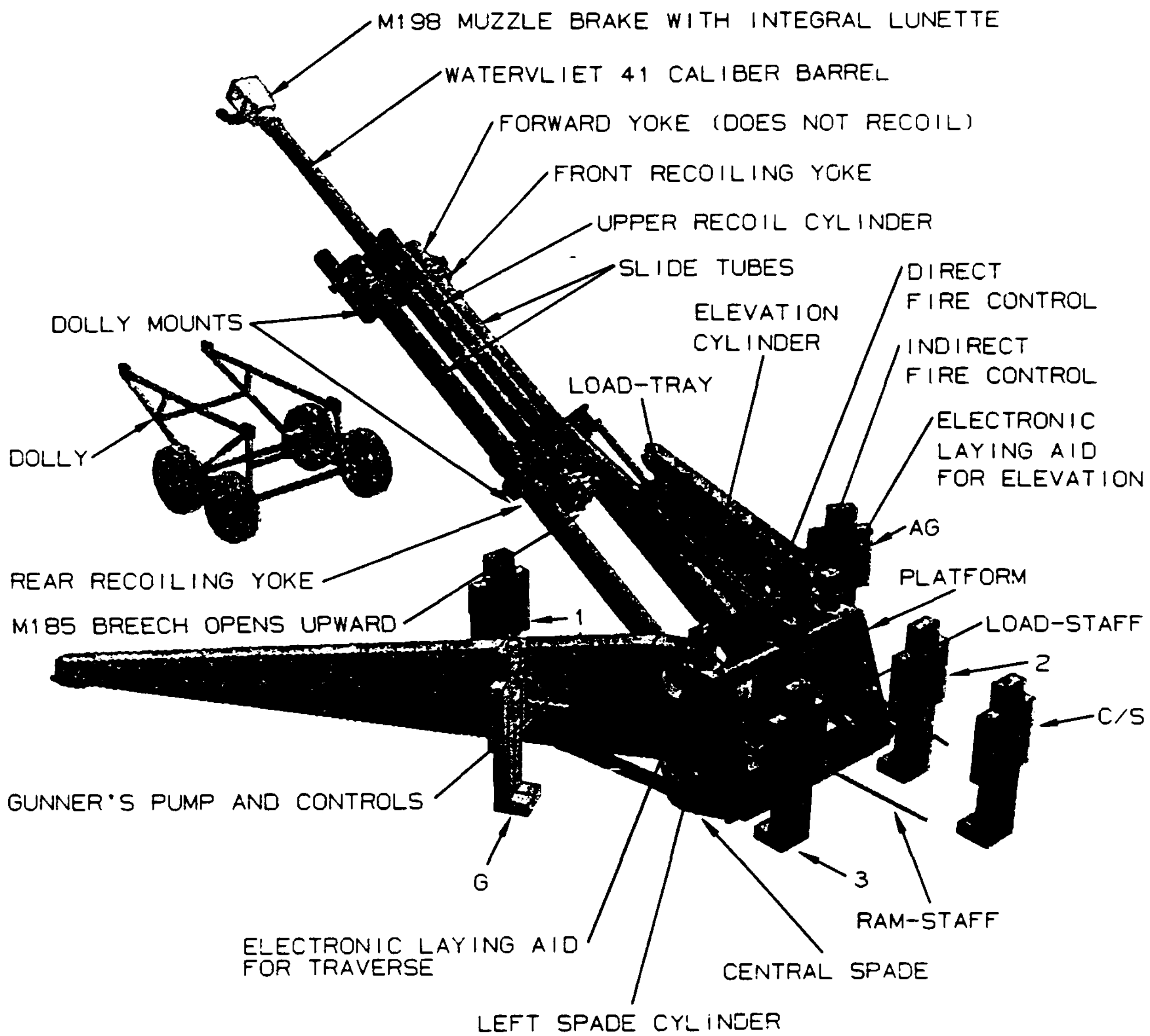



Figure 3-13. THE FIRING POSITION focuses the firing forces into a central spade and integral platform.

[redacted]

| Item | Weight Mean | SD | Material | Qty | Figure Number |
|---|---|---|---|---|---|
| Assembly: | 8,972 | 28 | | 1 | 3-13 |
| Cannon: | 3,756 | 12.73 | | 1 | |
| Barrel (41-caliber) | 2,600 | 10 | Steel | 1 | 3-31;13 |
| Breech (M185 but open up) | 800 | 6 | Steel | 1 | 3-31;13 |
| Breech band | 105 | 1 | Metal | 1 | 3-31 |
| Breech band bearing | 6 | 0.03 | Same as trunnion bearing | 2 | 3-31 |
| Muzzle plug | 5 | 0.02 | Plastic | 1 | |
| M198 muzzle brake with pintle | 240 | 5 | Metal | 1 | 3-31;13 |
| Carriage: | 5,216 | 25.05 | | 1 | |
| Structure: | 1,652 | 21.54 | | 1 | |
| Basic issue items | 150 | 3 | Various | 1 | |
| Claw--primary | 10 | 0.30 | Metal | 1 | 3-17 |
| Claw--secondary | 20 | 0.60 | Metal | 2 | 3-17 |
| Dolly: | 545 | 20 | Composite/metal | 1 | 3-32;13 |
| Brakes | | | Metal/rubber | 4 | |
| Dolly clamps | | | Metal | 4 | |
| HMMWV tire | | | Rubber/nylon | 4 | 3-32 |
| HMMWV--compatible rim | | | Aluminum or composite | 4 | 3-32 |
| Strap winch | | | Metal/nylon | 1 | 3-32 |
| Link-trail positioning | 36 | 0.50 | Metal | 2 | 3-32 |
| Platform | 220 | 5 | Composite/foam/metal | 1 | 3-32;13 |
| Safety "chain" | 5 | 0.02 | Steel/nylon | 1 | |
| Skid plate | 10 | 0.01 | Composite or metal | 2 | 3-32 |
| Spade | 200 | 3 | Composite or titanium | 1 | 3-32;13,39 |
| Spade bearing | 11 | 0.03 | Same as trunnion bearing | 2 | 3-32 |
| Spade mounting shaft | 30 | 0.25 | Composite | 1 | |
| Spade cylinder | 70 | 1 | Metal/composite | 2 | 3-32;13,39 |
| Trail--left | 135 | 3 | Composite/foam/metal | 1 | 3-32 |
| Trail--right | 135 | 3 | Composite/foam/metal | 1 | |
| Trail bearing | 5 | 0.02 | | 4 | |
| Traverse bearings | 5 | 0.02 | | 3 | |
| Travel lock--trail portion | 20 | 0.20 | Metal | 2 | 3-32 |
| Trunnion | 45 | 1 | Composite/foam/metal | 1 | 3-32 |

Figure 3-14. THE BILL OF MATERIAL includes a weight budget, which accounts for the variation in component weights and provides an average weight of under 9,000 pounds. (Sheet 1)

[redacted]

| Item | Weight Mean | SD | Material | Qty | Figure Number |
|---|---|---|---|---|---|
| Slide: | 1,091 | 6.06 | | 1 | |
| Breech cam | 45 | 1 | Metal | 1 | 3-35 |
| Carrier for projectile | 10 | 0.10 | Composite | 1 | |
| Elevation yoke | 230 | 2.50 | Metal/composite | 1 | 3-35 |
| Front recoiling yoke | 130 | 1.40 | Metal or composite | 1 | 3-35;13, 16,32,37 |
| Load-tray: | 110 | 3 | Composite/metal | 1 | 3-35;13 |
| Cleanout cover | | | Composite or metal | 1 | |
| Loading staff | | | Composite/rubber | 1 | 3-13 |
| Tray lever | | | Composite/rubber | 1 | |
| Ramming staff | 10 | 0.10 | Composite/rubber | 1 | 3-35;13 |
| Rear recoiling yoke | 135 | 1.50 | Metal or composite | 1 | 3-35;13,22,37 |
| Slide tube | 360 | 4 | Composite/foam/metal | 2 | 3-35;13,32 |
| Spacer, recoiling yokes | 50 | 0.50 | Metal or composite | 2 | |
| Trunnion bearing | 11 | 0.03 | Self-lube spherical bearing | 2 | 3-35 |
| Recoil system: | 1,567 | 10.51 | | 1 | |
| Dolly mounting bushing | 20 | 0.05 | Metal/rubber | 4 | 3-35;16,32 |
| Forward yoke: | 230 | 2.50 | Metal or composite | 1 | 3-37;13,32 |
| Firing lock mechanism | 30 | 0.40 | Metal | 2 | 3-37 |
| Into battery cushion | 4 | 0.08 | Metal/elastomer | 2 | |
| Travel lock--yoke portion | 10 | 0.10 | Metal | 2 | 3-37 |
| Recoil accumulator: | 155 | 2 | Metal/composite/N2 | 2 | 3-29;37,38,39 |
| Counterrecoil check | | | Metal/rubber | 2 | 3-38 |
| Fluid (pounds) | | | MIL-H-6083D | | |
| Recoil cylinder | 1,100 | 10 | Metal/teflon/rubber | 2 | 3-38;13, 32,37,39 |
| Front recoiling end cap | | | | 1 | 3-38 |
| Orifice ring | | | | 1 | 3-38 |
| Rear recoiling end cap | | | | 1 | 3-38 |
| Recoiling inner cylinder | | | | 1 | 3-38 |
| Recoiling outer cylinder | | | | 1 | 3-38 |
| Recoiling piston | | | | 1 | 3-38 |
| Stationary cylinder | | | | 1 | 3-38 |
| Stationary end cap | | | | 1 | 3-38 |
| Stationary piston | | | | 1 | 3-38 |
| Stationary piston rod | | | | 1 | 3-38 |

Figure 3-14. THE BILL OF MATERIAL includes a weight budget, which accounts for the variation in component weights and provides an average weight of under 9,000 pounds. (Sheet 2)

[redacted]

| Item | Weight Mean | SD | Material | Qty | Figure Number |
|---|---|---|---|---|---|
| Recoil cylinder shroud | 10 | 0.3 | Composite | 1 | 3-37;29 |
| Slide bearing and scraper | 8 | 0.03 | Teflon/rubber/metal | 2 | 3-35;37 |
| Hydraulic system: | 327 | 2.13 | | 1 | |
| Assistant gunner's elevation control valve | 8 | 0.04 | Same as gunner's | 1 | 3-39;40 |
| Assistant gunner's pump | 20 | 0.10 | Same as gunner's | 1 | 3-39;40 |
| Assistant gunner's reservoir | 50 | 0.50 | Same as gunner's | 1 | 3-39;40 |
| Fluid (pounds) | 90 | 2 | MIL-H-6083D | | |
| Gunner's elevation control valve | 8 | 0.04 | Metal/rubber | 1 | 3-39;40 |
| Gunner's pump | 20 | 0.10 | Metal/rubber | 1 | 3-40;13,39 |
| Gunner's reservoir: | 50 | 0.50 | Metal or composite | 1 | 3-40;39 |
| Gunner's spade control valve | 8 | 0.04 | Same as elevation control | 1 | 3-40;39 |
| Gunner's--traverse control valve | 8 | 0.04 | Same as elevation control | 1 | 3-40;39 |
| Hardline | 25 | 0.03 | | | |
| Hose | 20 | 0.02 | | | |
| Portable pump | 20 | 0.10 | Metal/rubber | 1 | 3-39 |
| Fire control | 150 | 2 | | 1 | |
| measurement: | | | | 1 | |
| Direct fire control (DFC) | | | M138/M18/M172 | 1 | 3-40;13 |
| Electronic laying aid--elevation | | | Composite/electronics | 1 | 3-40;13,41 |
| Electronic laying aid--traverse | | | Composite/electronics | 1 | 3-40;13,41 |
| Indirect fire control (IFC) mount--primary | | | Metal | 1 | 3-40 |
| IFC mount--secondary | | | Metal | 1 | 3-40 |
| IFC | | | M137/M171/M17 | 1 | 3-40;13 |
| Traverse: | 55 | 0.50 | | 1 | |
| Traverse cylinder | 45 | 0.50 | Metal/composite/rubber | 1 | 3-39;40 |
| Traverse XDCR: IFC to platform | 5 | 0.02 | Metal/electronics | 1 | |
| Traverse XDCR: platform to gun | 5 | 0.02 | Metal/electronics | 1 | |

Figure 3-14. THE BILL OF MATERIAL includes a weight budget, which accounts for the variation in component weights and provides an average weight of under 9,000 pounds. (Sheet 3)

[redacted]

| Item | Weight Mean | SD | Material | Qty | Figure Number |
|---|---|---|---|---|---|
| Elevation: | 374 | 2.83 | | 1 | |
| Elevation cylinder | 227 | 2 | Metal/composite/rubber | 1 | 3-42;13,39,40 |
| Belleville spring set | | | Composite | 1 | 3-42 |
| Depression piston and rod | | | | 1 | 3-42 |
| Elevation cylinder--inner | | | | 1 | 3-42 |
| Elevation cylinder--outer | | | | 1 | 3-42 |
| Elevation cylinder shroud | | | Composite | 1 | 3-29;40 |
| Elevation piston assembly | | | | 1 | 3-42 |
| Piston | | | | 1 | |
| Tube | | | | 1 | |
| Clevis--lower | | | | 1 | |
| Lower cylinder bearings | | | Self-lube spherical bearing | 1 | |
| Lower end cap | | | | 1 | 3-42 |
| Upper cylinder bearings | | | Same as trunnion bearings | 2 | |
| Upper end cap and clevis | | | | 1 | 3-42 |
| Elevation XDCR: IFC to platform | 5 | 0.02 | Metal/electronics | 1 | |
| Elevation XDCR: platform to cannon | 5 | 0.02 | Metal/electronics | 1 | |
| Equilibrator | 135 | 2 | Metal/composite/N2 | | 3-38;39,40 |
| Equilibrator hose | 2 | 0.02 | Metal | 1 | |

Figure 3-14. THE BILL OF MATERIAL includes a weight budget, which accounts for the variation in component weights and provides an average weight of under 9,000 pounds. (Sheet 4)

[redacted]

### 3.2.2.1 Deployment

The LTHD meets or exceeds most M198 specifications, but takes exception to two overall size dimensions that involve deployment--stowed height (2 inches higher) and stowed length (5 feet longer).

The stowed height increase is not expected to create a problem, because the critical height, determined by the C130 for LAPES and air-drop, increases with the distance from the last part of the howitzer to exit the plane. The FMC LTHD maximum height occurs further forward than does the M198 maximum height.

The stowed length is also set by the C130. As described in paragraph 3.1.1.9, this should not present a problem. The reasons for this length increase are as follows:

1. Longer barrel (41 caliber), necessitated by higher recoil velocities (explained in more detail in paragraph 3.3.1.1)

2. The stationary platform, which allows the firing forces to be focused into the ground, (thus, reducing weight) adds length behind the breech.

Figure 3-15 illustrates the LTHD from a tow/stow perspective. The tow configuration's tandem wheels and low center of gravity improve towing stability relative to the M198. The reduced height for stow is necessary for LAPES, specifically from the C130, to clear the top of the exit door during parachute extraction. Reduction ot the height (for LAPES) requires these two steps:

1. The dolly mounting bushing holders must be reversed.

2. The lunette height must be adjusted (figure 3-16).

### 3.2.2.2 Emplacement

Positioning the LTHD requires a smaller patch of solid ground than conventional howitzers due to the configuration's capability to focus the firing forces into an integral platform and central spade. Figure 3-17 shows the additional area from the three claws which, when combined with the ability to retract the spade, simplify emplacement upon rocky terrain.

The emplacement procedure is shown in figure 3-18. The LTHD is assumed to be disconnected from the helicopter or truck, and in position at the site at the start of the emplacement cycle.

Figure 3-19 shows the emplacement steps (summarized below) timelined for a crew of four. These steps are:

1. Extend platform

2. Spread trails

3. Unlatch spade

4. Open breech

5. Elevate cannon to 250 mils

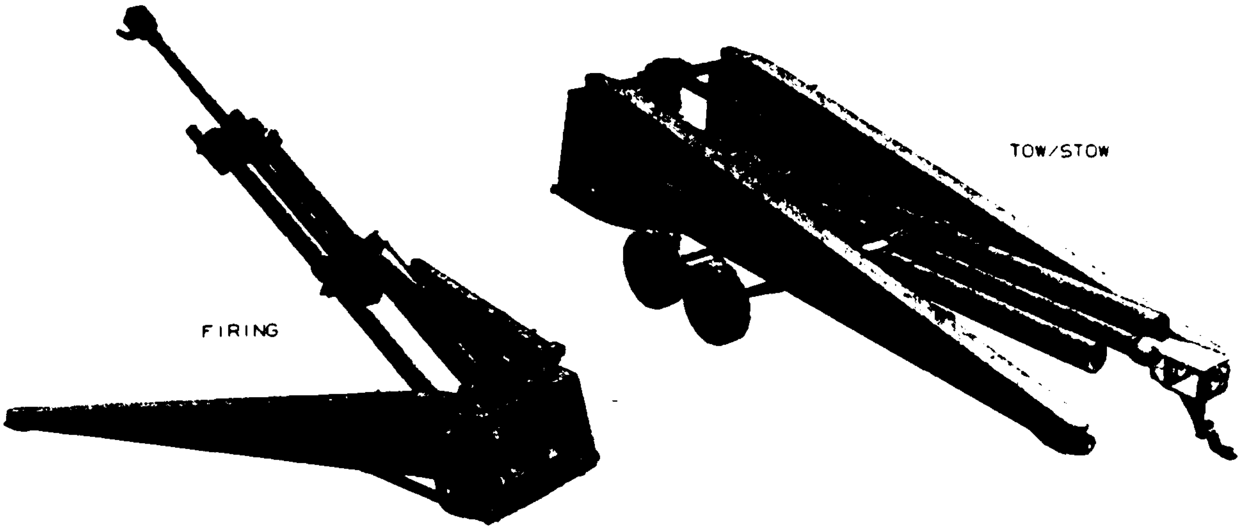
6. Unlatch dolly

7. Remove dolly

8. Verify yoke-tube locks

9. Position spade

[redacted]




| CONFIGURATIONS | FMC LTHD | M198 (REV 5 [illegible], APR [illegible] 198[illegible]) |
|---|---|---|
| TOWED | | |
| WEIGHT (AVG W/B[illegible]) | 8,972 LB | 15,760 LB |
| LENGTH x WIDTH x HEIGHT | 30'0" x 8'0" x 8'1" | 40'3" x 9'2" x 9'6" |
| ITEM CUBIC | 1940 CU FT | 3506 CU FT |
| LUNETTE LOAD | 250 LB | 500 LB |
| LUNETTE HEIGHT | 30" | 30" |
| • FORWARD MOST COMPONENT | LUNETTE | MUZZLE BRAKE |
| GROUND CLEARANCE | 14" | 13" |
| ANGLE OF DEPARTURE | 25 DEGREES | ? |
| TIRES | | |
| SIZE | 36 x 12.50 - LT | 16.5 x 19.5, 16 PLY |
| • QUANTITY | FOUR TANDEM | TWO |
| • PRESSURE | 35 PSI | 45 PSI |
| BRAKES | | |
| SERVICE | MANUALLY OPERATED DISK | MANUALLY OPERATED DISK |
| PARKING | AIR/OIL POWER DISK | AIR/OIL POWER DISK |
| MAXIMUM SPEED | | |
| CROSS-COUNTRY | 5 MPH | 5 MPH |
| SECONDARY ROADS | 25 TO 30 MPH | 25 TO 30 MPH |
| IMPROVED ROADS | 45 MPH | 45 MPH |
| STOWED | | |
| WEIGHT (AVG W/B | 8,972 LB | 15,760 LB |
| • LENGTH x WIDTH x HEIGHT | 30'0" x 8'0" x 7'2" | 24'8" x 9'2" x 7'0" |
| ITEM CUBIC | 1720 CU FT | 1483 CU FT |
| • LUNETTE LOAD | 300 LB | 3500 LB |
| LUNETTE HEIGHT | 30" | 30" |
| FORWARD MOST COMPONENT | LUNETTE | MUZZLE BRAKE |
| FIRING | | |
| WEIGHT (AVG W/B[illegible]) | 8,427 LB | 15,760 LB |
| LENGTH x WIDTH x HEIGHT | 24'0" x **34**'0" x 9'10" | 37'2" x 23'9" x [illegible] |
| ITEM CUBIC | **11367** CU FT | 9032 CU FT |
| ON-CARRIAGE ELEVATION | -75 TO +1275 MILS | -75 TO +1275 MILS |
| ON-CARRIAGE TRAVERSE | 400 MILS L AND 400 MILS R | 400 MILS L AND 400 MILS R |

• ADDITIONAL IMPROVEMENTS

Figure 3-15. FMC LTHD OPERATIONAL CONFIGURATIONS provide additional improvements over the M198 in critical areas.

[redacted]

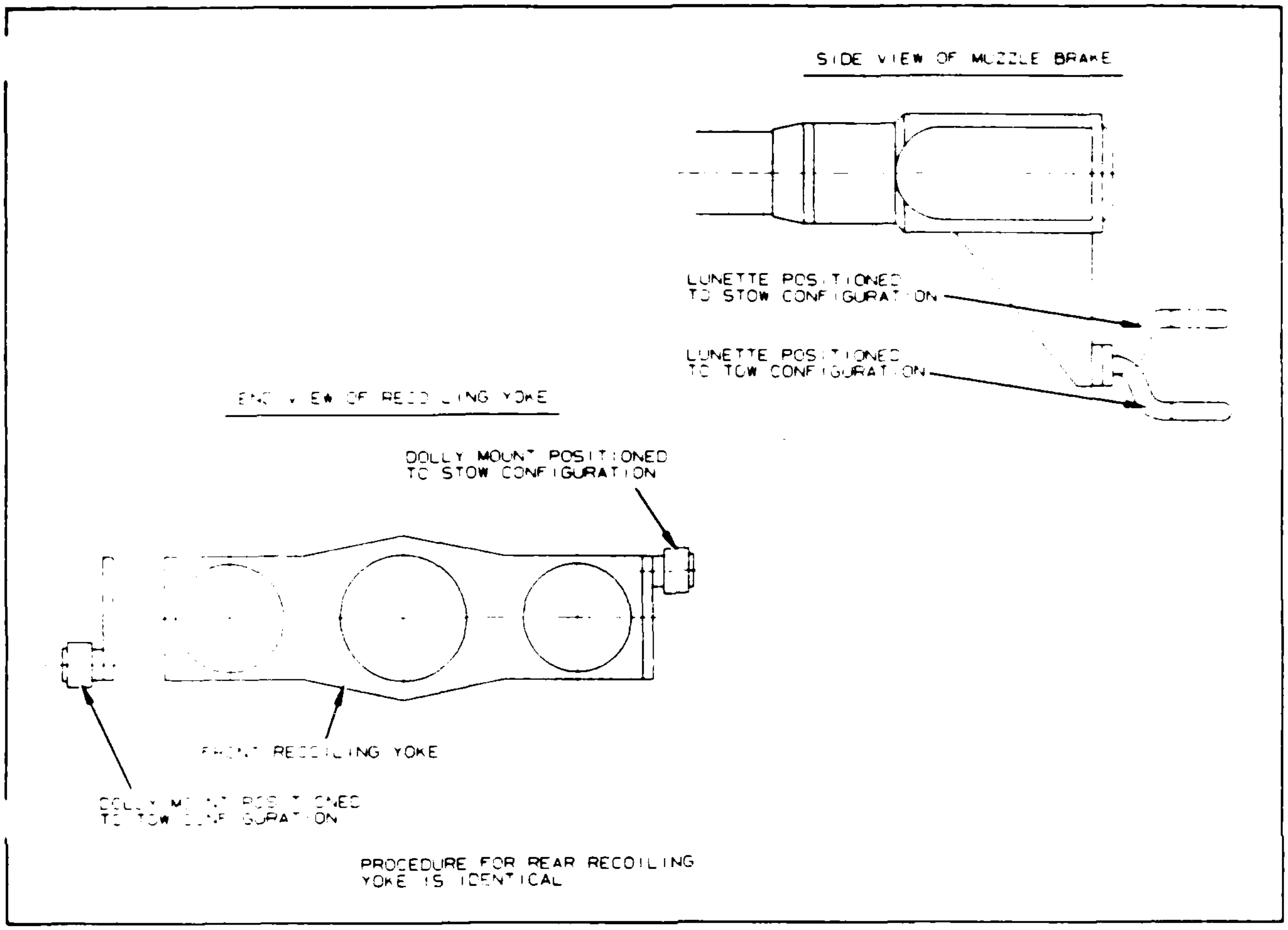



Figure 3-16. THE STOWED CONFIGURATION requires repositioning dolly mounts and lunette.

[redacted]

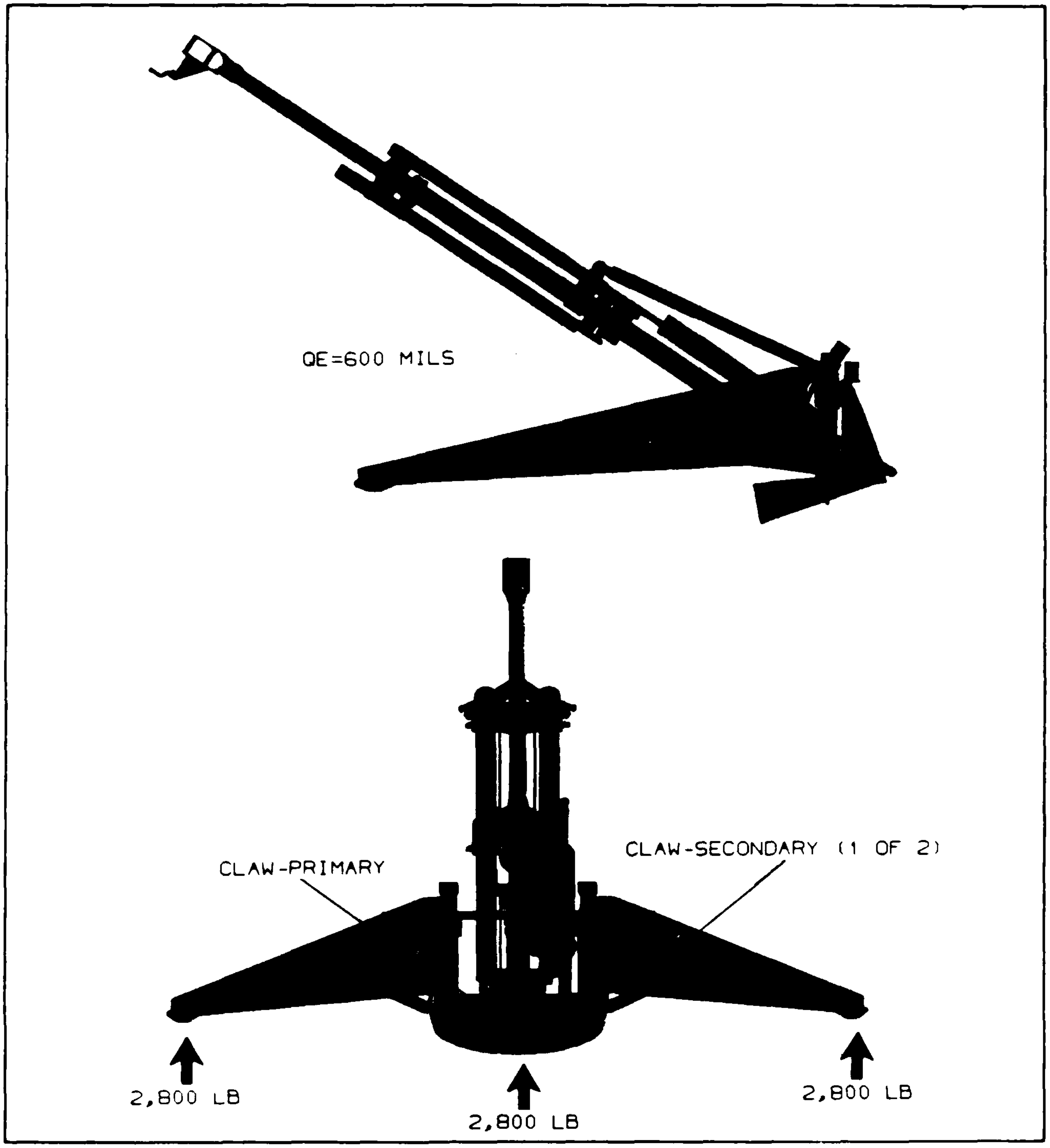



Figure 3-17. AGGRESSIVE GROUND ENGAGEMENT is enhanced by weight balance.

[redacted]

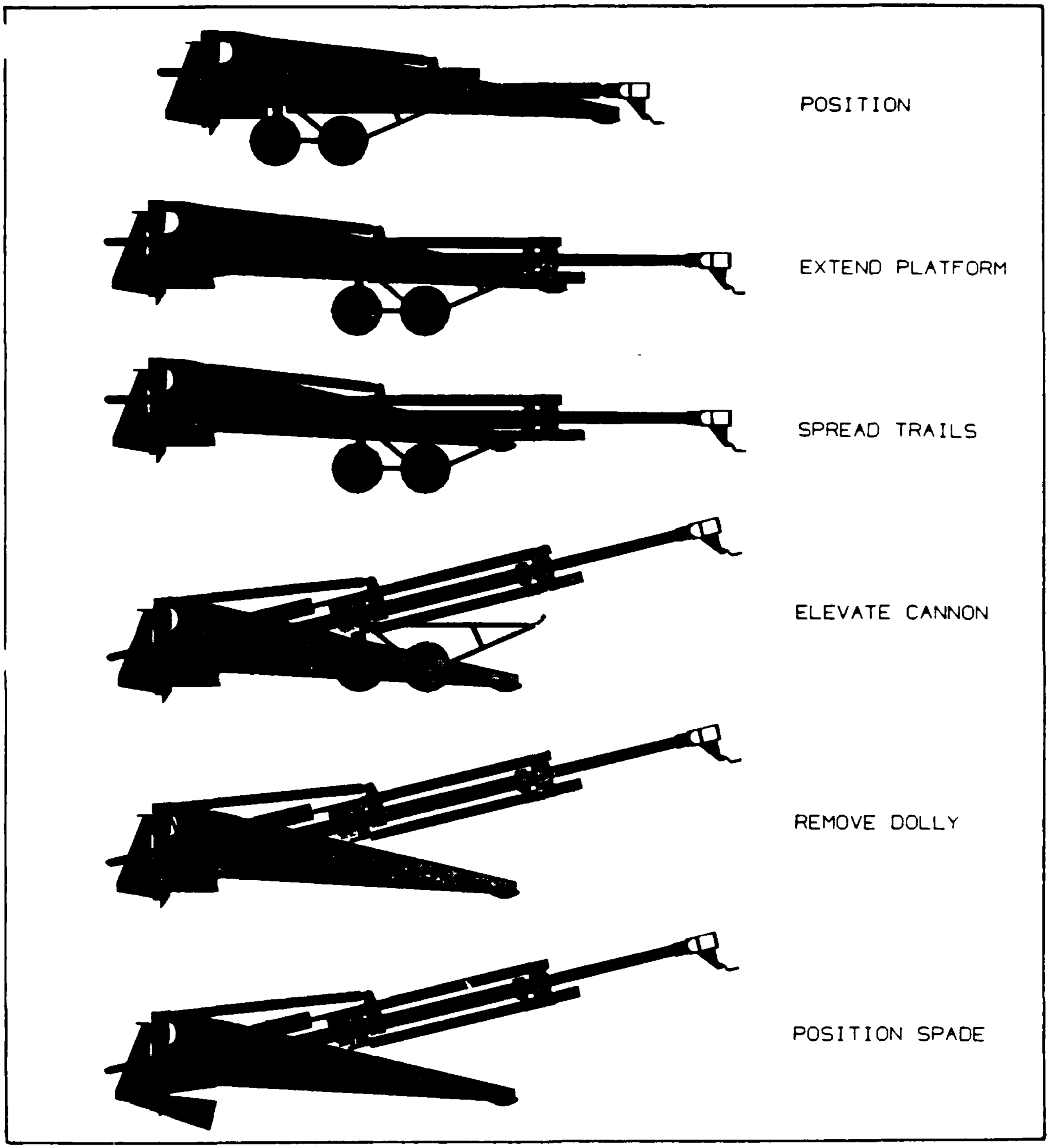



Figure 3-18. EMPLACEMENT is simplified by the integral firing platform and integral spade.

[redacted]

| Step | Crewmember | (TIME IN MINUTES) |
|---|---|---|
| 1. EXTEND PLATFORM | CANNONEER 1 AND 2 | 2.5 |
| 2. SPREAD TRAILS | GUNNER AND ASSISTANT GUNNER | 2.0 |
| 3. UNLATCH SPADE | GUNNER | .5 |
| 4. OPEN BREECH | ASSISTANT GUNNER | .5 |
| 5. ELEVATE CANNON TO 250 MILS | GUNNER | .5 |
| 6. UNLATCH DOLLY CLAMPS | ASSISTANT GUNNER | .5 |
| 7. REMOVE DOLLY | CANNONEER 1 AND 2 | .5 |
| 8. VERIFY YOKE-TUBE LOCKS | ASSISTANT GUNNER | .5 |
| 9. POSITION SPADE | GUNNER | .5 |

Figure 3-19. EMPLACEMENT TIME is . minutes with a crew of four.

A more detailed description of these steps follows:

1. Extend platform via dolly winch pulling on elevation yoke. (The nylon strap winch is mounted on the dolly.) The winch load is roughly 1,200 pounds for a 9-foot pull. This is calculated as 0.20 horsepower input to the winch (assuming an 80-percent efficient winch).

NOTE

Two crewmembers can perform this step in 2 minutes (with 30 seconds allowed for getting into position). The strap winch on the dolly used to extend the platform will either have a dual handle or the crewmembers will take turns operating the winch. The CG shifts rearward, but still remains between the tandem wheels.

[redacted]

2. Unlock trails; spread and lock trails. Two pins on the outside of each trail connect to the link from the platform. One pin holds the trail in the firing position; the other pin holds the link in the tow configuration. The trail is held in the tow configuration by the travel lock described in the displacement procedure (paragraph 3.2.2.6).
3. Unlatch spade. The LTHD is towed with the spade in the up position.
4. Manually open breech. This is necessary the first time only. Thereafter, the breech is opened by counterrecoil.
5. Elevate cannon to 250 mils. This step (done in conjunction with step 6 [unlatching dolly clamps]) lowers the platform to the ground. As the cannon elevates, first the front two clamps are released, and then the rear two clamps are released. At 250 mils, the dolly mounting bushings (mounted to the front and rear recoiling yokes) are sufficiently above the dolly to allow the dolly to be pulled out.
6. Unlatch the four dolly clamps. This step must be coordinated with step 5 (elevating the cannon). Unlatching involves unscrewing a knob on a swivel bolt and swiveling the bolt over. This enables the clamp, holding the bushing down, to swing out of the way, and allows the bushing to lift out of the clamp bottom as the cannon is elevated.
7. Remove dolly. The dolly weighs about 600 pounds and must be pulled out by hand if the LTHD is to be fired at elevations below 300 mils. At elevations above 300 mils, the dolly can be left under the slide.
8. Verify yoke-tube lock is secure:

   a. The two yoke-tube locks (one on each side of the forward yoke) are spring-loaded and slip into a metal groove in the end of each slide tube. When the locks slip in, a second spring-loaded pin slips into its groove and prevents the first pin from coming out. The position of both pins is visible from the crew positions.
   b. At displacement, the second pin must be pulled out and the knob on the first pin screwed to extract the first pin from the groove. This knob has a spring loaded detent antirotation feature to prevent it from moving during firing.

9. Hydraulically position the spade. The spade is positioned from the gunner's position by setting the spade control valve to "up" or "down" and pumping. The position of the spade is primarily determined by local soil conditions. The options include the following:

   a. Do not set spade at all if rock surface is sufficient to hold howitzer.
   b. Set spade into a predug trench to improve bite.
   c. Set spade in a few inches, and increase depth a few more inches each time a round is fired.
   d. Set spade at full depth if soil is very soft.

[redacted]

If below-zero QE firing is required, a trench must be dug as shown in figure 3-20. Without a trench, the lunette will hit the ground at a -10 mils. The maximum trench depth is 32 inches on level ground. This is a result of the reduced trunnion height, a necessity for stability. If the trench is not deep enough and the LTHD is fired, the lunette mounted on the muzzle brake, being the low point, will dig a trench. The recoil accumulators (mounted beneath the slide tubes for vulnerability reasons) do not recoil and will not be damaged if the trench is of insufficient depth.

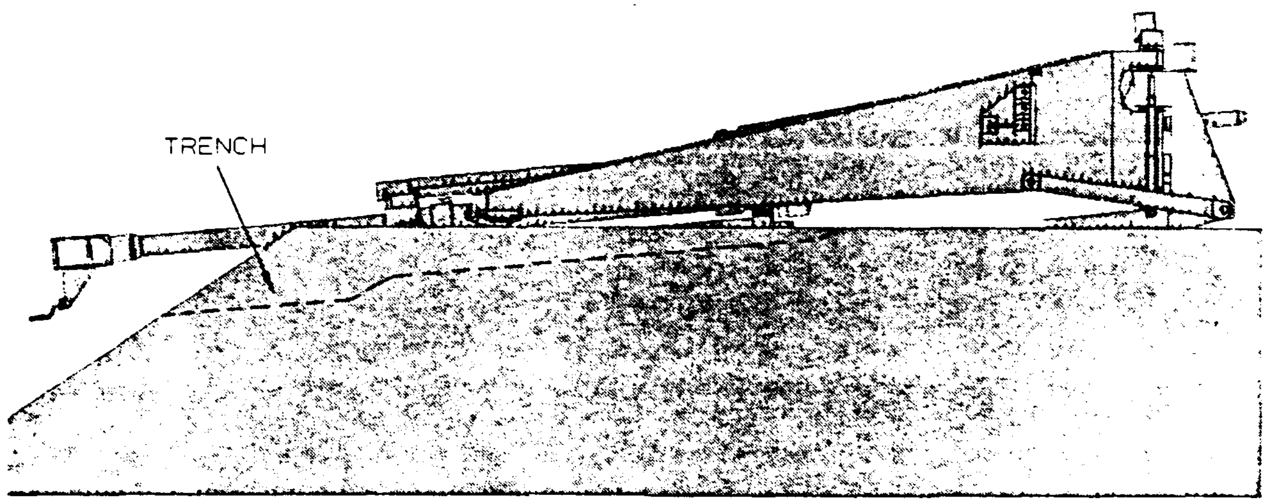



Figure 3-20. FIRING AT NEGATIVE QE requires careful site selection or the digging of a trench.

[redacted]

### 3.2.2.3 Firing

The LTHD crew positions are shown in figure 3-21. Locating the trunnion behind the breech at full recoil enables the section chief position to be at the focal point of operations. From this position, the section chief can see all personnel, check the fuze settings as the projectiles enter the load-tray, see the prescribed tube lay, and observe the status of the cannon relative to the prescribed tube lay. In addition, all personnel are further from the muzzle brake than the M198 layout permits, which results in a reduction of the blast overpressure to which the crew is exposed.

The LTHD employs a load-tray to facilitate mechanical breech access. This loading operation is a two-cycle process (figure 3-22). The two cycles can be operated together, to provide a 4-rounds-per-minute rate of fire (as timelined in figure 3-23), or separately, to provide a 4-round burst capability.

Table 3-1 lists the terminology used with the load-tray operation and its timeline. Preparation of the charge, projectile, fuze, and chamber are not included. Delivery of the projectile is included, but charge delivery is not.

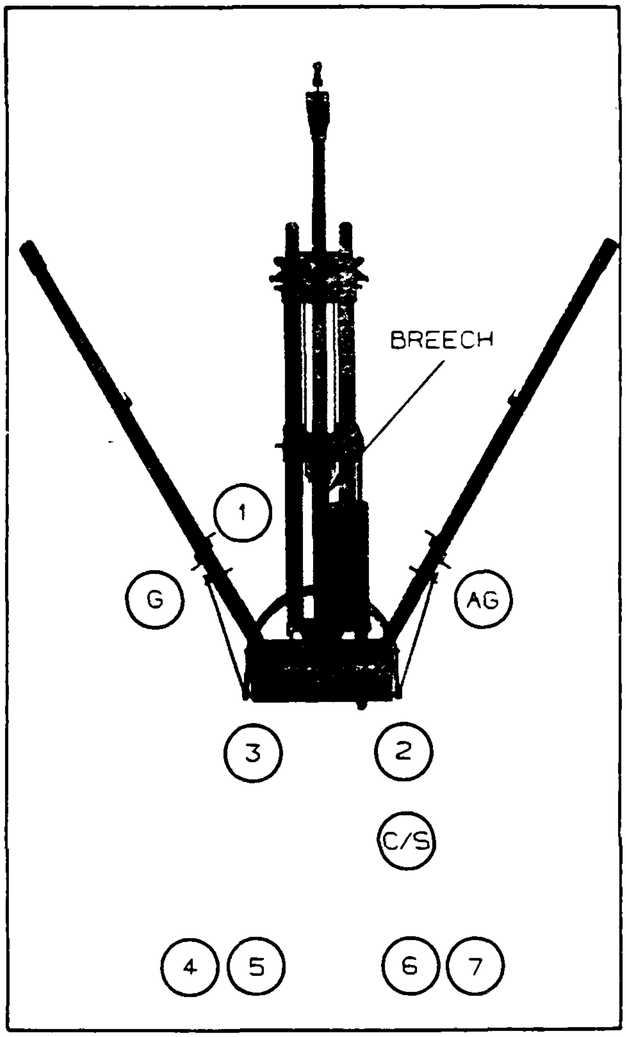



Figure 3-21. CREW POSITIONS reduce the exposure to blast overpressure.

[redacted]

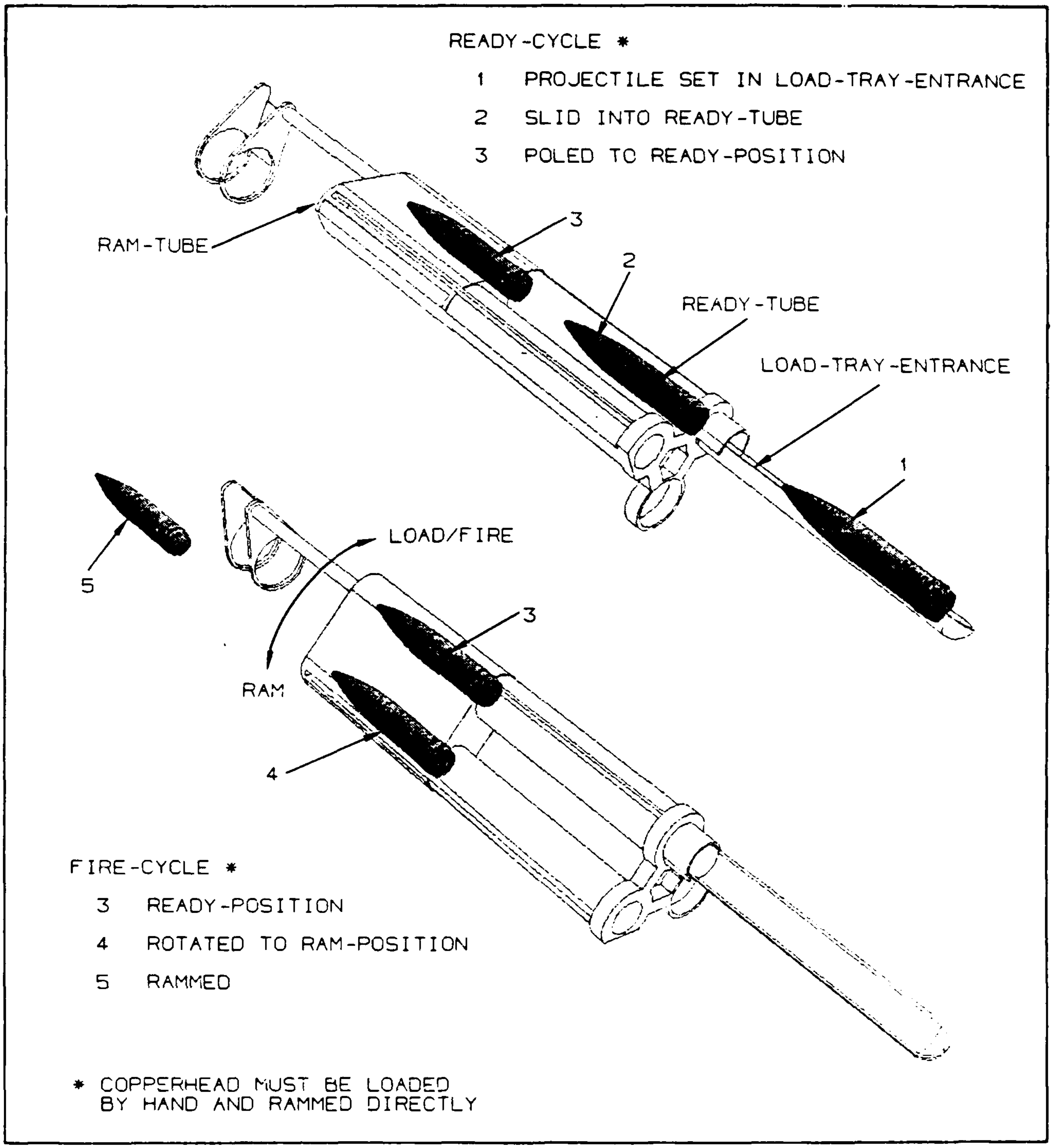



Figure 3-22. LOAD-TRAY facilitates a four-round burst.

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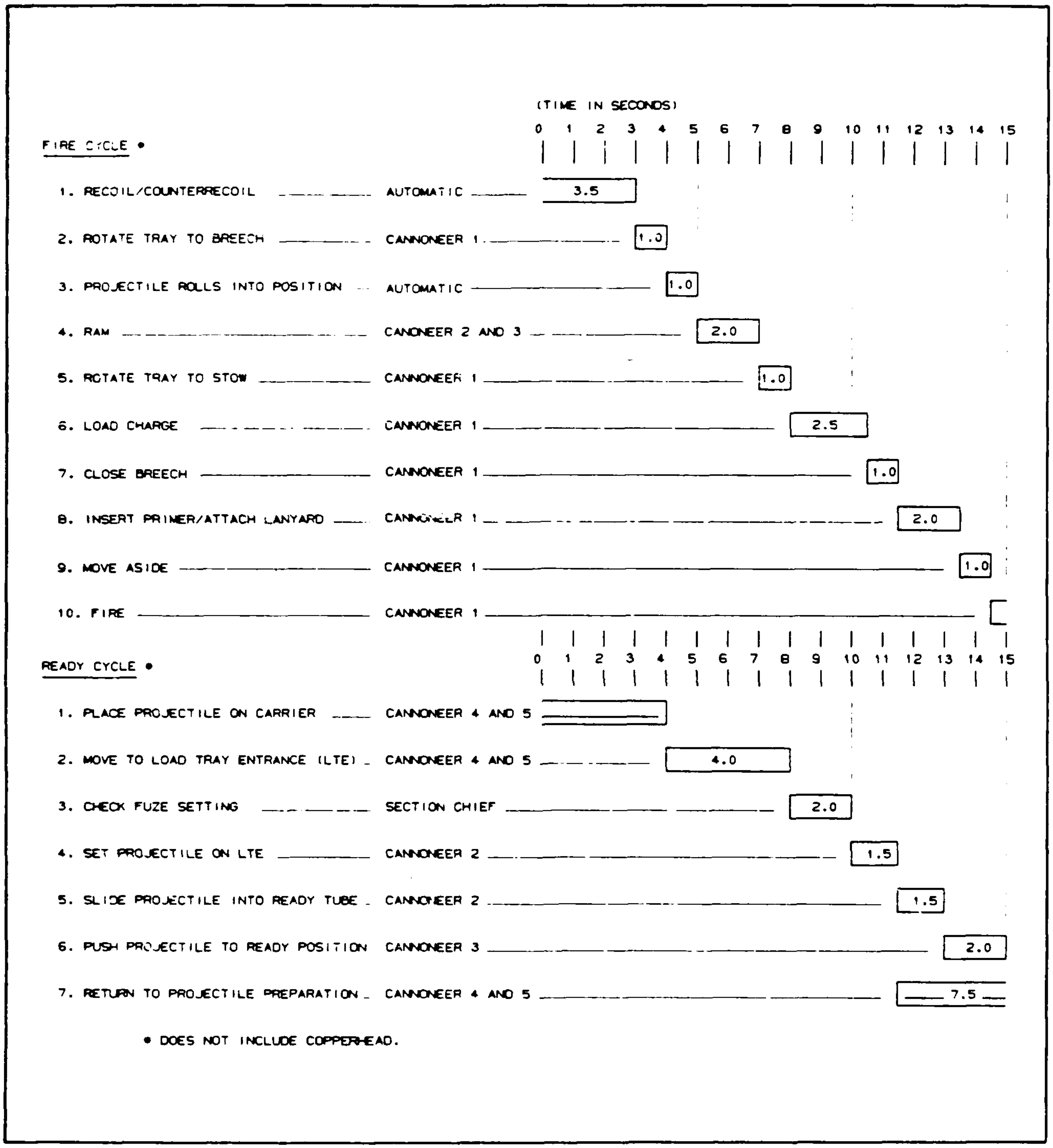


Figure 3-23. THE FMC LTHD will fire four rounds per minute.

[redacted]

Table 3-1. Load-Tray Terminology

| Name | Definition |
|---|---|
| Load-tray | Composed of load-tray-entrance (LTE), ready-tube, and ram-tube |
| Load-tray-entrance (LTE) | First portion of load-tray the projectile passes |
| Ready-tube | Second portion of load-tray the projectile passes |
| Load-staff | Staff used with ready-tube, permanently attached |
| Ram-tube | Last portion of load-tray the projectile passes |
| Ram-staff | Staff used with ram-tube |
| Ready-cycle | Process of getting the projectile from preparation to the LTE and moving it to the ready-position |
| Ram-cycle | Moving the projectile from the end of the ready-cycle and seating it in the forcing cone. (The ready-cycle is the feeder process that provides projectiles to the ram-cycle. The ram-cycle is part of the fire-cycle.) |
| Load-cycle | Ready-cycle and ram-cycle |
| Fire-cycle | Process required to fire the LTHD; includes the ram-cycle as well as other steps required during the fire-cycle |
| Burst-cycle | Special cycle that integrates only the necessary steps from the ready-cycle with the fire-cycle to achieve minimum delivery time for four projectiles |
| Ready-position | Point of termination of ready-cycle |
| Load/fire-position | Load-tray swiveled away from breech |
| Ram-position | Load-tray swiveled in front of breech |

[redacted]

The load-tray provides the ram-cycle with the following:

1. Mechanical assistance to ease the breech-loading operation
2. Ability to maintain the ramming staff handgrip at an optimum height (figure 3-24)
3. Increase in ramming force (over and above that required for the M198) (figure 3-25), compensated for by room for more hands on the ramming staff when needed

The load-cycle has the following QE limitations:

1. From 450 to 525 mils: cannoneer 1 must be of average height or above to load the charge. (Figure 3-26 shows how the breech height increases with QE.)

2. From 525 to 800 mils:

   a. Cannon must be depressed to allow charge to be loaded.
   b. The swivel joint between positions 1 and 2 will not allow a projectile in position 1 to pass to position 2 (figure 3-22). This also limits the burst to 3 rounds, because the projectile in position 1 (figure 3-22) cannot be advanced.

The resultant rate of fire is discussed in paragraph 3.3.3.3.

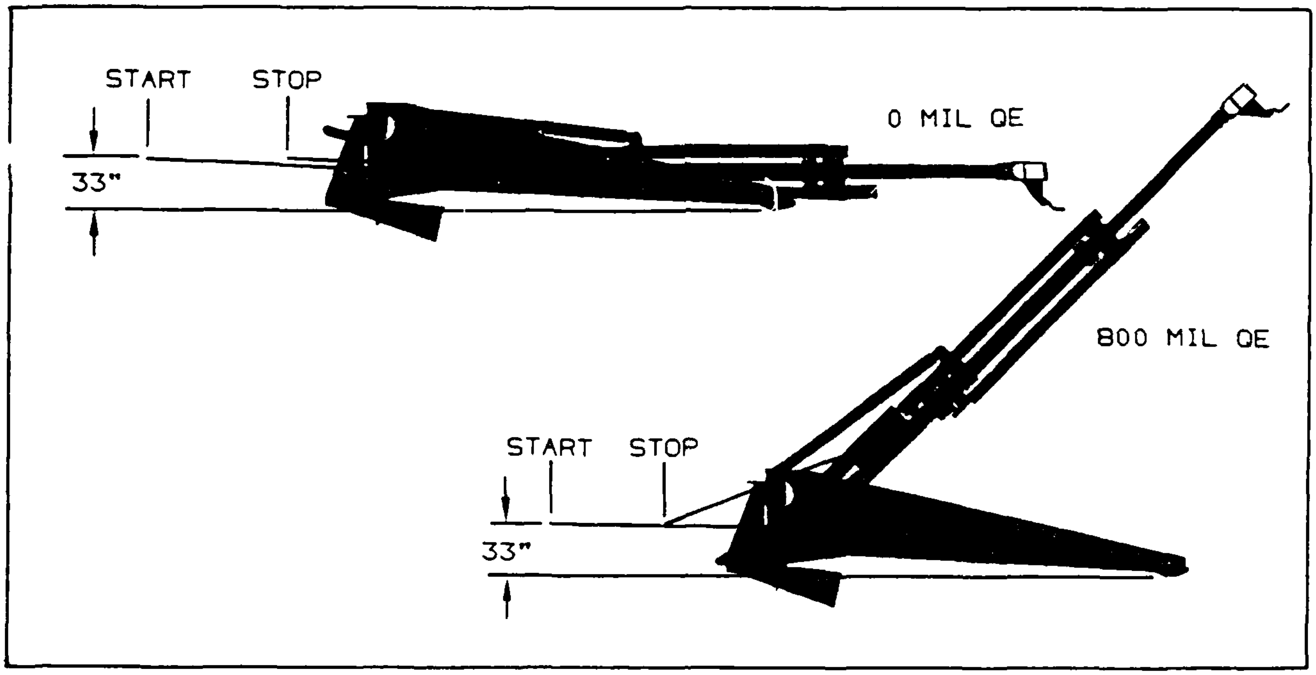


Figure 3-24. THE LOAD-TRAY allows the ram-staff handle to be held at the height most effective for the crew.



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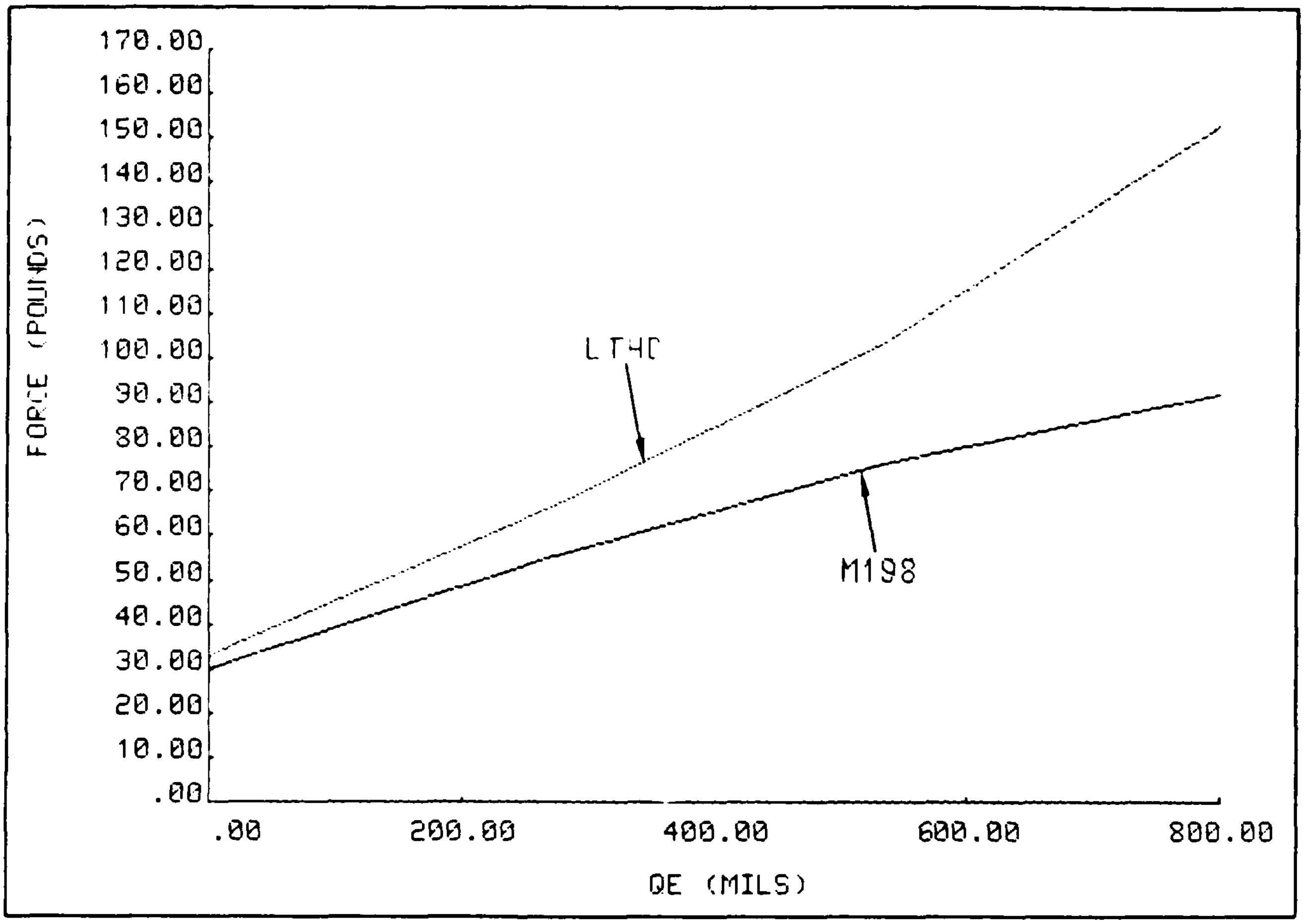


Figure 3-25. ADDITIONAL FORCE required to overcome projectile weight due to the load-tray is compensated for by room for more hands on the handle.

[redacted]

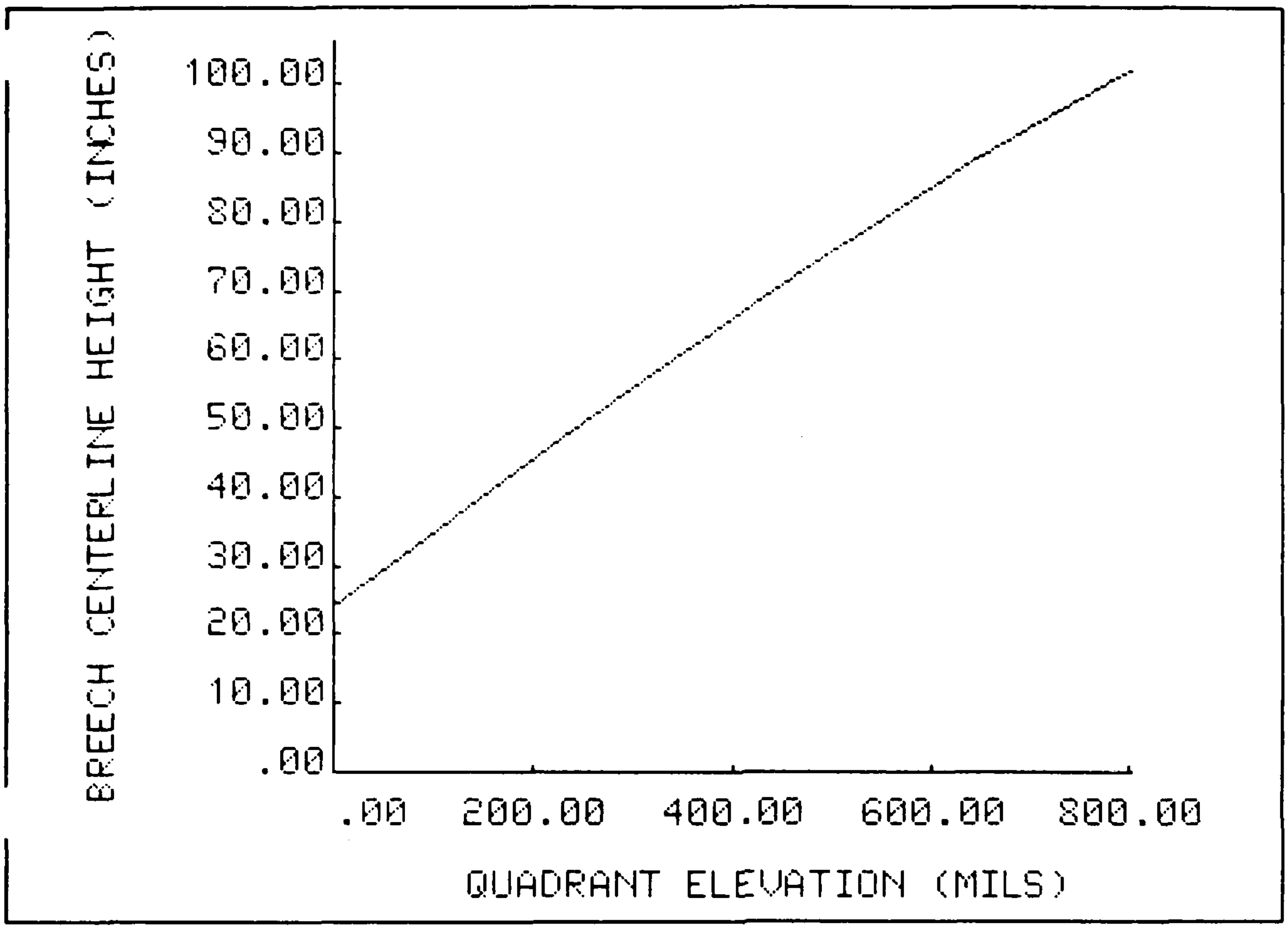


Figure 3-26. BREECH HEIGHT increases with QE; cannoneer 1 must be of average height to load charge at QE's of 450 to 525 mils.

 [redacted]

Loading the 54-inch-long COPPERHEAD M712 Guided Projectile would be done manually or with the dolly. Use of the dolly would involve these steps:

1. Set COPPERHEAD on dolly (in cradle provided).
2. Elevate cannon to 300 mils.
3. Roll dolly with COPPERHEAD on it into position.
4. Depress cannon (slightly) until open breech is at same level as COPPERHEAD.
5. Push COPPERHEAD into chamber.
6. Swivel load-tray into ram position and ram COPPERHEAD.
7. Elevate cannon to remove dolly.
8. Continue firing sequence, starting at step 5 (rotate load-tray to stow, figure 3-23).

3.2.2.4 Speed Shifting

Speed shifting (figure 3-27) involves setting the LTHD back on the dolly, locking one of the rear brakes, tipping the LTHD up on the rear wheels, and swiveling the howitzer around. If the net rolling resistance at the rolling wheel is assumed to be 750 pounds, the required horizontal force at the muzzle break is 200 pounds. With four people, this translates into 50 pounds per person for 1 minute or 0.4 hp per person. Figure 3-28 provides a timeline of the speed shift steps required.

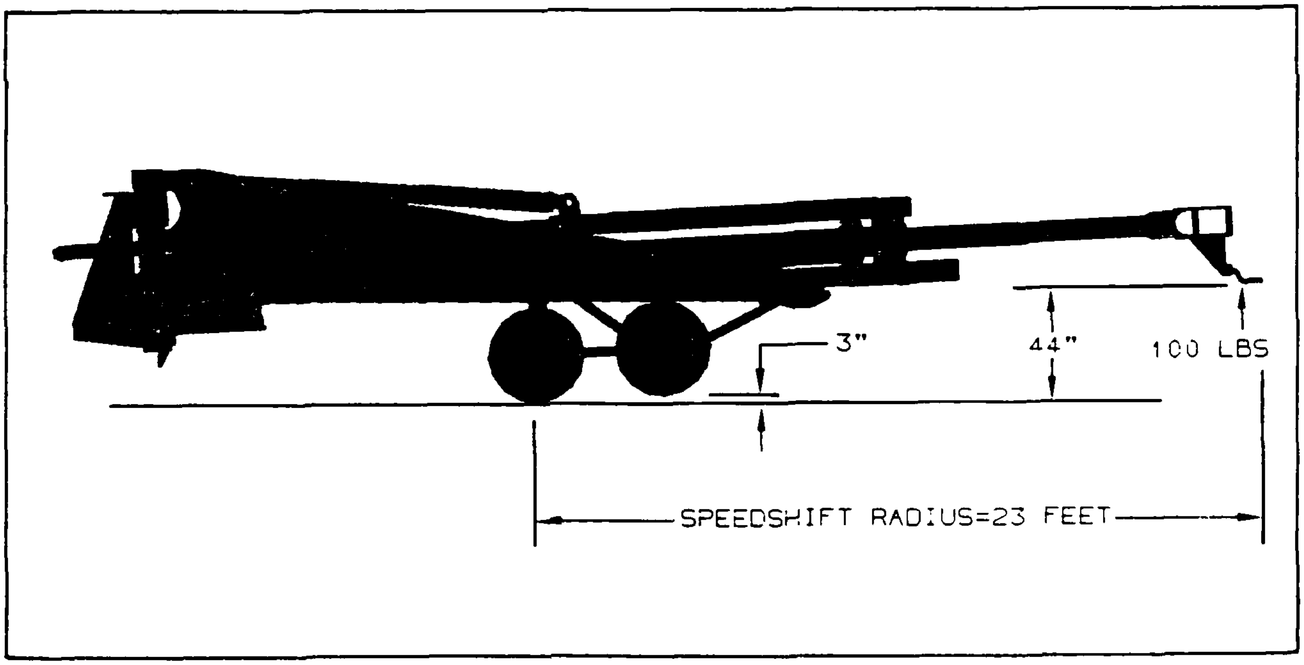


Figure 3-27. THE SPEED SHIFT FUNCTION adds no parts or weight to the FMC LTHD; speed shifting is accomplished on two wheels.

[redacted]

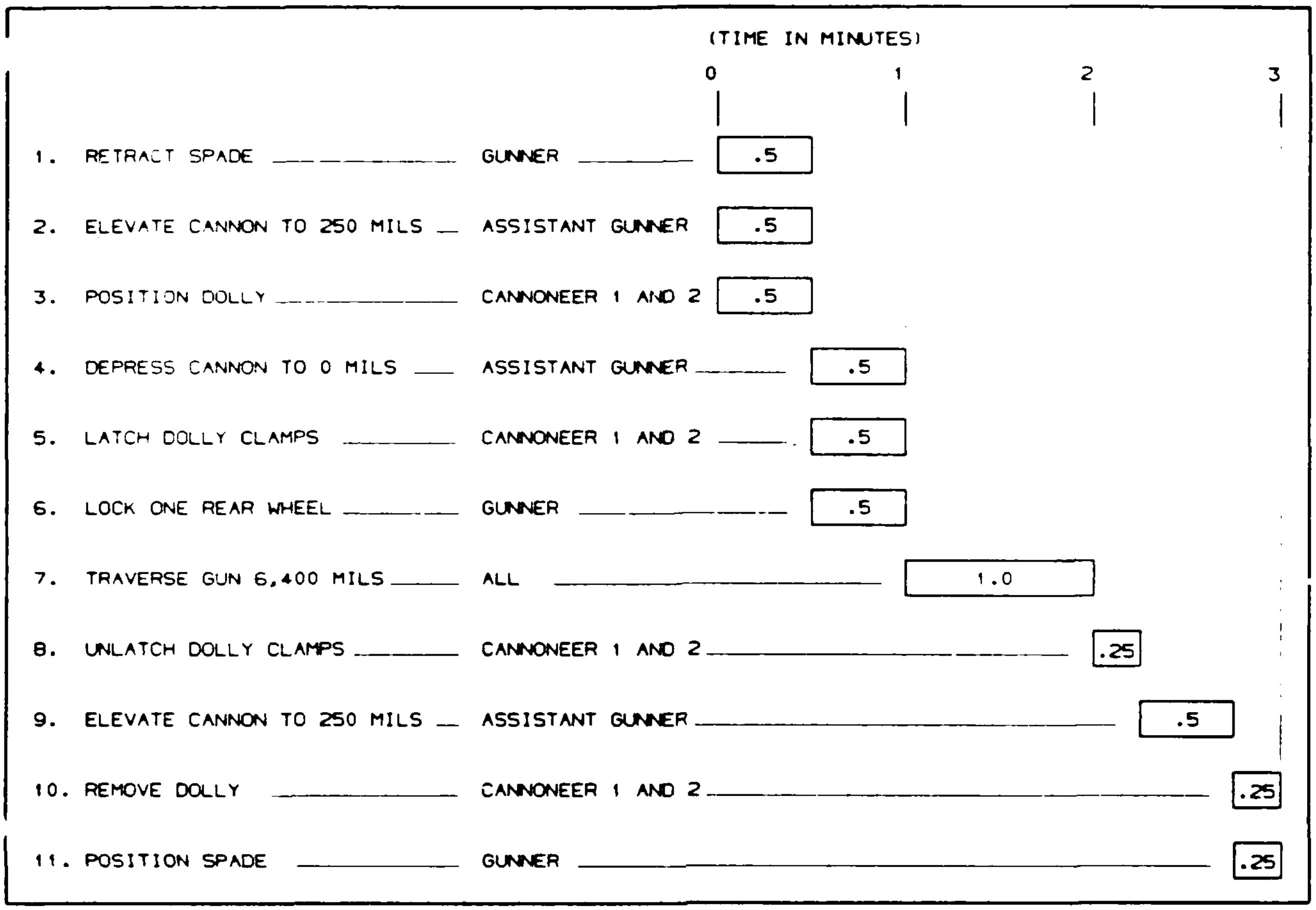


Figure 3-28. SPEED SHIFT TIME is 3 minutes with a crew of four.

### 3.2.2.5 Vulnerability to Aerial Bursts

The FMC LTHD minimizes vulnerability to aerial bursts (figure 3-29) to improve survivability through component placement and the selective use of armor by the following:

1. Mounting recoil accumulators beneath the slide tubes, exposing only a small area
2. Designing the recoil cylinders so dynamic sealing surfaces do not interface with the outside wall. (Instead, the inside of the outer cylinder provides the orifice function.) The precision surfaces are buried deeper within the assembly.
3. Providing a protective shroud for the upper recoil cylinder rod to protect it during the 3-second recoil/counterrecoil cycle
4. Providing a protective shroud for the elevation cylinder to protect its rod surface

[redacted]

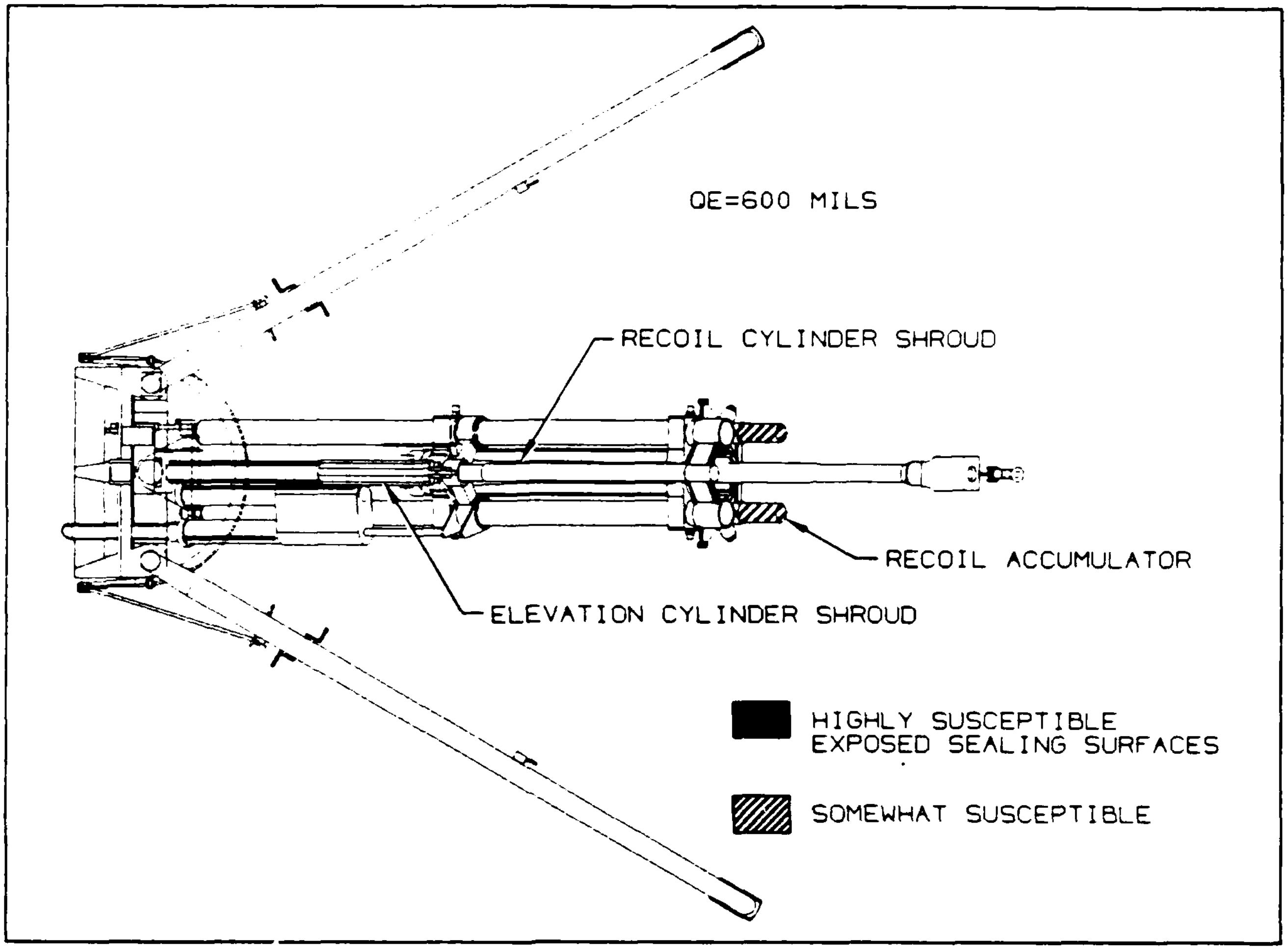


Figure 3-29. VULNERABILITY TO AERIAL BURSTS is minimized with careful component placement and shrouds.

3.2.2.6 Displacement

The displacement procedure is essentially the reverse of the emplacement procedure described in paragraph 3.2.2.2, with the exception of step 10 (figure 3-30). This step involves guiding the pins on the forward yoke into receptacles on the inside of either trail (in a staggered fashion) to tie the trails and rear recoiling yoke together during towing. This configuration serves as a travel lock for the elevation cylinder, traverse cylinder, rear recoiling yoke, and, in turn, the cannon.

[redacted]

| Task | Crew | Time (minutes) |
| --- | --- | --- |
| 1. RAISE SPADE | GUNNER | .5 |
| 2. ELEVATE CANNON TO 250 MILS | ASSISTANT GUNNER | .5 |
| 3. POSITION DOLLY | CANNONEER 1 AND 2 | .5 |
| 4. RELEASE YOKE-TUBE LOCK | GUNNER | .5 |
| 5. DEPRESS CANNON TO 0 MILS | ASSISTANT GUNNER | .5 |
| 6. RETRACT PLATFORM | CANNONEER 1 AND 2 | 2.5 |
| 7. LATCH SPADE | GUNNER | .75 |
| 8. LATCH DOLLY CLAMPS | ASSISTANT GUNNER | .75 |
| 9. CLOSE AND LOCK TRAILS | GUNNER AND ASSISTANT GUNNER | .75 |
| 10. SECURE TRAVEL LOCKS | GUNNER AND ASSISTANT GUNNER | .5 |

(TIME IN MINUTES) 0 1 2 3

Figure 3-30. DISPLACEMENT TIME is 3 minutes with a crew of four.

## 3.3 DESCRIPTION OF SUBSYSTEMS

> Components compatible with conventional composite technology, supported by the analytical power of our Central Engineering Laboratories (CEL), combines with the reliability of the Watervliet cannon to produce the minimum-risk FMC LTHD.

The following subparagraphs describe the hardware output from the analytical approach. As items of concern are covered, the underlying logic and supporting analysis is defined. Due to the critical nature of the strength and weight considerations, a description explaining the load paths employed to arrive at a minimum weight structure is provided when deemed appropriate.

### 3.3.1 Cannon

The LTHD employs a conventional technology cannon similar to the M199 (figure 3-31). This cannon maintains the capability to fire all 155-mm conventional and improved munitions and consists of the following items:

1. Barrel (weight-reduced 41-caliber version of the M199 that saves 1,250 pounds)

[redacted]

2. Breech (M185 that opens up)
3. Muzzle brake (M199 with integral lunette for towing)
4. Breech band (one that controls cannons X, Y, and Z as well as angular coordinates)

Table 3-2 shows the optimal recoiling mass determined at the system level (paragraph 3.1.4.1).

Table 3-2. Optimal Recoiling Mass for FMC LTHD

| Item | Recoiling Mass (Pounds Mass) |
| --- | --- |
| Barrel | 2,600 |
| M185 breech | 800 |
| Breech band | 105 |
| Muzzle brake with integral lunette | 240 |
| Recoiling yoke assembly | 315 |
| Recoiling portion of recoil cylinders | 640 |
| Total recoiling mass | 4,700 |

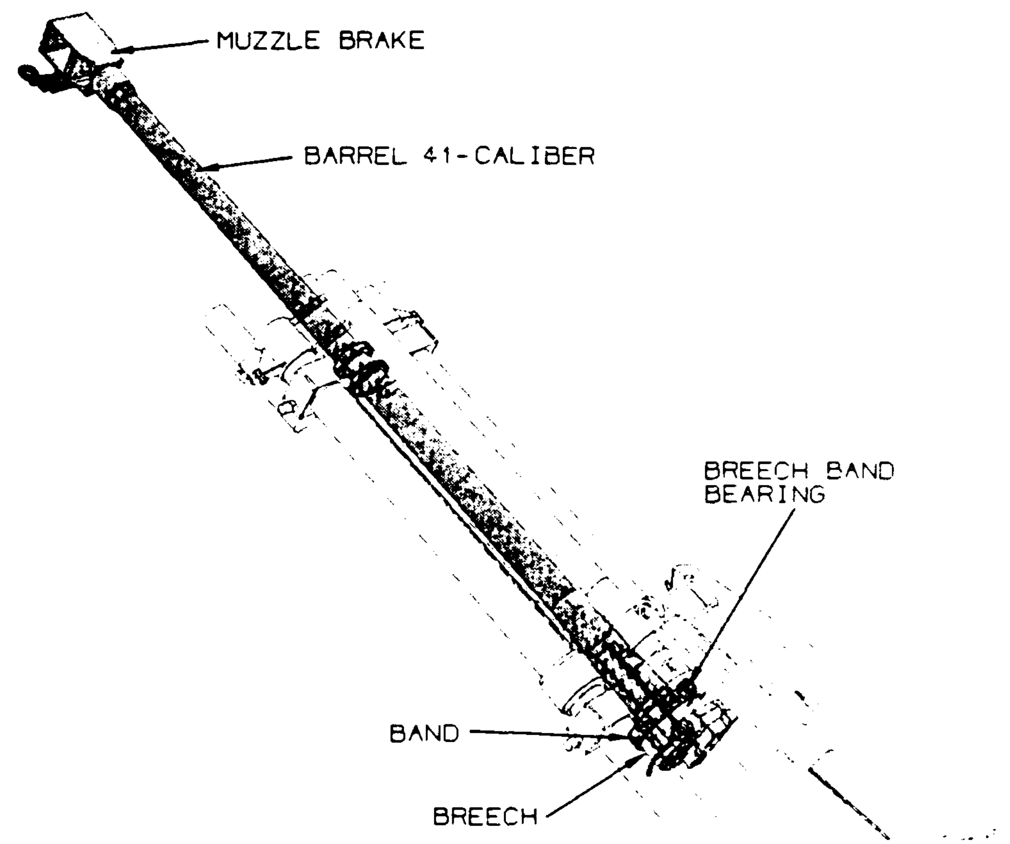


Figure 3-31. WATERVLIET will supply the conventional cannon.

[redacted]

3.3.1.1 Barrel

The 41-caliber barrel is designed to maintain muzzle velocity equal to the M198. The details of how we selected this caliber are as follows:

1. The M198 recoil velocity is approximately 43 feet per second.
2. Reducing the recoiling mass from 7,000 (M198) to 4,700 pounds (LTHD) increases the recoil velocity to 65 fps.
3. Increasing the muzzle velocity 22 fps relative to the barrel is necessary to maintain the muzzle velocity relative to the ground.
4. Ballistic similitude has been approximated with the M203 and the M483A1 projectile family.
5. Increasing the caliber to 41 and the combustion chamber from 1,188 to 1,265 cubic inches achieves the 22 fps muzzle velocity increase and maintains the same expansion ratio as the M199. The expansion ratio has been defined as the ratio of the combustion volume at shot ejection to that at shot start.

In the interest of weight savings, the LTHD was structured to accommodate a tapered barrel. (The barrel outside diameter is not used to guide cannon motion during recoil.)

Alternatives to the 41-caliber, tapered, conventional barrel that were considered but dropped in the interest of maintaining a low-risk approach include the following:

1. Composite-wrapped barrels. One barrel involved a copper-coated graphite filament overwind; the other involved an SiC/Al metal matrix overcasting. As the system concept development progressed, the desirability of a lightweight barrel lessened, because the optimal recoiling mass (table 3-2) did not require it.
2. Longer caliber barrels. Increasing the caliber to the 45 to 47 range produced a weight reduction due to the lower pressure. The lower pressure resulted from an increase in the combustion chamber volume to maintain the M199 expansion ratio and, in turn, maximize ballistic similitude. Secondary benefits included reduced blast overpressure due to the reduction of muzzle pressure from increased distance from the crew. This approach was abandoned due to the droop and overall length increases.

3.3.1.2 Breech

The primary reasons for using the M185 breech are weight, cost, and inventory.

We initially did not plan to employ the auto-opening feature. When the feasibility of a four-round burst developed (as a result of the desirability of mechanical breech access [paragraph 3.1.3, Evaluation of Alternatives]), the breech cam appeared justifiable.

The M199 breech was considered, but was dropped in favor of the M185 breech because of the weight-cost-inventory considerations and the automatic opening feature. The temperature indicator was not a factor due to its availability on the upcoming M185 breech.

The breech was not positioned to open to the side because of space problems. The decision to open up versus down was made on the basis of these tradeoffs:

1. Breech opening upward:

   a. Facilitates lower trunnion height without digging
   b. Keeps breech away from mud and shields breech from rain
   c. Provides more room for auto-primer option

[redacted]

d. Ensures a clear path for propellant loading at high QE

2. Breech opening downward:

a. Automatically knocks load-tray out of the way if breech closes before the tray has been moved out of the way
b. Ensures cannoneer 1 does not have to reach over the bleed hole to remove the primer in the event of a misfire

3.3.1.3 Muzzle Brake

The M198 muzzle brake design was chosen because of the known and acceptable crew risk levels. The lunette was added to the muzzle brake, because it provides a very substantial tow point. The lunette is attached to a very substantial portion of the towed mass with a minimum weight penalty.

A more efficient muzzle brake, coupled with the same blast overpressure, was considered. Statistical analysis of empirical data available suggested this may be possible. This effort was abandoned due to the what-if-it-fails-to-materialize risk.

3.3.1.4 Breech Band

The breech band (figure 3-31) performs a number of functions with minimal weight addition by virtue of the recoil system configuration. The breech band (by virtue of its mounting to the rear recoiling yoke) guides the cannon motion, applies recoil force, and constrains the torque reaction through lugs mounted in self-aligning bearings. These self-aligning bearings are mounted to the rear recoiling yoke. Therefore, the key used to lock the barrel to the breech and, in turn, to the band, will be used to carry torques caused by projectile spin. The LTHD's self-lubricating trunnion bearings are the same design as those currently used on the M1 tank.

3.3.2 Carriage

The carriage is composed of the structure, slide, recoil system, and hydraulic system.

3.3.2.1 Structure

The primary purpose of the structure is to position the cannon and transfer the firing forces into the ground. The main components are the platform and trails (plus the dolly in the tow configuration). Figure 3-32 locates and identifies the components.

The structure will be described, first from a firing load perspective, then from a towing load perspective. The firing load path to the ground is made up of nine major steps:

1. When the LTHD is fired, the recoil cylinders retard the motion of the cannon and impart a load on the forward yoke to which they are anchored. This loads the slide tubes in compression.
2. The load then proceeds to the outer diameter of the trunnion bearings, which are mounted on the end of the slide tubes. The inner diameter of the trunnion bearings are mounted on metal stub shafts, which are part of the trunnion.
3. The load path continues through the trunnion to its vertical bore.
4. The force is transferred through the traverse bearings into the equilibration accumulator cylinder. This cylinder is mounted within the platform. The load path splits:

   a. Some of the load is transmitted directly into the ground via the claw-primary.
   b. The balance of the load enters the platform and splits again.

5. The vertical component of the force flows through the base of the platform and is directed into the ground.

[redacted]

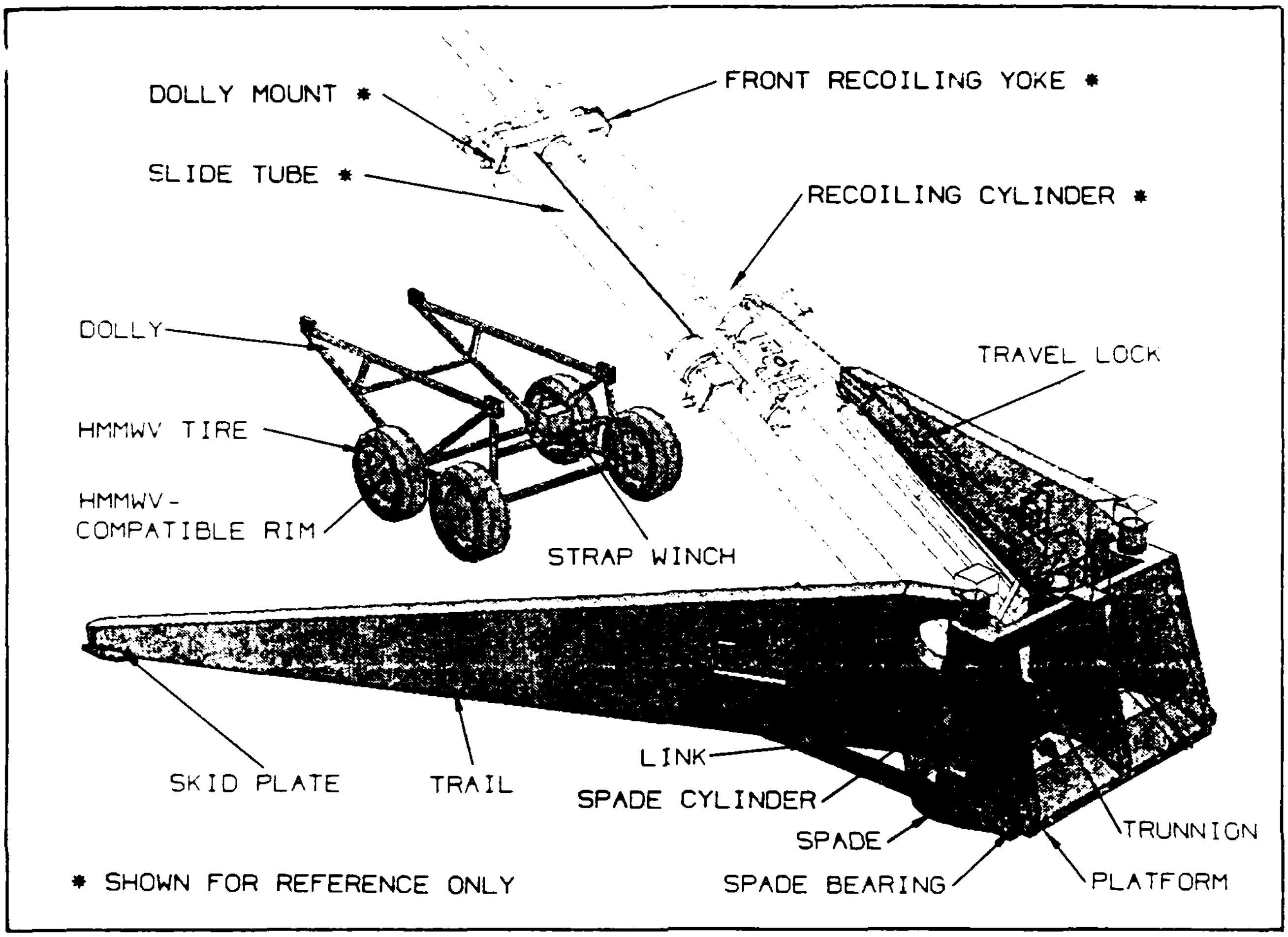


Figure 3-32. THE STRUCTURE is composed almost entirely of composite components.

6. The horizontal component of the force flows into the claw-secondary (via the reservoir cylinders) and the spade mounting in the platform. The path continues into the spade mounting shaft, the spade bearings, and the spade.
7. The spade is shaped to carry the bulk of the loading in tension (it pulls into the ground) rather than bending.
8. The force is then transmitted into the substructure of the spade. This substructure gives the composite core of the spade a soft shell to protect it from rock damage. Figure 3-33 shows one of the finite element analysis grids employed at FMC's CEL as part of the component level dynamic analysis done on this spade. The spade is field repairable.
9. The force path enters the ground. As the force enters the ground, structural resonance serves to hammer the spade rearward, possibly resulting in more slide. When the recoil force ends, a rebound effect may occur.



[redacted]

These issues will be addressed through analysis at the system level at CEL. An example of the contribution that composites make toward improvement in this area is shown in figure 3-34.

Towing loads follow a much simpler path. The major loads are assumed to be from large potholes. The towing load path, induced by potholes, is listed below:

1. The load enters the tire and the shock is attenuated, to some degree, by the increased deformability of the large cross-section HMMWV tires.
2. The load then continues through the wheels, hubs, bearings, shafts, dolly structure, and into the dolly mounting bushings on the front and rear recoiling yokes. The dolly mounting bushings (hard rubber) also attenuate some of the load.
3. The load passes through the fron and rear recoiling yokes and into th cannon, which is accelerated upwar by the load.

Three different approaches to the "wheels portion of the towing function were con sidered and are outlined below (number was chosen):

1. Wheel units, attached permanentl to the trails, were swiveled up an down for towing and firing. Thes wheel units have the advantage o being permanently attached, bu have the disadvantage of bein heavier and complicated the proces of swinging the trails into position.
2. Wheel units, attached permanentl to the recoiling yokes, provide th advantage of increasing the re coiling mass. Unfortunately, t make the wheel structure withstan the 200-plus g's involved, the weigh and risk increase beyond acceptabl levels.

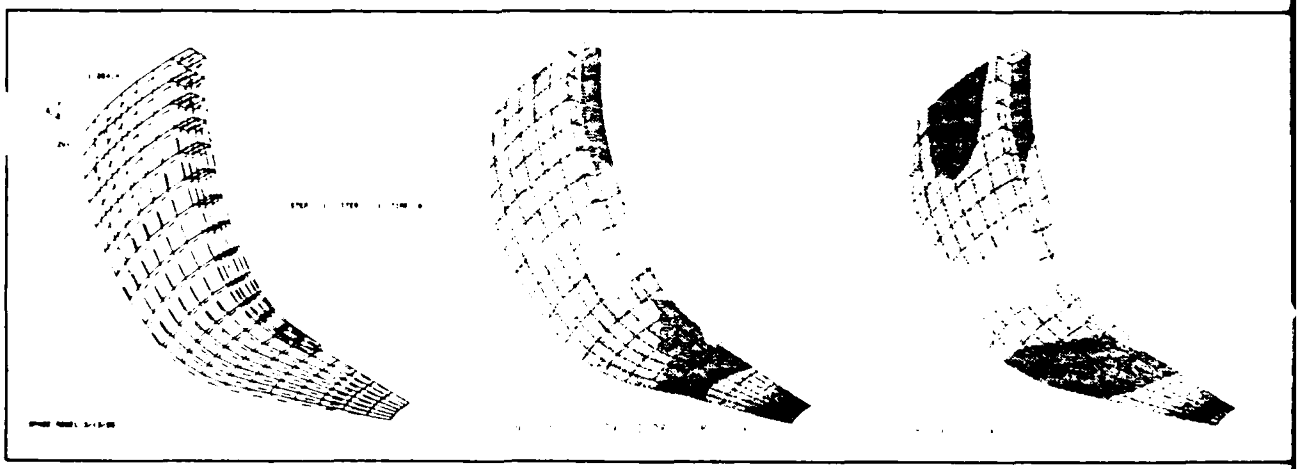

Figure 3-33. WEIGHT REDUCTION of the central spade through the use of composites i encouraged by the finite element analysis performed at our Central Engineering Laboratories.

[redacted]

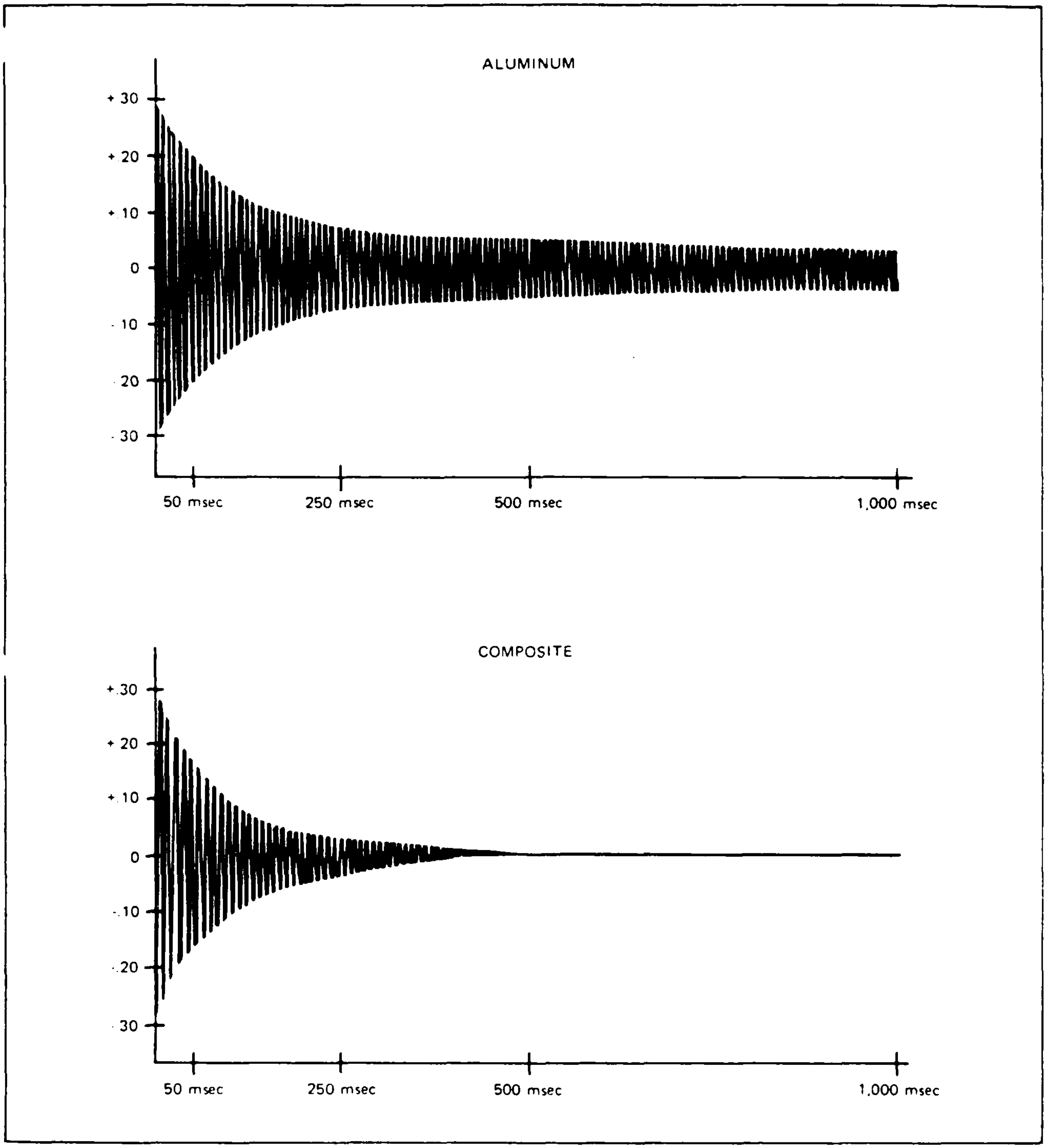


Figure 3-34. THE DAMPING CHARACTERISTICS attainable with composite materials will improve the resistance of the FMC LTHD structure to shock, resonance, and rebound.

[redacted]

3. A separate dolly that attaches to the recoiling yoke provides the lowest weight solution. This approach provides these additional benefits over the others considered:

   a. Should high loading necessitate the addition of a suspension (due to towing conditions), this could be more easily handled on a unit separate from the main structure.
   b. The dolly could possibly provide additional functions at the site.
   c. Separating the LTHD from the dolly reduces the total configuration weight by 600 pounds. This would enable a helicopter to lift the LTHD on a hot day (when the combined weight would be beyond the helicopter limits). The speed shift would have to be performed in some other manner.

Use of the M198 wheels was considered, but was dropped in favor of the HMMWV tires and HMMWV-compatible wheels (also used on the trailing arm drive vehicle developed by Standard Manufacturing, a potential prime mover) for the following reasons:

1. Weight reduction
2. Reduction of the probability for the need of a suspension due to the reduction in air pressure. The narrow M198 tire is rated at 100 psi. Scaling down to 9,000 pounds yields 100 multiplied by 9,000/16,000 which equals 56 psi. A set of four HMMWV tires provides a rating of 11,000 pounds at 35 psi.
3. Tandem footprint (which should improve pothole resistance, although scrubbing on turns may shorten tire life)
4. Logistics
5. The option of adding the HMMWV run-flat/bead-lock option

® Registered trademark of DuPont.

The HMMWV-compatible wheels were chosen over the HMMWV wheels with the following in mind:

1. Aluminum or Composite wheels (compared to the HMMWV's steel wheels) provide weight reduction.
2. If either type of HMMWV wheels are used on the LTHD, compatibility is maintained.

### 3.3.2.2 Slide

The primary purpose of the slide is to hold the cannon and guide it during recoil. The major elements are the slide tubes, load-tray, and front and rear recoiling yokes. Components are shown in figure 3-35. Load-tray operation is covered in paragraph 3.2.2.3

Two loads occur during firing, one from the recoil force and one from the torque on the cannon due to spin-up of the projectile by the rifling. Each load case will be outlined.

Firing loads are carried into the slide tubes by the forward yoke via the metal grooved disks on the end of the slide tubes that receive the yoke-tube lock. The slide tubes are 10.5 inches in diameter and made of a fiber-wound-composite/foam-filled construction. Metal bearing housings on the trunnion end of the slide tubes transfer the load into the structure.

Torque loads are delivered to the rear recoiling yoke by the breech band bearings. The path continues as follows:

1. The load flows through the yoke and into the slide bearings. The bearing pressures are sufficiently low (under 250 psi) to permit the use of Teflon ®.

[redacted]

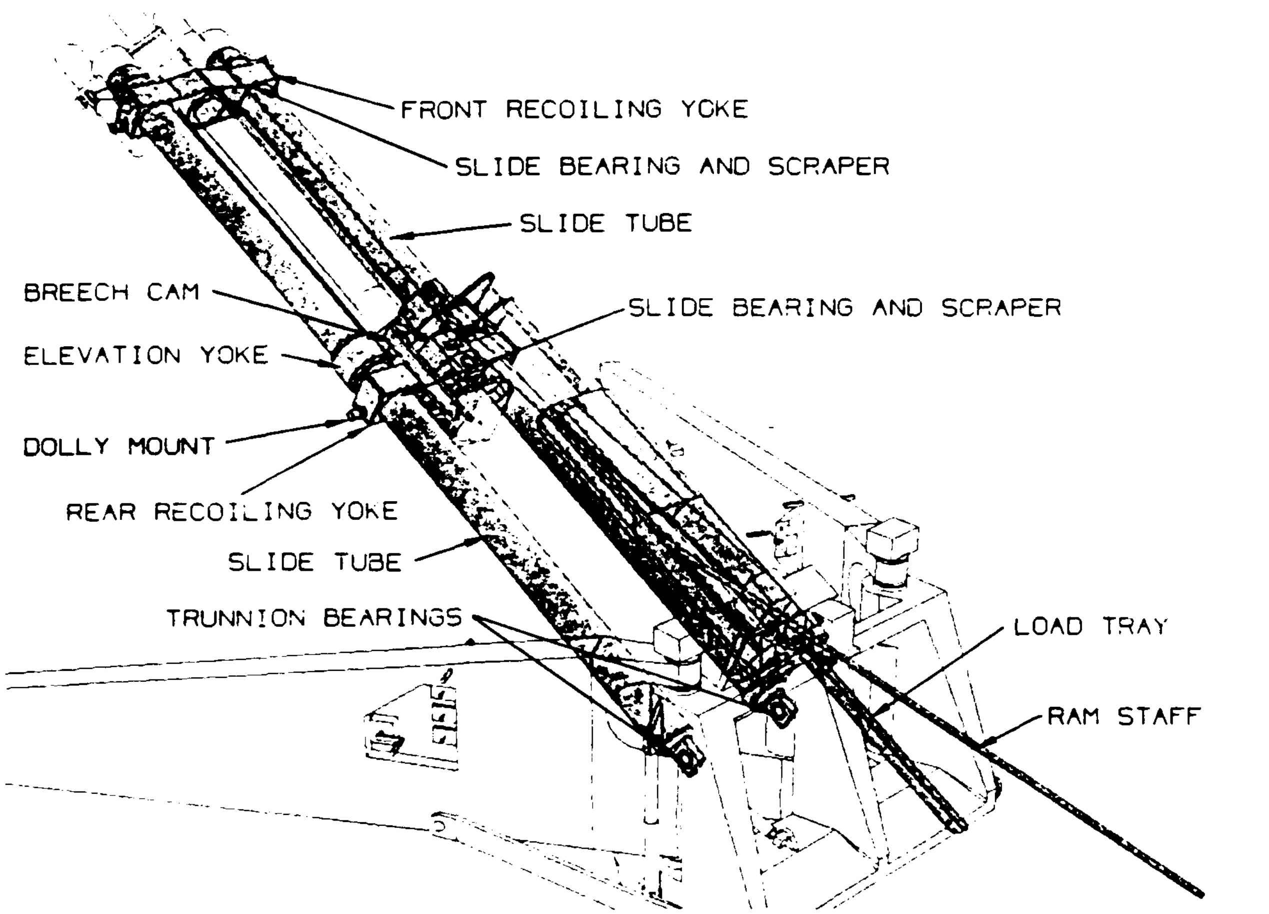


Figure 3-35. THE SLIDE CONFIGURATION provides natural protection to the crew from the increased recoil stroke.

2. As the load path continues, it creates an upward load on one slide tube, coupled with a downward load on the other slide tube. The slide tubes combine with the elevation and the forward yoke to form a torque tube. This strength/stiffness requirement mandated the 10.5 inch outside diameter of the slide tubes (to obtain sufficient section properties).
3. The torque reaction finally appears at the trunnion bearings primarily in the form of vertical components (up on one side and down on the other).

The slide mounting to the platform was evaluated in both vertical and horizontal configurations. The horizontal configuration was chosen. Attributes for each configuration are discussed below:

1. Horizontal:

   a. Provides lower overall height, required by LAPES and air-drop
   b. Facilitates lower trunnion height, important for firing and towing stability
   c. Raises slide tubes farther above the ground

[redacted]

d. Reduces aerial vulnerability of one recoil cylinder and the recoil accumulators

2. Vertical:

   a. Provides compatibility with the side-opening breech (M199 or M185)
   b. Reduces aerial vulnerability to one of the slide tubes (which are not particularly susceptible to damage)

The mechanical breech access (paragraph 3.1.3) creates the weight penalty of a load-tray. This penalty, however, is significantly less than the weight saved via the focused structure concept.

Two load-tray appr aches were considered. The first was a tr y that swiveled in over the trails. The pivot centerline was near the platform and vertical at zero elevation. The second, and preferred approach, was a tray that pivoted about an axis parallel to the slide. The factors considered in making this choice are outlined below:

1. Horizontal slide orientation is feasible. (The first tray required vertical slides.) The advantages of the horizontal over the vertical slides were discussed earlier.
2. Loading times would be reduced.
3. Trails could be higher. This reduces weight by virtue of the deeper section and increases utility as storage vessels.
4. Four-round burst capability appeared feasible.
5. Load-tray operation is less awkward at high QE loading.
6. This configuration eliminates the cantilevered beam associated with the former approach, reducing stress, deflection, and weight problems.

The ram-tube portion of the load tray design selected falls short of the barrel face by 19 inches, due to the clearance required for the upward swinging breech. We are currently evaluating the following ideas, en route to eliminating this issue:

1. Extend (strong) fingers with the rammer to bridge the gap.
2. Angle the breech.
3. Swivel the breech down.
4. Angle the slide.
5. Move the slide tubes farther apart.
6. Move slide tubes off center.

3.3.2.3 Recoil System

The recoil system approach will be described in these four steps:

1. Generic approach to the lightweight challenge
2. Numeric solution to the LTHD system
3. Mechanical operation of the recoil system
4. Mechanical operation of the recoil cylinder

3.3.2.3.1 Generic Approach to the Lightweight Challenge

The generic purpose of the recoil system is to provide a controlled negative acceleration to the cannon to stop it in a reasonable distance. Reducing the recoiling mass increases the necessary retarding force, while increasing the recoil stroke reduces this force. Thus, the first major consideration is whether the recoiling mass should be reduced. If the recoiling mass is not reduced, the following situation exists. The M198 recoiling mass is 7,000 pounds. Thus, the balance of the howitzer would have to weigh in at 2,000 pounds to achieve the 9,000 pound requirement. Because the M198 weighs 15,760 pounds, the M198 nonrecoiling mass weighs 8,760 pounds. Therefore, the

[redacted]

strength-to-weight ratio of the nonrecoiling mass would have to increase by a factor of 4.5 to 1. This is not impossible, but is not an optimal solution, considering the risk element.

If the recoiling mass is reduced, the following will result:

1. The required force to stop the cannon in a reasonable distance increases (figure 3-3).
2. This increased recoil force will produce an increased load on the structure which will, in turn, create larger deflections at the time of shot ejection. This will have an undesirable effect on downrange accuracy.

The second major consideration is whether the stroke should be increased. Increasing the stroke:

1. Reduces the required retarding force (figure 3-2)
2. Increases the resultant breech to ground distance at high QE's

3.3.2.3.2 Numeric Solution to the LTHD System

The numeric solution involved hundreds of computer runs performed during the concept evolution of the FMC LTHD, at both the system and component levels (paragraph 3.1.4). The result is the trunnion loading force profile listed below and plotted in figure 3-36.

The total stroke of 102 inches breaks down as follows:

| | |
|---|---|
| 4.25 | inches free recoil |
| .75 | inches fluid compression |
| 93.00 | inches major energy absorption |
| 4.00 | inches overtravel allowance |
| 102.00 | inches total |

The recoil retarding force (equivalent to trunnion loading) is shaped to provide the following features:

1. A free recoil distance of 4.25 inches minimizes the force input to the firing platform prior to shot ejection.
2. Fluid compression to the full recoil force consumes 0.75 inch.
3. The initial force (following fluid compression) is sufficient to maintain a positive safety moment (stabilizing moment less overturning moment) with the 12,500 pound second charge.
4. Thereafter, the decreasing distance of the CG to the pivot will result in a decreasing stabilizing moment, and the recoil force is reduced accordingly to maintain a positive and fairly constant safety moment. Figure 3-11 graphically depicts this safety moment.
5. The final force is the force necessary to stop the cannon at the end of the 98-inch nominal stroke. A 4.0-inch cushion was arbitrarily chosen to allow for overtravel conditions caused by fluid, temperature, manufacturing, and miscellaneous variations.

3.3.2.3.3 Mechanical Operation of the Recoil System

The mechanical operation of the recoil system is illustrated in figure 3-37. The major items are the recoil cylinders, the recoil accumulators, and the forward yoke.

The recoil system load path has three steps:

1. When the cannon is fired and recoils, the recoil cylinders provide the programmed force profile shown in figure 3-36. An equalization passage in the forward yoke balances the pressure in the two cylinders.



[redacted]

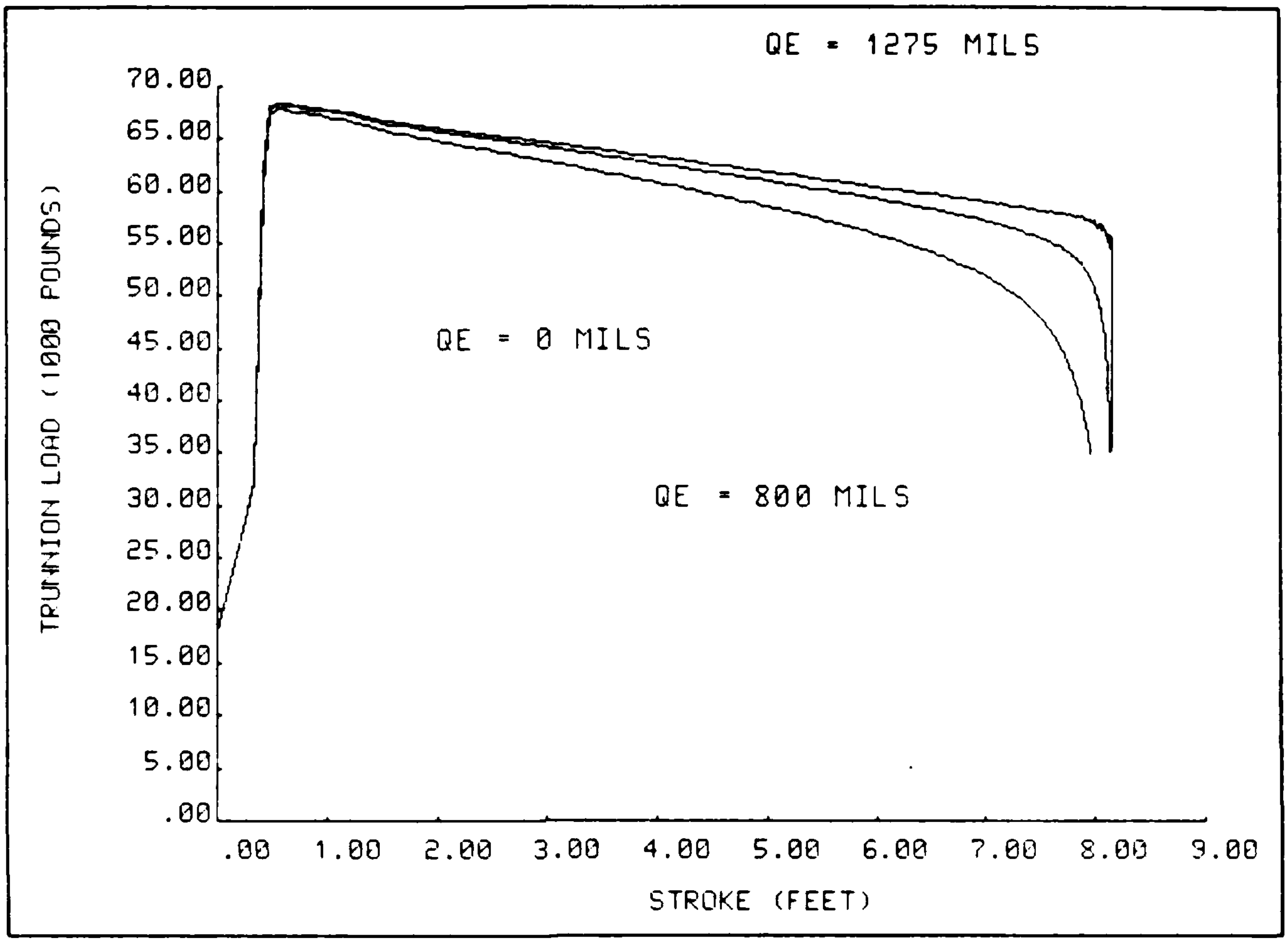


Figure 3-36. THE RECOIL FORCE PROFILE is shaped to achieve maximum firing stability, while enhancing downrange accuracy, by keeping forces low until projectiles exit.

[redacted]

2. From the recoil cylinder mounting point in the forward yoke, the load path flows to the yoke-tube lock (one for each slide tube).
3. The yoke-tube lock transfers the load into the slide tubes. Operation of the yoke-tube lock is covered in paragraph 3.2.2.2.

3.3.2.3.4 Mechanical Operation of the Recoil Cylinder

The mechanical operation of the recoil cylinder (figure 3-38) includes the recoil cycle and the counterrecoil cycle.

The recoil cycle consists of this sequence of events:

1. When the cannon recoils, the recoiling mass moves to the right.
2. The fluid in the programmed pressure chamber is pressurized by the orifice ring. This provides the required force-distance profile by virtue of the contoured inside diameter of the recoiling outer cylinder. The recoiling outer cylinder, combined with the orifice ring, forms an annular orifice.

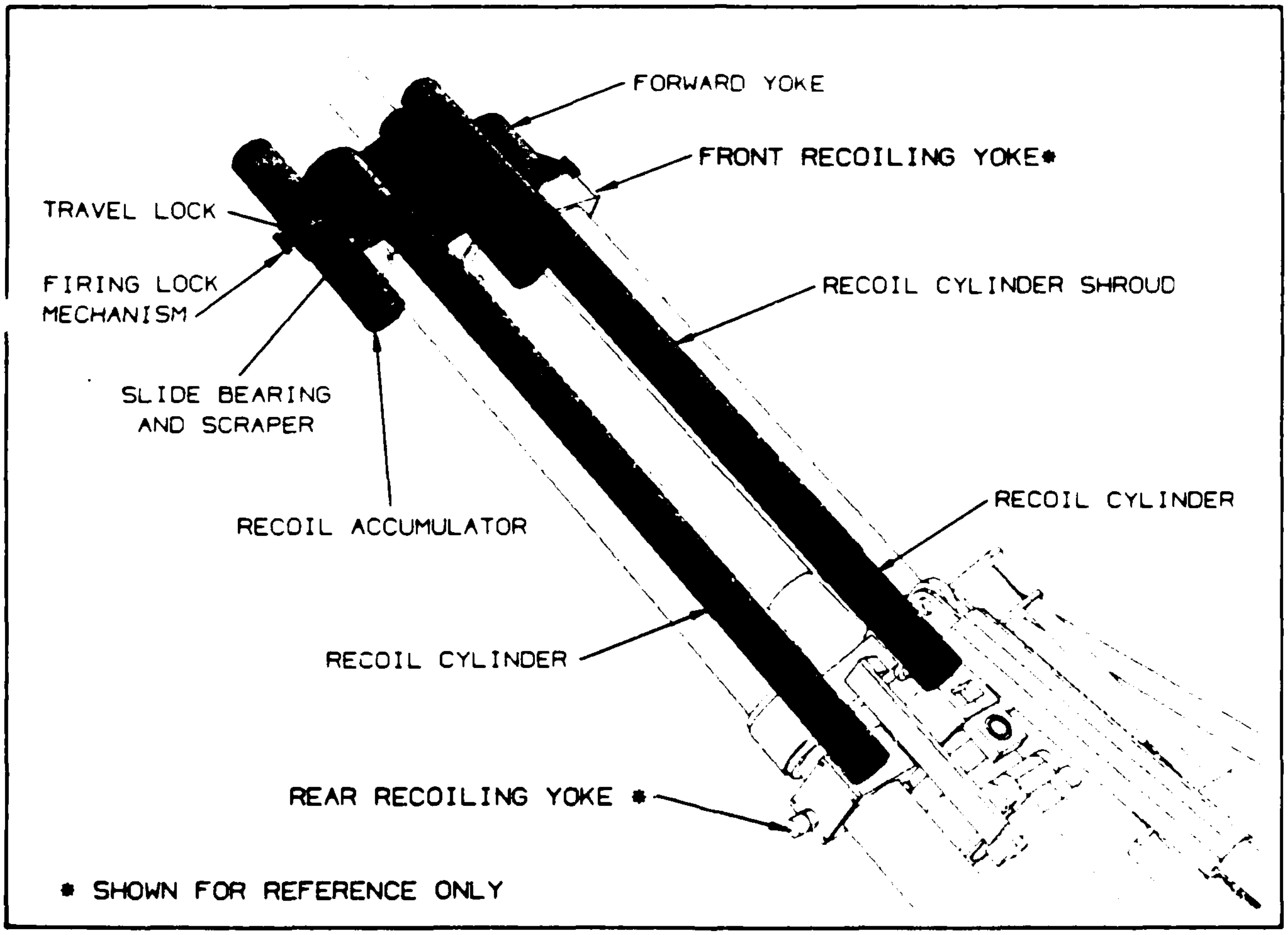


Figure 3-37. THE RECOIL SYSTEM operates on the conventional hydropneumatic principle to reduce risk.

[redacted]

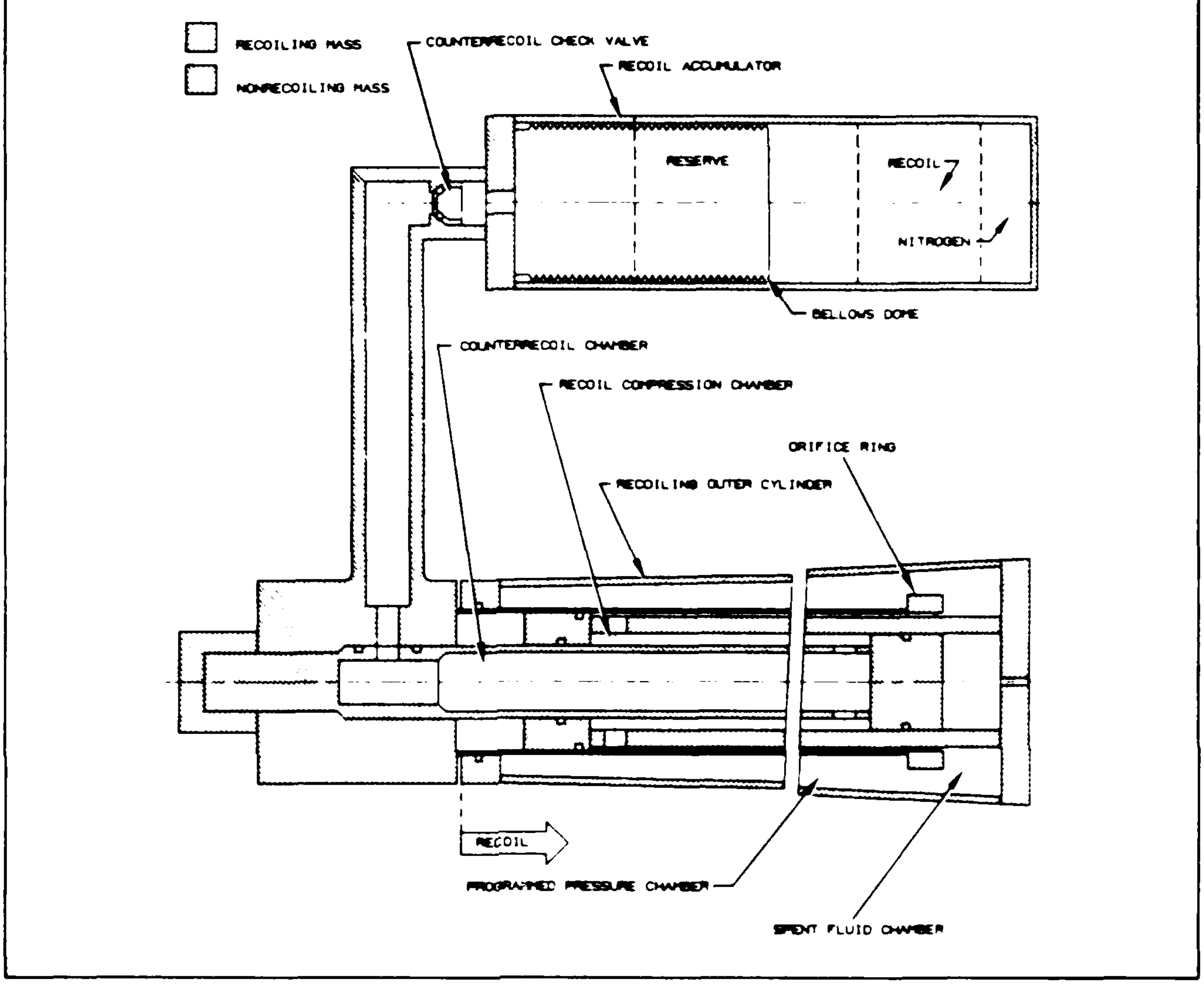


Figure 3-38. THE FMC LTHD RECOIL CYLINDERS improve RAM-D by orificing against the outer wall (reducing sensitivity to outside damage) and bellows accumulators (reducing sensitivity to outside damage and eliminating nitrogen maintenance).

3. The flow of fluid from the programmed pressure chamber to the spent fluid chamber, combined with the displacement of the recoiling mass, reduces the volume in the spent fluid chamber.
4. The volume reduction in the recoil compression chamber increases the volume in the spent fluid chamber beyond the reduction mentioned in the above step, thus displacing fluid to the counterrecoil chamber.
5. The fluid added to the counterrecoil chamber is stored in the recoil accumulator.

The counterrecoil cycle consists of this sequence of events:

1. The fluid displaced to the recoil accumulator results in a counterrecoil pressure.
2. The magnitude of this counterrecoil pressure that acts upon the recoil

[redacted]

cylinder to return the cannon to the battery is controlled by the orifice in the counterrecoil check valve.

3. The counterrecoil buffers, which are external and mounted on the forward yoke, ease the cannon movement into battery.

The logic behind our design of the recoil cylinder includes the following points:

1. The orificing is performed against the inside surface of the outer wall for these reasons:

   a. Scrubbing the working fluid against the outer wall will increase heat transfer and the feasibility of a composite overwrap. (Conventional composites are poor conductors of heat.)
   b. The lack of dynamic seals may facilitate a linerless composite cylinder, resulting in further weight reduction.
   c. Moving the sealing surfaces inward insulates the recoil cylinder from damage to a greater degree.

2. The majority of the recoil cylinder recoils to maximize the recoiling mass.
3. The recoil cylinders are, in effect, self-displacing. The high internal flow rates are contained and only enough volume is displaced to the recoil accumulator to provide reasonable at-battery forces from reasonable nitrogen pressures.
4. The scheme allows the recoil accumulators to provide makeup fluid. This fluid store can be replenished by the portable pump of the hydraulic system (figure 3-39).
5. The recoil accumulators do not recoil because bellows accumulators were chosen to perform that function. Bellows accumulators were employed because of the elimination of dynamic seals. This resulted in:

   a. Elimination of nitrogen precharge maintenance
   b. Reduction in the sensitivity of the inner wall to damage. (Bellows accumulators can operate under conditions that would seize a piston-type accumulator.)

Two constraints on the application of bellows accumulators are necessary to reap these benefits:

a. Avoidance of high flow to prevent damaging pressure drop across open bellows
b. Avoidance of mounting on recoiling mass (in excess of 200 g's could damage bellows)

#### 3.3.2.4 Hydraulic System

The hydraulic system (figure 3-38) supports the following functions, and an operational description is provided for each in the paragraphs listed below:

| Function | Paragraph |
|---|---|
| Elevation (from gunner or assistant gunner's position) | 3.3.3.3 |
| Elevation with failed equilibrator (from portable pump) | 3.3.3.3 |
| Equilibrator temperature compensation (from portable pump) | 3.3.3.3 |
| Recoil cylinder fluid replenishment (from portable pump) | 3.3.2.3 |
| Spade positioning (from gunner's position) | 3.2.2.2 |
| Traverse (from gunner's position) | 3.3.3.2 |



[redacted]

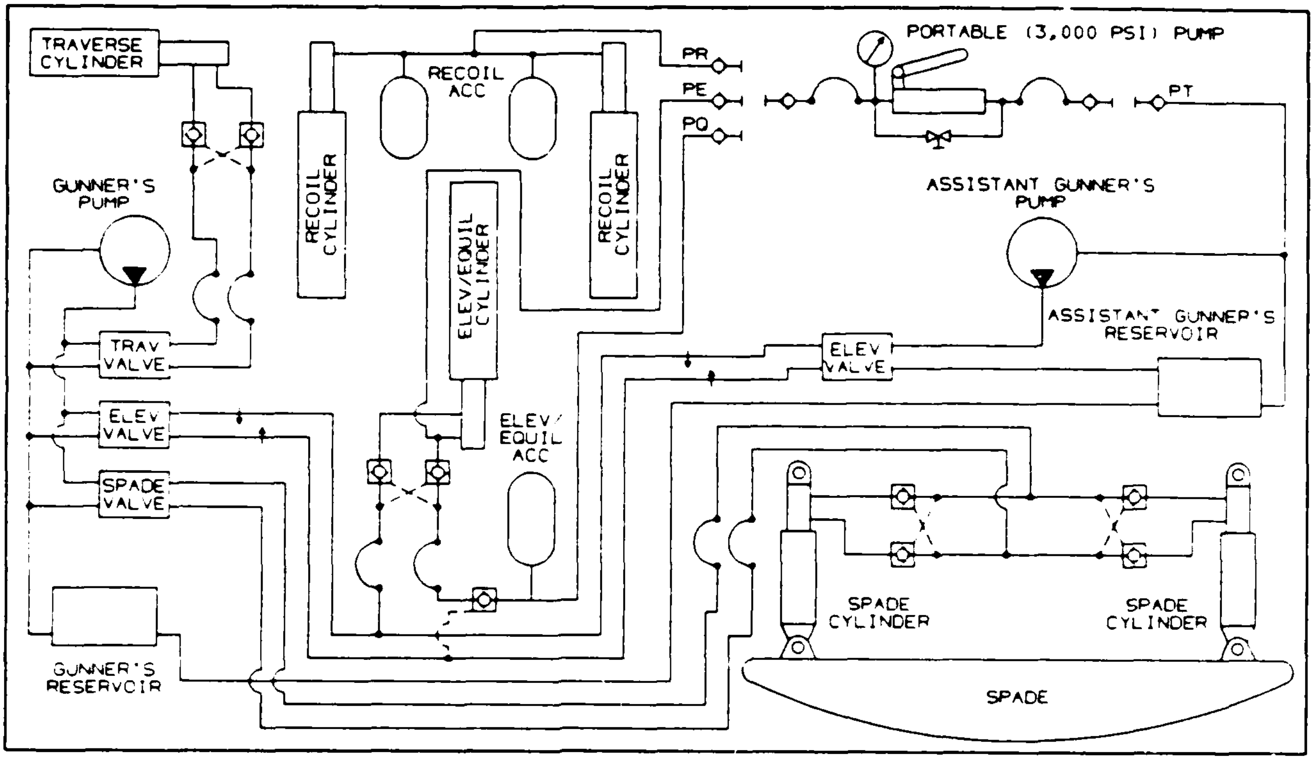


Figure 3-39. CENTRALIZATION OF THE HYDRAULIC SYSTEM reduces weight; controls at the gunner and assistant gunner positions provide for flexibility and degraded operations.

Several hydraulic cylinders are employed. In general, pilot-operated check valves hold the rod positioned. Where practical, composite-wound cylinders are employed to reduce weight.

The portable pump saves weight by providing the multiple functions that are not directly tied to the firing operation.

### 3.3.3 Fire Control

The M198 optics, enhanced by radio battery-operated electronics (with provision for manual backup), are combined with hydraulic cylinders to provide fire control. The components are identified in figure 3-40.

#### 3.3.3.1 Lay

The M198 direct fire control (DFC) unit pivots on the bearing centerline of the platform end of the elevation cylinder. The elevation cylinder moves with traverse. A link to the slide provides elevation.

The M198 indirect fire control (IFC) unit is mounted just behind the DFC on the platform. The IFC maintains platform lay. Electronics are used to measure tube lay relative to platform lay. The difference between these actual and the desired tube lay are displayed on electronic laying aids.

[redacted]

The two electronic laying aids (figure 3-41), one for elevation and one for traverse, are mounted above the trail pivots (figure 3-40). Each has a digital set point and green lights. The lights indicate the lay of the cannon relative to where it should be. A sunshade/guard for the lights, plus an intensity-adjusting on-off knob, accommodates bright sunlight to pitch-dark-in-the-rain operations. As the desired lay is approached, blue indicators light. When three indicators are lit, the cannon is within 1 mil of the desired lay. When all the indicators light, the cannon is within the prescribed resolution. This prescribed resolution is set by an adjustable "null band" to provide the sensitivity versus time tradeoff necessary from a specific mission perspective.

The electronic laying aids can be swiveled so either the gunner/assistant gunner or the section chief can set the lay. The lights allow the section chief to see the proximity of the cannon to desired lay for both elevation and traverse (figure 3-21).

Indicator lights (with a light and protection shade) were chosen over digital or analog meter displays for ruggedness, operation in a range of ambient lighting, broad field of view, and simplified field repair.

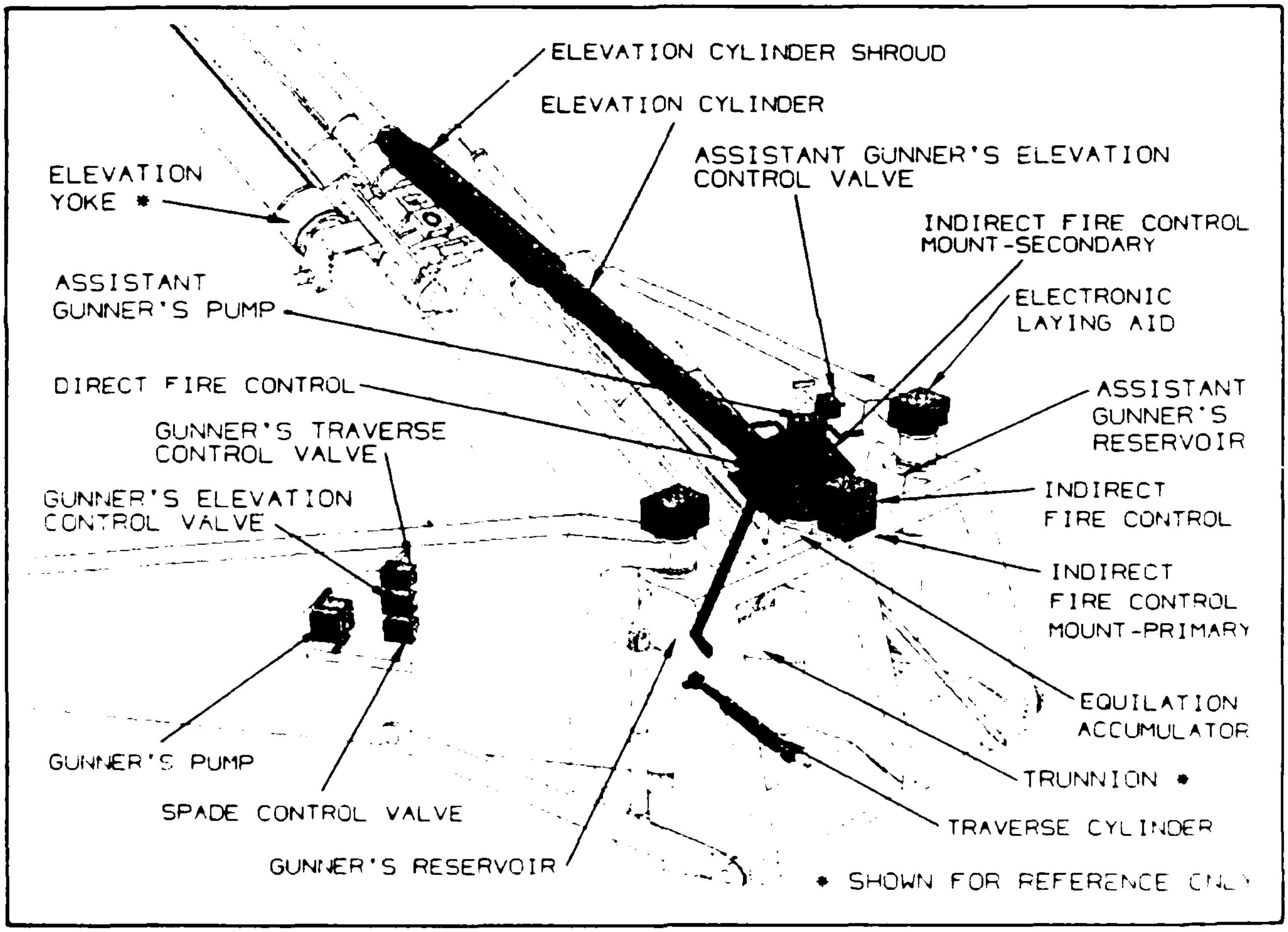


Figure 3-40. FIRE CONTROL SYSTEM WEIGHT is reduced through a single elevation cylinder; RAM-D is improved with a bellows accumulator (reducing sensitivity to outside damage and eliminating nitrogen maintenance).

[redacted]

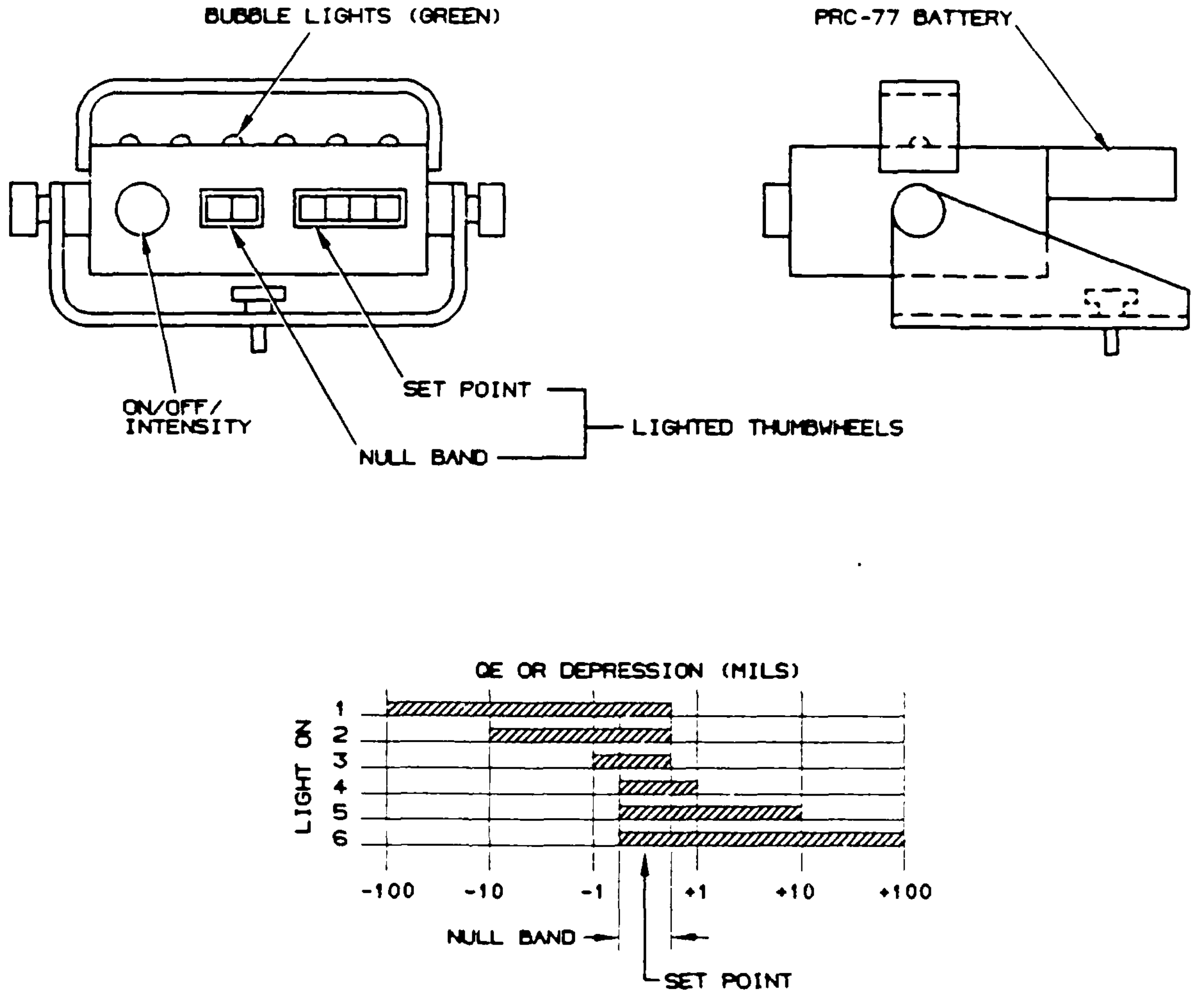


Figure 3-41. THE ELECTRONIC LAYING AIDS reduce the time required to set lay while accommodating the FMC LTHD low trunnion height and stationary platform.

[redacted]

In the event of an electronic failure, the 'FC will be moved to the secondary IFC mount. The secondary IFC mount is located just in front of the primary mount and is integral with the DFC mount. Since the gunner and assistant gunner would not be able to see the fire control levels, a third person would be required to announce the fire-control-level status during elevation and traverse.

3.3.3.2 Azimuth

The traversing function is provided by a hydraulic cylinder operable from the gunner's position (figure 3-21). Hydraulic power is provided by a foot or hand-operated pump at the gunner's position. Directional control is provided by the traverse control valve at the gunner's position. Fluid is locked into the cylinder with pilot-operated check valves when a position is to be held (figure 3-39).

3.3.3.3 Elevation

The elevating function, provided by a single two-chamber hydraulic cylinder (figure 3-42), is operable from the gunner's or gunner's assistant position (figure 3-21) and provides the minimum weight solution. Hydraulic power is provided by a foot or hand-operated pump at either position. Directional control is provided by the elevation control valve at either position. Fluid is locked into the cylinder with pilot-operated check valves when a position is to be held (figure 3-39).

The cannon is raised by the (over-equilibrated) equilibration chamber in the elevation cylinder (figure 3-42) and lowered by the depression chamber. The gunner or assistant gunner will move the elevation control valve in the elevation direction and stroke the pump once to open the pilot-operated check valve, which will allow the equilibrator to raise the cannon. To depress the cannon, the gunner or assistant gunner will move the valve to the depress position and pump the cannon down. To hold position, the valve would be moved to the center "hold" position.

Recoil energy recovery schemes were investigated, but in every case, the overall system weight and complexity increased beyond reasonable limits. However, we have tried to minimize the energy required for the elevation function through the use of reduced seal friction, more accurate temperature compensation, and the introduction of a nonlinear spring assist.

Dynamic analysis of the resultant depression and elevation cycle times, in combination with the load and fire times (figure 3-23), and the QE limitation (paragraph 3.2.2.3), indicates 4 rounds per minute are attainable to 525 mils QE, 2 rounds per minute to 800 mils QE, and 1 round per minute at 1,275 mils QE. (Above rates do not apply to COPPERHEAD.)

Equilibration temperature compensation is accomplished by altering the volume of oil in the equilibration chamber with the portable pump (figure 3-39). The portable pump is connected to the reservoir (PT, figure 3-39) and equilibration chamber (PQ) via quick-disconnects. Fluid will be added to or removed from the equilibration chamber until the cannon elevates at the desired rate. This method was chosen due to weight savings and elimination of these three, normally unavoidable, variances:

1. Knowledge of the ambient temperature
2. Variation in nitrogen precharge pressure (at some standard conditions)
3. Seal friction variations (new and due to wear-in)

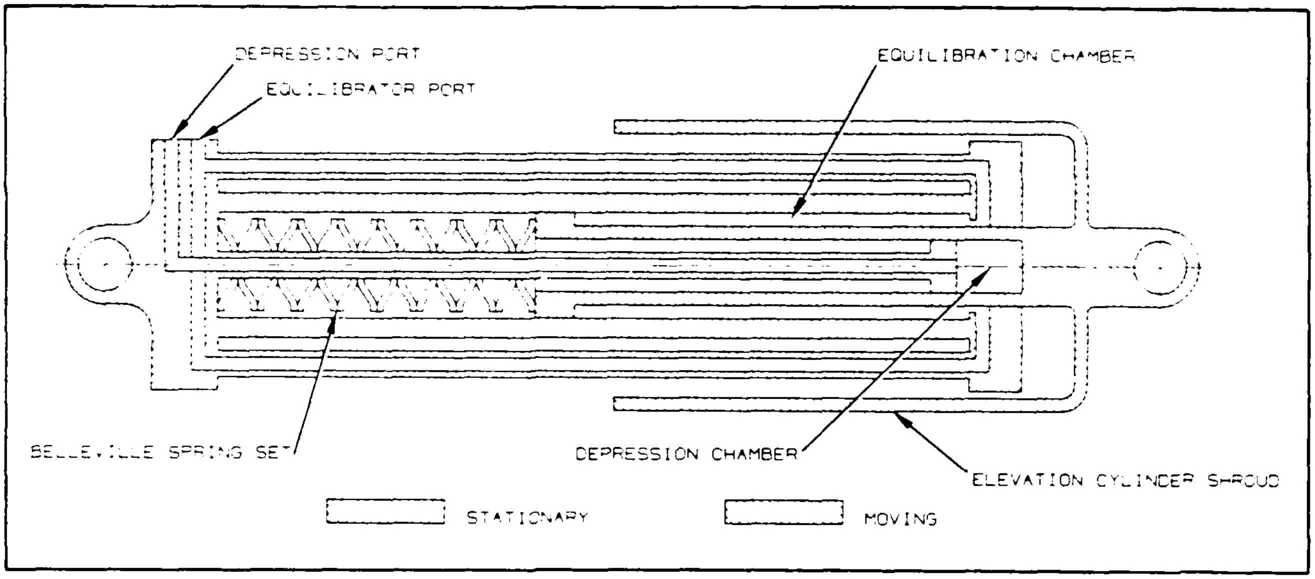


Figure 3-42. THE ELEVATION CYLINDER employs a simple, two-chamber design with integral equilibrator to minimize weight and reduce friction.

A bellows-type accumulator was chosen to provide the equilibration chamber with fluid for the following reasons:

1. The elimination of dynamic seals eliminates the need for periodic precharge maintenance.
2. The excellent heat transfer across the bellows to the fluid reduces the time required to as little as 1 minute for the equilibration pressure to stabilize, after significant changes in the elevation setting. Conventional accumulators take many times this amount of time to stabilize. During this time, additional energy is required, because the cannon is not properly equilibrated.

The equilibration accumulator is mounted within the center post in the platform. This location necessitates the use of a metal hose which, if damaged, would eliminate the equilibration function. This mounting was done with the following in mind:

1. The platform provides excellent protection to the accumulator itself.
2. The accumulator housing doubles as the traverse shaft, thus reducing weight.
3. Should the equilibrator or hose fail, the portable pump would be connected to port PQ (figure 3-39). Elevation would involve pumping; depression would involve bleeding fluid back to the reservoir.

The nonlinear Belleville spring set (figure 3-42) minimizes the mismatch between the equilibration force needed and accumulator force-supplied curves. Without the spring set (or if it fails), the energy required to depress the cannon would increase at QE's above 800 mils.

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BAFO RESPONSE

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FMC

# Northern Ordnance Division

BEST AND FINAL OFFER

155 mm Lightweight Towed Howitzer
System Demonstrator

and

Innovative Recoil Mechanism

RFP DAAK10-85-R-0254

25 November 1985

FMC, Northern Ordnance Division
4800 East River Road
Minneapolis, Minnesota
55421

# Foreward

FMC's response to the Negotiation Issues attached to ARDC's Request for Best and Final Offers for the 155MM Lightweight Howitzer Demonstrator and Innovative Recoil Mechanism, dated 13 November 1985, is organized in the same sequence as provided by ARDC. We have specifically attempted to keep our direct responses to the issues raised as brief as possible, and then provided detailed discussions and descriptions in referenced appendices. We have also numbered all elements (pages, figures, appendices, etc.) of our response to the issues with keyed prefixes for easy identification, should you desire to separate the document. The key we've used for this purpose is as follows:

| Issue Identifier | Key |
|---|---|
| First Letter: | |
| Lightweight Howitzer Demonstrator | H |
| Innovative Recoil Mechanism | R |
| Second Letter: | |
| Technical Issues | T |
| Management Issues | M |
| Cost Issues | C |
| Numerical: | |
| Issue Number | Numeric |

Pages, figures, and tables are sequentially identified with dashed numerics, and appendices are sequentially identified with dashed alphabetics for each issue. Thus, HT4-3 identifies page 3 of our response to Howitzer Technical Issue 4. Similarly, RT3-A2 identifies page 2 of Appendix A of our response to Issue 3 of the Technical Issues for the Innovative Recoil Mechanism. We hope this approach will make it easy to identify elements of our response should they become separated from our complete document.

[redacted]

Negotiation Issues

FMC

155MM LIGHTWEIGHT HOWITZER DEMONSTRATOR

Technical Issues:

Issue 1. The proposed demonstrator size exceeds the M198 envelope. How do you propose to reduce the envelope size to that of the M198?

FMC Response. The FMC LTHD exceeds the six M198 stow and tow envelope dimensions in two categories, overall length (30' vs 24'8") and overall height (7'2" versus 7'), both in the stow configuration (see Figure 3-15 in proposal). Our response will be twofold. First we will review the items considered and illustrate that the FMC LTHD (with a minor modification) is compatible with the transportation-driven size constraints. Then we will introduce a revision to the original concept proposed, which we call VERSION 1.1, that, among other things, eliminates the height variance and reduces the overall length variance from 5'4" to 1'0".

We reviewed the following items relative to precursory transportation requirements compatibility of the FMC LTHD:

1. Opening and cargo compartment dimensions and restrictions. Since the FMC LTHD is narrower than the M198, no problems were expected here. The different profile and shifted center of gravity necessitated additional investigation, particularly relative to cresting during LAPES, the findings of which are detailed below.

2. Structural limitations of ramp and cargo compartment. Since the LTHD is lighter than the M198, no problems are expected here.

3. Pressure and G-loading. Preliminary stress calculations assumed the following G-levels: forward, 8; aft, 1.5; lateral, 1.5; vertical, 18.5 (ground impact following parachute extraction).

Figures HT1-1, -2, and -3 show the FMC LTHD (VERSION 1.0) being pintle loaded into a C130E. The dimensions of the C130E (used in Figures HT-1 thru -7) were obtained by measuring such an aircraft at the Minnesota Air National Guard Air Base in Minneapolis, and talking to the pilots and technicians familiar with the C130 family. The shaded area will be removed from the concept to eliminate potential interference.

Figure HT1-4 shows the end view of the FMC LTHD in a C130E. Although the FMC LTHD does not conform with the aisle requirements (MIL-A-8421) states that the aisle is necessary because the C130 does not have a catwalk, the fact that the LTHD is 14" narrower than the M198 indicates that the LTHD deviation from specification will be significantly less than the M198.

[redacted] [redacted]

Technical Issues:

Issue 1. (Cont'd.)

Figures HT1-5, -6, and -7 show the FMC LTHD being parachute extracted from a C130E. Note that the roof clearance necessary for tip-off experienced during parachute extraction is achieved by palletizing the LTHD in a muzzle-tipped-up-30" configuration onto a 3.5 inch-thick pallet. Note also that the load center of gravity has been adjusted for addition of the (estimated) 2,500 lbm pallet with honey comb.

Figure HT1-8 illustrates the relationship of the FMC LTHD to the tip-off curves for the C130.

Figure HT1-9 illustrates the relationship of the FMC LTHD to the tip-off curves for the C141. This shows the tip-off constraints of the C141 to be less restrictive than the C130.

FMC LTHD VERSION 1.1 (pictured in Figure HT2-1) eliminates the height variance relative to the M198 and reduces the length variance from 5'4" to 1'0" by providing an overall length of 25'8". The favorable width variance of 14" for the FMC LTHD relative to the M198 is maintained. VERSION 1.1 also significantly increases the angle of departure relative to the initial proposal, which will, in turn, improve cross-country capability and compatibility with amphibious landing craft, should the need arise.

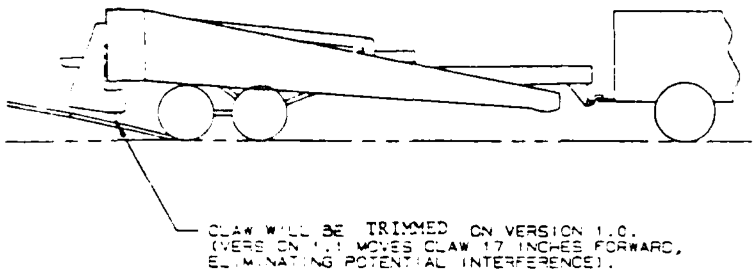



FIGURE HT1-1.
LOADING INTO C130E; FIRST
POTENTIAL INTERFERENCE POINT

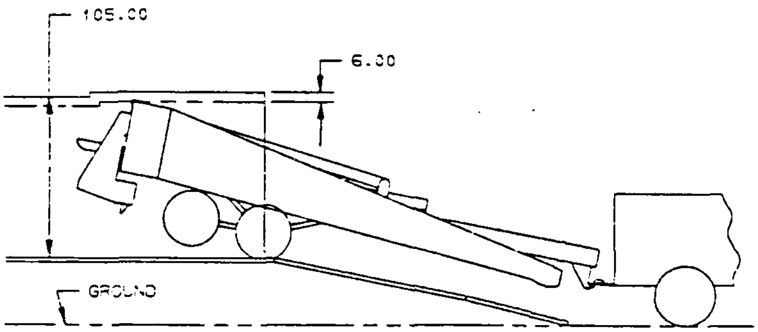



FIGURE HT1-2.
LOADING INTO C130E; SECOND
POTENTIAL INTERFERENCE POINT

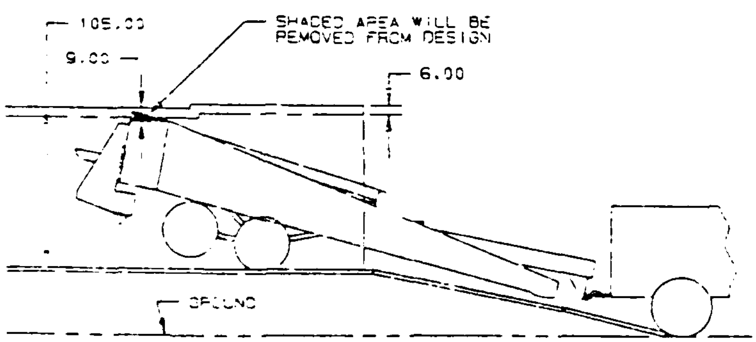
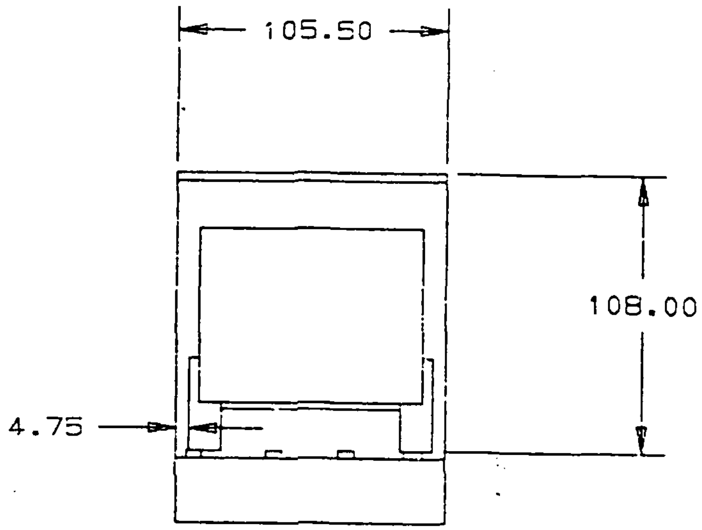



FIGURE HT1-3.
LOADING INTO C130E; THIRD
(AND FINAL) POTENTIAL
INTERFERENCE POINT.

[redacted] [redacted]




END VIEW

Figure HT1-4.

Loading Into C130E;
End View

[redacted]

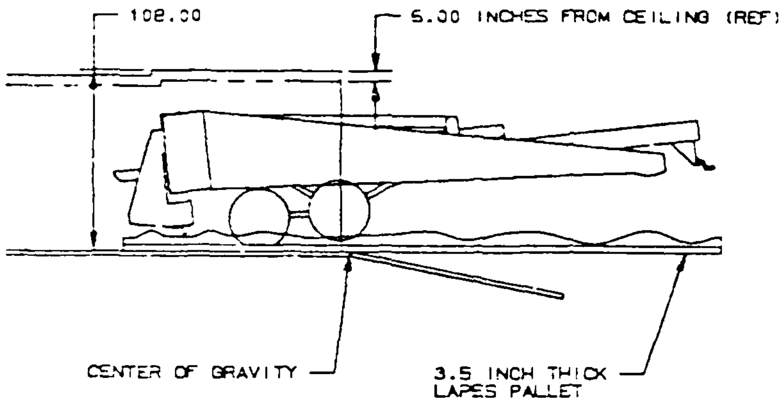



FIGURE HT1-5.
PARACHUTE EXTRACTION FROM C130E; JUST PRIOR TO TIPPING AT RAMP HINGE.

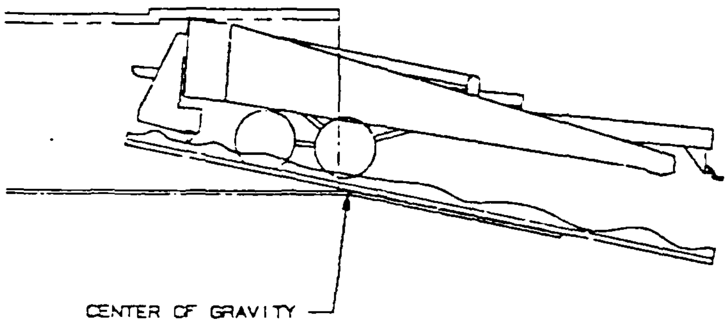



FIGURE HT1-6.
PARACHUTE EXTRACTION FROM C130E; JUST AFTER TIPPING AT RAMP HINGE.

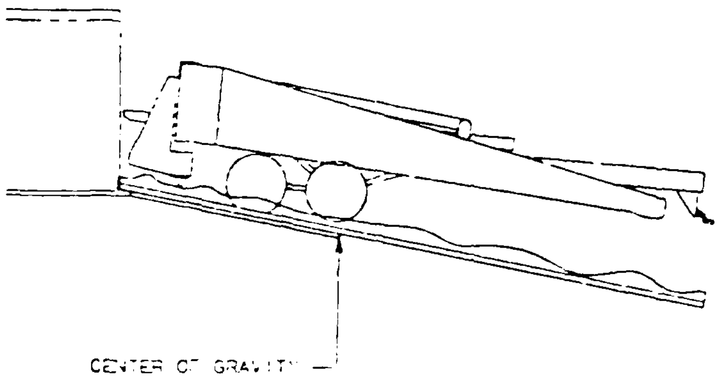


FIGURE HT1-7.
PARACHUTE EXTRACTION FROM C130E; CENTER OF GRAVITY AT END OF RAMP.

[redacted] [redacted]

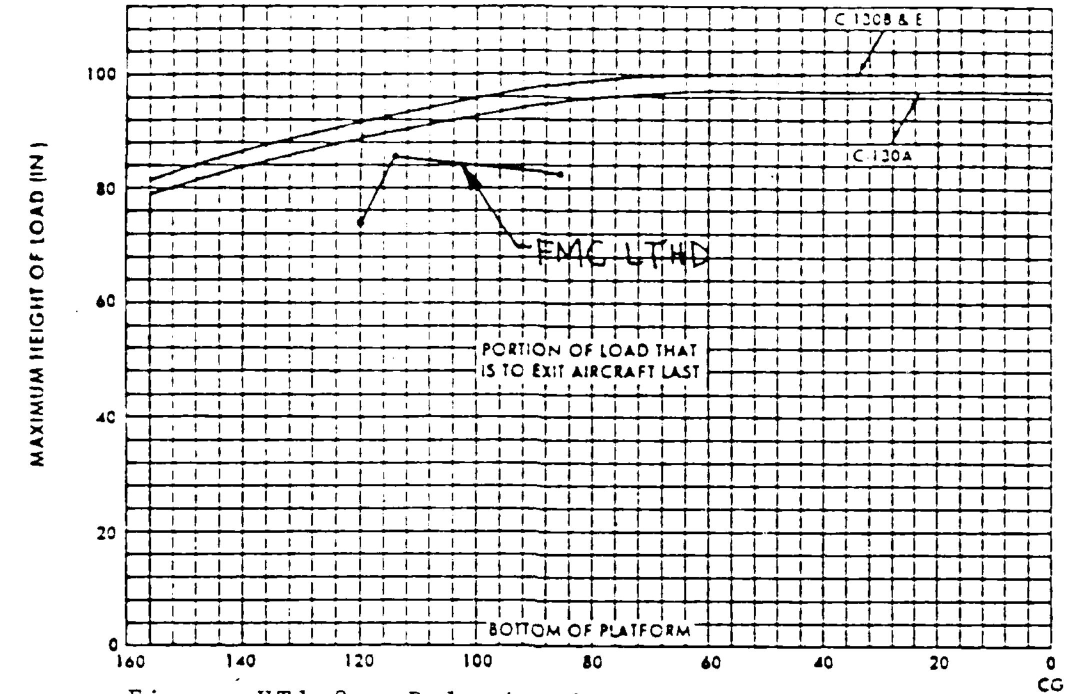



Figure HT1-8. Relationship of FMC LTHD on 3.5 inch pallet to C130 tip off curves (from AFSC Design Handbook 1-11).

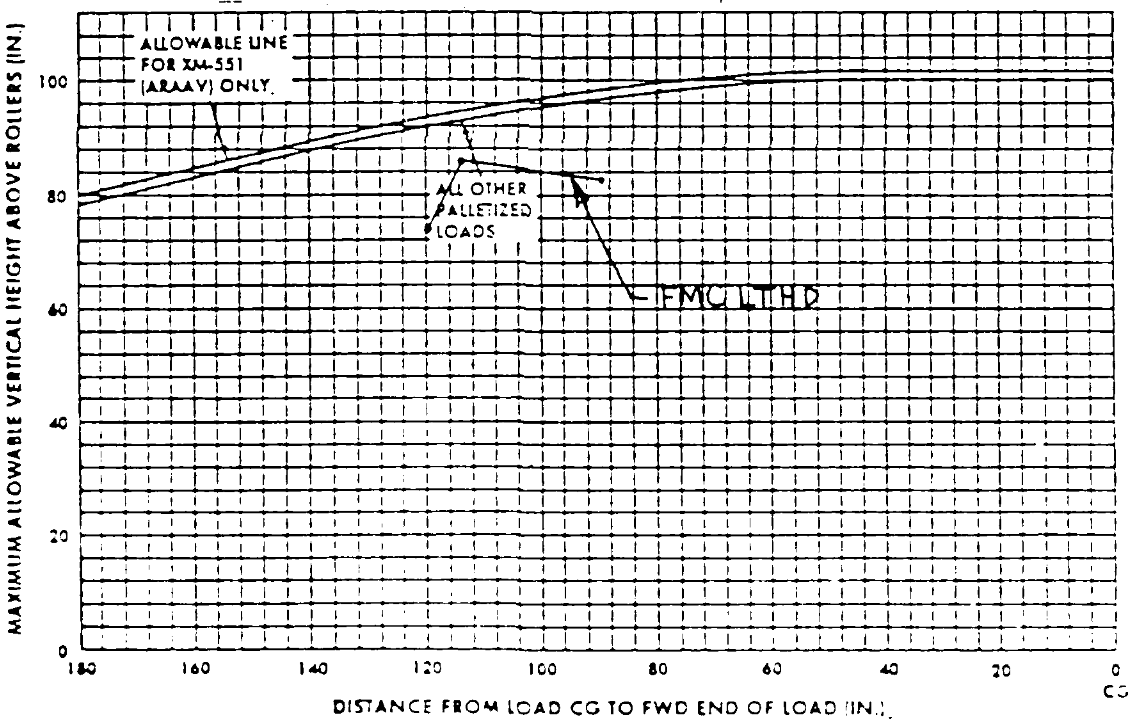



Figure HT1-9. Relationship of FMC LTHD on 3.5 inch pallet to C141 tip off curves (from AFSC Design Handbook 1-11).

[redacted] [redacted]

Negotiation Issues

FMC

155MM LIGHTWEIGHT HOWITZER DEMONSTRATOR

Technical Issues:

Issue 2. The proposal fails to meet firing rate requirements at max QE due to loading limitations. How do you propose to meet these requirements?

FMC Response. An enhancement of the original proposal addresses and fulfills these requirements. We refer to this enhancement as VERSION 1.1. Figure HT2-1 illustrates Version 1.1. Figure HT2-2 provides the time line of the firing operation. Appendix HT2-A provides an operational and component description relative to the LTHD originally proposed.

The human factors aspect of how VERSION 1.1 provides four rounds per minute (at max QE without exceeding M198 human factors requirements) is discussed in the RESPONSE to QUESTION 4.

[redacted] [redacted]

| Color Code | |
|---|---|
| Light Orange | Primer Feeder |
| Dark Orange | Elevation Cylinders |
| Yellow | Ram Tray (Shown 20 Inches Forward to Improve View of Trunnion) |
| Pink | Platform |
| Green | Spades |
| Red | Trunnion |

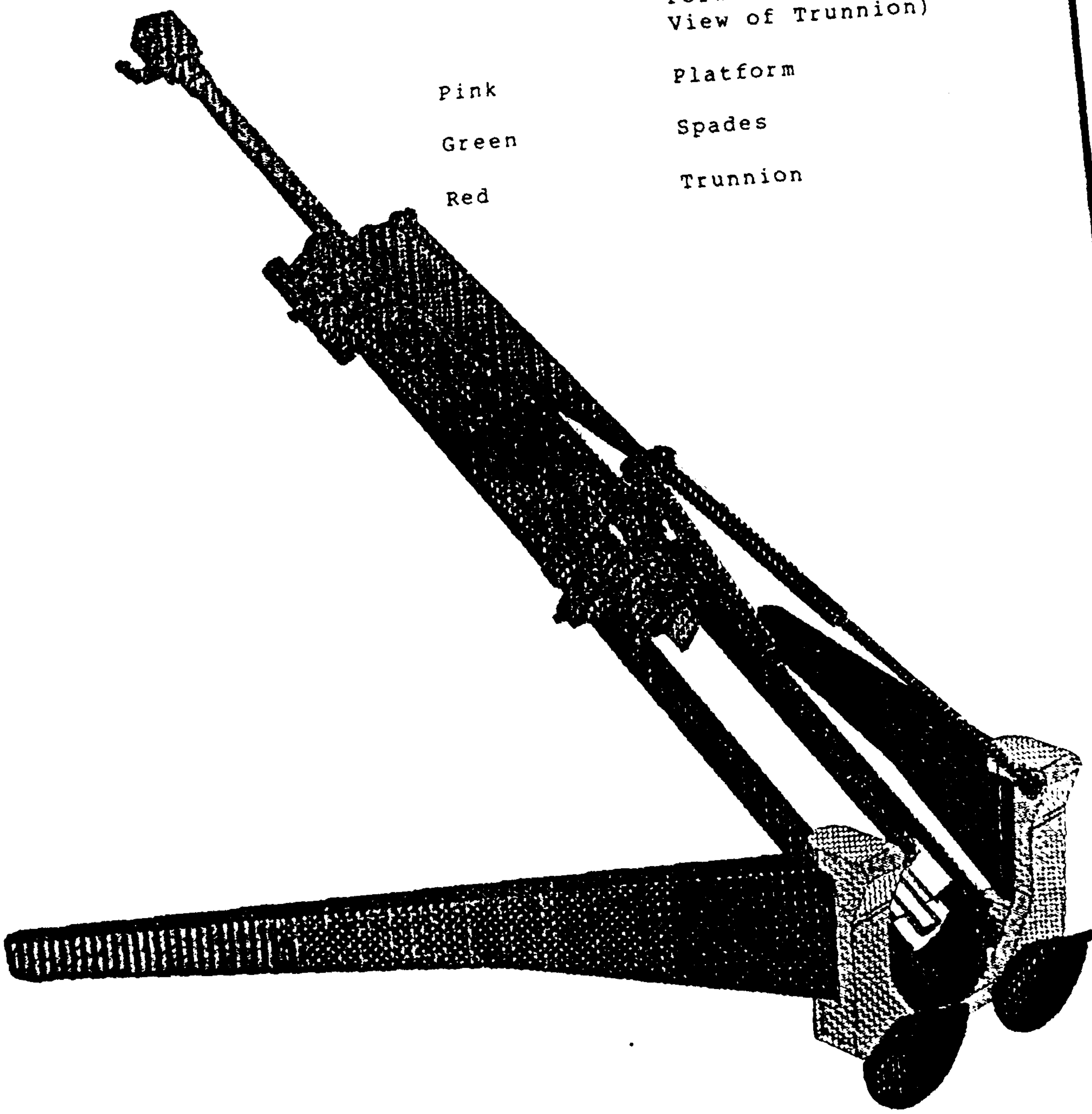


Figure HT2-1. FMC LTHD Version 1.1.

[redacted] [redacted]

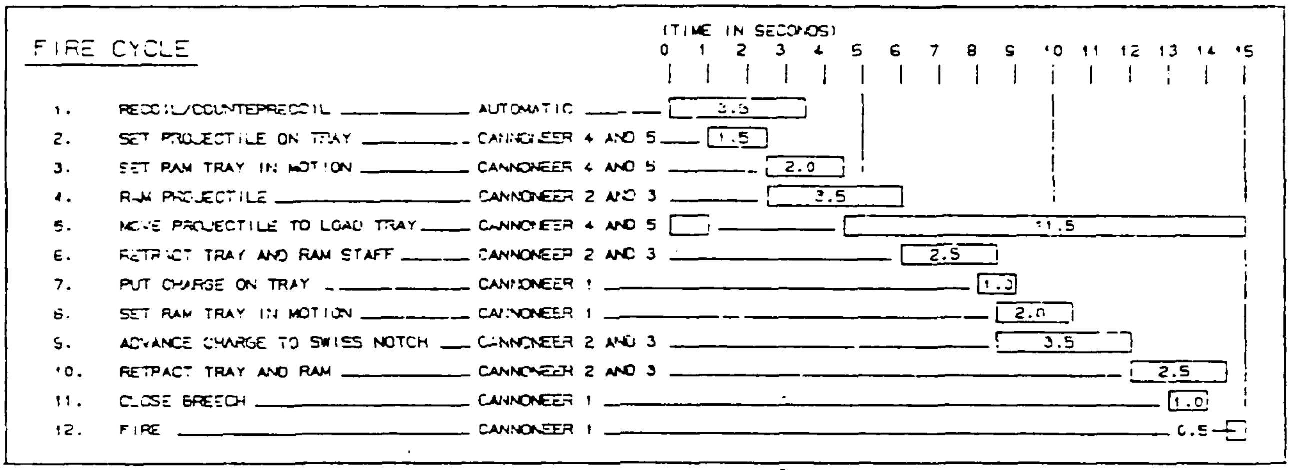
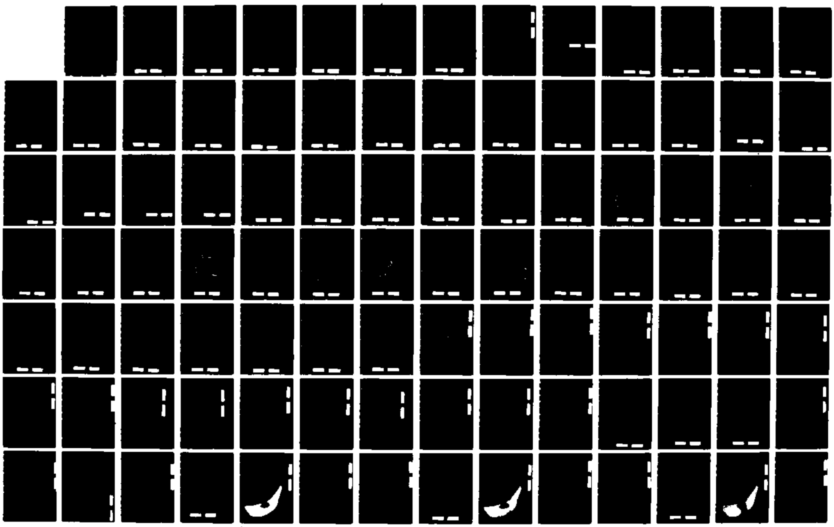
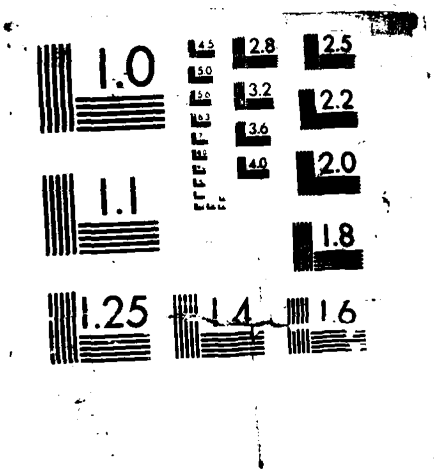



Figure HT2-2. Firing Time Line for FMC LTHD
Version 1.1

AD-A183 983 LIGHTWEIGHT TOWED HOWITZER DEMONSTRATOR PHASE 1 AND 2/4
PARTIAL PHASE 2 VOLUM (U) FMC CORP MINNEAPOLIS MINN
NORTHERN ORDNANCE DIV R RATHE ET AL APR 87
UNCLASSIFIED FMC-E-3041-VOL-B-PT-1 DAAA21-86-C-0047 F/G 19/6 NL






MICROCOPY RESOLUTION TEST CHART

## HT2-A Description of VERSION 1.1.

The FMC LTHD VERSION 1.1 (the concept described in the 4 June 85 proposal is considered VERSION 1.0) addresses a number of opportunities to improve the LTHD concept, as highlighted by ARDC's technical questions during the best and final offer.

VERSION 1.1 further simplifies the FMC LTHD structure, while reducing its size and improving high QE loading capability as well as human factors.

The OPERATIONAL and COMPONENT CHANGES are described below.

### Operational Changes

Relative to Version 1.0, the following changes (all to the firing sequence) are necessary. Emplacement, speedshifting, and displacement are essentially unchanged (hydraulic extraction of the spade has been replaced by manual extraction).

Cannoneer 1
: Is now positioned behind the trails, no longer positions tray, places charge into ram tray instead of into breech, trips breech cam with a linkage to it, reloads the automatic primer feeder every ten rounds, and uses a permanently attached lanyard.

Cannoneers 2 & 3
: No longer handle projectile, still ram projectile, and now also advance charge on ram tray to Swiss notch.

Cannoneers 4 & 5
: Still deliver projectile to tray, but now also accelerate ram tray toward breech (with short staffs that double as spade pry bars) to assist cannoneers 2 & 3 in ramming function.

### Component Changes (Relative to Version 1.0) with Rationale

Automatic Primer Feeder
: Necessary to achieve four rounds per minute without depressing tube. FMC is currently fabricating a prototype to fit on the M185 breech (for HEL's M109 test bed demonstrator). Adds 50 pounds.

Breech Trip Linkage
: To close breech at high QE firing, a trip link, operable from platform, is necessary. Adds 15 pounds.

Elevation/Equibration Cylinder
: One converted to two and mounted in a V to permit direct access to breech (via ram tray mounted between slides), thus eliminating swivel load tray. Bellvelle springs eliminated due to elimination of the need to elevate/depress for each round at high QE. Adds 115 pounds.

[redacted] [redacted]

**Elevation Yoke**

Elevation cylinder attachment can be lowered due to elimination of swivel tray clearance constraint. Saves 10 pounds.

**Equilibration Accumulator**

One converted to two and moved from platform into trails. Adds 30 pounds.

**Fire Control**

Access to trunnion pins permits fire control to be moved to trunnions (like M198), thus eliminating electronics, transducers, and batteries. Saves 60 pounds.

**Hydraulic Reservoirs**

Moved into trails to allow thicker walled equilibration accumulators to double as trail hinges (more effective use of weight). Saves 15 pounds.

**Ram Tray**

Converted from swivel-in-load-and-ram-tray to roller-slide-ram-tray design to facilitate high QE loading. Mechanism integral to ram tray locks ramming piston (attached to end of ramming staff) to ram tray. Ram tray with projectile (or charge) is staffed up slides until pin on elevation yoke is engaged, at which time mechanism releases ramming piston, allowing it to continue into combustion chamber. When ramming piston is retracted into ram tray, ramming piston is again locked to ram tray and tray is in turn released from elevation yoke.

Eliminates "span to reach breech" difficulties caused by swivel-in-load-and-ram-tray when coupled with (preferred) swivel up (M185) breech. Saves 75 pounds.

**Platform**

Shortened to provide overall howitzer length reduction. Redesigned to accommodate new trunnion (which moves traverse bearing forward 17 inches). Elevation cylinder mounting moved closer to trail hinge, reducing loads carried by platform. Two of three claws eliminated. Single claw retained ties into traverse bearing (and thus moves forward 17 inches, averting potential interference with air cargo loading ramps). Traverse bearing is two foot diameter. Trail links attach to platform between trails (in a V) instead of outside. Gunner's and assistant gunner's pumps and controls moved into platform (from trails) to improve access (weight still carried under Hydrualic System). Saves 25 pounds.

**Recoil Accumulator**

Combining recoil cylinders into one longer one and integrating it with the upper recoil cylinder shield/elevation yoke to forward yoke brace will reduce weight and reduce number of accumulators on weapon from three to two. Saves 10 pounds.

[redacted] [redacted] HT2-A2

Spade

Shortening platform moved trail pivots forward, which in turn forced trail pivots out (to maintain clearance for 800 mil traverse range). This did not leave enough room for spade and spade cylinder on sides of platform without going beyond eight foot width. It was also desirable to drop bottom edge of trails to increase bearing span, which forward spade had heretofore prevented.

Thus one spade became two, conical in shape to enhance "natural" load carrying ability, and mounted at the rear of the platform, which facilitated manual extraction with ram tray lever. Adds 10 pounds.

Traverse Cylinder

Two elevation cylinders allow traverse to be accomplished by displacing oil from one cylinder to another, while holding equilibration constant. Precursory calculations indicate an average stroke of .015"/mil of azimuth, felt to be a reasonable sensitivity. Saves 35 pounds.

Trunnion

Facilitates rear access to breech. Also clears path for parts that could come loose during recoil, that, with previous trunnion design, could have been deflected, thus averting possible injury to personnel. Adds 10 pounds.

Advantages

- QE loading limit increased to 1300 mils (versus 1.0).
- Human factors improved when loading at high QE (versus 1.0).
- Reduced overall length (versus 1.0).
- Angle of departure improved (versus 1.0).
- Cannoneer 1 is moved behind trails (versus 1.0).
- Distance of nearest crew position to muzzle brake increased by roughly nine feet (versus M198), significantly reducing exposure to blast overpressure.
- Fire control mounted to trunnion pin (versus 1.0).
- Compatible with soft recoil (versus 1.0 and M198).

Areas that require additional investigation.

- Reduced overall length may necessitate a slight reduction in trunnion height to maintain stability.
- There may be a correlation between azimuth and equilibration, which may increase depression loads at some azimuths.
- Mounting fire control at low trunnion height may adversely impact work space and accessibility.
- A simple method of limiting QE and AZ will be necessary.

[redacted] [redacted] HT2-A3

155MM LIGHTWEIGHT HOWITZER DEMONSTRATOR

<u>Technical Issues</u>:

Issue 3. What are the traverse limits?

FMC Response. 400 mils left and 400 mils right (see Figure 3-15 in our Technical Proposal Volume 3A, last line).

[redacted] [redacted]

Negotiation Issues

FMC

155MM LIGHTWEIGHT . 'TZER DEMONSTRATOR

Technical Issues:

Issue 4. The concept has various human engineering problems associated with loading the weapon at high QE, including operation of the breech and forces required to push the projectile into the forcing cone. This concept requires a trench to be dug when firing below 0° QE. How do you propose to alleviate these problems?

FMC Response. This question has been broken into the six sub-questions listed and addressed below.

A. FORCE REQUIRED TO RAM PROJECTILE AT HIGH QE. Figure HT4-1 provides the calculated forces to ram VERSION 1.1 at high QE. The VERSION 1.1 ramming procedure (relative to the M198 procedure) is summarized as follows:

   Where the M198 uses two cannoneers to deliver the projectile and hold it in front of the breech for ramming, VERSION 1.1 provides a ram tray onto which they set the projectile and then accelerate both the tray and projectile approximately one-third of the distance to the breech.

   The same cannoneers that handle ramming with the M198 then complete the ramming function with VERSION 1.1.

   Where the M198 places the ramming cannoneers just behind the projectile handlers, VERSION 1.1 places them roughly ten feet behind the projectile handlers, thus reducing congestion during the loading function.

   VERSION 1.1's force levels, as well as the means and heights of application, are on a par with the M198 at max QE, and provide an improvement over those of the M198 at the lower (most common) QE's. Additionally, the horizontal force component (applied by the cannoneer's waist) moves the load to a very strong part of the anatomy (see Figure HT4-1). It will, however, require that the ramming path (about 11' long, behind the trunnion) provide medium to high traction (per MIL-STD-1472C, TABLE XXV).

B. PROPELLANT LOADING AT HIGH QE. VERSION 1.1 employs the tray and ramming staff used for the projectile to advance the charge to the Swiss notch.

[redacted] [redacted]

Technical Issues:

Issue 4. (Cont'd.)

C. PRIMER INSERTION AT HIGH QE. VERSION 1.1 employs an automatic primer feed mechanism. A ten primer clip is proposed. Thus, the clip would have to to be replaced after each ten rounds.

To maintain a sustained rate of fire is two rounds per minute (determined by the thermal warning device in service and published as two rounds per minute by US ARMY publications), the crew would have 2.5 minutes to depress the gun to 500 mils, reload the auto primer, and elevate. Preliminary calculations for the original FMC LTHD suggested a depress/elevate cycle from max QE (with the non-linear Bellvelle spring) would take 0.75 minutes.

If a sustained rate of fire higher than two rounds per minute at high QE were required (until the barrel temperature danger threshold is reached), the clip size could be increased, a means of changing the clip from the ground might be feasible, and/or a ladder-like structure could be integrated with the slide.

D. BREECH OPERATION AT HIGH QE. The breech is opened automatically during counterrecoil. Closing would be handled with a linkage connected to the breech cam that is accessible from ground level.

E. LANYARD OPERATION AT HIGH QE. The lanyard would be permanently attached.

F. TRENCH REQUIREMENT AT NEGATIVE QE. Two options were suggested in the original proposal when using the FMC LTHD as proposed at negative QE (1) find terrain that provides the trench "naturally", or (2) dig a trench. This problem occurs due to the low trunnion height, which is desirable from a firing stability viewpoint.

If neither of these solutions is acceptable, the trunnion height could be made adjustable. The trunnion would be raised two feet (providing the same four foot trunnion height as the M198) to accommodate negative QE firing. This, of course, has an adverse impact upon firing stability, particularly if the M203 charge is used.

To put negative QE firing in perspective; at about 60,000 lbf of rod pull, the M198 has a "QE safety margin" of about 10 degrees (arc of the tangent of 15,600/60,000 less the max negative QE of 5 degrees); the LTHD, to maintain the M198's negative QE spec while achieving a 9,000 lbm weight, assuming similar rod pulls, has a "QE safety margin" of only 3.5 degrees.

[redacted] [redacted]

RAMMING FORCE SUMMARY

| QE | CANNONEERS | M198 APPLIED THRU | M198 HEIGHT | M198 DIRECTION | M198 FORCE | FMC LTHD VERSION 1.1 APPLIED THRU | FMC LTHD VERSION 1.1 HEIGHT | FMC LTHD VERSION 1.1 DIRECTION | FMC LTHD VERSION 1.1 FORCE |
|---|---|---|---|---|---|---|---|---|---|
| 1280 | 2 & 3 | Wrist | 6-60" | With pole | 88 | Waist | 36" | With pole | 79 |
| | | | | Horizontal | 27 | | | Horizontal | 54 |
| | | | | Vertical | 84 | | | Vertical | 46 |
| | 4 & 5 * | Wrist | 30" | Vertical | 57 | Wrist | 6-60" | With tray | 88 |
| | | | | | | | | Horizontal | 27 |
| | | | | | | | | Vertical | 84 |
| 500 | 2 & 3 | Wrist | 20-40" | With pole | 63 | Waist | 36" | With pole | 29 |
| | | | | Horizontal | 55 | | | Horizontal | 28 |
| | | | | Vertical | 30 | | | Vertical | 7 |
| | 4 & 5 * | Wrist | 36" | Vertical | 57 | Wrist | 20-40" | With tray | 63 |
| | | | | | | | | Horizontal | 55 |
| | | | | | | | | Vertical | 30 |
| 0 ** | 2 & 3 | Wrist | 48" | Horizontal | 38 | Waist | 36" | Horizontal | 17 |
| | 4 & 5 * | Wrist | 48" | Vertical | 57 | Wrist | 36" | Vertical | 57 |

* Cannoneers 4 & 5 are assigned as tray handlers on M198 for this comparison.
** Cannoneers 4 & 5 do not set RAM tray in motion at zero QE.

Figure HT4-1. Human Factors for Loading at Various QE's; FMC LTHD Version 1.1 Compared to M198. Ramming Force Analysis Procedure is in Appendix HT4-A.

[redacted] [redacted]

Appendix HT4-A. Ramming Force Analysis (sheet 1)

Assumptions

1. Relative differences in friction between M198 and FMC LTHD Version 1.1 are insignificant (Version 1.1 tray is on rollers).

2. Necessary ramming velocity is 15 FPS.

3. Difference in weights of M198 ramming staff and Version 1.1 ramming staff is insignificant.

4. M198 Load tray weighs 10 lbm.

5. Version 1.1 Ram tray weighs 15 lbm.

6. Averaging from endpoints is representative of relative magnitudes (as compared to the increased accuracy available from analysis via differential equations).

M198 Ramming (104 LBM Projectile)

Force required to offset gravity:

F1 = (104 LBM) * (SIN QE)

Force required to accelerate projectile from 0 to 15 FPS in 4.73 feet:

((15 FPS ** 2)/(2 * 4.73 ft))/32.2) * 104 = 76.82 LBF

Total ramming force per cannoneer (2 assumed):

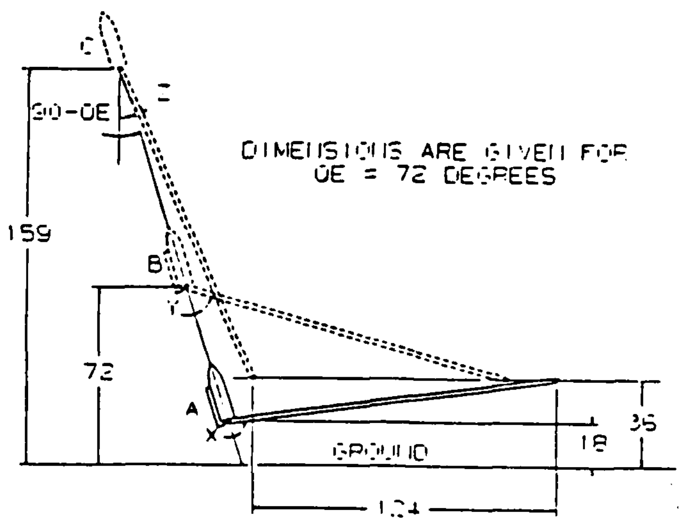
FR = (F1 + 76.82)/2 [redacted] [redacted]

Horizontal component:

$FR_H$ = FR * COS QE

Vertical component: $FR_V$ = FR * SIN QE

FMC LTHD Version 1.1 Ramming (104 LBM Projectile)




Point A is starting point (ram staff pivot). Cannoneers 4 & 5 move projectile and tray from A to B (4.73'). Cannoneers 2 & 3 ram projectile from B to C (7.62'). Point C represents a rammed projectile. Ramming staff is 11'3" long (CL to CL).

| QE | X | Y | Z |
|---|---|---|---|
| 53 | 60.5 | 41.3 | 4.9 |
| 72 | 79.5 | 56.5 | 6.3 |
| 28.1 | 35.6 | 24.4 | 5.5 |
| 45 | 52.5 | 35.6 | 5.0 |

## Moving From A to B at 72° QE

Assume that cannoneer 4 & 5 accelerate projectile portion of projectile & load tray unit to 15 FPS over 4.73 ft. distance (thus equaling M198 ramming force) from point A to B.

Cannoneer 2 & 3 are thus responsible for accelerating 15 LBM load tray to 15 FPS from point A to B.

To find the required ramming force here, a computer program was written (shown below) for a dynamic analysis:

```
10   REM PROGRAM TO DETERMINE RAMMING FORCE FROM A TO B
20   F = 80
30   TIME = 0
40   T = .01
50   QE = 72
60   QE = QE*3.14159/180
70   VO = 0
80   PO = 0
90   PRINT "TIME", "POSITION", "VELOCITY", "ANGLE"
100  HT = PO*SIN(QE)-1.5
110  LE = (11.25**2 - HT**2)**.5
120  ANG = QE - ATN(HT/LE)
130  A = (F*SIN(3.14159/2-ANG)-15*SIN(QE))/(15/32.2)
140  V = VO+A*T
150  VO = V
160  P - PO+V*T+.5*A*T**2
170  PO = P
180  PRINT TIME, P, V, ANG*180/3.14159
190  IF P   = 4.731 THEN GOTO 220
200  TIME + TIME+T
210  GOTO 100
220  END
```

Program results show that a constant 80 lb. total ramming force results in a 15 fps load tray speed at point B. (Forces higher than 80 lbs. result in greater speeds). Minimum force values for any QE can be determined the same way. The total force can then be resolved into its horizontal and vertical components. Horizontal components:

Point A: 40 LBF * COS (72 - 79.5) = 39.7

Point B: 40 LBF * COS (72 - 56.5) = 38.5

Average: 39.1 LBF

Vertical Components:

Point A: 40 LBF * SIN (72 - 79.5) = -5.2

Point B: 40 LBF * SIN (72 - 56.5) = 10.7

Average: 2.75

[redacted] [redacted]

Moving B to C at 72° QE

Cannoneer 2 & 3 are responsible for maintaining the average velocity of 15 FPS from point B to C. This requires that the weight of tray and projectile be matched by the ramming force.

The ramming force each cannoneer must provide is:

Point B = $FRB = (((15 + 104) * \text{SIN } QE)/\text{COS } Y) * .5$

Point C = $FRC = (((15 + 104) * \text{SIN } QE)/\text{COS } Z) * .5$

Average $FR_{BC} = (FRB + FRC)/2$

Resolving this force into the horizontal force component each cannoneer must provide:

Point B = $FHB = (FR_{BC}) * \text{COS } (QE - Y)$

Point C = $FHC = (FR_{BC}) * \text{COS } (QE - Z)$

Average = $FH_{BC} = (FHB + FHC)/2$

Resolving this force into the vertical force component each cannoneer must provide:

Point B = $FVB = (FR_{BC}) * \text{SIN } (QE - Y)$

Point C = $FVC = (FR_{BC}) * \text{SIN } (QE - Z)$

Average = $FV_{BC} = (FVB + FVC)/2$

Moving A to C at 0° QE

Force required to accelerate projectile and load tray to 15 FPS in 12.35 ft. (per cannoneer): (((15 FPS * * 2)/(2 * 12.35 ft))/32.2) * (104 + 15)/2 = 16.8 LBF

[redacted] [redacted]

Negotiation Issues

FMC

155MM LIGHTWEIGHT HOWITZER DEMONSTRATOR

Technical Issues:

Issue 5: Precursory stability analysis to support the submitted graphs are missing. Provide this analysis.

FMC Response. A computer simulation model was developed to analyze the LTHD's stability under a wide range of operating conditions. The model is similar to one developed by the Weapons Division, Large Caliber Weapon Systems Laboratory (Technical Note 84-001). Both models assume that the gun is not able to slide backward at any time during firing and that a rear ground "pivot" point exists.

The two models differ, however, in a number of important aspects. The most important difference is that the LTHD analysis model accounts for changes in the systems' center of gravity and mass moment of inertia which result from the recoil and counter-recoil motion of the gun barrel and other movable components. Another important difference is that the model considers very specific firing conditions, including barrel quadrant elevation (QE), azimuth, and forward and side slopes of the ground. In addition, rather than using an average input force over the duration of the firing cycle, a trapezoidal input force is used that much more closely matches empirical data for specified firing conditions.

A complete list of inputs and a discussion of how they were obtained is provided in Appendix HT5-A. A list of outputs is contained in Appendix HT5-B. A discussion of program method, is presented in Appendix HT5-C. Appendix HT5-D contains the computer printout for 92-inch stroke (less than original proposal) as part of stroke sensitivity analysis. Note that weapon remains stable at six inch reduction in stroke with 12,500 lb-sec impulse.

[redacted] [redacted]

## Appendix HT5-A Stability Analysis Inputs

In defining inputs to the LTHD analysis model, an x,y,z coordinate system was established. The ground plane defines the z/x plane. Hence, y is up and perpendicular to the ground plane, -z is back-to-front along the ground, x is side-to-side along the ground and positive to the right when facing forward.

The model requires the following inputs:

A. System Geometry
   1. Recoiling components
      a. individual component weights
      b. individual component locations (y and -z,)
   2. Stationary components
      a. individual component weights
      b. individual component locations (y and -z)
   3. Other measurements
      a. distance from rear pivot to barrel tip, along -z axis
      b. distance from rear pivot to tip of trails, along -z axis
      c. angle between trails and -z axis
      d. distance from rear pivot to point at which input force is applied, along y axis
      e. distance from rear pivot to point at which input force is applied, along -z axis
      f. distance from side pivot to point at which input force is applied, along x axis
      g. distance from side pivot to the center of gravity of the stationary components, along x axis
      h. amount of play in end of trails (zero in this analysis)
      i. spring constant of each trail (rigid in this analysis)

B. Firing Conditions
   1. Quadrant elevation of gun barrel
   2. Azimuth angle of gun barrel
   3. Forward slope of hill (angle between ground and true horizontal, along -z axis)
   4. Side slope of hill (angle between ground and true horizontal, along x axis.)

[redacted] [redacted]

C. Input Force and Recoil Stroke Position
   1. Recoil/counter-recoil force profile, force vs. time
   2. Recoil/counter-recoil stroke profile, position vs. time

The system geometry inputs were obtained from a solid modeling analysis of the LTHD performed on GEOMOD. Firing conditions can be varied, depending on the situation to be analyzed. In general, worst-case conditions occur when the QE and azimuth values are zero. When non-zero values of hill slopes are specified, the worst-case condition of firing "uphill" is analyzed.

The determination of input force and recoil stroke position data requires a more involved explanation. In describing the approach, worst-case conditions are considered.

The worst-case input force is one that imparts a 12,500 lb-sec impulse to the system. In order to meet the objective of optimum stability, we want to distribute this force as evenly as possible throughout the recoil stroke, such that the resulting overturning moment is less than the stabilizing moment at all times. The recoil system used should ideally accomplish this.

Thus, an input force is specified which is thought to result in the overturning moment being less than the stabilizing moment over the recoil stroke. Its profile over the stroke length is trapezoidal, and is estimated to impart a 12,500 lb-sec impulse to the system. This profile is used as an input to a program that simulates gun recoil (RECOIL.FORT, FMC Corp., E.C. 1133). Given the recoiling mass of the LTHD, the specified input force profile, stroke length, and other firing conditions, the program outputs a time profile of the recoil mass velocities, barrel positions, and the force values which stop the recoiling mass within the specified recoil stroke. This data is then input into an orifice sizing program, which outputs the data required to completely configure a recoil cylinder system.

The trapezoidal force profile and the recoil cylinder data is then input back into RECOIL.FORT to determine the best estimate of the impulse to be imparted to the system. If the impulse differs from the 12,500 lb-sec requirement, a new force trapezoid must be determined and the above process is repeated. If the impulse requirement is met, the output of RECOIL.FORT, consisting of the time profile of input force and barrel positions, is input into the LTHD stability model.

The stability model then uses this data, along with the system geometry and firing condition information, to determine how well the stabilizing moment exceeds the overturning moment throughout the firing cycle. If the results show a system that is unstable or too stable, a new trapezoidal force is specified and the complete process just described is repeated.

A similar, yet simpler procedure is used when the ballistic properties of a specified projectile/charge combination are used instead of an impulse requirement.

[redacted] [redacted]

## Appendix HT5-B Stability Analysis Outputs

The LTHD analysis model produces the following outputs:

A. Summary of Initial Conditions
   1. Total weight of recoiling components
   2. Total weight of stationary components
   3. Total weight of system
   4. Location of systems' starting center of gravity
   5. Systems' starting mass moment of inertia
   6. Deflection of trails (zero for this analysis--assumed rigid)

B. Moments About Rear Pivot Throughout Firing Cycle
   1. Stabilizing moments
   2. Overturning moments
   3. Safety moments

C. System Condition Throughout Firing Cycle
   1. Force trails exert on ground if trails are on the ground
   2. Hop height if trails are off the ground

D. Maximum Input Force Values Throughout Firing Cycle
   1. Maximum allowable input force without causing backward "hop"
   2. Maximum allowable input force without causing sideways "hop"

The summary of initial conditions describes the state of the system if it were on level ground and the barrel was at 0° QE and azimuth. Moments about the rear pivot and the system condition (trails are on the ground or off the ground) are output at specified time intervals throughout the firing cycle. Maximum allowable input force values are output at specified increments of the recoil stroke.

[redacted] [redacted]

# Appendix HT5-C Stability Analysis Method

## Description of Method

The summary of initial conditions in the output are simply calculations of system characteristics in a static situation. The component masses and the coordinate locations of their centers of gravity are used to determine the system center of gravity and system mass moment of inertia. In order to obtain better approximations for these values, here and throughout the analysis, a technique is used which divides the barrel into small mass segments. After the initial conditions are calculated, the system is geometrically repositioned for the input firing conditions.

The system safety moment is defined as the net moment acting on the system about the pivot point. When specific input force values and barrel positions are known at very small time intervals throughout the firing cycle, a safety moment for a given time interval can be calculated.

Because the systems' center of gravity and mass moment of inertia change with barrel position, moment arm lengths with respect to the pivot point will also change. Thus, the model recalculates these values for each point in time analyzed during the firing cycle. At this same time, the input force and system weight are broken down into those components which want to "stabilize" the system and those which want to "overturn" the system. By repeating this procedure throughout the firing cycle, a profile of stabilizing, overturning, and safety moments is created.

Under the given firing conditions, should the overturning moment acting on the system exceed the stabilizing moment at any time during the firing cycle, the system becomes unstable. In this event, the model uses equations of angular motion to find the resulting height of "hop". As shown in Figures 3-11 and 3-12 of Volume 3A, the LTHD analysis yielded positive safety moments and no hop occurred during the firing cycles.

A similar approach to that used in determining the safety moments is used to determine the maximum allowable input force at any given position of the gun barrel. The maximum force is that which results in all moments acting on the system summing to zero. The maximum force thus creates a situation of "borderline stability" in either the backward direction or sideways direction. As in the safety moment determination, the calculation uses the systems' center of gravity location that corresponds to the gun barrel position being analyzed.

[redacted] [redacted]

Appendix HT5-D. Stability Analysis Print-out (sheet 1)

INITIAL CONDITIONS:
WEIGHT OF RECOILING COMPONENTS (LB) = 4527
WEIGHT OF NON-RECOILING COMPONENTS (LB) = 3774
SYSTEM WEIGHT (LB) = 8301
INDIV. TRAIL'S SPRING CONSTANT (LB/IN) = 0
PLAY IN END OF TRAILS (IN) = 0

AT MAXIMUM EXTENSION OF BARREL:
CGZ (IN) = 203.2339
CGY (IN) = 25.38302
CGX (IN) = 47.99132
DEFLECTION OF TRAILS (IN) = 0
MASS MOMENT OF INERTIA (LB-IN-SEC) = 1154324

SWEEP ANGLE LEFT (DEGREES) = 0
ELEVATION ANGLE (DEGREES) = 0
UPWARD SLOPE OF HILL - FORWARD (DEGREES) = 0
UPWARD SLOPE OF HILL - SIDE (DEGREES) = 0

DATA FILE: B:DPLT.DAT (For 12,500 lb-sec impulse)

| STROKE, INCHES | CG -Z, INCHES | STABLE MOMENT, FT-LBS | OVERTURN-ING MOM., FT-LBS | SAFETY MOMENT FT-LBS | WT. AT EA TRAIL, LBS |
|---|---|---|---|---|---|
| 0 | 203.2339 | 140587.1 | 0 | 140587.1 | 234.3118 |
| 0 | 203.2339<br>234.3119 | 140587.1 | -3.849308E-02 | | 140587.1 |
| .00168 | 203.233 | 140586.5 | 44625.88 | 95960.59 | 159.9343 |
| .01392 | 203.2264 | 140581.9 | 44627.93 | 95953.94 | 159.9232 |
| .05652 | 203.2031 | 140565.8 | 44635.38 | 95930.38 | 159.884 |
| .16308 | 203.145 | 140525.6 | 44654.11 | 95871.44 | 159.7857 |
| .37056 | 203.0319 | 140447.3 | 44690.86 | 95756.44 | 159.5941 |
| .69972 | 202.8524 | 140323.1 | 44749.46 | 95573.65 | 159.2894 |
| 1.15128 | 202.6061 | 140152.8 | 44829.86 | 95322.91 | 158.8715 |
| 1.713 | 202.2998 | 139940.9 | 44930.29 | 95010.56 | 158.351 |
| 2.36328 | 201.9451 | 139695.6 | 50105.62 | 89589.91 | 149.3165 |
| 3.07944 | 201.5546 | 139425.4 | 56573.7 | 82851.68 | 138.0861 |
| 3.84408 | 201.1375 | 139136.9 | 61903.72 | 77233.21 | 128.722 |
| 4.64448 | 200.7011 | 138835 | 93675.74 | 45159.22 | 75.26536 |
| 5.46144 | 200.2555 | 138526.8 | 120391.8 | 18134.92 | 30.22486 |
| 6.28116 | 199.8085 | 138217.5 | 128051.1 | 10166.47 | 16.94412 |
| 7.10268 | 199.3605 | 137907.6 | 128058.2 | 9849.386 | 16.41564 |
| 7.925761 | 198.9116 | 137597.1 | 127786.4 | 9810.636 | 16.35106 |
| 8.749561 | 198.4623 | 137286.3 | 127491.1 | 9795.188 | 16.32531 |
| 9.573839 | 198.0128 | 136975.3 | 127169.5 | 9805.833 | 16.34306 |

[redacted] [redacted]

HT5-D1

## Appendix HT5-D. Stability Analysis Print-out (sheet 2)

| | | | | | |
|---|---|---|---|---|---|
| 10.39788 | 197.5634 | 136664.5 | 126778 | 9886.511 | 16.47752 |
| 11.2212 | 197.1144 | 136353.9 | 126378.9 | 9974.958 | 16.62492 |
| 12.04332 | 196.6661 | 136043.8 | 125894.5 | 10149.22 | 16.91537 |
| 12.86364 | 196.2187 | 135734.3 | 125398.3 | 10335.94 | 17.22656 |
| 13.68168 | 195.7726 | 135425.7 | 124870.1 | 10555.61 | 17.59269 |
| 14.49696 | 195.328 | 135118.1 | 124225.8 | 10892.26 | 18.15377 |
| 15.30888 | 194.8852 | 134811.8 | 123567.1 | 11244.75 | 18.74125 |
| 16.11696 | 194.4444 | 134506.9 | 122764.4 | 11742.51 | 19.57089 |
| 16.92072 | 194.0062 | 134203.7 | 121872.9 | 12330.81 | 20.55134 |
| 17.71968 | 193.5704 | 133902.3 | 121053 | 12849.38 | 21.41563 |
| 18.51372 | 193.1374 | 133602.8 | 120393.1 | 13209.63 | 22.01605 |
| 19.30284 | 192.707 | 133305.1 | 119822.8 | 13482.29 | 22.47049 |
| 20.08704 | 192.2794 | 133009.2 | 119325.6 | 13683.64 | 22.80606 |
| 20.86632 | 191.8544 | 132715.3 | 118866.9 | 13848.32 | 23.08054 |
| 21.64068 | 191.4321 | 132423.1 | 118440.4 | 13982.68 | 23.30447 |
| 22.41024 | 191.0124 | 132132.8 | 118106.5 | 14026.25 | 23.37709 |
| 23.17488 | 190.5954 | 131844.4 | 117762.8 | 14081.58 | 23.46931 |
| 23.93472 | 190.181 | 131557.7 | 117507.3 | 14050.44 | 23.4174 |
| 24.68976 | 189.7693 | 131272.9 | 117206 | 14066.86 | 23.44476 |
| 25.44 | 189.3601 | 130989.8 | 116962.9 | 14026.88 | 23.37813 |
| 26.18532 | 188.9536 | 130708.7 | 116754.4 | 13954.21 | 23.25702 |
| 26.92596 | 188.5497 | 130429.2 | 116548.5 | 13880.73 | 23.13456 |
| 27.6618 | 188.1484 | 130151.6 | 116329 | 13822.61 | 23.0377 |
| 28.39284 | 187.7498 | 129875.9 | 116083.3 | 13792.59 | 22.98766 |
| 29.1192 | 187.3536 | 129601.9 | 115829.6 | 13772.25 | 22.95375 |
| 29.84064 | 186.9602 | 129329.7 | 115609.2 | 13720.51 | 22.86752 |
| 30.5574 | 186.5693 | 129059.3 | 115402.8 | 13656.52 | 22.76087 |
| 31.26948 | 186.181 | 128790.7 | 115111.9 | 13678.79 | 22.79799 |
| 31.97676 | 185.7952 | 128523.8 | 114915.4 | 13608.42 | 22.6807 |
| 32.67936 | 185.4121 | 128258.8 | 114660.4 | 13598.4 | 22.664 |
| 33.37728 | 185.0315 | 127995.5 | 114437.6 | 13557.89 | 22.59648 |
| 34.0704 | 184.6535 | 127734 | 114193.3 | 13540.67 | 22.56778 |
| 34.75896 | 184.278 | 127474.2 | 113971.1 | 13503.18 | 22.5053 |
| 35.44272 | 183.9051 | 127216.3 | 113757.7 | 13458.61 | 22.43101 |

[redacted] [redacted]

HT5-D2

## Appendix HT5-D. Stability Analysis Print-out (sheet 3)

| | | | | | |
|---|---|---|---|---|---|
| 36.12192 | 183.5346 | 126960.1 | 113519 | 13441.01 | 22.40169 |
| 36.79632 | 183.1668 | 126705.6 | 113326.5 | 13379.17 | 22.29862 |
| 37.46616 | 182.8016 | 126452.9 | 113065.2 | 13387.7 | 22.31284 |
| 38.13132 | 182.4388 | 126202 | 112783.5 | 13418.45 | 22.36409 |
| 38.79192 | 182.0785 | 125952.8 | 112624.1 | 13328.72 | 22.21454 |
| 39.44784 | 181.7208 | 125705.3 | 112373.7 | 13331.58 | 22.21932 |
| 40.09908 | 181.3657 | 125459.7 | 112128.2 | 13331.43 | 22.21905 |
| 40.74588 | 181.0129 | 125215.6 | 111931.5 | 13284.09 | 22.14017 |
| 41.38788 | 180.6628 | 124973.5 | 111731.5 | 13242 | 22.07001 |
| 42.02544 | 180.3151 | 124732.9 | 111479.4 | 13253.52 | 22.08921 |
| 42.65844 | 179.9699 | 124494.1 | 111229.5 | 13264.63 | 22.10772 |
| 43.28676 | 179.6273 | 124257.1 | 110983.8 | 13273.32 | 22.12222 |
| 43.91052 | 179.2871 | 124021.8 | 110843.1 | 13178.69 | 21.96449 |
| 44.52984 | 178.9493 | 123788.2 | 110617.4 | 13170.74 | 21.95124 |
| 45.14448 | 178.6142 | 123556.3 | 110392.8 | 13163.45 | 21.93909 |
| 45.75468 | 178.2814 | 123326.1 | 110149.5 | 13176.56 | 21.96095 |
| 46.36032 | 177.9511 | 123097.6 | 109900.1 | 13197.48 | 21.99581 |
| 46.96152 | 177.6232 | 122870.8 | 109684.5 | 13186.26 | 21.97711 |
| 47.55816 | 177.2978 | 122645.7 | 109464.7 | 13181 | 21.96835 |
| 48.15024 | 176.9749 | 122422.3 | 109195.8 | 13226.48 | 22.04415 |
| 48.73788 | 176.6545 | 122200.6 | 109006.8 | 13193.8 | 21.98969 |
| 49.32108 | 176.3364 | 121980.6 | 108846.5 | 13134.11 | 21.89021 |
| 49.89984 | 176.0208 | 121762.3 | 108606.4 | 13155.92 | 21.92655 |
| 50.47404 | 175.7076 | 121545.6 | 108340.4 | 13205.26 | 22.00879 |
| 51.04392 | 175.3968 | 121330.7 | 108102.3 | 13228.36 | 22.0473 |
| 51.60924 | 175.0885 | 121117.4 | 107872.2 | 13245.17 | 22.0753 |
| 52.17012 | 174.7827 | 120905.8 | 107693.1 | 13212.72 | 22.02122 |
| 52.72668 | 174.4791 | 120695.8 | 107461.4 | 13234.45 | 22.05743 |
| 53.27868 | 174.1781 | 120487.6 | 107252.3 | 13235.27 | 22.05881 |
| 53.82648 | 173.8793 | 120280.9 | 107045.7 | 13235.23 | 22.05874 |
| 54.36972 | 173.5831 | 120076 | 106840.2 | 13235.78 | 22.05966 |

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HT5-D3

Appendix HT5-D. Stability Analysis Print-out (sheet 4)

| | | | | | |
|---|---|---|---|---|---|
| 54.90864 | 173.2892 | 119872.7 | 106636.9 | 13235.81 | 22.0597 |
| 55.44312 | 172.9977 | 119671 | 106415.8 | 13255.25 | 22.0921 |
| 55.97328 | 172.7086 | 119471 | 106095.4 | 13375.58 | 22.2926 |
| 56.499 | 172.4219 | 119272.7 | 105889 | 13383.73 | 22.3062 |
| 57.02052 | 172.1375 | 119075.9 | 105710.3 | 13365.61 | 22.2760 |
| 57.5376 | 171.8555 | 118880.9 | 105503 | 13377.86 | 22.2964 |
| 58.05036 | 171.5759 | 118687.4 | 105297.7 | 13389.7 | 22.3162 |
| 58.5588 | 171.2986 | 118495.6 | 105088.1 | 13407.56 | 22.3459 |
| 59.06292 | 171.0237 | 118305.4 | 104776.8 | 13528.68 | 22.5478 |
| 59.56272 | 170.7511 | 118116.9 | 104607.4 | 13509.44 | 22.5157 |
| 60.05832 | 170.4808 | 117929.9 | 104410.9 | 13519.03 | 22.5317 |
| 60.54949 | 170.2129 | 117744.6 | 104212.3 | 13532.27 | 22.5538 |
| 61.03644 | 169.9474 | 117560.9 | 103970.3 | 13590.65 | 22.6511 |
| 61.51908 | 169.6841 | 117378.8 | 103705.2 | 13673.61 | 22.7894 |
| 61.99752 | 169.4232 | 117198.3 | 103497.4 | 13700.86 | 22.8348 |
| 62.47176 | 169.1646 | 117019.4 | 103207.8 | 13811.64 | 23.0194 |
| 62.94168 | 168.9083 | 116842.1 | 103023.5 | 13818.66 | 23.0311 |
| 63.4074 | 168.6543 | 116666.4 | 102853.4 | 13812.99 | 23.0216 |
| 63.8688 | 168.4027 | 116492.4 | 102614.8 | 13877.53 | 23.1292 |
| 64.32612 | 168.1533 | 116319.8 | 102331.4 | 13988.38 | 23.3140 |
| 64.77912 | 167.9063 | 116148.9 | 102157.9 | 13991.02 | 23.3184 |
| 65.22805 | 167.6615 | 115979.6 | 101868.8 | 14110.79 | 23.5180 |
| 65.67264 | 167.419 | 115811.8 | 101653.7 | 14158.11 | 23.5968 |
| 66.11316 | 167.1788 | 115645.6 | 101418.4 | 14227.28 | 23.7121 |
| 66.54948 | 166.9408 | 115481 | 101187.9 | 14293.17 | 23.822 |
| 66.98172 | 166.7051 | 115318 | 101013.4 | 14304.52 | 23.8409 |
| 67.40976 | 166.4716 | 115156.5 | 100813.4 | 14343.04 | 23.9051 |
| 67.8336 | 166.2405 | 114996.6 | 100559.3 | 14437.29 | 24.0622 |
| 68.25336 | 166.0116 | 114838.2 | 100277.8 | 14560.45 | 24.2674 |
| 68.66905 | 165.7849 | 114681.4 | 100033.9 | 14647.51 | 24.4125 |

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HT5-D4

## Appendix HT5-D. Stability Analysis Print-out (sheet 5)

| | | | | | |
|---|---|---|---|---|---|
| 69.08052 | 165.5605 | 114526.1 | 99842.31 | 14683.83 | 24.47313 |
| 69.48804 | 165.3382 | 114372.4 | 99548.76 | 14823.64 | 24.70613 |
| 69.89136 | 165.1183 | 114220.2 | 99365.4 | 14854.82 | 24.75811 |
| 70.29061 | 164.9005 | 114069.6 | 99133.32 | 14936.28 | 24.89388 |
| 70.68576 | 164.685 | 113920.5 | 98903.48 | 15017.05 | 25.0285 |
| 71.07696 | 164.4717 | 113772.9 | 98714.51 | 15058.43 | 25.09746 |
| 71.46396 | 164.2607 | 113627 | 98417.35 | 15209.59 | 25.3494 |
| 71.847 | 164.0518 | 113482.4 | 98145.72 | 15336.71 | 25.56127 |
| 72.22596 | 163.8451 | 113339.5 | 97930.91 | 15408.54 | 25.68099 |
| 72.60096 | 163.6406 | 113198 | 97718.09 | 15479.9 | 25.79992 |
| 72.972 | 163.4382 | 113058 | 97418.9 | 15639.11 | 26.06527 |
| 73.33896 | 163.2381 | 112919.5 | 97149.66 | 15769.88 | 26.28322 |
| 73.70185 | 163.0402 | 112782.6 | 96966.56 | 15816.07 | 26.36023 |
| 74.06088 | 162.8444 | 112647.2 | 96751.62 | 15895.54 | 26.49268 |
| 74.41584 | 162.6508 | 112513.3 | 96451.84 | 16061.41 | 26.76912 |
| 74.76696 | 162.4594 | 112380.8 | 96177.62 | 16203.19 | 27.00542 |
| 75.114 | 162.2701 | 112249.9 | 95904.22 | 16345.64 | 27.24284 |
| 75.4572 | 162.0829 | 112120.4 | 95675.32 | 16445.05 | 27.40854 |
| 75.79644 | 161.8979 | 111992.4 | 95473.74 | 16518.65 | 27.5312 |
| 76.13171 | 161.7151 | 111865.9 | 95195.25 | 16670.65 | 27.78454 |
| 76.46316 | 161.5343 | 111740.8 | 94918.06 | 16822.75 | 28.03805 |
| 76.79065 | 161.3557 | 111617.3 | 94684.91 | 16932.39 | 28.22077 |
| 77.11428 | 161.1792 | 111495.2 | 94482.03 | 17013.16 | 28.3554 |
| 77.43396 | 161.0049 | 111374.6 | 94227.59 | 17146.98 | 28.57844 |
| 77.7498 | 160.8326 | 111255.4 | 93928.69 | 17326.71 | 28.878 |
| 78.0618 | 160.6625 | 111137.7 | 93642.22 | 17495.46 | 29.15925 |
| 78.36996 | 160.4944 | 111021.4 | 93376.75 | 17644.69 | 29.40797 |
| 78.67428 | 160.3285 | 110906.6 | 93063.98 | 17842.64 | 29.73789 |
| 78.97476 | 160.1646 | 110793.2 | 92770.62 | 18022.62 | 30.03786 |
| 79.27151 | 160.0028 | 110681.3 | 92520.1 | 18161.2 | 30.26883 |
| 79.56444 | 159.843 | 110570.8 | 92340.81 | 18229.95 | 30.38342 |

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Appendix HT5-D. Stability Analysis Print-out (sheet 6)

| | | | | | |
|---|---|---|---|---|---|
| 79.85332 | 159.6854 | 110461.7 | 92057.85 | 18403.84 | 30.67326 |
| 80.13876 | 159.5298 | 110354.1 | 91778.16 | 18575.9 | 30.96002 |
| 80.4204 | 159.3762 | 110247.8 | 91501.09 | 18746.69 | 31.24467 |
| 80.69808 | 159.2248 | 110143 | 91181.38 | 18961.65 | 31.60294 |
| 80.97216 | 159.0753 | 110039.6 | 90894.72 | 19144.9 | 31.90837 |
| 81.24251 | 158.9278 | 109937.6 | 90612.6 | 19325 | 32.20855 |
| 81.50905 | 158.7825 | 109837.1 | 90312.31 | 19524.77 | 32.54151 |
| 81.77196 | 158.6391 | 109737.9 | 90012.01 | 19725.84 | 32.87664 |
| 82.03116 | 158.4978 | 109640 | 89708.47 | 19931.57 | 33.21953 |
| 82.28665 | 158.3584 | 109543.7 | 89404.06 | 20139.59 | 33.56623 |
| 82.5384 | 158.2212 | 109448.7 | 89121.22 | 20327.46 | 33.87935 |
| 82.78668 | 158.0858 | 109355 | 88827.31 | 20527.7 | 34.21309 |
| 83.03112 | 157.9524 | 109262.7 | 88516.85 | 20745.89 | 34.57674 |
| 83.27208 | 157.821 | 109171.8 | 88208.99 | 20962.82 | 34.93831 |
| 83.50931 | 157.6917 | 109082.3 | 87905.26 | 21177.07 | 35.2954 |
| 83.74296 | 157.5642 | 108994.2 | 87613.09 | 21381.09 | 35.63543 |
| 83.973 | 157.4388 | 108907.4 | 87303.06 | 21604.29 | 36.00745 |
| 84.19944 | 157.3153 | 108821.9 | 86985.22 | 21836.68 | 36.39479 |
| 84.4224 | 157.1937 | 108737.8 | 86668.38 | 22069.39 | 36.78264 |
| 84.64164 | 157.0741 | 108655.1 | 86365.32 | 22289.74 | 37.1499 |
| 84.85751 | 156.9564 | 108573.6 | 86062.13 | 22511.46 | 37.51944 |
| 85.06968 | 156.8407 | 108493.5 | 85761.57 | 22731.98 | 37.88698 |
| 85.27848 | 156.7268 | 108414.7 | 85446.68 | 22968.05 | 38.28045 |
| 85.48368 | 156.6149 | 108337.3 | 85118.89 | 23218.43 | 38.69777 |
| 85.6854 | 156.5049 | 108261.2 | 84794.47 | 23466.71 | 39.11157 |
| 85.88364 | 156.3968 | 108186.4 | 84469.02 | 23717.36 | 39.52934 |
| 86.0784 | 156.2906 | 108112.9 | 84158.61 | 23954.27 | 39.9242 |
| 86.2698 | 156.1862 | 108040.7 | 83845.23 | 24195.42 | 40.32612 |
| 86.45761 | 156.0838 | 107969.8 | 83528.08 | 24441.71 | 40.73663 |
| 86.64204 | 155.9832 | 107900.2 | 83198.25 | 24701.93 | 41.17034 |

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HT5-D6

## Appendix HT5-D. Stability Analysis Print-out (sheet 7)

| | | | | | |
|---|---|---|---|---|---|
| 86.82312 | 155.8845 | 107831.9 | 82855.78 | 24976.06 | 41.62724 |
| 87.00072 | 155.7876 | 107764.8 | 82462.66 | 25302.15 | 42.17075 |
| 87.17496 | 155.6926 | 107699.1 | 82090.5 | 25608.56 | 42.68144 |
| 87.34584 | 155.5994 | 107634.5 | 81770.36 | 25864.18 | 43.10749 |
| 87.51336 | 155.508 | 107571.3 | 81440.7 | 26130.63 | 43.55158 |
| 87.67752 | 155.4185 | 107509.4 | 81102.63 | 26406.74 | 44.01179 |
| 87.83832 | 155.3308 | 107448.7 | 80773.91 | 26674.77 | 44.45853 |
| 87.99588 | 155.2449 | 107389.2 | 80447.35 | 26941.85 | 44.90369 |
| 88.15008 | 155.1608 | 107331 | 80121.65 | 27209.39 | 45.3496 |
| 88.30104 | 155.0785 | 107274.1 | 79791.71 | 27482.34 | 45.80453 |
| 88.44864 | 154.998 | 107218.3 | 79464.43 | 27753.91 | 46.25716 |
| 88.59312 | 154.9192 | 107163.8 | 79133.24 | 28030.57 | 46.71829 |
| 88.73424 | 154.8422 | 107110.5 | 78796.22 | 28314.31 | 47.19121 |
| 88.87212 | 154.767 | 107058.5 | 78454.35 | 28604.1 | 47.67422 |
| 89.00676 | 154.6936 | 107007.7 | 78087.72 | 28919.94 | 48.20063 |
| 89.13828 | 154.6219 | 106958 | 77711.65 | 29246.37 | 48.7447 |
| 89.26656 | 154.5519 | 106909.6 | 77364.58 | 29545.01 | 49.24246 |
| 89.3916 | 154.4837 | 106862.4 | 77038.66 | 29823.73 | 49.70701 |
| 89.51364 | 154.4172 | 106816.3 | 76712.18 | 30104.14 | 50.17439 |
| 89.63232 | 154.3524 | 106771.5 | 76389.09 | 30382.41 | 50.6382 |
| 89.748 | 154.2893 | 106727.8 | 76063.36 | 30664.45 | 51.1083 |
| 89.86056 | 154.228 | 106685.3 | 75743.33 | 30941.99 | 51.57088 |
| 89.97 | 154.1683 | 106644 | 75421.73 | 31222.26 | 52.03803 |
| 90.07632 | 154.1103 | 106603.8 | 75086.59 | 31517.24 | 52.5297 |
| 90.17952 | 154.054 | 106564.9 | 74743 | 31821.9 | 53.03749 |
| 90.27972 | 153.9994 | 106527 | 74403.84 | 32123.18 | 53.53966 |
| 90.3768 | 153.9464 | 106490.4 | 74096.82 | 32393.55 | 53.9903 |
| 90.47088 | 153.8951 | 106454.8 | 73792.2 | 32662.64 | 54.43881 |
| 90.56184 | 153.8455 | 106420.5 | 73489.56 | 32930.93 | 54.88599 |
| 90.64992 | 153.7975 | 106387.2 | 73190.38 | 33196.85 | 55.32921 |
| 90.73488 | 153.7512 | 106355.1 | 72894.46 | 33460.67 | 55.76896 |

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HT5-D7

## Appendix HT5-D. Stability Analysis Print-out (sheet 8)

| | | | | | |
|---|---|---|---|---|---|
| 90.81696 | 153.7064 | 106324.1 | 72601.29 | 33722.8 | 56.20588 |
| 90.89592 | 153.6633 | 106294.3 | 72308.13 | 33986.14 | 56.6448 |
| 90.972 | 153.6218 | 106265.5 | 72021.52 | 34244.01 | 57.07462 |
| 91.04508 | 153.582 | 106237.9 | 71741.97 | 34495.95 | 57.49456 |
| 91.11528 | 153.5437 | 106211.4 | 71480.07 | 34731.31 | 57.88686 |
| 91.18248 | 153.507 | 106186 | 71225.3 | 34960.67 | 58.26916 |
| 91.24668 | 153.4721 | 106161.7 | 70976.81 | 35184.93 | 58.64297 |
| 91.30812 | 153.4385 | 106138.5 | 70735.29 | 35403.19 | 59.00678 |
| 91.36656 | 153.4067 | 106116.4 | 70500.5 | 35615.89 | 59.36131 |
| 91.42212 | 153.3763 | 106095.4 | 70274.9 | 35820.47 | 59.70231 |
| 91.4748 | 153.3476 | 106075.4 | 70057.82 | 36017.61 | 60.03093 |
| 91.5246 | 153.3205 | 106056.6 | 69849.76 | 36206.87 | 60.3464 |
| 91.57152 | 153.2949 | 106038.8 | 69650.32 | 36388.51 | 60.64918 |
| 91.61556 | 153.2708 | 106022.2 | 69460.6 | 36561.58 | 60.93766 |
| 91.65672 | 153.2484 | 106006.6 | 69281.5 | 36725.08 | 61.2102 |
| 91.69512 | 153.2275 | 105992 | 69113.35 | 36878.68 | 61.46623 |
| 91.73051 | 153.2082 | 105978.7 | 68956.41 | 37022.23 | 61.70553 |
| 91.76328 | 153.1903 | 105966.2 | 68810.93 | 37155.27 | 61.9273 |
| 91.79304 | 153.1741 | 105954.9 | 68677.56 | 37277.38 | 62.13086 |
| 91.82004 | 153.1594 | 105944.7 | 68556.29 | 37388.4 | 62.31593 |
| 91.84428 | 153.1462 | 105935.5 | 68446.72 | 37488.76 | 62.48326 |
| 91.86564 | 153.1345 | 105927.4 | 68349.09 | 37578.26 | 62.63246 |
| 91.88412 | 153.1244 | 105920.3 | 68263.62 | 37656.68 | 62.76321 |
| 91.89996 | 153.1158 | 105914.3 | 68190.51 | 37723.75 | 62.87504 |
| 91.91279 | 153.1088 | 105909.4 | 68129.93 | 37779.43 | 62.96788 |
| 91.92301 | 153.1032 | 105905.4 | 68082.03 | 37823.41 | 63.04122 |
| 91.93032 | 153.0992 | 105902.6 | 68046.9 | 37855.7 | 63.09508 |
| 91.93488 | 153.0967 | 105900.8 | 68024.62 | 37876.19 | 63.12927 |
| 91.93656 | 153.0958 | 105900.1 | 68015.25 | 37884.87 | 63.14379 |

INITIAL DEFLECTION (IN) OF TRAILS = 0

DEFLECTION (IN) OF GUN BARREL AFTER 15 MSEC = -3.293527E-02

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HT5-D8

Negotiation Issues

FMC

155MM LIGHTWEIGHT HOWITZER DEMONSTRATOR

Technical Issues:

Issue 6. Provide supporting data to verify claimed weight of components.

FMC Response. The component breakdown for the FMC LTHD has been restructured to conform to M198 terminology and is shown in Figure HT6-1. To this list has been added the stress analysis method and accuracy used to arrive at the planned material; the estimated probability this material would be used in the demonstrator, and material volume and density estimates used to arrive at the estimated component weights.

Using the average component weights provided in Figure HT6-1 to compare with the M198 equivalents, we find the LTHD weights to be as follows:

| Item | M198 | FMC LTHD |
|---|---|---|
| Cannon | 4,850 | 3,756 |
| Carriage | 8,610 | 3,471 |
| Recoil | 2,150 | 1,525 |
| Fire control | 150 | 220 |
| Total | 15,760 | 8,972 |

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HT6-1

## Figure HT6-1. FMC LTHD Component Breakdown (Sheet 1)

| LINE | DESCRIPTION | QTY | STRESS ANALYSIS MTHD | STRESS ANALYSIS ACCUR | PLAN MATERIAL | PROBA-BILITY | DENSITY (#/IN3) | TOTAL FOR QTY VOLUME (IN3) | TOTAL FOR QTY WEIGHT (LBM) | LVL |
|---|---|---|---|---|---|---|---|---|---|---|
| A | B | C | D | E | F | G | H | I | K | L |
| A1000 | .LTHD Assembly (Version 1.0) | 1 | | | | | | | 8,972 | 1 |
| C1000 | ..Cannon | 1 | | | | | | | 3,756 | 2 |
| C1050 | ...Barrel (41-caliber) | 1 | | | Steel | 99 | 0.28 | 9,286 | 2,600 | 3 |
| C1100 | ...Breech | 1 | | | Steel | 99 | 0.28 | 2,857 | 800 | 3 |
| C1150 | ...Breech band | 1 | TRAD | 30 | Steel | 80 | 0.28 | 375 | 105 | 3 |
| C1200 | ...Breech band bearing | 2 | PUBL | 5 | Torrington 27SFL44 | 90 | | | 11 | 3 |
| C1300 | ...M198 muz brk w/ pintle | 1 | TRAD | 30 | Steel | 70 | 0.28 | 857 | 240 | 3 |
| F1000 | ..Fire control system | 1 | | | | | | | 224 | 2 |
| F1050 | ...Optics and mounting | 1 | | | | | | | 164 | 3 |
| F1100 | ....Assistant gunner | 1 | | | | | | | 44 | 4 |
| F1150 | .....M138 | 1 | | | M138 | 99 | | | 8 | 5 |
| F1200 | .....M172 | 1 | | | M172 | 99 | | | 28 | 5 |
| F1250 | .....M18 | 1 | | | M18 | 99 | | | 8 | 5 |
| F1300 | ....Gunner | 1 | | | | | | | 115 | 4 |
| F1350 | .....M137 | 1 | | | M137 | 99 | | | 17 | 5 |
| F1400 | .....M171 | 1 | | | M171 | 99 | | | 75 | 5 |
| F1450 | .....M17 | 1 | | | M17 | 99 | | | 8 | 5 |
| F1500 | .....Primary mt (to pltfrm) | 1 | | | Al | 80 | 0.10 | 40 | 4 | 5 |
| F1550 | .....Scndry mt (moves w QE) | 1 | | | | | | | 11 | 5 |
| F1570 | ......Mount set | 1 | | | Al 7075-T6 | 80 | 0.10 | 80 | 8 | 6 |
| F1580 | ......Link | 1 | | | CF/E | 80 | 0.057 | 53 | 3 | 6 |
| F1600 | ...Electronics | 1 | | | | | | | 60 | 3 |
| F1650 | ....Elect laying aid (QE) | 1 | | | CF/E box, elect, battry | | | | 20 | 4 |
| F1700 | ....Elev XDCR: IFC-pltfrm | 1 | | | | 60 | | | 5 | 4 |
| F1750 | ....Elev XDCR: pltfrm-cannon | 1 | | | | | | | 5 | 4 |
| F1800 | ....Elect laying aid (AZ) | 1 | | | CF/E box, elect, battry | 60 | | | 20 | 4 |
| F1850 | ....Trav XDCR: IFC-pltfrm | 1 | | | | | | | 5 | 4 |
| F1900 | ....Trav XDCR: pltfrm-cannon | 1 | | | | | | | 5 | 4 |

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FIELD EXPLANATIONS AND ABBREVIATIONS EXPLAINED ON LAST SHEET

# Figure HT6-1. FMC LTHD Component Breakdown (Sheet 2)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 61000 | ..Carriage assembly | 1 | | | | | | | 3,471 | 2 |
| 61050 | ...Cradle assembly | 1 | | | | | | | 1,275 | 3 |
| 61100 | ....Elevation yoke assy | 1 | | | | | | | 300 | 4 |
| 61150 | .....Elevation yoke | 1 | TRAD | | | | | | 230 | 5 |
| 61170 | ......Frame | 1 | | | Ti | 70 | 0.16 | 719 | 115 | 6 |
| 61180 | ......Set of inserts | 1 | | | Fiberglass | 60 | 0.07 | 1,643 | 115 | 6 |
| 61200 | .....Breech cam | 1 | | | Ti | 70 | 0.16 | 250 | 40 | 5 |
| 61250 | .....Travel lock (to trail) | 2 | | | | | | | 30 | 5 |
| 61300 | ......Lifting eye | 1 | | | Ti | 70 | 0.16 | 44 | 7 | 6 |
| 61325 | ......Travel lock mechanism | 1 | | | Ti | 70 | 0.16 | 50 | 8 | 6 |
| 61350 | ....Elevation cylinder | 1 | | | - | | | | 298 | 4 |
| 61400 | .....Belleville springs | 1 | | | CF/E | 50 | 0.057 | 439 | 25 | 5 |
| 61450 | .....Depressn pstn & rod | 1 | TRAD | 30 | Al 7075-T6 | 80 | 0.10 | 360 | 36 | 5 |
| 61500 | .....Elev cyl-inner | 1 | TRAD | 30 | Al 7075-T6 | 80 | 0.10 | 600 | 60 | 5 |
| 61550 | .....Elev cyl-outer | 1 | TRAD | 30 | Al 7075-T6 | 80 | 0.10 | 700 | 70 | 5 |
| 61600 | .....Elev cyl-shroud | 1 | | | Fiberglass | 80 | 0.07 | 286 | 20 | 5 |
| 61650 | .....Elev piston | 1 | | | Al 7075-T6 | 80 | 0.10 | 140 | 14 | 5 |
| 61700 | .....Clevis--lower | 1 | | | Al 7075-T6 | 80 | 0.10 | 100 | 10 | 5 |
| 61750 | .....Lower cyl brg | 1 | PUBL | 5 | Torrington 27SFL44 | 60 | | | 6 | 5 |
| 61800 | .....Lower end cap | 1 | | | Al 7075-T6 | 80 | 0.10 | 110 | 11 | 5 |
| 61850 | .....Upper cyl brgs | 2 | PUBL | 5 | Torrington 27SFL44 | 60 | | | 11 | 5 |
| 61900 | .....Upper endcap & clevis | 1 | TRAD | | Al 7075-T6 | 80 | 0.10 | 350 | 35 | 5 |
| 62000 | ....Equil accumulator | 1 | TRAD | | Metal Bellows Corp | 90 | | | 135 | 4 |
| 62050 | ....Equilibrator hose | 1 | | | Metal Bellows Corp | 50 | | | 2 | 4 |
| 62100 | ....Load-tray | 1 | | | | | | | 115 | 4 |
| 62150 | .....Cleanout cover | 1 | | | Al 7075-T6 | 50 | 0.10 | 50 | 5 | 5 |
| 62200 | .....Loading staff | 1 | | | FRP rod | 80 | 0.07 | 143 | 10 | 5 |
| 62250 | .....Tray lever | 1 | | | Al 7075-T6 | 50 | 0.10 | 50 | 5 | 5 |
| 62300 | .....Ramming staff | 1 | | | FRP rod | 80 | 0.07 | 143 | 10 | 5 |
| 62350 | .....Load tray hsg assy | 1 | | | | | | | 85 | 5 |
| 62360 | ......Frame | 1 | TRAD | | Ti | 70 | 0.16 | 281 | 45 | 6 |
| 62370 | ......Wrap | 1 | | | Kevlar/epoxy | 70 | 0.05 | 700 | 35 | 6 |
| 62380 | ......Coating | 1 | | | Urethane | 70 | 0.05 | 100 | 5 | 6 |
| 62400 | ....Slide unit | 1 | | | | | | | 425 | 4 |
| 62450 | .....Slide tubes | 2 | | | | | | | 360 | 5 |
| 62460 | ......Basic tube | 1 | TRAD | | Pultruded CF/E | 60 | 0.057 | 2,456 | 140 | 6 |
| 62470 | ......Overwrap | 1 | | | Fiberglass | 60 | 0.07 | 429 | 30 | 6 |
| 62480 | ......Inner core | 1 | | | Foam | 50 | 0.0015 | 6,665 | 10 | 6 |
| 62500 | .....Yoke-tube lock endplt | 2 | TRAD | 30 | Al 7075-T6 | 60 | 0.10 | 190 | 19 | 5 |
| 62550 | .....Trunnion mount unit | 2 | TRAD | | | | | | 46 | 5 |
| 62600 | ......Lifting eyes | 1 | | | Ti | 60 | 0.16 | 50 | 8 | 6 |
| 62625 | ......Trunnion brg mount | 1 | | | Ti | 60 | 0.16 | 94 | 15 | 6 |

FIELD EXPLANATIONS AND ABBREVIATIONS EXPLAINED ON LAST SHEET



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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| G2650 | ...Platform & trunnion assy | 1 | | | | | | | 392 | 3 |
| G2700 | ....Platform | 1 | TRAD | | See Appendix HT7-A | 60 | | | 210 | 4 |
| G2750 | ....Claw--primary | 1 | | | Ti | 50 | 0.16 | 63 | 10 | 4 |
| G2800 | ....Claw--secondary | 2 | | | Ti | 20 | 0.16 | 125 | 20 | 4 |
| G2850 | ....Traverse bearings | 3 | PUBL | 5 | Purchased | | | | 15 | 4 |
| G2900 | ....Trunnion | 1 | | | | | | | 60 | 4 |
| G2920 | .....Spaceframe | 1 | TRAD | | Ti | 80 | 0.16 | 188 | 30 | 5 |
| G2930 | .....Panels | 1 | | | Fiberglass | 60 | 0.07 | 429 | 30 | 5 |
| G2950 | ....Trunnion bearing | 2 | PUBL | 5 | Torrington 27SFL44 | 90 | | | 11 | 4 |
| G2975 | ....Trunnion pins | 2 | | | Steel | 80 | 0.28 | 54 | 15 | 4 |
| G3000 | ....Spade mounting shafts | 2 | | | Ti | 60 | 0.16 | 119 | 19 | 4 |
| G3050 | ....Traverse cylinder | 1 | TRAD | 30 | | | | | 32 | 4 |
| G3100 | .....Piston and rod | 1 | | | | | | | 5 | 5 |
| G3120 | ......Piston | 1 | | | Al 7075-T6 | 90 | 0.10 | 10 | 1 | 6 |
| G3130 | ......Rod | 1 | | | Ti | 90 | 0.16 | 25 | 4 | 6 |
| G3150 | .....Cylinder | 1 | | | Al 7075-T6 | 90 | 0.10 | 160 | 16 | 5 |
| G3200 | .....Front end cap | 1 | | | Al 7075-T6 | 90 | 0.10 | 40 | 4 | 5 |
| G3250 | .....Rear end cap | 1 | | | Al 7075-T6 | 90 | 0.10 | 50 | 5 | 5 |
| G3300 | .....Tie rods | 4 | | | Steel | 90 | 0.28 | 7 | 2 | 5 |
| G3350 | ...Trails (set of) | 1 | | | | | | | 356 | 3 |
| G3400 | ....Trail positioning link | 2 | | | | | | | 36 | 4 |
| G3420 | .....Ends | 1 | | | Ti | 60 | 0.16 | 75 | 12 | 5 |
| G3430 | .....Tube | 1 | | | CF/E | 60 | 0.057 | 105 | 6 | 5 |
| G3450 | ....Trail w integral brg-LH | 1 | TRAD | | See Appendix HT7-A | 60 | | | 140 | 4 |
| G3500 | ....Trail w integral brg-RH | 1 | TRAD | | See Appendix HT7-A | 60 | | | 140 | 4 |
| G3550 | ....Trav lock to elev yoke | 2 | | | Ti | 60 | 0.16 | 125 | 20 | 4 |
| G3600 | ....Skid plates | 2 | | | | | | | 20 | 4 |
| G3620 | .....Outer shell set | 1 | | | Fiberglass | 70 | 0.07 | 129 | 9 | 5 |
| G3630 | .....Inner core | 1 | | | Foam | 90 | 0.006 | 167 | 1 | 5 |
| G3650 | ...Spade assembly | 1 | | | | | | | 285 | 3 |
| G3700 | ....Spade | 1 | FEA | 10 | See Appendix HT7-A | 50 | | | 210 | 4 |
| G3750 | ....Spade bearing | 2 | PUBL | 5 | Torrington 27SFL44 | 50 | | | 11 | 4 |
| G3800 | ....Spade cylinder | 2 | TRAD | 30 | | | | | 64 | 4 |
| G3850 | .....Piston and rod | 1 | | | | | | | 5 | 5 |
| G3870 | ......Piston | 1 | | | Al 7075-T6 | 90 | 0.10 | 10 | 1 | 6 |
| G3880 | ......Rod | 1 | | | Ti | 90 | 0.16 | 25 | 4 | 6 |
| G3900 | .....Cylinder | 1 | | | Al 7075-T6 | 90 | 0.10 | 160 | 16 | 5 |
| G3950 | .....Front end cap | 1 | | | Al 7075-T6 | 90 | 0.10 | 40 | 4 | 5 |
| G4000 | .....Rear end cap | 1 | | | Al 7075-T6 | 90 | 0.10 | 50 | 5 | 5 |
| G4050 | .....Tie rods | 4 | | | Steel | 90 | 0.28 | 7 | 2 | 5 |
| G4100 | ...Hydraulic system | 1 | | | | | | | 327 | 3 |
| G4150 | ....Gunner's hardware | | | | | | | | 94 | 4 |
| G4200 | .....Elev ctrl valve | 1 | | | Purchased | 90 | | | 8 | 5 |
| G4250 | .....Pump | 1 | | | Purchased | 90 | | | 20 | 5 |
| G4300 | .....Reservoir | 1 | | | Al | 60 | 0.10 | 500 | 50 | 5 |
| G4350 | .....Spade ctrl valve | 1 | | | Purchased | 90 | | | 8 | 5 |

FIELD EXPLANATIONS AND ABBREVIATIONS EXPLAINED ON LAST SHEET



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## Figure HT6-1. FMC LTHD Component Breakdown (Sheet 4)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| G4400 | .....Traverse ctrl valve | 1 | | | Purchased | 90 | | | 8 | 5 |
| G4450 | ....AG hardware hardware | | | | | | | | 78 | 4 |
| G4500 | .....Elevation ctrl valve | 1 | | | Purchased | 90 | | | 8 | 5 |
| G4550 | .....Pump | 1 | | | Purchased | 90 | | | 20 | 5 |
| G4600 | .....Reservoir | 1 | | | Al | 60 | 0.10 | 500 | 50 | 5 |
| G4650 | ....Hydraulic fluid | | | | MIL-H-6083D | 99 | | | 90 | 4 |
| G4700 | ....Hardline | 1 | | | Steel | 80 | 0.28 | 89 | 25 | 4 |
| G4750 | ....Hose | 1 | | | Purchased | 90 | | | 20 | 4 |
| G4800 | ....Portable pump | 1 | | | Purchased | 90 | | | 20 | 4 |
| G4850 | ...Dolly assembly | 1 | | | | | | | 671 | 3 |
| G4900 | ....Dolly framework | 1 | | | | | | | 110 | 4 |
| G4920 | .....Frame | 1 | TRAD | | Filament wound CF/E | 60 | 0.057 | 1,754 | 100 | 5 |
| G4930 | .....Core | 1 | | | Foam | 50 | 0.002 | 5,000 | 10 | 5 |
| G4950 | ....Brake calipers | 4 | | | Kelsey-Hayes series 70 | 70 | | | 44 | 4 |
| G5000 | ....Air-over-oil actuator | 1 | | | Purchased | 80 | | | 15 | 4 |
| G5050 | ....Brake rotor | 4 | | | CI | 50 | 0.26 | 162 | 42 | 4 |
| G5100 | ....Whl hubs w brgs & bolts | 4 | | | | | | | 52 | 4 |
| G5120 | .....Hubs | 1 | | | Al 7075-T6 | 60 | 0.10 | 90 | 9 | 5 |
| G5130 | .....Set of brgs and bolts | 1 | | | Purchased (steel) | 80 | | | 4 | 5 |
| G5150 | ....Axles | 4 | | | Ti | 60 | | | 20 | 4 |
| G5200 | ....HMMWV tire | 4 | | | Goodyear | 99 | | | 248 | 4 |
| G5250 | ....HMMWV compatible rim | 4 | | | Purchased | 99 | | | 120 | 4 |
| G5300 | ....Strap winch | 1 | | | Purchased | 90 | | | 15 | 4 |
| G5350 | ....Brake lines | 1 | | | Steel | 70 | 0.28 | 18 | 5 | 4 |
| G5400 | ...Loose items | 1 | | | | | | | 165 | 3 |
| G5450 | ....Basic issue items | 1 | | | | | | | 145 | 4 |
| G5500 | ....Safety "chain" (tow) | 1 | | | | | | | 5 | 4 |
| G5520 | .....Rope | 1 | | | Kevlar | 80 | 0.05 | 20 | 1 | 5 |
| G5530 | .....Hooks | 2 | | | Ti | 60 | 0.16 | 25 | 4 | 5 |
| G5550 | ....Carrier for proj | 1 | | | Fiberglass/epoxy | 80 | 0.07 | 143 | 10 | 4 |
| G5600 | ....Muzzle plug | 1 | | | Wood | 90 | | | 5 | 4 |

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FIELD EXPLANATIONS AND ABBREVIATIONS EXPLAINED ON LAST SHEET

# Figure HT6-1. FMC LTHD Component Breakdown (Sheet 5)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| R1000 | ..Recoil system | 1 | | | | | | | 1,525 | 2 |
| R1050 | ...Non-recoiling group | 1 | | | | | | | 754 | 3 |
| R1100 | ....Forward yoke assy | 1 | | | | | | | 548 | 4 |
| R1150 | .....Recoil accumltr unit | 2 | TRAD | | | | | | 156 | 5 |
| R1200 | ......Bellows accumulator | 1 | | | Metal Bellows Corp | 90 | | | 77 | 6 |
| R1250 | ......Counterrecoil check | 1 | | | Kepner cartridge | 50 | | | 1 | 6 |
| R1300 | .....Forward yoke | 1 | | | | | | | 220 | 5 |
| R1320 | ......Spaceframe | 1 | TRAD | | Ti | 70 | 0.16 | 750 | 120 | 6 |
| R1330 | ......Set of plate inserts | 1 | | | Fiberglass | 60 | 0.07 | 1,429 | 100 | 6 |
| R1350 | .....Yoke-tube lock | 2 | TRAD | 30 | Ti | 60 | 0.16 | 188 | 30 | 5 |
| R1400 | .....Into battery cushion | 2 | | | Urethane | 50 | 0.05 | 80 | 4 | 5 |
| R1450 | .....Hydraulic fluid | | | | MIL-H-6083D | 99 | | | 120 | 5 |
| R1500 | .....Recoil cyl shroud | 1 | | | CF/E | 80 | 0.057 | 175 | 10 | 5 |
| R1550 | .....Slide brg and scraper | 2 | | | Teflon & urethane | 80 | 0.07 | 114 | 8 | 5 |
| R1600 | ....Recoil cyl (fixed prtn) | 2 | | | | | | | 206 | 4 |
| R1650 | .....Orifice ring | 1 | TRAD | 30 | Al 7075-T6 hc anodized | 80 | 0.10 | 40 | 4 | 5 |
| R1700 | .....Stationary cylinder | 1 | TRAD | 30 | Al 7075-T6 | 80 | 0.10 | 450 | 45 | 5 |
| R1750 | .....Stationary end cap | 1 | | | Al 7075-T6 | 80 | 0.10 | 160 | 16 | 5 |
| R1800 | .....Stationary piston | 1 | | | Al 7075-T6 | 80 | 0.10 | 30 | 3 | 5 |
| R1850 | .....Stationary pstn rod | 1 | TRAD | 30 | Al 7075-T6 | 80 | 0.10 | 350 | 35 | 5 |
| R1900 | ...Recoiling group | 1 | | | | | | | 771 | 3 |
| R1950 | ....Front recoiling yoke | 1 | | | | | | | 130 | 4 |
| R1970 | .....Space frame | 1 | TRAD | | Ti | 70 | 0.16 | 500 | 80 | 5 |
| R1980 | .....Set of plate inserts | 1 | | | Fiberglass | 60 | 0.07 | 714 | 50 | 5 |
| R2000 | ....Recoiling yoke spacer | 2 | TRAD | | Al 7075-T6 | 50 | 0.10 | 400 | 40 | 4 |
| R2050 | ....Rear recoiling yoke | 1 | | | | | | | 135 | 4 |
| R2070 | .....Space frame | 1 | TRAD | | Ti | 70 | 0.16 | 531 | 85 | 5 |
| R2080 | .....Set of plate inserts | 1 | | | Fiberglass | 60 | 0.07 | 714 | 50 | 5 |
| R2100 | ....Slide brg & scraper | 4 | TRAD | 30 | Teflon and urethane | 80 | 0.07 | 229 | 16 | 4 |
| R2150 | ....Dolly mounting bsg | 4 | | | Urethane | 50 | 0.05 | 400 | 20 | 4 |
| R2200 | ....Recoil cyl (reclng prtn) | 2 | | | | | | | 430 | 4 |
| R2250 | .....Front recoiling end cap | 1 | | | Al 7075-T6 | 90 | 0.10 | 50 | 5 | 5 |
| R2300 | .....Rear recoiling end cap | 1 | | | Al 7075-T6 | 90 | 0.10 | 100 | 10 | 5 |
| R2350 | .....Recoiling inner cyl | 1 | TRAD | 30 | Al 7075-T6 | 90 | 0.10 | 800 | 80 | 5 |
| R2400 | .....Recoiling outer cyl | 1 | TRAD | 30 | Al 7075-T6 | 90 | 0.10 | 1,150 | 115 | 5 |
| R2450 | .....Recoiling piston | 1 | | | Al 7075-T6 | 90 | 0.10 | 50 | 5 | 5 |

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FIELD EXPLANATIONS AND ABBREVIATIONS EXPLAINED ON LAST SHEET

FIELDS - EXPLANATION AND ABBREVIATIONS

FIELD C: QUANTITY FOR NEXT HIGHEST LEVEL (GIVEN BY FIELD L).

FIELD D: METHOD USED FOR STRESS ANALYSIS.
TRAD = TRADITIONAL
PUBL = PUBLISHED
FEA = FINITE ELEMENT ANALYSIS

FIELD E: ESTIMATED ACCURACY OF STRESS ANALYSIS (IF FIELD D HAS AN ENTRY BUT FIELD E HASN'T, DESIGN HAS CHANGED SINCE ANALYSIS).

FIELD F: MATERIAL
CF/E = carbon fiber with epoxy resin
FRP = fiberglass reinforced plastic

FIELD G: ESTIMATED PROBABILITY THAT MATERIAL LISTED WILL BE FINAL CHOICE.

FIELD I: TOTAL VOLUME FOR QUANTITY OF ITEMS REQUIRED (FIELD C).

FIELD K: TOTAL WEIGHT FOR QUANTITY OF ITEMS REQUIRED (FIELD C).

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Negotiation Issues

FMC

155MM LIGHTWEIGHT HOWITZER DEMONSTRATOR

Technical Issues:

Issue 7. Clarify the use of composite materials or material concepts which incorporate the use of composite material.

FMC Response. This is largely provided by Figure HT6-1 in our response to Issue 6. The general methodology used and planned, with discussion of a few of the more involved components, is discussed in Appendix HT7-A.

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## Appendix - HT7-A

### Material Considerations

The following paragraphs describe the methodology planned in selecting materials/processes and performing stress analysis to insure that the selection is not suboptimal from either a component or system viewpoint. Then the approaches under consideration for three composite components (the spade, platform, and trails) are discussed.

Overview: Some components will not be considered for composites due to the weight-cost-RAM-D tradeoff. Examples of (currently) pre-designated materials include steel (for cannon components exposed to combustion pressures), aluminum (where high pressure sealing is involved), nitrided titanium (where high pressure sealing surfaces with potential exposure to nicks and dings are involved), and standard components whose potential weight savings do not justify development cost and/or RAM-D risk, such as fire contol, bellows accumulators, and bearings.

Components designated to be made of aluminum constitute 1837 lbm of FMC's LTHD, 1737 lbm of which are currently planned for alloy 7075-T6. When the new lithium alloys of aluminum become available, their 9 to 10% weight savings could reduce the aggregate weight of the 7075-T6 components by 165 lbm.

The balance of components will be considered for composite construction. The default material is carbon fiber/epoxy. When conceptual functions initially take form, a precursory material selection and approximate stress analysis will be undertaken to evaluate one general approach versus alternatives. Stress analysis will be taken to greater degrees as the overall concept advances and the role of the component within the overall system becomes critical.

Complex parts, where needed and justified, will be built from modular structural elements and easily assembled into the total structure. Part replacement is therefore easily made if localized damage occurs. Composite plate structures will be used in the structure to absorb load and provide damping of impulse loads as required.

Composite Components: Composite components will be designed to be easily replaced (e.g., failure from unanticipated nonstructural loads). Use of multiple prepreg or wet lay-up woven roving sheets to facilitate load bearing panel construction is an element of the unit construction/modular construction method to be used, i.e., the FMC LTHD is to be constructed of easily fabricated modular parts to form a monocoque structure. Use of cored sandwich panels is preferred for bolt-on structural panels under bending loads.

System Integration: Extensive use of an overall finite element model for the entire structure will permit design optimization to be performed over all load conditions and reaction load angle inputs due to firing, towing, air transportation, and ground impact from parachute and LAPES drops.

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Spade

The spade analysis in Appendices HT7-B, -C, and -D provides an example of the component design process planned. This precursory design meets all structural requirements as well as it's initial weight target. ANSYS finite element analysis for several trial designs, under static and dynamic loading, indicates the superiority of a space-frame design over all-titanium, all-steel or all-FG/EP designs for several anticipated load cases.

Other possibilities include Al/SiC.

Platform

Plan: Design of the platform is performed from modular built-up components. A space frame composed of carbon fiber/epoxy filament wound tubes and/or composite built-up sections made from carbon-fiber woven rovings (with cored inserts) will comprise this component.

The rearward impulse loads from the recoil cylinders are to be reacted into this structure together with reactive spade loads and other static loads. These input loads can be made to induce (mostly) tensile and bending stress within the platform by proper design.

Use of optimized (for the given load direction and magnitude) multilayer bonded carbon/epoxy woven roving plates in this structure to absorb load completes the monocoque design. Additional stiffening elements can be bonded onto existing structural components to improve capability in certain directions if a directional failure mode exists; i.e., the structure can be selectively reinforced in certain directions. Metal bearings and other load bearing and load transfer surfaces can be constructed with weld-on attachments to facilitate bolting/bonding of the adjacent composite structure to complete load paths.

Use of alternate materials to reduce cost is dependent upon advanced stress analysis.

Trails

Plan: The planned trail design contains a three-dimensional, space-frame lattice-work of (carbon fiber/epoxy) filament wound tubes. These tubes are bolted/bonded to longitudinal box beams through special end-connection junctions. Reinforcement with Rohacell foam inserts will increase both bending stiffness and energy absorption capability.

Use of additional side and top bolt-on plates made from a choice of carbon, E-glass or Kevlar/epoxy bonded woven rovings then closes the structure and provides additional stiffness for bending shear and tension loads. Kevlar over-wraps cover outside parts of the structure to increase scuff resistance greatly while providing some armor capability.

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Option 1: Use of filament over-wraps over modular, bolt together sections of space-frame networks is also a viable alternative construction technique. Choice of materials, part dimensions, and final configuration are dependent upon stress analysis results, failure mode analysis, and energy absorption capability. (An option to this construction would be use of a tapered I-beam made from carbon fiber roving layers built up over a central foam core web. Advanced analysis will decide the optimum construction method.)

Summary: Several advanced iterations in the design process are expected in order to select a near-optimum design. Quasi-static and dynamic tests of representative structural elements will be performed to access stress adequacy; tension-field tests on built-up composite layer plates with different layer stack-up sequences, as well as standard ASTM shear and tensile/compressive tests, then will confirm materials properties used to obtain optimum solutions from finite element analysis.

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APPENDIX HT7 - B1

# FMC Central Engineering Laboratories Santa Clara

Interoffice

To B. Anderson - Northern Ordnance | Date April 17, 1985

From C. R. Ortloff | cc R. Kazares, E. Thuse

Subject Further Work on the Lightweight Howitzer Additional Composite Spade Load Cases

This memo addresses further load cases of importance to the lightweigh composite howitzer spade design. These cases relate to loading originating from rock impact upon spade seating during gun firing. For the first case, point loading of 60,000 lbf is assumed to occur at the spade bottom edge at the centerline (Figure 1) while the top edge is fixed. The material of the spade is carbon fiber and properties have been listed in the previous memo (CRO to BA, 4/1/85). Figure 1 indicates that the maximum SIGE stress in the fiber-wound frame is 55 ksi which is less than the material breaking strength of 120 ksi. Vertical deflection under load (Figure 2) does not exceed 0.1 inches indicating that the internal beam lattice network (Figure 4) is effective in absorbing vertical load. Beam stress values in this grid network are listed in Figures 5 and 6 and are generally low indicating adequate stress safety margin. Stress in the waffle plate (Figure 3 insert (which lies inside of the "picture frame" spade boundary (Figure and over the beam lattice network (Figure 4) and is bonded together by urethane "poured" into the waffle plate channels and depressions) is less than 13 ksi . Stress in the urethane plugs that fill the waffle plate depressions is likewise low (Figure 7). The net conclusion of the stress analysis is that the lightweight composite spade can easily survive point loading on its lower edge corresponding to impulsive impact with imbedded rock. Although cases run are for static loading, a prior memo (M. [illegible] to B. Anderson 3/27/85) indicates a 25% increase in stress levels for dynamic loading. With this increase over static stress levels adequate safety margin remains to insure survivability of the composite spade.

The next load case considered consists of a concentrated, localized force load set (Figures 8, 9) acting on the spade outer face. This loading arises from impact with a ground imbedded stone upon rearward movement of the spade resulting from gun recoil. The magnitude of the total force acting as shown in Figures 8, 9 is 60,000 lbf, i.e., 15,000 lbf at each of four nodes. SIGE stress results, Figure 10, indicate high localized stress around the spade attachment arms at the fixed end. Since this fixed end is pinned in actuality and can be easily redesigned to withstand high loads, the end zone loads should be ignored. On the filament wound "picture frame", stress is less than 85 ksi, still below the failure strength of the carbon fiber. Waffle plate stresses (Figure 11) are less than 105 ksi in the region around the load points. The thickness of the plate can be increased over the value used for the present design (0.4 inches) to [illegible]

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this stress without significant weight increase. The waffle plate can therefore be easily modified to withstand localized impact loading without failure. Figure 12 represents the stress distribution in the web frame between the side beams. Again, these stresses may be reduced by increasing web plate thickness over the original value (0.5 inches). Beam lattice stress (Figures 13, 14) indicate values to 65 ksi in the vicinity of the load points. This stress is less than the failure stress of the individual beams. The urethane plug stress, Figure 15, again indicate stress levels below failure stress for that material. Addition of Kevlar cover plates over the waffle plate sides will further add to the safety margin of the structure.

From the two load cases presented, it can be concluded that composite spade impact upon ground imbedded stones resulting from gun recoil forces does not cause spade failure. Localize high stress regions can easily be redesigned (usually in the form of a part thickness increase) without a large weight penalty. These two load cases considered together with two prior cases indicate that the composite spade design proposed has the capability to withstand typical service loads without experiencing part failure and still retain a total weight less than 200 lb.

C.R. Ortloff

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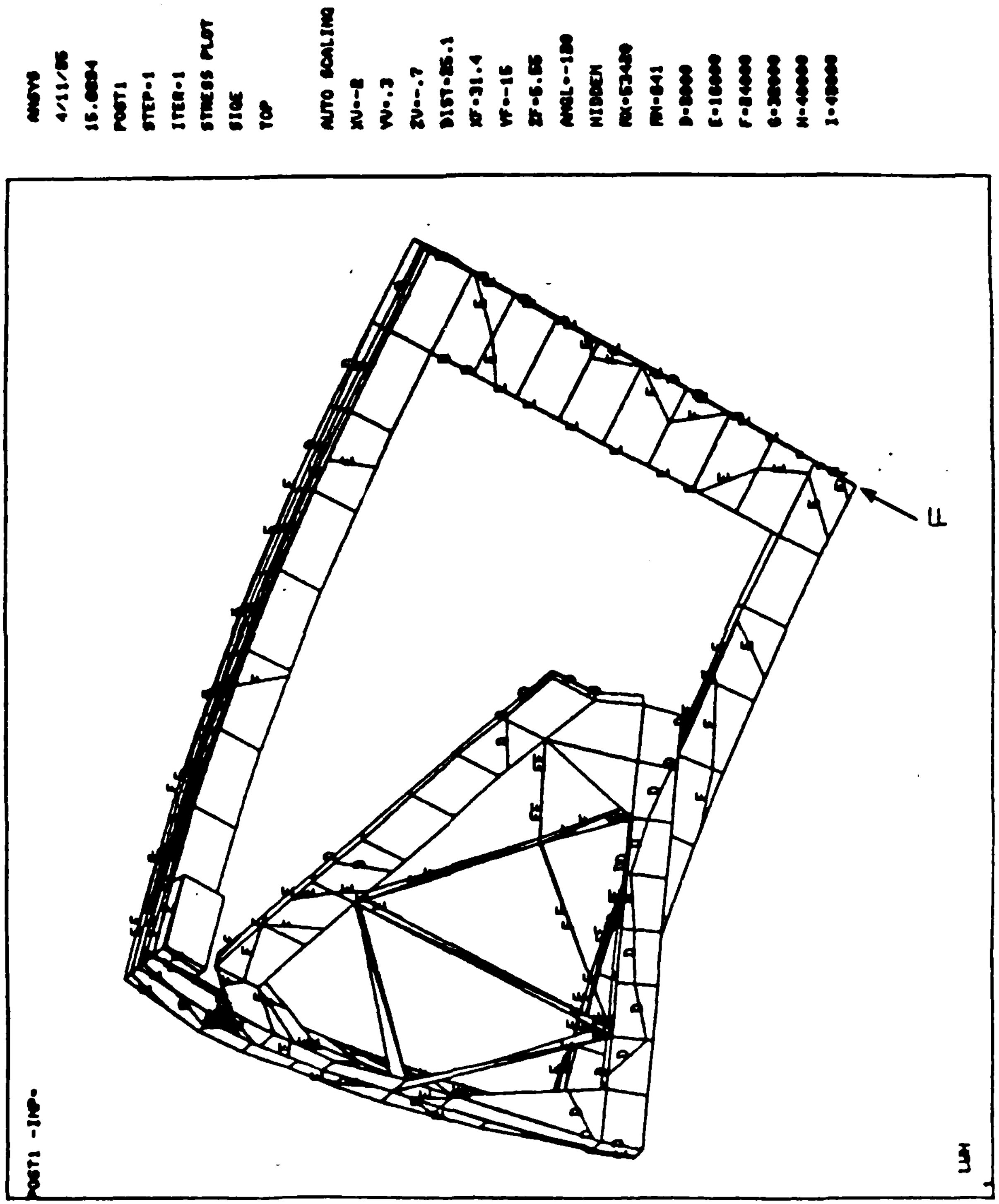
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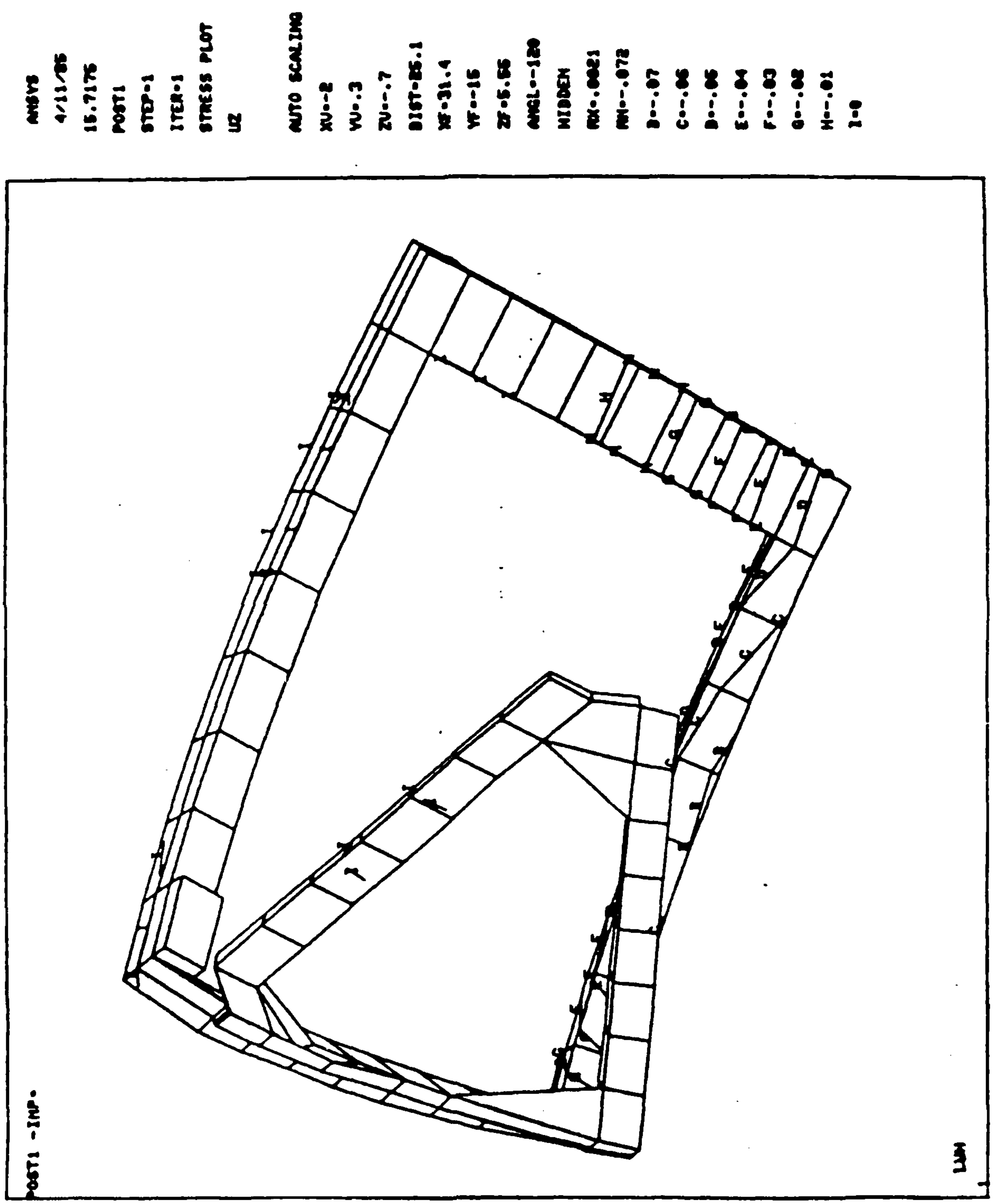


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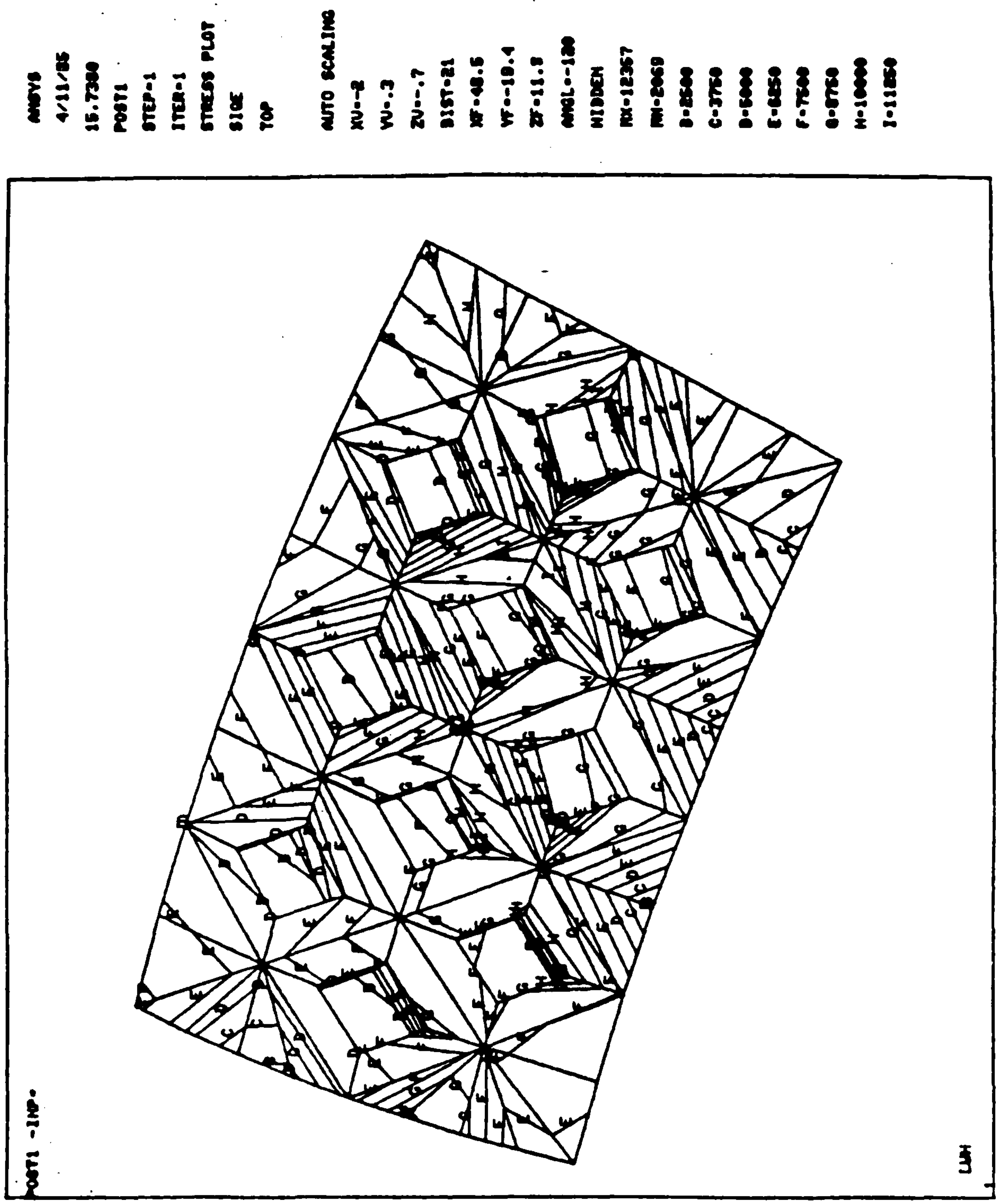


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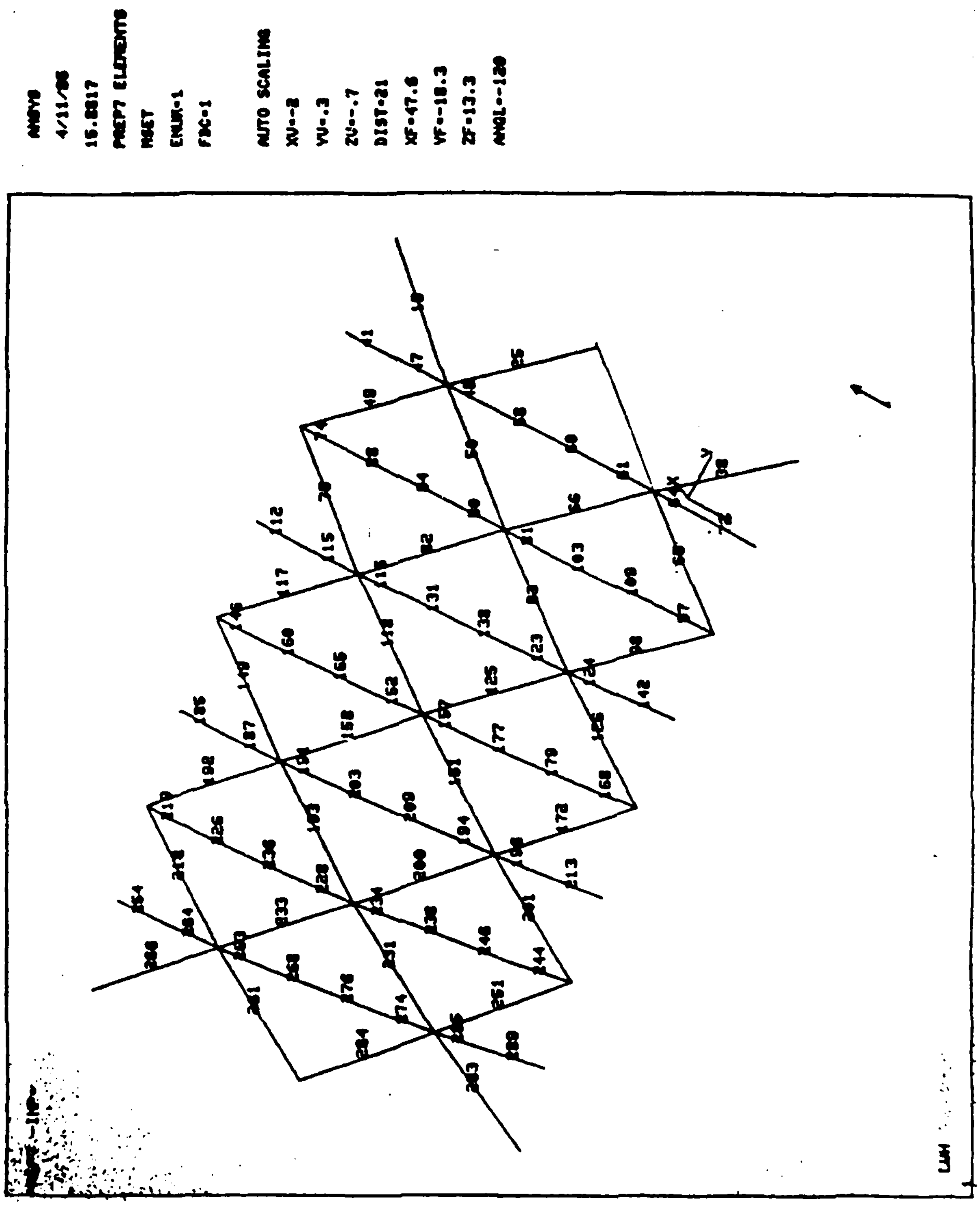
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AUTO SCALING
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YV=-3
ZV=-.7
DIST=21
XF=47.6
YF=-18.3
ZF=13.3
ANGL=-120

[redacted]

```
*RSTR,1,8
PRINT ELEMENT STRESS ITEMS PER ELEMENT

      ***** POST1 ELEMENT STRESS LISTING *****

 LOAD STEP      1  ITERATION=     1  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1

 ELEM       SDIR          SBZ          SBY          SIG1         SIG2
   15    -1805.0       878.38       1820.2       201.46      -3901.5
   25     3766.6      -328.88      -60.327       4166.2       3377.0
   38    -1663.8       79.014       478.46      -1066.3      -2121.2
   41     2476.6      -194.88       160.11       2831.5       2181.7
   47     2472.3      -804.31       62.478       3339.1       1605.5
   48     4934.7      -222.12       670.88       5827.7       4041.7
   49     3109.5      -144.96       786.45       4040.9       2178.1
   50    -1214.6      -568.06      -753.28       96.767      -2525.9
   58     431.09       926.23      -245.89       1603.2      -741.03
   60     429.22       1364.0       43.405       1836.6      -978.17
   61     4431.3       6640.7      -473.33       11545.      -2682.7
   64     2821.9       2993.2       827.84       6042.9      -399.17
   65     1600.7       1633.0       2179.1       5412.8      -2211.6
   68    -1187.0      -778.97       29.080      -380.92      -1893.0
MORE (YES,NO OR CONTINUOUS)=

C

      ***** POST1 ELEMENT STRESS LISTING *****

 LOAD STEP      1  ITERATION=     1  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1

 ELEM       SDIR          SBZ          SBY          SIG1         SIG2
   72     2826.9       265.14       128.32       3220.3       2433.4
   74     3166.0      -255.16     0.15065E-01    3421.2       2910.8
   76     412.04      -660.68      -3442.6       4515.3      -3691.3
   80    -98.487       4276.8       104.46       4282.8      -4479.7
   81     776.68      -301.60      -269.61       1346.8       204.57
   82    -8011.9       467.09       928.06      -616.72      -3407.0
   83    -3067.7       620.60      -768.91      -1678.2      -4457.2
   88    -683.98      -41.818       71.457      -570.71      -797.26
   94    -689.35       359.06       38.742      -291.66      -1087.1
   97     8431.3       6734.4       160.08       9325.8      -4463.3
   98    -3428.7      -1704.5      -2615.3       891.03      -7748.4
  103    -1168.8       2060.3      -460.76       1342.3      -3679.9
  109    -1168.1       2332.9       40.365       1205.2      -3541.4
  112    -992.85      -1172.8      -83.104       863.04      -2248.7

      ***** POST1 ELEMENT STRESS LISTING *****

 LOAD STEP      1  ITERATION=     1  SECTION=  1
 TIME=   0.00000E+00      LOAD CASE=  1

 ELEM       SDIR          SBZ          SBY          SIG1         SIG2
  115    -994.79      -184.19      -89.311      -781.89      -1208.3
  116     871.60      -836.36       144.48       1261.6      -708.17
  117    -2870.3       808.18       2487.6       485.39      -6166.1
  118    -1060.4      -880.03       581.82
```

[redacted]

[redacted]

H77-11

6

888.8 -3853.6

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIG2 |
|---|---|---|---|---|---|
| 152 | -992.04 | 6895.9 | 636.27 | 8340.1 | -8324.2 |
| 157 | 768.53 | 813.86 | -88.421 | 1070.8 | 466.25 |
| 158 | -2877.1 | 1110.7 | 2297.2 | 530.75 | -6284.9 |
| 160 | -1473.1 | -162.75 | 343.00 | -977.36 | -1968.9 |
| 165 | -1478.7 | 1841.1 | -3.7799 | 468.24 | -3421.6 |
| 168 | 2313.7 | 7082.1 | 12.239 | 9408.0 | -4780.7 |
| 172 | -1840.7 | -746.90 | -786.02 | 232.22 | -2713.6 |
| 177 | -1112.3 | 1880.7 | 187.54 | 955.94 | -3180.6 |
| 179 | -1118.4 | 2388.5 | 3.9343 | 1280.0 | -3604.8 |
| 185 | -1894.7 | -1407.3 | -96.142 | -392.30 | -3397.1 |
| 187 | -1900.8 | 974.30 | -45.700 | -880.75 | -2920.9 |
| 191 | -278.04 | 78.173 | 551.86 | 349.40 | -906.47 |
| 192 | -1872.1 | 858.48 | 2083.5 | 869.84 | -4614.0 |
| 193 | -1068.2 | 721.73 | -887.41 | 642.95 | -2776.3 |

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIG2 |
|---|---|---|---|---|---|
| 194 | -420.60 | 8561.1 | 382.38 | 8523.0 | -9364.0 |
| 196 | 1526.3 | 2604.9 | -183.21 | 4313.4 | -1862.9 |
| 200 | -2274.3 | 979.59 | -2574.5 | 1879.8 | -6828.4 |
| 201 | -3738.9 | -2033.7 | 2723.6 | 1018.3 | -8496.1 |
| 203 | -1804.1 | 8314.4 | 490.02 | 1000.2 | -4608.5 |
| 209 | -1806.0 | 3256.0 | 17.787 | 1468.8 | -5078.7 |
| 213 | 1530.7 | 187.61 | -27.906 | 1748.8 | 1315.2 |
| 218 | -2370.4 | -408.91 | -1275.8 | -687.76 | -4063.1 |
| 219 | -1368.1 | 438.24 | 55.173 | -888.70 | -1855.5 |
| 226 | -1487.0 | 1157.8 | 346.76 | 77.564 | -2931.5 |
| 228 | -806.13 | 6260.5 | 182.57 | 6237.0 | -6649.8 |
| 231 | -990.90 | -1417.3 | -1931.7 | 2349.1 | -4348.9 |
| 233 | -630.08 | 306.41 | -2897.6 | 2444.0 | -3788.1 |
| 234 | 1330.5 | 180.73 | 869.01 | 2308.8 | 888.73 |

***** POST1 ELEMENT STRESS LISTING *****

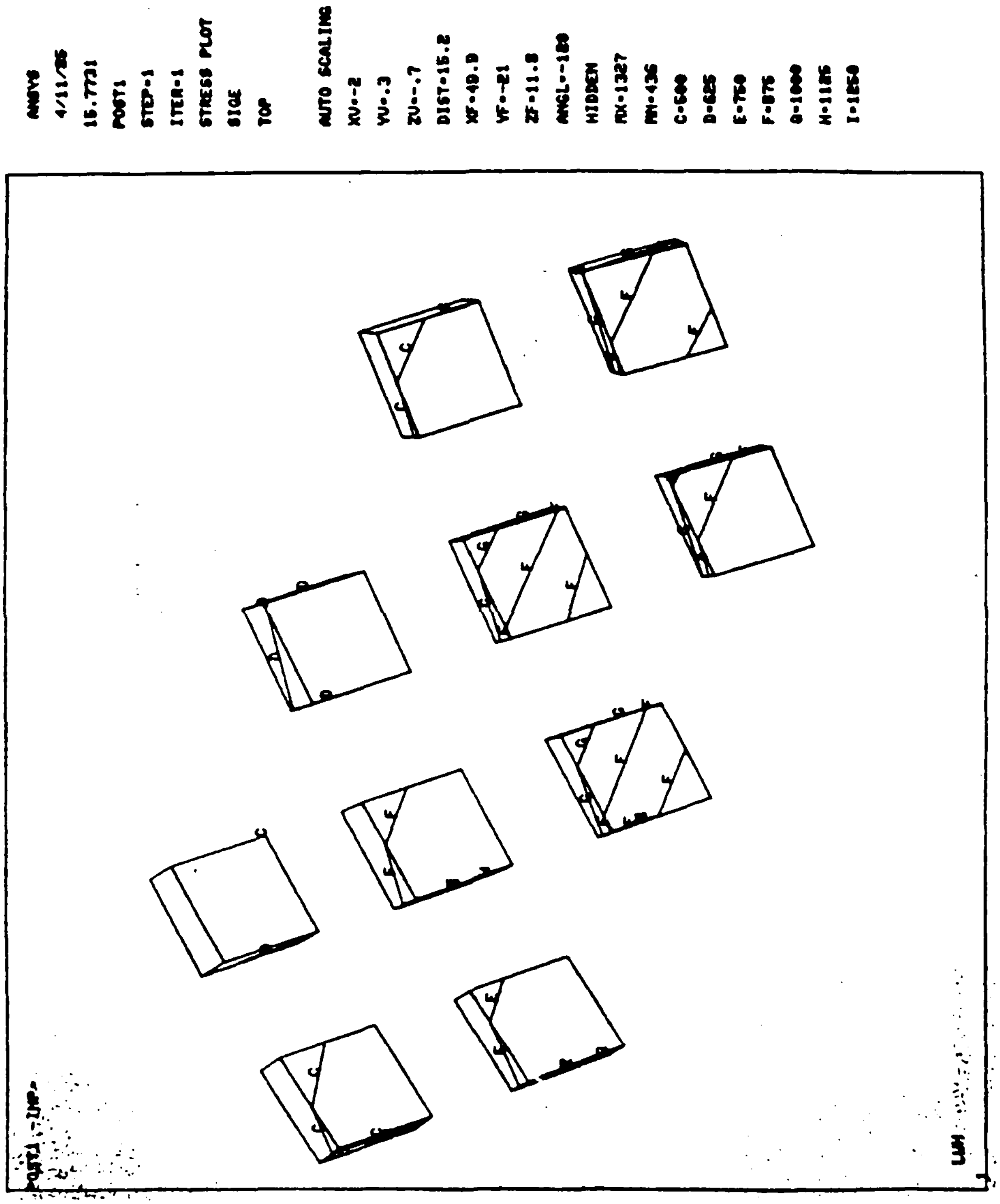
LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIG2 |
|---|---|---|---|---|---|
| 236 | -1488.3 | 2181.2 | 25.538 | 778.30 | -3836.1 |
| 238 | -464.66 | 1788.8 | 1380.3 | 2581.9 | -3611.0 |

[redacted]

[redacted]

HT7-12

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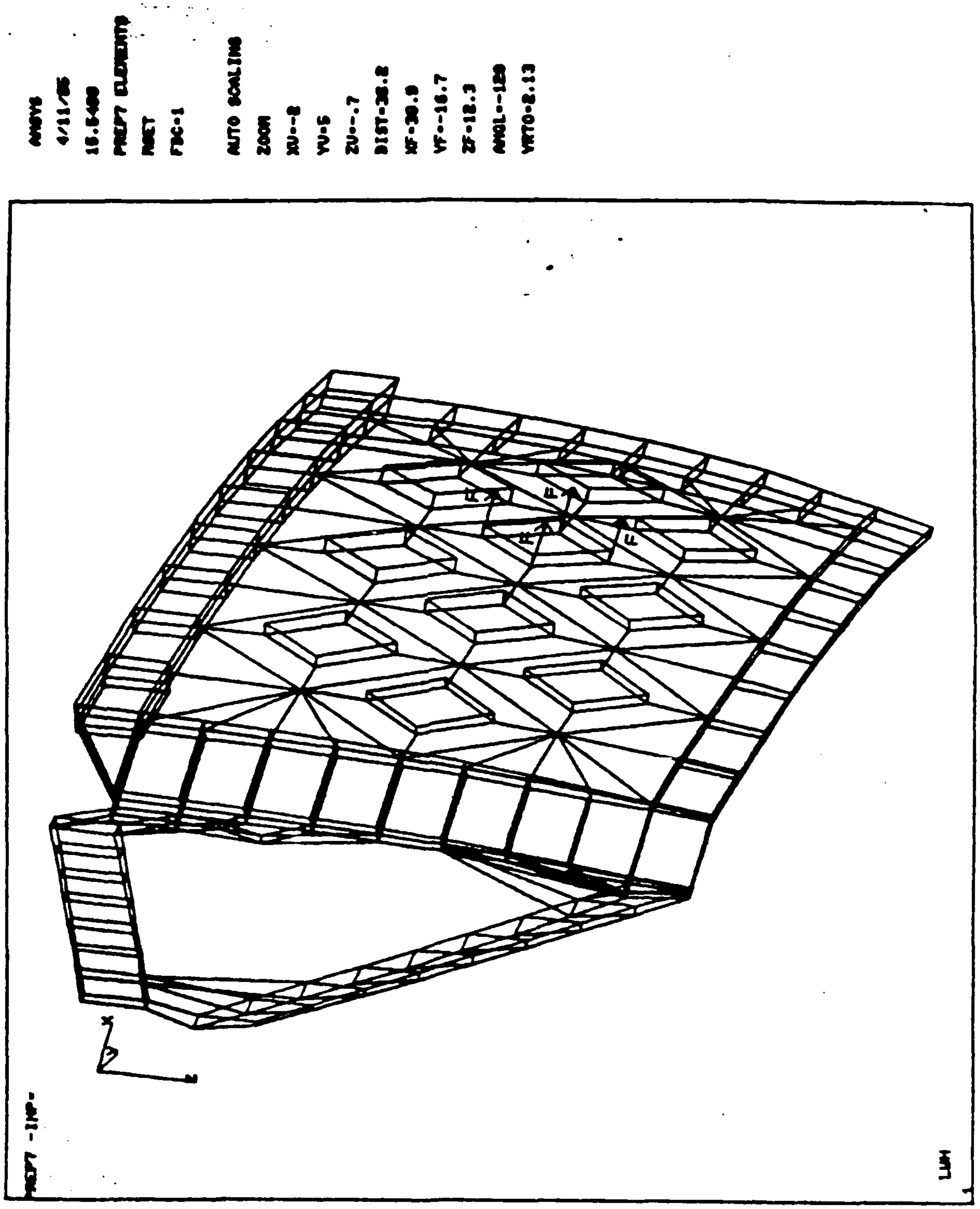


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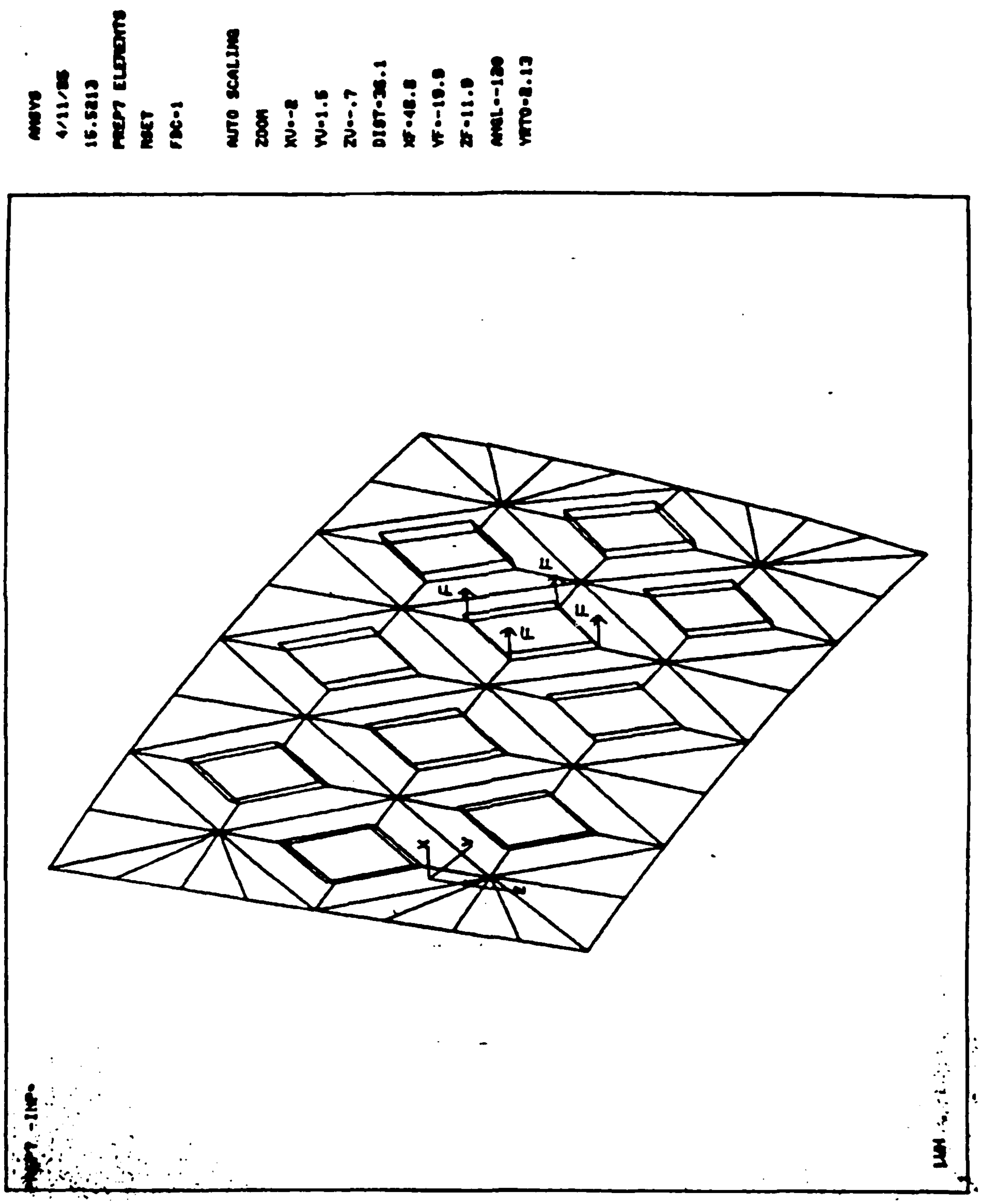
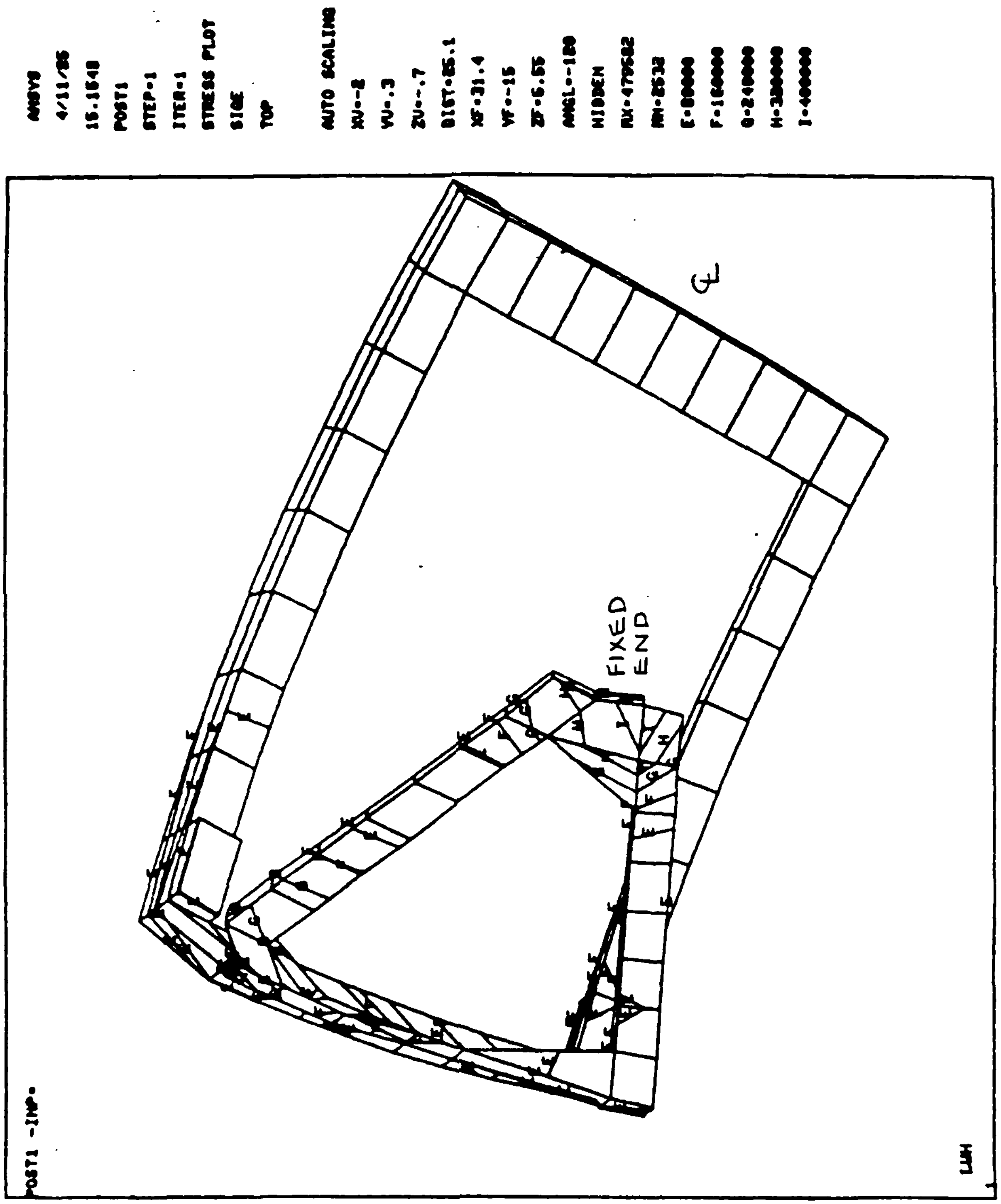



[redacted] [redacted]

10

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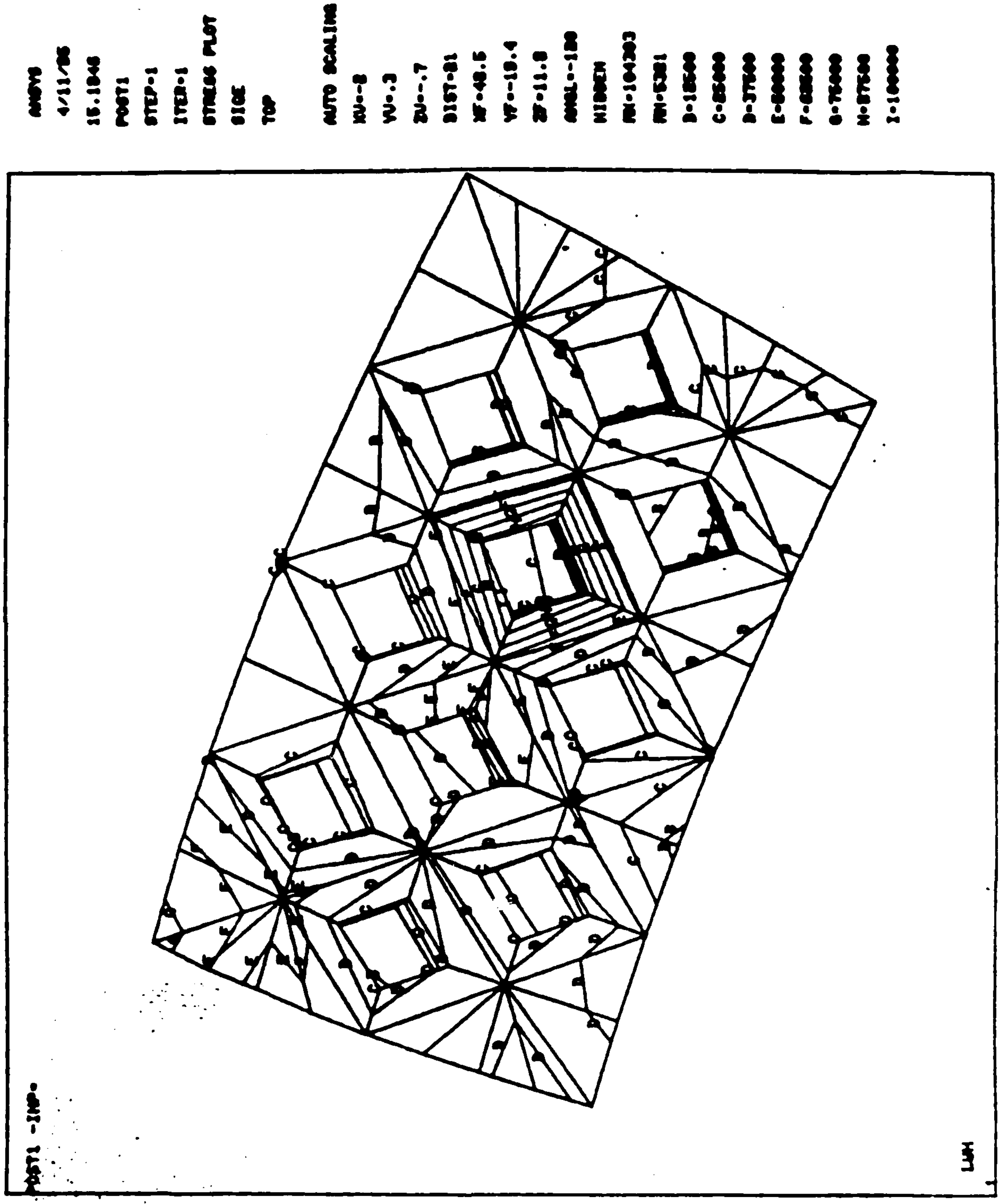


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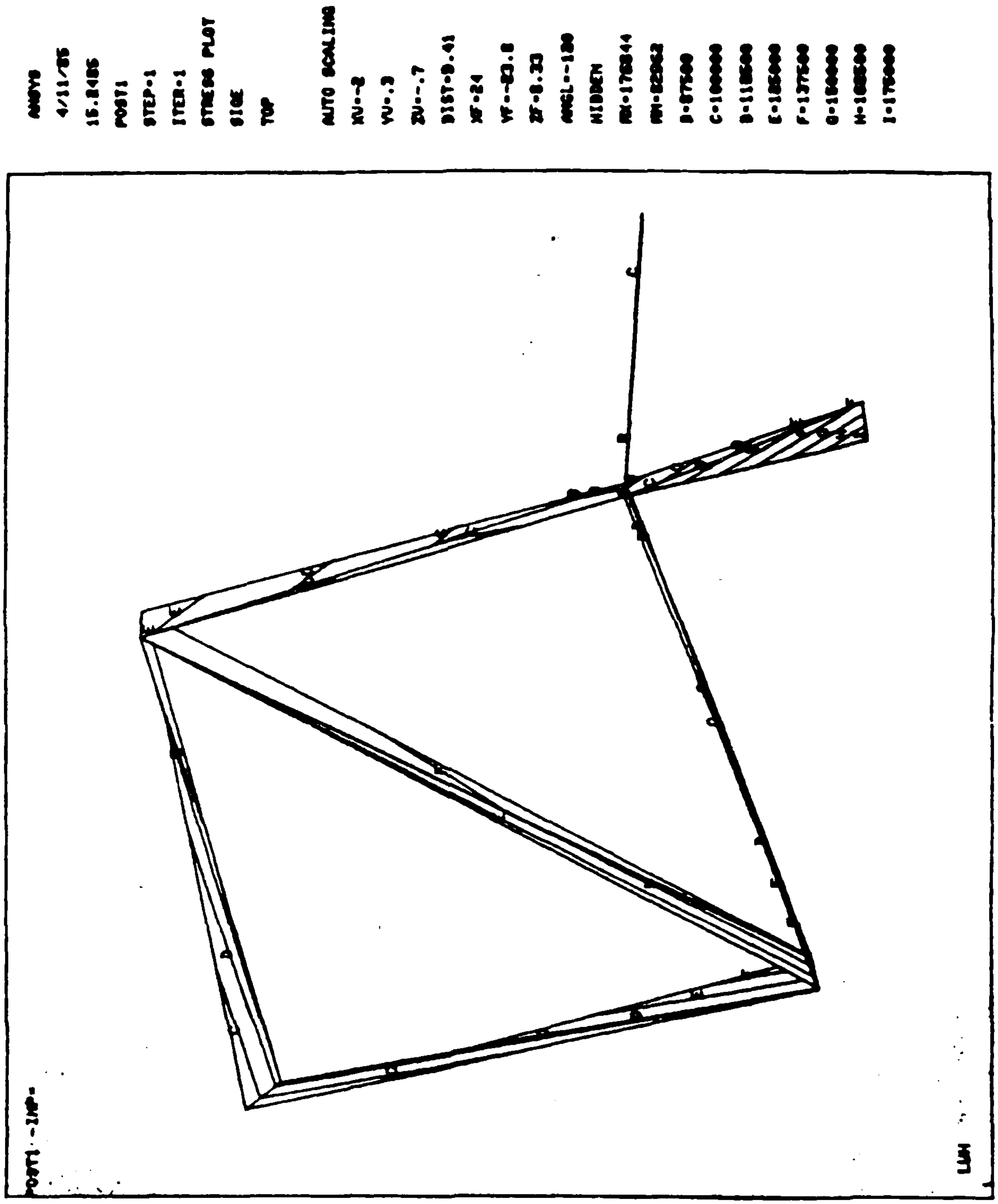
HT7-17

12




[redacted] [redacted]

[redacted]

PRSTR,1,8

PRINT ELEMENT STRESS ITEMS PER ELEMENT

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SDZ | SDY | SIG1 | SIG3 |
|---|---|---|---|---|---|
| 15 | 14885. | -184.87 | -6756.0 | 21767. | 7883.1 |
| 25 | -15700. | 3004.8 | 3580.6 | -8306.7 | -23276. |
| 38 | 8850.4 | -8864.8 | -10381. | 25430. | -8837.7 |
| 41 | -4034.7 | -1648.6 | -348.86 | -8003.3 | -5886.2 |
| 47 | -4028.0 | -428.69 | 15.118 | -3601.1 | -4466.7 |
| 48 | -10720. | 3810.9 | -734.25 | -6185.6 | -15274. |
| 49 | -20021. | 2082.8 | 3231.0 | -14707. | -25335. |
| 50 | 18123. | -2748.5 | -646.75 | 21511. | 14735. |
| 58 | -11581. | -832.88 | -2166.8 | -9180.9 | -13980. |
| 60 | -11679. | 3737.8 | -671.97 | -7160.5 | -15889. |
| 61 | -8328.6 | 3343.8 | -1767.2 | -3817.4 | -13440. |
| 64 | -2407.7 | -5083.3 | 613.35 | 3888.8 | -8104.3 |
| 65 | -11661. | 3375.4 | 7085.8 | -1190.6 | -22132. |
| 66 | 18806. | -3808.5 | 6249.0 | 23034. | 8768.9 |

MORE (YES,NO OR CONTINUOUS)=

C

[redacted]

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SDZ | SDY | SIG1 | SIG3 |
|---|---|---|---|---|---|
| 72 | -2413.8 | -2103.8 | -100.83 | -200.24 | -4627.4 |
| 74 | -868.87 | -4130.7 | 6030.1 | 9900.6 | -10446. |
| 75 | 18948. | 1741.7 | -4548.3 | 25238. | 12658. |
| 80 | 7455.3 | 12469. | 6349.7 | 26264. | -11364. |
| 81 | 8100.8 | 12891. | -8964.2 | 30118. | -13794. |
| 82 | -1942.1 | 6621.8 | 16620. | 21308. | -25193. |
| 83 | 3534.0 | 6456.4 | -17640. | 27630. | -20562. |
| 88 | 1443.5 | -3809.1 | 2618.7 | 7871.3 | -4984.3 |
| 94 | 1425.9 | 1888.9 | 13.412 | 3328.2 | -476.37 |
| 97 | 885.84 | -2233.0 | -6302.6 | 9221.4 | -7849.7 |
| 98 | 11482. | -7577.7 | -8549.1 | 27580. | -4664.4 |
| 103 | 2724.8 | 10634. | -3045.6 | 17804. | -11756. |
| 109 | 2751.5 | 1381.1 | -550.67 | 4593.3 | 809.72 |
| 118 | 10408. | 1868.2 | -41.215 | 18307. | 8608.5 |

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SDZ | SDY | SIG1 | SIG3 |
|---|---|---|---|---|---|
| 115 | 10488. | -[illegible] | -11.609 | 18790. | [illegible] |
| 116 | 11748. | -7183.4 | -840.87 | 18578. | 3813.5 |
| 117 | [illegible] | [illegible] | 806.53 | [illegible] | [illegible] |
| 118 | [illegible] | [illegible] | [illegible] | [illegible] | -23173. |
| 123 | 17887. | 44780. | -708.48 | [illegible] | -[illegible] |
| 124 | 15173. | -[illegible] | 555.88 | [illegible] | 7856.8 |
| 125 | -[illegible] | 8106.8 | -11000. | 11107. | -15111. |
| 126 | [illegible] | -1208.4 | -1881.6 | 24081. | 17581 |

1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SDZ | SDY | SIG1 | SIG3 |
|---|---|---|---|---|---|
| 154 | 8018.0 | 23067. | -6181.6 | 30858. | -26820. |
| 157 | 6060.1 | 13677. | 6176.1 | 26013. | -13483. |
| 158 | 11594. | 3317.6 | 643.06 | 15515. | 7672.5 |
| 160 | -6223.3 | -3558.8 | -2904.6 | 330.00 | -18777. |
| 165 | -6248.0 | 6081.1 | -120.53 | 768.65 | -13253. |
| 168 | 2106.1 | 2341.6 | 4010.5 | 16467. | -12086. |
| 172 | -21081. | -3062.8 | -6760.8 | -12187. | -31706. |
| 177 | -1000.8 | 10072. | -3070.5 | 14368. | -17768. |
| 179 | -1673.8 | 6175.3 | 193.84 | 4606.3 | -8043.0 |
| 185 | -13475. | -4068.8 | 86.810 | -8710.8 | -18840. |
| 187 | -13403. | 7074.3 | -819.43 | -6100.3 | -20707. |
| 191 | -10003. | 4330.0 | 182.38 | -15532. | -24454. |
| 192 | 11003. | 800.30 | 4860.5 | 16164. | 6001.0 |
| 193 | -10601. | 8401.8 | -6317.4 | -4781.6 | -34020. |

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SDZ | SDY | SIG1 | SIG3 |
|---|---|---|---|---|---|
| 194 | -13814. | 20448. | -604.96 | 15130. | -42767. |
| 196 | 3756.8 | 8002.8 | 128.59 | 11088. | -4374.6 |
| 200 | -7878.2 | -4345.0 | -3411.0 | -219.87 | -15733. |
| 201 | 4630.0 | -1832.8 | -121.71 | 6402.6 | 2585.0 |
| 203 | -23656. | 3041.6 | -476.74 | -10239. | -20073. |
| 208 | -23681. | 14403. | 300.15 | -8787.5 | -30624. |
| 213 | 3770.0 | 1774.4 | -122.00 | 6087.3 | 1874.3 |
| 218 | -37006. | -3046.6 | 2015.1 | -31046. | -43668. |
| 219 | -23736. | 2087.1 | -3305.1 | -17364. | -30108. |
| 226 | -17040. | 4140.3 | 143.08 | -13654. | -22224. |
| 228 | -13512. | 22451. | -4250.8 | 13190. | -40823. |
| 231 | -10380. | -2000.8 | 919.34 | -6411.0 | -14820. |
| 233 | 15006. | 190.19 | -6002.6 | 21400. | 2023.3 |
| 234 | -6318.1 | 2077.4 | 1601.4 | -1819.3 | -10017. |

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

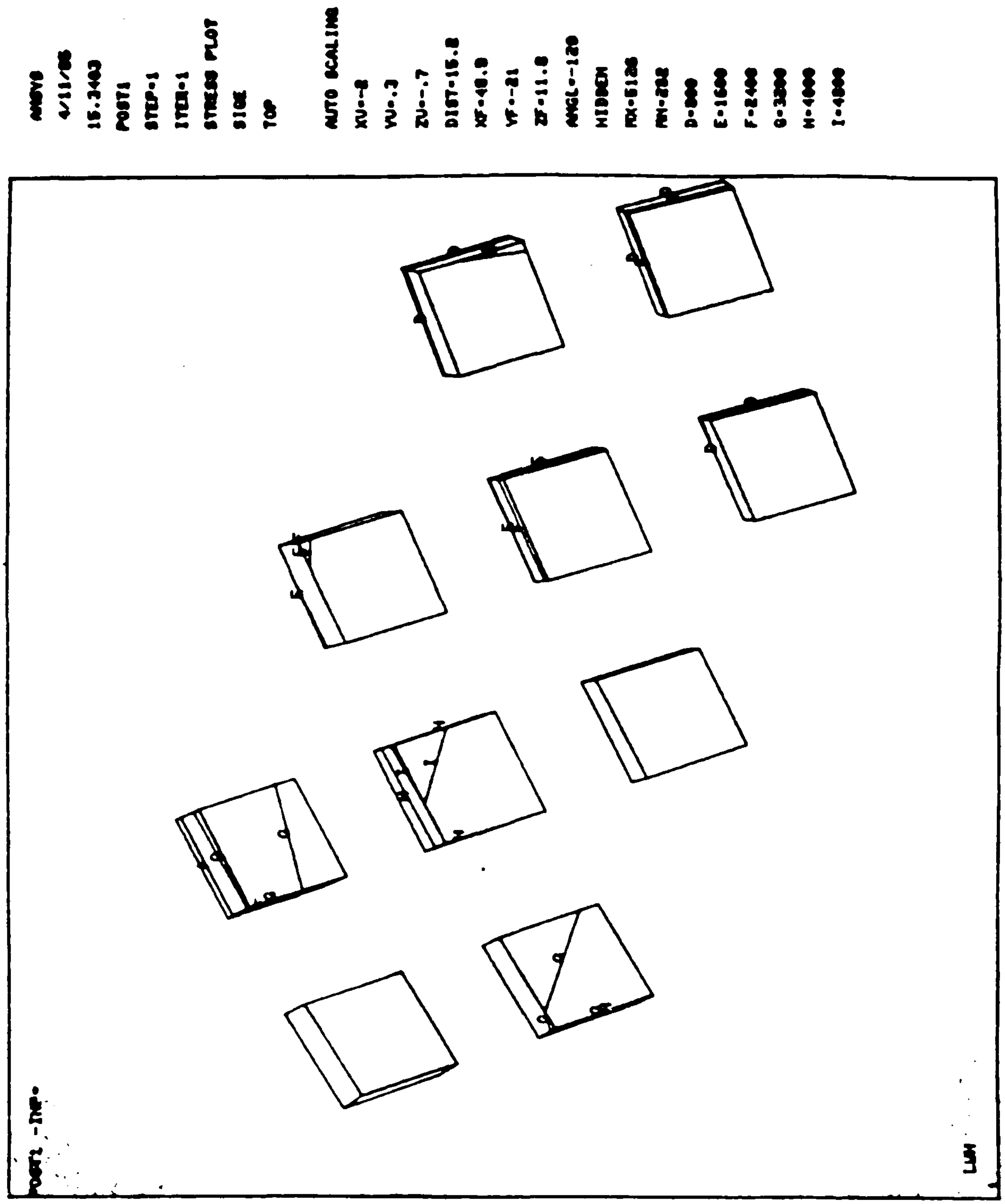
| ELEM | SDIR | SDZ | SDY | SIG1 | SIG3 |
|---|---|---|---|---|---|
| 236 | -17044. | 10490. | 105.31 | -7330.1 | -20549. |
| 238 | -10916. | 6040.8 | -482.60 | -4308.0 | -17430. |
| 244 | -8070.3 | 27060. | 2100.8 | 27060. | -38180. |
| 246 | -10082. | 18505. | | | |

[redacted]

H77-20

15

APPENDIX HT7 - B17

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HT7-21

APPENDIX HT7 - C1

**FMC Corporation**
**Central Engineering Laboratories**

**Interoffice**

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**To:** Bart Anderson
Northern Ordnance Division

**Date:** April 1, 1985

**From:** C.R. Ortloff

**cc:** R. Kazares
E. Thuse

**Subject:** Lightweight Howitzer Design

The design of a lightweight composite howitzer spade is accomplished by means of the following elements:

1. An outer "picture frame" structure (Figure 1) with an integral lattice network of beam elements. Additional beam elements (Figure 2) also provide structural stiffening to the side frame elements. All elements may be metal or composite material. in the latter case a straight, hollow, carbon fiber, filament wound structure (with a multiplicity of wind angles) and with a trapezoidal cross-section may be made and deformed into the configuration shown in Figure 1 before curing and bonding. Beam elements may be bonded into this structure.

2. A "waffle" plate (Figures 3, 4) of multiple layers of cross-oriented carbon fiber woven roving bonded by a suitable epoxy. This plate is inserted into the inside of the picture frame and fits over the beam lattice network.

3. Chopped fiber reinforced urethane plugs (Figure 5). This material (Figure 3) is poured into the box depressions and channels of the waffle plate to bond the bar elements to the carbon fiber waffle plate so that the waffle plate, bar elements and outer picture frame act as an integral structural unit under load.

4. Bonded cover plates. These plates cover the inner and outer surfaces of the waffle plate and provide scuff resistance. These plates may be a few layers of Kevlar.

The net configuration of the space is shown in Figures 6, 7 and 8 (with the outer covering plates removed).

The presence of a metal lower edge to prevent scuffing of the composite lower edge upon spade ground entry (during firing) is a point of later design consideration. The design of the pin connection ends are omitted for purposes of this survey.

The next questions to be answered are:

1. Does the design presented have the capability to withstand impulsive pressure loading (Figure 9) on its inner concave face without failure?

[redacted] [redacted]

Bart Anderson April 1, 1985

2. Can the proposed design withstand edge loading of 60,000 lbf from gun-firing spade seating without structural failure?

3. Can the above be achieved for a total composite spade structural weight less than 200 lb?

Results of static loading to 65,000 lbf/normal area of spade are shown in Figures 9 to 17. For a total weight of 148.5 lb (Figure 9), SIGE stresses in the carbon fiber wound frame are less than the ultimate stress of the carbon fiber matrix (>150 ksi tensile) while stresses in the carbon fiber woven roven waffle plate (Figure 11) is less than 16 ksi. Stresses in the urethane filler plugs (Figure 12) are less than the material ultimate stress of 7 ksi. Stress in elements of the inner cover sheet (Figure 13) are far less than design ultimate stress. Stress in the bar network (element numbers, Figure 14) are listed in Figure 15. These stresses are far lower than the failure stress. Deflections in the frame center line are about 1.5 inches (Figure 16) while maximum waffle plate deflections are on the same order (Figure 17). Property tables for materials are given in Figure 18 while reals are given in Figure 19. The material and real numbers are given in Figure 2, 3, and 5. The reals follow the same number code as the material number code except for real constant set 2 for which the listing represent Area, IXX, IZZ, hX and hZ where hX represents the distance from beam neutral axis to outer fiber for example.

Results from an edge loading case (30,000 lbf on the lower half-section edge at 72° to the horizontal, top edge fixed) indicate adequate margins of safety in SIGE (Figure 20) in the spade area. Figure 21 indicates adequate waffle plate margins of safety in stress. Figure 22 and 23 indicate that the bar lattice stresses are low (less than 2 ksi) for the 0.5 X 0.5 inch bars. Deflections (Figures 24 and 25) are likewise low in both X and Z directions. Dimensions of the composite spade are contained in ANSYS file DVA1:[ORTLOFF.ABX]LWH.F16;1 on storage at CEL.

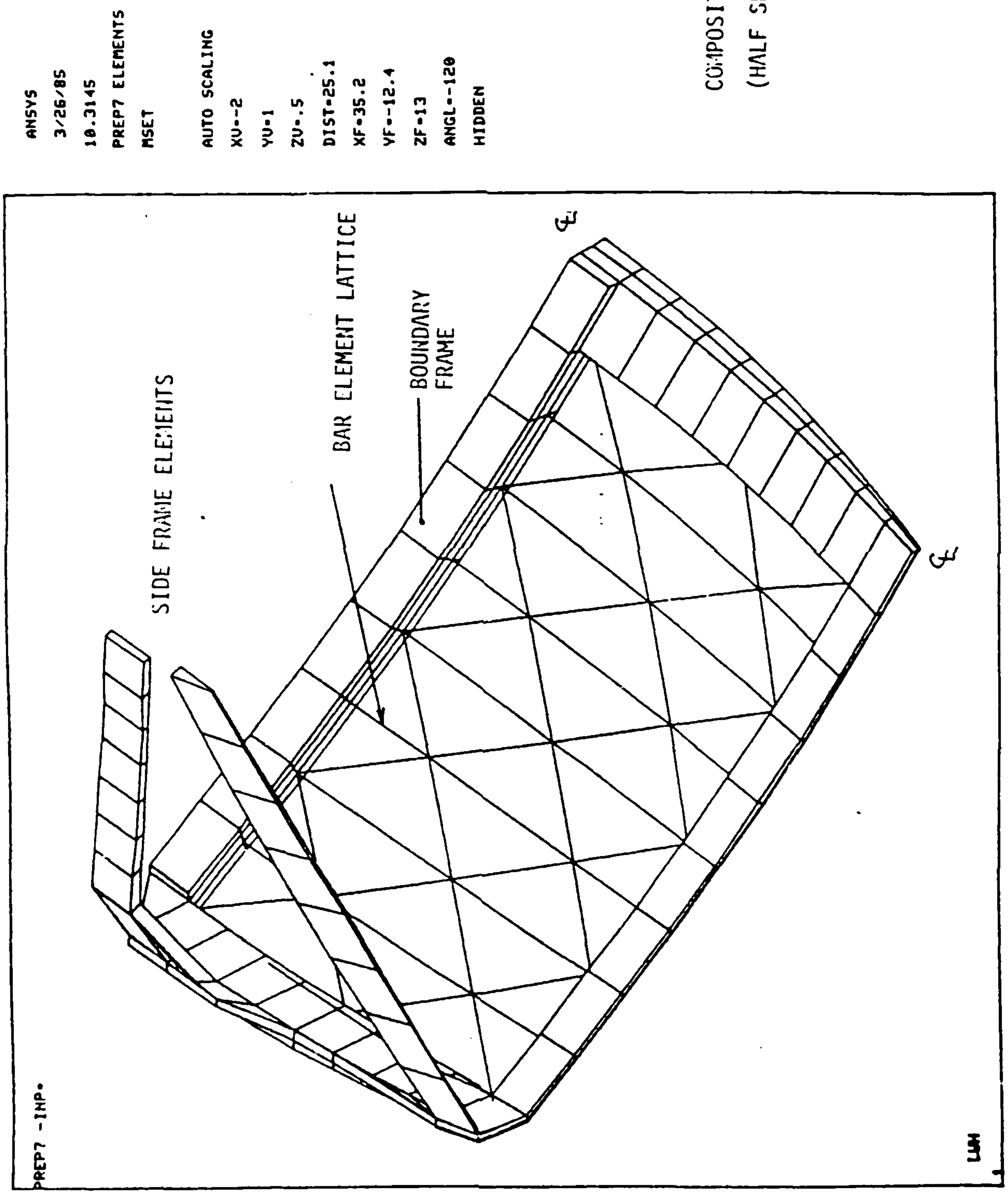
In total, the low weight of 148.5 lb indicates that additional part strengthening can be made resulting in lower stress levels. The spade to side frame element joining regions are the sources of high stress and can be redesigned to lower the stress level and still keep within the upper weight margin. The feasibility of the composite spade has therefore been demonstrated; optimization of the design will await formal contract award.

CROrtloff

C. R. Ortloff

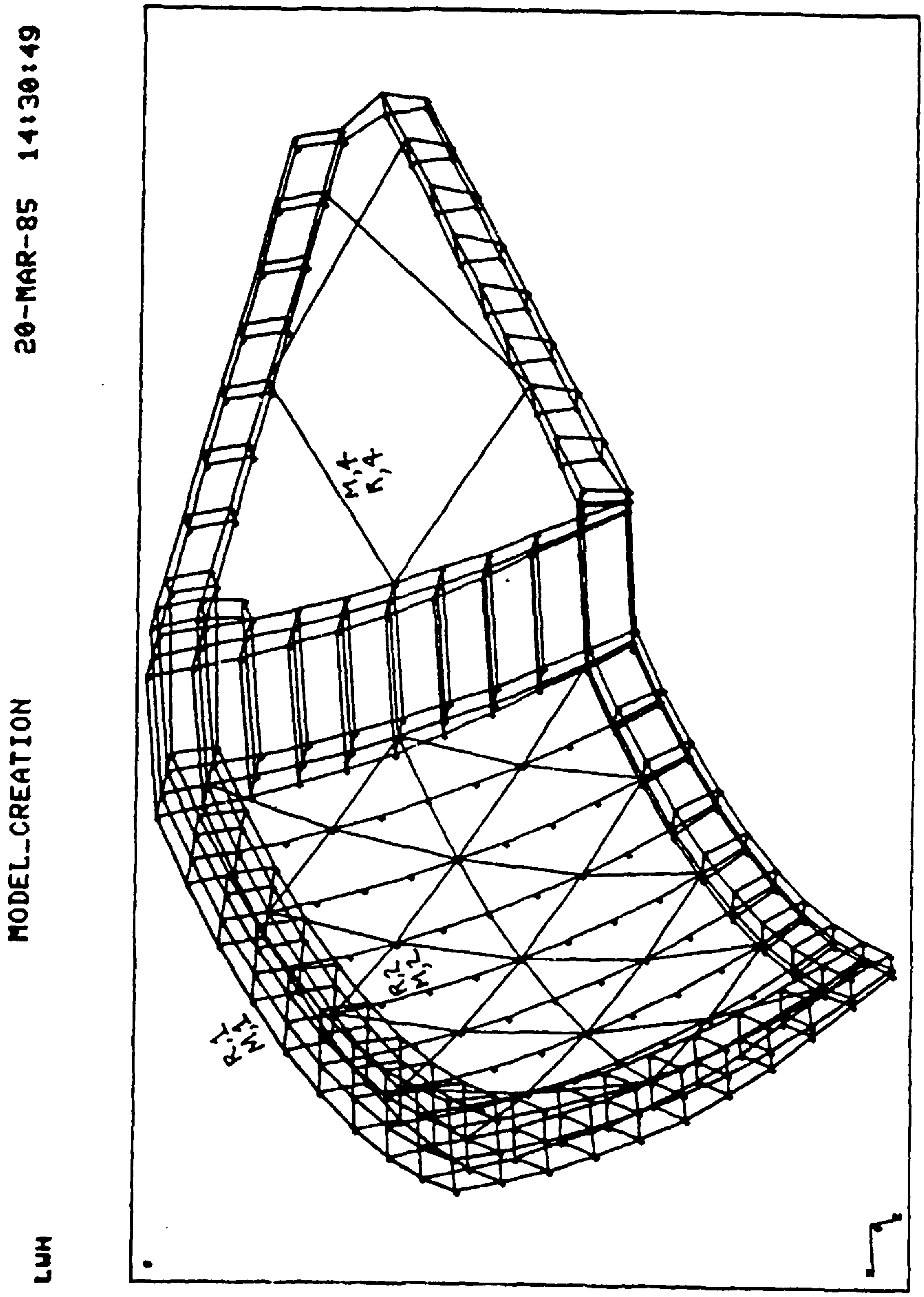
ja

[redacted] [redacted]



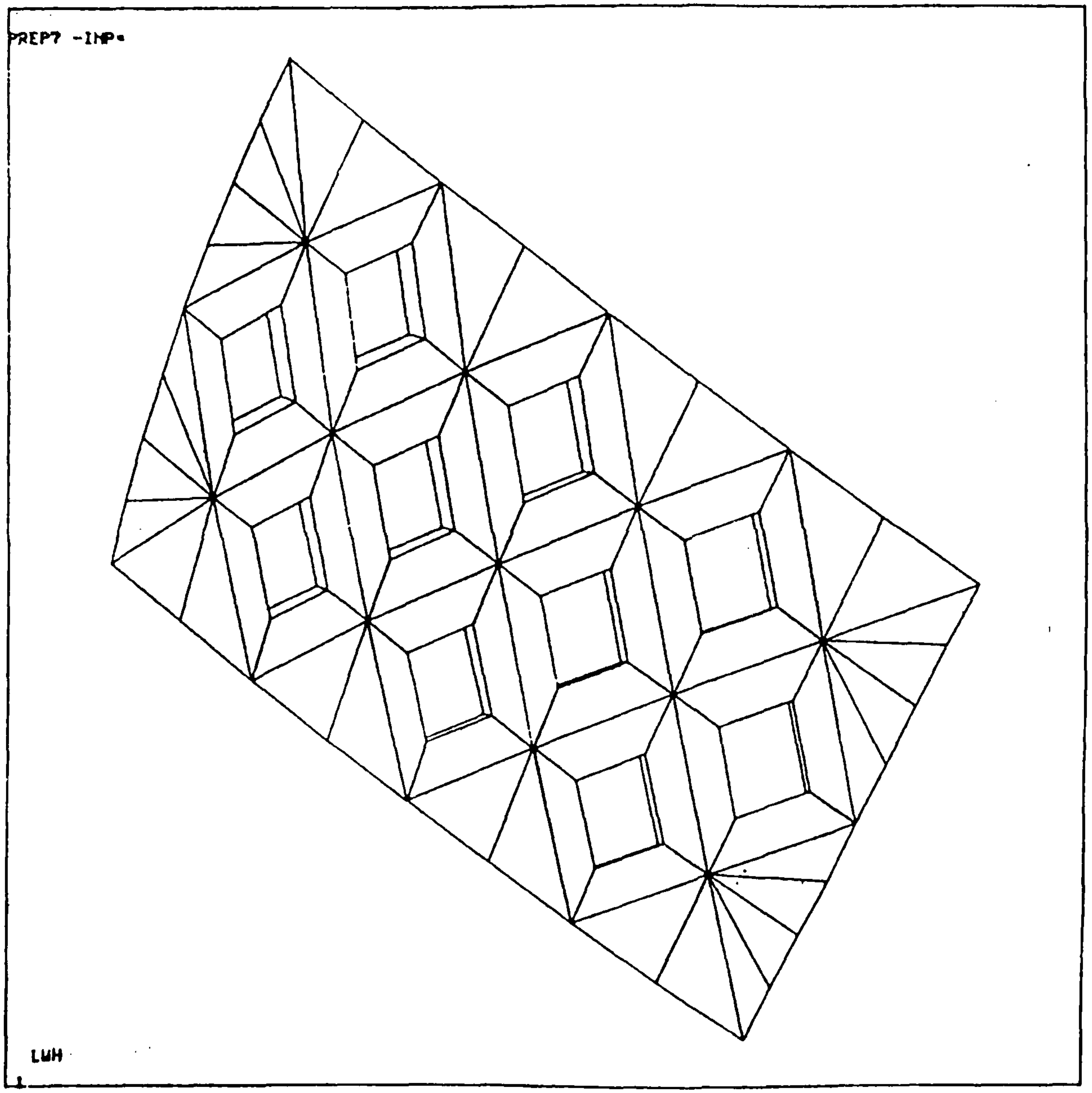

COMPOSITE SPADE
(HALF SECTION)

[redacted]




SCHEMATIC OF THE COMPOSITE SPADE DESIGN

[redacted]




ANSYS
3/26/85
9.5165
PREP7 ELEMENTS
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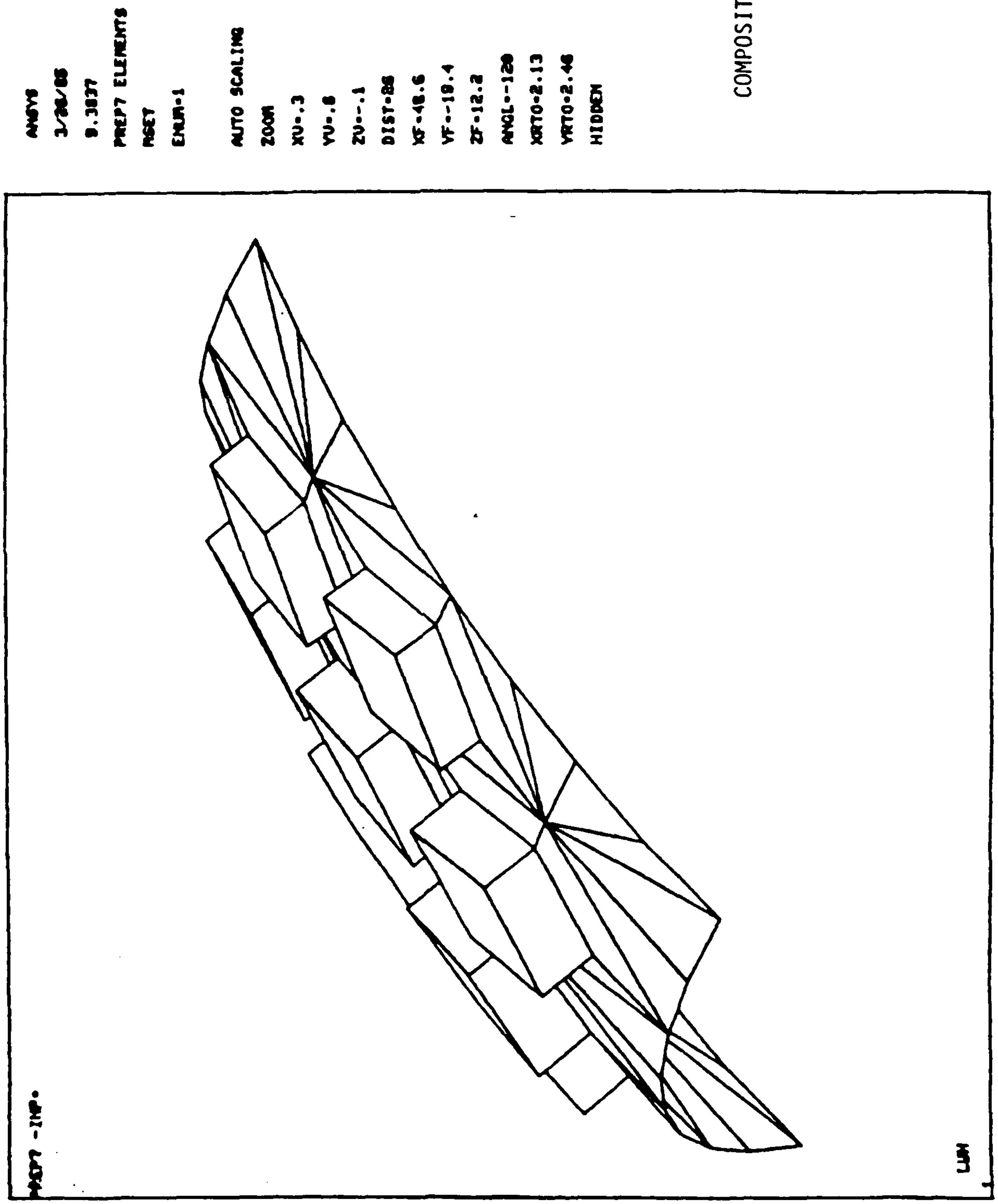
NNUM=1

AUTO SCALING
ZOOM
XV=-3
YV=.2
ZV=.4
DIST=46.1
XF=48
YF=-19.5
ZF=11.5
ANGL=-120
XRTO=2.13
YRTO=2.46
HIDDEN

COMPOSITE WAFFLE PLATE
M,3
R,3

[redacted]

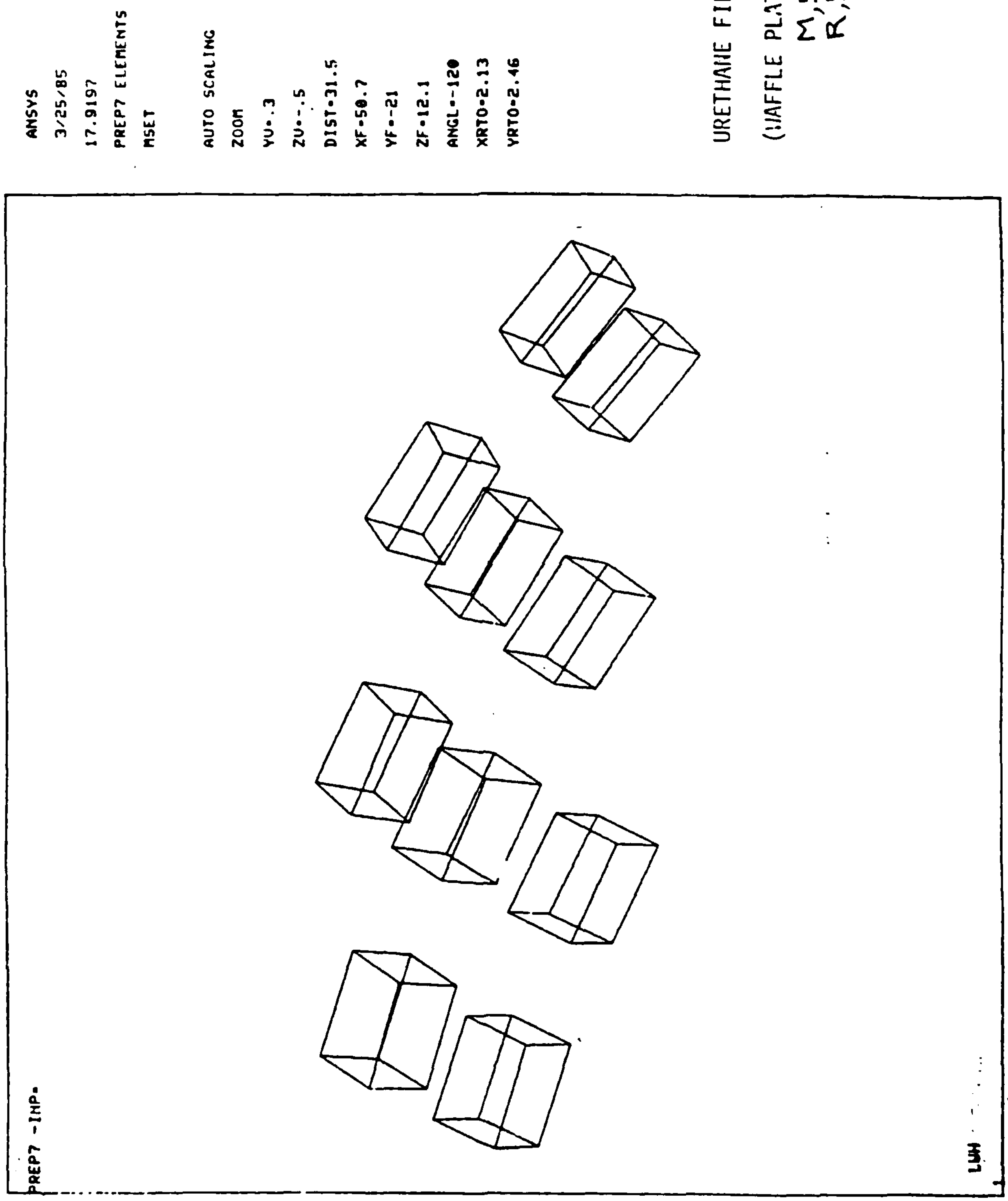
[redacted]




COMPOSITE WAFFLE PLATE

M,3
R,3

[redacted]




URETHANE FILLER PLUGS

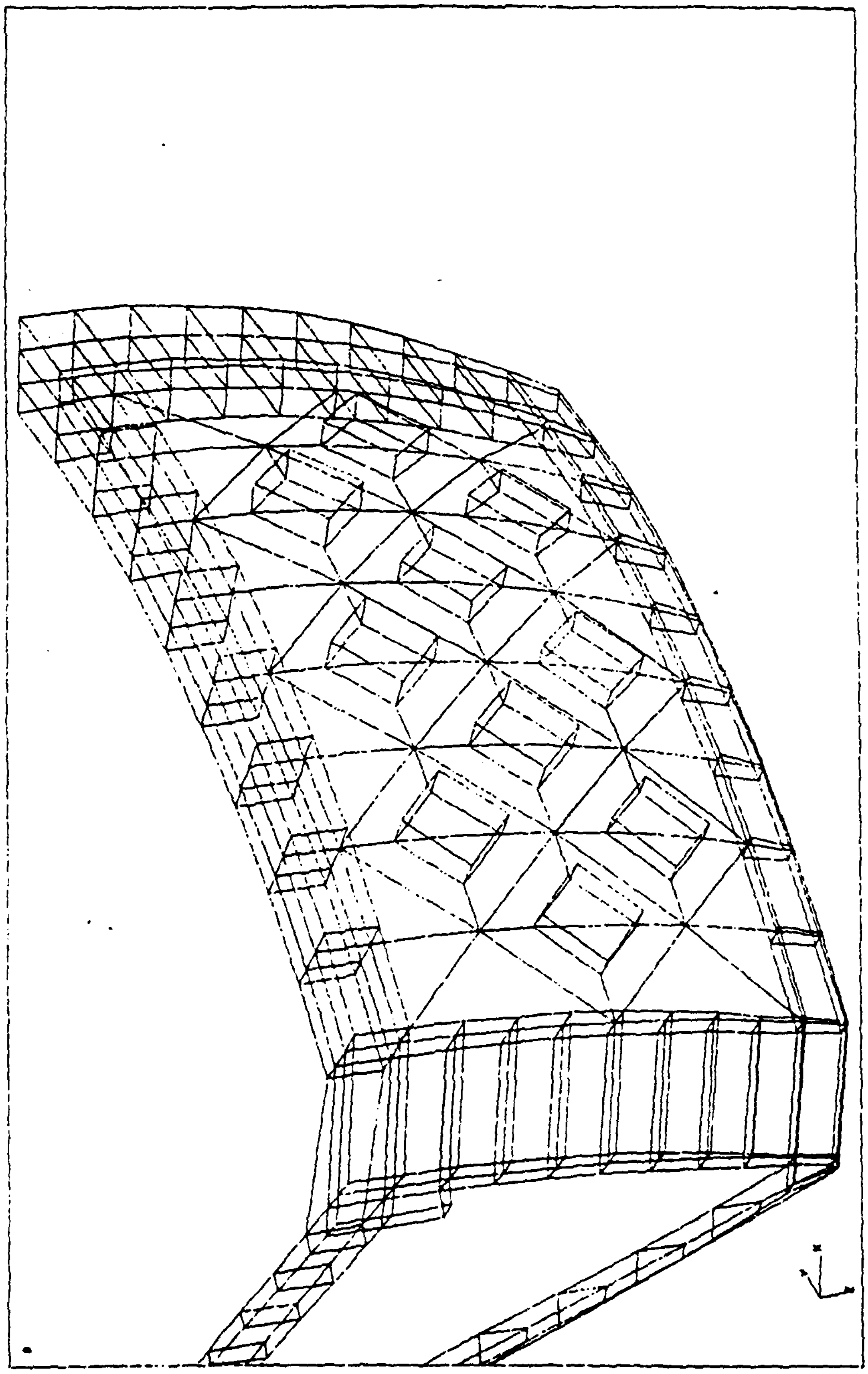
(WAFFLE PLATE INSERTS)

M,5
R,5

[redacted] [redacted]

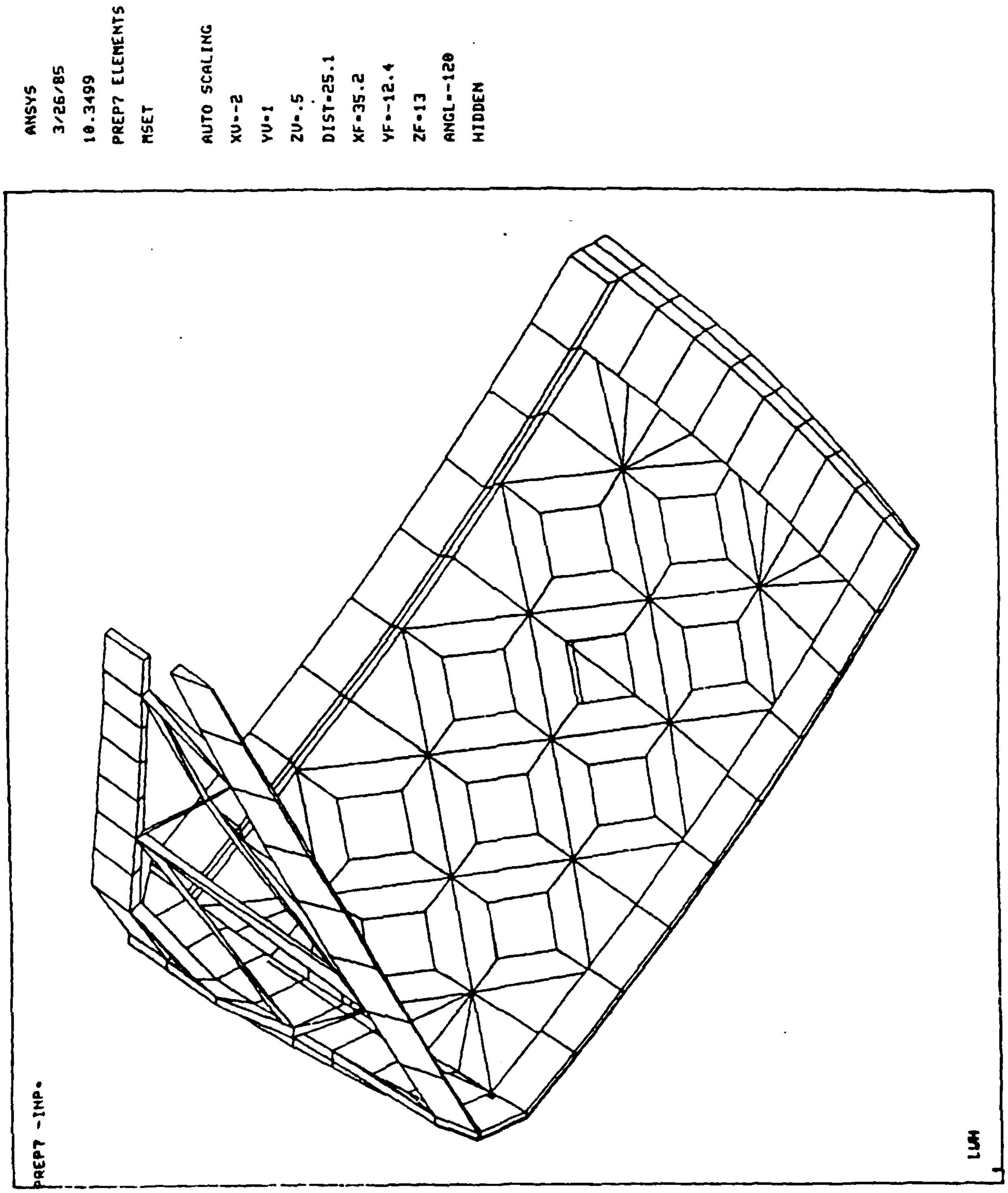
MODEL_CREATION 21-MAR-85 08:58:59

LWH



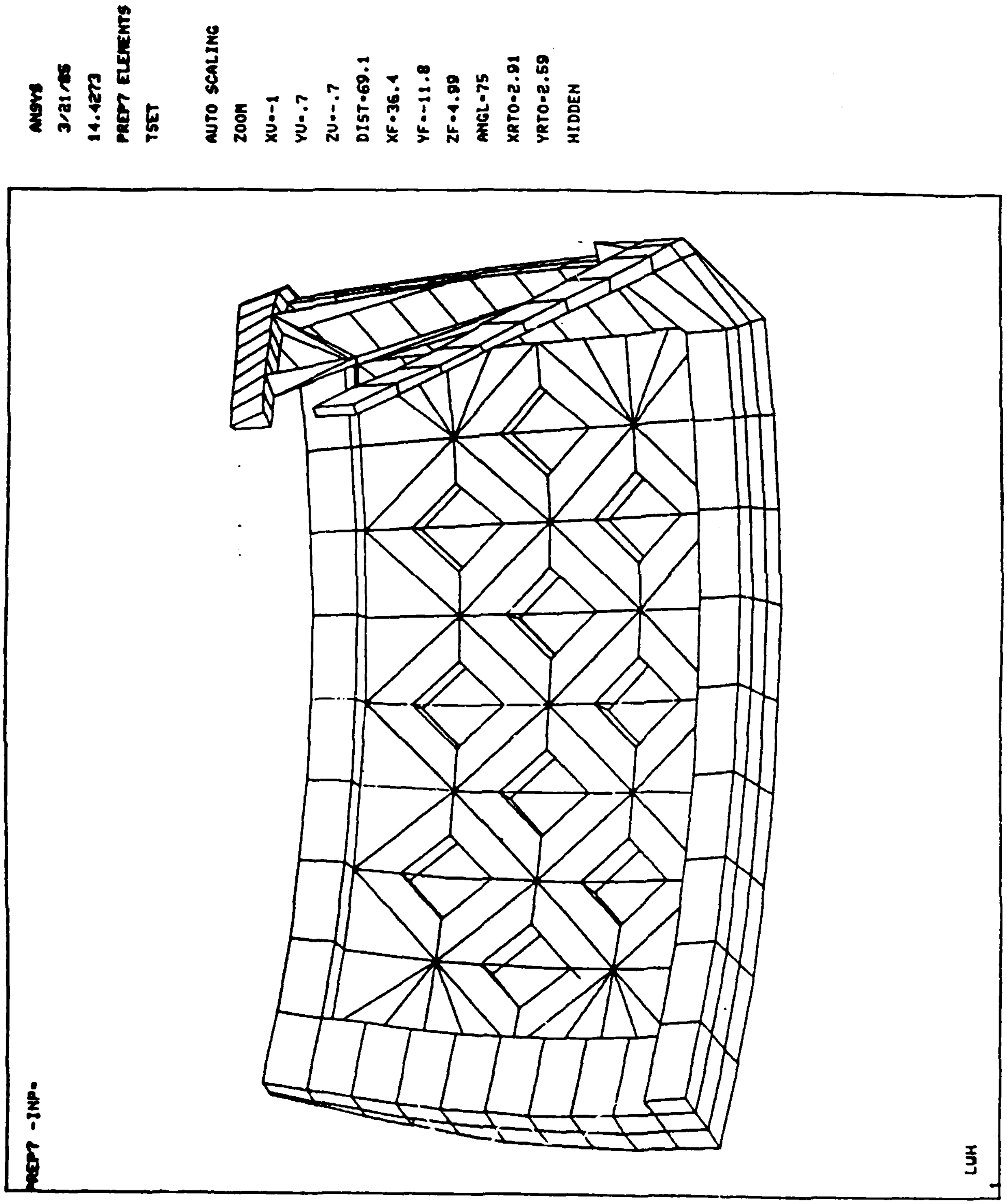
ASSEMBLED VIEW OF THE COMPOSITE LIGHTWEIGHT HOWITZER SPADE

[redacted] [redacted]




HIDDEN LINE VIEW OF THE COMPOSITE SPADE
(COVER PLATE REMOVED)

[redacted] [redacted]



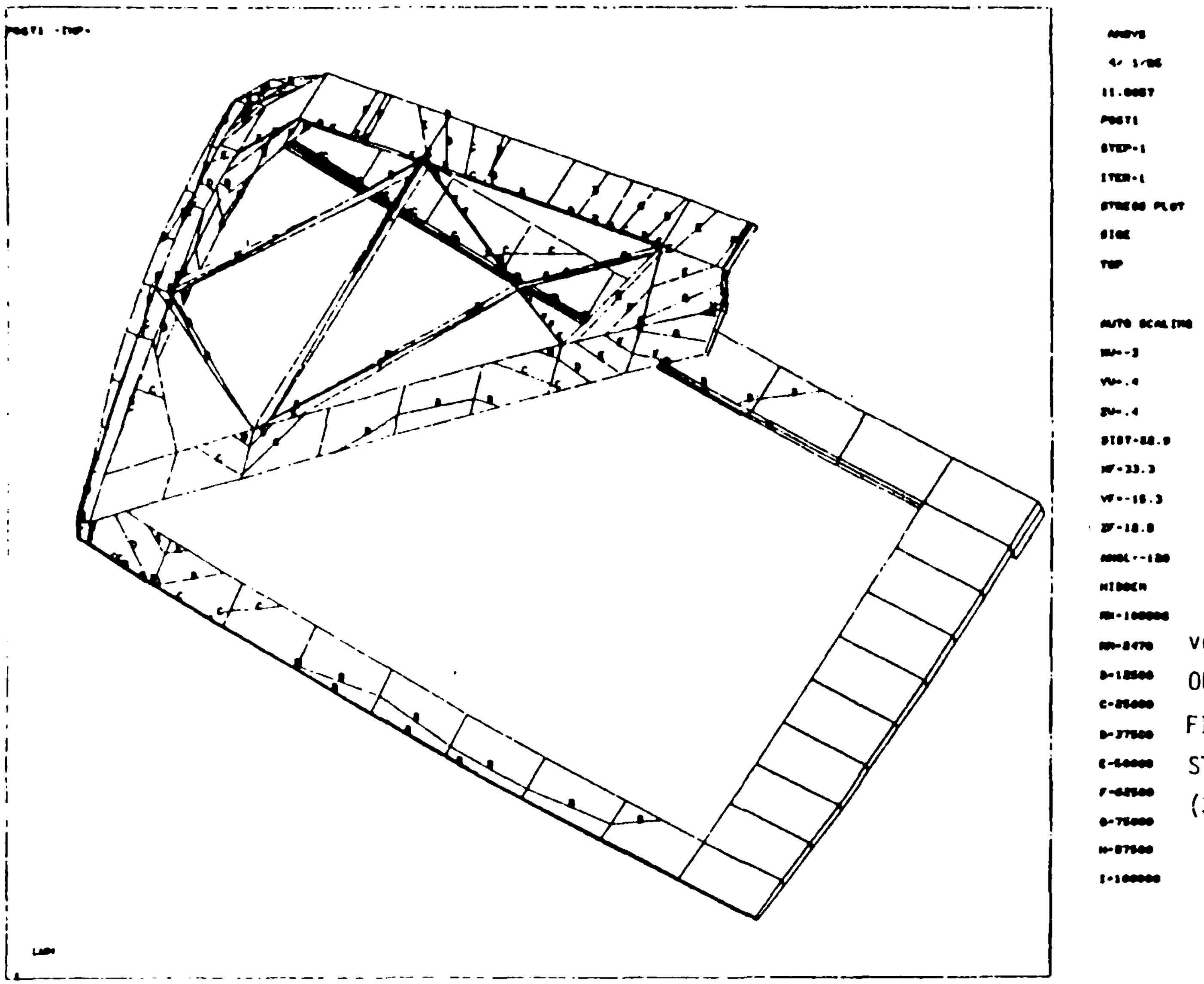

HIDDEN LINE VIEW OF THE COMPOSITE SPADE

[redacted] [redacted]

```
381 L.S.=   1 ITER=    1 CP= 384.000
ELEMENT FORMATION    ELEM= 385 L.S.=   1 ITER=    1 CP= 384.370

      ***** CENTROID, MASS, AND MASS MOMENTS OF INERTIA *****
 CALCULATIONS ASSUME ELEMENT MASS AT ELEMENT CENTROID
 TOTAL MASS = 0.10016 (148.5 lb)
                          MOM. OF INERTIA       MOM. OF INERTIA
   CENTROID                ABOUT ORIGIN          ABOUT CENTROID
 XC =   40.077          IXX =   137.7         IXX =   80.07
 YC =  -81.864          IYY =   466.8         IYY =   87.62
 ZC =   10.070          IZZ =   647.8         IZZ =   30.86
                        IXY =   184.8         IXY =   -8.400
                        IYZ =    41.68        IYZ =   -0.1800
                        IZX =   -80.86        IZX =    0.3874

 *** MASS SUMMARY BY ELEMENT TYPE ***
 TYPE       MASS
   1   0.140064
   2   0.8500870E-02
   3   0.2473812E-01
   4   0.4860860E-02
   5   0.4300800E-02

 RANGE OF ELEMENT MAXIMUM STIFFNESS IN GLOBAL COORDINATES

 MAXIMUM= 0.1000180E+11  AT ELEMENT    337.
 MINIMUM= 0.6896000E+06  AT ELEMENT     80.

  *** ELEMENT STIFFNESS FORMULATION TIMES
 TYPE  NUMBER  STIF   TOTAL CP   AVE CP
   1      90     46   104.400    1.863
   2      87      4     8.570    0.000
   3     142     63   132.270    1.082
   4      14     63     6.710    0.470
   5      10     63    13.800    1.388

 TIME AT END OF ELEMENT STIFFNESS FORMULATION  CP=    368.800

 MAXIMUM IN-CORE WAVE FRONT ALLOWED FOR REQUESTED MEMORY SIZE=  579.
 EQUATION SOLUTION     ELEM=  15  L.S.=   1  ITER=   1  CP=  370.000
 EQUATION SOLUTION     ELEM=  37  L.S.=   1  ITER=   1  CP=  376.780
 EQUATION SOLUTION     ELEM=  64  L.S.=   1  ITER=   1  CP=  384.300
 EQUATION SOLUTION     ELEM=  80  L.S.=   1  ITER=   1  CP=  388.600
 EQUATION SOLUTION     ELEM=  86  L.S.=   1  ITER=   1  CP=  390.310
 EQUATION SOLUTION     ELEM= 100  L.S.=   1  ITER=   1  CP=  400.830
 EQUATION SOLUTION     ELEM= 118  L.S.=   1  ITER=   1  CP=  414.300
 EQUATION SOLUTION     ELEM= 137  L.S.=   1  ITER=   1  CP=  431.070
 EQUATION SOLUTION     ELEM= 139  L.S.=   1  ITER=   1  CP=  438.880
 EQUATION SOLUTION     ELEM= 142  L.S.=   1  ITER=   1  CP=  473.310
 EQUATION SOLUTION     ELEM= 147  L.S.=   1  ITER=   1  CP=  440.830
 EQUATION SOLUTION     ELEM= 167  L.S.=   1  ITER=   1  CP=  449.670
 EQUATION SOLUTION     ELEM= 181  L.S.=   1  ITER=   1  CP=  460.560
 EQUATION SOLUTION     ELEM= 184  L.S.=   1  ITER=   1  CP=  466.430
 EQUATION SOLUTION     ELEM= 190  L.S.=   1  ITER=   1  CP=  467.190
 EQUATION SOLUTION     ELEM= 200  L.S.=   1  ITER=   1  CP=  470.730
 EQUATION SOLUTION     ELEM= 210  L.S.=   1  ITER=   1  CP=  479.600
 EQUATION SOLUTION     ELEM= 213  L.S.=   1  ITER=   1  CP=  486.800
 EQUATION SOLUTION     ELEM= 218  L.S.=   1  ITER=   1  CP=  497.060
 EQUATION SOLUTION     ELEM= 237  L.S.=   1  ITER=   1  CP=  499.430
 EQUATION SOLUTION     ELEM= 240  L.S.=   1  ITER=   1  CP=  500.800
 EQUATION SOLUTION     ELEM= 256  L.S.=   1  ITER=   1  CP=  516.800
 EQUATION SOLUTION     ELEM= 264  L.S.=   1  ITER=   1  CP=  521.760
 EQUATION SOLUTION     ELEM= 274  L.S.=   1  ITER=   1  CP=  528.050
 EQUATION SOLUTION     ELEM= 286  L.S.=   1  ITER=   1  CP=  533.800
 EQUATION SOLUTION     ELEM= 287  L.S.=   1  ITER=   1  CP=  538.760
 EQUATION SOLUTION     ELEM= 290  L.S.=   1  ITER=   1  CP=  540.680
 EQUATION SOLUTION     ELEM= 298  L.S.=   1  ITER=   1  CP=  546.780
 EQUATION SOLUTION     ELEM= 303  L.S.=   1  ITER=   1  CP=  558.150
 EQUATION SOLUTION     ELEM= 304  L.S.=   1  ITER=   1  CP=  564.640
 EQUATION SOLUTION     ELEM= 312  L.S.=   1  ITER=   1  CP=  566.730
 EQUATION SOLUTION     ELEM= 325  L.S.=   1  ITER=   1  CP=  568.180
 EQUATION SOLUTION     ELEM= 338  L.S.=   1  ITER=   1  CP=  578.300
 EQUATION SOLUTION     ELEM= 347  L.S.=   1  ITER=   1  CP=  577.840
 EQUATION SOLUTION     ELEM= 349  L.S.=   1  ITER=   1  CP=  578.740

 MAXIMUM IN-CORE WAVE FRONT=    180.

     MATRIX SOLUTION TIMES
 READ IN ELEMENT STIFFNESSES    CP=      13.380

 NODAL COORD. TRANSFORMATION    CP=       0.000
 MATRIX TRIANGULARIZATION       CP=     180.070

 TIME AT END OF MATRIX TRIANGULARIZATION  CP=     588.400

 TIME AT START OF BACK SUBSTITUTION   CP=  588.530     LOAD STEP=   1  ITERAT
ION=    1  CUM. ITER.=   1

 ***** DISPLACEMENT SOLUTION *****  TIME =  0.00000E+00  LOAD STEP=   1  ITERAT
ION=    1  CUM. ITER.=   1
   NODE       UX             UY           UZ             ROTX           RO
TY             ROTZ
   268    -1.[illegible]    0.35645     -1.[illegible]
   269    -1.[illegible]    0.33061     -1.13870
   270    -1.17[illegible]  0.[illegible]  -1.01[illegible]
   271    -0.[illegible]    0.[illegible]  -0.[illegible]
   272    -0.[illegible]    0.13578     -0.785540
   273    -0.101160         0.01770     -0.640631
   274     0.183430         1.87700     -0.516461
   275     0.400004         1.71013     -0.380711
   276     0.570040         1.[illegible]  -0.[illegible]
   277     0.[illegible]     1.[illegible]  -0.148570
   278    -1.85810          0.41818     -1.84018
   279    -1.40[illegible]  0.[illegible]  -1.13100      -0.[illegible]E-01   0.1112
64E-01     0.7063772E-01
   280    -1.14004          0.35[illegible]  -1.01100    -0.[illegible]E-01   0.[illegible]
81E-02     0.7940[illegible]E-01
   281    -0.[illegible]    0.[illegible]  -0.[illegible]  -0.[illegible]E-01   0.[illegible]
54E-02     0.7007[illegible]E-01
   282    -0.400018         0.18040     -0.785130     -0.[illegible]E-01   0.1067
11E-01     0.7004[illegible]E-01
   283    -0.143400         0.07201     -0.640311     -0.[illegible]E-01   0.1133
06E-01     0.7084[illegible]E-01
   284     0.153871         1.53101     -0.515130     -0.[illegible]E-01   0.1388
01E-01     0.7510[illegible]E-01
   285     0.460113         1.70[illegible]  -0.380471  -0.[illegible]E-01   0.1388
30E-01     0.7883[illegible]E-01
   286     0.714840         1.[illegible]  -0.[illegible]  -0.[illegible]E-01   0.1[illegible]
10E-01     0.[illegible]E-01
   287     0.[illegible]     1.40435     -0.140483     -0.[illegible]E-01   0.1087
63E-01     0.[illegible]E-01
   288    -1.[illegible]    0.[illegible]  -1.84701
   289    -1.47047          0.45170     -1.13837      -0.[illegible]E-01   0.1076
01E-01     0.7807[illegible]E-01
   290    -1.18001          0.41000     -1.01086      -0.[illegible]E-01   0.1018
03E-01     0.[illegible]E-01
   291    -0.780304         0.34187     -0.[illegible]  -0.[illegible]E-01   0.1064
78E-01     0.7941[illegible]E-01
   292    -0.448181         0.[illegible]  -0.784040  -0.[illegible]E-01   0.1127
74E-01     0.7876[illegible]E-01
   293    -0.117877         0.18[illegible]  -0.640[illegible]  -0.[illegible]E-01   0.1[illegible]
53E-01     0.7761[illegible]E-01
   294     0.181[illegible]  1.[illegible]  -0.515[illegible]  -0.[illegible]E-01   0.13[illegible]
83E-01     0.7587178E-01
   295     0.480183         1.08116     -0.380530     -0.[illegible]E-01   0.1516
81E-01     0.7304[illegible]E-01
   296     0.74[illegible]   1.84000     -0.[illegible]  -0.[illegible]E-01   0.1[illegible]
06E-01     0.7158[illegible]E-01
   297     0.[illegible]     1.44[illegible]  -0.148[illegible]  -0.[illegible]E-01   0.[illegible]
87E-01     0.7161[illegible]E-01
   298    -1.79[illegible]  0.[illegible]  -1.84311
   299    -1.44[illegible]  0.4[illegible]  -1.18783   -0.[illegible]E-01   0.1004
84E-01     0.78[illegible]E-01
   300    -1.16[illegible]  0.44010     -1.0[illegible]  -0.[illegible]E-01   0.1048
80E-01     0.7015[illegible]E-01
   301    -0.750[illegible]  0.3[illegible]  -0.[illegible]  -0.[illegible]E-01   0.1107
81E-01     0.7076[illegible]E-01
   302    -0.421440         0.[illegible]  -0.783004   -0.[illegible]E-01   0.1[illegible]
47E-01     0.7847[illegible]E-01
```

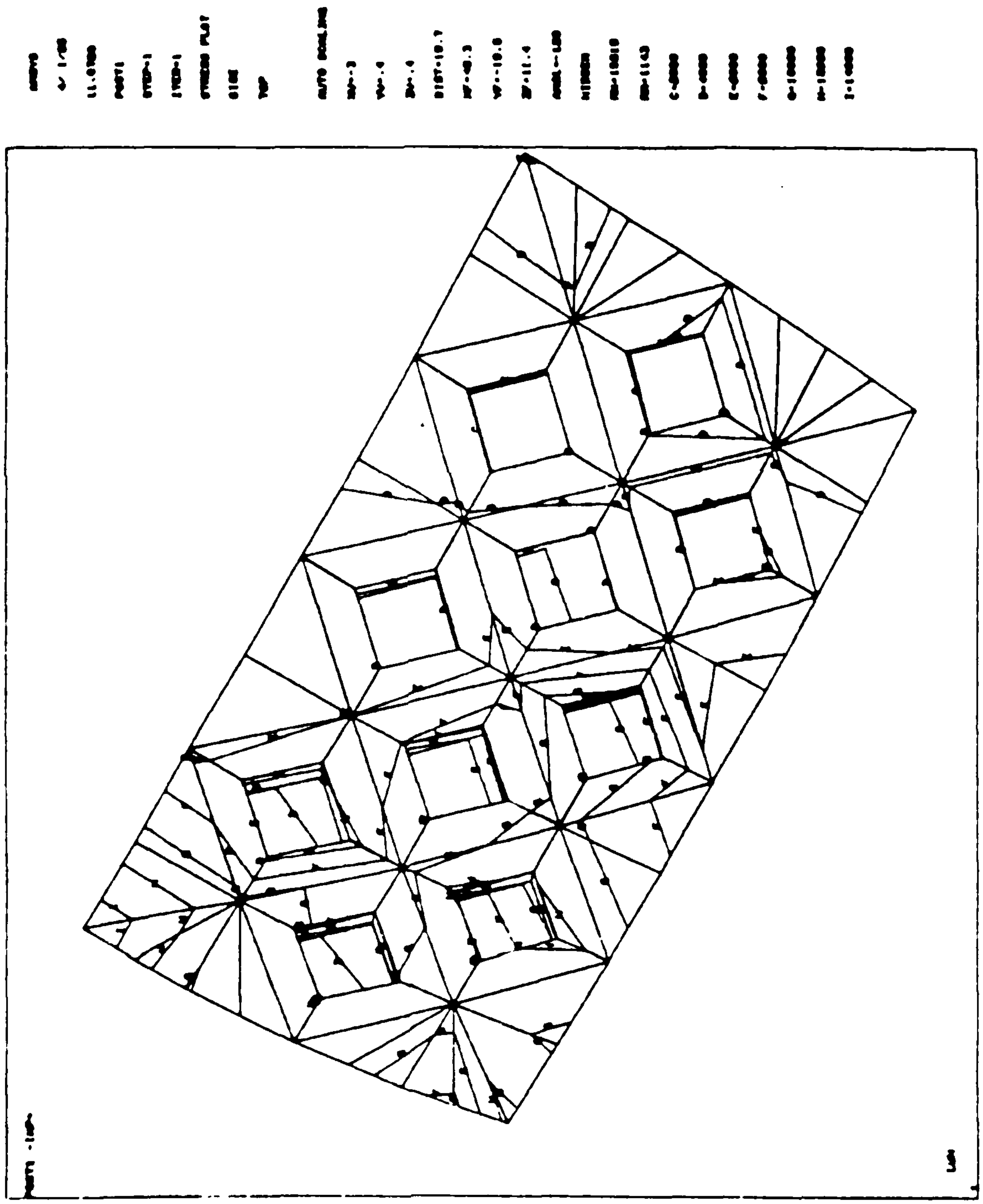
WEIGHT SUMMARY

[redacted] [redacted]

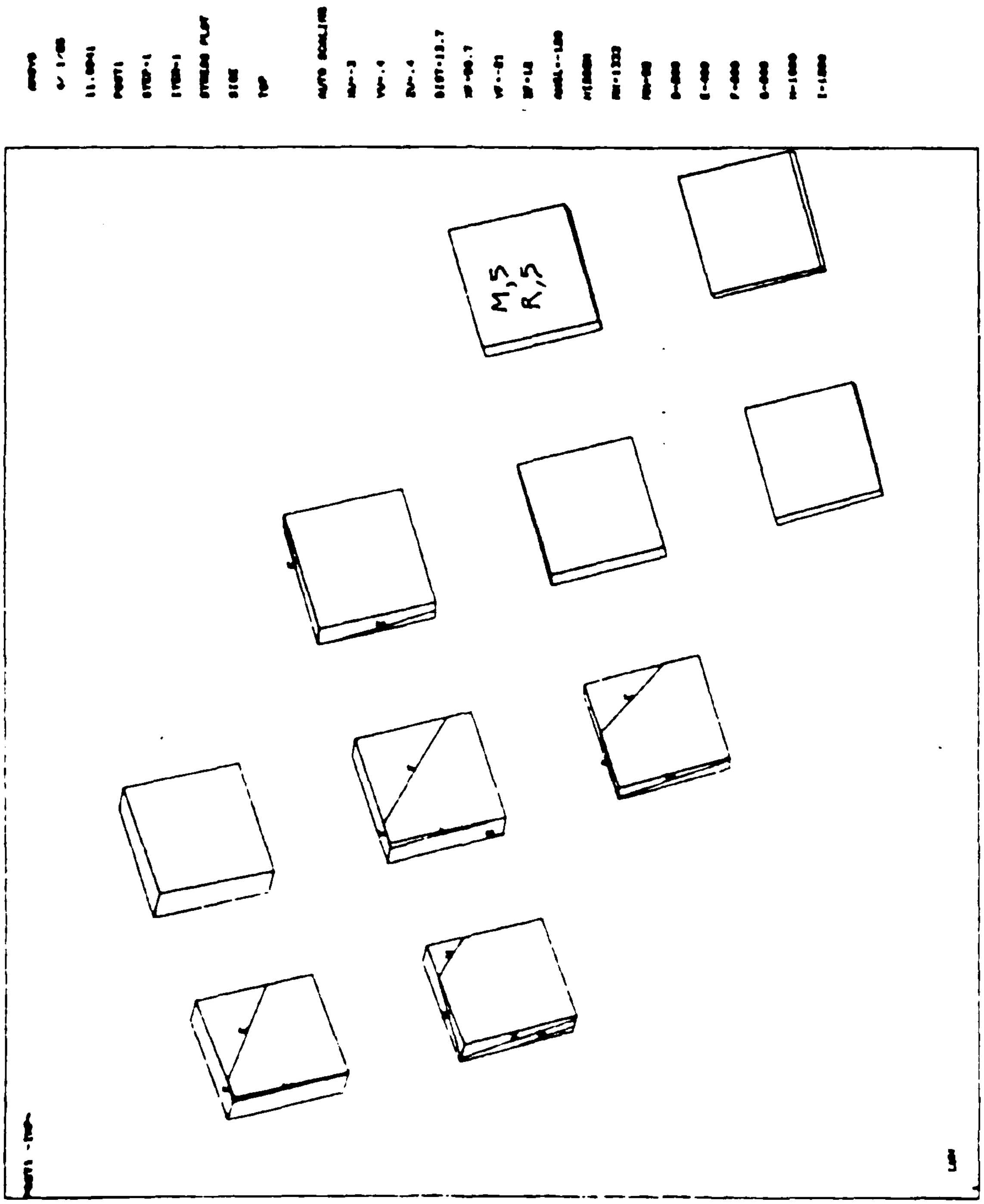


von MISES STRESS CONTOURS
OUTER FRAME MEMBERS
FIGURES 10 to 17
STATIC PRESSURE LOADING
(30 psi on curved surface)

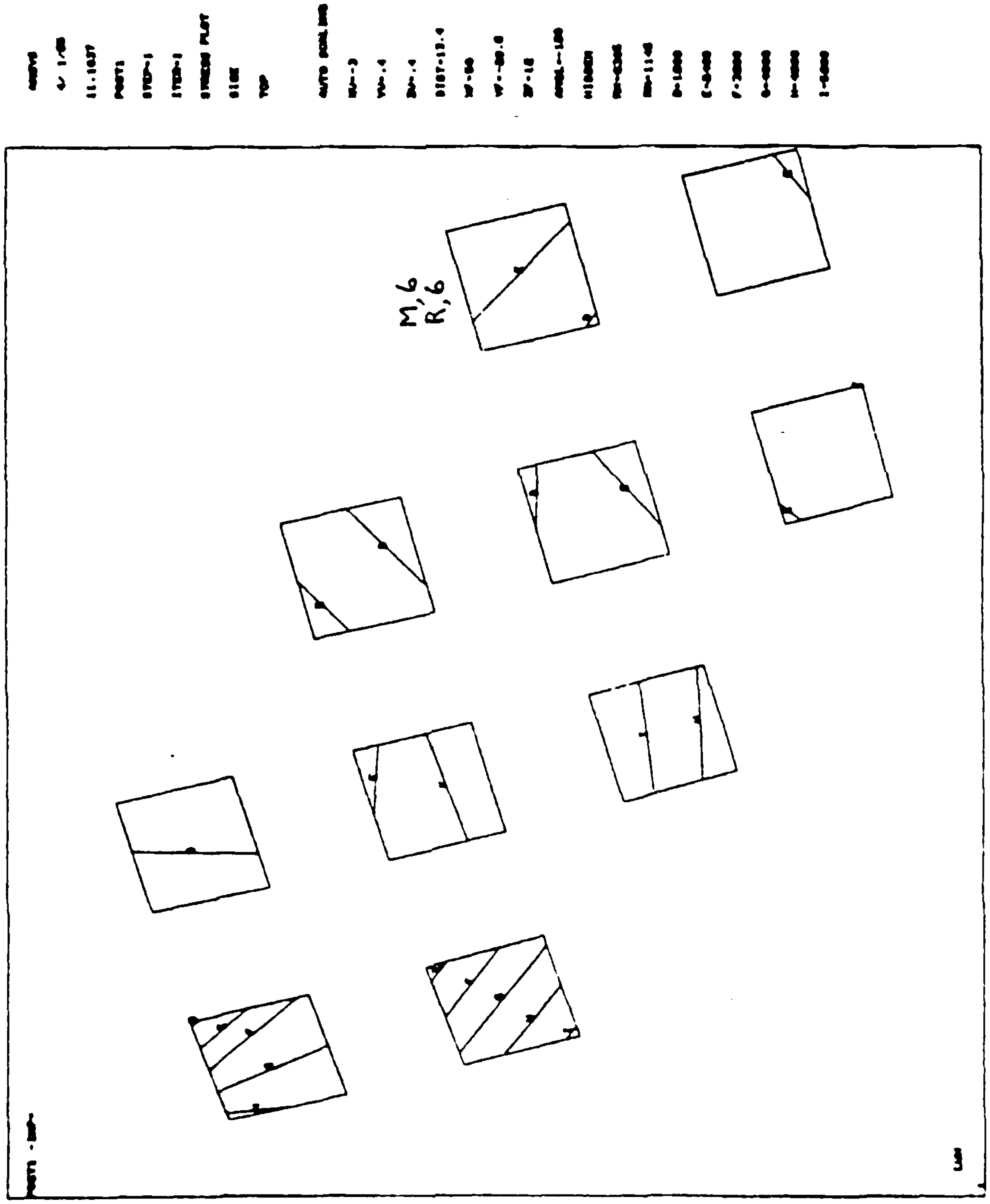
COMPOSITE WAFFLE PLATE



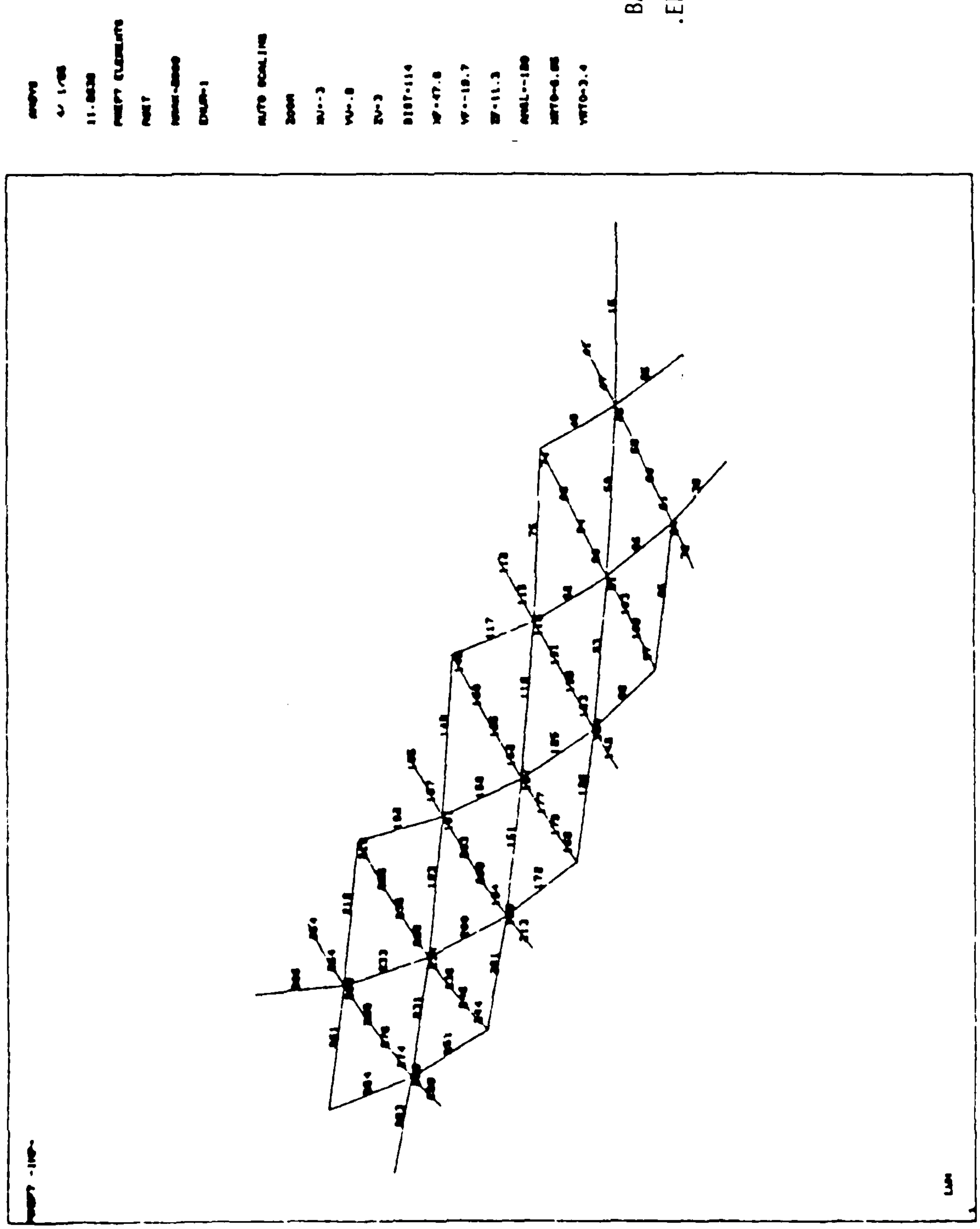
URETHANE PLUGS



SEGMENTS OF THE OUTER COVER SHEET



BAR ELEMENT LATTICE
.ELEMENT NUMBERS



POST0,1,0

PRINT ELEMENT STRESS ITEMS PER ELEMENT

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIGE |
|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

MORE (YES,NO OR CONTINUOUS)=

C

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIGE |
|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIGE |
|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIGE |
|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIGE |
|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIGE |
|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

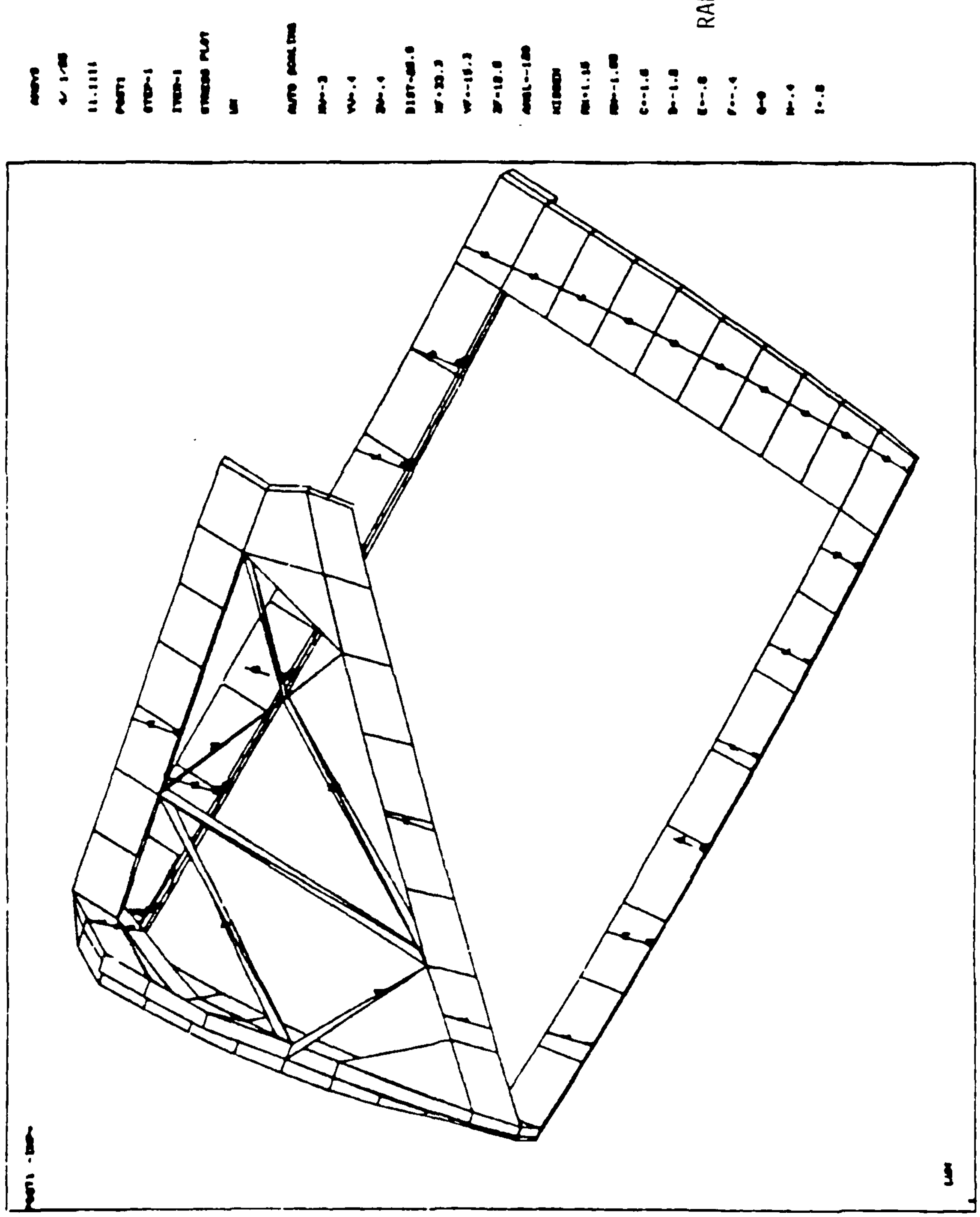
***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIGE |
|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

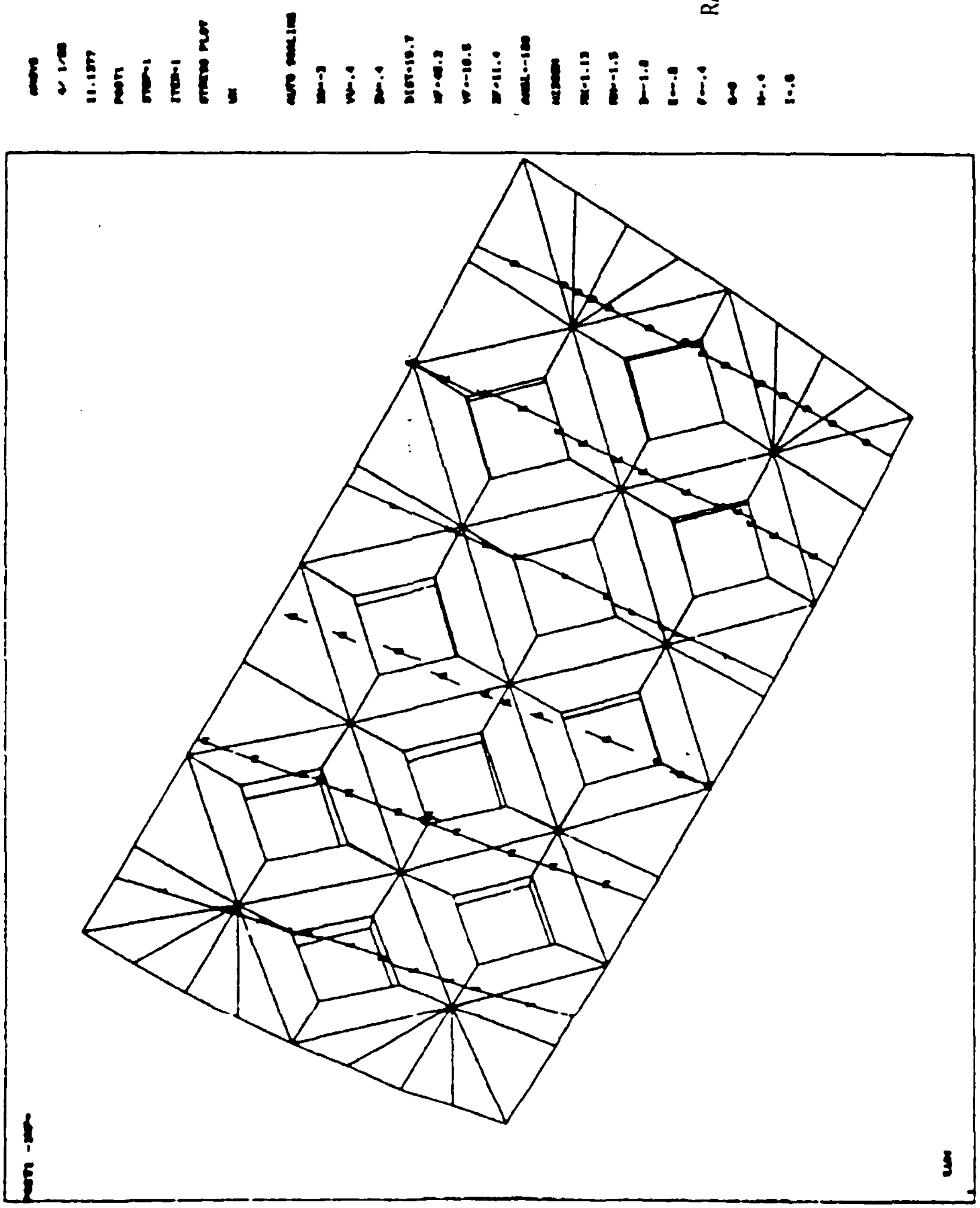
POST1 - INP=

BAR ELEMENT STRESSES



RADIAL DEFLECTION

RADIAL DEFLECTION



```
LIST MATERIALS    1 TO    5 BY   1

PROPERTY TABLE EX     MAT=   1  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3000000E+08  2300.000      0.3000000E+08

PROPERTY TABLE EY     MAT=   1  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3000000E+08  2300.000      0.3000000E+08

PROPERTY TABLE EZ     MAT=   1  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3000000E+08  2300.000      0.3000000E+08

PROPERTY TABLE NUXY   MAT=   1  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3300000      2300.000      0.3300000

PROPERTY TABLE DENS   MAT=   1  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.1000000E-03  2300.000      0.1000000E-03

PROPERTY TABLE EX     MAT=   2  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3000000E+08  2300.000      0.3000000E+08

PROPERTY TABLE NUXY   MAT=   2  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3300000      2300.000      0.3300000

PROPERTY TABLE DENS   MAT=   2  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.1000000E-03  2300.000      0.1000000E-03

PROPERTY TABLE EY     MAT=   2  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3000000E+08  2300.000      0.3000000E+08

PROPERTY TABLE EX     MAT=   3  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3000000E+08  2300.000      0.3000000E+08

PROPERTY TABLE EY     MAT=   3  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3000000E+08  2300.000      0.3000000E+08

PROPERTY TABLE NUXY   MAT=   3  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3000000      2300.000      0.3000000

PROPERTY TABLE DENS   MAT=   3  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.1000000E-03  2300.000      0.1000000E-03

PROPERTY TABLE EX     MAT=   4  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3000000E+08  2300.000      0.3000000E+08

PROPERTY TABLE EY     MAT=   4  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3000000E+08  2300.000      0.3000000E+08

PROPERTY TABLE NUXY   MAT=   4  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3300000      2300.000      0.3300000

PROPERTY TABLE DENS   MAT=   4  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.1000000E-03  2300.000      0.1000000E-03

PROPERTY TABLE EX     MAT=   5  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00   3000000.       2300.000       3000000.

PROPERTY TABLE EY     MAT=   5  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00   3000000.       2300.000       3000000.

PROPERTY TABLE NUXY   MAT=   5  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3300000      2300.000      0.3300000

PROPERTY TABLE DENS   MAT=   5  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
```

```
   0.0000000E+00 0.4000000E-03  2300.000      0.4000000E-03

PROPERTY TABLE EX     MAT=   6  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3000000E+08  2300.000      0.3000000E+08

PROPERTY TABLE EY     MAT=   6  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3000000E+08  2300.000      0.3000000E+08

PROPERTY TABLE NUXY   MAT=   6  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.3300000      2300.000      0.3300000

PROPERTY TABLE DENS   MAT=   6  NUM. POINTS=  2
      TEMPERATURE        DATA          TEMPERATURE        DATA
   0.0000000E+00 0.1000000E-03  2300.000      0.1000000E-03
PREP7 -INP=

ETLIST

LIST ELEMENT TYPES FROM  1 TO 20 BY 1

NO. STIF         KEYOPT VALUES          INOTPR
 1   45   0  0  0  0  0  0  0  0  0   0  ISOPAR. STRESS SOLID, 3-D
 2    4   0  0  0  0  0  0  0  0  0   0  ELASTIC BEAM, 3-D
 3   63   0  0  0  0  0  0  0  0  0   0  QUAD. FLAT SHELL
 4   63   0  0  0  0  0  0  0  0  0   0  QUAD. FLAT SHELL
 5   63   0  0  0  0  0  0  0  0  0   0  QUAD. FLAT SHELL
PREP7 -INP=
```

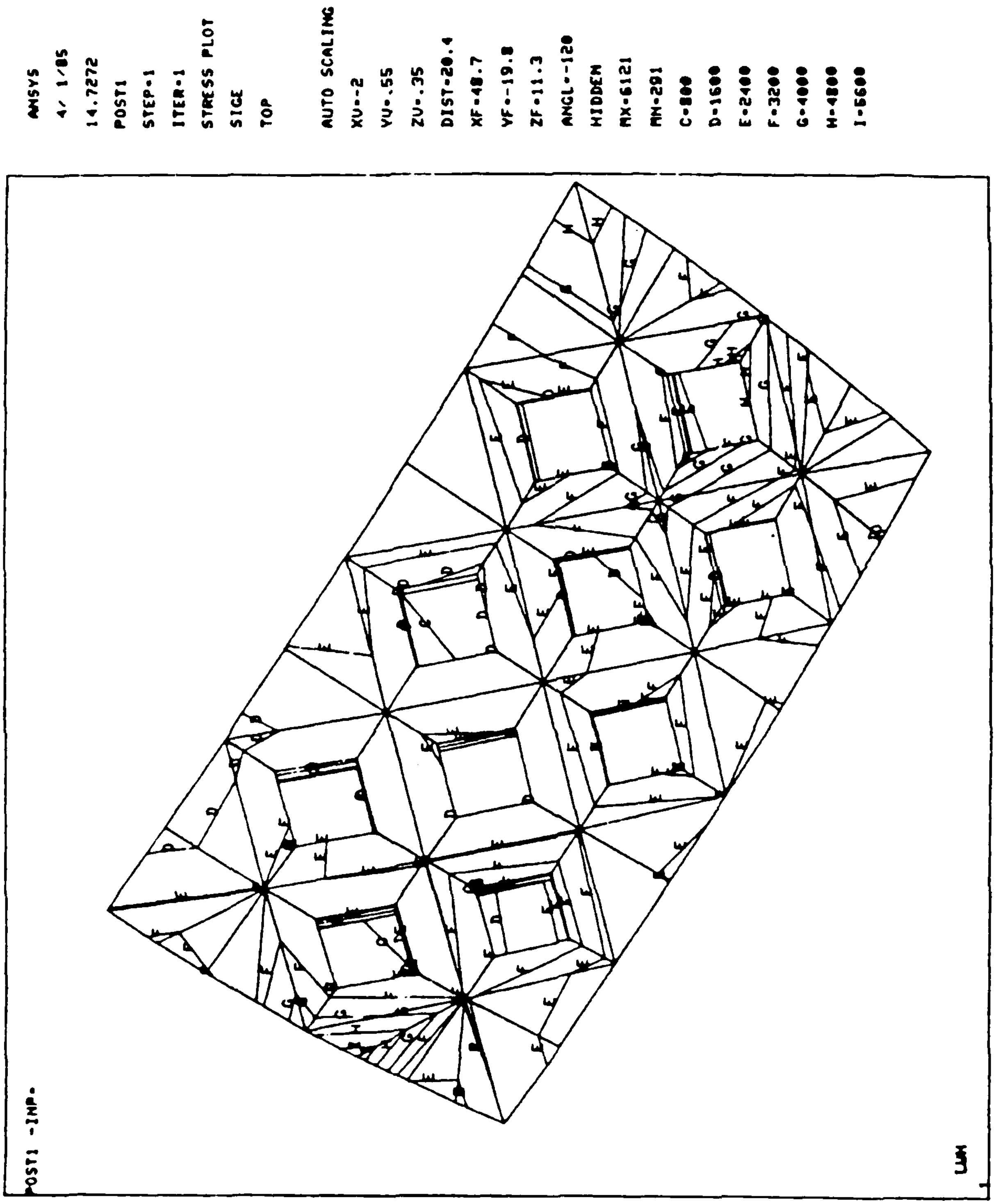
MATERIAL PROPERTY TABLE

[redacted] [redacted]

[illegible]

REAL PROPERTY TABLE

[redacted] [redacted]


ANSYS
4/ 1/85
14.7272
POST1
STEP=1
ITER=1
STRESS PLOT
SIGE
TOP
AUTO SCALING
XV=-2
YV=.55
ZV=.35
DIST=20.4
XF=48.7
YF=-19.8
ZF=11.3
ANGL=-120
HIDDEN
MX=6121
MN=291
C=800
D=1600
E=2400
F=3200
G=4000
H=4800
I=5600
POST1 -INP-

PRSTR,1,2

PRINT ELEMENT STRESS ITEMS PER ELEMENT

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIG3 |
|---|---|---|---|---|---|
| 15 | -1703.1 | -7.0446 | 438.51 | -1257.5 | -2148.6 |
| 25 | 1940.6 | -74.032 | -197.39 | 2212.0 | 1669.2 |
| 38 | -244.59 | 293.72 | 797.89 | 847.01 | -1336.2 |
| 41 | -164.24 | -719.39 | 48.844 | 604.00 | -932.48 |
| 47 | -165.82 | -301.67 | 16.684 | 152.54 | -484.17 |
| 48 | 250.12 | -14.431 | 236.00 | 500.55 | -0.30662 |
| 49 | 1189.1 | -60.091 | 116.83 | 1366.0 | 1012.2 |
| 50 | -1614.3 | -545.35 | -649.10 | -419.80 | -2808.7 |
| 58 | -1088.9 | 66.436 | 92.241 | -930.23 | -1247.6 |
| 60 | -1089.3 | 618.19 | 25.517 | -445.64 | -1733.1 |
| 61 | -222.56 | 1881.1 | -230.04 | 1888.6 | -2333.7 |
| 64 | -342.30 | 1232.7 | 142.40 | 1032.8 | -1717.4 |
| 65 | -712.93 | 45.152 | 214.47 | -453.31 | -972.56 |
| 66 | 8.3367 | -143.85 | -283.89 | 436.07 | -419.40 |

MORE (YES,NO OR CONTINUOUS)=

C

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIG3 |
|---|---|---|---|---|---|
| 72 | -339.45 | 339.88 | 100.02 | 100.45 | -779.36 |
| 74 | -233.50 | -326.65 | -33.864 | 127.01 | -594.02 |
| 75 | -315.26 | -401.38 | -1516.4 | 1602.5 | -2233.0 |
| 80 | -1709.2 | 890.46 | 17.960 | -800.79 | -2617.6 |
| 81 | -1582.5 | -301.44 | -103.09 | -1178.0 | -1987.0 |
| 82 | -537.19 | 219.69 | 368.12 | 50.618 | -1125.0 |
| 83 | -2410.5 | 260.31 | 77.251 | -2073.0 | -2748.1 |
| 88 | -1318.4 | 287.86 | 114.08 | -916.43 | -1720.3 |
| 94 | -1321.7 | -112.01 | 15.143 | -1194.6 | -1448.9 |
| 97 | -1004.8 | 1744.8 | -29.542 | 769.58 | -2779.2 |
| 98 | -687.79 | -215.55 | -432.75 | -39.484 | -1336.1 |
| 103 | -1606.8 | 257.62 | 141.05 | -1208.2 | -2005.5 |
| 109 | -1607.0 | 982.14 | 32.757 | -592.12 | -2621.9 |
| 112 | -1289.4 | -1019.9 | -45.338 | -224.21 | -2354.6 |

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIG3 |
|---|---|---|---|---|---|
| 115 | -1290.1 | -115.98 | -37.918 | -1136.2 | -1444.0 |
| 116 | -1304.8 | 62.198 | -18.142 | -1234.4 | -1375.1 |
| 117 | -1115.9 | 854.58 | 549.44 | -311.93 | -1920.0 |
| 118 | -930.86 | -822.63 | 277.66 | -430.65 | -1440.0 |
| 123 | -1886.1 | 1409.8 | -130.16 | -265.35 | -3514.8 |
| 124 | -1559.4 | -41.883 | 18.311 | -1499.8 | -1618.9 |
| 126 | -448.01 | 77.743 | -326.84 | -44.624 | -851.40 |
| 128 | -1908.8 | -594.18 | 1837.8 | -71.886 | -3734.0 |
| 131 | -1616.4 | 430.12 | 83.649 | -1102.8 | -8130.1 |

| | | | | | |
|---|---|---|---|---|---|
| 138 | -1616.3 | 902.85 | -16.301 | -807.15 | -2625.6 |
| 142 | -1557.9 | -27.467 | 35.523 | -1495.0 | -1620.9 |
| 146 | -661.89 | -363.86 | 20.878 | -287.16 | -1036.6 |
| 149 | 879.16 | -131.68 | -697.15 | 1708.0 | 50.332 |
| 151 | -745.58 | -135.66 | 520.49 | -89.441 | -1401.7 |

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIG3 |
|---|---|---|---|---|---|
| 152 | -1499.1 | 1813.0 | 229.54 | 543.44 | -3541.7 |
| 157 | -1289.3 | -19.991 | 148.96 | -1120.4 | -1458.3 |
| 158 | -1071.1 | 416.54 | 640.66 | -13.923 | -2128.3 |
| 160 | -946.03 | -429.41 | 147.65 | -368.97 | -1523.1 |
| 165 | -947.7 | 614.32 | -6.6396 | -326.74 | -1568.7 |
| 168 | -1468.6 | -16.345 | -28.349 | -1423.9 | -1513.3 |
| 172 | 304.08 | 220.53 | 230.32 | 754.92 | -146.76 |
| 177 | -1349.7 | -314.14 | 446.82 | -588.75 | -2110.7 |
| 179 | -1349.7 | 248.25 | 12.200 | -1089.2 | -1610.1 |
| 185 | -679.03 | -835.35 | -39.774 | 196.09 | -1554.2 |
| 187 | -681.52 | 76.451 | -29.689 | -575.38 | -787.66 |
| 191 | -777.53 | 790.39 | 271.19 | 284.05 | -1839.1 |
| 192 | -1087.0 | 227.76 | 482.03 | -377.15 | -1796.7 |
| 193 | 355.98 | 215.40 | -559.28 | 1130.7 | -418.70 |

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

| ELEM | SDIR | SBZ | SBY | SIG1 | SIG3 |
|---|---|---|---|---|---|
| 194 | -1199.7 | 188.08 | 313.97 | -697.67 | -1701.8 |
| 196 | -1470.4 | -893.98 | -171.30 | -405.16 | -2535.7 |
| 200 | -948.17 | 564.66 | -1086.4 | 702.92 | -2599.3 |
| 201 | -1126 | | | | |

[redacted] [redacted]

HT7-44

| | | | | | |
|---|---|---|---|---|---|
| | 8.49 | 594.83 | 10.081 | 186.52 | -1023.5 |
| 238 | -606.76 | -218.75 | 537.86 | 149.85 | -1363.4 |
| 244 | -1531.6 | -2208.9 | 77.524 | 754.85 | -3818.0 |
| 246 | -605.10 | -452.48 | -2.4914 | -150.14 | -1060.1 |
| 251 | 827.71 | 322.32 | 170.54 | 1329.6 | 325.85 |
| 254 | -908.18 | -835.65 | -0.43088 | -72.098 | -1744.3 |
| 261 | 946.29 | -60.211 | 748.39 | 1754.9 | 137.69 |
| 263 | -1626.3 | 341.46 | 364.51 | -920.38 | -2332.3 |
| 264 | -909.87 | 52.197 | 48.802 | -808.87 | -1010.9 |
| 266 | -1596.8 | -139.86 | -176.10 | -1280.7 | -1912.9 |
| 268 | -1187.7 | 253.93 | 189.64 | -744.10 | -1631.2 |
| 274 | -1236.0 | -1012.9 | 473.79 | 250.71 | -2722.7 |
| 276 | -1185.9 | 138.54 | 10.983 | -1036.3 | -1335.4 |
| 283 | -134.28 | -218.53 | 390.72 | 474.98 | -743.54 |

***** POST1 ELEMENT STRESS LISTING *****

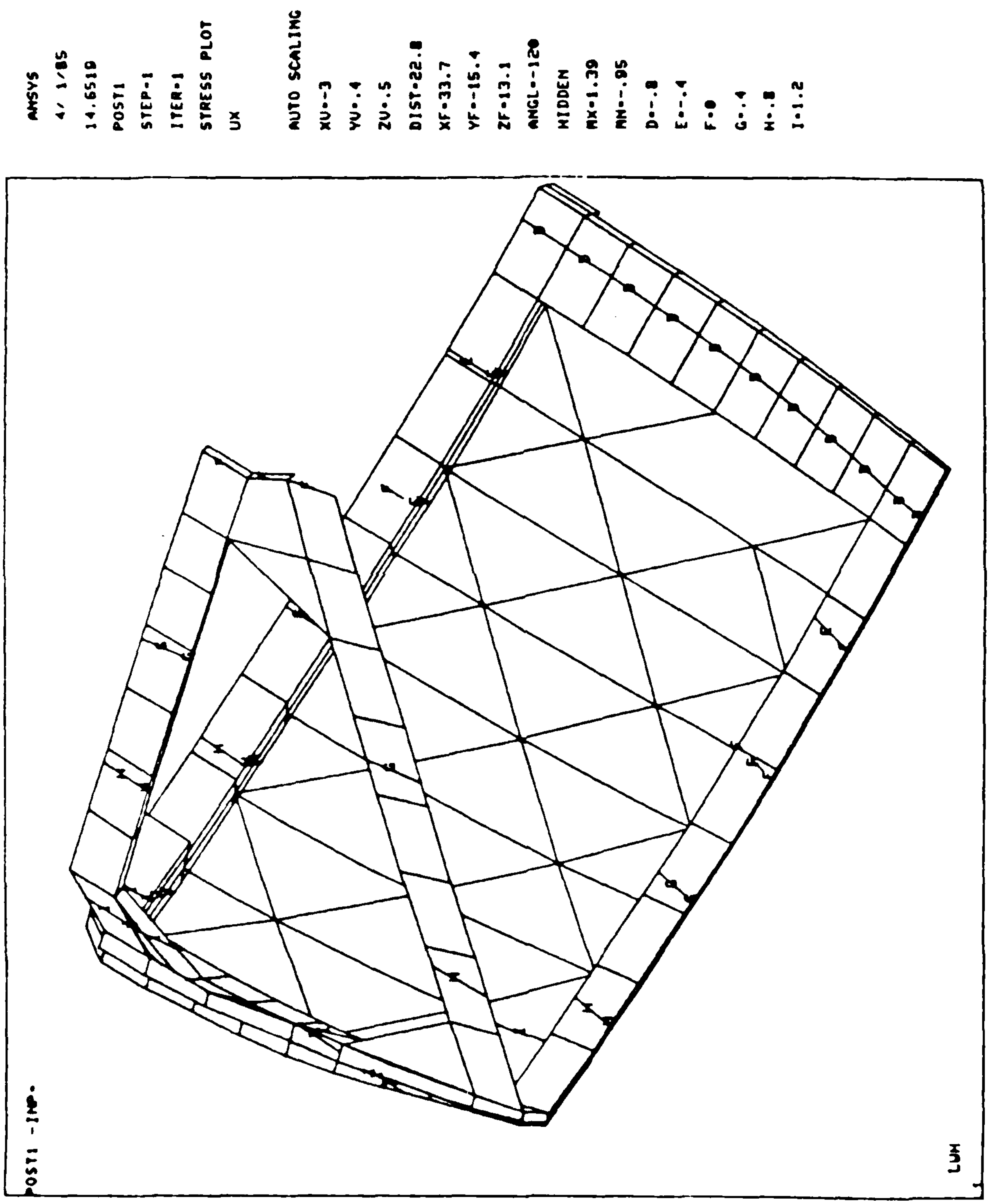
LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

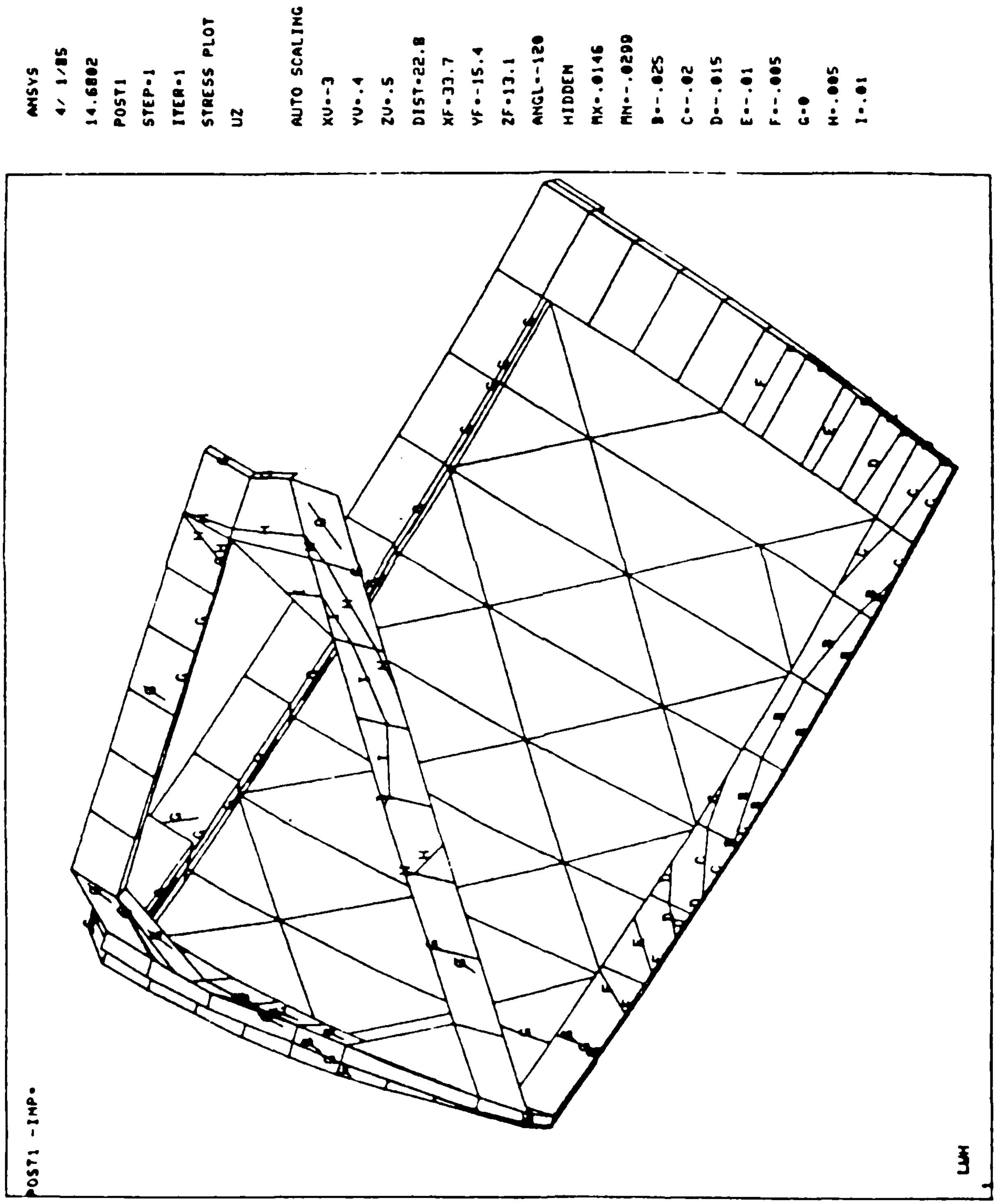
| ELEM | SDIR | SBZ | SBY | SIG1 | SIG3 |
|---|---|---|---|---|---|
| 284 | -828.94 | 140.99 | 5.6855 | -682.27 | -975.62 |
| 285 | -2044.2 | -2025.8 | -108.82 | 90.454 | -4178.8 |
| 289 | -2046.2 | -630.17 | -43.199 | -1372.8 | -2719.5 |

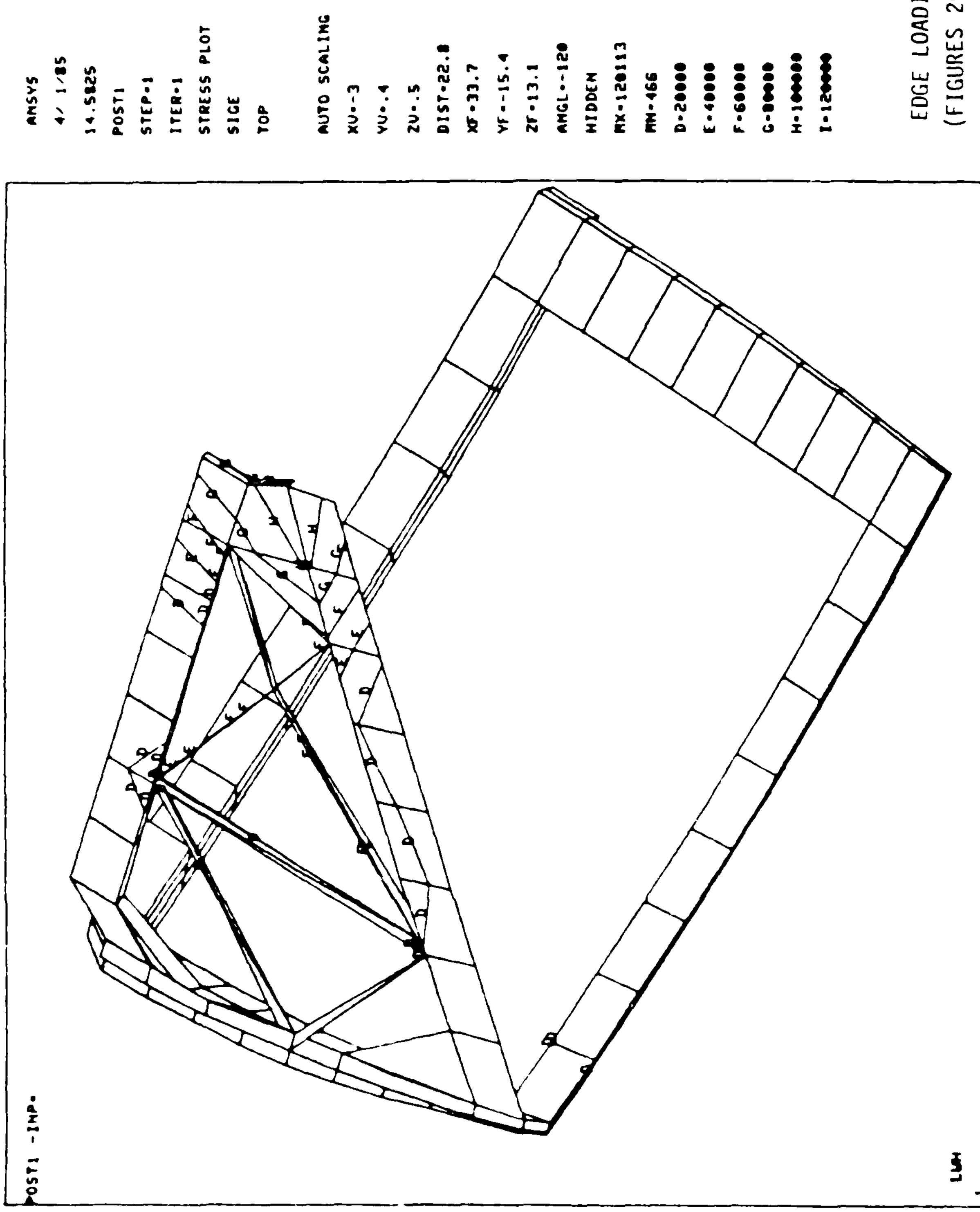
POST1 -INP-

[redacted]

[redacted]


ANSYS
4/ 1/85
14.6519
POST1
STEP=1
ITER=1
STRESS PLOT
UX
AUTO SCALING
XV=-3
YV=.4
ZV=.5
DIST=22.8
XF=33.7
YF=-15.4
ZF=13.1
ANGL=-120
HIDDEN
MX=1.39
MN=-.95
D=-.8
E=-.4
F=0
G=.4
H=.8
I=1.2
POST1 -INP-
LUH


ANSYS
4/ 1/85
14.6802
POST1
STEP=1
ITER=1
STRESS PLOT
UZ
AUTO SCALING
XV=-3
YV=.4
ZV=.5
DIST=22.8
XF=33.7
YF=-15.4
ZF=13.1
ANGL=-120
HIDDEN
MX=.0146
MN=-.0290
B=-.025
C=-.02
D=-.015
E=-.01
F=-.005
G=0
H=.005
I=.01
POST1 -INP-




EDGE LOADING
(FIGURES 20 to 25
are for edge loading)

**FMC Corporation** APPENDIX HT7 - D1

**Central Engineering Laboratories**

INTEROFFICE

| | | | |
|---|---|---|---|
| TO: | C. Ortloff | DATE: | March 27, 1985 |
| FROM: | Michael Coulter | cc: | E. Thuse<br>R. Kazares |
| SUBJECT: | Lightweight Howitzer - Spade Analysis<br>Preliminary Stress Calculations (Static & Dynamic)<br>on All-Metal (Steel, Titanium) & FG/EP<br>Thick-Spade (Figure 1) Configurations | | |

Per your request, three different configurations of the spade concept described in Figure 1 have been analyzed; steel, titanium and fiberglass. The results of these preliminary analyses are summarized in Table 1. The loading for these analyses consists of a static pressure (corresponding to max recoil force of 65,000 lb) distributed as shown in Figure 2 (red outlines). Due to symmetry only half of the structure was modeled. A fixed constraint was used as the boundary condition as shown in Figure 2. Stress contour plots along with displacement plots for each of these configurations are shown in Attachments A-C. Disregard the high stresses at the locations where the model was constrained as this area was not modeled accurately for this preliminary study. The maximum stress in the region where the pressure load was applied is approximately 8000 psi. for each case analyzed.

In addition to the above analyses, one transient dynamic pressure load case was run for the steel spade for the purpose of determining dynamic effects of the loading described in Figure 3. The maximum stress in the pressure surface region increases 25% from the static load case to 15,000 psi. Displacement and stress contour plots are shown in Attachment D.

Each of the above load cases assumes the spade is already embedded into the ground. The final load case analyzed for the steel spade consists of a compressive force (60,000 lb) being applied as shown in Figure 4 (red arrows). This is just an estimate of the force applied to the spade if gun were fired without the spade being embedded into the ground. A maximum stress of 45? psi results from this loading. Deflection and stress contour plots are shown in Attachment F.

[redacted] [redacted]

C. Ortloff March 27, 1985

The results of this preliminary analysis indicates that each of the configurations analyzed can withstand the given loading. However, it should be noted that the purpose of this analysis was to determine if this concept is a viable one, not to do a detailed analysis of the proposed design.

Mike Coulter

[redacted] [redacted]

# APPENDIX HT7 - D3

## TABLE 1

### LOAD CASE SUMMARY

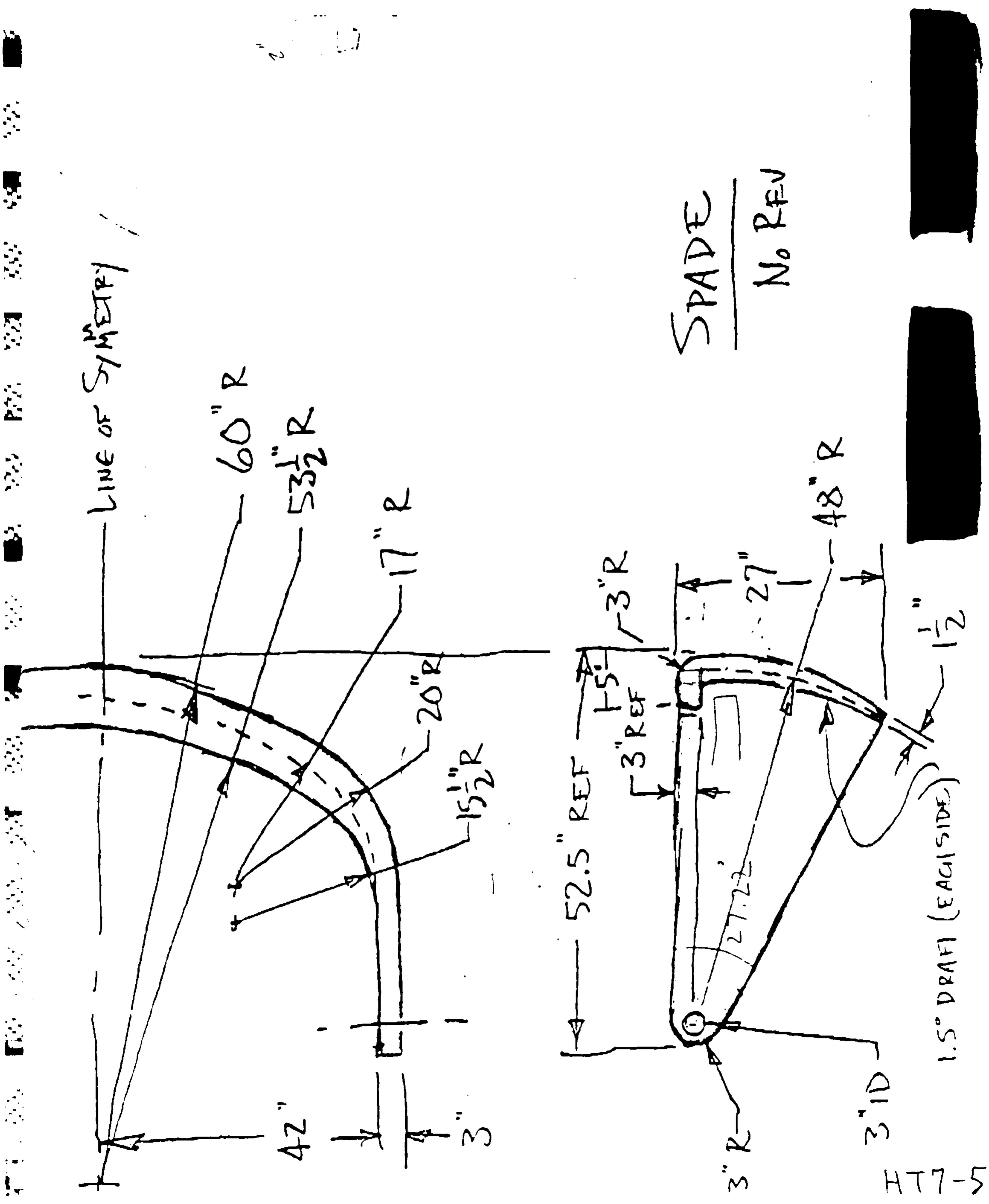
| MATERIAL | TOTAL WEIGHT | MAX. DEFLECTION | MAX STRESS ON PRESSURE SURFACE |
|---|---|---|---|
| STEEL | 2300 lb. | 0.15 in. | 8000 psi. |
| TITANIUM | 1300 lb. | 0.27 in. | 8000 psi. |
| FIBERGLASS | 800 lb. | 1.25 in. | 8000 psi. |

### MATERIAL PROPERTIES

| MATERIAL | YOUNGS MODULUS | POISSON RATIO | DENSITY |
|---|---|---|---|
| STEEL | $30X10^6$ $lb/in^2$ | 0.3 | 0.283 $lb/in^3$ |
| TITANIUM | $17X10^6$ $lb/in^2$ | 0.33 | 0.161 $lb/in^3$ |
| FIBERGLASS* | $5X10^6$ $lb/in^2$ | 0.20 | 0.10 $lb/in^3$ |

* GXY = GXZ = GYZ = $6X10^5$ $lb/in^2$

[redacted] [redacted]




[redacted]

[redacted]

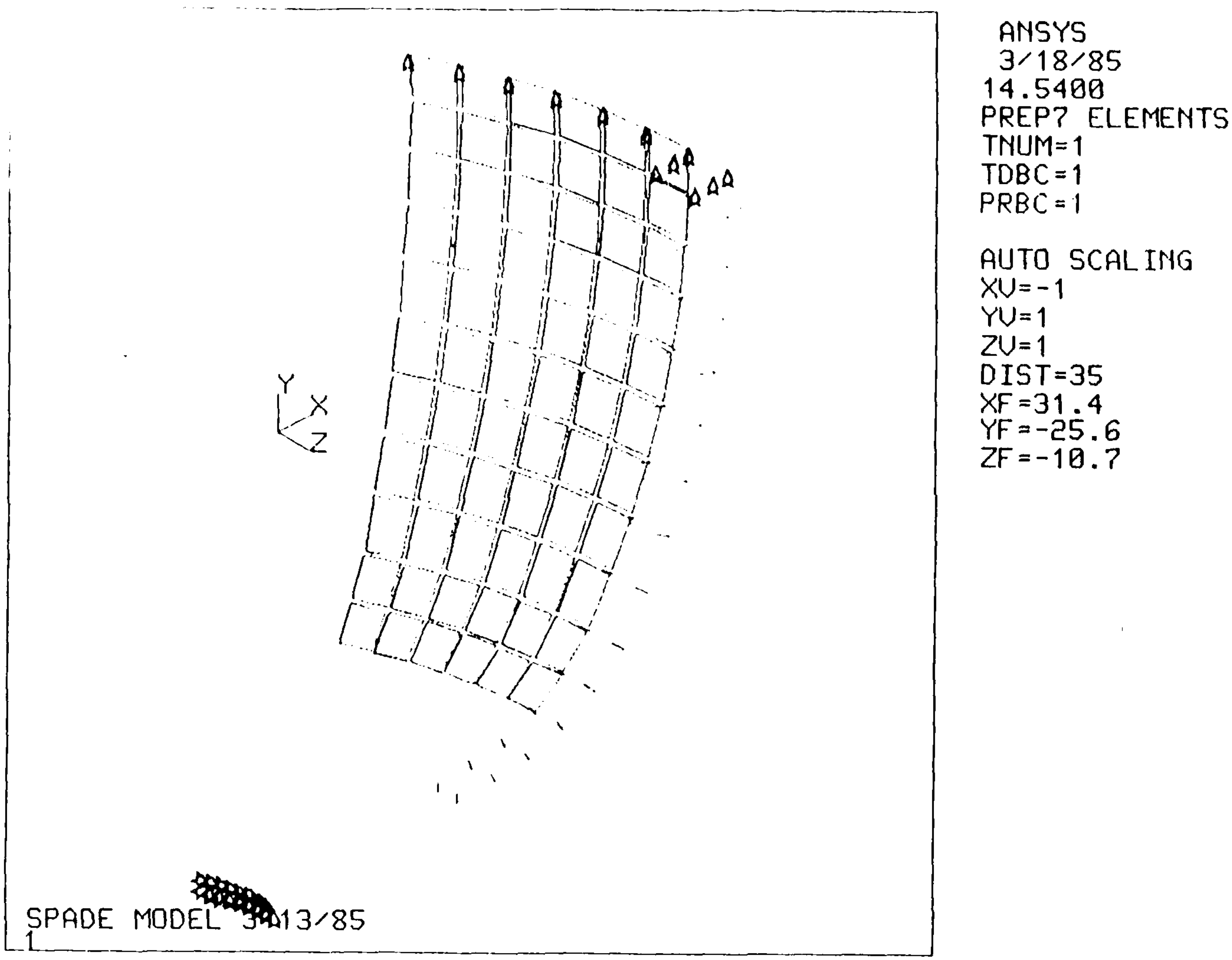



FIGURE 2

FINITE ELEMENT MODEL WITH PRESSURE LOAD & DISPLACEMENT CONSTRAINTS

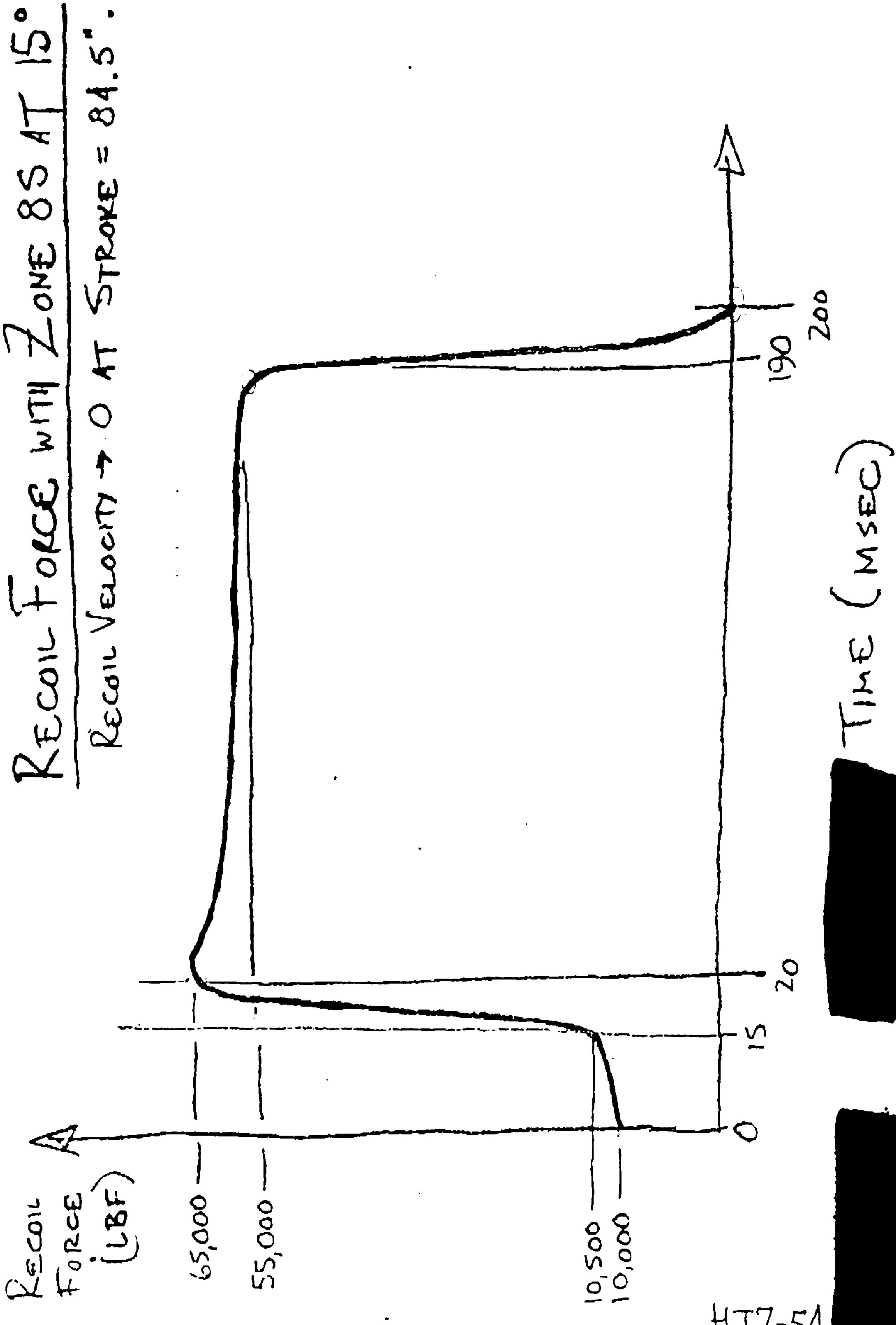



FIGURE 3

[redacted]

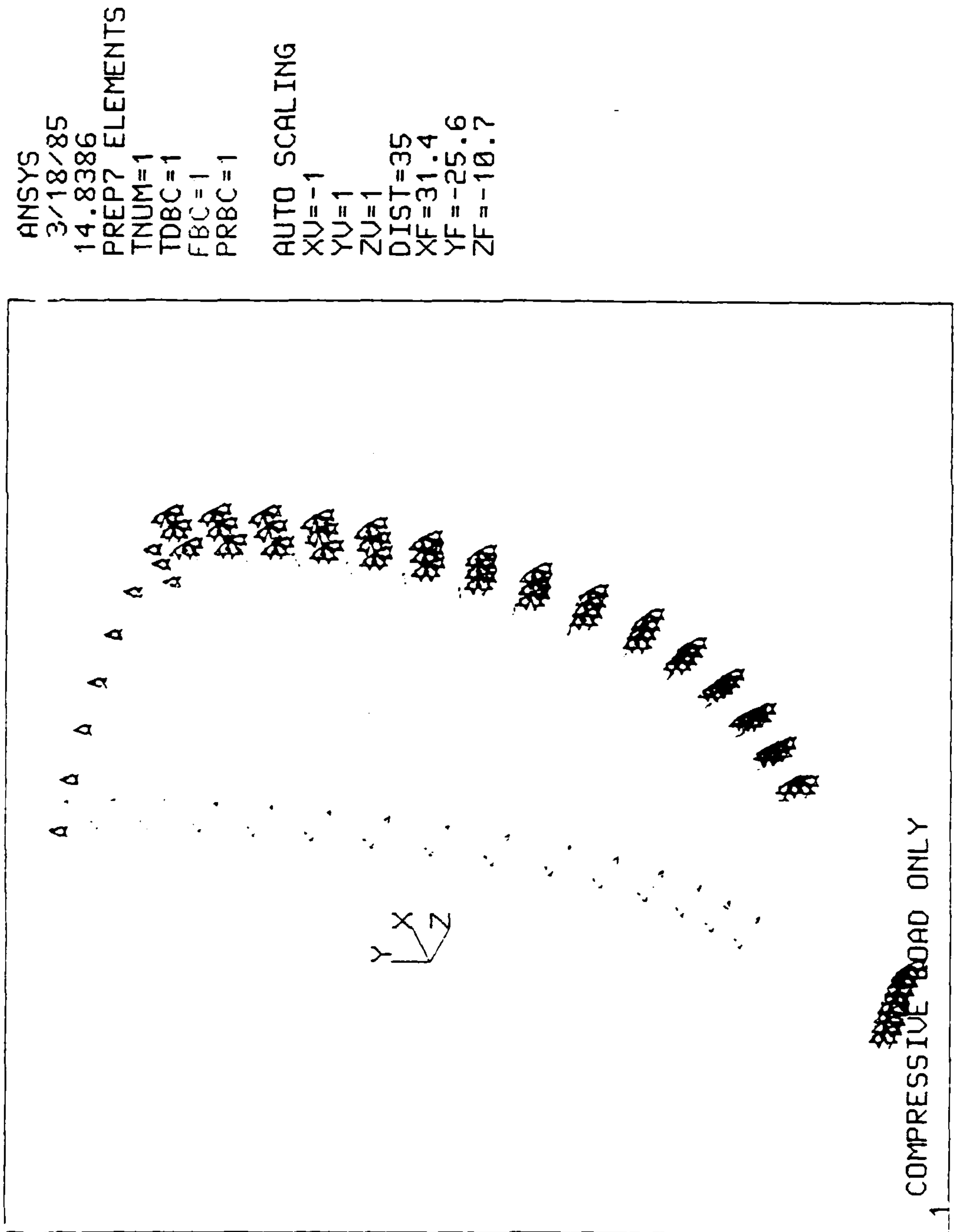



FIGURE 4

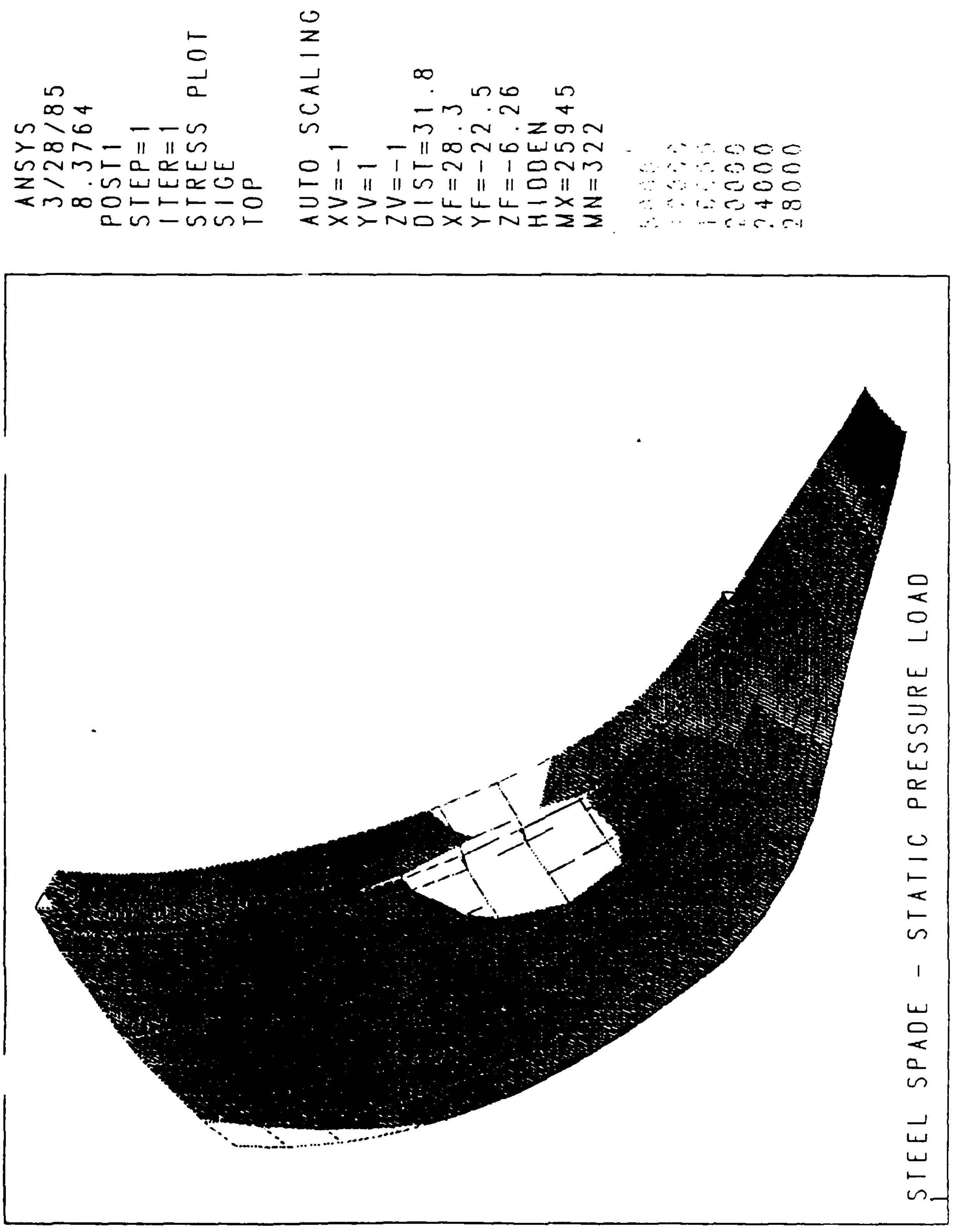
DESCRIPTION OF COMPRESSIVE LOAD CASE

# APPENDIX HT7 - D8

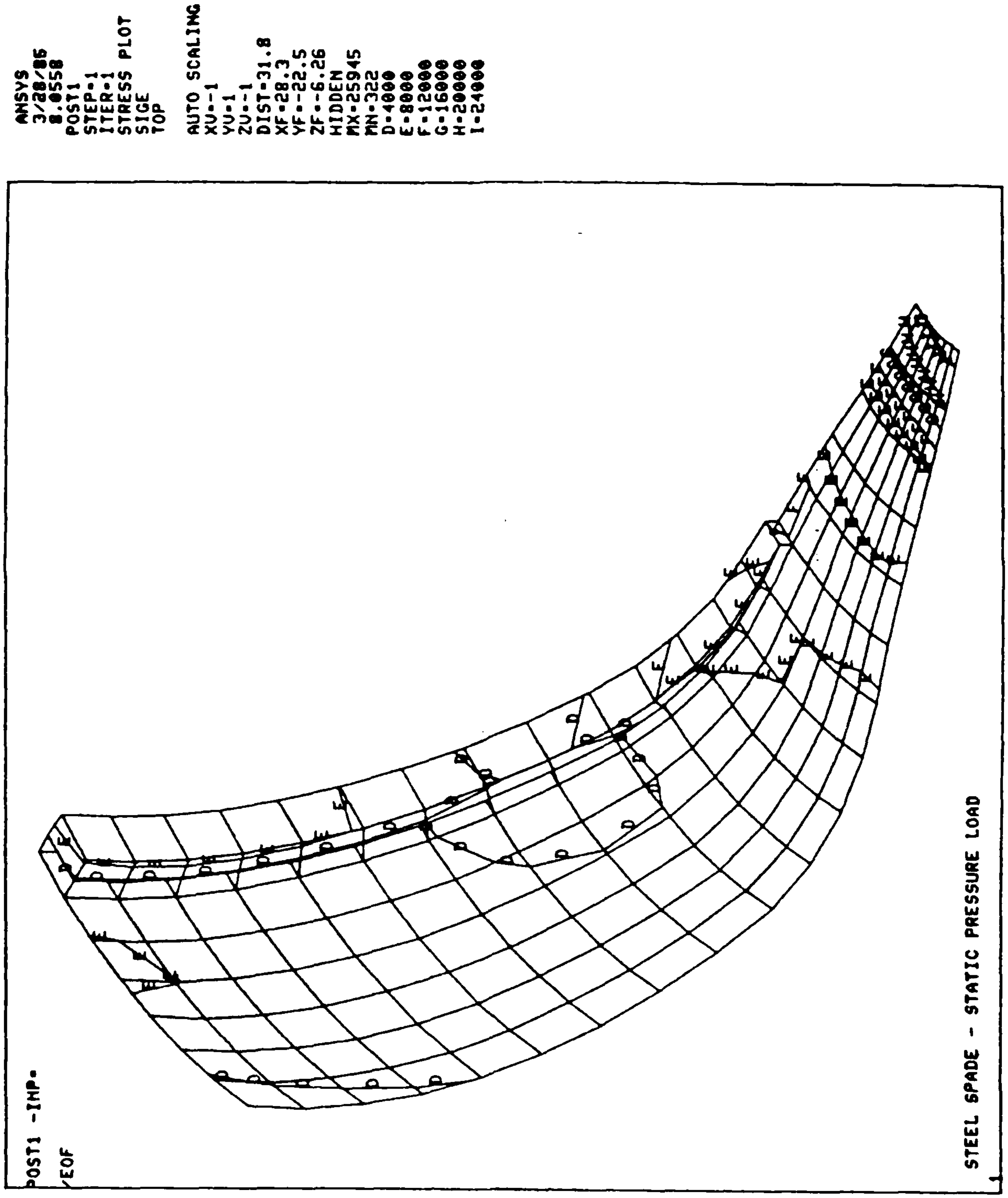
## ATTACHMENT A

Displacement and Stress Contour Plots - Steel Spade

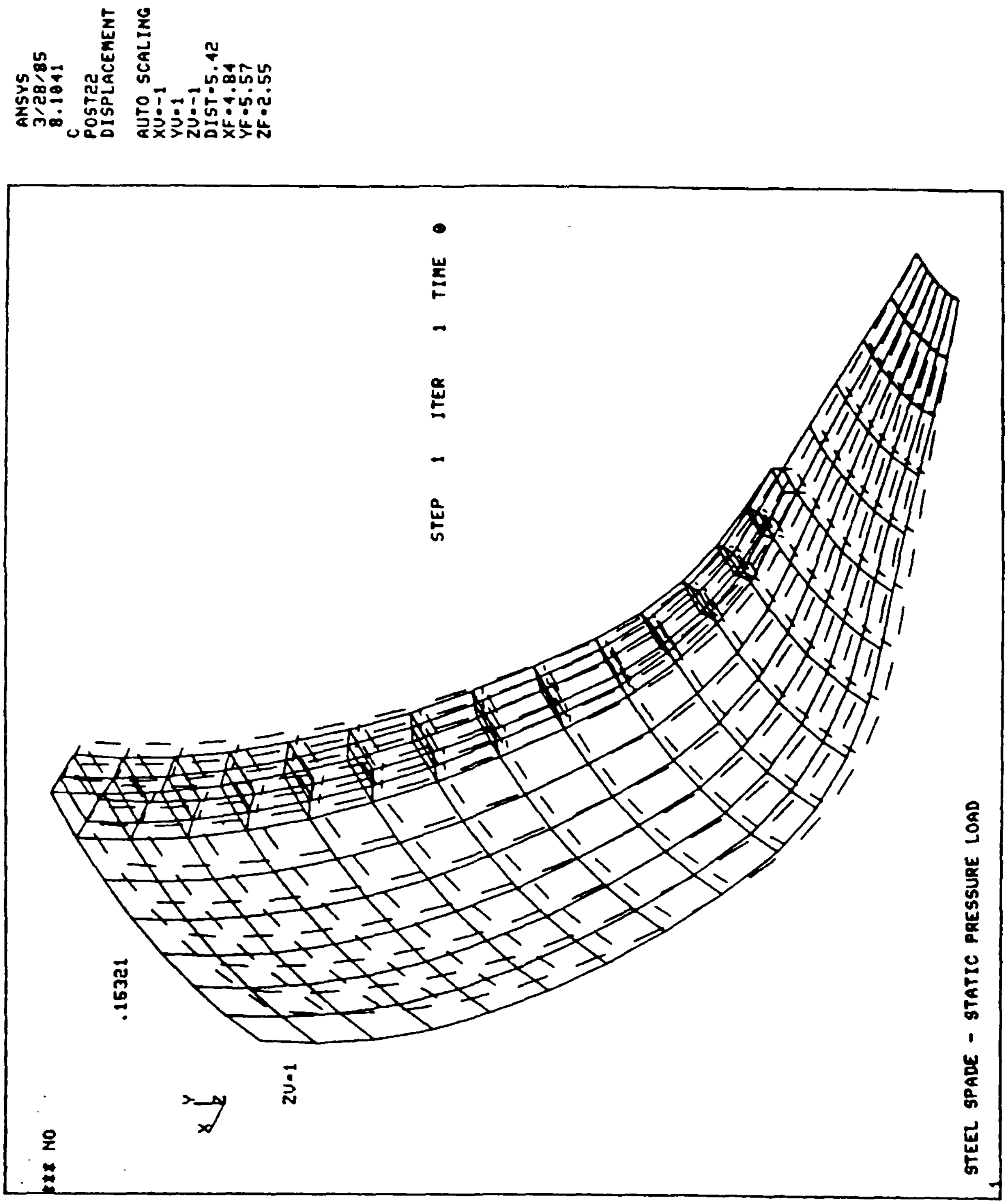
[redacted] [redacted]




STEEL SPADE - STATIC PRESSURE LOAD



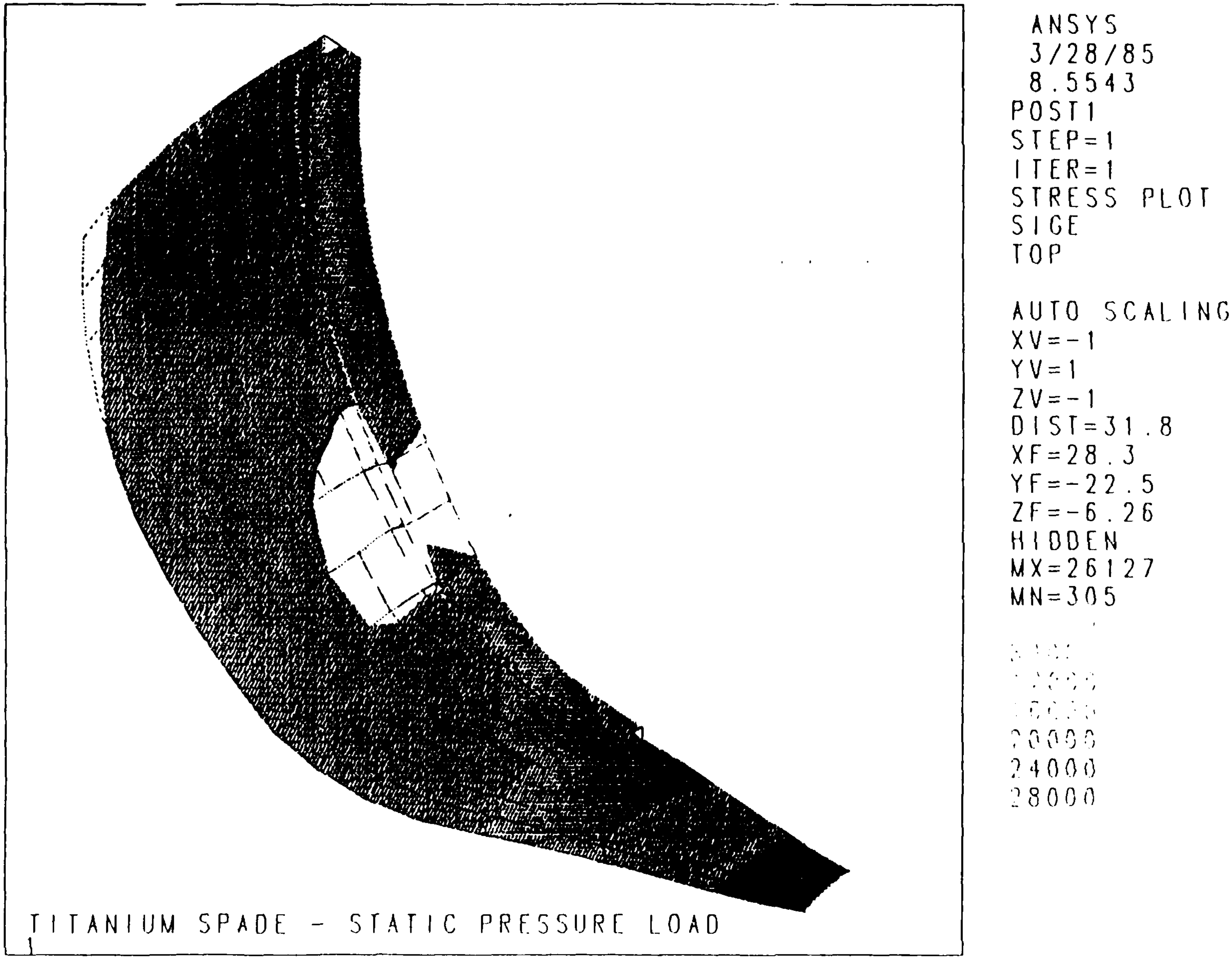

STEEL SPADE - STATIC PRESSURE LOAD


ANSYS
3/28/85
8.1041
C
POST22
DISPLACEMENT
AUTO SCALING
XV=-1
YV=1
ZV=-1
DIST=5.42
XF=4.84
YF=5.57
ZF=2.55
STEP 1 ITER 1 TIME 0
.15321
ZV=1
*** NO
STEEL SPADE - STATIC PRESSURE LOAD

## ATTACHMENT B

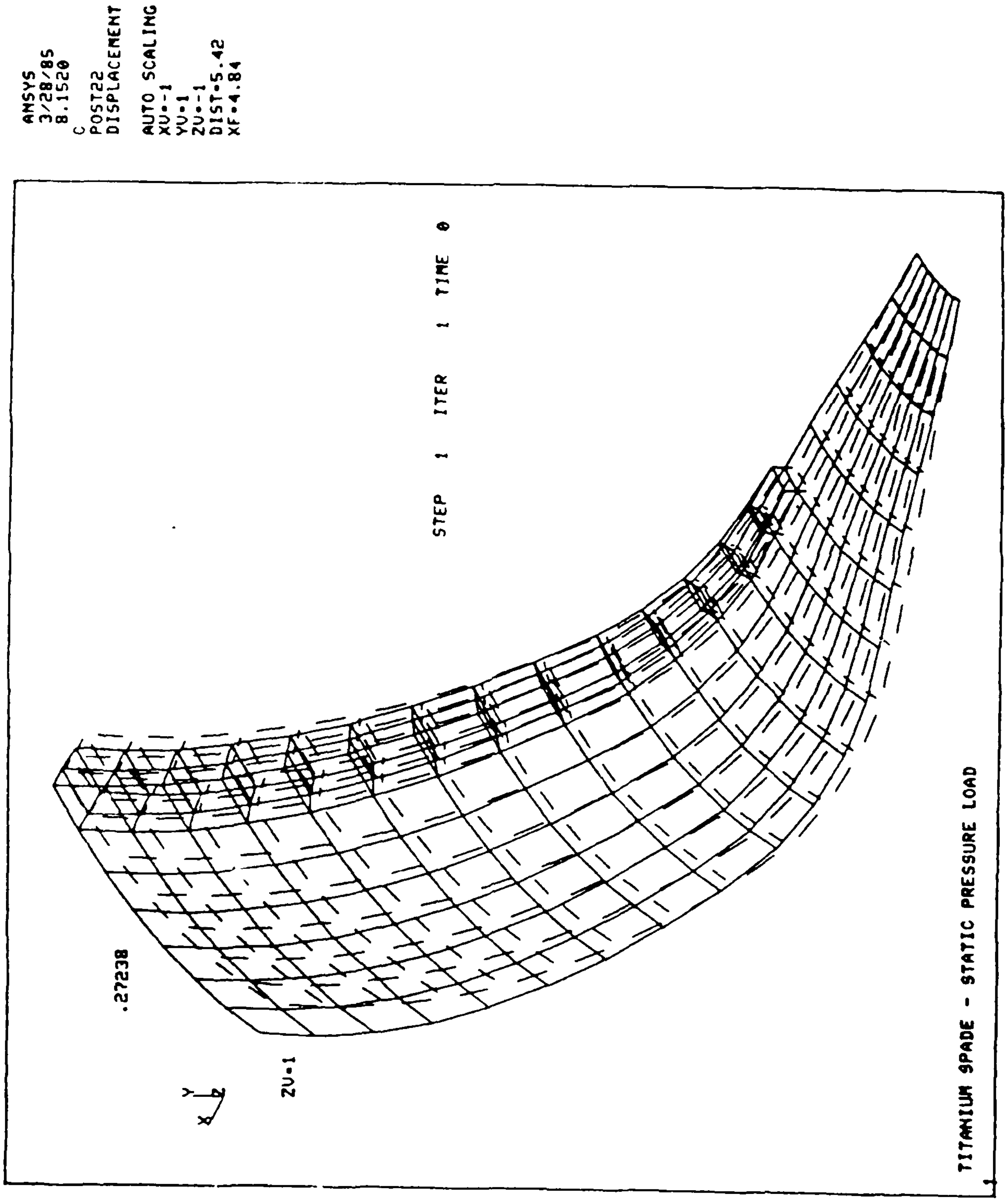
### Displacement and Stress Contour Plots - Titanium Spade

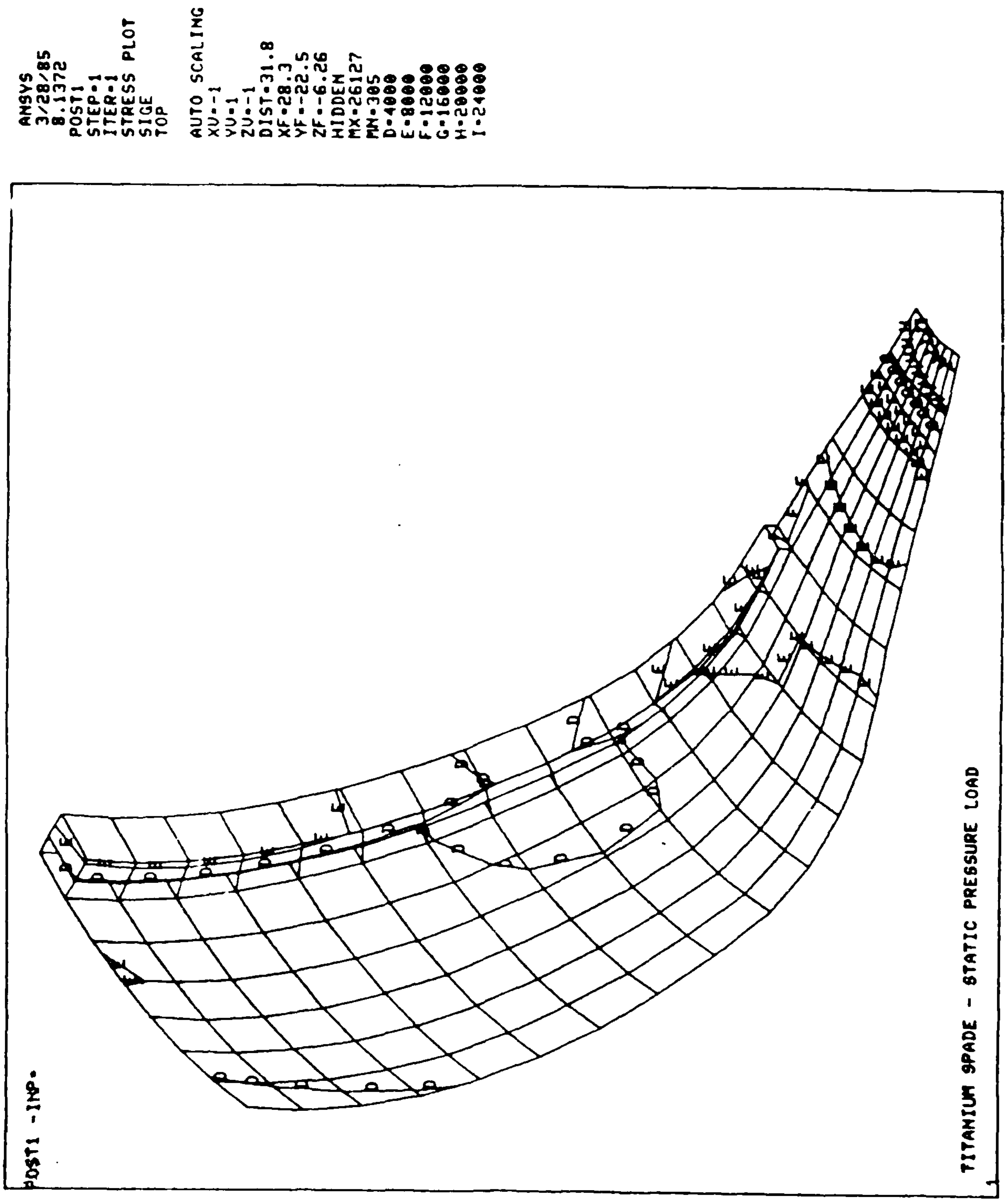
[redacted] [redacted]




TITANIUM SPADE - STATIC PRESSURE LOAD

[redacted] [redacted]


ANSYS
3/28/85
8.1520
C
POST22
DISPLACEMENT
AUTO SCALING
XV=-1
YV=1
ZV=-1
DIST=5.42
XF=4.84
STEP 1 ITER 1 TIME 0
.27238
ZV=1
Y
X
TITANIUM SPADE - STATIC PRESSURE LOAD



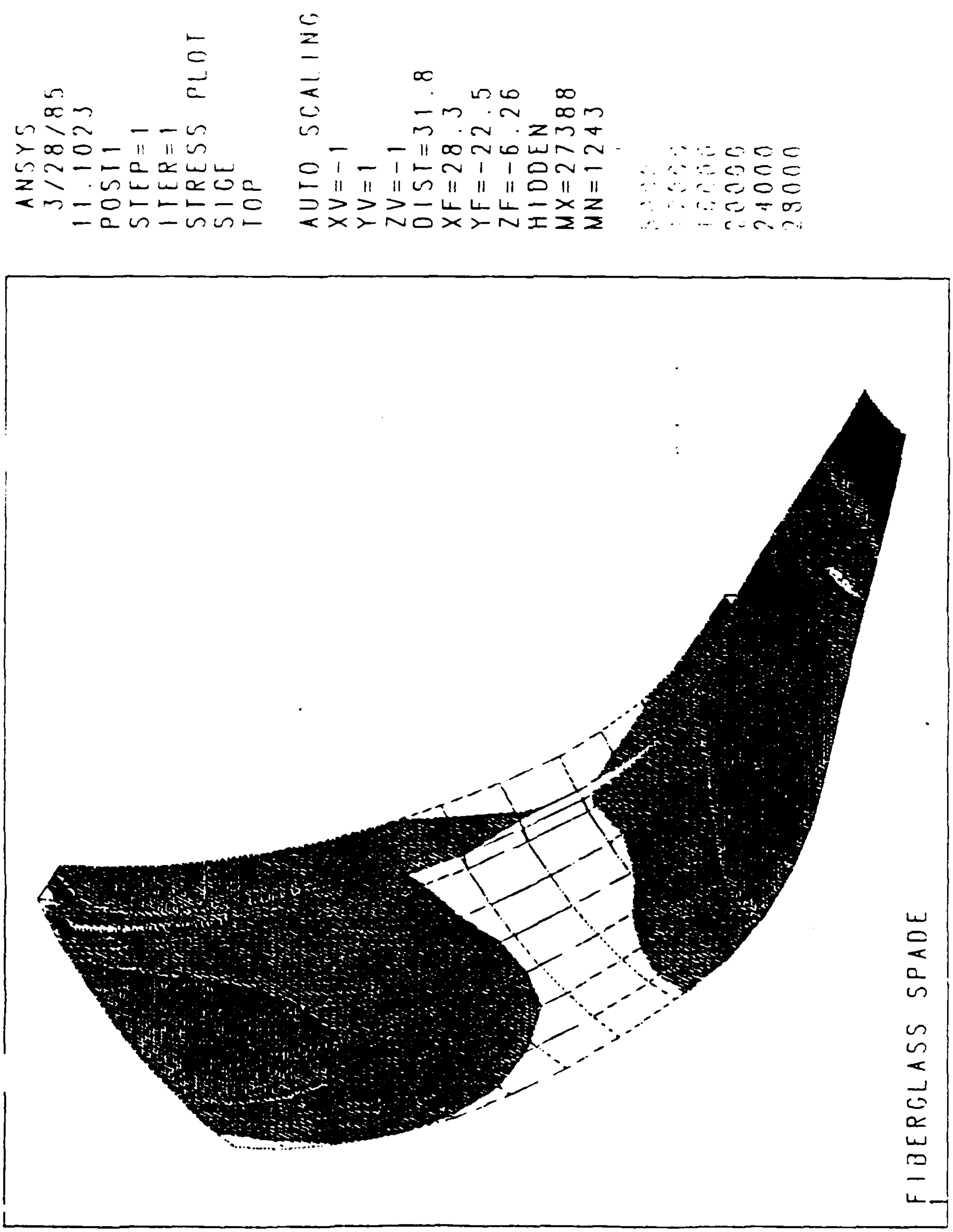

TITANIUM SPADE - STATIC PRESSURE LOAD

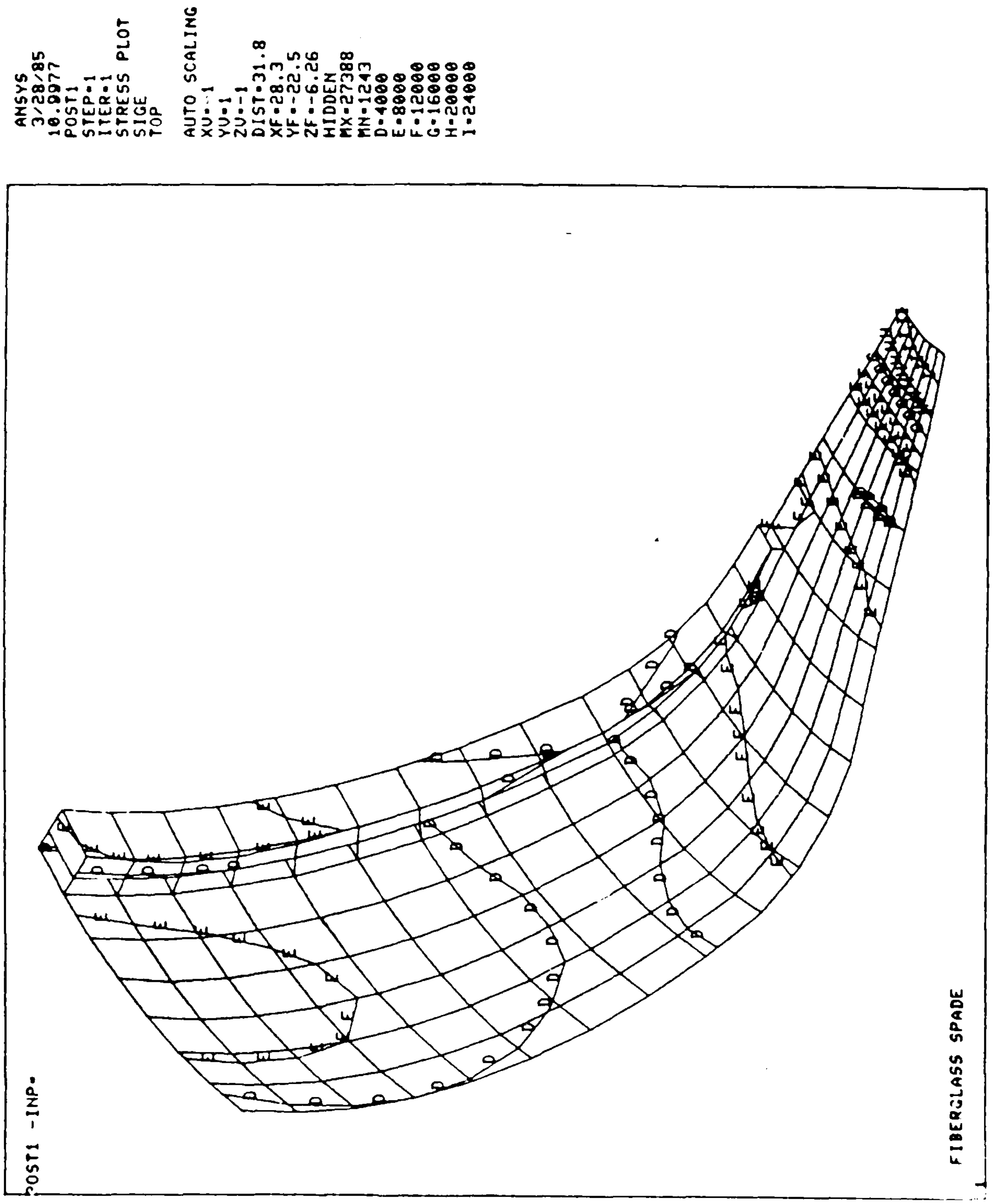
# APPENDIX HT7 - D16

## ATTACHMENT C

Displacement and Stress Contour Plots - Fiberglas Spade

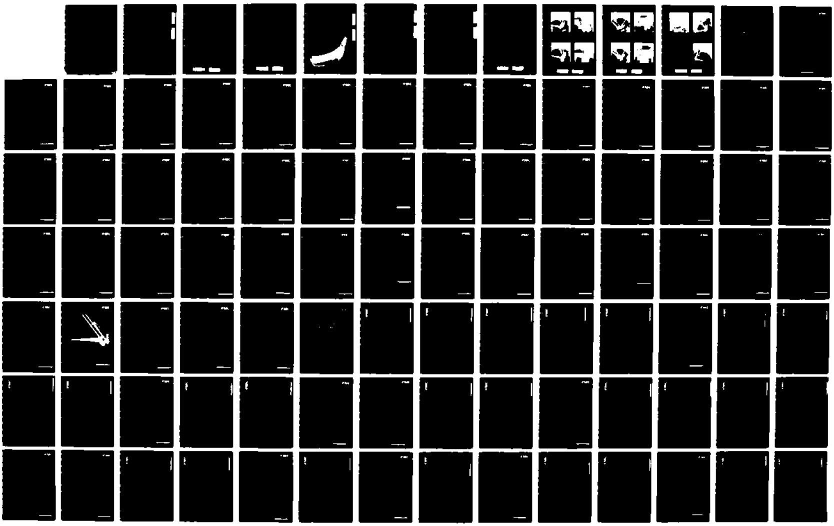
[redacted] [redacted]

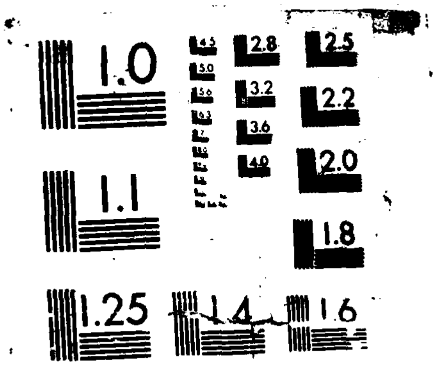

ANSYS
3/28/85
11.1023
POST1
STEP=1
ITER=1
STRESS PLOT
SIGE
TOP
AUTO SCALING
XV=-1
YV=1
ZV=-1
DIST=31.8
XF=28.3
YF=-22.5
ZF=-6.26
HIDDEN
MX=27388
MN=1243
20000
24000
28000
FIBERGLASS SPADE


ANSYS
3/28/85
10.9977
POST1
STEP=1
ITER=1
STRESS PLOT
SIGE
TOP
AUTO SCALING
XV=-1
YV=1
ZV=-1
DIST=31.8
XF=28.3
YF=-22.5
ZF=-6.26
HIDDEN
MX=27388
MN=1243
D=4000
E=8000
F=12000
G=16000
H=20000
I=24000
POST1 -INP-
FIBERGLASS SPADE

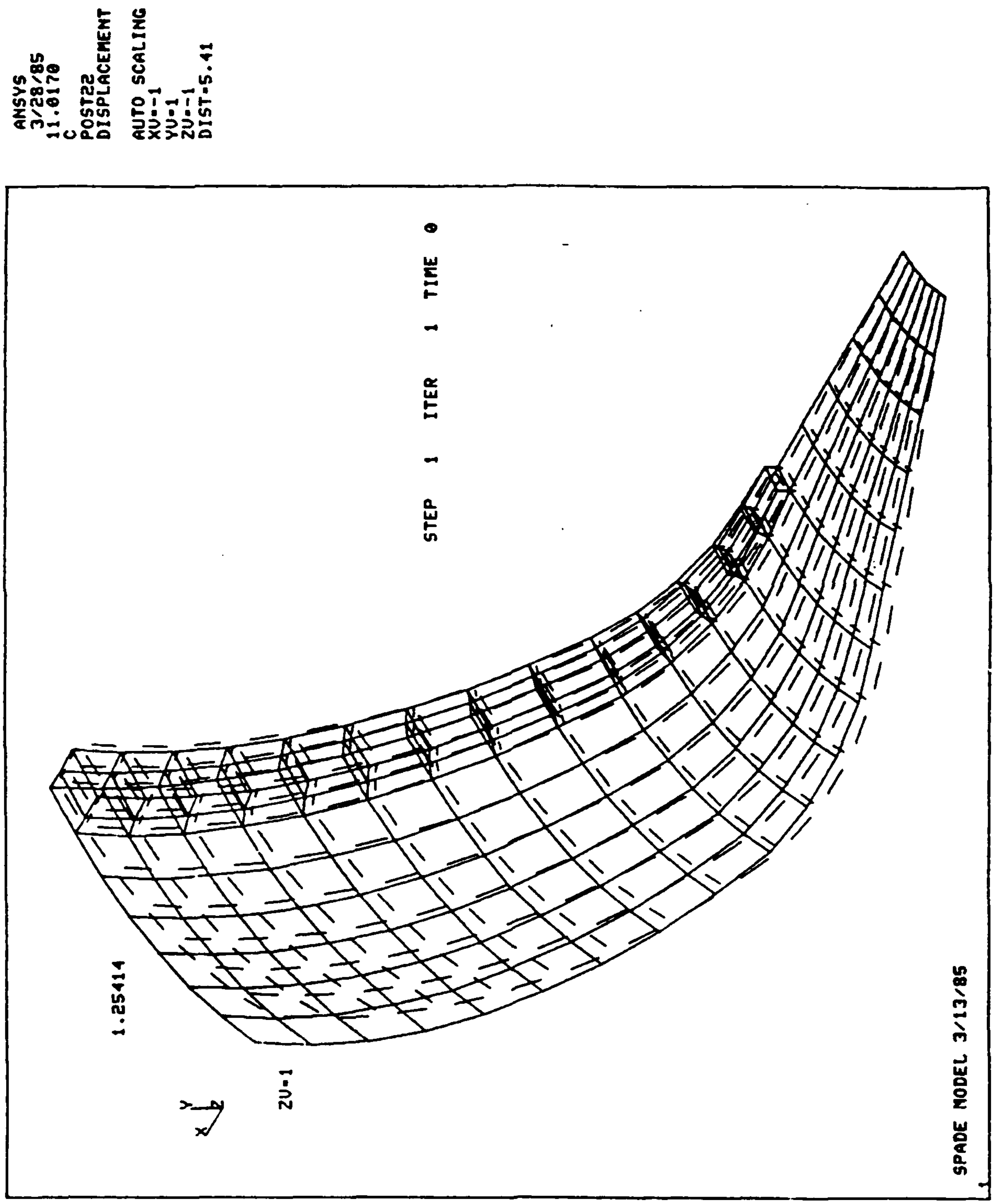
AD-A183 983 LIGHTWEIGHT TOWED HOWITZER DEMONSTRATOR PHASE 1 AND PARTIAL PHASE 2 VOLUM (U) FMC CORP MINNEAPOLIS MINN NORTHERN ORDNANCE DIV R RATHE ET AL APR 87 3/4

UNCLASSIFIED FMC-E-3041-VOL-B-PT-1 DAAA21-86-C-0047 F/G 19/6 NL






MICROCOPY RESOLUTION TEST CHART


ANSYS
3/28/85
11.0170
C
POST22
DISPLACEMENT
AUTO SCALING
XV=-1
YV=1
ZV=-1
DIST=5.41
STEP 1 ITER 1 TIME 0
1.25414
ZV=1
SPADE MODEL 3/13/85

APPENDIX HT7 - D20

ATTACHMENT D

Displacement and Stress Contour Plots - Steel Spade
**Transient Dynamic Analysis Results**

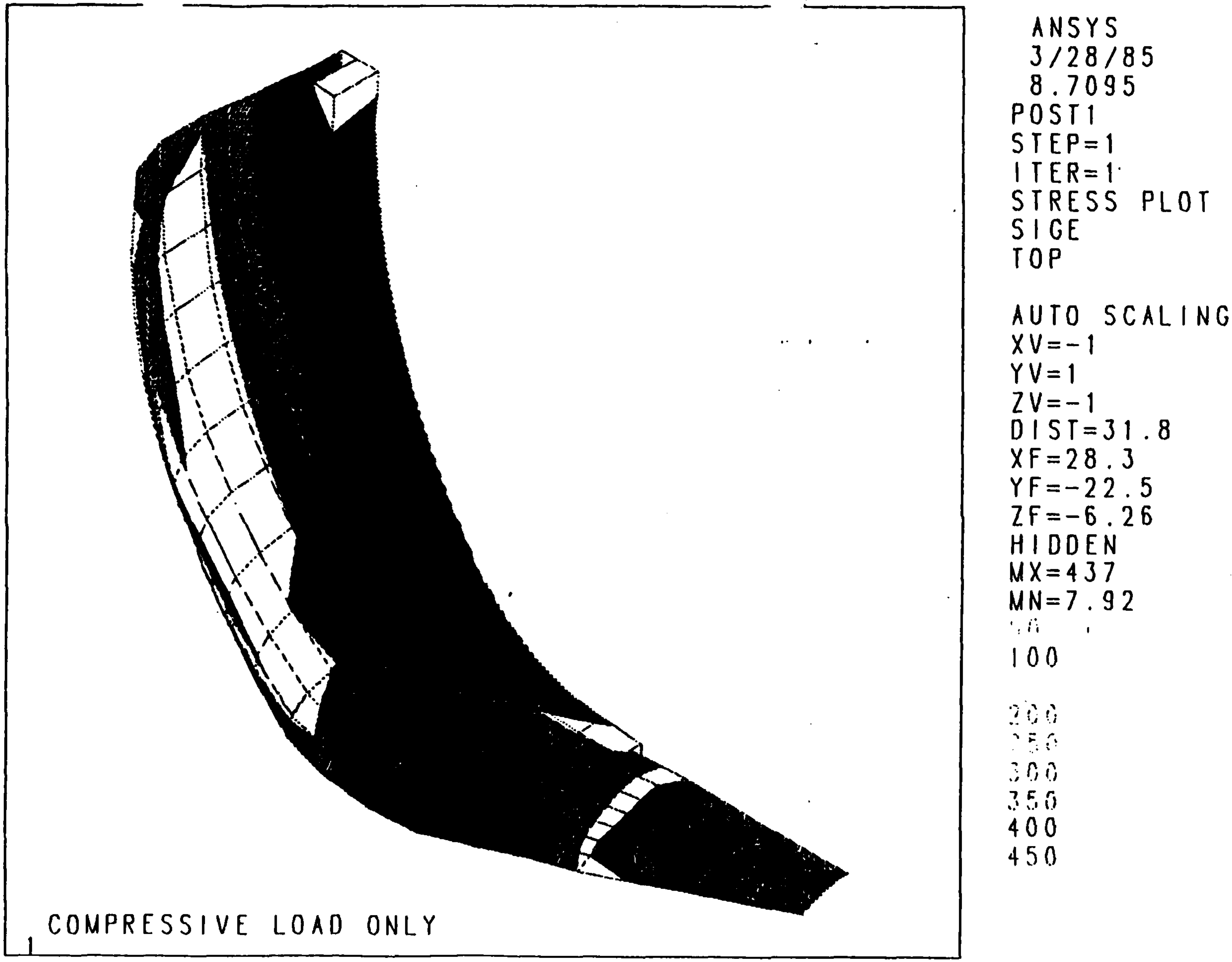
[redacted] [redacted]

# ATTACHMENT E

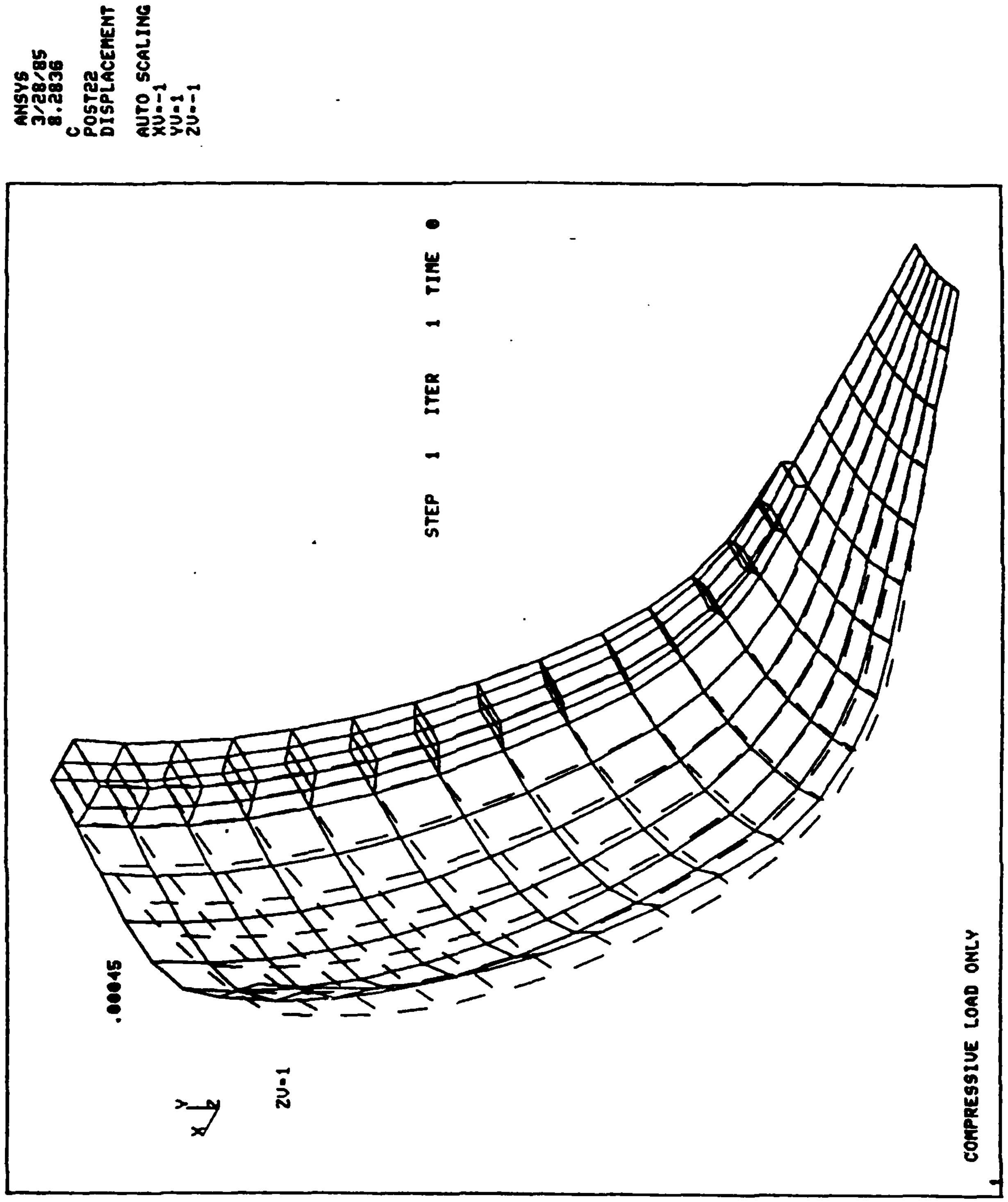
## Displacement and Stress Contour Plots - Steel Spade

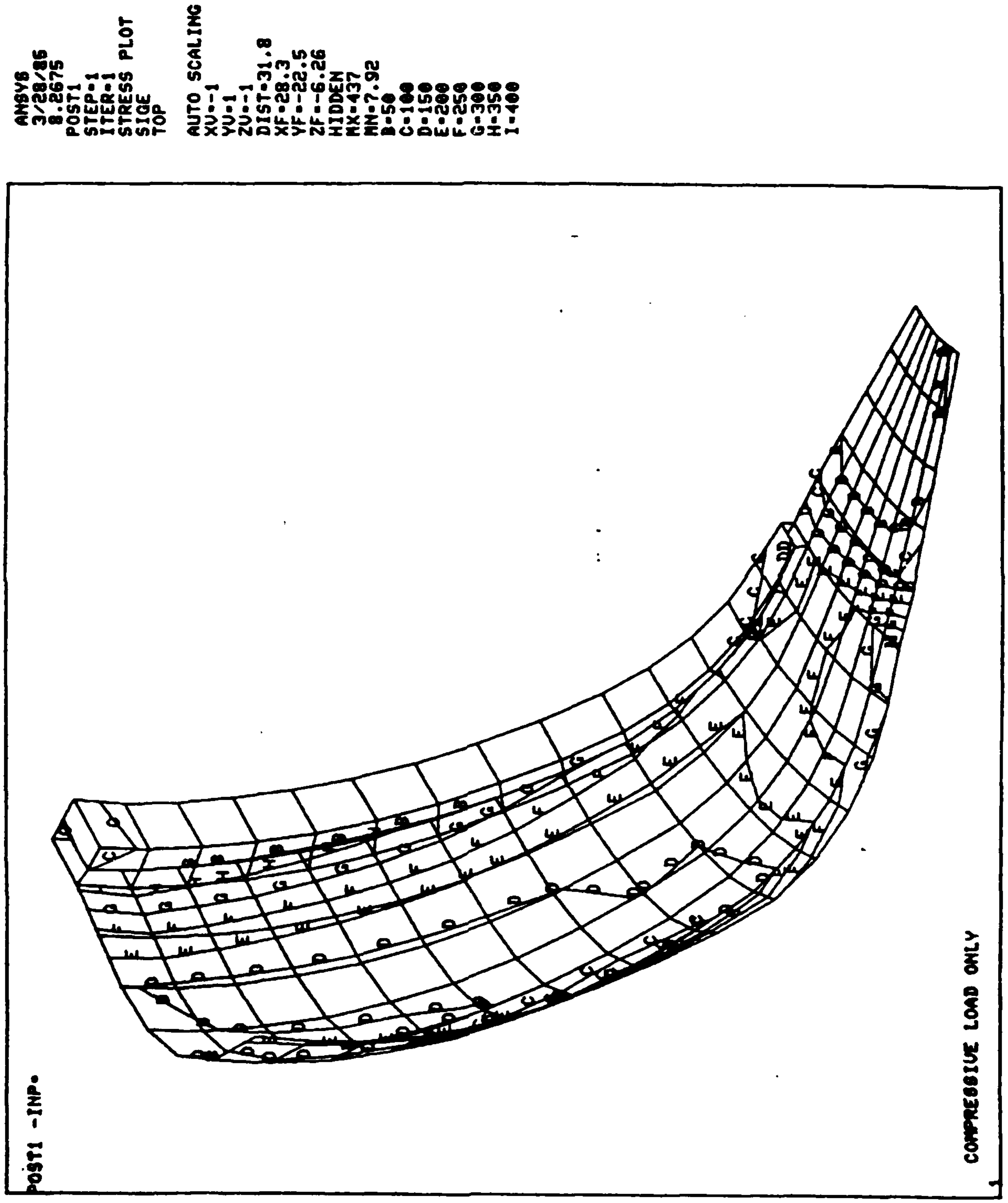
**Compressive Load Case Results**

[redacted] [redacted]


ANSYS
3/28/85
8.7095
POST1
STEP=1
ITER=1
STRESS PLOT
SIGE
TOP
AUTO SCALING
XV=-1
YV=1
ZV=-1
DIST=31.8
XF=28.3
YF=-22.5
ZF=-6.26
HIDDEN
MX=437
MN=7.92
100
200
250
300
350
400
450
COMPRESSIVE LOAD ONLY
1

[redacted]


ANSYS
3/28/85
8.2836
C
POST22
DISPLACEMENT
AUTO SCALING
XV=-1
YV=1
ZV=-1
STEP 1 ITER 1 TIME 0
.00045
ZV=1
COMPRESSIVE LOAD ONLY


ANSYS
3/28/85
8.2675
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STEP=1
ITER=1
STRESS PLOT
SIGE
TOP
AUTO SCALING
XV=-1
YV=1
ZV=-1
DIST=31.8
XF=28.3
YF=-22.5
ZF=-6.26
HIDDEN
MX=437
MN=7.92
B=50
C=100
D=150
E=200
F=250
G=300
H=350
I=400
POST1 -INP.
COMPRESSIVE LOAD ONLY

Negotiation Issues

FMC

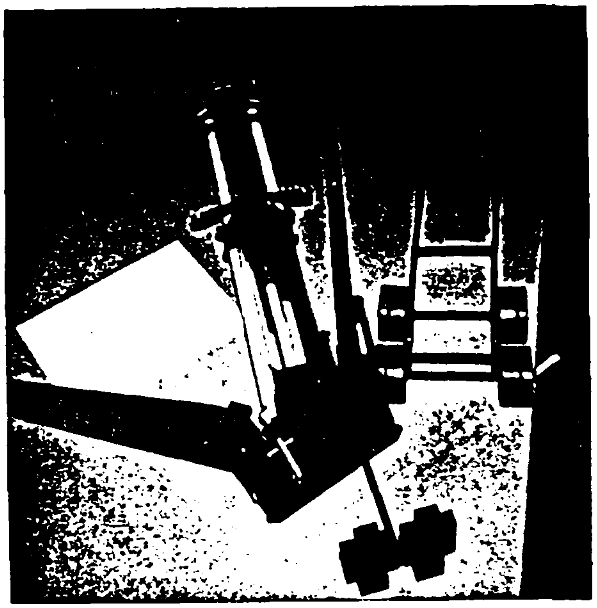
155MM LIGHTWEIGHT HOWITZER DEMONSTRATOR

Technical Issues:

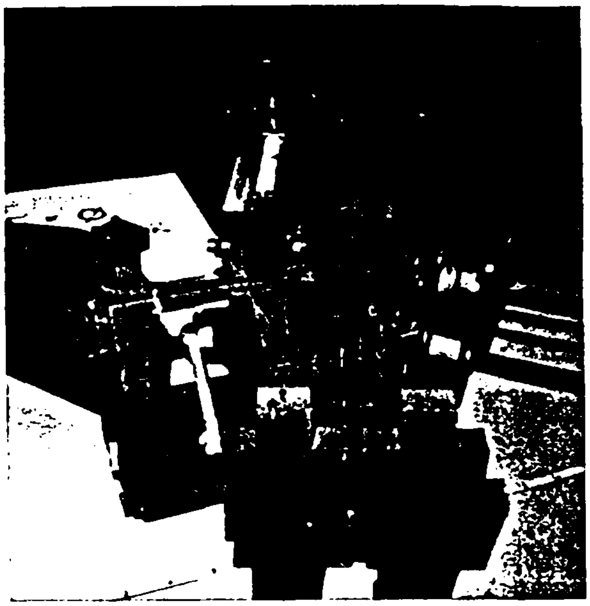
Issue 8. Provide additional detail to illustrate the operation of key subsystems; i.e., traverse mechanism operation and load tray interference at various traverse positions.

FMC Response. Photographs of the FMC LTHD model (1:12 scale) shown in Figures HT8-1 through -3 illustrate the operation of the traverse cylinder and load tray at traverse and elevation extremes during loading and ramming. The traverse cylinder has been color-coded "wood pencil yellow" for easy identification. The traverse cylinder attachment points have been color-coded "oil-base clay green" for the same reason.

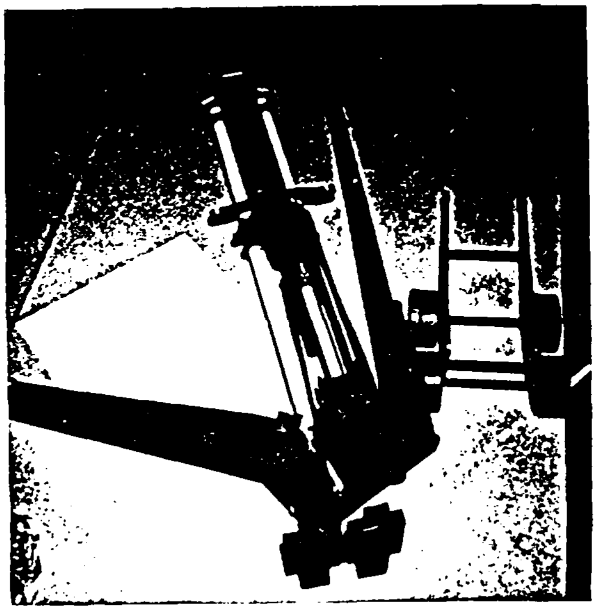
[redacted] [redacted]



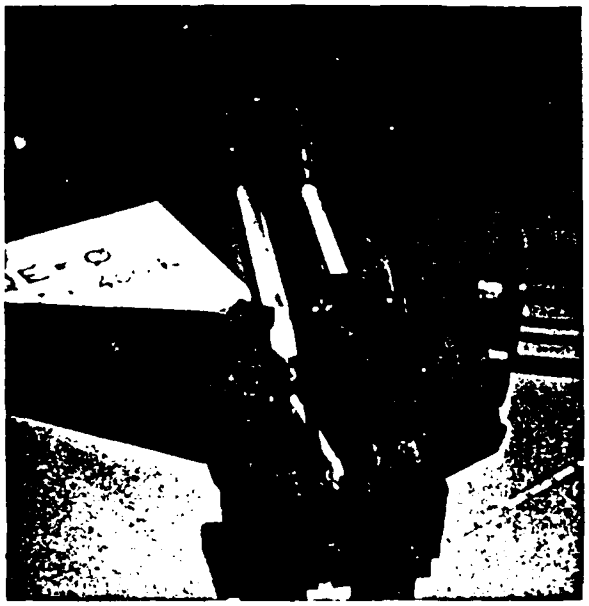
Loading



Loading Close-Up



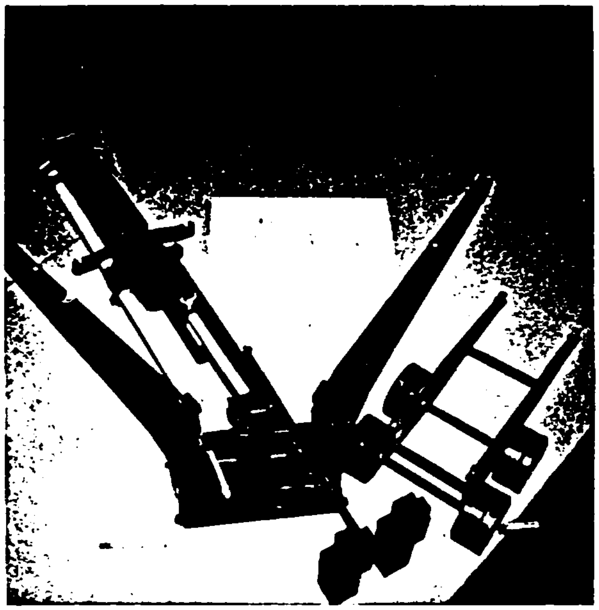
Ramming



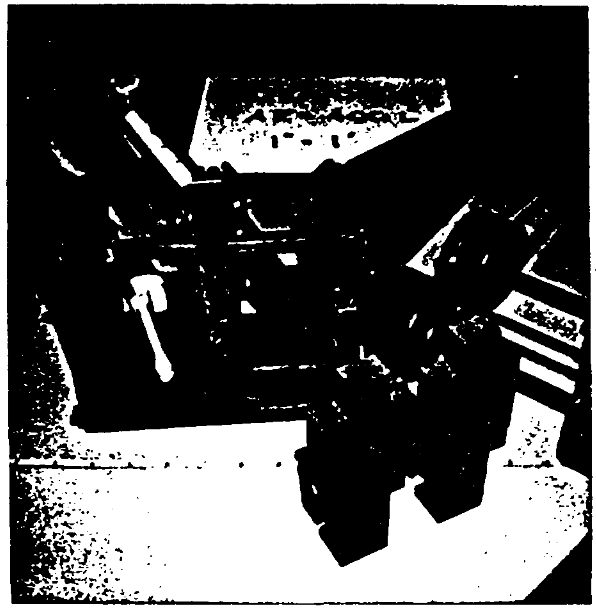
Ramming Close-Up

Figure HT8-1. Load Tray Operation at 400 Mils Right Traverse (Zero QE).

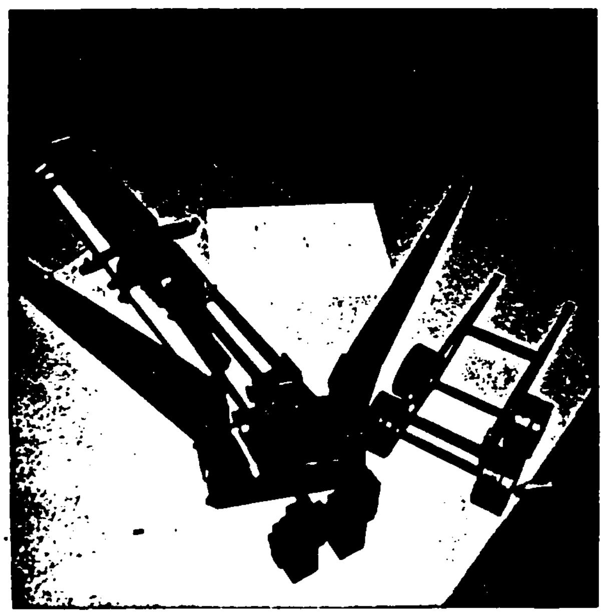
[redacted]



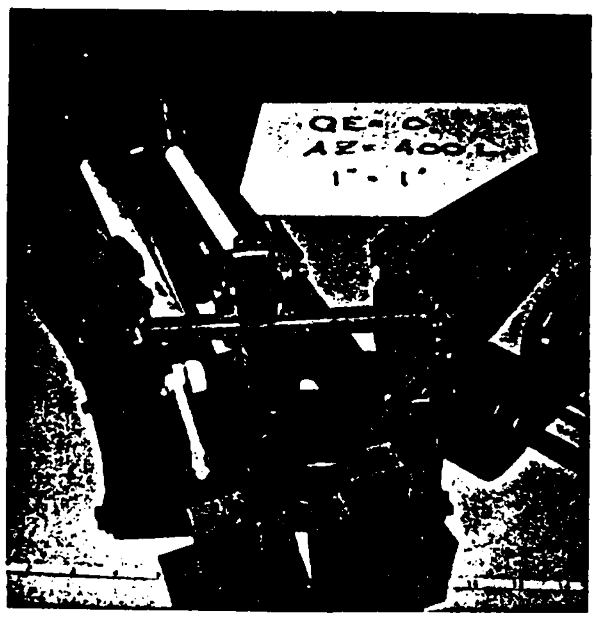
Loading



Loading Close-Up



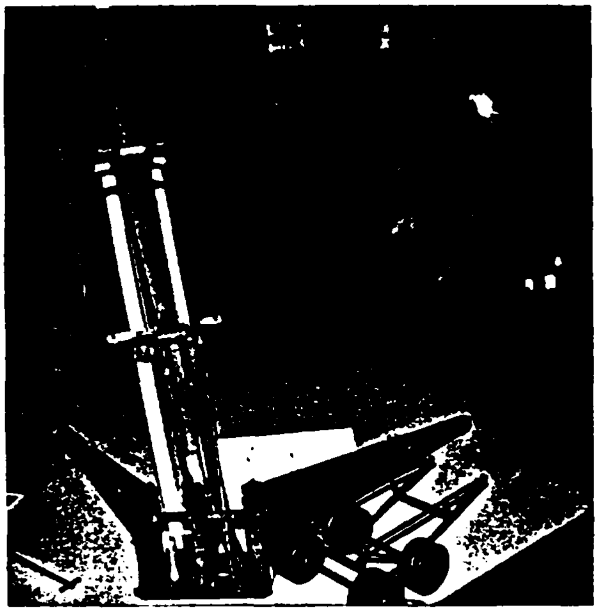
Ramming



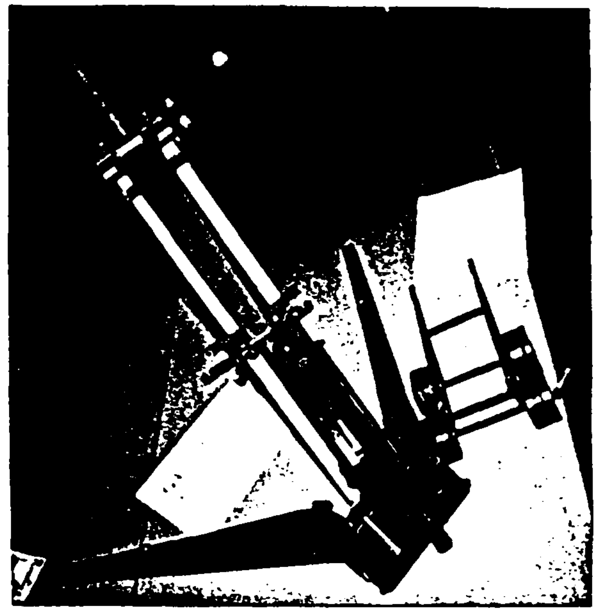
Ramming Close-Up

Figure HT8-2. Load Tray Operation at 400 Mils Left Traverse (Zero QE).

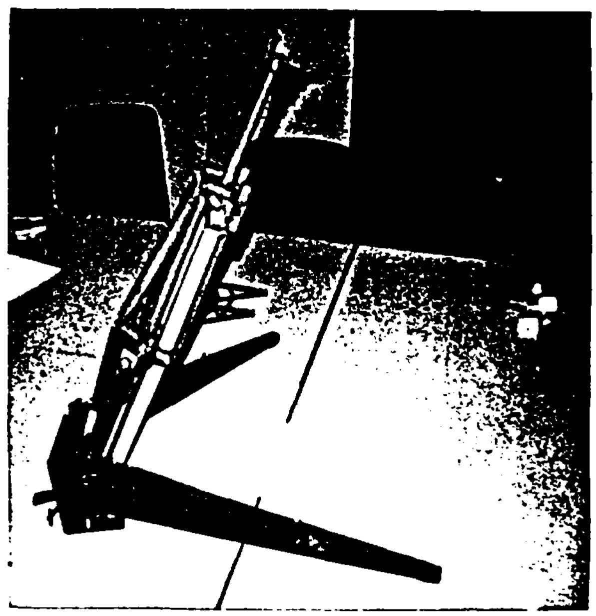
[redacted] [redacted]



400 Mils Left



400 Mils Right



Side View

Figure HT8-3. Load Tray Clearance at 1300 Mils QE.

[redacted] [redacted]

B/300

04 MAR 86

TECHNICAL
PRESENTATION
PHASE I

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# FMC LTHD DESIGN REVIEW

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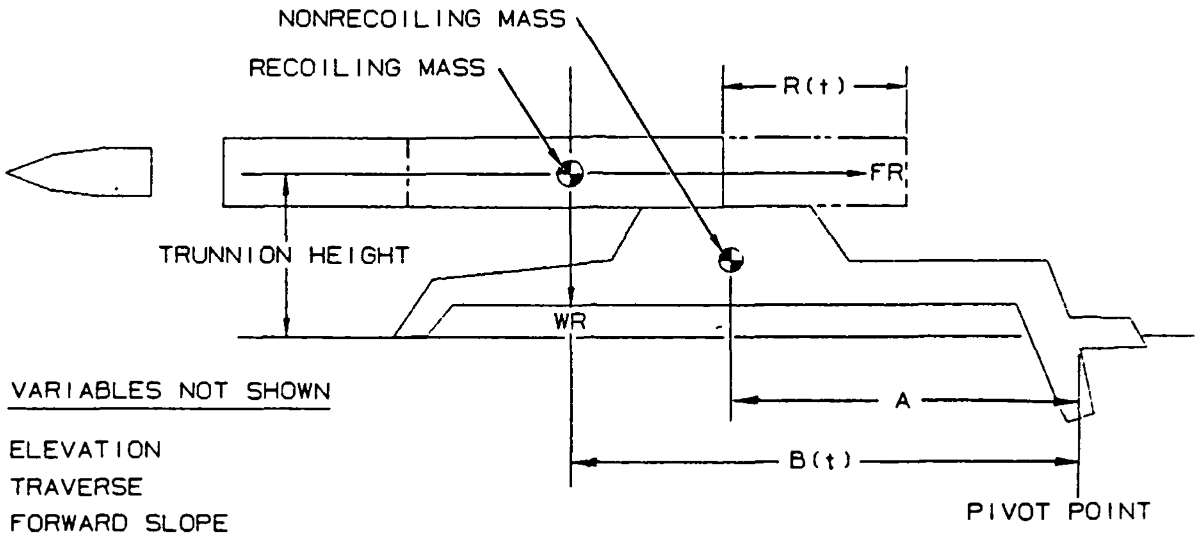
# THE WEIGHT-STABILITY RELATIONSHIP




VARIABLES NOT SHOWN

ELEVATION
TRAVERSE
FORWARD SLOPE
SLIDE SLOPE
SYSTEM ELASTICITY

HOP IS NORMALLY VIEWED AS "REARWARD HOP", AS SHOWN.
"SIDE HOP" IS ALSO ANALYZED, BUT NOT SHOWN.

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OVERVIEW OF THE CONFIGURATION

THREE 1/12 SCALE MODELS
HAVE BEEN CONSTRUCTED
FROM COMPUTER MODELS
TO VALIDATE OUR CONCEPTS

#1 ILLUSTRATES THE SYSTEM CONCEPT INITIALLY PROPOSED

ADDITIONAL MODELS VALIDATE SUBSYTEM REVISIONS FROM BAFO
(ADDRESSING HIGH QE LOADING)
#2: LOAD TRAY TO FACILITATE HIGH QE LOADING
#3: PLATFORM-SPADES-GIMBAL UNIT COMPATIBLE WITH LOAD TRAY

EVENTUALLY #1 WILL BE UPGRADED
TO INCLUDE THE SUBSYSTEM MODELS
CURRENTLY UNDER CONCEPTUAL DEVELOPMENT

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## Overview of the Configuration, continued

A. Emplacement

1. Extend Platform, which opens breech
   - Using the strap winch mounted to dolly
   - Yoke tube locks should snap into place
2. Verify Yoke-Tube Locks.
3. Release Travel Locks
4. Unlatch, Spread, and Relatch Trails
5. Unlatch Spades, Swivel Down, Relatch
   a. Latching of spades is achieved by
      - Bolt going thru spade perimeter into platform
      - Multiple holes are provided in spade perimeter
   b. Spade Depth (Arc) can be varied to suit terrain
6. Remove Helicopter Sling
7. Unlatch Dolly Clamps
8. Elev Cannon off Dolly (driving Spades into Ground)
9. Remove Dolly (if Firing below 250 mils)

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## OVERVIEW OF THE CONFIGURATION, CONTINUED

B. COMPONENTS

1. M185 STYLE BREECH (AUTO OPENING)
   - A. OPEN WITH LOOSE WRENCH INTEAD OF STANDARD HANDLE
     - STANDARD HANDLE HITS LOAD TRAY
     - LONGER HANDLE OVERCOMES STRONGER SPRING
   - B. STRONGER CLOSING SPRING FOR HIGH QE CLOSURE
2. AUTO PRIMER IS MOUNTED TO THE BREECH
   - A. SPENT PRIMER IS EJECTED
     - WHEN BREECH OPENS, OR
     - VIA TRIPPING A LEVER
   - B. NEW PRIMER IS INSERTED
     - WHEN BREECH CLOSES, OR
     - BY REVERSING THE TRIPPING LEVER
   - C. CLIP HOLDS TEN PRIMERS.
3. 39.3 CALIBER BARREL WITH M199 COMBUSTION CHAMBER
   - A. SAME MAXIMUM RANGE AS M198
   - B. SAME RESISTANCE TO STICKERS AS M198
4. M199 MUZZLE BRAKE WITH INTEGRAL LUNETTE
   - A. EMPLOYING BARREL AS BACKBONE DURING TOWING
5. RECOIL CYLINDERS ABOVE AND BELOW CANNON
   - A. FREE RECOIL DELAYS LOADING UNTIL SHOT EJECTION
   - B. 98 INCH EFFECTIVE STROKE PLUS 4 INCH OVERTRAVEL
6. SLIDE TUBES (10.5 INCH OD COMPOSITE) GUIDE RECOIL
   - A. PROVIDE MAXIMUM STIFFNESS AT MINIMUM WEIGHT
   - B. PROTECT CREW FROM SUPERLONG RECOIL STROKE

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## OVERVIEW OF THE CONFIGURATION, CONTINUED

B. COMPONENTS, CONTINUED

7. TITANIUM GIMBAL CARRIES LOAD INTO PLATFORM

8. INTEGRAL PLATFORM-SPADES-GIMBAL UNIT
   A. ELIMINATES LOOSE SPADES

9. TWO ELEV CYLS PROVIDE EQUIL, AZ, HI QE BREECH ACCESS

10. SWIVEL DOWN LOAD TRAY
    A. INCREASES RAMMING ACCELERATION DISTANCE
       - REDUCING RAMMING FORCES AT MAX QE
    B. KEEPS ARMS OUT OF BREECH, REDUCING RISK OF INJURY

11. FORWARD COMPOSITE TRAILS
    A. PROVIDES BALANCED WEIGHT DISTRIBUTION
    B. PLACES ALMOST 3,000 POUNDS OVER SPADES

12. DOLLY EMPLOYS HMMWV TIRES IN TANDEM
    A. SIMPLIFIES LOGISTICS
    B. "WHEELBASE" IMPROVES POTHOLE RESISTANCE
    C. PIGGYBACKS HMMWV WHEEL-TIRE WEIGHT SAVINGS EFFORTS

## OVERVIEW OF THE CONFIGURATION, CONTINUED

C. LAYING TUBE

1. EQUIL AND ELEV FORCES ARE PROVIDED BY HYDRAULICS

2. THESE FUNCTIONS ARE COMBINED INTO EACH CYLINDER

3. THE CYLINDERS ARE ATTACHED NEAR TRAILS
   - A. FACILITATES AN OPEN CENTER FOR HIGH QE LOADING
     - INITIAL CONCEPT USED ONE CENTERED CYLINDER WHICH OBSTRUCTED RAMMING STAFF ACCESS
   - B. CANNON ELEVATION LOADS BYPASS PLATFORM
     - SIMPLIFIES AND LIGHTENS PLATFORM

4. CYLINDERS ARE SIMPLIFIED THRU OVER-EQUILIBRATION
   - A. RESULTING IN THE NEED FOR ONLY 2 CONTROL CHAMBERS
     - CHAMBER 1 PROVIDES DEPRESSION FORCE
     - CHAMBER 2 PROVIDES EQUILIBRATION FORCE
       - CHAMBERS 2L AND 2R ARE COMMONED
   - B. ALL CONTROL IS ACHIEVED THRU CHAMBER 1
     - ADJUSTING OIL VOL UNIFORMLY IN 1L & 1R SETS QE
       - ELEV IS ACHIEVED BY VENTING TO TANK
       - DEPRESSION IS ACHIEVED BY PRESSURIZATION
     - TRANSFERRING OIL BETWEEN 1L AND 1R SETS AZ

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## OVERVIEW OF THE CONFIGURATION, CONTINUED

D. LOADING AND FIRING

1. ADJUST RAMMING STAFF LENGTH FOR ELEVATION
   A. SIX FOOT HANDLE BELOW 600 MILS
   B. FOUR FOOT HANDLE FROM 600 TO 800 MILS
   C. TWO FOOT HANDLE ABOVE 800 MILS

2. MOVE PROJECTILE FROM CARRIER INTO LOAD TRAY
   A. SLIDE FORWARD BELOW 800 MILS
   B. FLIP BACKWARD ABOVE 800 MILS

3. DROP LOAD TRAY (TWO HANDS REQUIRED)

4. PROJECTILE HANDLERS INITIATE MOTION (ABOVE 600 MILS)
   - APPLY FORCE TO RAMMING STAFF IN DIRECTION OF BREECH

5. PROJECTILE IS POSITIONED FOR RAM ONE FOOT FROM BREECH

6. PROJECTILE IS RAMMED THRU A 54 INCH STROKE (AT MAX QE)

7. RAMMING STAFF IS PARTIALLY RETRACTED

8. PROPELLANT IS SET INTO LOAD TRAY

9. PROPELLANT IS POSITIONED IN THE CHAMBER

10. THE RAMMING STAFF IS FULLY RETRACTED, WHICH HELPS

11. RETRACT THE LOAD TRAY, WHICH

12. TRIPS BREECH CLOSED, WHICH

13. INSERTS THE PRIMER.

14. TWIST LANYARD ROD
    A. THIS ACTUATES A LEVER ON THE AUTO PRIMER WHICH
    B. TRIPS THE LANYARD LEVER ON THE AUTO PRIMER

15. IGNITION AND RECOIL

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## OVERVIEW OF THE CONFIGURATION, CONTINUED

D. LOADING AND FIRING, CONTINUED

16. COUNTER-RECOIL, WHICH

17. OPENS BREECH, AND

18. EJECTS PRIMER.

19. EVERY TEN ROUNDS OR WITH STICKERS AND COOKOFFS
    A. TUBE SHOULD BE DEPRESSED
    B. COMBUSTION CHAMBER SHOULD BE SWABBED OUT
    C. PRIMER CLIP SHOULD BE REPLACED

E. MISFIRES

1. WAIT THREE MINUTES, IF NO RECOIL

2. REPLACE SPENT PRIMER
    A. HOOK LEVER ON AUTO PRIMER WITH RAMMER
    B. PULL DOWN, EJECTING SPENT PRIMER
    C. INSPECT PRIMER
    D. IF MECHANISM APPEARS TO BE WORKING SATISFACTORILY
    E. PUSH UP LEVER ON AUTO PRIMER WITH RAMMER
    F. WHICH INSERTS NEW PRIMER

3. RESUME LOAD-FIRE PROCESS AT STEP 14, TWIST LANYARD

F. HANGFIRES

1. WAIT THREE MINUTES

2. IF NO RECOIL, TREAT AS MISFIRE

3. IF RECOIL, RESUME LOAD-FIRE PROCESS FROM THE TOP

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## OVERVIEW OF THE CONFIGURATION, CONTINUED

G. STICKERS

1. WAIT THREE MINUTES
2. COMBUSTION CHAMBER IS VENTED
   A. HOOK LEVER ON AUTO PRIMER WITH RAMMER
   B. PULL DOWN, EJECTING PRIMER AND RELEASING GAS
3. TUBE IS DEPRESSED
4. BREECH IS OPENED WITH WRENCH
5. PROJECTILE IS REMOVED (UNLESS PLAN IS LARGER CHARGE)
6. PRIMER CLIP IS REPLACED IF NECESSARY
7. TUBE IS ELEVATED
8. LOAD-FIRE PROCESS IS RESUMED
   A. WITH NEW PROJECTILE, STEP 2 (LOAD PROJECTILE)
   B. WITH LARGER CHARGE, STEP 8 (LOAD PROPELLANT)

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## OVERVIEW OF THE CONFIGURATION, CONTINUED

### H. COOKOFF

1. SWIVEL LOAD TRAY UP
   - A. TO THE STOP, TO COMPLETE LOAD-FIRE PROCESS
   - B. PARTIALLY, TO BURN CHARGE IN THE ATMOSPHERE
     - SLOSH WATER UP LOAD TRAY TO PROTECT IT FROM HEAT
     - DEPRESS TUBE TO CLEAN OUT COMBUSTION CHAMBER
     - RESUME LOAD-FIRE PROCESS, STEP 8 (LOAD CHARGE)
2. NOTE POSITION OF TEMPERATURE INDICATOR

### I. SPEEDSHIFT

1. UNLATCH, SWIVEL UP, RELATCH SPADES
2. ELEVATE CANNON TO 250 MILS
3. POSITION DOLLY UNDER THE CANNON
4. DEPRESS CANNON TO ZERO QE
5. LATCH AT LEAST TWO (DIAGONAL) DOLLY CLAMPS
6. LOCK ONE REAR WHEEL
7. LIFT CANNON AT THE MUZZLE BRAKE AND TRAVERSE
8. UNLATCH DOLLY CLAMPS
9. UNLATCH, SWIVEL DOWN, RELATCH SPADES
10. ELEVATE CANNON OFF DOLLY (DRIVING SPADES INTO GROUND)
11. REMOVE DOLLY (IF FIRING BELOW 250 MILS)

## OVERVIEW OF THE CONFIGURATION, CONTINUED

J. DISPLACEMENT

1. UNLATCH, SWIVEL UP, RELATCH SPADES
2. ELEVATE CANNON TO 250 MILS
3. POSITION DOLLY UNDER THE CANNON
4. DEPRESS CANNON TO ZERO QE
5. RELEASE YOKE-TUBE LOCKS
6. LIFT BREECH CAM AND CLOSE BREECH
7. LATCH DOLLY CLAMPS
8. RETRACT PLATFORM WITH STRAP WINCH
9. UNLATCH, CLOSE, RELATCH TRAILS
10. SECURE TRAVEL LOCKS

# A View of the FMC Approach in Retrospect

The Traditional Howitzer Configuration
has been altered

because it
Retains M198 Stability at below Weight Target

while facilitating the use of
Traditional Lightweight Structures

and reducing
System Risk through Diversification of Subsystem Risk

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## A VIEW OF THE FMC APPROACH IN RETROSPECT, CONTINUED

A. RECONFIGURATION RETAINS M198 STABILITY THROUGH

1. LOWER TRUNNION REDUCES OVERTURNING MOMENT ARM
2. SUPERLONG RECOIL STROKE REDUCES RECOIL FORCES
3. MINIMIZATION OF NON-RECOILING MASS WITH COMPOSITES
4. MAXIMIZING RECOILING MASS REDUCES RECOIL FORCES
5. SHAPING OF RECOIL FORCE PROFILE MAXIMIZES STABILITY
6. INCREASED VERTICAL SPADE LOADS RESIST LIFT-OUT
   - DUE TO BALANCED DISTRIBUTION OF WEIGHT
7. INCREASED SPADE AREA (INCREASES SKID RESISTANCE)



[redacted]

## A View of the FMC Approach in Retrospect, continued

B. Traditional Lightweight Structures include

1. Organic Composite Construction
   - a. Trails
   - b. Slide tubes used to guide cannon recoil
   - c. Projectile Carrier
   - d. Load Tray
2. Metal/Organic Composite construction
   - a. Two Cannon Mounting Yokes
   - b. Recoil Mounting Yoke
   - c. Platform
   - d. Bellows Accumulators
3. Titanium
   - a. Spades
   - b. Breech Cam
   - c. Gimbal
4. 7075-T6
   - a. Recoil Cylinder Assemblies
   - b. Elevation/Equilibration Cylinder Assemblies
5. Space Frame construction
   - a. Dolly

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## A VIEW OF THE FMC APPROACH IN RETROSPECT, CONTINUED

C. SUBSYSTEM RISK IS DIVERSIFIED THROUGH

1. EMPLOYMENT OF A TRADITIONAL (BUT LONG) RECOIL SYSTEM
2. COMPATIBILITY WITH SOFT RECOIL THROUGH FORWARD TRAILS
3. COMPATIBILITY WITH SUPERLONG MICROPROCESSOR RECOIL
4. TANDEM HMMWV TIRES TO REDUCE "SUSPENSION" STIFFNESS
   - M198 TIRES ARE 3+ TIMES STIFFER (45 VS 20 PSI)
5. DOLLY SIMPLIFIES ADDITION OF SUSPENSION (IF NEEDED)
   - IF SOFTER TIRES AREN'T ENOUGH DUE TO
   - REDUCED MOMENT OF INERTIA FROM LESS WEIGHT
   - HIGHER CG FROM WEIGHT REDUCED LOWER CARRIAGE
6. REDUCED BLAST OVERPRESSURE EXPOSURE TO CREW
   - MUZZLE BRAKE IS ROUGHLY TEN FEET FURTHER FROM CREW
7. CONTINGENCIES FOR ADDITIONAL HOP/SLIDE MARGIN
   - RECOIL OVERTRAVEL BUFFERS COULD REDUCE FORCES 4%
   - NO FREE RECOIL COULD REDUCE FORCES ANOTHER 4%
   - ADDITION OF MINI-SPADES ON TRAIL ENDS COULD
     - INCREASE RECOIL FORCE NECESSARY TO PRODUCE HOP
     - INCREASE SPADE AREA RESISTING SKID
   - SPADE MODIFICATIONS COULD PROVIDE A SECONDARY RECOIL

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A VIEW OF THE FMC APPROACH IN RETROSPECT, CONTINUED

8. MANY COMPONENTS COMPATIBLE WITH MULTIPLE TECHNOLOGIES
   - SPADES (STEEL, TI, OR SIC/AL METAL MATRIX)
   - OUTER ELEVATION CYLINDER (AL, AL/LI, SIC/AL, CFE/TI)
   - OUTER RECOIL CYLINDER (AL, AL/LI, SIC/AL, OR CFE/TI)
     - ALREADY CONFIGURED FOR HEAT REJECTION (CFE/TI)
       - BY ORIFICING AGAINST OUTER CYLINDER
   - GIMBAL (TI OR AL)
   - YOKES (TI/COMPOSITE, AL, OR TI)
   - RECOIL ACCUMULATORS (BELLOWS OR PISTON)
   - DOLLY (RACE CAR SPACE FRAME TECHNOLOGIES)

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Purpose: Optimal Design

To Date
what will Do.

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ANALYSIS AND DESIGN

1. BALLISTICS

BL
worst case
Zone 1

2. FIRING STABILITY

Recoil R.C. Design
Clee.

3. TOWING STABILITY

SF
Dyn.

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# BALLISTICS

- BARREL LENGTH
- ZONE 8S
- ZONE 1

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## LTHD BARREL LENGTH TO MAINTAIN M198 RANGE

| | M198 | LTHD |
|---|---|---|
| RECOIL COMPONENT WEIGHT, LBS | 7258 | 4611 |
| RECOIL COMPONENT MASS, SLUGS | 225 | 143 |
| TIME PROJECTILE IS IN BARREL, MILLISECONDS | 12.79 | 12.74 |
| MUZZLE VELOCITY WITH RESPECT TO GROUND, FT/SEC | 2831.1 | 2825.6 |
| RANGE, METERS | 24309 | 25252 |

LTHD BARREL LENGTH = M198 BARREL LENGTH + 1.8 INCHES

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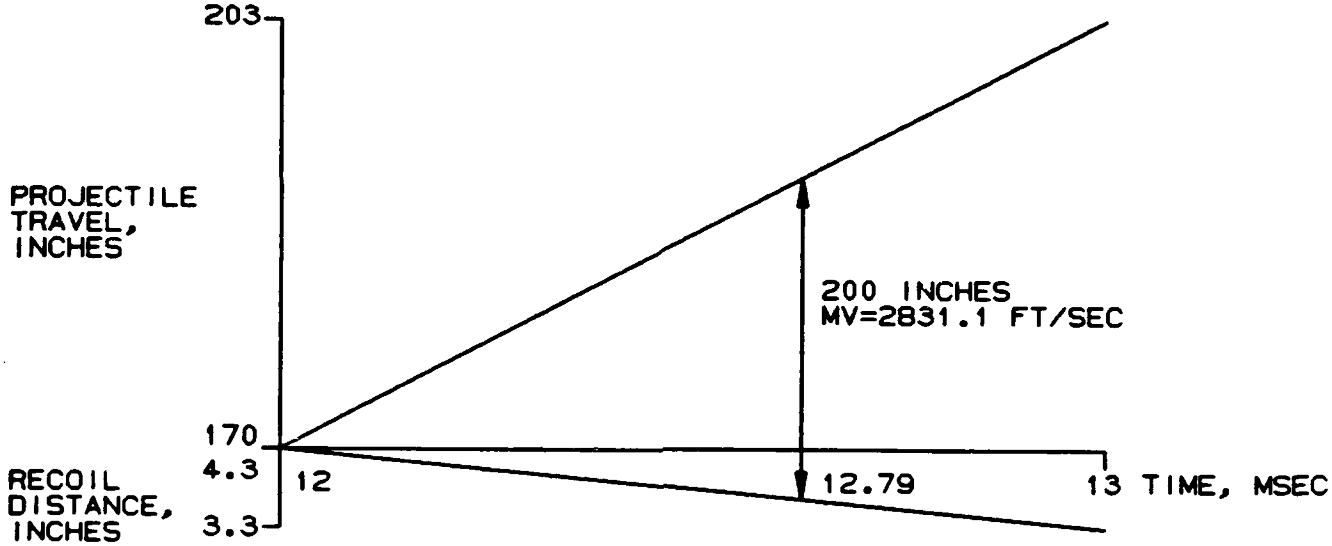
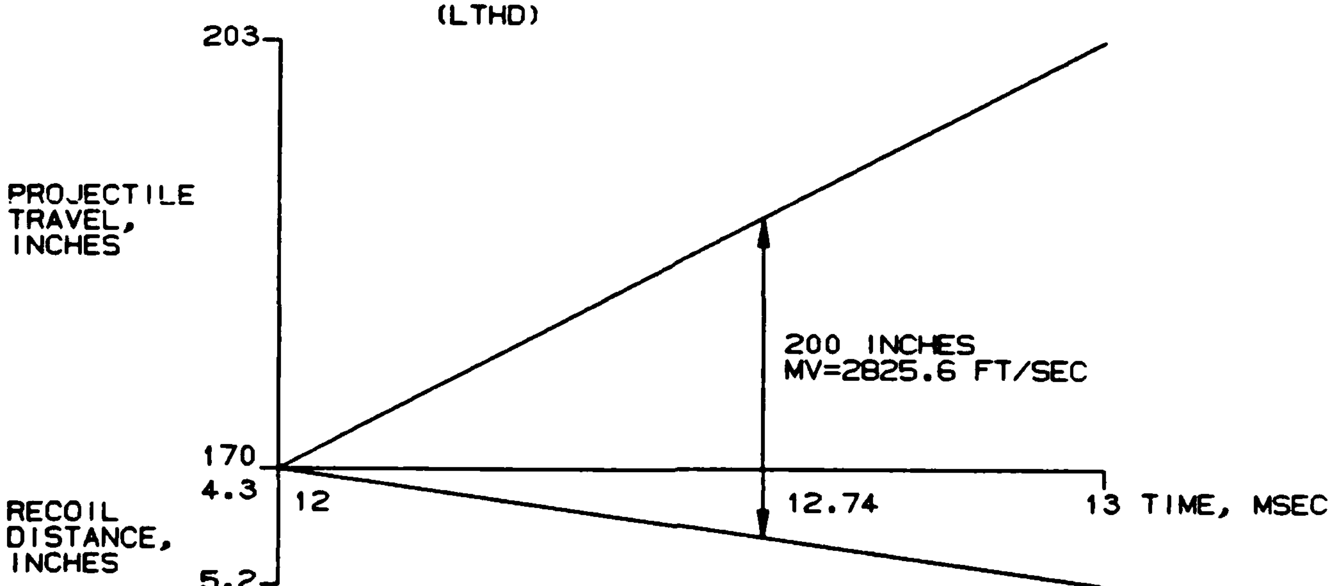
RECOILING MASS=225 SLUGS (7258 LBS)
(M198)




RECOILING MASS=143 SLUGS (4611 LBS)
(LTHD)

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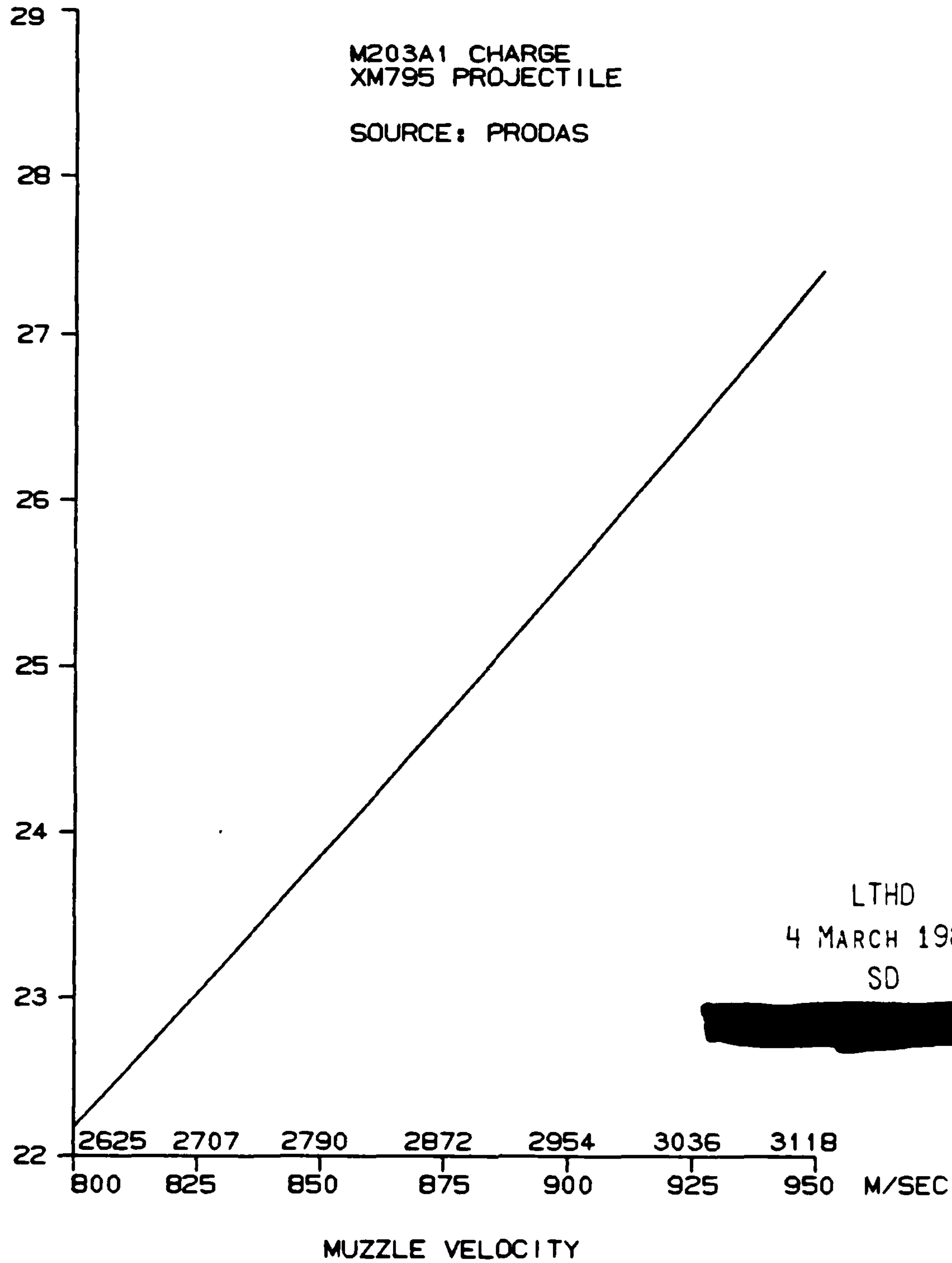
MUZZLE VELOCITY VS RANGE

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ZONE 8S (WORST CASE) BALLISTICS

TEMPERATURE:

145 DEGREES F

CHARGE: ZONE 8S

M203

M203A1

PROJECTILE:

M549 (96 LBS)

XM795 (105.6 LBS)

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## BALLISTIC PARAMETERS

| | |
|---|---|
| BORE CROSS-SEC AREA, SQ. IN. | 29.81 |
| BORE DIAMETER, IN | 6.16 |
| SHOT START PRESSURE, PSI | 2000 |
| BARREL RESISTANCE PROFILE INCHES, PSI | |
| 0.4 | 2512 |
| 1.0 | 3712 |
| 1.6 | 2719 |
| 2.1 | 2437 |
| 4.5 | 1875 |
| 212 | 1365 |
| PROJECTILE WEIGHT, LBS | |
| M549 PROJECTILE | 96 |
| XM795 PROJECTILE | 105.6 |
| BARREL LENGTH, INCHES | |
| M198 | 198.6 |
| LTHD | 198.6 + 1.8 |
| CHAMBER VOLUME, CU. IN. | |
| WITH M549 PROJECTILE | 1147 |
| WITH XM795 | 1188 |

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# CHARGE CHARACTERISTICS - M203

| | |
|---|---|
| PRIMER | |
| WEIGHT, LBS | .25 |
| CO-VOL, CU. IN. /LB | 24.3 |
| IMPETUS,IN-LBF/LB | 1260000 |
| RATIO OF SP. HEATS | 1.25 |
| FLAME TEMP, K | 2380 |
| PROPELLANT - M30A1 | |
| WEIGHT, LBS | 26.3 |
| CO-VOL, CU. IN. /LB | 29.13 |
| IMPETUS,IN-LBF/LB | 4312800 |
| RATIO OF SP. HEATS | 1.2380 |
| FLAME TEMP, K | 3025 |
| DENSITY,LB/CU. IN. | .06 |
| GRAIN DIA, IN | .4514 |
| GRAIN LENGTH, IN | 1.0124 |
| BURNING RATE COEFF, IN/SEC/PS | .0049310 |
| BURNING RATE EXPONENT | .6743 |
| PERFORATION DIA., IN | .0451 |
| PERFS PER GRAIN | 1 |
| WITH M549 PROJECTILE: | |
| MAX PRESSURE, PSI (145 DEG F) | 54400 |
| MUZZLE VELOCITY, FT/SEC | 2843 |

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## CHARGE CHARACTERISTICS - M203A1

PRIMER

| | |
|---|---|
| WEIGHT, LBS | .10625 |
| CO-VOL, CU. IN. /LB | 24.3 |
| IMPETUS,IN-LBF/LB | 1260000 |
| RATIO OF SP. HEATS | 1.25 |
| FLAME TEMP, K | 2380 |

PROPELLANT - M30A1

| | |
|---|---|
| WEIGHT, LBS | 28.0 |
| CO-VOL, CU. IN. /LB | 27.23 |
| IMPETUS,IN-LBF/LB | 3982200 |
| RATIO OF SP. HEATS | 1.2506 |
| FLAME TEMP, K | 2629 |
| DENSITY,LB/CU. IN. | .0593 |
| GRAIN DIA, IN | .240 |
| GRAIN LENGTH, IN | 29.00 |
| BURNING RATE COEFF, IN/SEC/PS | .0009173 |
| BURNING RATE EXPONENT | .8074 |
| PERFORATION DIA., IN | .080 |
| PERFS PER GRAIN | 1 |

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# CHARGE CHARACTERISTICS - M203A1 CONTINUED

COMBUSTIBLE CASE - NC

| | |
|---|---|
| WEIGHT, LBS | 1.75 |
| CO-VOL, CU. IN. /LB | 30.00 |
| IMPETUS,IN-LBF/LB | 2160000 |
| RATIO OF SP. HEATS | 1.250 |
| FLAME TEMP, K | 1553 |
| DENSITY,LB/CU. IN. | .0340 |
| GRAIN DIA, IN | 6.25 |
| GRAIN LENGTH, IN | 30.35 |
| BURNING RATE COEFF, IN/SEC/PS | .0015 |
| BURNING RATE EXPONENT | 1.0 |
| PERFORATION DIA., IN | 6.226 |
| PERFS PER GRAIN | 1 |

WITH M549 PROJECTILE:

| | |
|---|---|
| MAX PRESSURE, PSI (145 DEG) | 56000 |
| MUZZLE VELOCITY, FT/SEC | 2820 |

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# VARIATION IN IMPULSE CALCULATIONS

CONDITIONS:

M203 CHARGE (8S) - 145 DEGREES F

M549 PROJECTILE

| MUZZLE BRAKE MOMENTUM INDEX | IMPULSE (LB-SEC) | | |
|---|---|---|---|
| | FMC | ARDC | % VAR |
| 0 (NO BRAKE) | 12,285 | 13,500 | -9.0 |
| .73 | 10,200 | 10,500 | -2.4 |
| 1.45 | 8,140 | 8,800 | -7.5 |

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ZONE 1 BALLISTICS

-- FOR CAM SIZING

TEMPERATURE:

-60 DEGREES F

CHARGE: ZONE 1

M3A1 ZONE 1

XM215

PROJECTILE:

M549 (96 LBS)

M485 (92 LBS)

MINIMUM STROKE: 14.9 INCHES

MINIMUM IMPULSE: 2,073 LB-SEC

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## CHARGE CHARACTERISTICS - M3A1 (ZONE 1)

| | |
|---|---|
| **PRIMER** | |
| WEIGHT, LBS | .25 |
| CO-VOL, CU. IN. /LB | 24.3 |
| IMPETUS,IN-LBF/LB | 1260000 |
| RATIO OF SP. HEATS | 1.25 |
| FLAME TEMP, K | 2380 |
| **PROPELLANT - M1** | |
| WEIGHT, LBS | 1.7688 |
| CO-VOL, CU. IN. /LB | 30.57 |
| IMPETUS,IN-LBF/LB | 3660000 |
| RATIO OF SP. HEATS | 1.2593 |
| FLAME TEMP, K | 2417 |
| DENSITY,LB/CU. IN. | .0567 |
| GRAIN DIA, IN | .1079 |
| GRAIN LENGTH, IN | .4963 |
| BURNING RATE COEFF, IN/SEC/PS | .0032310 |
| BURNING RATE EXPONENT | .6857 |
| PERFORATION DIA., IN | .0451 |
| PERFS PER GRAIN | 1 |
| **WITH M549 PROJECTILE:** | |
| MAX PRESSURE, PSI (-60 DEG F) | 4900 |
| MUZZLE VELOCITY, FT/SEC | 695 |

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## CHARGE CHARACTERISTICS - XM215

| | |
|---|---|
| PRIMER | |
| WEIGHT, LBS | .10625 |
| CO-VOL, CU. IN. /LB | 24.3 |
| IMPETUS,IN-LBF/LB | 1260000 |
| RATIO OF SP. HEATS | 1.25 |
| FLAME TEMP, K | 2380 |
| PROPELLANT - M1 | |
| WEIGHT, LBS | 3.3 |
| CO-VOL, CU. IN. /LB | 30.57 |
| IMPETUS,IN-LBF/LB | 3660000 |
| RATIO OF SP. HEATS | 1.2593 |
| FLAME TEMP, K | 2417 |
| DENSITY,LB/CU. IN. | .05670 |
| GRAIN DIA, IN | .0514 |
| GRAIN LENGTH, IN | .2245 |
| BURNING RATE COEFF, IN/SEC/PS | .0032310 |
| BURNING RATE EXPONENT | .6857 |
| PERFORATION DIA., IN | .018 |
| PERFS PER GRAIN | 1 |

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## CHARGE CHARACTERISTICS - XM215 CONTINUED

COMBUSTIBLE CASE - NC

| | |
|---|---|
| WEIGHT, LBS | .5 |
| CO-VOL, CU. IN. /LB | 30.00 |
| IMPETUS, IN-LBF/LB | 2160000 |
| RATIO OF SP. HEATS | 1.250 |
| FLAME TEMP, K | 1553 |
| DENSITY, LB/CU. IN. | .0340 |
| GRAIN DIA, IN | 5.8 |
| GRAIN LENGTH, IN | 7.0 |
| BURNING RATE COEFF, IN/SEC/PS | .0015 |
| BURNING RATE EXPONENT | 1.0 |
| PERFORATION DIA., IN | 5.766 |
| PERFS PER GRAIN | 1 |

WITH M549 PROJECTILE:

| | |
|---|---|
| MAX PRESSURE, PSI (-60 DEG F) | 8010 |
| MUZZLE VELOCITY, FT/SEC | 894 |

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FIRING STABILITY

RECOIL

RECOIL CYLINDER

SYSTEM FLEXIBILITY

COUNTER-RECOIL

CUSHION

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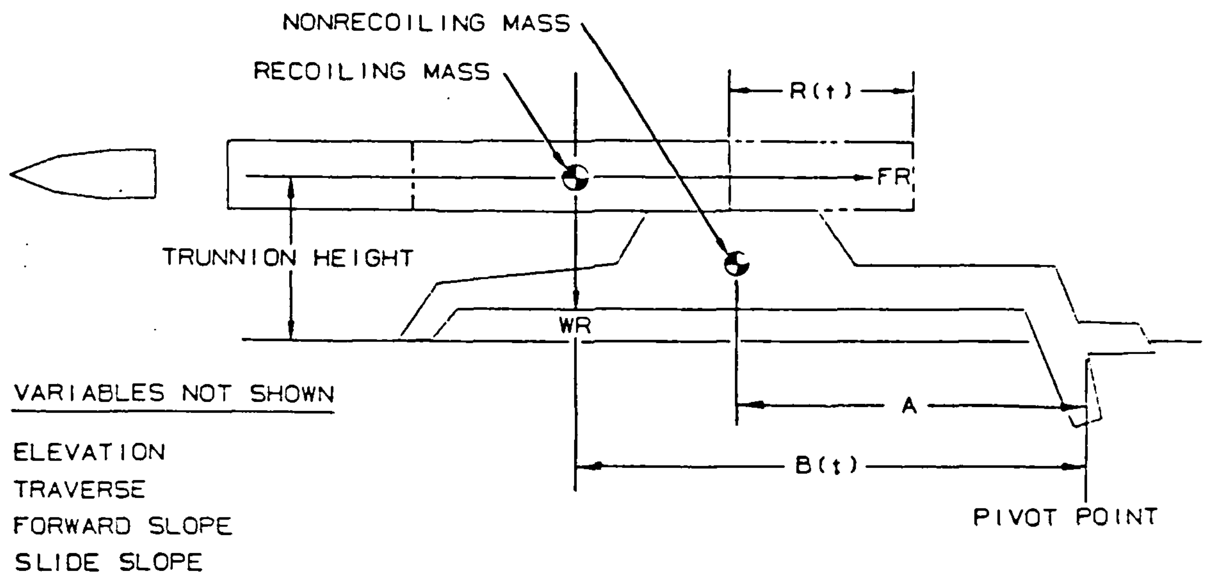


HOP IS NORMALLY VIEWED AS "REARWARD HOP", AS SHOWN.
"SIDE HOP" IS ALSO ANALYZED, BUT NOT SHOWN.

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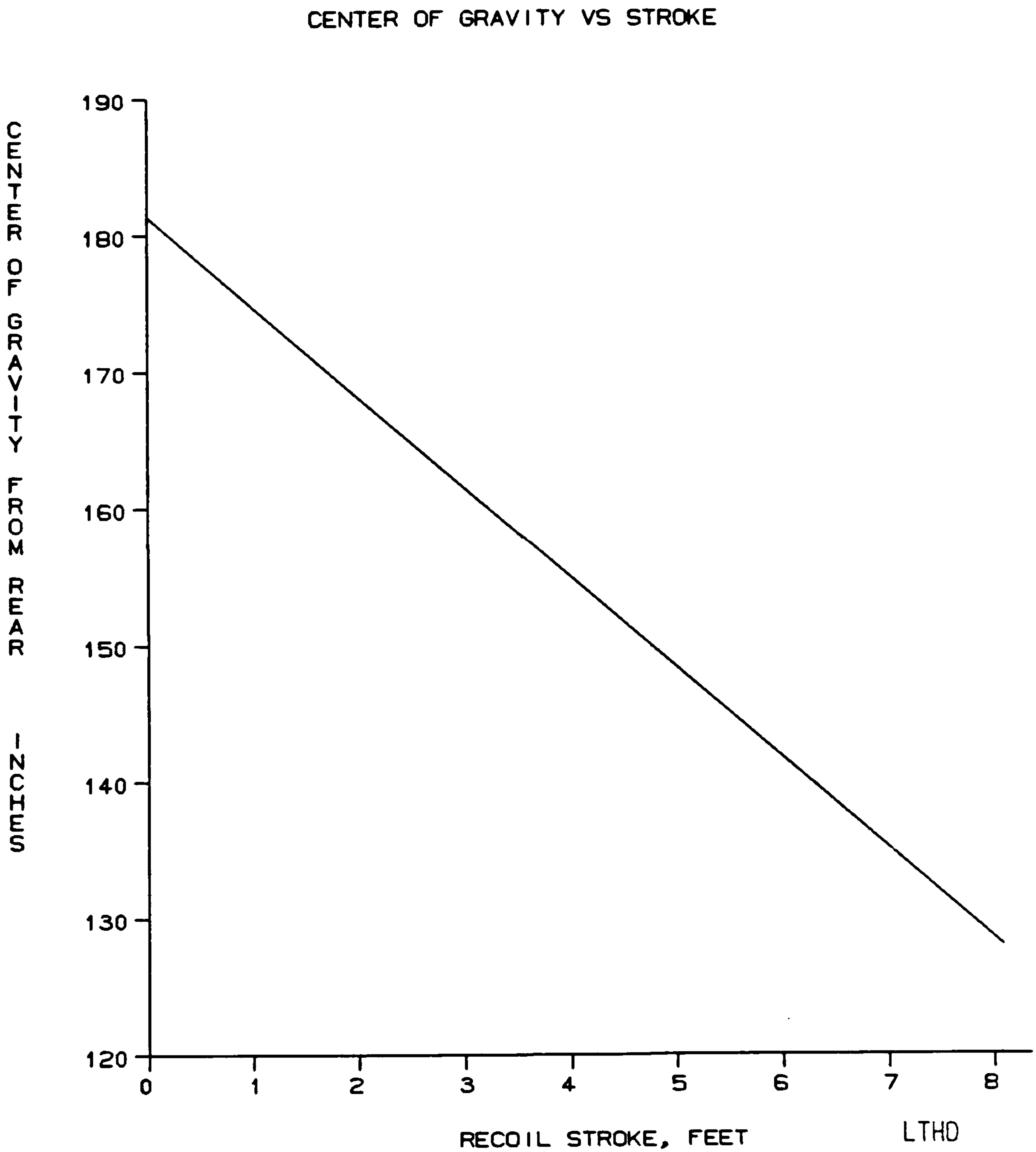


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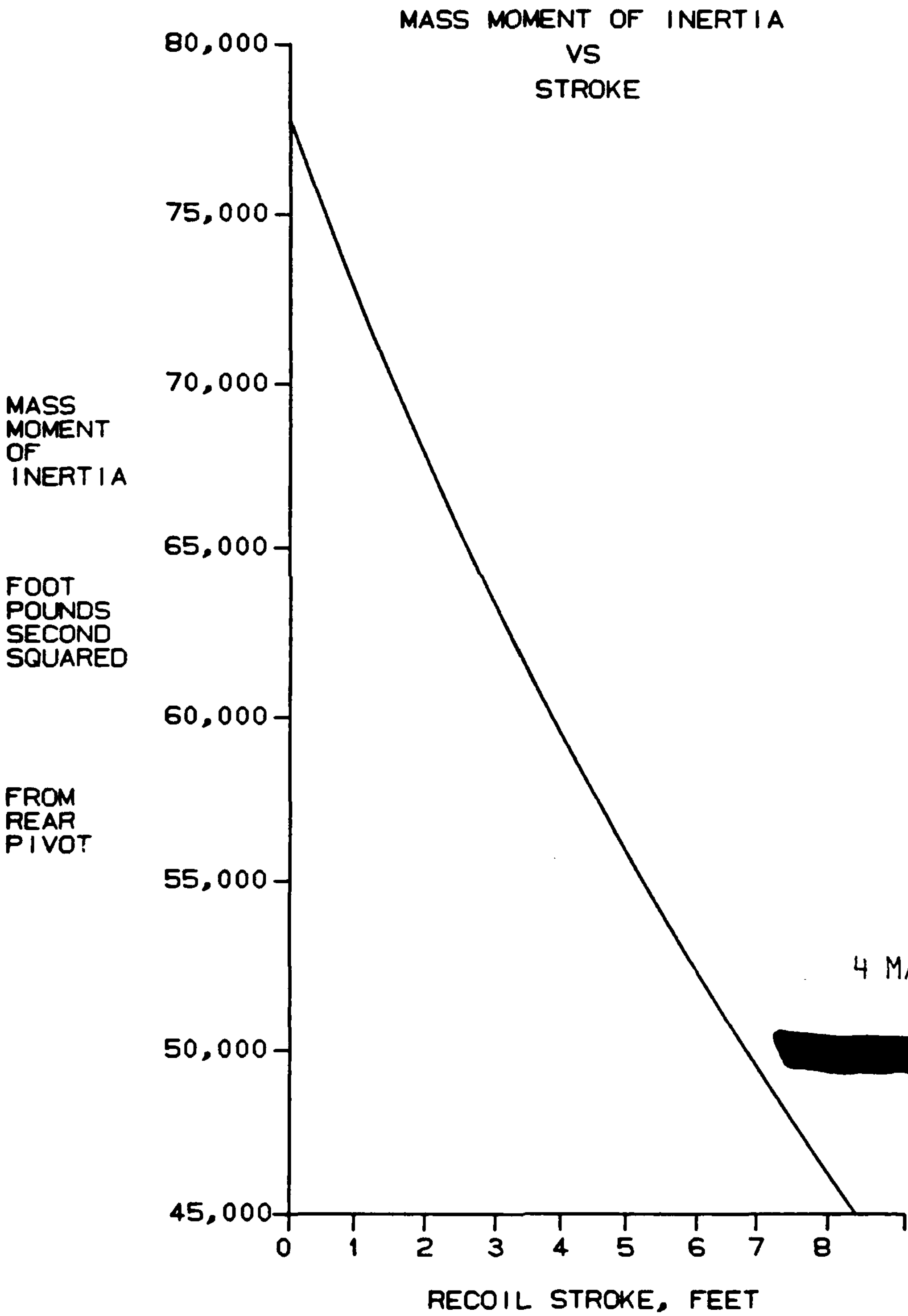


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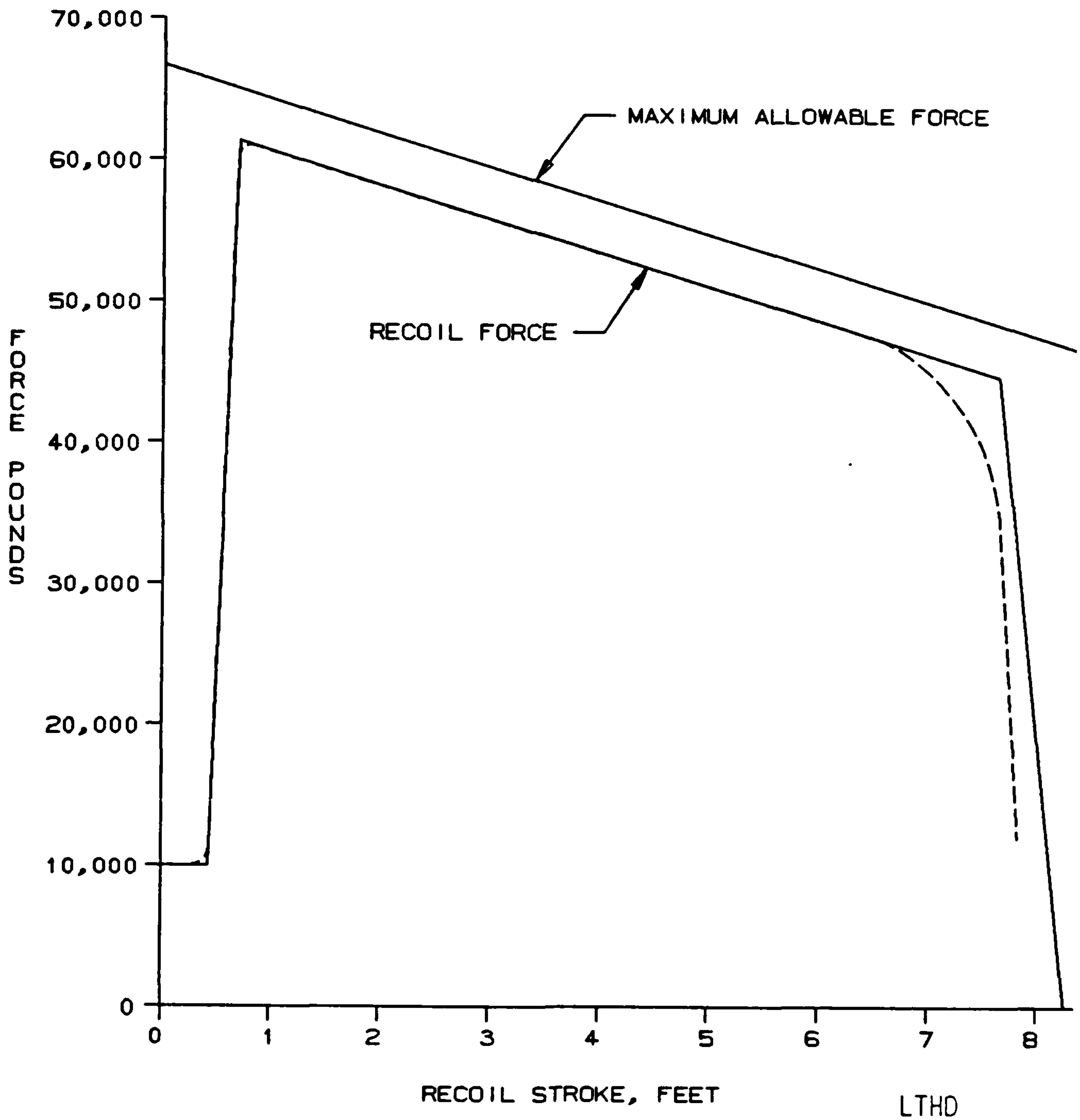
RECOIL FORCE VS STROKE
WORST CASE

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FIRING STABILITY RESULTS

WORST CASE

RECOIL FORCE:

ALWAYS AT LEAST 6.9% UNDER MAX ALLOWABLE FORCE ON FLAT GROUND

ALWAYS AT LEAST 4.6% UNDER MAX ALLOWABLE FORCE ON 10% GRADE FORWARD AND SIDE

UNSTABLE AT:

23% GRADE UPHILL (13 DEGREES)

OR 38% GRADE SIDE SLOPE (21 DEGREES)

OR 19% GRADE UPHILL AND SIDE SLOPE (11 DEGREES)

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# SYSTEM FLEXIBILITY

TRAILS:

PRELIMINARY

| TRAIL SPRING CONSTANT, LB/INCH | HOP HT, IN. | DIST IN STROKE, IN | TIME, MSEC |
|---|---|---|---|
| RIGID | 0 | -- | -- |
| 100,000 | 0.131 | 12.9 | 21 |
| 50,000 | 0.301 | 17.0 | 27 |
| 10,000 | 1.428 | 33.8 | 50 |
| 5,000 | 2.28 | 43.9 | 66 |
| 2,500 | 3.42 | 57.0 | 88 |

OTHER COMPONENTS:

NON-LINEAR ELEMENTS - FEA MODELS USED

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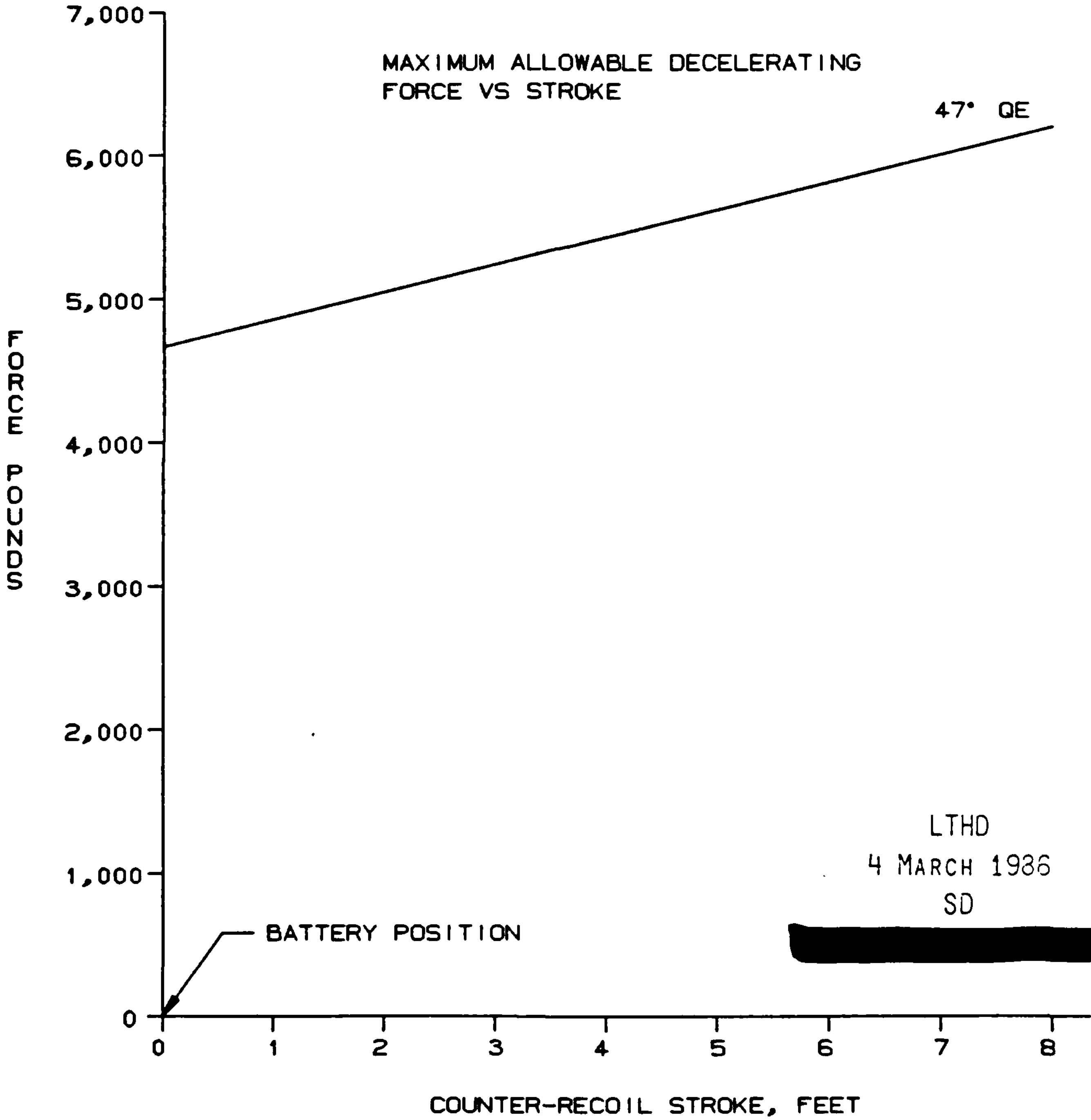
COUNTER-RECOIL CUSHION

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TOWING STABILITY

STATIC

TIPPING ANGLE

DYNAMIC

BUMPS AND HOLES

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TOWING

## STATIC ANALYSIS

| | STOW M198 | TOW M198 | LTHD |
|---|---|---|---|
| C.G. HEIGHT, IN. | T.B.D. | 53.1 | 52.8 |
| DIST. BETW. WHEELS IN. | 92.8 | 92.8 | 83.0 |
| TIPPING ANGLE | T.B.D. | 41.1 | 38.2 |

WHEEL LOCATIONS OPTIMAL

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TOWING

## DYNAMIC ANALYSIS

| | M198 | LTHD |
|---|---|---|
| TIRE SPRING CONSTANT, LB/IN | 4,507 | 1,312 |
| DAMPING COEFFICIENT | .019 | .019 |
| TOW WEIGHT, LBS | 15,780 | 8,982 |
| TIPPING MASS MOMENT OF INERTIA (FROM WHEEL ALONG AXLE), FT-LB-SECß2 | 19,065 | 9,272 |

TOW SPEEDS

5, 25, 45 MPH

MODEL BOTH LTHD & M198, BUMPS, HOLES

PLAN: ADAMS

DRAM

DEVELOP OWN SOFTWARE

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WORK UNDERWAY AT CEL

A. FINITE ELEMENT MODEL AT CEL WILL MODEL (DURING PHASE 1)

1. PLATFORM,
2. SPADES,
3. TRAILS,
4. GIMBAL,
5. TRAVERSE BEARINGS,
6. SLIDES, AND
7. REPRESENTATIONS OF THE
   - ELEVATION CYLINDERS
   - ELEVATION YOKE

B. THIS WILL PROVIDE

1. CONFIGURATION CANDIDATES
2. BETTER WEIGHT AND COST ESTIMATES
3. A MEASURE OF STRUCTURAL ELASTICITY
   - WHICH WILL IMPACT FIRING STABILITY ANALYSIS
   - FEASIBILITY OF QE/AZ CYLINDER ANCHORS NEAR TRAILS

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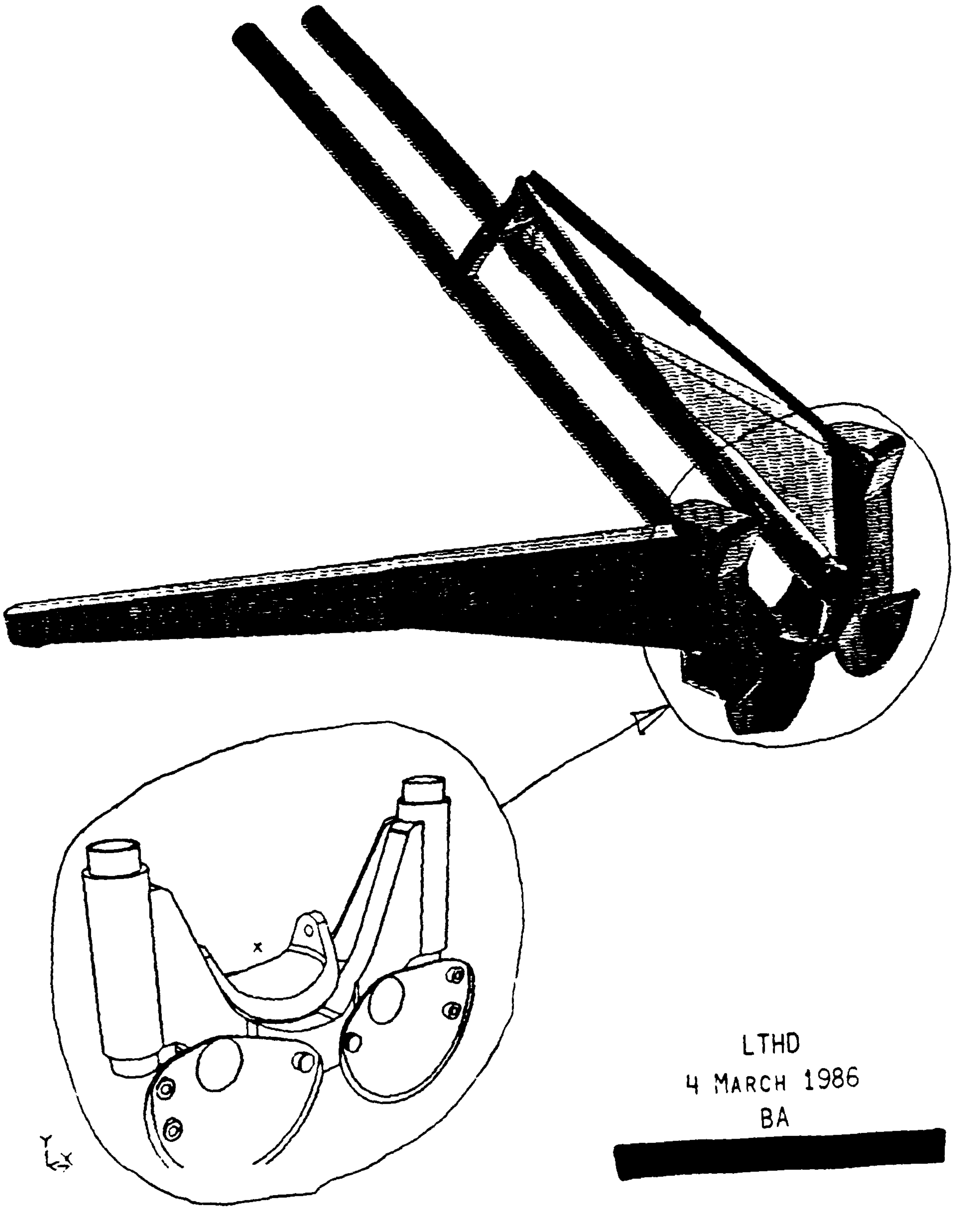

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AREAS OF CURRENT DESIGN EMPHASIS

A. MATERIALS

1. BEHAVIOR OF TEFLON ON COMPOSITE SLIDES DURING RECOIL?
2. IS F111, B1, HELICOPTER JOINT TECHNOLOGY APPLICABLE?
3. IS THE COMPOSITE JOINT ANALYSIS VALID?
4. ARE ANY MATERIALS ON CRITICAL TECHNOLOGIES LIST?
5. ARE THE COMPONENTS REASONABLY PRODUCIBLE?
6. WHAT ARE NECESSARY INCOMING AND IN-PROCESS QC POINTS?
7. WHAT IS THE SUSCEPTIBILITY TO
   - OVER-THE-ROAD
   - OPERATING
   - BALLISTIC DAMAGE?
8. HOW EASILY AND WELL CAN THE DAMAGE BE REPAIRED?
9. WOULD A SPECIAL (TITANIUM) HMMWV WHEEL BE PRACTICAL?

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## Areas of Current Design Emphasis, continued

B. Operational

1. Will breech spring close breech at max QE?
2. Can manual primer ejection/insertion be simplified?
   - Integration with Lanyard Lever Mechanism
3. Will the Tube Lay vary significantly from fire control?
   - Or will slide deflection be sufficiently repeatable?
4. What is the impact of system elasticity on stability?
5. Will the El/Eq/Az cylinders concept prove feasible?
   (Does weight savings justify a break from tradition?)
   + Transfers equilibration load around Platform
     (Reducing complexity and weight of Platform)
   - Difficulty in laying due to AZ/QE cross-correlation?
     (About the same as that caused by 7-8% grade)
   - Equilibration might vary with AZ?
     (Cross-correlation may increase human factors)
   - Is AZ sensitivity at max QE accepable?
     (Resolution about one-third of that below 1000 mils)
   - Will the AZ and QE limiting methods prove reasonable?
     ("Natural limit" is elliptical, not rectangular)
   - Will maintaining the null setpoint be practical?
     (or will it "drift" and hamper traverse operations?)
   - Will it impact firing stability?
     (System elasticity impacts firing stability)
6. Should the Primary Fire Control be Electronic or optical?
   - Electronics relieves congestion around gimbal.
7. Accuracy of transfer function for HMMWV tires adequate?
   - For comparisons to M198 towability
8. Do the Subsystems address degradation of operations?
9. How to make the "long" cyls survive the high G's?
   - 10 G's from Railroad Hump Test
   - 18 G's from LAPES

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TECHNICAL ISSUES

1. CORRELATING NOD IMPULSE DATA WITH ARDC.
   - AS OUTLINED BY SCOTT.

2. WHAT IS WEIGHT BREAKDOWN OF BASIC ISSUE ITEMS ON M198?
   - FOR INTEGRATION INTO OVERALL WEIGHT BUDGET.

3. WHAT IS RAMMING DISTANCE FOR M198 AT MAX QE?
   - TO DEVELOP STANDARD OF COMPARISON FOR LTHD.

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B/400

04 JUNE 86

TECHNICAL PRESENTATION

PHASE I

FMC

PROJECT REVIEW

4 JUNE 1986

LIGHTWEIGHT TOWED HOWITZER DEMONSTRATOR

DAAA21-86-C-0047

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## DATES AND EVENTS

| | |
|---|---|
| CONTRACT AWARD | 20 DEC 1985 |
| START OF WORK | 02 JAN 1986 |
| PROJECT REVIEW #1 | 04 MAR 1986 |
| PHA | 17 MAR 1986 |
| REQUEST FOR GFE | 13 MAY 1986 |
| PROJECT REVIEW #2 | 04 JUN 1986 |
| DELIVERY OF LEVEL 1 DRAWINGS | 10 JUN 1986 |
| DELIVERY OF DYNAMIC ANALYSIS REPORT | 10 JUN 1986 |
| OTHER DOCUMENTATION | 20 JUN 1986 |

- PRELIMINARY SYSTEM SPECIFICATIONS
- UPDATED PHA
- PRELIMINARY PRODUCT ASSURANCE LIST

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## AGENDA
PROGRAM REVIEW
4 JUNE 1986

### LIGHTWEIGHT TOWED HOWITZER DEMONSTRATOR

| | | |
|---|---|---|
| 09:00 A.M. | 1. INTRODUCTION | PETERSON |
| 09:15 A.M. | 2. PROGRAM UPDATE | THEUMER |
| 09:30 A.M. | 3. FIRST PROGRAM REVIEW ISSUES | THEUMER |
| 09:45 A.M. | 4. CONFIGURATION | ANDERSON |
| 11:15 A.M. | 5. STUDIES AND ANALYSES | DACKO |
| 01:00 P.M. | 6. STRUCTURES AND MATERIALS | ORTLOFF/CHEN |
| 02:00 P.M. | 7. SYSTEM REQUIREMENTS | THEUMER |
| 02:45 P.M. | 8. CLOSING REMARKS | PETERSON |

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# PROGRAM UPDATE

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ITEMS FROM PROJECT REVIEW #1

1. EMPLACEMENT
2. SLIDE
3. LOADING AND FIRING
4. COOK-OFF
5. SPEED SHIFT
6. DISPLACEMENT
7. BALLISTICS
8. FIRING STABILITY
9. TOWING STABILITY
10. DESIGN EMPHASIS

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## Section 4. Configuration

### Overview



### Operational Viewpoint



### Component Viewpoint



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# CONFIGURATION

- FMC APPROACH
- WEIGHT BREAKDOWN
- SINCE THE MAR 4 DESIGN REVIEW

## OPERATIONAL VIEWPOINT

- C130E DEPLOYMENT
- TOWING

- LTHD EMPLACEMENT
- M198 EMPLACEMENT
- ELEVATION AND TRAVERSE
- LOADING AND FIRING

- MISFIRES
- HANGFIRES
- STICKERS
- COOKOFF
- SPEEDSHIFT
- DISPLACEMENT

## COMPONENT VIEWPOINT

- CANNON
- RECOIL SYSTEM
- CARRIAGE

- HYDRAULIC CONTROLS
- FIRE CONTROL

- GROUND ENGAGEMENT

- DOLLY

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THE FMC APPROACH

- 2.700 LB VERSION OF M199 BARREL
  WITH M185 STYLE BREECH AND M198 MUZZLE BRAKE WITH INTEGRAL LUNETTE
- SUPER LONG RECOIL (TO MINIMIZE RECOIL FORCE)
- LOW TRUNNION HEIGHT (TO MINIMIZE OVERTURNING MOMENT)
- FORWARD POINTING TRAILS (PROVIDING BALANCED WEIGHT DISTRIBUTION)
- ACCESS TO BREECH VIA A LOADING TRAY (TO KEEP CREW AWAY FROM LONG RECOIL STROKE)
- AND A SEPARABLE DOLLY.

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WEIGHT BREAKDOWN

| | |
|---|---|
| GUN WITH PERMANENTLY ATTACHED FIRE CONTROL ITEMS | 7,975 |
| FIRE CONTROL ITEMS REMOVED FOR TRANSPORTATION | 25 |
| BASIC ISSUE ITEMS | 240 |
| DOLLY | 730 |
| ONE STANDARD DEVIATION | 30 |
| | ----- |
| TOW-AWAY WEIGHT (85TH PERCENTILE) | 9,000 |

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SINCE THE MAR 4 DESIGN REVIEW - OPERATIONALLY

FIRING AT MAX QE IS ACCOMPLISHED BY LOADING AT 800 MILS AND ELEVATING TO FACILITATE THE USE OF THE M185 OR XM284 AUTOMATIC OPENING BREECH REDUCE HUMAN FACTORS FOR RAMMING

(DEPRESSION/ELEVATION ENERGY SUPPLIED BY RECOIL ENERGY RECOVERY)

SWABBING IS ACCOMPLISHED BY A WATER SPRAY FROM A FIXED NOZZLE DIRECTED AT THE CHAMBER BECAUSE THE CHAMBER IS NOT DIRECTLY IN FRONT OF CREW

SPEEDSHIFTING IS ACCOMPLISHED WITH A SPEEDSHIFT STOOL SET UNDER SLIDE AT THE FIRING CG

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SINCE THE MARCH 4 DESIGN REVIEW - COMPONENT-WISE

THE RECOIL PATH BEARING HAS BEEN CHANGED
FROM THE OUTSIDE OF TWO COMPOSITE TUBES
TO LONG BEARING STRIPS INSIDE A LARGE TUBULAR SLIDE
TO INCREASE SLIDE STIFFNESS
AND AVOID EXPERIMENTATION WITH NEW RECOIL BEARING MATERIALS

PLATFORM EMPLOYS UPPER TRAVERSE BEARING ALMOST FOUR FEET ABOVE
LOWER BEARING
REDUCING PLATFORM STRESSES
AND FORMING A NATURAL ROLL BAR

A CONVENTIONAL ELEVATION AND TRAVERSE LAYOUT HAS BEEN ADOPTED
TO GET AROUND THE CROSS-COUPLING OF THE MARCH 4 CONCEPT

COMPOSITE CABLES ATTACH EQUILIBRATION CYLINDERS TO GIMBAL
TO MINIMIZE WEIGHT WHILE ATTACHING NEAR CG OF SLIDE AND
INCREASING STABILIZING MOMENT

AN ENERGY RECOVERY SYSTEM HAS BEEN ADDED
WITH A MINIMAL (UNDER 40 POUND) WEIGHT PENALTY

PIVOTING CLAWS HAVE BEEN ADDED TO THE FORWARD END OF THE TRAILS
TO REDUCE SKID AND HOP
PROVIDE PROTECTION AGAINST CRITICAL DAMAGE DUE TO JACK-
KNIFING WHILE BACKING UP

A WALKING BEAM SUSPENSION HAS BEEN ADDED TO THE DOLLY
TO IMPROVE TOWING STABILITY

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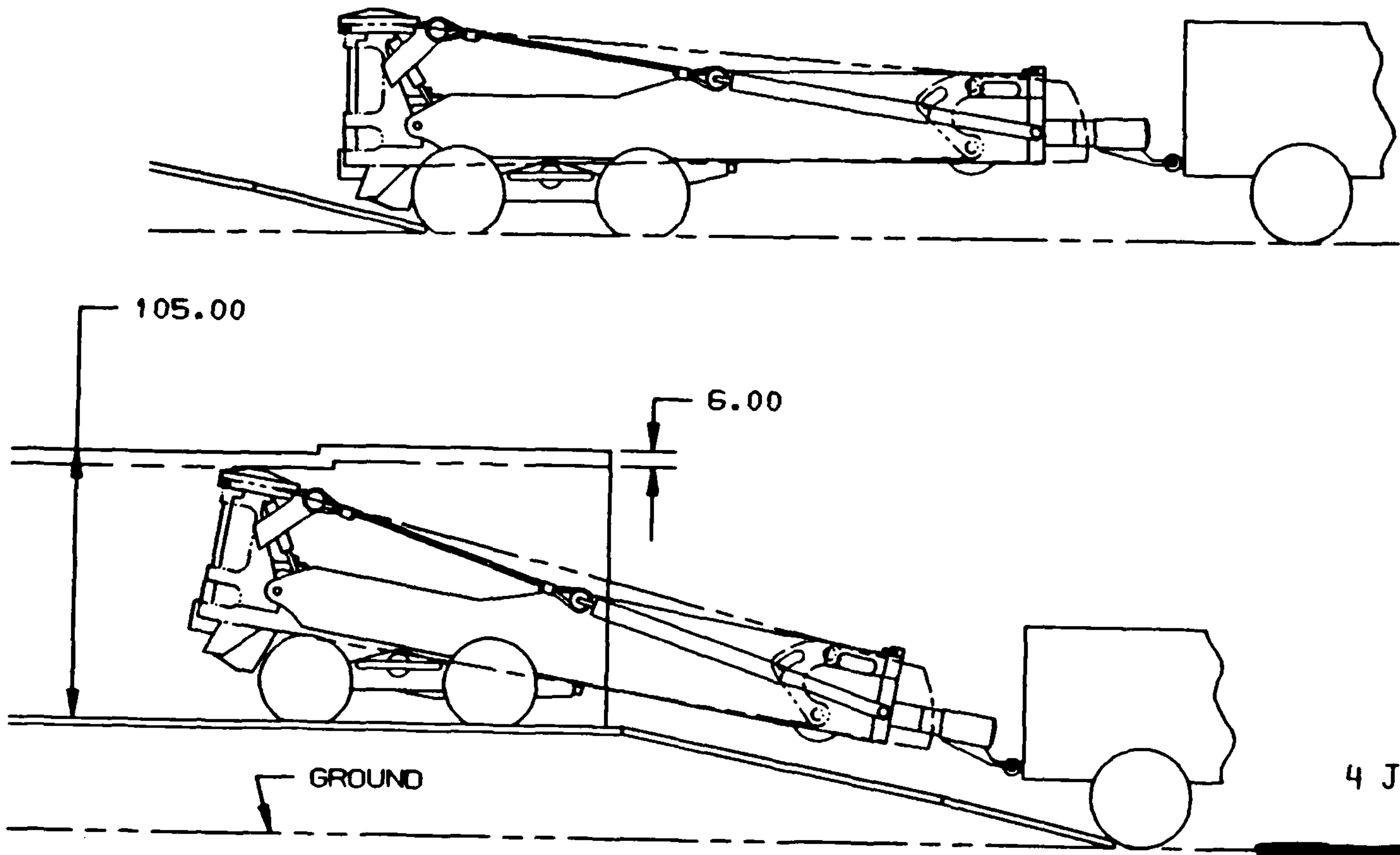
OPERATIONAL VIEWPOINT

C130E DEPLOYMENT

LOADING FMC LTHD INTO A C130

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LTHD EMPLACEMENT (3 MINUTES WITH CREW OF 4)

HOWITZER ON GROUND WITH BRAKES SET. TAKE TO POINT OF BEING READY TO INSTALL FIRE CONTROL AND LAY THE HOWITZER.

1. RELEASE AIR BRAKE LINE BETWEEN SLIDE AND DOLLY
2. RELEASE OUT-OF-BATTERY LOCK PIN
3. EXTEND PLATFORM (BREECH OPENS AND DOLLY LATCH RELEASES AT BATTERY POSITION). SET EXTEND-PLATFORM-VALVE TO "EXTEND", RETURN TO "NORMAL" WHEN COMPLETE.
4. UNLATCH LEFT CLAW-TO-SLIDE TRAVEL LOCK AND REPOSITION CLAW-TO-TRAIL LOCK .
6. REPEAT FOR RIGHT TRAIL.
5. REMOVE LEFT TRAIL TO PLATFORM LOCKS (TOTAL OF TWO), SWIVEL TRAIL OUT, AND REINSTALL
7. REPEAT FOR RIGHT TRAIL.
8. HYDRAULICALLY PRESS CLAWS INTO GROUND
   SET LOAD-TRAILS-VALVE TO "LOAD", RETURN TO "NORMAL" WHEN PENETRATION SLOWS
9. ELEVATE GUN
   SET ELEVATION-LOCK-VALVE "UNLOCK" AND SET ELEVATION-VALVE TO "ELEVATE"
   SET ELEVATION-LOCK-VALVE TO "NORMAL" AND SET ELEVATION-LOCK-VALVE TO "LOCK"
10. RELEASE DOLLY BRAKES AND REMOVE DOLLY (NECESSARY ONLY IF FIRING BELOW 200 MILS)
11. IF SPADES ENGAGE GROUND LESS THAN SIX INCHES; RAISE PLATFORM, DIG IN, AND DROP PLATFORM. PLATFORM IS RAISED AND LOWERED WITH PLATFORM-LIFT-VALVE.

# M198 Emplacement Procedure

Howitzer on ground with brakes set.

Take to point of being ready to install fire control and lay the howitzer.

1. Remove left-to-right trail retaining pin
2. Unlock left-to-right trail lock
3. Remove left trail locking pin, open trail, remove spade.
   install on end of trail, replace pin
4. Repeat for right trail
5. Remove firing baseplate from left trail and position under ball
6. Lock firing baseplate into position
7. Release brakes
8. Pump wheels down
9. Release wheel locks
10. Vent pressure and allow howitzer to settle on firing baseplate
11. Pump wheels up
12. Lock wheels in the up position
13. Release QE travel lock
14. If spades are less than 6 inches into ground, lift trails and dig in

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## ELEVATION AND TRAVERSE

ALL CONTROL VALVES ARE AT THE REAR OF THE GIMBAL
- LEFT SIDE FOR THE GUNNER, RIGHT SIDE FOR THE ASSISTANT GUNNER

### TRAVERSE

SET TRAVERSE-LOCK-VALVE TO "OFF", WHICH RELEASES THE BEAR-LOC ON THE TRAVERSE ACTUATOR
- BEAR-LOC IS A TM OF YORK HYDRAULICS
- A BEAR-LOC CONSISTS OF AN INTERFERENCE-FITTED SLEEVE THAT HOUSES THE ACTUATOR ROD
- APPLICATION OF PRESSURE TO THE ID LIFTS THE SLEEVE AND RELEASES THE ROD

SET TRAVERSE-VALVE TO "LEFT" OR "RIGHT"

RETURN THE TRAVERSE-VALVE TO "NORMAL" WHEN AZ IS REACHED

RETURN TRAVERSE-LOCK-VALVE TO "ON"

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ELEVATION AND TRAVERSE - CONTINUED

ELEVATION

SET ELEVATION-LOCK-VALVE TO "OFF" WHICH RELEASES BEAR-LOCS ON THE EQUILIBRATORS ACTUATORS

EQUILIBRATORS ARE FED THRU A SLIP RING BY A BELLOWS ACCUMULATOR HOUSED WITHIN THE SLIDE

THE EQUILIBRATORS ARE TIED TO THE GIMBAL VIA KEVLAR CABLES

SET ELEVATION-VALVE TO "ELEVATE", WHICH EXTENDS THE RODS OF THE
ELEVATION
ACTUATORS

RETURN THE ELEVATION-VALVE TO "NORMAL" WHEN QE IS REACHED

RETURN ELEVATION-LOCK-VALVE TO "ON".

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LOADING AND FIRING (FOUR ROUNDS PER MINUTE, 1 ROUND PER MINUTE ABOVE LIMIT OF SWISS NOTCH)

RAM STAFF ADJUSTED FOR LOADING ELEVATION (LOW FOR BELOW 600 MILS, HIGH TO SWISS NOTCH LIMIT

1. PUSH SPRAY-CHAMBER-VALVE TO SQUIRT WATER INTO CHAMBER
2. MOVE PROJECTILE FROM CARRIER INTO LOAD TRAY
3. SET PROPELLANT INTO LOAD TRAY
4. SET RAMMING STAFF ON CROSS BAR ON LOAD TRAY
5. PUSH ON T-HANDLES TO ADVANCE LOAD TRAY TO LATCH POSITION FOR RAMMING
5. WITH FRONT HAND ON T-HANDLE AND REAR HAND ON REMOVABLE POLE, MOVE RAMMING STAFF FROM CROSS-BAR TO BEHIND PROJECTILE
6. RAM PROJECTILE (42 INCH STROKE)
7. RETRACT RAMMING STAFF UNTIL PROPELLANT ROLLS INTO POSITION
8. ADVANCE PROPELLANT TO SWISS NOTCH
9. RETURN RAMMING STAFF TO CROSS BAR ON LOAD TRAY
10. UNLATCH LOAD TRAY AND RETRACT TO GIMBAL POSITION
11. REMOVE RAMMING STAFF AND PLACE ON GROUND
12. TRIP BREECH CLOSED (AUTOMATICALLY INSERTING PRIMER)
13. TWIST LANYARD ROD
14. BREECH WILL OPEN AS CANNON RETURNS TO BATTERY

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MISFIRES

1. WAIT THREE MINUTES. IF NO RECOIL

2. REPLACE SPENT PRIMER
   - A. EJECT SPENT PRIMER (VIA MECHANISM FROM AUTO PRIMER DOWN SLIDE TO GIMBAL)
   - B. INSPECT PRIMER
   - C. IF MECHANISM APPEARS TO BE WORKING SATISFACTORILY
   - D. INSERT NEW PRIMER (VIA MECHANISM SIMILAR TO EJECT MECHANISM)

3. RESUME LOAD-FIRE PROCESS AT STEP 13. TWIST LANYARD

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HANGFIRES

1. WAIT THREE MINUTES

2. IF NO RECOIL, TREAT AS MISFIRE

3. IF RECOIL, RESUME LOAD-FIRE PROCESS FROM THE TOP

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STICKERS

1. WAIT THREE MINUTES

2. VENT COMBUSTION CHAMBER
   A. VIA SPENT PRIMER EJECTION MECHANISM

3. DEPRESS TUBE

4. OPEN BREECH WITH SPECIAL WRENCH

5. REMOVE PROJECTILE (UNLESS PLAN IS LARGER CHARGE)

6. REPLACE PRIMER CLIP IF NECESSARY

7. ELEVATE TUBE

8. RESUME LOAD-FIRE PROCESS
   A. WITH NEW PROJECTILE, STEP 2 (LOAD PROJECTILE)
   B. WITH LARGER CHARGE, STEP 3 (LOAD PROPELLANT)

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COOKOFF

1. RETRACT LOAD TRAY
   A. TO COMPLETE LOAD-FIRE PROCESS, CONTINUE LOAD-FIRE PROCESS
   B. TO BURN CHARGE IN THE ATMOSPHERE
      - DEPRESS TUBE TO CLEAN OUT COMBUSTION CHAMBER
      - RESUME LOAD-FIRE PROCESS, STEP 3 (LOAD PROPELLANT)

2. NOTE POSITION OF TEMPERATURE INDICATOR

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## Speedshift (3 minutes with crew of 4)

1. Elevate platform (extracting spade)
   Set Platform-Lift-Valve to "lift"

2. Depress cannon onto speedshift stool (positioned under slide at firing-CG mark)

3. Unload trails
   Set Load-Trails-Valve to "off", when composite cables go slack, set valve to "normal"

4. Release claw to trail latch, retract claws with ram staff, and relatch claw to trail

5. Retract platform cylinders
   Set Platform-Lift-Valve to "drop"

6. Trav 6400 mils by pushing on trails (one cannoneer at mid-trail, one at claw)

7. Release claw-to-trail latch, extend claws, and relatch claw to trail

8. Load trails

9. Elevate cannon off speedshift-stool and remove stool

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DISPLACEMENT (3 MINUTES WITH CREW OF 4)

1. ELEVATE PLATFORM
2. POSITION DOLLY UNDER CANNON
3. GUIDE DOLLY PIN INTO REAR YOKE WHILE DEPRESSING CANNON ONTO DOLLY
4. SET DOLLY BRAKES
5. RETRACT PLATFORM CYLINDERS
6. TRIP BREECH CLOSED
7. UNLOAD TRAILS
8. RELEASE CLAW TO TRAIL LATCH, RETRACT CLAWS WITH RAM STAFF, AND RELATCH CLAW TO TRAIL
9. REMOVE TRAIL TO PLATFORM LOCKS (TOTAL OF FOUR)
10. SWIVEL TRAILS IN AND REINSTALL TRAIL-TO-PLATFORM LOCKS WHILE LATCHING CLAWS TO SLIDE
11. RETRACT PLATFORM (CHECK TO MAKE SURE DOLLY PIN ENGAGES FORWARD YOKE)
12. SECURE OUT-OF-BATTERY LOCK PIN
13. CONNECT AIR BRAKE LINE BETWEEN SLIDE AND DOLLY

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Component Viewpoint

Cannon

39 Caliber Cannon Same as XM-284 except
- Lunette integral with titanium muzzle brake
- Titanium band
- Handle is replaced by a hex (for a wrench)
- Auto primer and thermal indicator will be simulated to control costs

41 caliber would improve jack-knife resistance of LTHD

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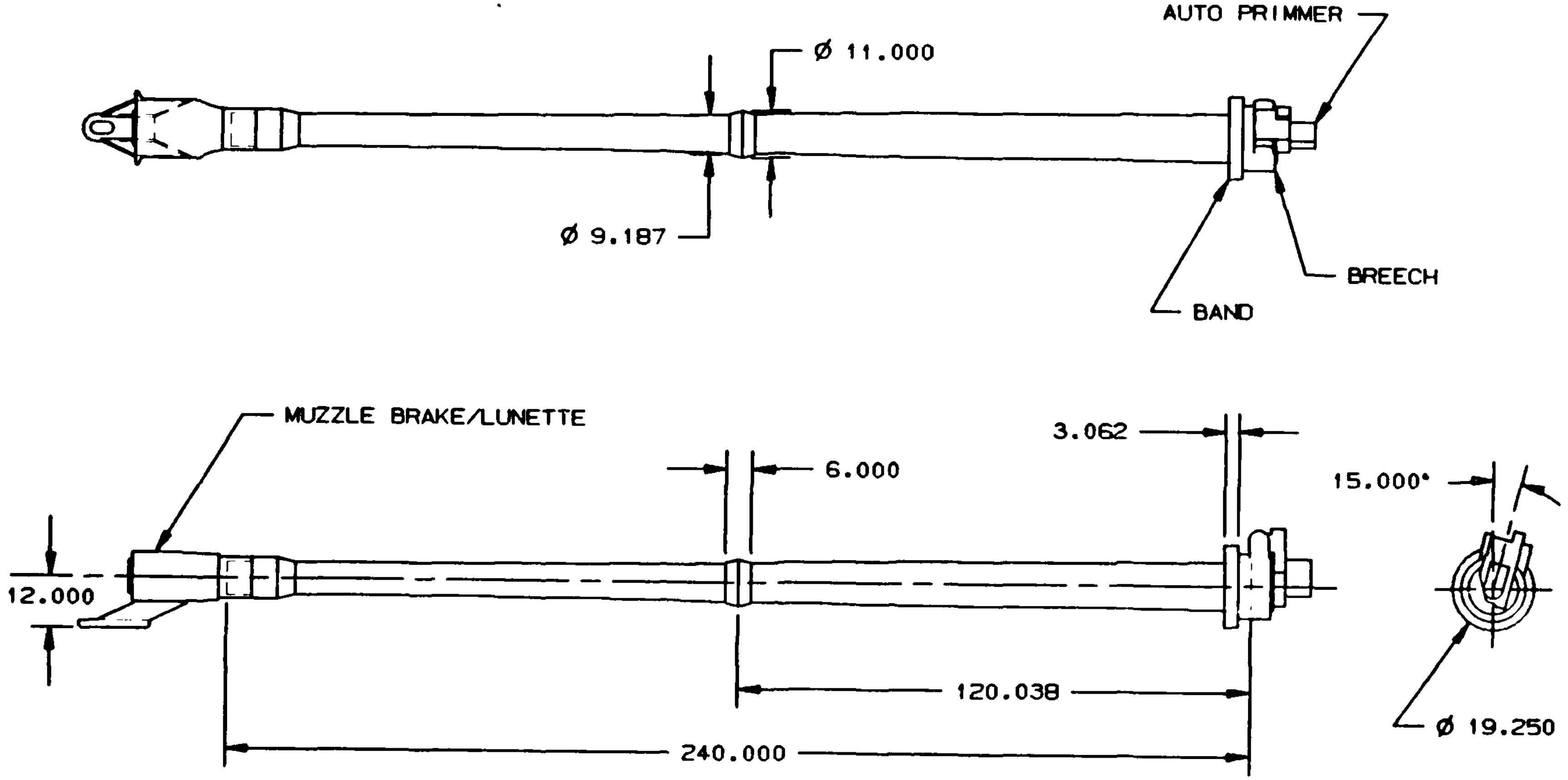
CANNON ASSEMBLY

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## Recoil System

Recoil cylinder stroke is increased
- X = 0 to 6 is free recoil
- X = 6 to 102 is effective recoil (was 5 to 96)
- X = 102 to 105 is overtravel cushion
- Kevlar-wrapped for weight reduction

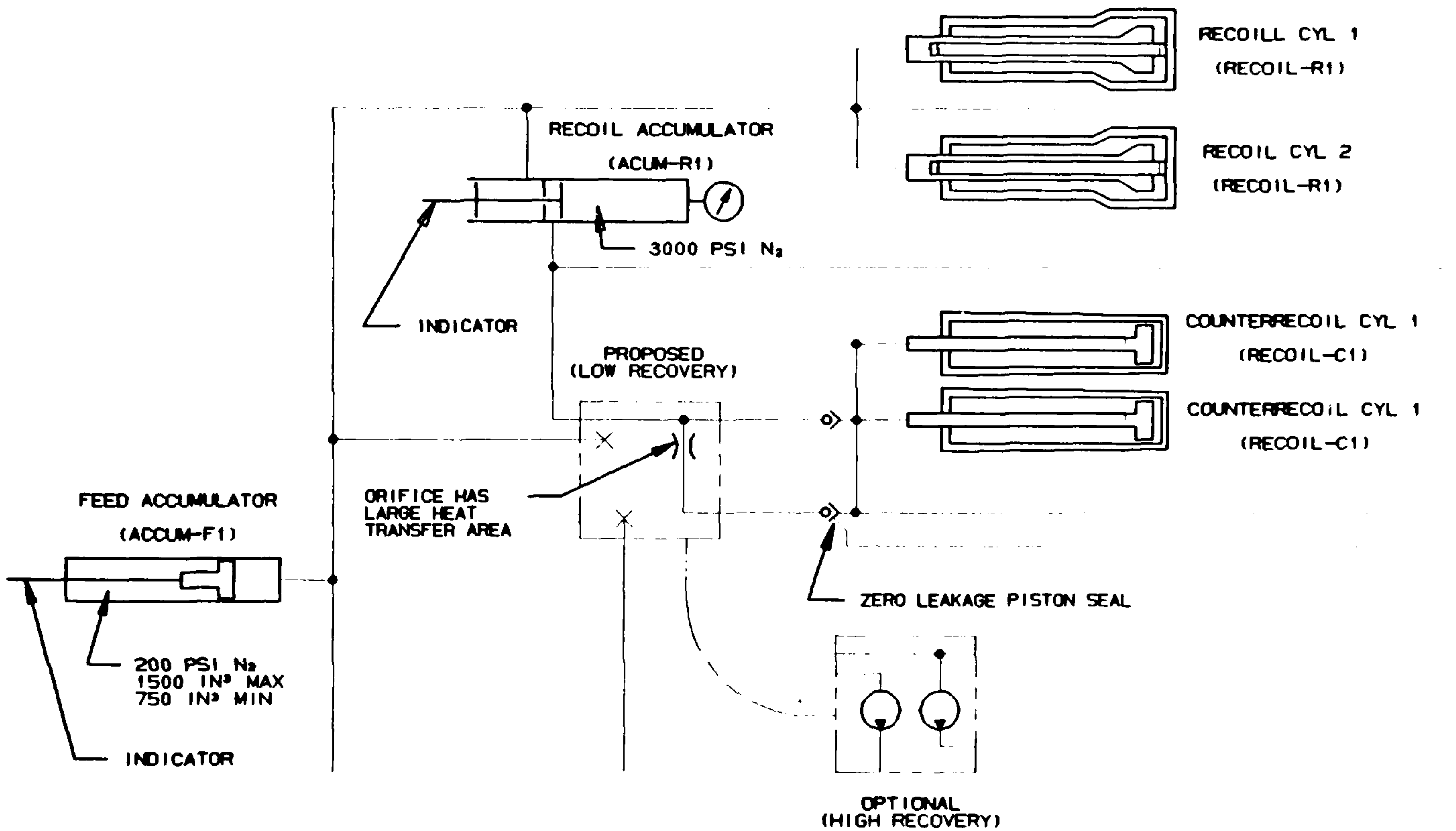
Counterrecoil cylinders carry more load than typical
- Facilitates a small amount of energy recovery from counterrecoil cushion
- Facilitates a large amount of energy recovery if a pump-motor orifice is employed
- Reduces amount of force required from recoil cylinders near stroke end (as velocity falls)
- Kevlar-wrapped for weight reduction

Recoil and counterrecoil cylinders used to shift CG to unload gun from dolly (although rods are exposed when in tow configuration)
- Elimination of strap winch on dolly
- Circuitry also allows gun to be caught in recoil for primer clip replenishment
- Elimination of yoke-tube locks of Mar 4 concept

Self-displacing accumulator is used for recoil/counterrecoil
- Traditional piston-type accumulator
- Indicator rod shows volume
- Drives oil back and forth between recoil cylinder and manifold to transfer heat to manifold
- Kevlar-wrapped for weight reduction

Slide Manifold
- Finned surface rejects heat from oil from recoil cylinders and counter-recoil check valves

## Recoil System

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# CARRIAGE

TRAVERSE BEARINGS POSITIONED ABOVE AND BELOW TRUNNION

- REDUCED STRESSES IN PLATFORM
- REDUCED BEARING WEIGHTS
- TOWING STABILITY IMPROVED VIA REDUCTION OF TOWING CG

ENLARGED "TUBULAR" SLIDE

- IMPROVED STIFFNESS THROUGH INCREASED SECTION
- ENCLOSED WAYS MINIMIZE DAMAGE TO WAY SURFACES
- COMPATIBILITY WITH "OFF-THE-SHELF" LINEAR BEARING MATERIALS
- WAYS OF GARLOCK DU
- SHOES (ON YOKES) OF STEEL OR NITRIDED TITANIUM WITH WAY SCRAPERS
- INTEGRATION OF SHIELD WITH STRUCTURAL MEMBER
- FACILITATES REDUCTION OF TRUNNION HEIGHT TO 18.25"
- PROTECTS CREW FROM SUPER-LONG RECOIL

ROLLING LOAD TRAY

- FACILITATES LOADING OUT OF BATTERY
- IMPROVES DELIVERY OF PROJECTILE TO LOADING SYSTEM

SPEEDSHIFT STOOL

- ELIMINATES SCRUBBING TIRE POTENTIAL OF MARCH 4 CONCEPT
- FACILITATES SPEED SHIFT ABOUT TRAVERSE CENTERLINE (UNDER PLATFORM)

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## Hydraulic Controls

Gunner's controls (left side of gimbal)

- Traverse Unlock...........(on/off, w/ gauge)
- Traver: ..................(left/right)
- Return To Battery.........(on/off)
- Recoil system pressure....(increase/decrease)
- Platform..................(extend/retract)
- Trail Load................(on/off)
- Power-assist..............(on/off)

Assistant gunner's controls (right side)

- Elevation Unlock..........(on/off, w/ gauge)
- Elevation.................(up/down)
- Water spray in chamber....(on/off)
- Equilibration Pressure....(increase/decrease)
- Stored energy.............(increase/decrease)
- Platform Lift.............(up/down)
- Power-assist............. (on/off)

Power Assist Pump input is normally from energy storage accumulator

- If pressure is sufficient, no pumping is required
- If pressure is insufficient, crew only supplies pressure differential
- Pump can also be used to pump up energy storage accumulator

Self-displacing accumulator is used for high and low pressure storage reservoir

- Traditional piston-type accumulator
- Indicator rod shows volume
- Kevlar-wrapped for weight reduction

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FIRE CONTROL

STANDARD M198 FIRE CONTROL
- MOUNTS TO SIDE OF GIMBAL, LINKED TO SLIDE FOR QE
- POSSIBLY SOME WEIGHT REDUCTION THROUGH MATERIAL BLOCK CHANGES IN SOME QUADRANT PARTS

TRAVERSE CYLINDER LOCKED IN PLACE WITH BEAR-LOC (TM OF YORK HYDRAULICS) KEVLAR-WRAPPED FOR WEIGHT REDUCTION

EQUILIBRATION CYLINDERS COMPOSITE CABLED TO GIMBAL AND SLIP-RINGED TO SLIDE MANIFOLD
- IMPROVES RAM-D (NO HOSES IN EQUILIBRATION SYSTEM)
- INCREASES SAFETY MOMENT (BY MOVING WEIGHT AS FAR FORWARD AS POSSIBLE)
- IMPROVES ABILITY TO DEAL WITH HIGH G ENVIRONMENTS
- ELIMINATES CORRELATION OF QE AND AZ PRESENT IN PREVIOUS CONCEPT
- BEAR-LOC'S WILL HOLD CANNON WITH COMPOSITE CABLE FAILURE OR HYDRAULIC COMPONENT LEAK
- KEVLAR-WRAPPED FOR WEIGHT REDUCTION

EQUILIBRATION ACCUMULATORS ARE OF BELLOWS TYPE
- BELLOWS ACCUMULATOR
  - MINIMIZES STICTION
  - IMPROVES HEAT TRANSFER BETWEEN OIL AND GAS (REDUCING ADIABATIC EXPONENT)
  - IMPROVES RAM-D
  - FACILITATES USE OF HE PRECHARGE
- HE PRECHARGE MAINTAINS SPRINGINESS AT HIGH PRESSURES AND CUTS WEIGHT
- TEMPERATURE COMPENSATION IS SIMPLIFIED THROUGH OIL VOLUME ADJUSTMENT
- KEVLAR-WRAPPED FOR WEIGHT REDUCTION

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## Ground Engagement

- Primary spade moved from rear to front of platform
  - Improves holding power of spade due to ground pressure of platform (about 2,500 lb)
  - Eliminates need to raise and lower spades manually (March 4 concept)
  - Integrality with platform minimizes loose pieces

- Spade area is increased through enlargement of primary spade and addition of claws
  - Improved skid resistance
  - Ground clearance of tow vehicle maintained (10.5"), although less than M198 (14")

- Claws added to forward end of trails
  - Improves skid resistance in soft soil
  - Guides return to lay with borderline hop in hard soils
  - Prevents damage to LTHD trails in the event of jack-knifing
  - Positive draft facilitates extraction (can be pryed out with ramming staff if necessary)

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# Dolly

- Walking beam suspension has been added
  - Improves towing stability
  - Improves angle of departure (by properly locking beams)
  - Tire track same as tow vehicle (M813) reduces exposure to bumps outside tow vehicle track
    - (M198 track is 26 inches wider)
- Narrower tires than the HMMWV tires proposed may be needed to retain M198 stability in turns

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Section 5. Studies and Analyses

FMC

STUDIES AND ANALYSES

- BALLISTICS
- RANGE
- RECOIL ANALYSES
- FIRING STABILITY
- SLIDE RESPONSE
- ELEVATION, EQUILIBRATION & TRAVERSE
- LOADING & HUMAN FACTORS
- TOWING STABILITY

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BALLISTICS

BALLISTIC PARAMETERS

WORST-CASE PROJECTILE/CHARGE COMBINATIONS

VARIATION IN IMPULSE CALCULATIONS

ZONE 1 CHARGES

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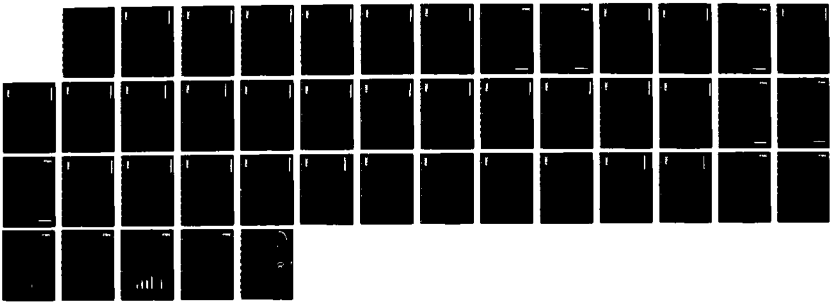
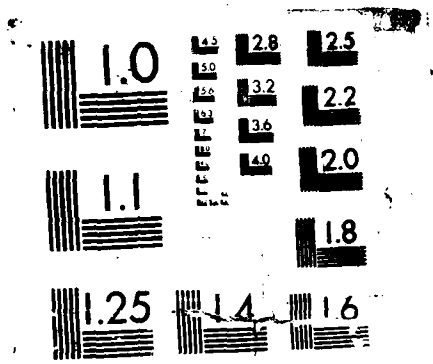
AD-A183 983 LIGHTWEIGHT TOWED HOWITZER DEMONSTRATOR PHASE 1 AND PARTIAL PHASE 2 VOLUM (U) FMC CORP MINNEAPOLIS MINN NORTHERN ORDNANCE DIV R RATHE ET AL APR 87 4/4

UNCLASSIFIED FMC-E-3041-VOL-B-PT-1 DAAA21-86-C-0047 F/G 19/6 NL






MICROCOPY RESOLUTION TEST CHART

## BALLISTIC PARAMETERS

| | |
|---|---|
| BORE CROSS-SEC AREA, SQ. IN. | 29.81 |
| BORE DIAMETER, IN | 6.102 |
| SHOT START PRESSURE, PSI | 2000 |
| BARREL RESISTANCE PROFILE | |
| INCHES, PSI | |
| 0.4 | 2512 |
| 1.0 | 3712 |
| 1.6 | 2719 |
| 2.1 | 2437 |
| 4.5 | 1875 |
| 212 | 1365 |
| PROJECTILE WEIGHT, LBS | |
| M549 PROJECTILE | 96 |
| XM795 PROJECTILE | 105.6 |
| BARREL LENGTH, INCHES | |
| M198 AND FMC LTHD | 198.6 |
| CHAMBER VOLUME, CU. IN. | |
| WITH M549 PROJECTILE | 1147 |
| WITH XM795 | 1188 |

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ZONE 8S (WORST CASE) BALLISTICS

TEMPERATURE:

145 DEGREES F

CHARGE: ZONE 8S

M203

M203A1

PROJECTILE:

M549 (96 LBS)

XM795 (105.6 LBS)

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## VARIATION IN IMPULSE CALCULATIONS

CONDITIONS:

M203 CHARGE (8S) AT 145 DEGREES F

M549 PROJECTILE

| MUZZLE BRAKE MOMENTUM INDEX | IMPULSE (LB-SEC) FMC | ARDC | % VAR |
|---|---|---|---|
| 0 (NO BRAKE) | 12.285 | 13.500 | -9.0 |
| .73 | 10.200 | 10.500 | -2.4 |
| 1.45 | 8.140 | 8.800 | -7.5 |

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ZONE 1 BALLISTICS

TEMPERATURE:

-60 DEGREES F

CHARGE: ZONE 1

M3A1 ZONE 1

XM215

PROJECTILE:

M549 (96 LBS)

M485 (92 LBS)

MINIMUM STROKE: 14.9 INCHES

MINIMUM IMPULSE: 2,073 LB-SEC

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COMPARISON OF FMC LTHD AND M198 RANGE

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M198 & FMC LTHD RANGE WITH M198 BARREL LENGTH

| | M198 | LTHD |
|---|---|---|
| | ---- | ---- |
| RECOIL COMPONENT WEIGHT, LBS | 7258 | 4228 |
| RECOIL COMPONENT MASS, SLUGS | 225 | 131.3 |
| TIME PROJECTILE IS IN BARREL, MILLISECONDS | 12.79 | 12.73 |
| MUZZLE VELOCITY WITH RESPECT TO GROUND, FT/SEC | 2831.1 | 2824.6 |
| RANGE, METERS | 24309 | 24241 |

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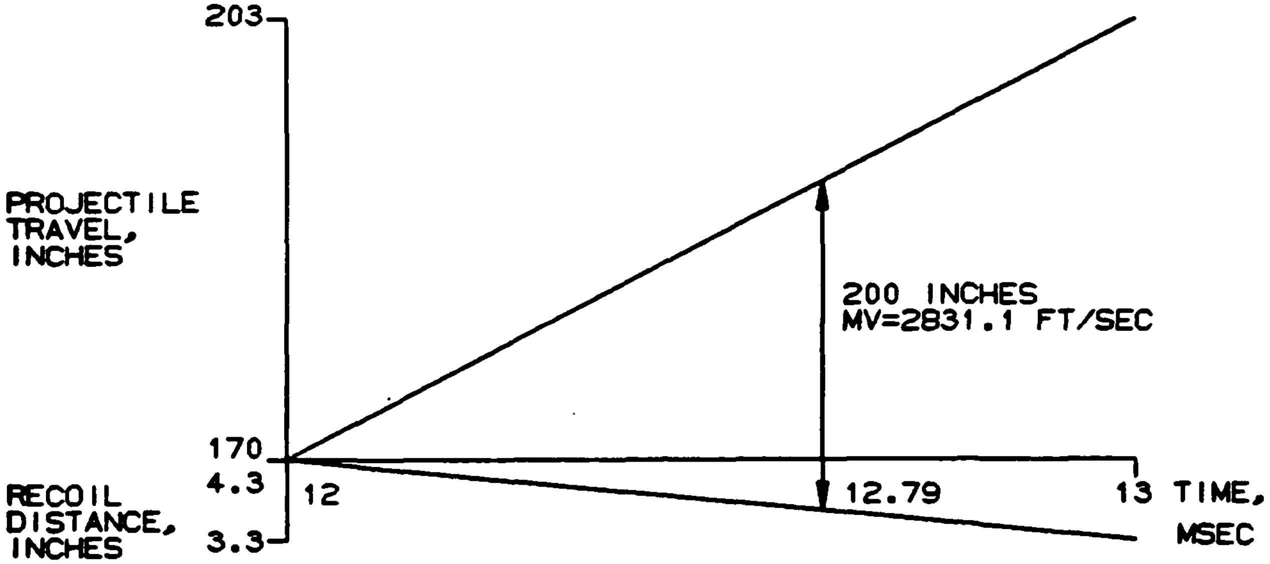
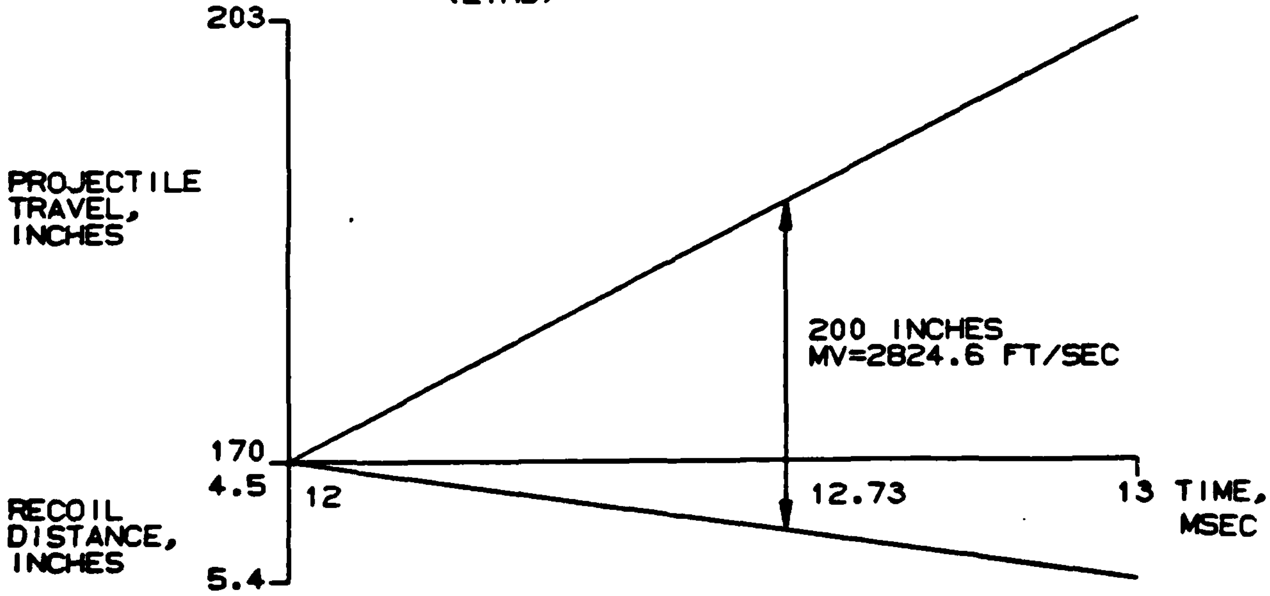
RECOILING MASS=225 SLUGS (7258 LBS)
(M198)




RECOILING MASS=131.3 SLUGS (4228 LBS)
(LTHD)

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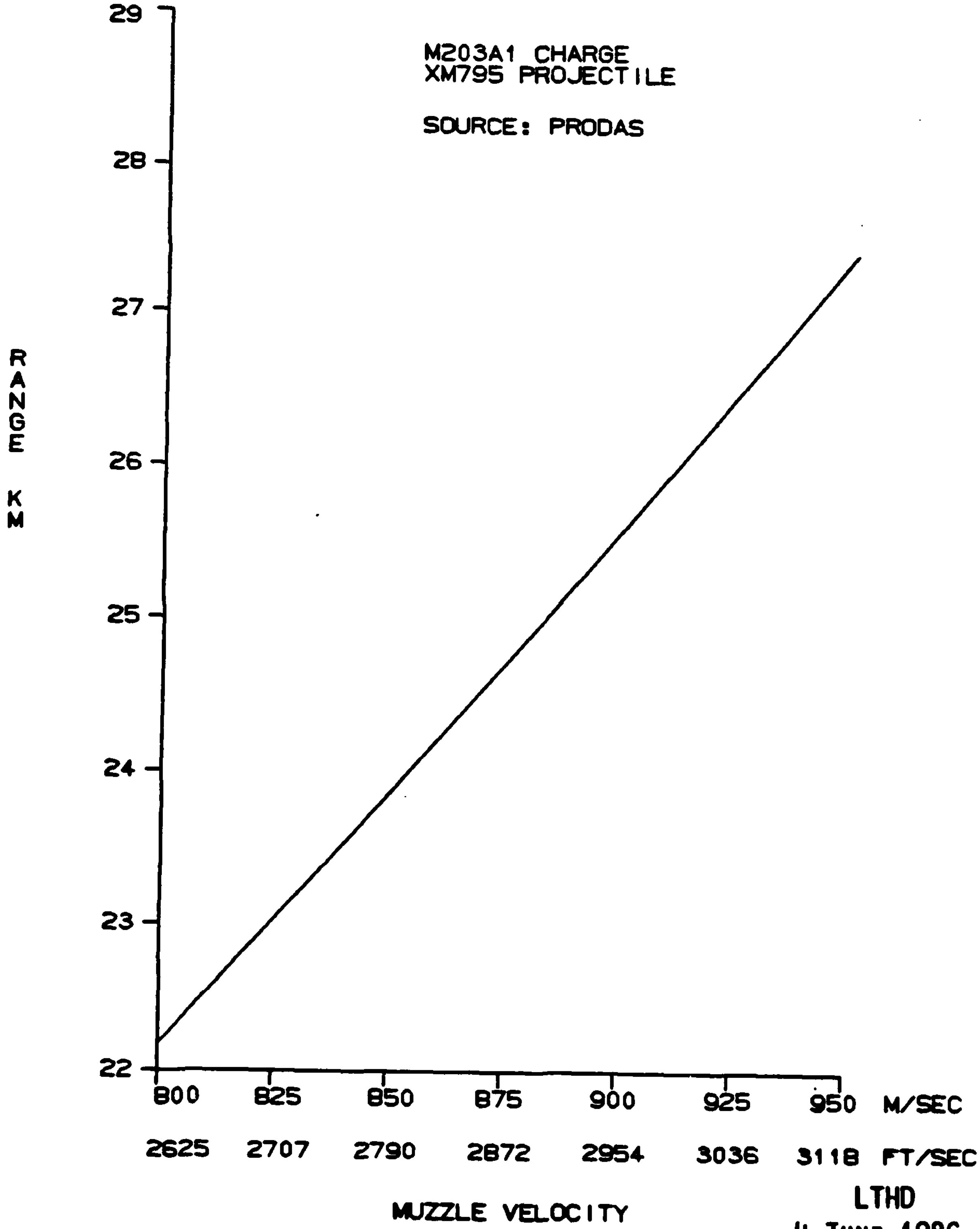
## MUZZLE VELOCITY VS RANGE

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RECOIL ANALYSES

RECOIL MOTION

COUNTER-RECOIL MOTION

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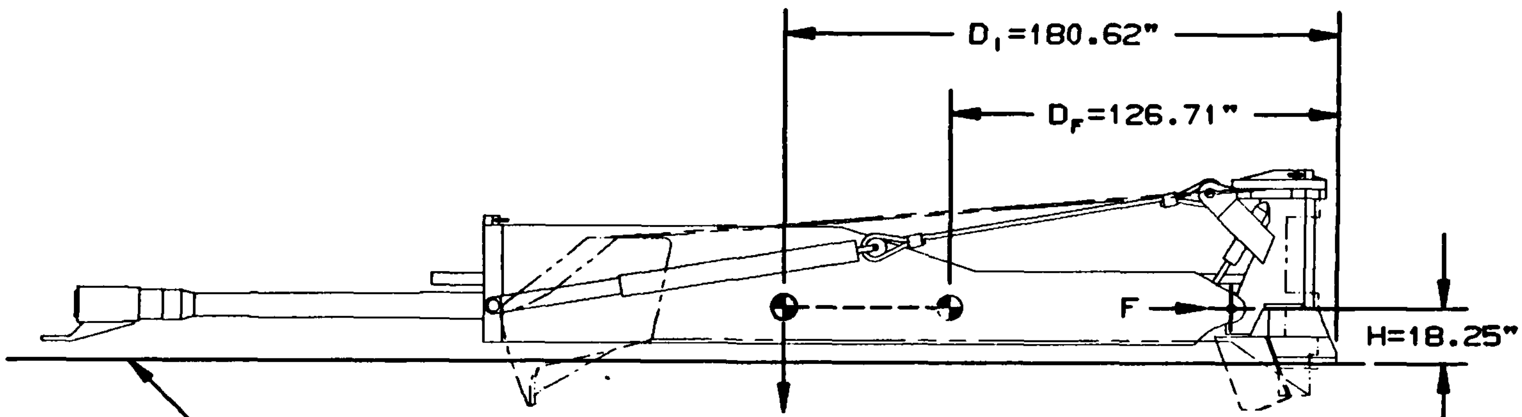
# FMC LTHD - BATTERY POSITION, 0° QE




MAXIMUM ALLOWABLE RECOIL FORCE, $F = \frac{WT \times D}{H}$ = 78,096 LBS IN BATTERY
54,785 LBS END OF STROKE

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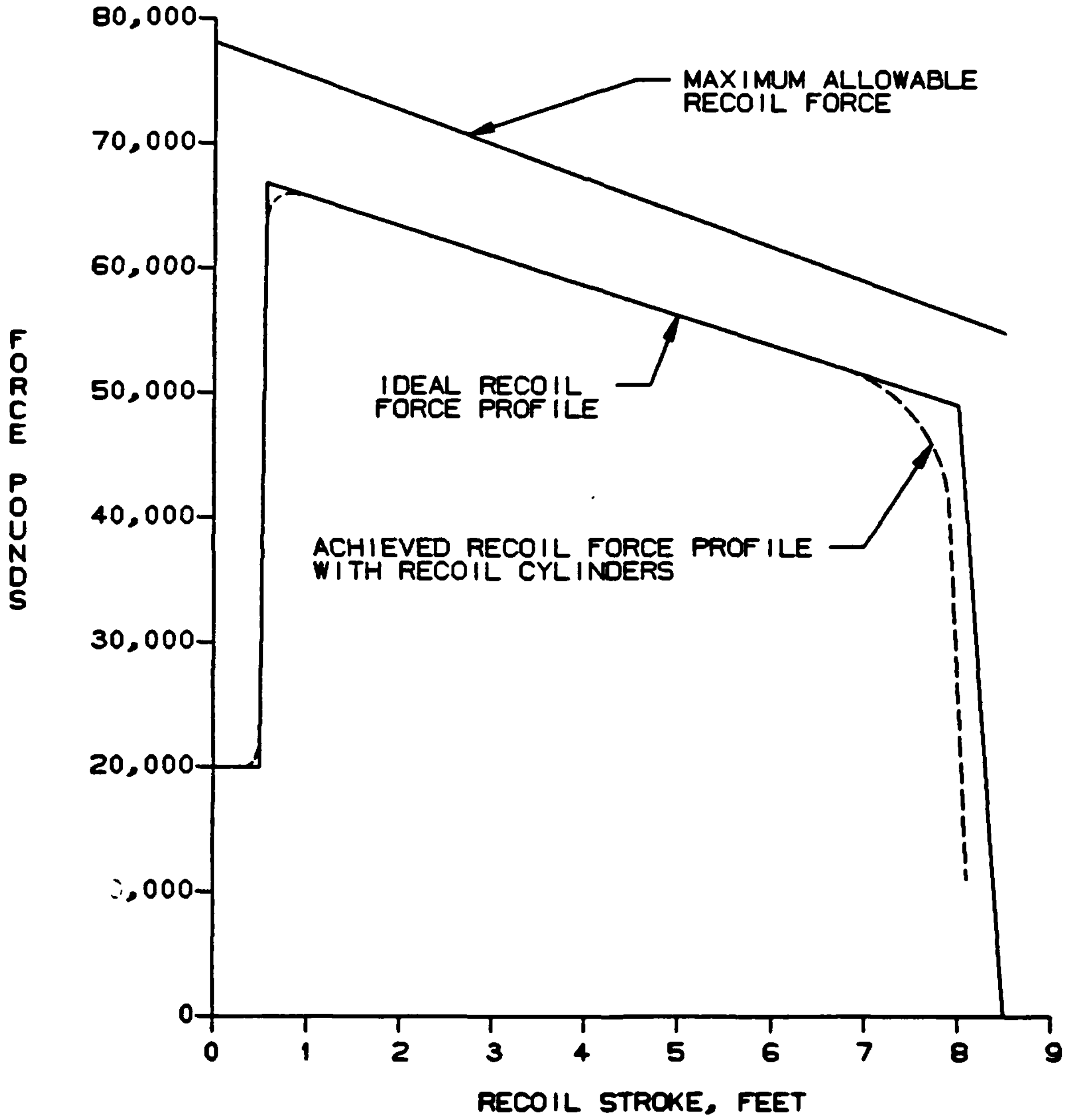
RECOIL FORCE VS STROKE
WORST CASE

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EFFECT OF FMC LTHD RECOIL FORCE PROFILE ON FIRING STABILITY

WITH WORST CASE BALLISTICS AND:

FIRING ON FLAT GROUND
- RECOIL FORCE IS ALWAYS AT LEAST 12.8% UNDER MAX ALLOWABLE RECOIL FORCE

FIRING ON 10% GRADE FORWARD AND SIDE
- RECOIL FORCE IS ALWAYS AT LEAST 10.5% UNDER MAX ALLOWABLE RECOIL FORCE

BORDERLINE STABILITY OCCURS AT:

38% GRADE UPHILL (21 DEGREES)
OR 55% GRADE SIDE SLOPE (29 DEGREES)
OR 28% GRADE UPHILL AND SIDE SLOPE (16 DEGREES)

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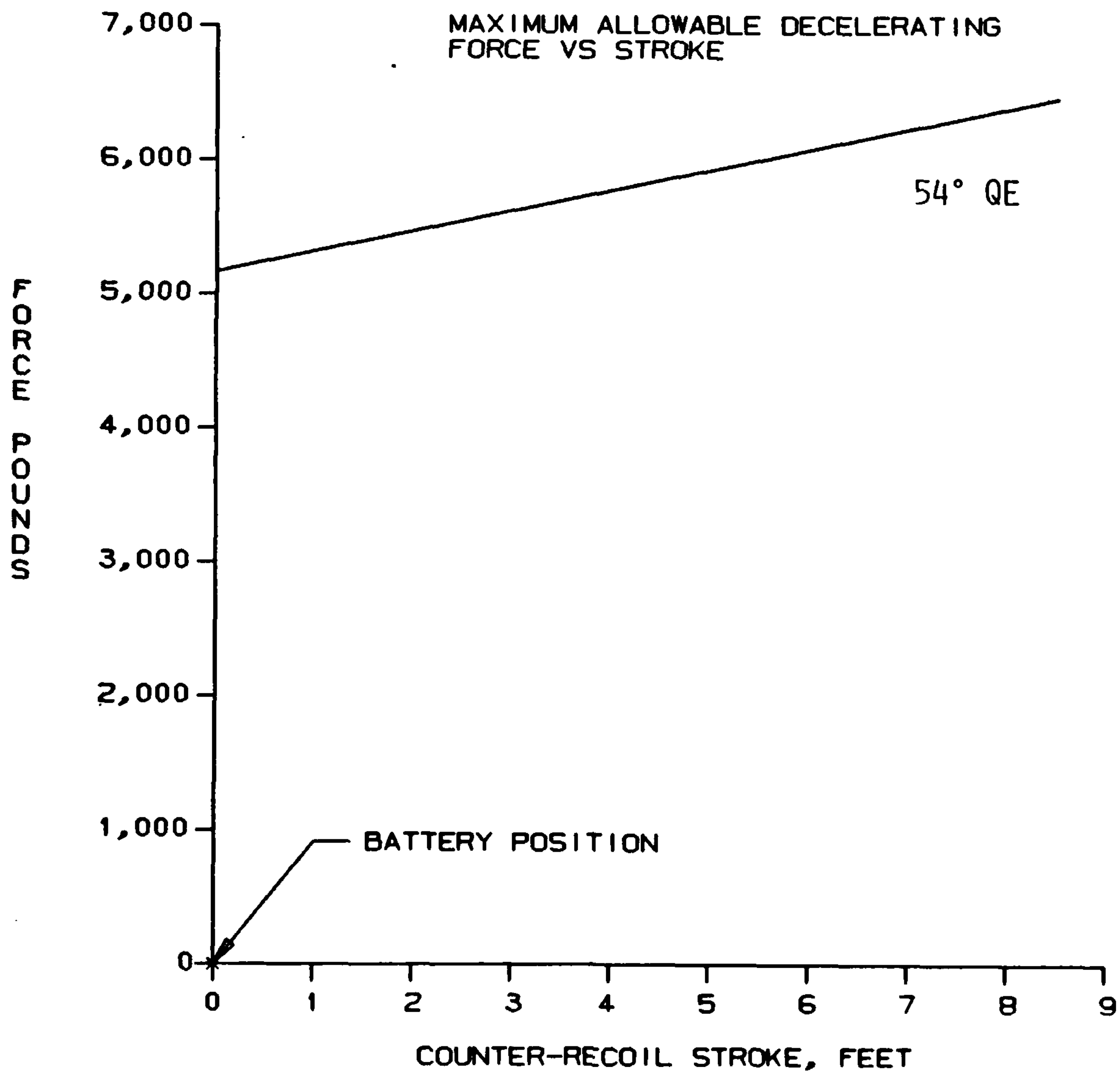
# COUNTER-RECOIL CUSHION

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FIRING STABILITY

- HOP PERFORMANCE
- SLIDE (SKID) PERFORMANCE
- WIND LOADING
- OTHER
- DEGRADED CONDITION

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## LTHD WORST-CASE HOP

ASSUMPTIONS & CONDITIONS:

- 0 DEGREES TRAVERSE
- NO SKID
- ZONE 8S, HOT (13,200 LB-SEC IMPULSE)
- TRAIL SPRING CONSTANT OF 3000 LB/IN EACH
- NO DAMPING IN TRAILS
- NO CLAWS ON ENDS OF TRAILS

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## LTHD WORST-CASE HOP

| QE, DEGREES | HOP HEIGHT, INCHES HARD GROUND (RIGID) | SOFT GROUND (PERFECTLY ELASTIC) |
|---|---|---|
| 0 | 2.33 | 2.53 |
| 5 | 1.04 | 1.20 |
| 10 | .41 | .48 |
| 15 | .10 | .12 |
| 16+ | 0 | 0 |

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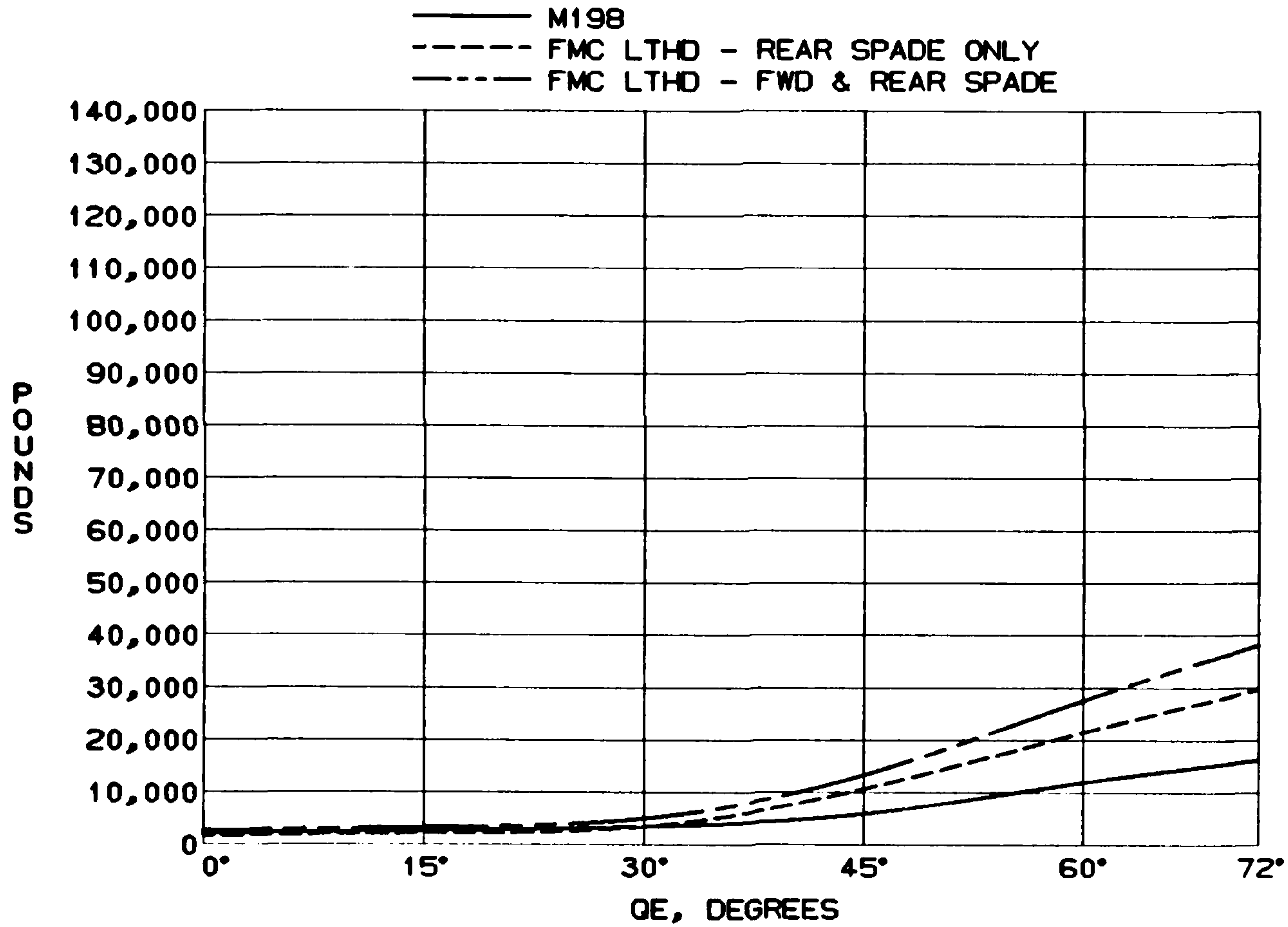
# FMC LTHD & M198 SPADE LOAD HOLDING CAPACITY IN CLAY




CLAY PROPERTIES

ø : 6° c : 201.6 LB/FT² G : 95.73 LB/FT³

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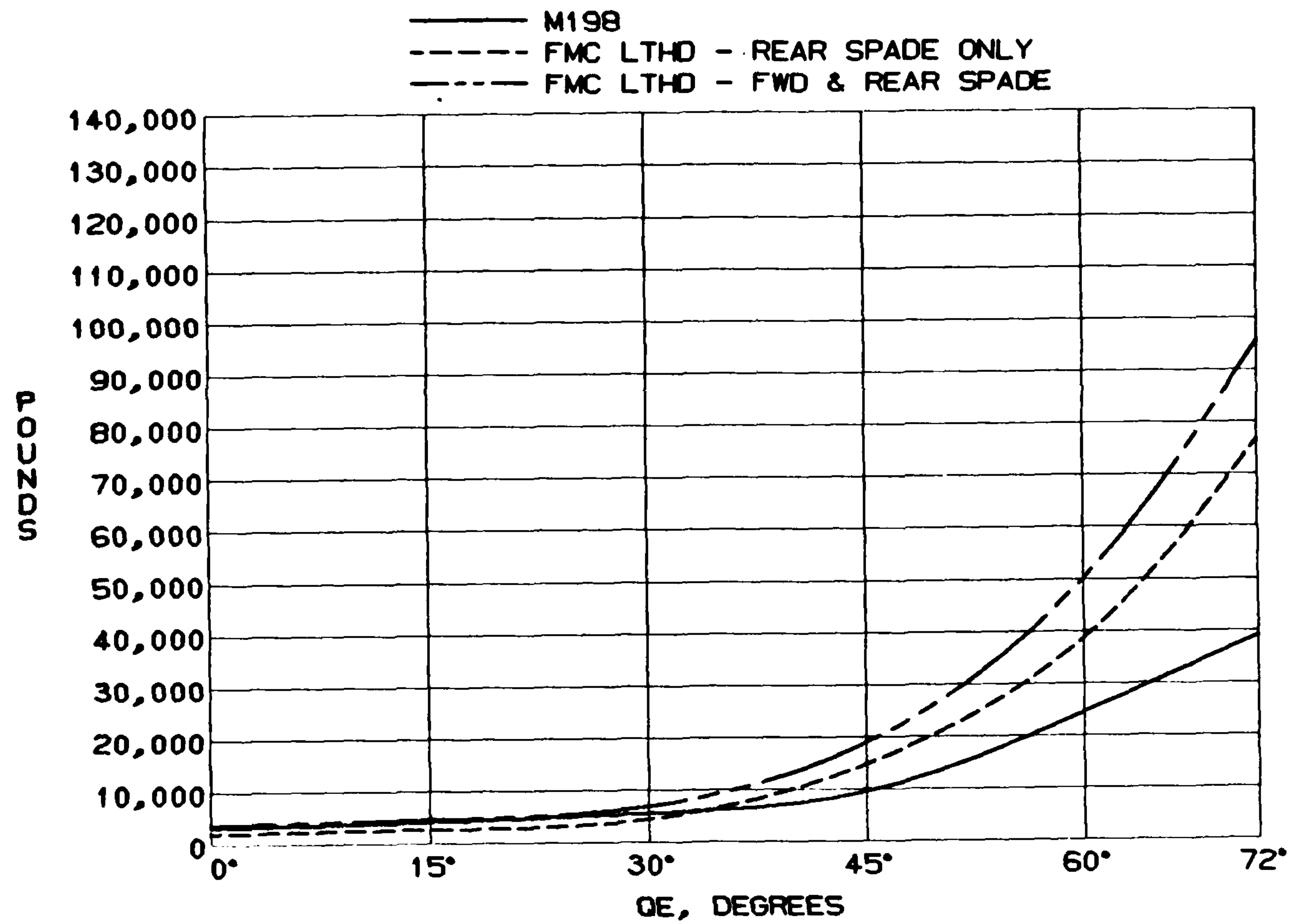
# FMC LTHD & M198 SPADE LOAD HOLDING CAPACITY IN LOAM




LOAM PROPERTIES

o : 28° c : 57.6 LB/FT² G : 102.3 LB/FT³

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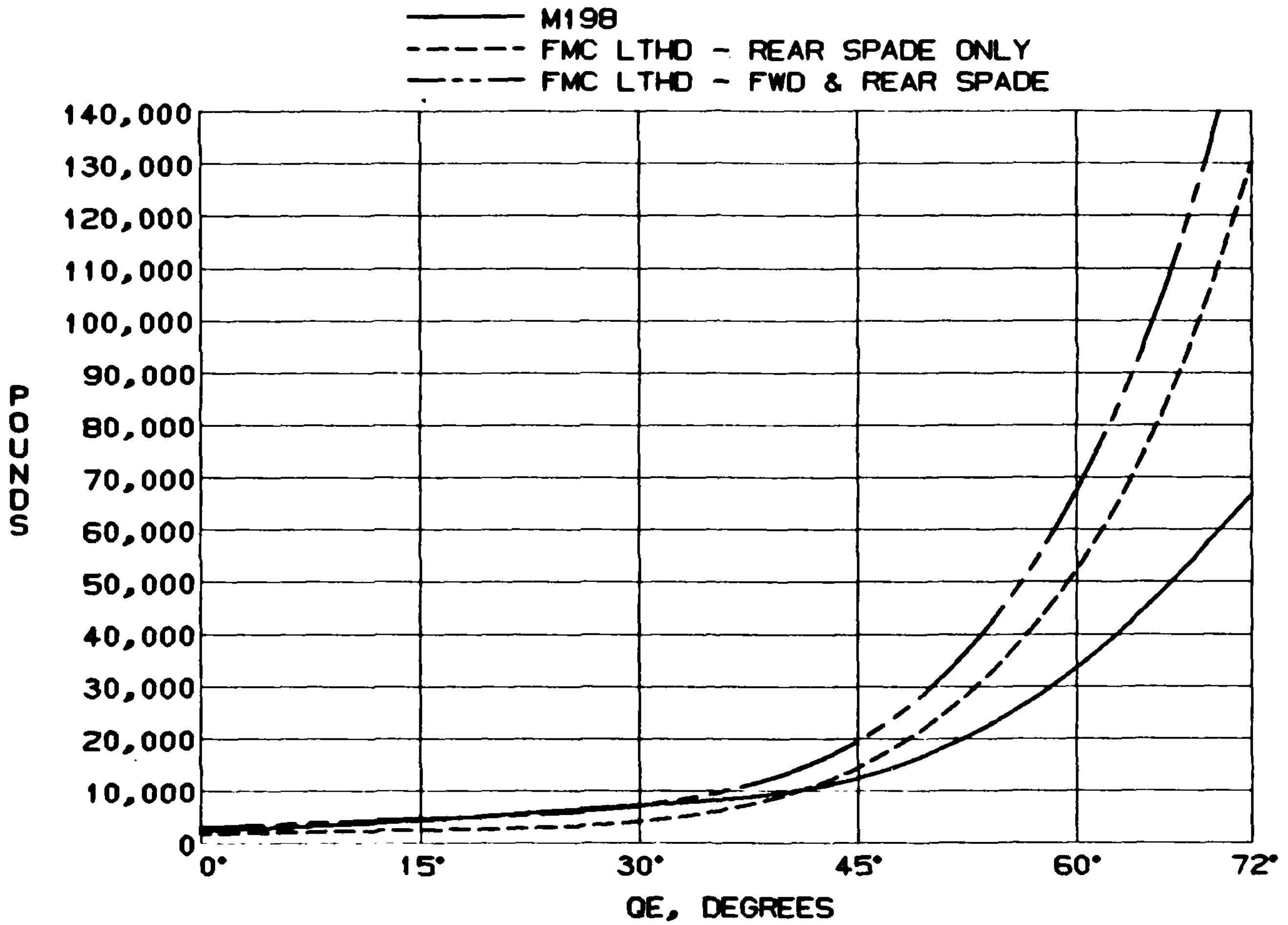
# FMC LTHD & M198 SPADE LOAD HOLDING CAPACITY IN SAND




| SAND PROPERTIES | | |
|---|---|---|
| ø : 35° | c : 0.0 LB/FT² | G : 104.89 LB/FT³ |

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## SLIDE (SKID) PERFORMANCE

NON-RIGID GROUND, WORST-CASE BALLISTICS

| | | SLIDE, IN, FOR SOIL CONDITION | | |
|---|---|---|---|---|
| | | SILTY SAND | CLAY & LOAM | HARD CLAY |
| 0 DEG'S QE | FMC LTHD | 10.38 | 8.68 | 7.09 |
| | M198 | 8.27 | 6.92 | 5.65 |
| 45 DEG'S QE | FMC LTHD | 4.18 | 3.50 | 2.87 |
| | M198 | 5.53 | 5.17 | 3.80 |
| 72 DEG'S QE | FMC LTHD | 0.57 | 0.48 | 0.39 |
| | M198 | 2.24 | 1.88 | 1.55 |

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DEGRADED CONDITIONS

| LOSS OF: | MAX CHARGE: |
|---|---|
| MUZZLE BRAKE | ZONE 8 |
| RECOIL CYLINDER (1) | ZONE 7 (3 FT/S AT 8.5 FT) |
| | ZONE 6 |
| MUZZLE BRAKE & RECOIL CYLINDER (1) | ZONE 6 (1 FT/S AT 8.5 FT) |
| | ZONE 5 |

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SLIDE RESPONSE

FRICTIONAL HEATING

BEARING LOADS

DEFLECTIONS

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EQUILIBRATION, ELEVATION & TRAVERSE

EQUILIBRATION CYLINDER

ELEVATION CYLINDER

TRAVERSE CYLINDER

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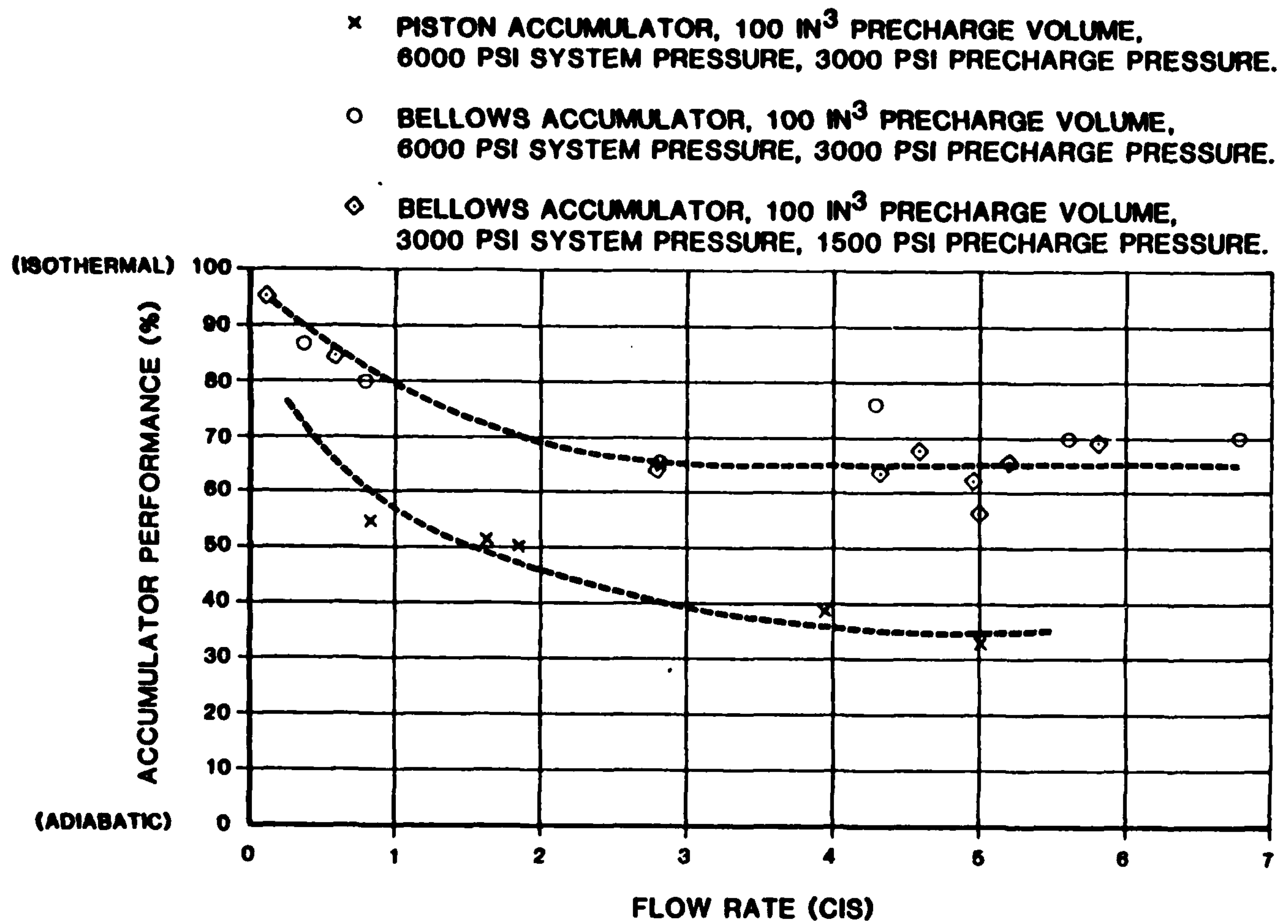


*Performance Efficiency Curves –*
*HIPRES Bellows vs Piston Accumulator*

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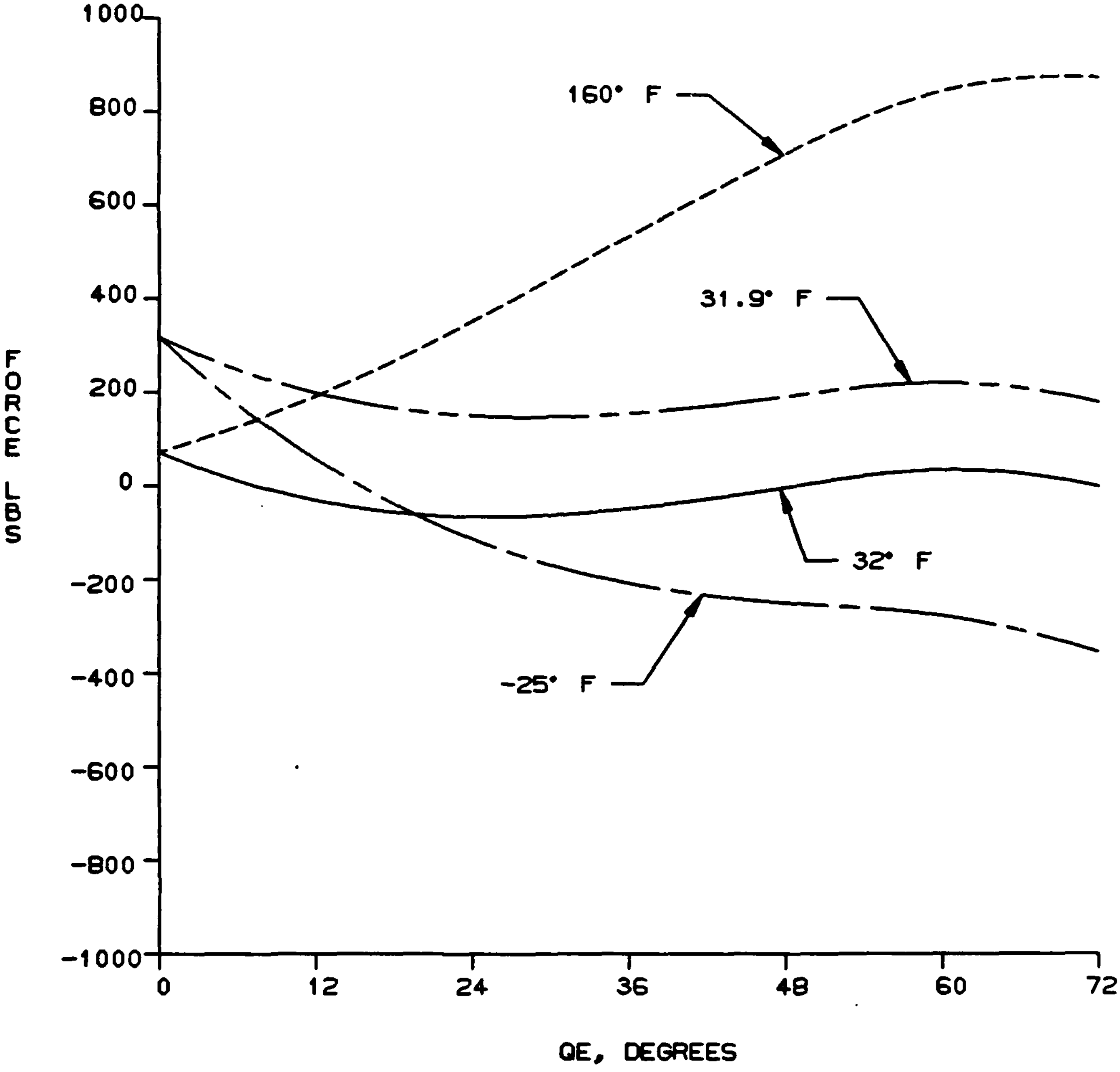
EQUILIBRATION FORCE MATCH : EQUILIBRATORS-CABLE
ISOTHERMAL CONDITIONS - $N_2$ OR He

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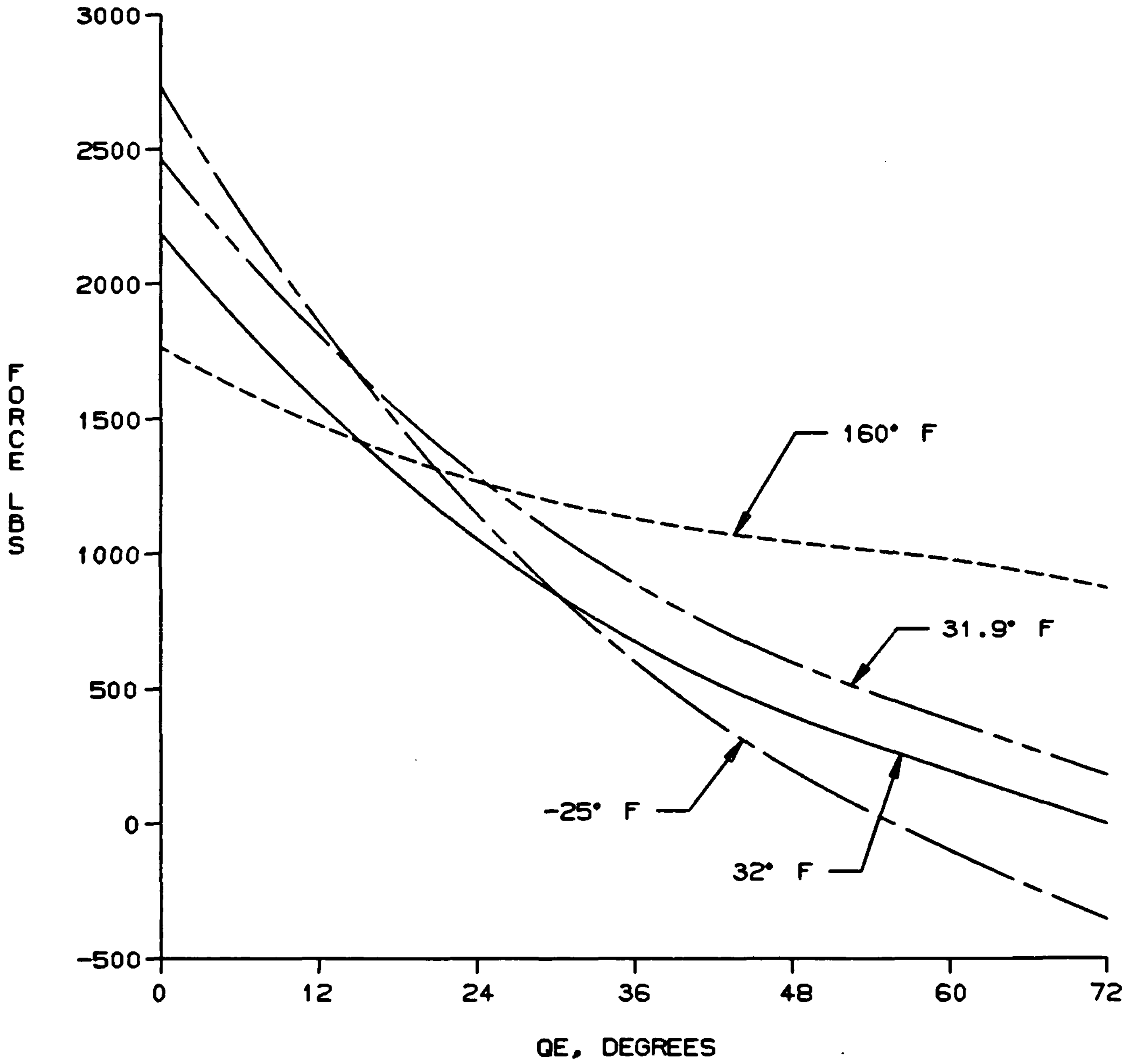
# EQUILIBRATION FORCE MATCH : EQUILIBRATORS-CABLE
## ADIABATIC CONDITIONS - $N_2$

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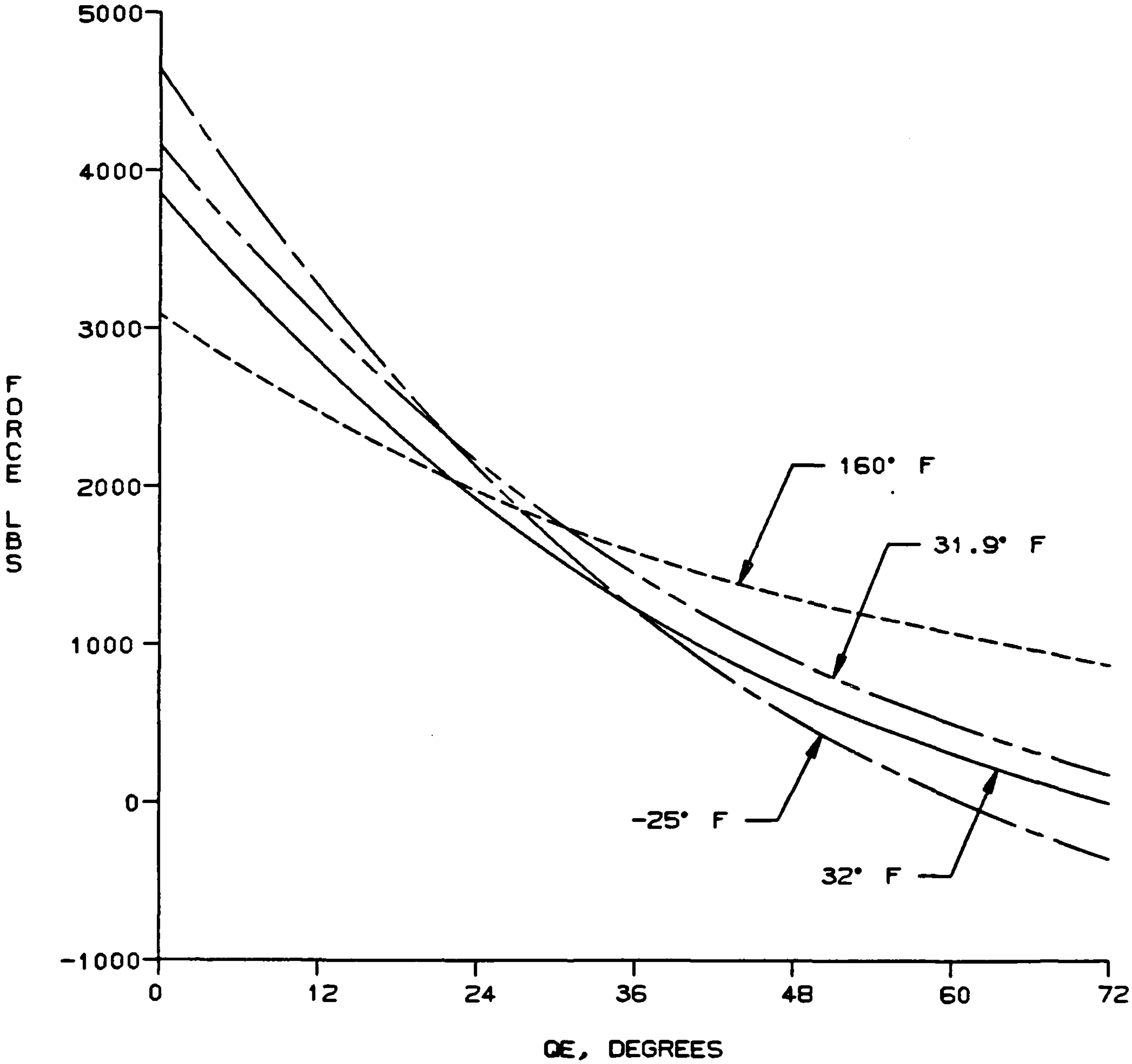
# EQUILIBRATION FORCE MATCH : EQUILIBRATORS-CABLE
## ADIABATIC CONDITIONS - He

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LOADING AND HUMAN FACTORS

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TOWING STABILITY

STATIC

DYNAMIC: RESPONSE TO ROAD CONDITIONS

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## TOWING STABILITY - STATIC

| | M198 TOW | LTHD |
|---|---|---|
| | ---- | ---- |
| C.G. HEIGHT, IN. | 53.84 | 48.29 |
| DIST. BETW. WHEELS CENTERS, IN | 93.0 | 73.0 |
| TIPPING ANGLE, DEG'S | 40.8 | 37.1 |

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TOWING STABILITY - DYNAMIC

| | M198 TOW | LTHD |
|---|---|---|
| | ---- | ---- |
| TIRE SPRING CONSTANT, LB/IN | 4,507 | 1,312 |
| DAMPING COEFFICIENT | .019 | .019 |
| ROLLING: NEGLIGIBLE | | |
| TOW WEIGHT, LBS | 15,600 | 8,982 |
| MOMENT OF INERTIA ABOUT ROLL AXIS, FT-LB-SEC^2 | 2096.5 | 562.7 |

TOW SPEED: 25 MPH

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## ENVIRONMENTAL REQUIREMENTS

THE ENVIRONMENTAL REQUIREMENTS WILL BE BUILT INTO THE DESIGN SPECIFICATIONS, THE NONDESTRUCTIVE TEST PLAN, THE PRODUCT ASSURANCE PLAN, THE TEST PLAN, AND THE OVERALL QUALITY PROGRAM PLAN. THIS WILL ASSURE THAT THE COMPONENTS ARE DESIGNED AND TESTED TO MEET THE REQUIREMENTS FROM THE EARLIEST POSSIBLE TIME OF THE DESIGN.

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## TYPICAL M198 ACCIDENTS

- o SERVICEMEN FALL OR JUMP OUT OF TOWING VEHICLE AND ARE RUN OVER BY TOWED HOWITZER.
- o TOES OR HANDS SMASHED BETWEEN TRAILS AND GROUND OR BY TOWING PINTLE/LUNNETTE.
- • STRUCK BY RECOILING ELEMENTS.
- • BREECH CLOSED ON HAND.
- o FIRE CONTROL ERROR PLACES ROUND IN FRIENDLY TROOP AREA.

## TYPICAL SLING LOAD ACCIDENTS

- • HIGH POINT OF EQUIPMENT (ELEVATED BARREL) CONTACTS HELO.
- o LOAD OSCILLATES, STRIKES HELO.
- o LOAD SLIPS FROM SLING.
- o SLING OR SLING POINT BREAKS, DROPS LOAD.

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## ACCIDENT-RISK FACTOR MATRIX

| PRODUCT PHASE | SHIP/ STORE | SET- UP | TRAIN | OPERATION | GROUND TRANS. | AIR TRS. | MAINT- ENANCE | DISPOSAL |
|---|---|---|---|---|---|---|---|---|
| ENERGY SOURCES | | | | | | | | |
| ELECTRICAL | | | | | | X | | |
| CHEMICAL | | | | | | | | |
| PROPELLANT | X | X | X | X | X | X | | X |
| PROJECTILE | X | | | X | X | X | | X |
| COMPOSITES | X | | | | | | | X |
| NBC | | | | X | | | | |
| FLUIDS | | | | X | | | X | X |
| PRESSURE | | | | | | | | |
| HYDRAULIC | | | | X | | | X | X |
| FIRING | | | | X | | | | |
| NOISE | | | | X | | | | |
| KINETIC | | | | | | | | |
| TRANSPORT | | | | | X | X | | |
| RECOIL | | | | X | | | | |
| BREECH | | | | X | | | | |
| BALLISTIC | | | | X | | | | |
| POTENTIAL | | | | | | | | |
| GUN MASS | | X | X | X | X | X | | |
| CREW POSITION | | X | | | X | X | | |

## PHA SUMMARY

| | | |
|---|---|---|
| CATEGORY I | CATOSTROPHIC | 22 |
| CATEGORY II | CRITICAL | 10 |
| CATEGORY III | MARGINAL | 7 |
| CATEGORY IV | NEGLIGIBLE | 0 |

IN THE CATEGORY I HAZARDS, AFTER THE APPLICATION OF PREVENTIVE MEASURES, NONE ARE RATED TO OCCUR AT LEVEL "C" - OCCASIONAL OR LIKELY TO OCCUR SEVERAL TIMES IN INVENTORY.

SIX (6) ITEMS ARE RATED TO OCCUR AT LEVEL "D" - UNLIKELY BUT CAN REASONABLY BE EXPECTED TO OCCUR IN INVENTORY. THEY INVOLVE BARREL RUPTURE, NBC, VEHICLE COLLISION, CREW RUNOVER, LAPES DAMAGE, AND BALLISTIC ERRORS.

THE REMAINDER OF THE CATEGORY I HAZARDS ARE RATED AS IMPROBABLE, CATEGORY "E".

| DESCRIPTION | CATEGORY | MISHAP DEFINITION |
|---|---|---|
| CATASTROPHIC | I | DEATH OR SYSTEM LOSS |
| CRITICAL | II | SEVERE INJURY, SEVERE OCCUPATIONAL ILLNESS, OR MAJOR SYSTEM DAMAGE |
| MARGINAL | III | MINOR INJURY, MINOR OCCUPATIONAL ILLNESS, OR MINOR SYSTEM DAMAGE |
| NEGLIGIBLE | IV | LESS THAN MINOR INJURY, OCCUPATIONAL ILLNESS, OR SYSTEM DAMAGE |

| DESCRIPTION* | LEVEL | SPECIFIC INDIVIDUAL ITEM | FLEET OR INVENTORY** |
|---|---|---|---|
| FREQUENT | A | LIKELY TO OCCUR FREQUENTLY | CONTINUOUSLY EXPERIENCED |
| PROBABLE | B | WILL OCCUR SEVERAL TIMES IN LIFE OF AN ITEM | WILL OCCUR FREQUENTLY |
| OCCASIONAL | C | LIKELY TO OCCUR SOMETIME IN LIFE OF AN ITEM | WILL OCCUR SEVERAL TIMES |
| REMOTE | D | UNLIKELY BUT POSSIBLE TO OCCUR IN LIFE OF AN ITEM | UNLIKELY BUT CAN REASONABLY BE EXPECTED TO OCCUR |
| IMPROBABLE | E | SO UNLIKELY, IT CAN BE ASSUMED OCCURRENCE MAY NOT BE EXPERIENCED | UNLIKELY TO OCCUR, BUT POSSIBLE |

*DEFINITIONS OF DESCRIPTIVE WORDS MAY HAVE TO BE MODIFIED BASED ON QUANTITY INVOLVED.

**THE SIZE OF THE FLEET OR INVENTORY SHOULD BE DEFINED.

FMC

## HUMAN FACTORS

MIL-STD-1472 AND 1474 WILL GUIDE THE DESIGN.

THERE ARE SEVERAL INSTANCES WHERE 1472 WILL NOT BE MET, WHICH IS NOT AN ANOMALY RESTRICTED TO THE LTHD BUT INHERENT IN ALL TOWED HOWITZERS OF THIS CALIBER OR LARGER DUE TO THE WEIGHT OF THE PROJECTILES ALONE.

IN SOME INSTANCES, THE LIFTING NECESSARY TO SPEED SHIFT, UNCOUPLE THE HOWITZER FROM THE TRUCK, ETC. CAN ALSO EXCEED LIFTING RESTRICTIONS IN 1472.

NOISE AND OVERPRESSURE BY THE CREW SHOULD NOT EXCEED THOSE OF THE M198, BUT ARE EXPECTED TO BE LOWER DUE TO THE DISTANCE BETWEEN MUZZLE BRAKE AND CREW POSITIONS. MODELING OF OVERPRESSURE IS INTENDED IN PHASE II.

LTHD
4 JUNE 1986
HT
[redacted]

FMC

## NONDESTRUCTIVE TESTING AND PRODUCT ASSURANCE LIST

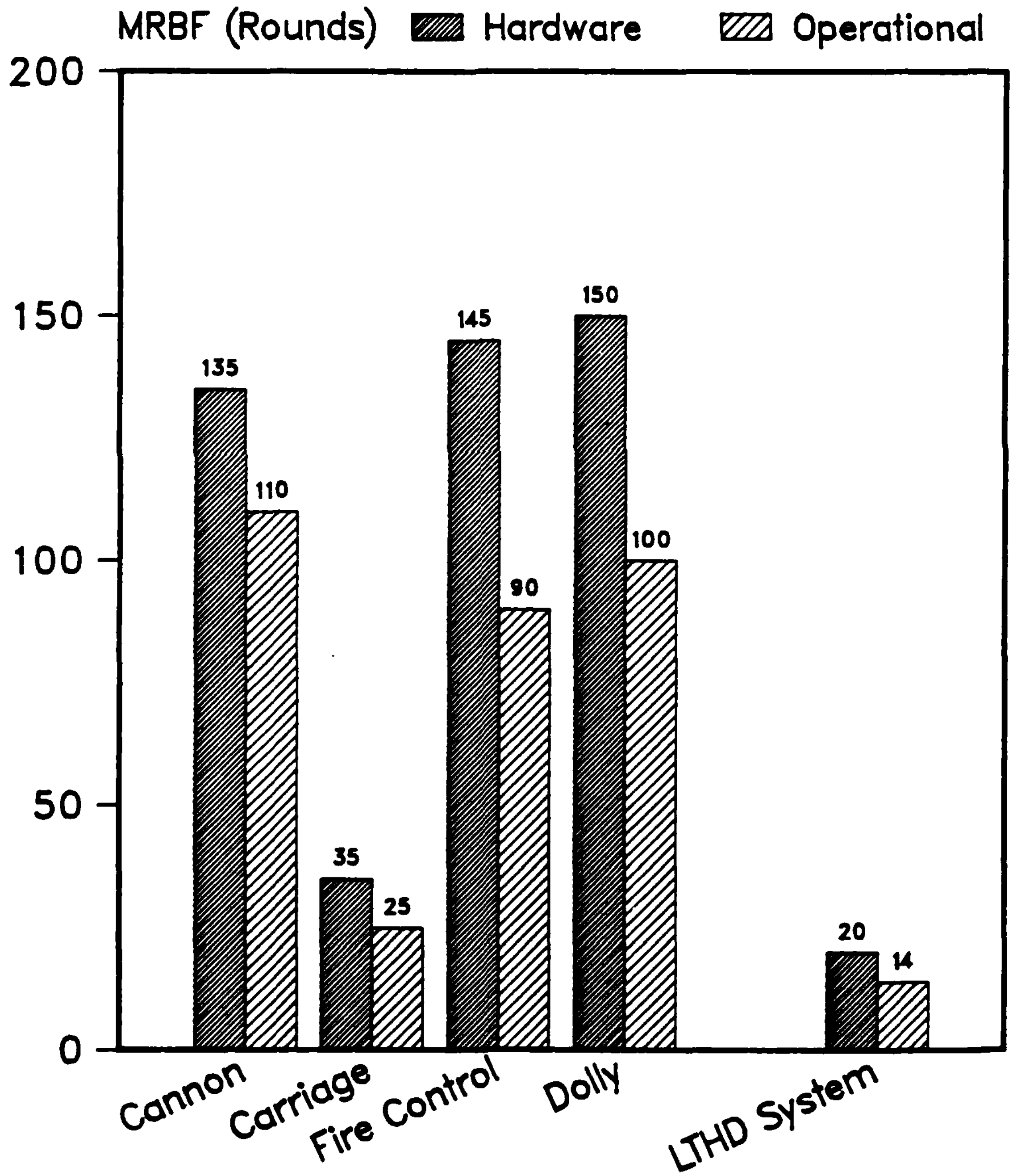
AN INITIAL DRAFT OF A PRELIMINARY LIST WAS SUBMITTED FOR REVIEW ON 29 MAY 1986.

THIS LIST CONSISTED OF AN OUTLINE OF THE PLANNED NONDESTRUCTIVE TESTING AND PRODUCT ASSURANCE PLAN TO BE DEVELOPED AS PART OF THE QUALITY PROGRAM PLAN IN PHASE II.

AFTER REVIEW AND INCORPORATION OF COMMENTS RECEIVED, THE FINAL PRELIMINARY LIST WILL BE SUBMITTED WITH OTHER DOCUMENTATION PRIOR TO THE END OF PHASE I.

LTHD
4 JUNE 1986
HT
[redacted]

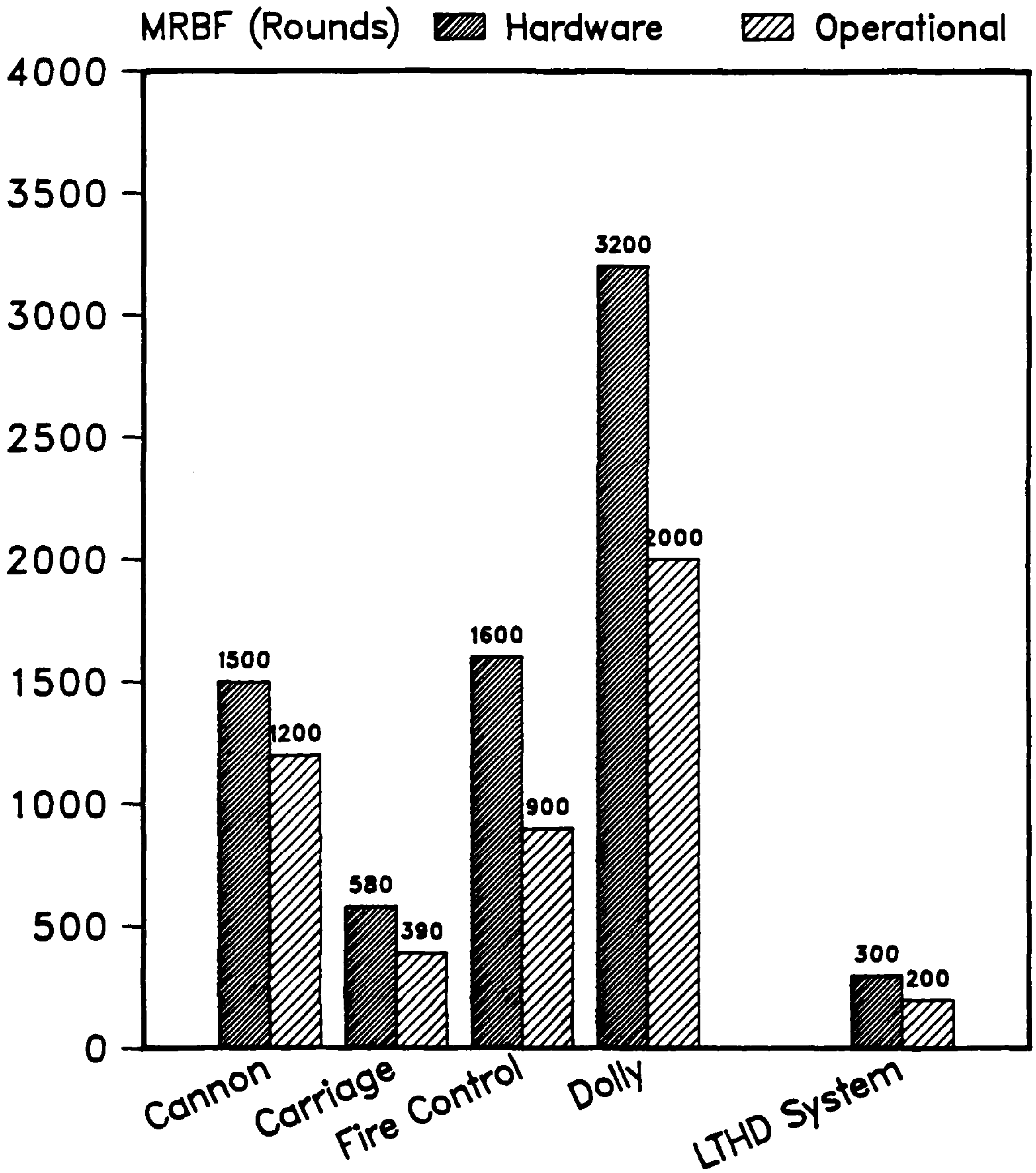
## LTHD Reliability Goals
## Based on M198 Howitzer Performance Data
## (Corrective Maintenance Failures)



LTHD RELIABILITY GOALS BASED ON M198 HOWITZER PERFORMANCE DATA
(CORRECTIVE MAINTENANCE FAILURES)

| | CORRECTIVE MAINTENANCE | |
|---|---|---|
| | HARDWARE MRBF (ROUNDS) | OPERATIONAL MRBF (ROUNDS) |
| CANNON | 135 | 110 |
| CARRIAGE (M198 - CARRIAGE, RECOIL AND SPADE/TRAIL) | 35 | 25 |
| FIRE CONTROL | 145 | 90 |
| DOLLY (M198 - SUSPENSION) | 150 (MMBF=870 MILES) | 100 (MMBF=580 MILES) |
| LTHD SYSTEM | MRBF = 20 ROUNDS | MRBF = 14 ROUNDS |

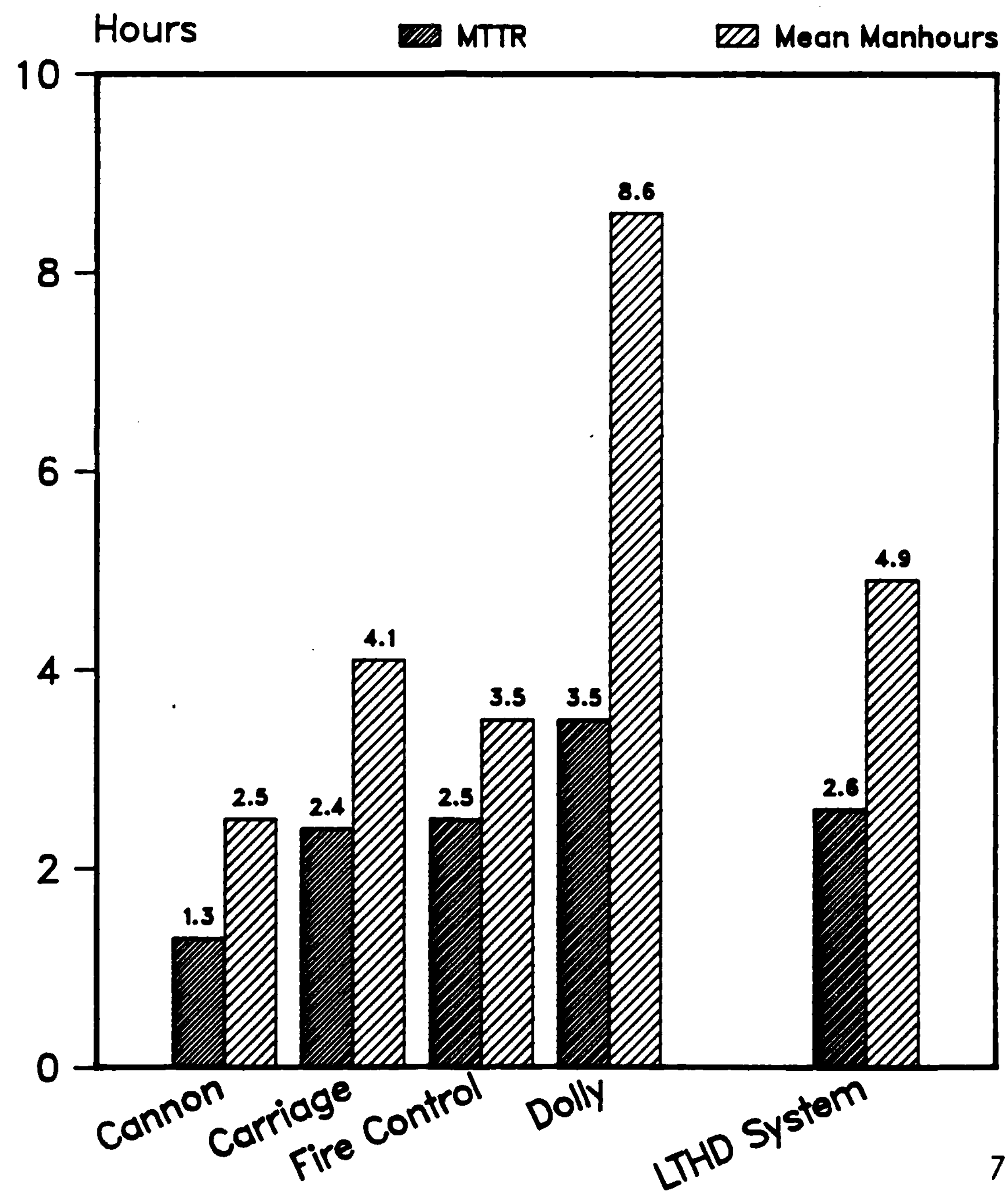
# LTHD Reliability Goals
# Based on M198 Howitzer Performance Data
# (Combat Abort Failures)



LTHD RELIABILITY GOALS BASED ON M198 HOWITZER PERFORMANCE DATA
(COMBAT ABORT FAILURES)

| | COMBAT ABORT | |
|---|---|---|
| | HARDWARE MRBF (ROUNDS) | OPERATIONAL MRBF (ROUNDS) |
| CANNON | 1,500 | 1,200 |
| CARRIAGE (M198 - CARRIAGE, RECOIL AND SPADE/TRAIL) | 580 | 390 |
| FIRE CONTROL | 1,600 | 900 |
| DOLLY (M198 - SUSPENSION) | 3,200 (MMBF = 18,500 MILES) | 2,000 (MMBF = 11,500 MILES) |
| LTHD SYSTEM | MRBF = 300 ROUNDS | MRBF = 200 ROUNDS |

# LTHD Maintainability Goals
# Based on M198 Howitzer Performance Data



LTHD MAINTAINABILITY GOALS BASED ON M198 HOWITZER PERFORMANCE DATA

| | MEAN TIME TO REPAIR (HRS) | MEAN MANHOURS (HRS) |
|---|---|---|
| CANNON | 1.3 | 2.5 |
| CARRIAGE (M198 - CARRIAGE, RECOIL AND SPADE/TRAIL) | 2.4 | 4.1 |
| FIRE CONTROL | 2.5 | 3.5 |
| DOLLY (M198 - SUSPENSION) | 3.5 | 8.6 |
| LTHD SYSTEM | 2.6 | 4.9 |

END

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