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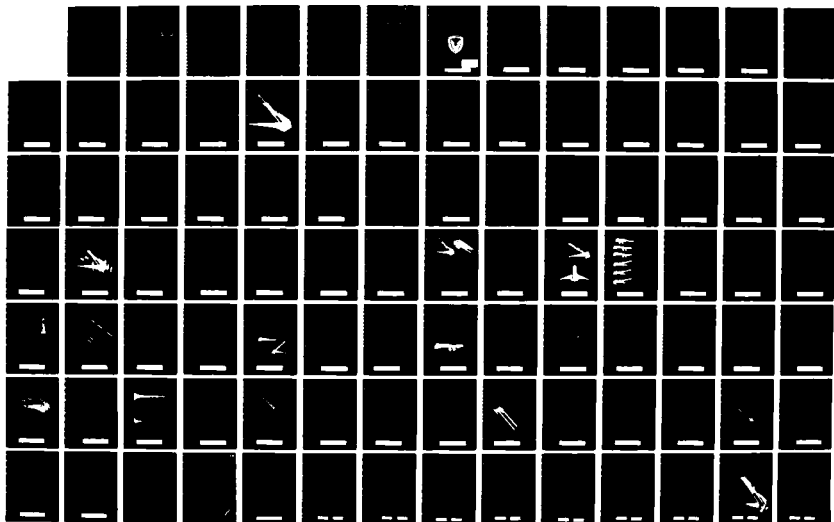
LIGHTWEIGHT TOWED HOWITZER DEMONSTRATOR PHASE 1 AND
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NORTHERN ORDANCE DIV R RATHE ET AL APR 87
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Lightweight Towed Howitzer Demonstrator

Final Report

Volume B

Technical Presentations - Part I

April 1987

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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 LTWD (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. <i>for report</i>		

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04 JUNE 85
PROPOSAL

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**



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

**FMC Corporation
Northern Ordnance Division
Minneapolis, Minnesota**

4 June 1985

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Abbreviations

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

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.

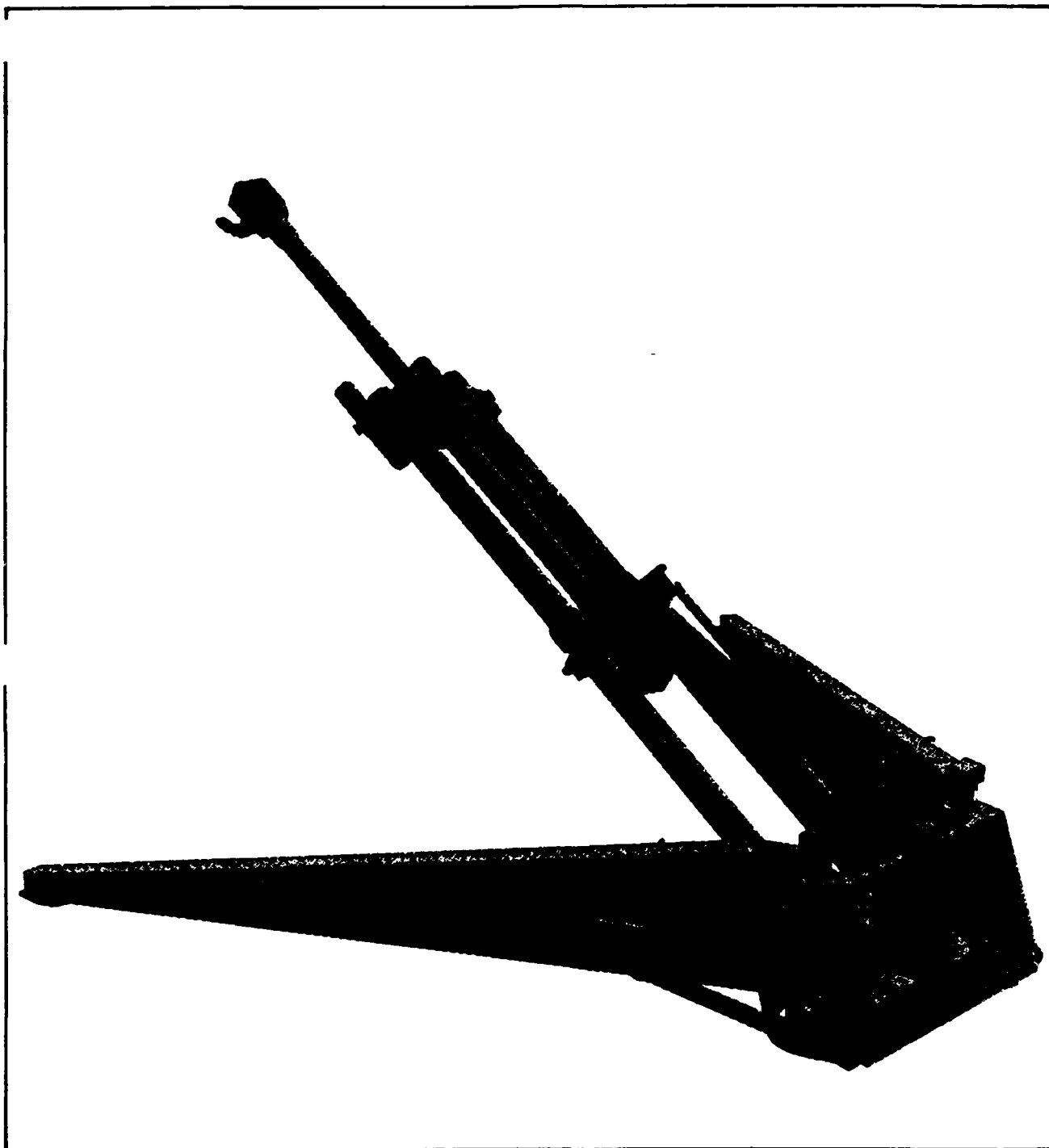


Figure 1-1. THE LTHD USES AN INNOVATIVE APPROACH to 155-mm howitzer configurations.

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.

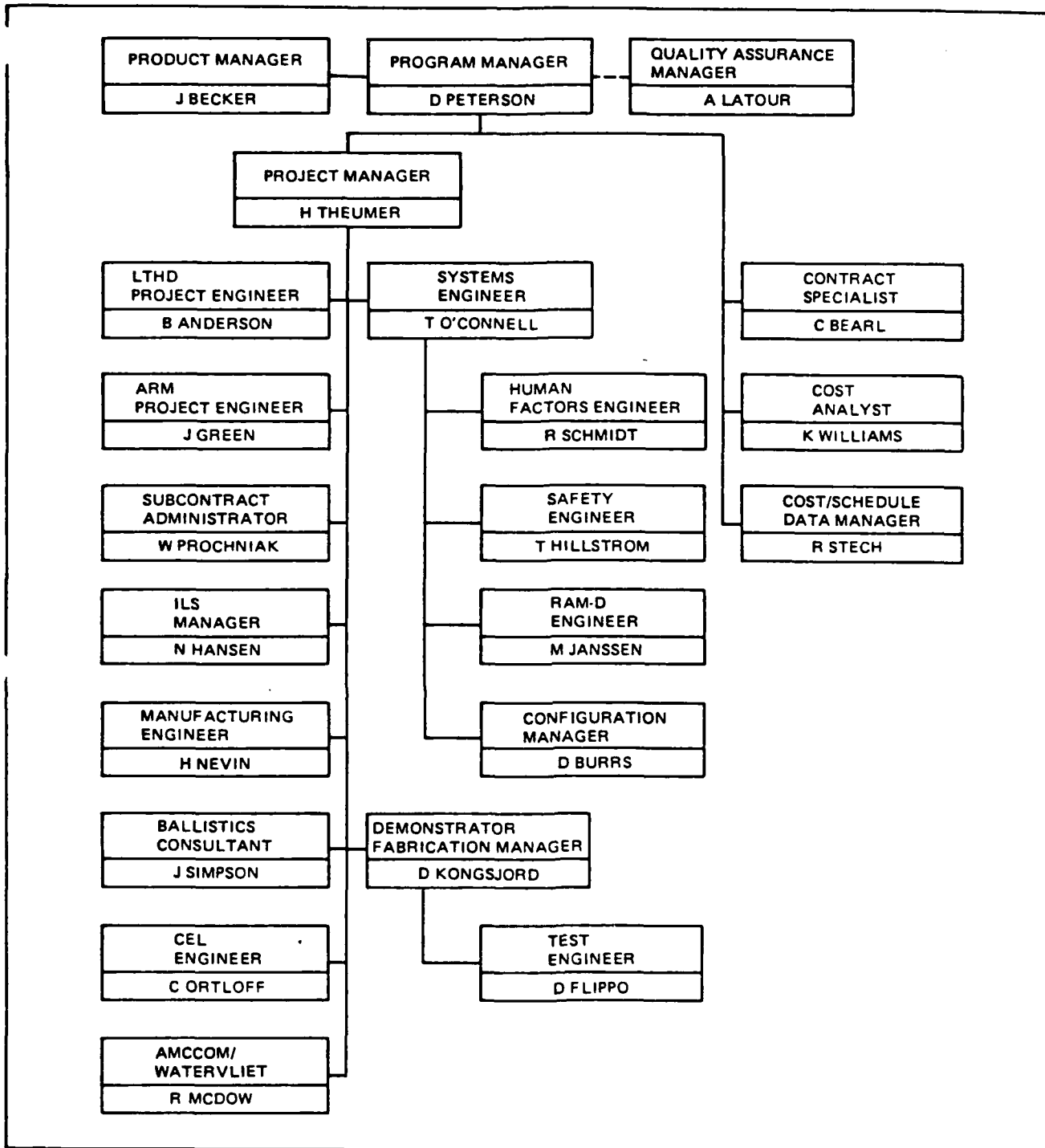


Figure 1-2. THE LIFWS PROJECT IS STAFFED with experienced design and development personnel.

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

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 judicious 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

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.

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

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

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.

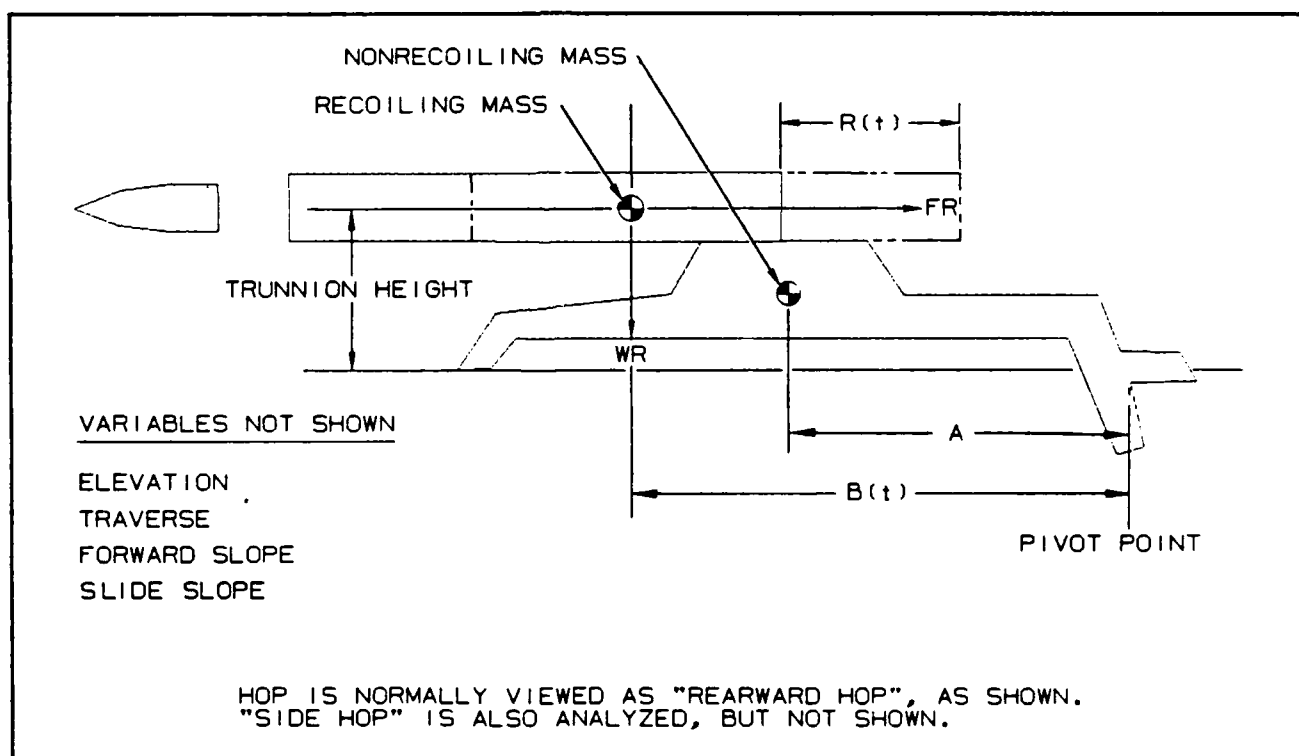


Figure 3-1. FIRING STABILITY MODEL accounts for moving CG, azimuth, ground slope, and QE.

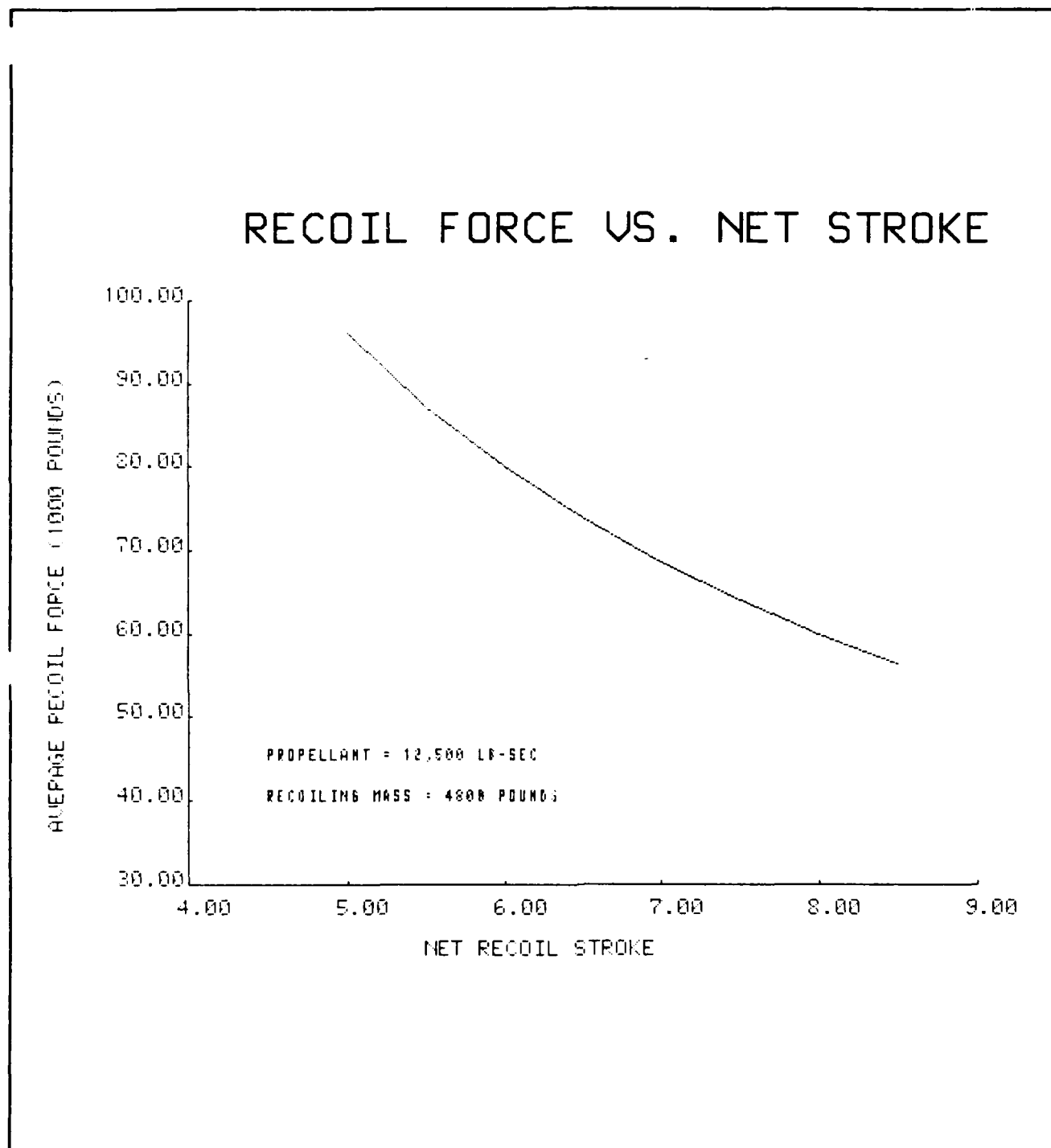


Figure 3-2. FIRING STABILITY CAN BE IMPROVED by increasing recoil stroke.

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.

RECOIL FORCE VS. MASS

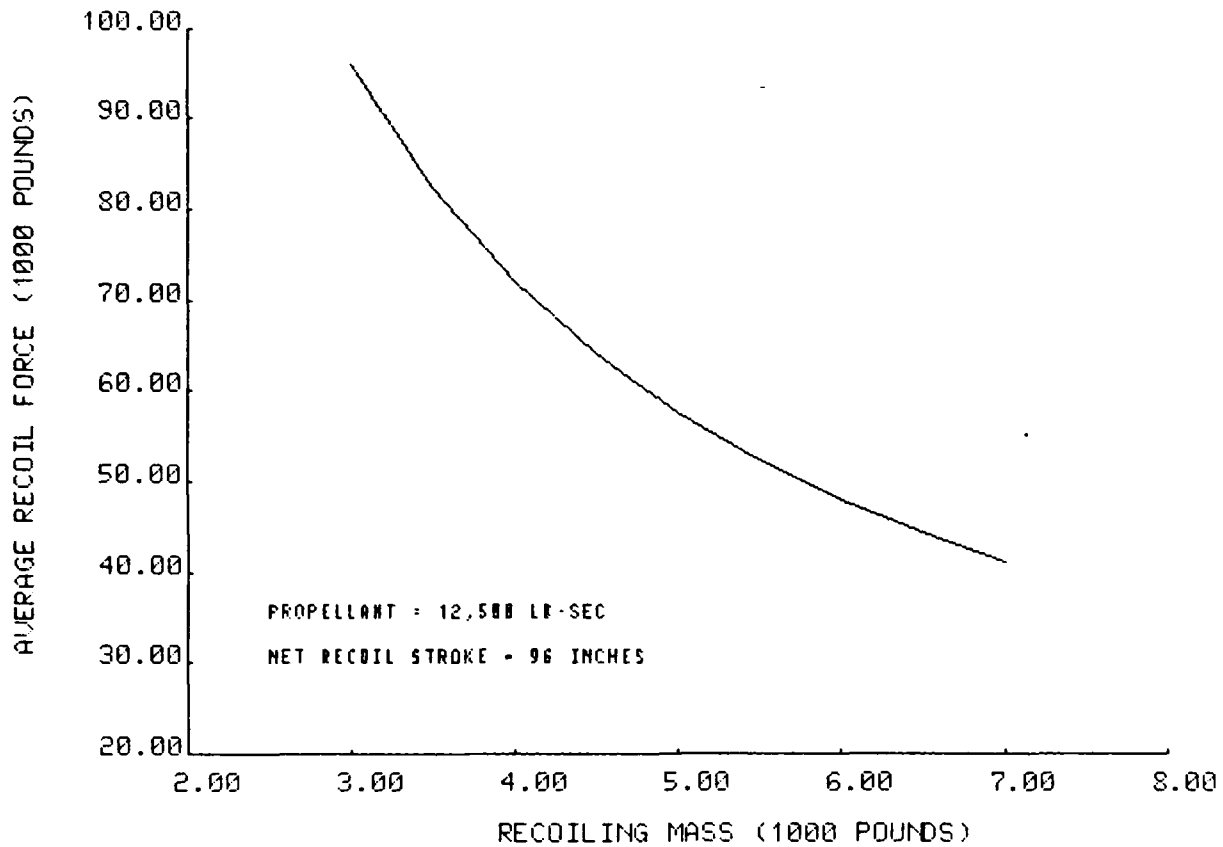


Figure 3-3. FIRING STABILITY IS REDUCED by reducing recoiling mass.

The recoiling mass is joined to the non-recoiling 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-non-recoiling 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

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 11
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, 1 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 1
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.

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

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.

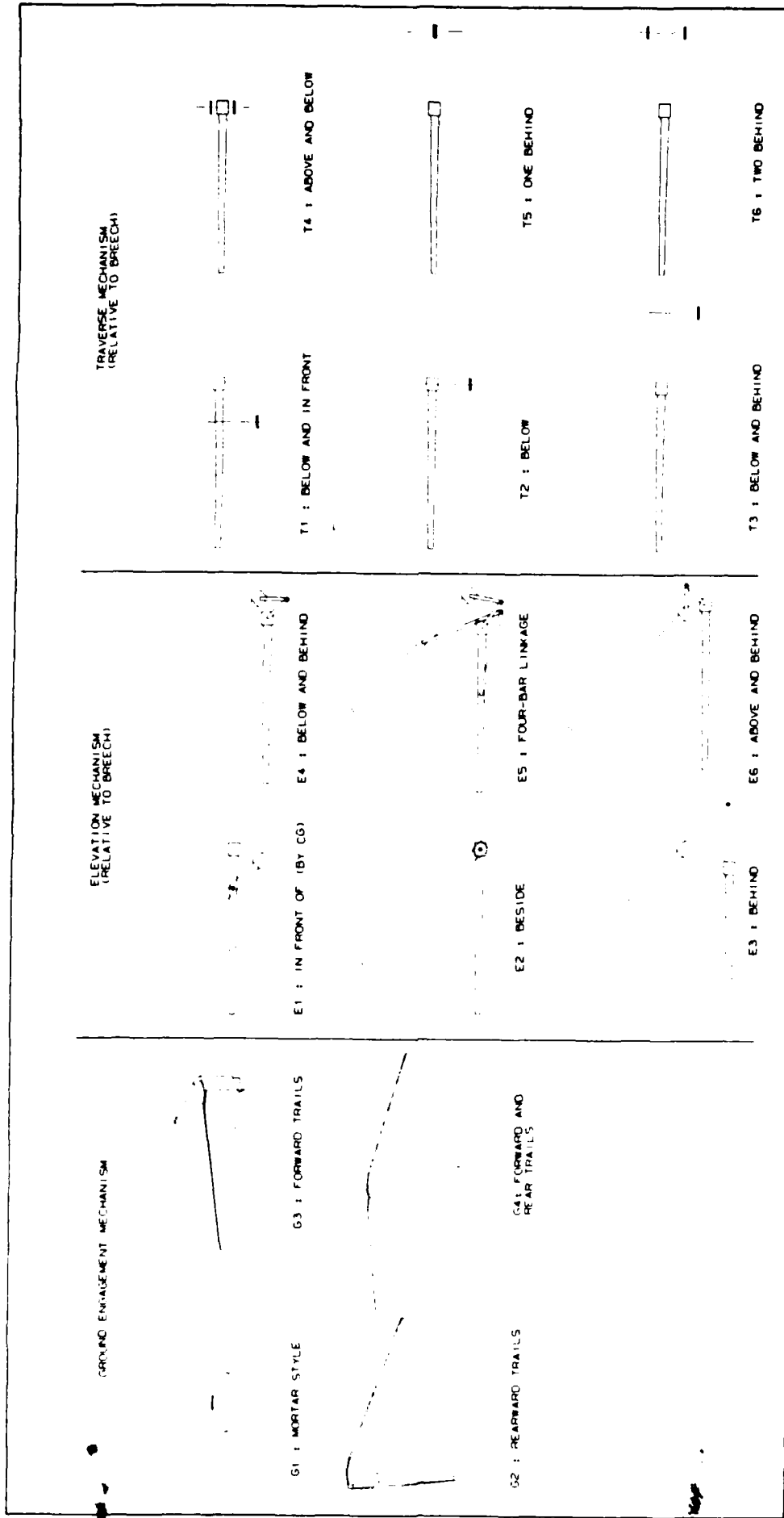


Figure 3-1. CLASSIFYING CONFIGURATION CONCEPTS provides a framework useful to the evolution of the FMC LTHD concept.

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

Ground Engagement Mechanism	Elevation Mechanism (Relative to Breech)	Traverse Mechanism (Relative to Breech)
G1 = Mortar-style	E1 = In front of (by C6)	T1 = Below and in front
G2 = Rearward trails	E2 = Beside	T2 = Below
G3 = Forward trails	E3 = Behind	T3 = Below and behind
G4 = Forward and rearward trails	E4 = Below and behind	T4 = Above and below
	E5 = Four-Bar linkage	T5 = One behind
	E6 = Above and 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 T2	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.

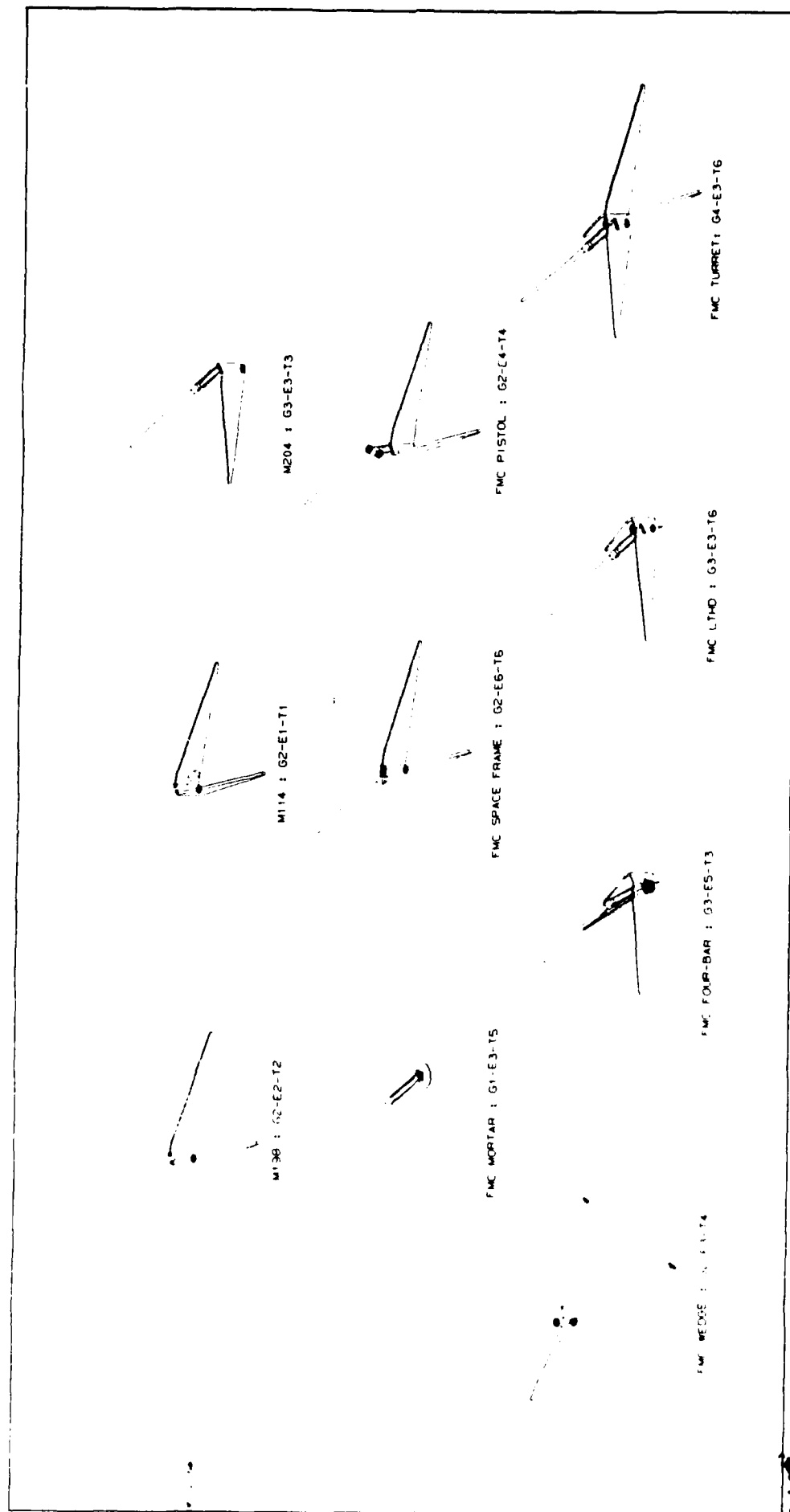


Figure 3-7. TEN of the 144 conceptual configurations are considered.

Characteristics Critical to LTHD Objectives	Points	M114	M198	M204	FMC						
					Mortar	Wedge	Pistol	Space Frame	LTHD	Four Bar	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 (or mechanical access if manual = 0)	3	3	3	3	0	2	2	2	0	2	0
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.

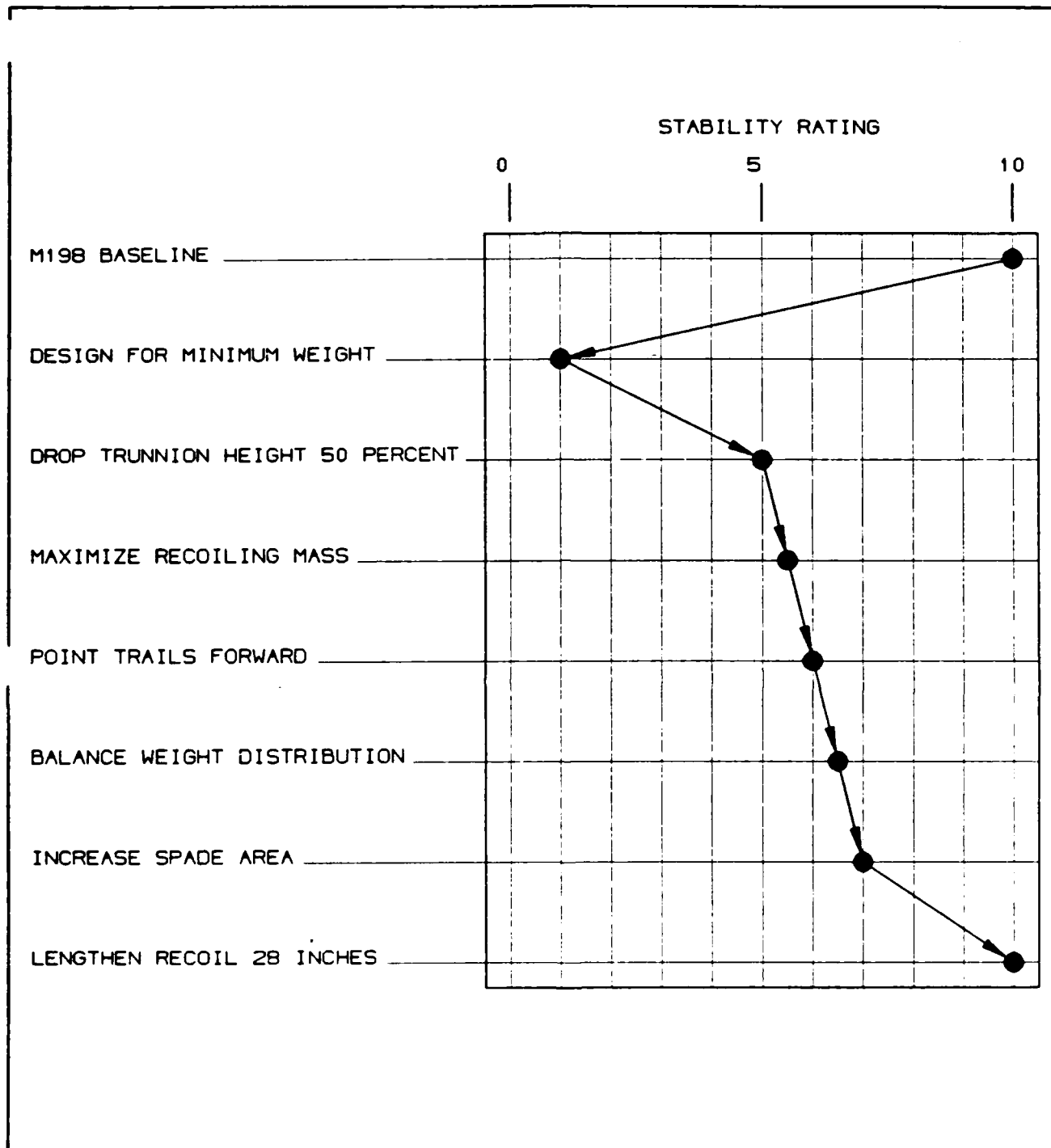


Figure 3-9. SEVEN STEPS provide the FMC LTHD with firing stability.

<u>Solution Element</u>	<u>Secondary Objective</u>	<u>Primary Objective</u>
0. Use M198 baseline	a. 30-km range	PERFORMANCE
1. Design for minimum weight	a. Concept compatible with composites b. Use composites to optimum degree	WEIGHT REDUCTION 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 b. Facilitate use of conventional barrel to minimize barrel risk	FIRING STABILITY LOW RISK
4. Point trails forward	a. Facilitate balanced weight distribution b. Soft recoil is option c. Forward pointing trails provide anti-hop firing suspension	FIRING STABILITY FIRING STABILITY FIRING STABILITY
5. Balance weight distribution	a. Increasing weight over spade improves holding power and stability b. Increasing weight on forward trails improves anti-hop effectiveness	FIRING STABILITY FIRING STABILITY
6. Increase spade area	a. Central spade reduces slide b. Three claws enhance spade in soft soil; replace spade in hard soil	FIRING STABILITY
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.

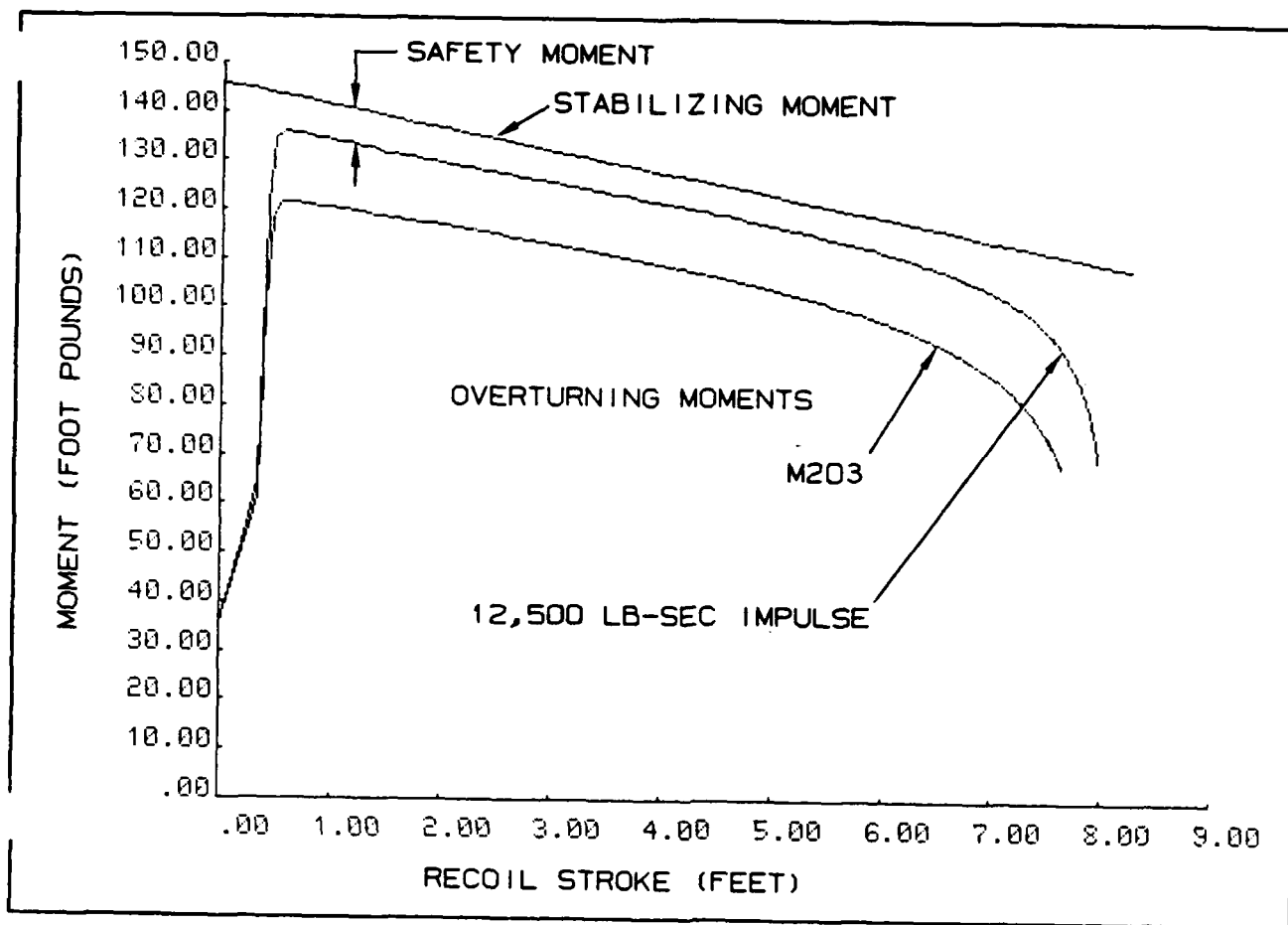


Figure 3-11. THE FMC LTHD provides a good margin of firing stability.

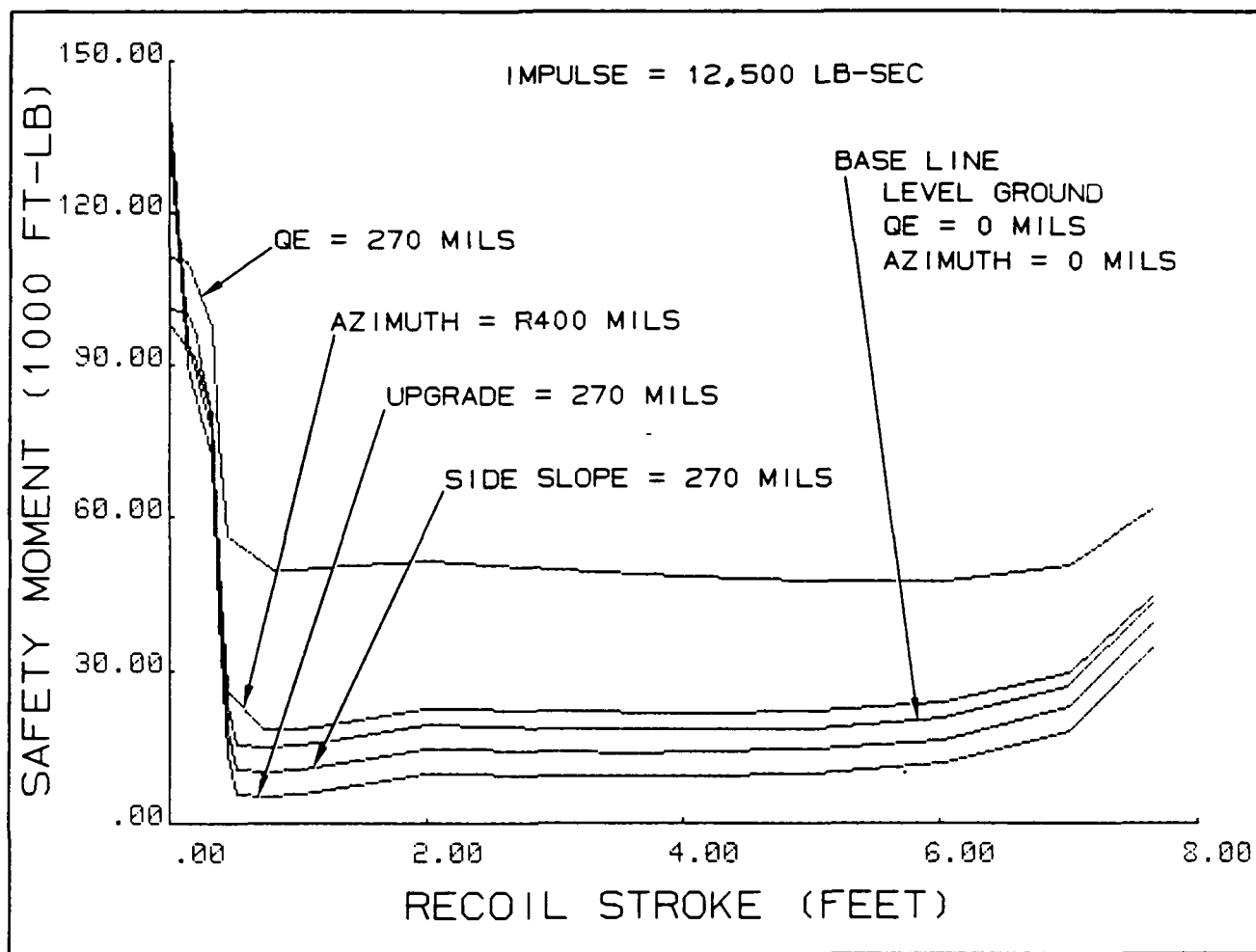


Figure 3-12. FIRING STABILITY is retained with traverse and on sloping terrain.

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

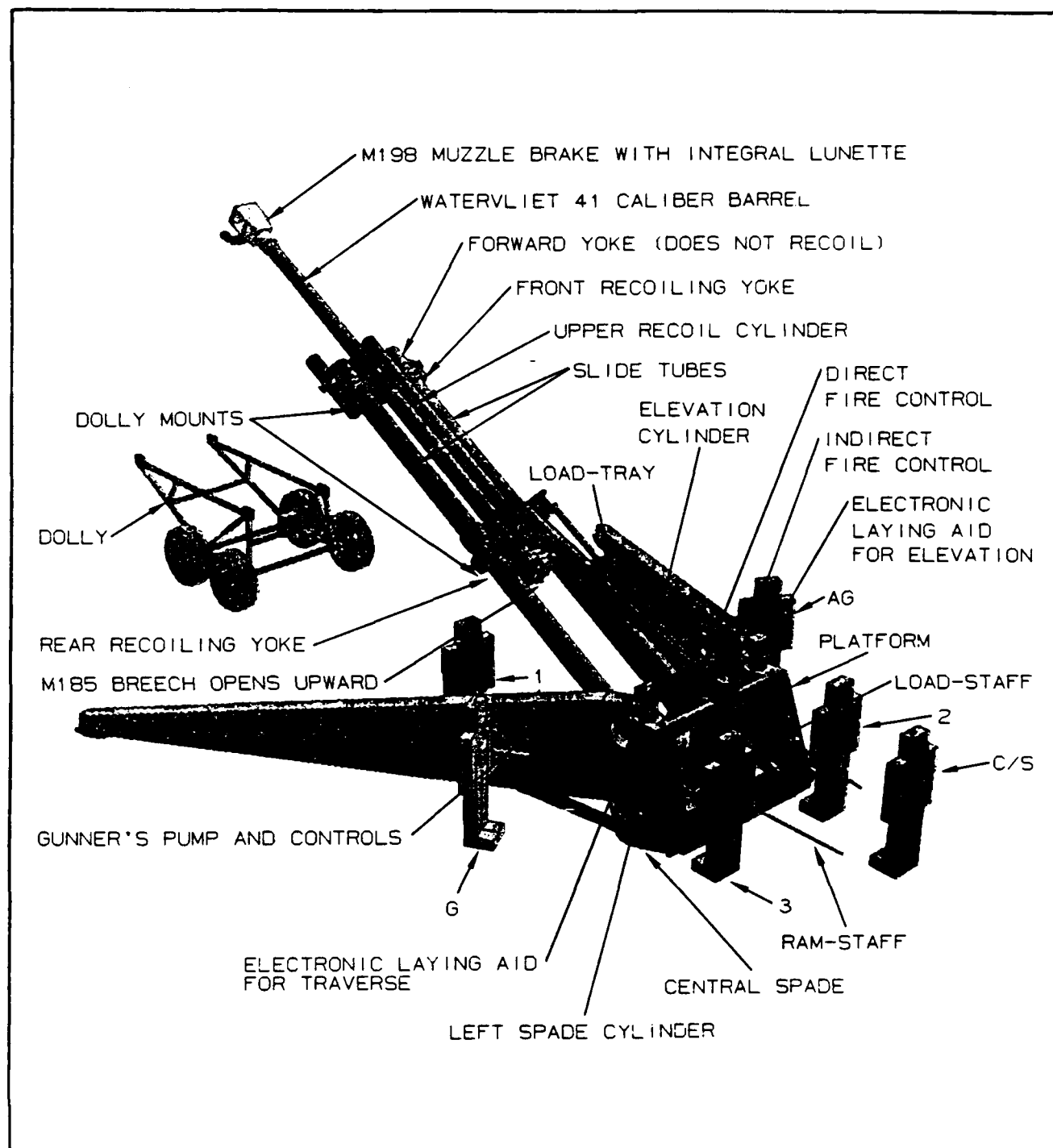


Figure 3-13. THE FIRING POSITION focuses the firing forces into a central spade and integral platform.

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)

<u>Item</u>	<u>Weight</u> <u>Mean</u>	<u>SD</u>	<u>Material</u>	<u>Qty</u>	<u>Figure</u> <u>Number</u>
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
Trav 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	20	0.05	Metal/rubber	4	3-35;16,32
bushing					
Forward yoke:	230	2.50	Metal or composite	1	3-37;13,32
Firing lock	30	0.40	Metal	2	3-37
mechanism					
Into battery cushion	4	0.08	Metal/elastomer	2	
Travel lock--yoke	10	0.10	Metal	2	3-37
portion					
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				1	3-38
cap					
Orifice ring				1	3-38
Rear recoiling end				1	3-38
cap					
Recoiling inner				1	3-38
cylinder					
Recoiling outer				1	3-38
cylinder					
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)

Item	Weight		Material	Qty	Figure Number
	Mean	SD			
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 measurement:	150	2		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)

<u>Item</u>	<u>Weight Mean</u>	<u>SD</u>	<u>Material</u>	<u>Qty</u>	<u>Figure Number</u>
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)

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 of 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) timed 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

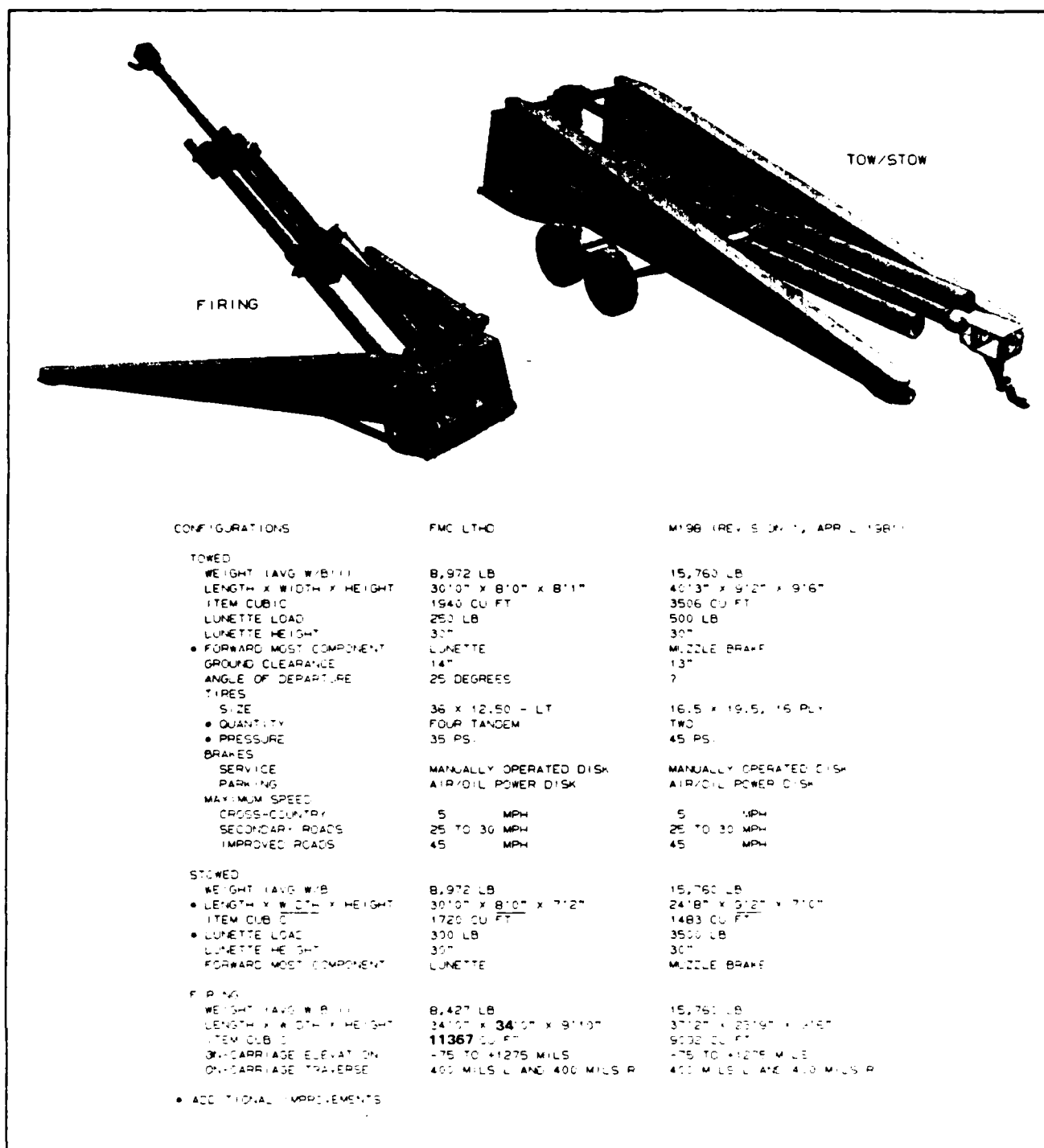


Figure 3-15. FMC LTHD OPERATIONAL CONFIGURATIONS provide additional improvements over the M198 in critical areas.

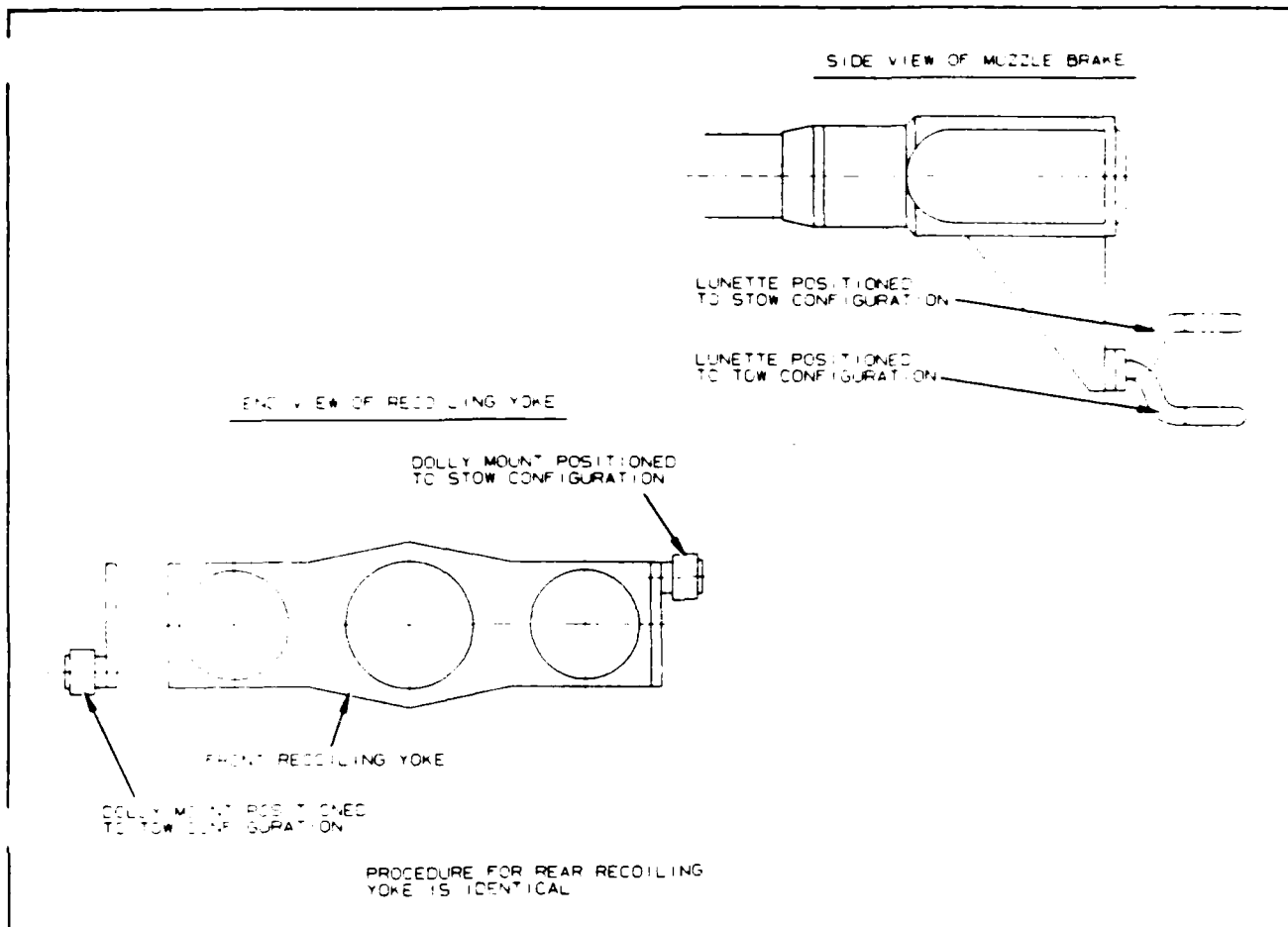


Figure 3-16. THE STOWED CONFIGURATION requires repositioning dolly mounts and lunette.

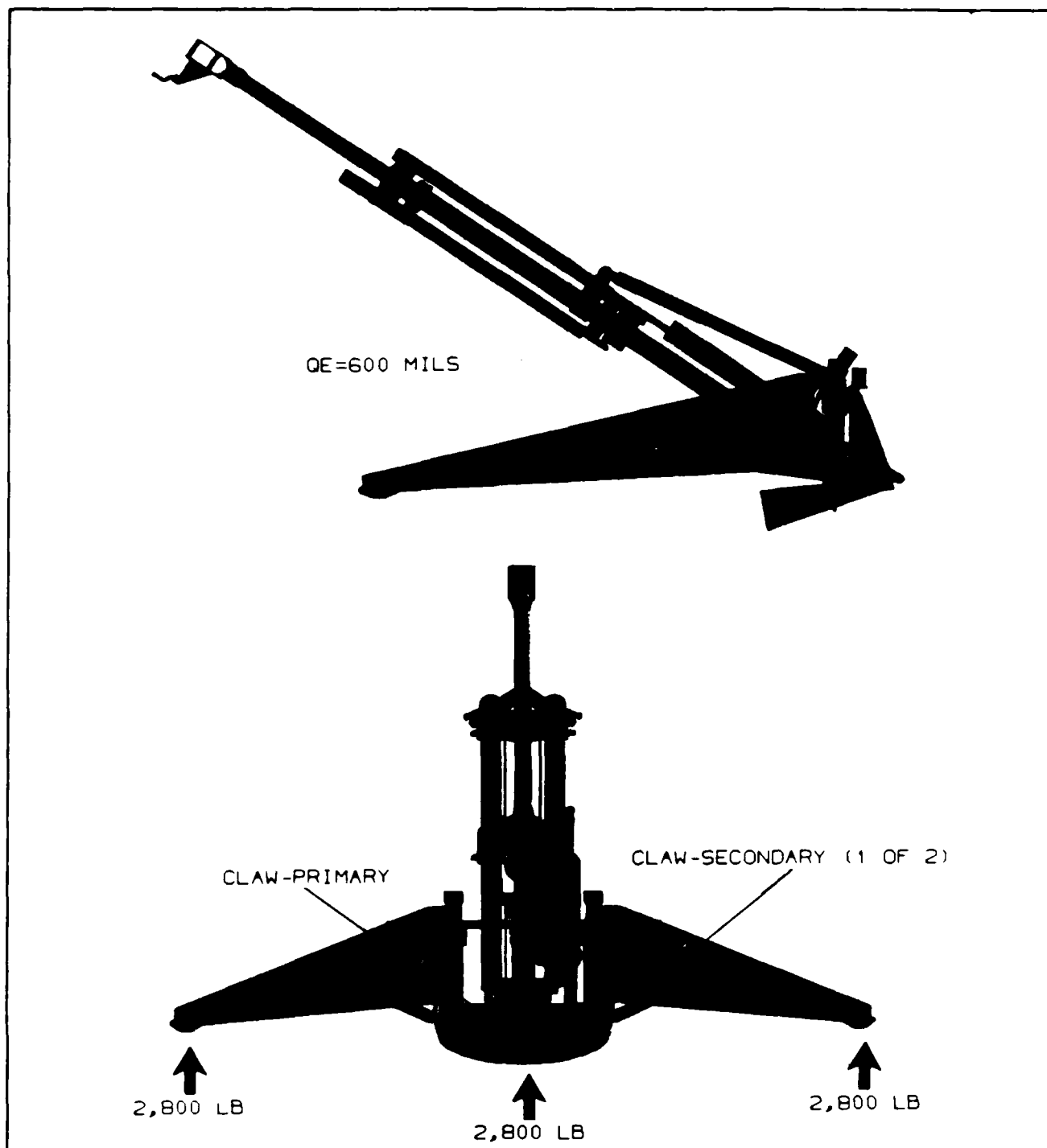


Figure 3-17. AGGRESSIVE GROUND ENGAGEMENT is enhanced by weight balance.



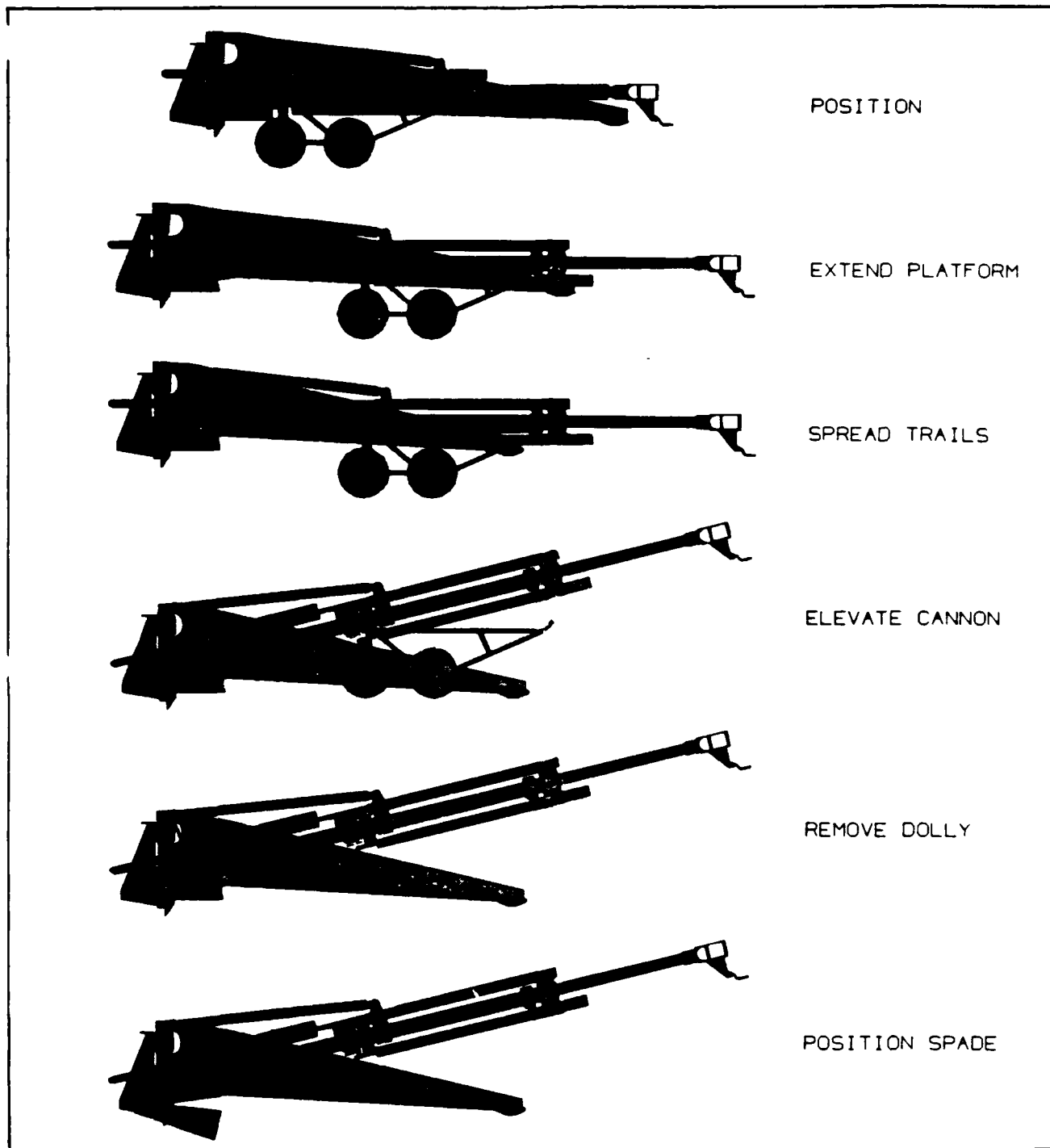


Figure 3-18. EMLACEMENT is simplified by the integral firing platform and integral spade.

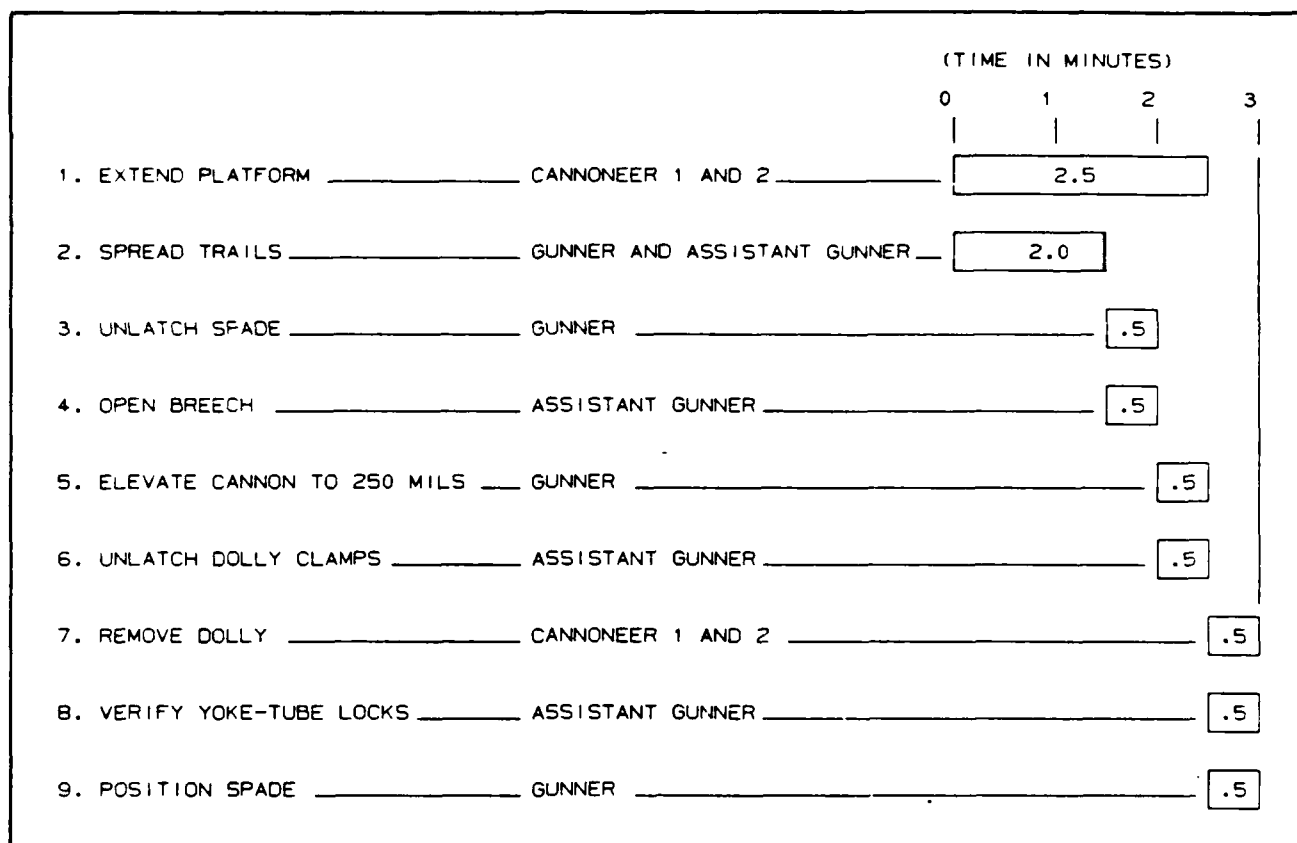


Figure 3-19. EMPLACEMENT TIME is . minutes with a crew of four.

A more detailed description of these steps follows:

NOTE

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).

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.

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.

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.

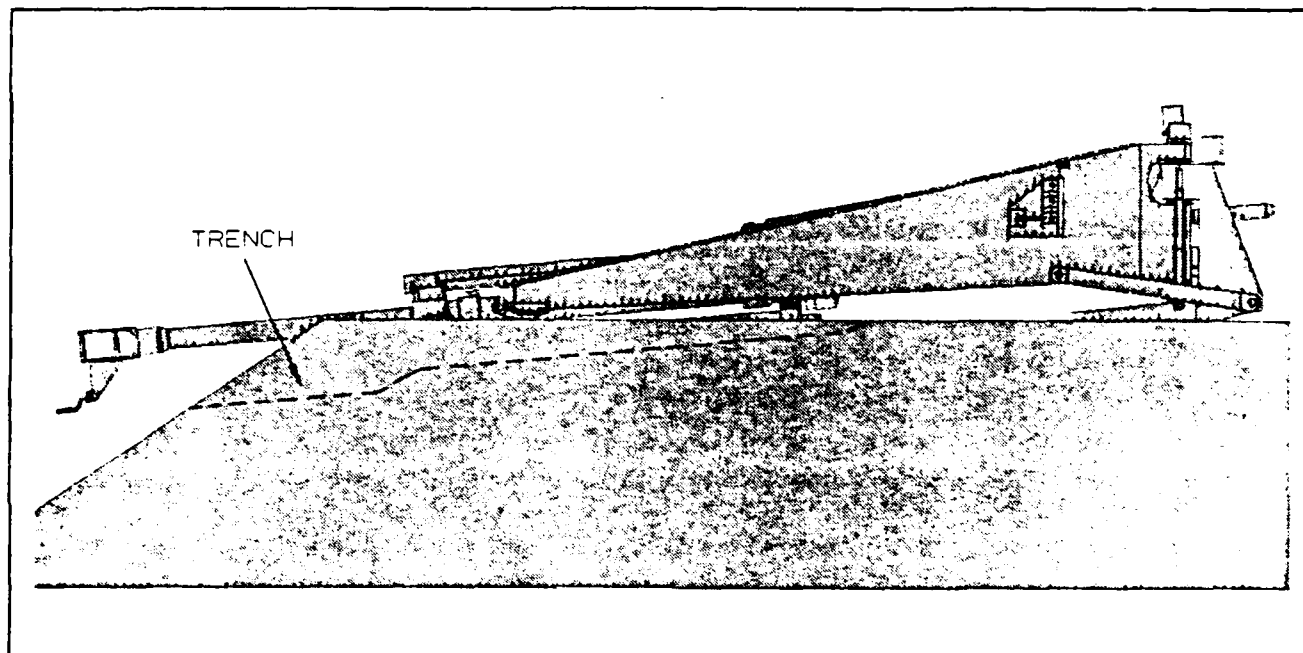


Figure 3-20. FIRING AT NEGATIVE QE requires careful site selection or the digging of a trench.

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 timed 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.

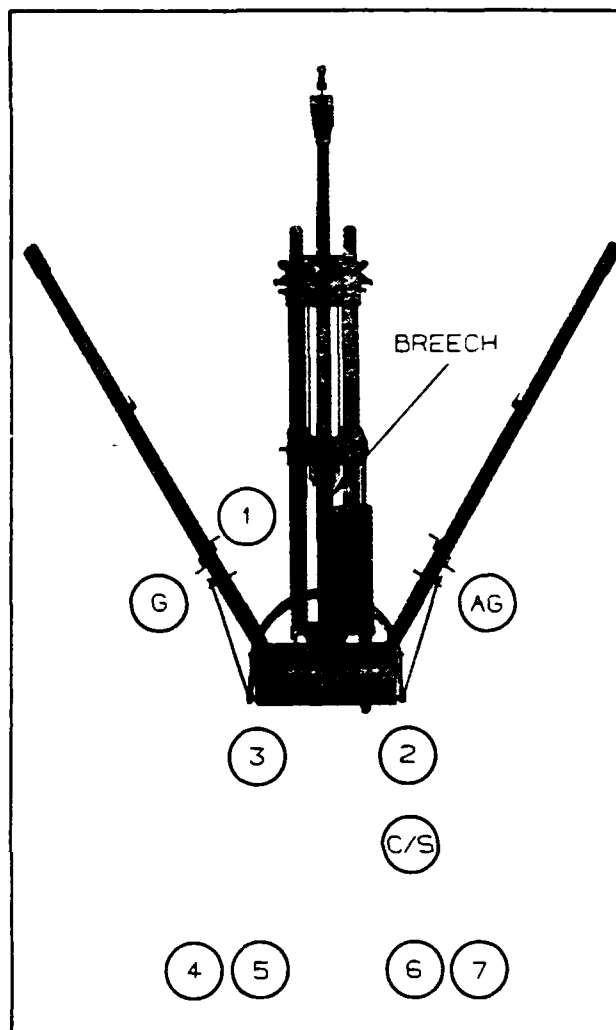


Figure 3-21. CREW POSITIONS reduce the exposure to blast overpressure.

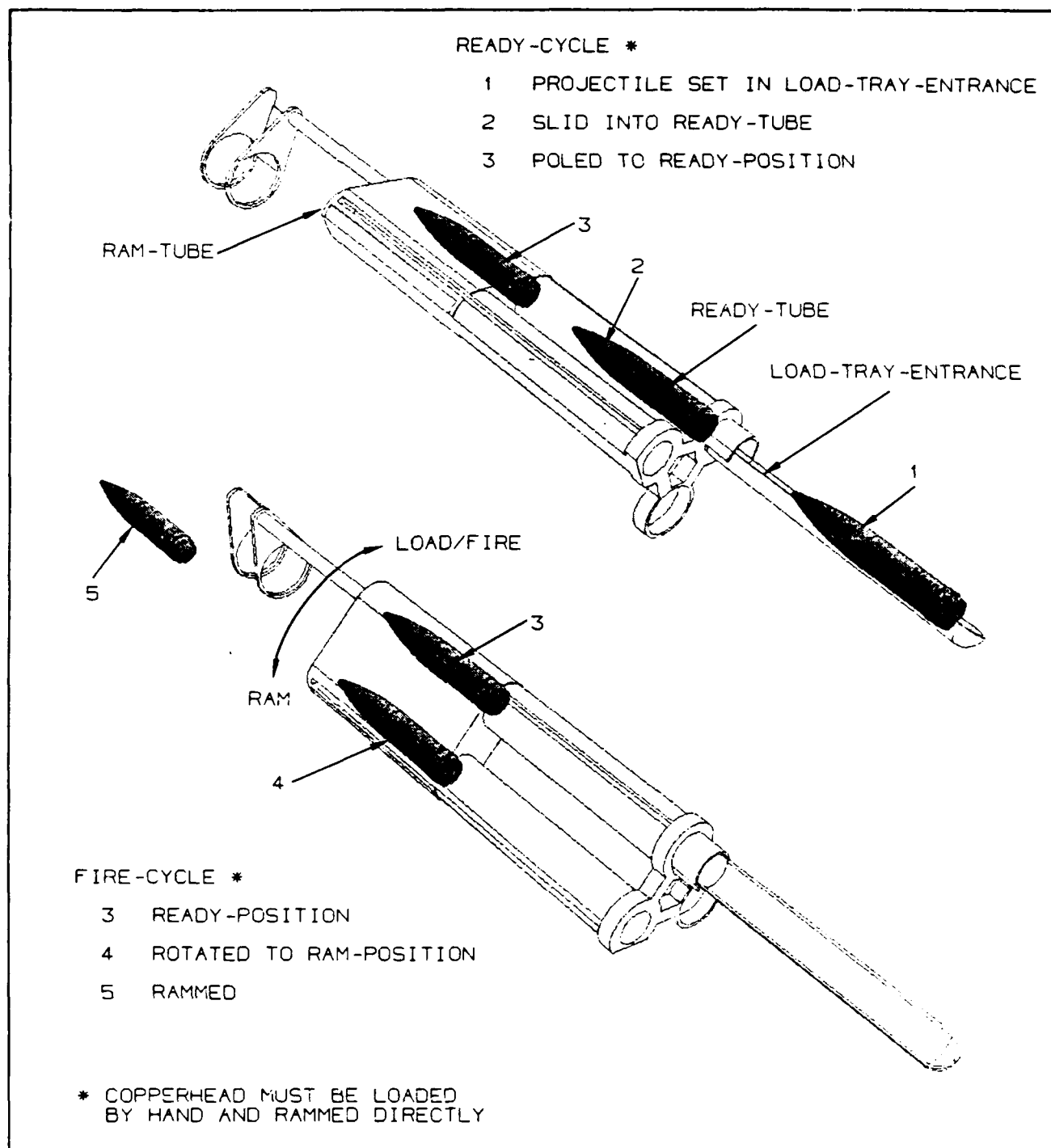


Figure 3-22. LOAD-TRAY facilitates a four-round burst.

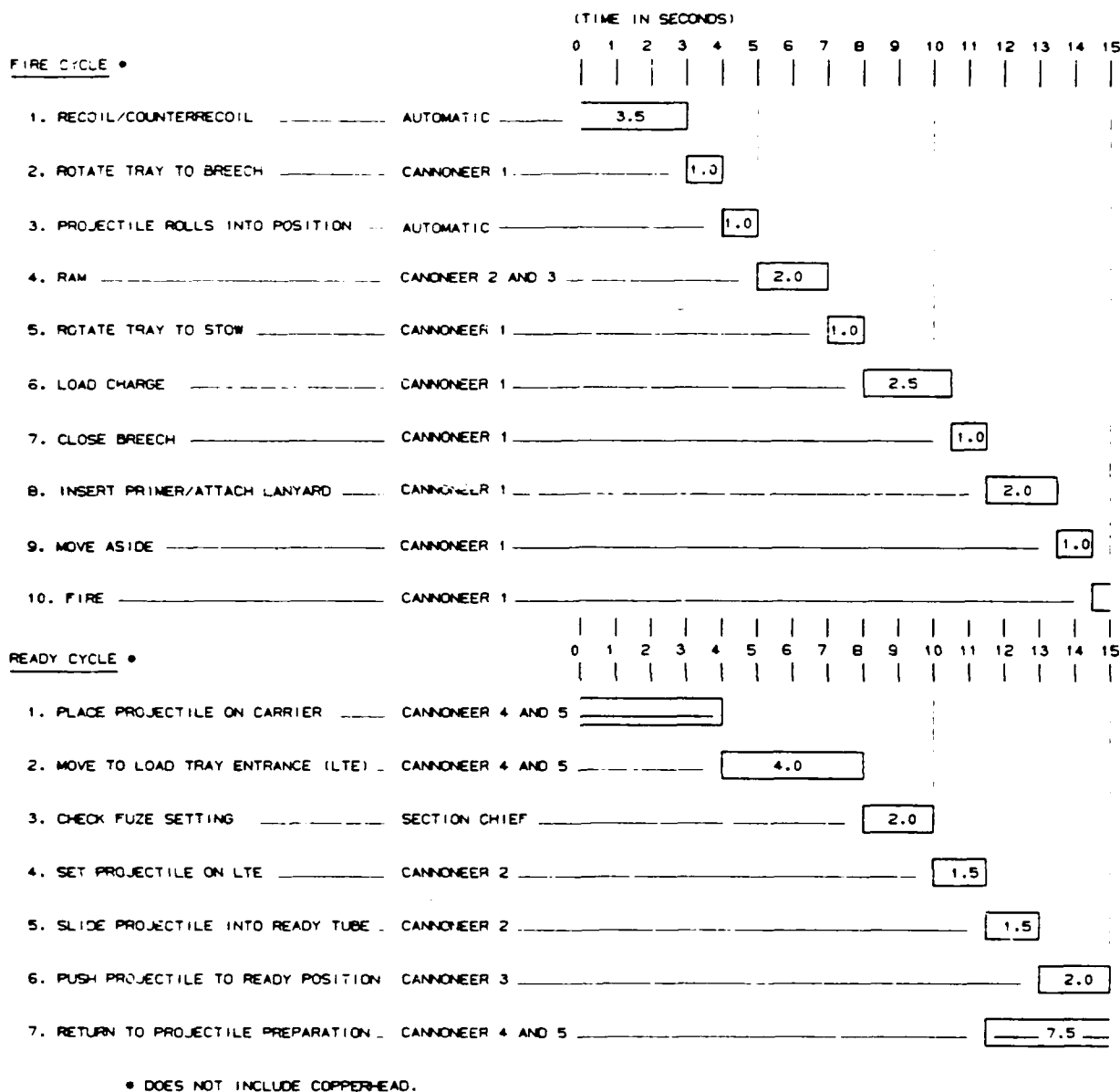


Figure 3-23. THE FMC LTHD will fire four rounds per minute.

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

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.

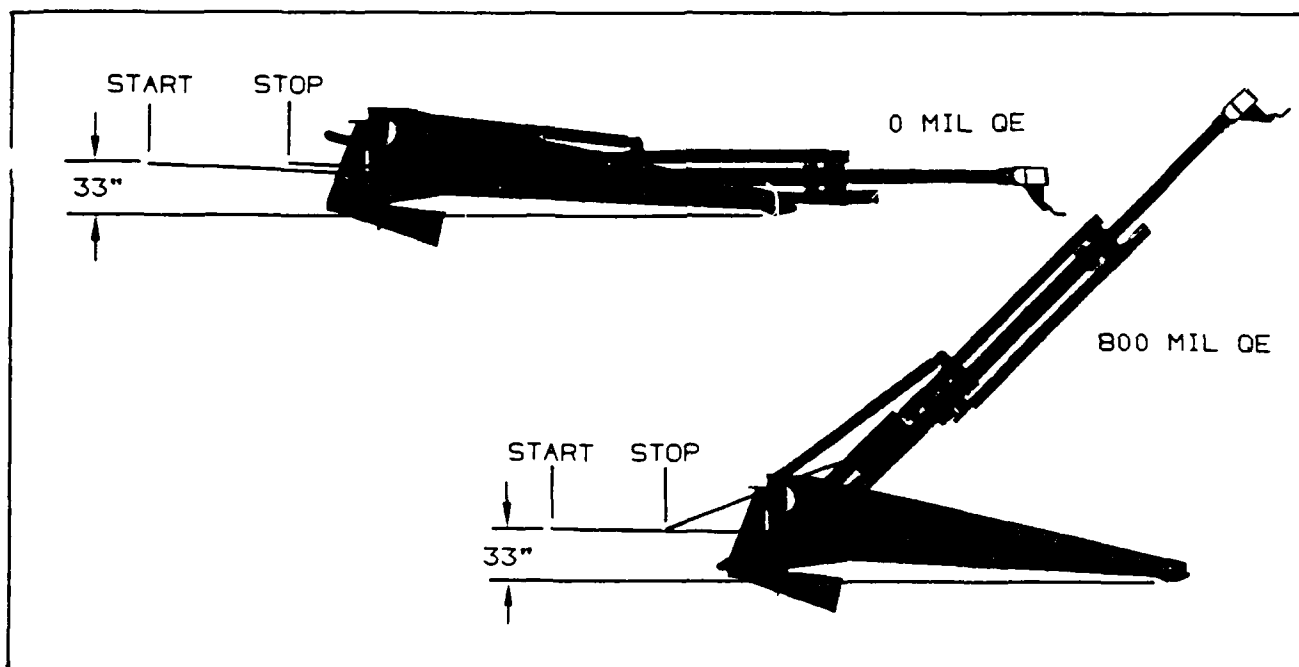


Figure 3-24. THE LOAD-TRAY allows the ram-staff handle to be held at the height most effective for the crew.

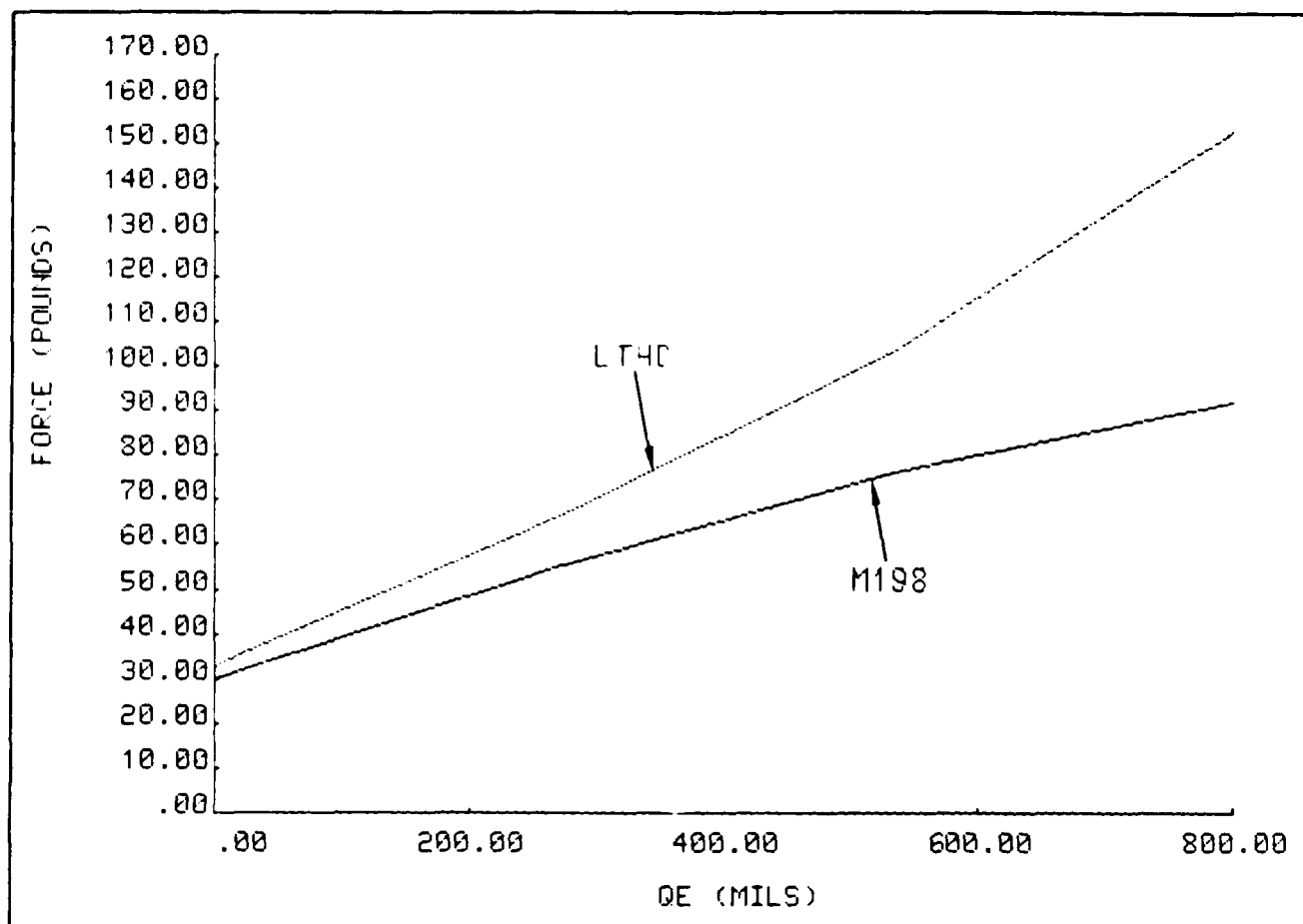


Figure 3-25. ADDITIONAL FORCE required to overcome projectile weight due to the load-tray is compensated for by room for more hands on the handle.

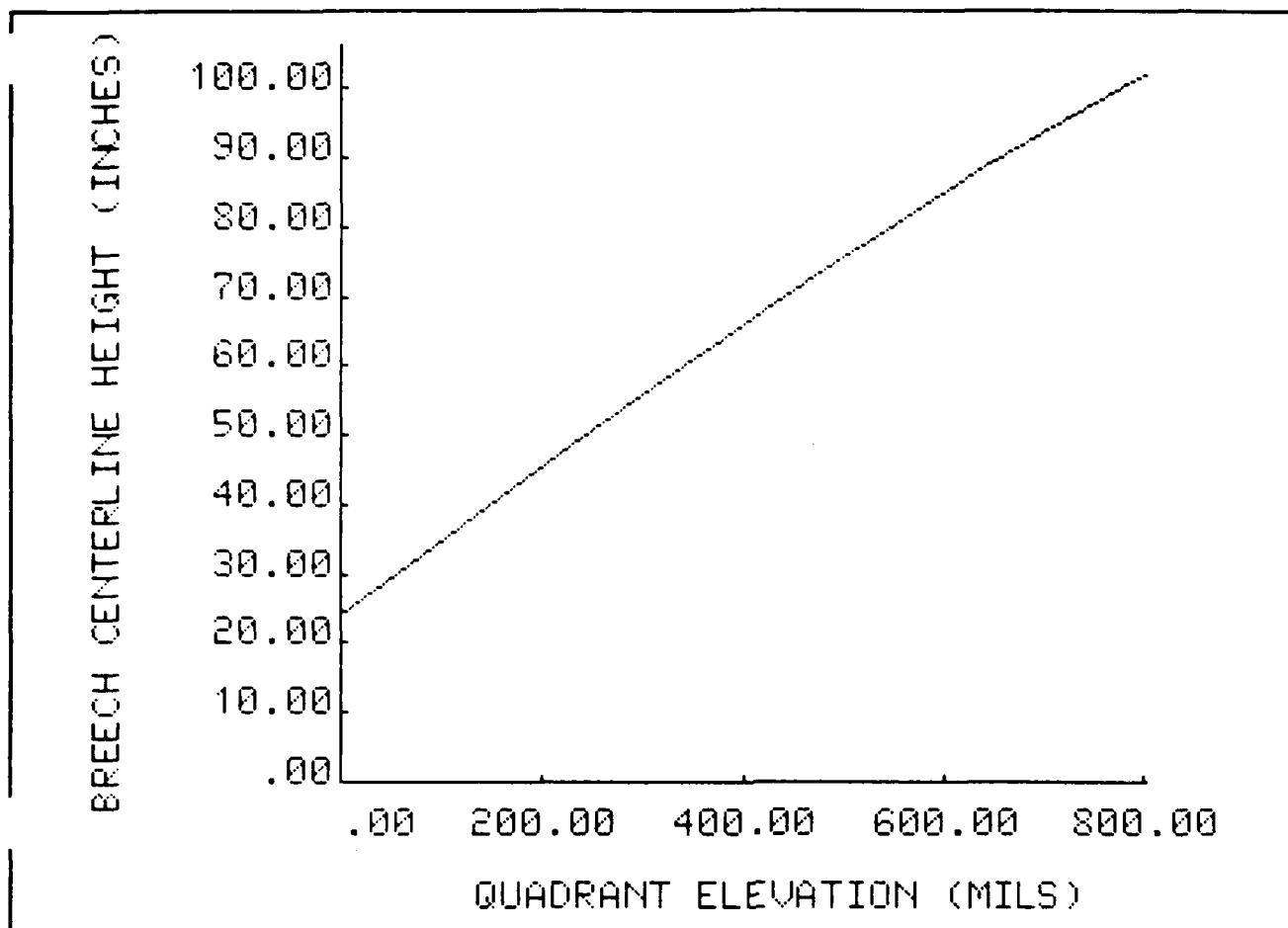


Figure 3-26. BREECH HEIGHT increases with QE; cannoneer 1 must be of average height to load charge at QE's of 450 to 525 mils.

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.

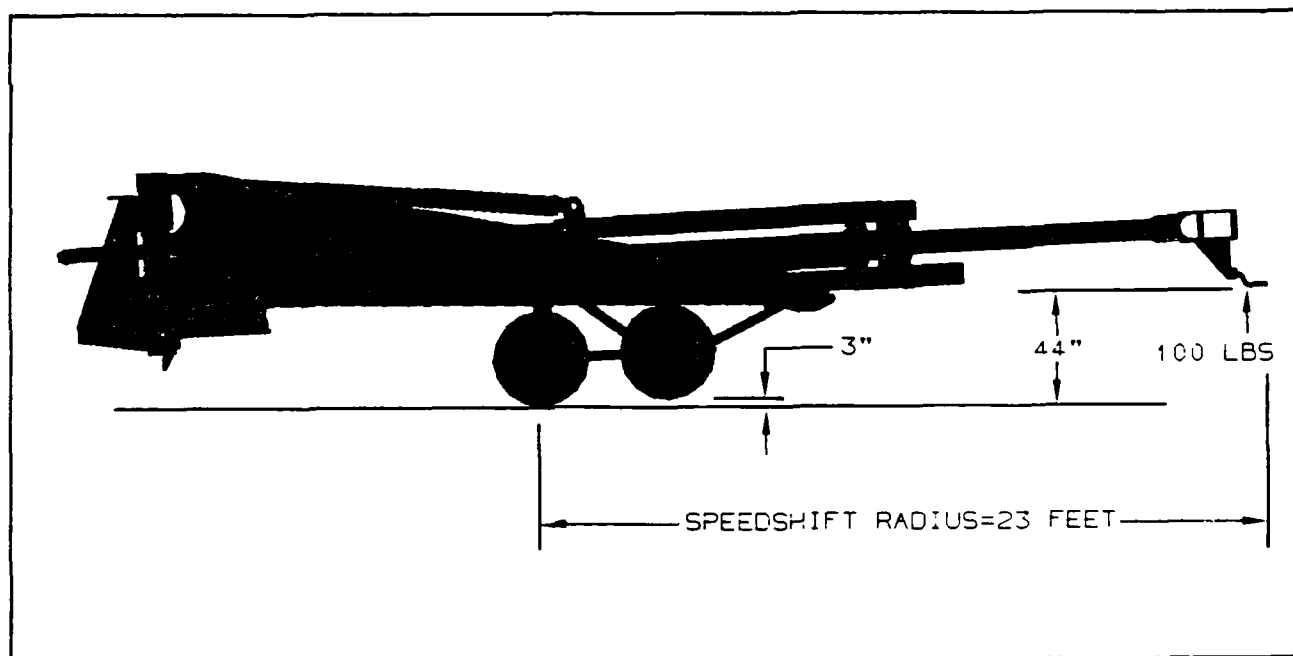


Figure 3-27. THE SPEED SHIFT FUNCTION adds no parts or weight to the FMC LTHD; speed shifting is accomplished on two wheels.

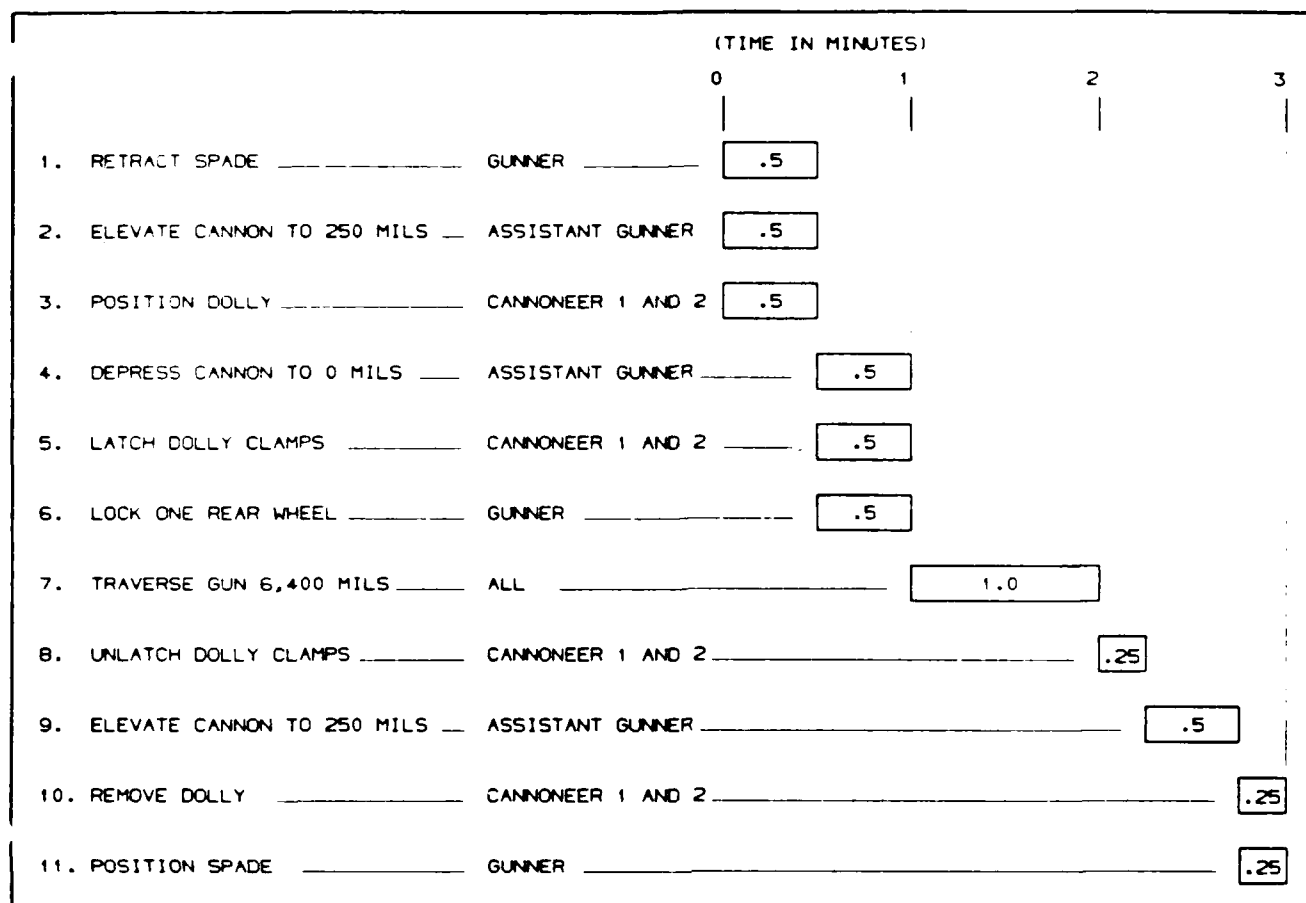


Figure 3-28. SPEED SHIFT TIME is 3 minutes with a crew of four.

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

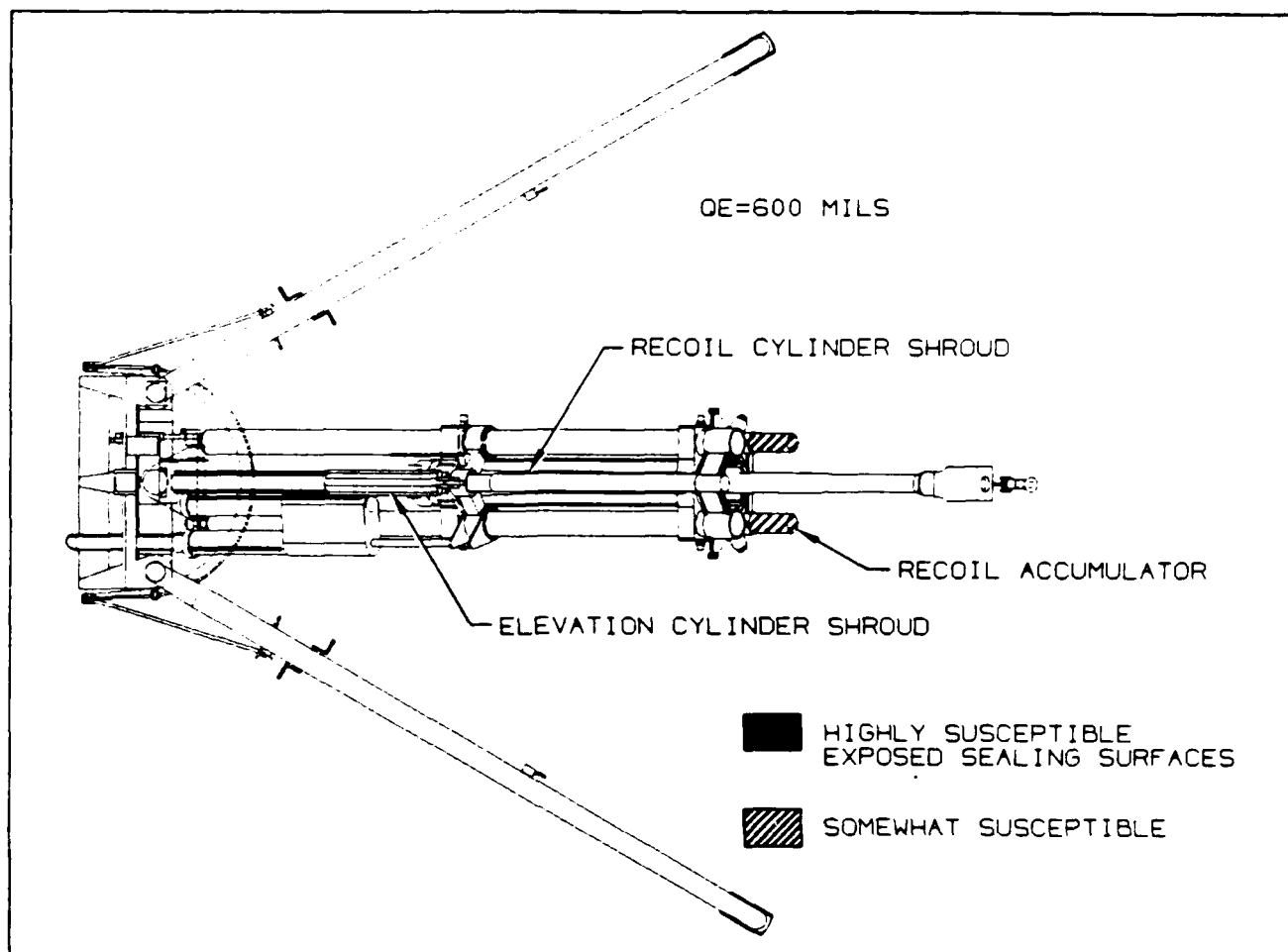


Figure 3-29. VULNERABILITY TO AERIAL BURSTS is minimized with careful component placement and shrouds.

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.

			(TIME IN MINUTES)			
			0	1	2	3
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

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)

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	<u>640</u>
Total recoiling mass	4,700

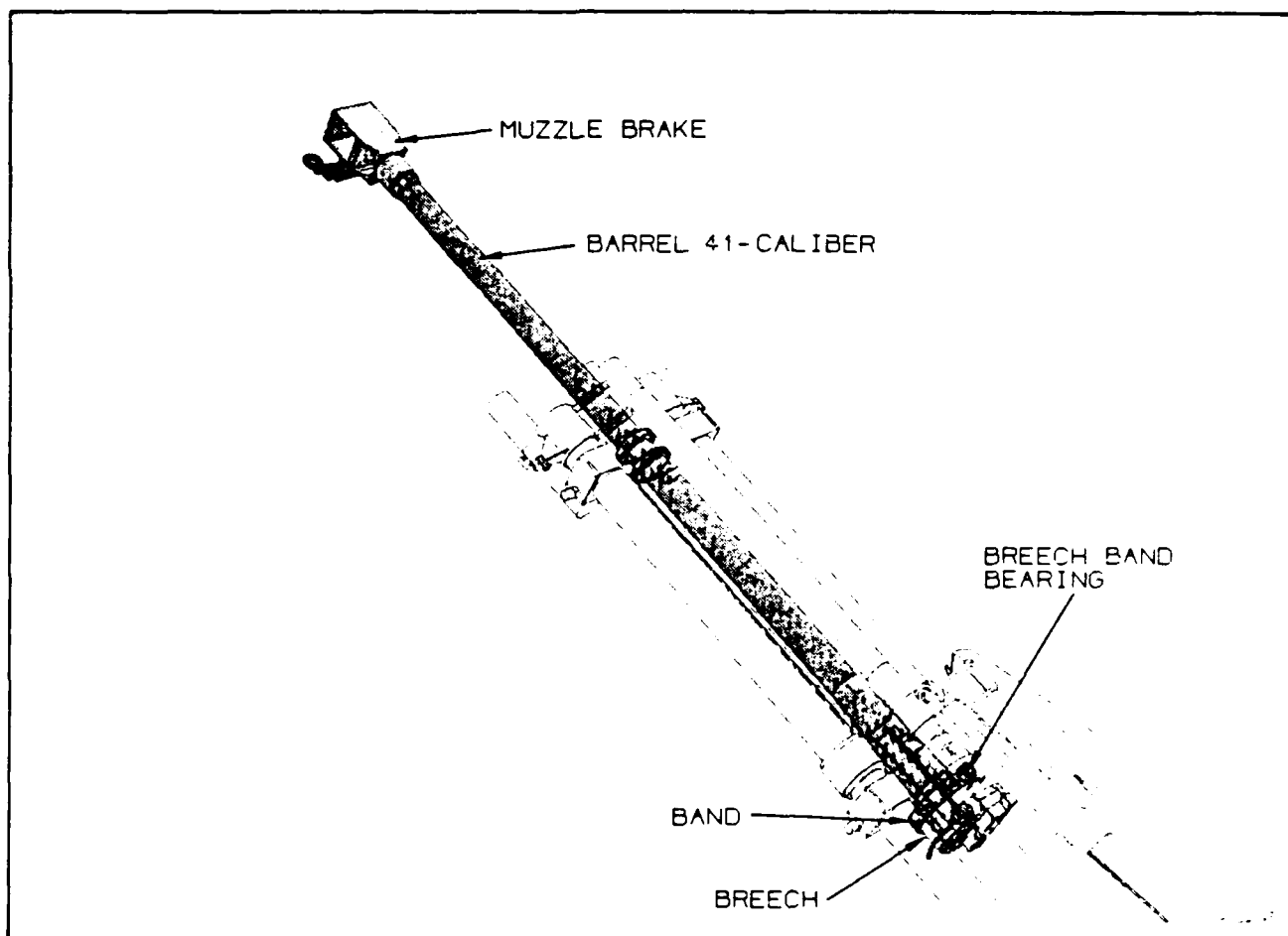


Figure 3-31. WATERVLIET will supply the conventional cannon.

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

- 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.

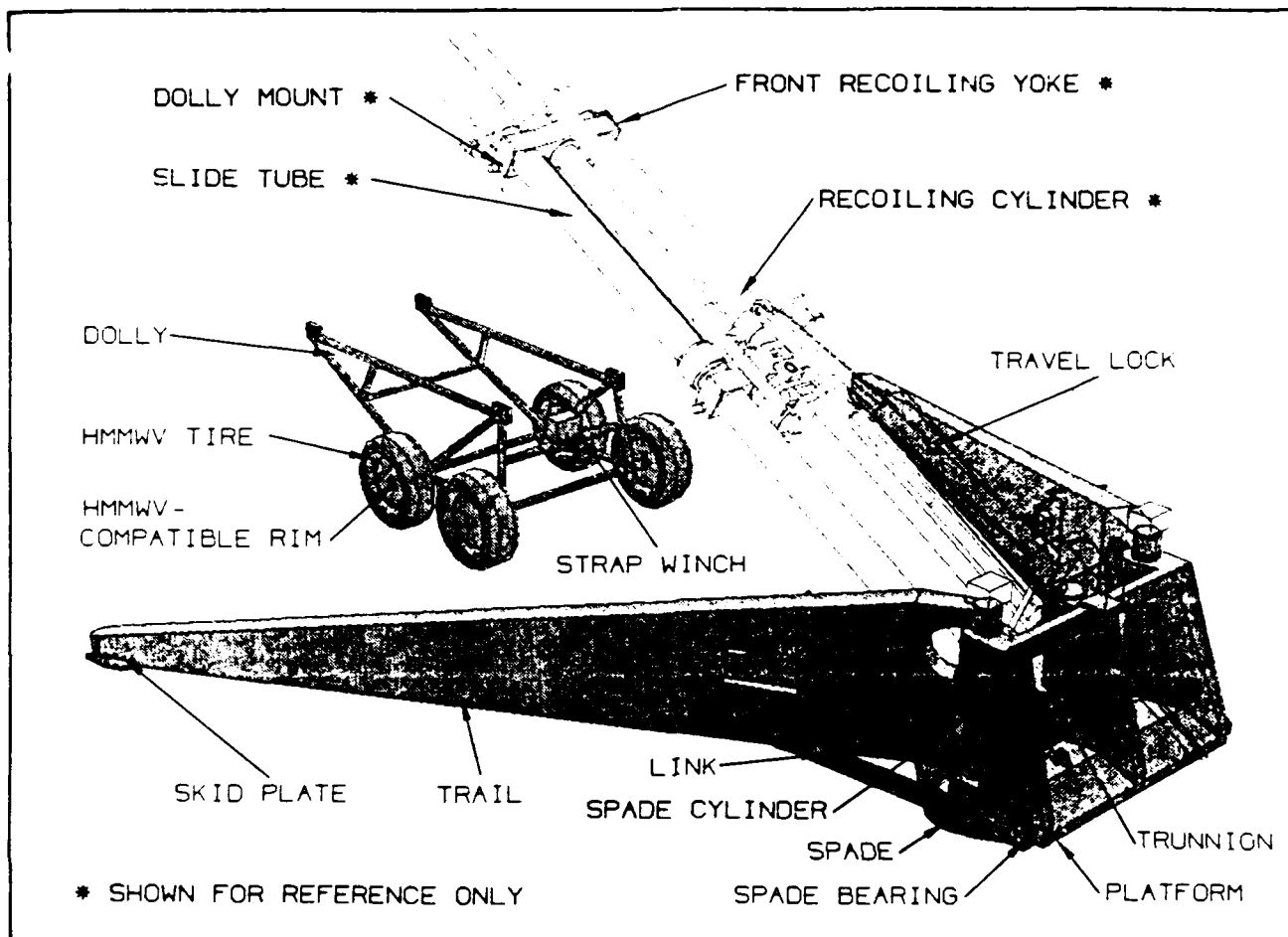


Figure 3-32. THE STRUCTURE is composed almost entirely of composite components.

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.

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 front and rear recoiling yokes and into the cannon, which is accelerated upward by the load.

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

1. Wheel units, attached permanently to the trails, were swiveled up and down for towing and firing. These wheel units have the advantage of being permanently attached, but have the disadvantage of being heavier and complicated the process of swinging the trails into position.
2. Wheel units, attached permanently to the recoiling yokes, provide the advantage of increasing the recoiling mass. Unfortunately, to make the wheel structure withstand the 200-plus g's involved, the weight and risk increase beyond acceptable levels.

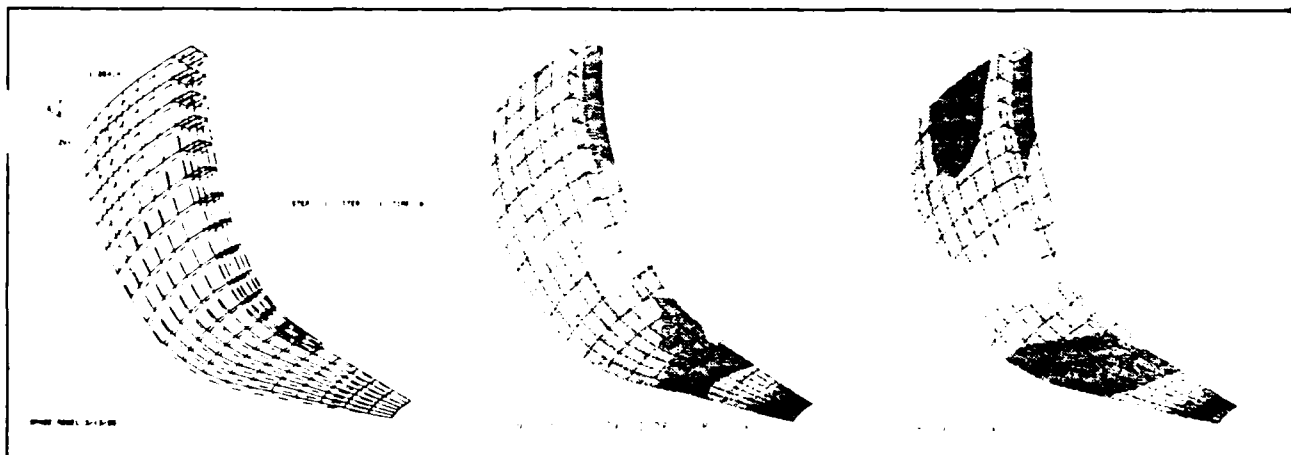


Figure 3-33. WEIGHT REDUCTION of the central spade through the use of composites is encouraged by the finite element analysis performed at our Central Engineering Laboratories.

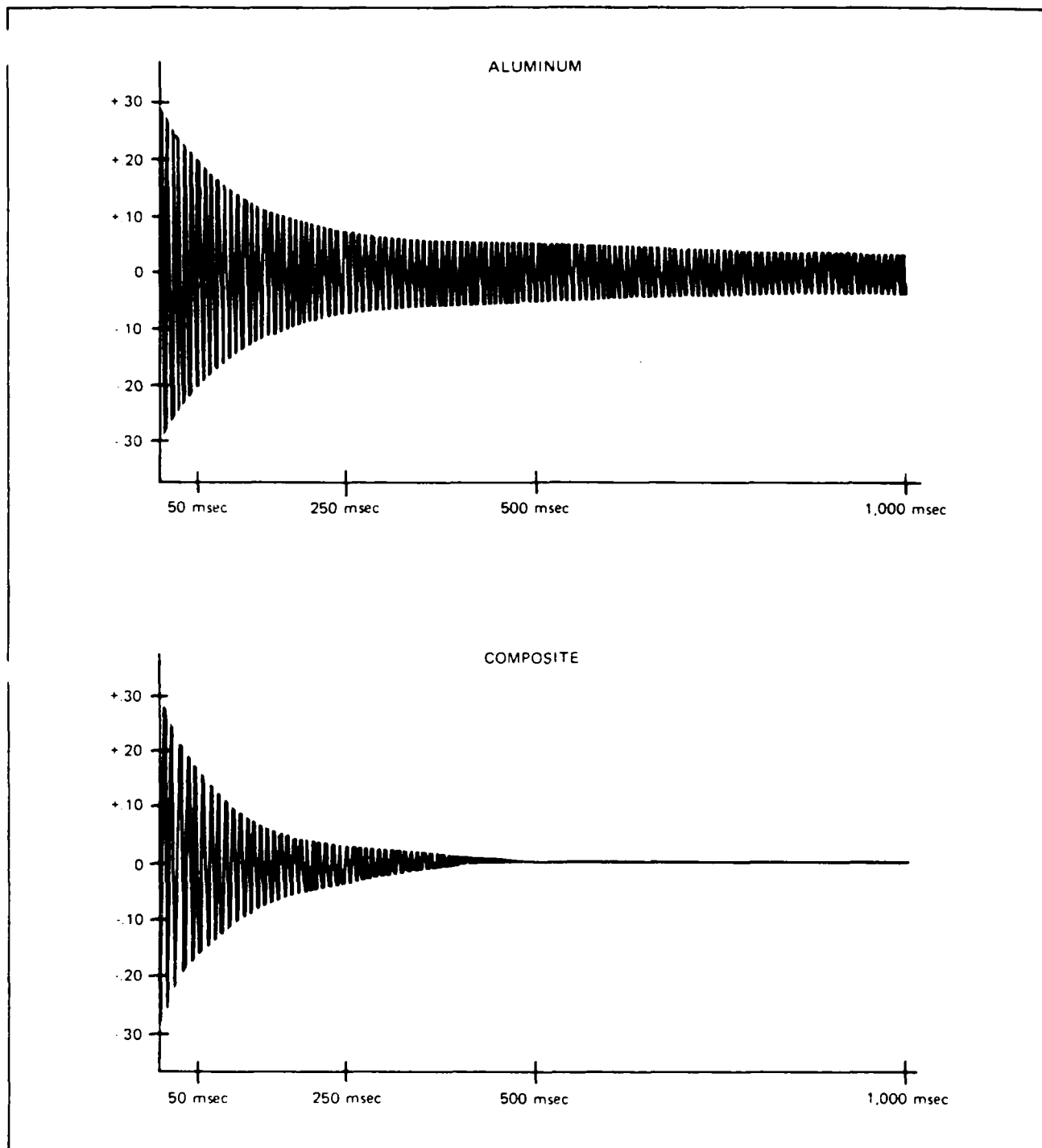


Figure 3-34. THE DAMPING CHARACTERISTICS attainable with composite materials will improve the resistance of the FMC LTHD structure to shock, resonance, and rebound.

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

® Registered trademark of DuPont.

5. The option of adding the HMMWV run-flat/bead-lock option

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 ®.

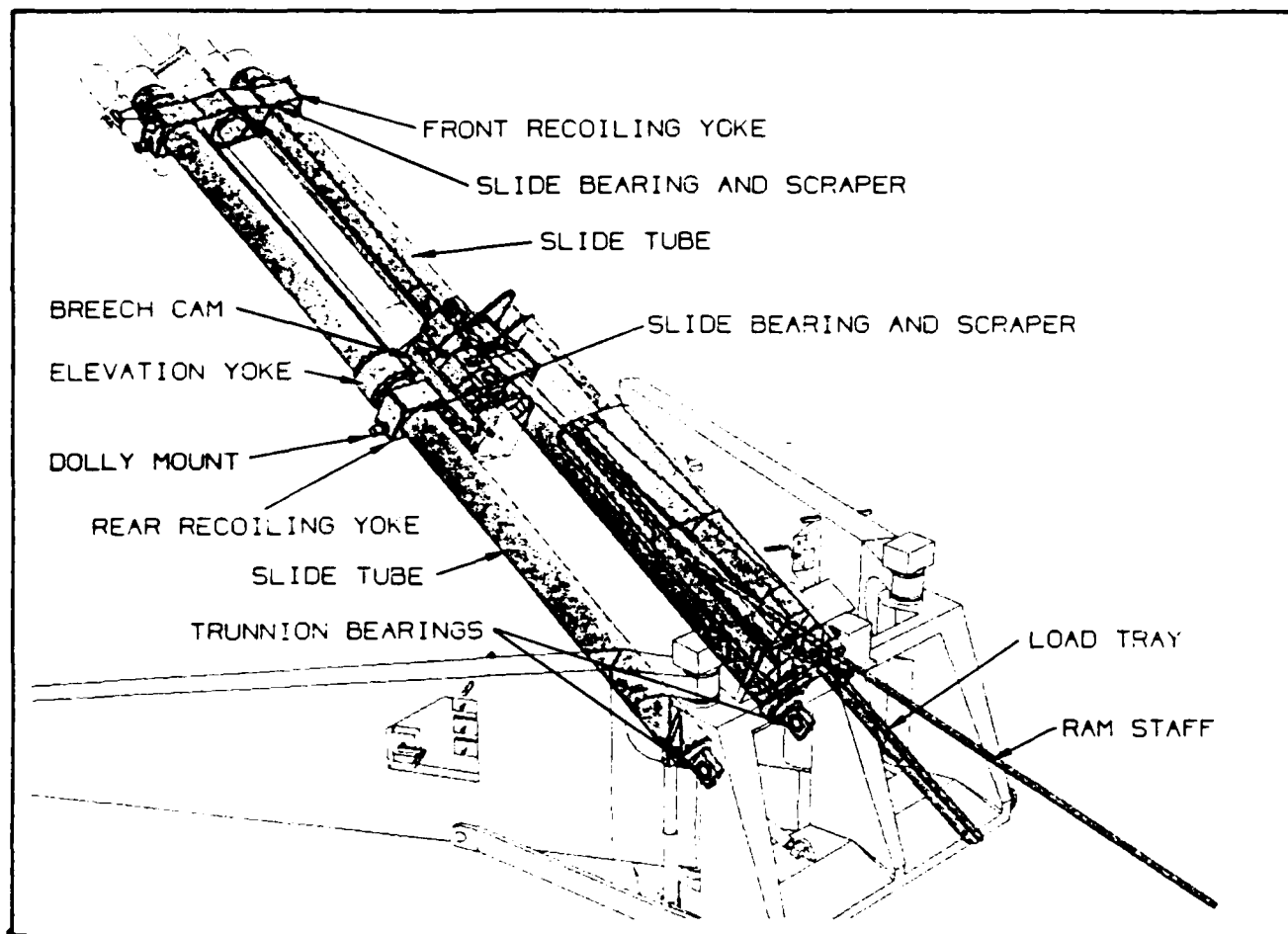


Figure 3-35. THE SLIDE CONFIGURATION provides natural protection to the crew from the increased recoil stroke.

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:

- I. 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

- 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 approaches were considered. The first was a tray 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

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.

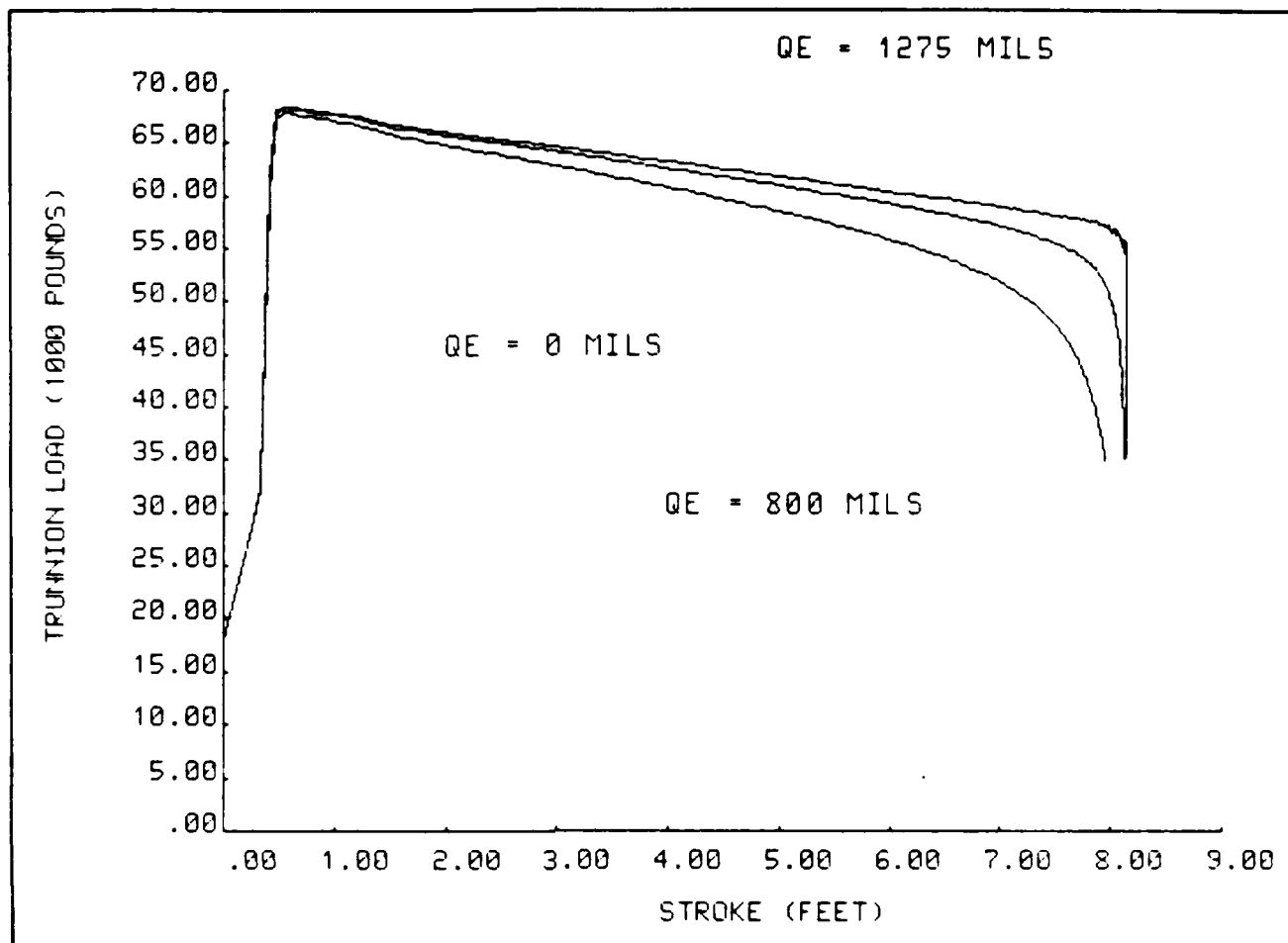


Figure 3-36. THE RECOIL FORCE PROFILE is shaped to achieve maximum firing stability, while enhancing downrange accuracy, by keeping forces low until projectiles exit.

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.

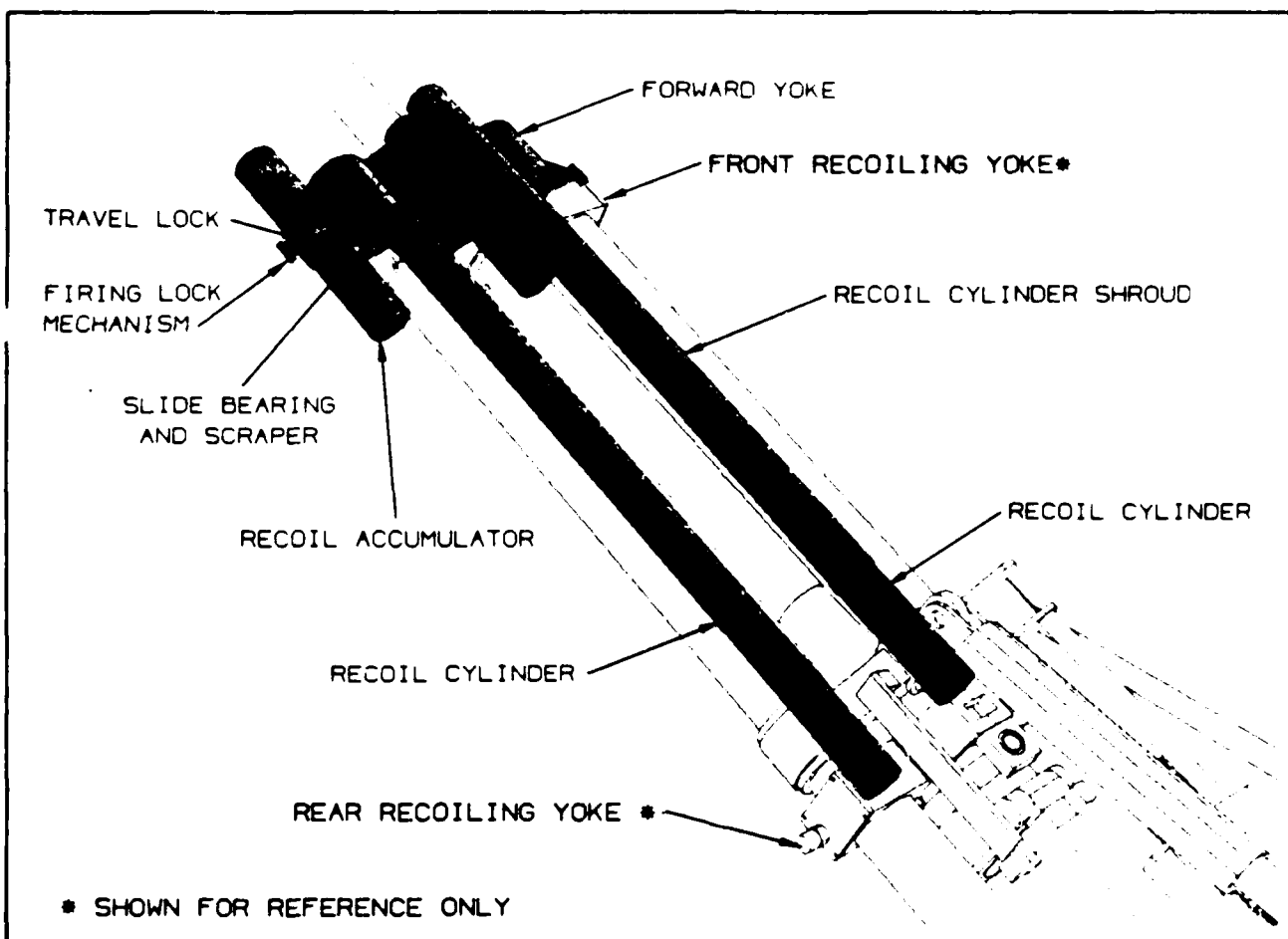


Figure 3-37. THE RECOIL SYSTEM operates on the conventional hydropneumatic principle to reduce risk.

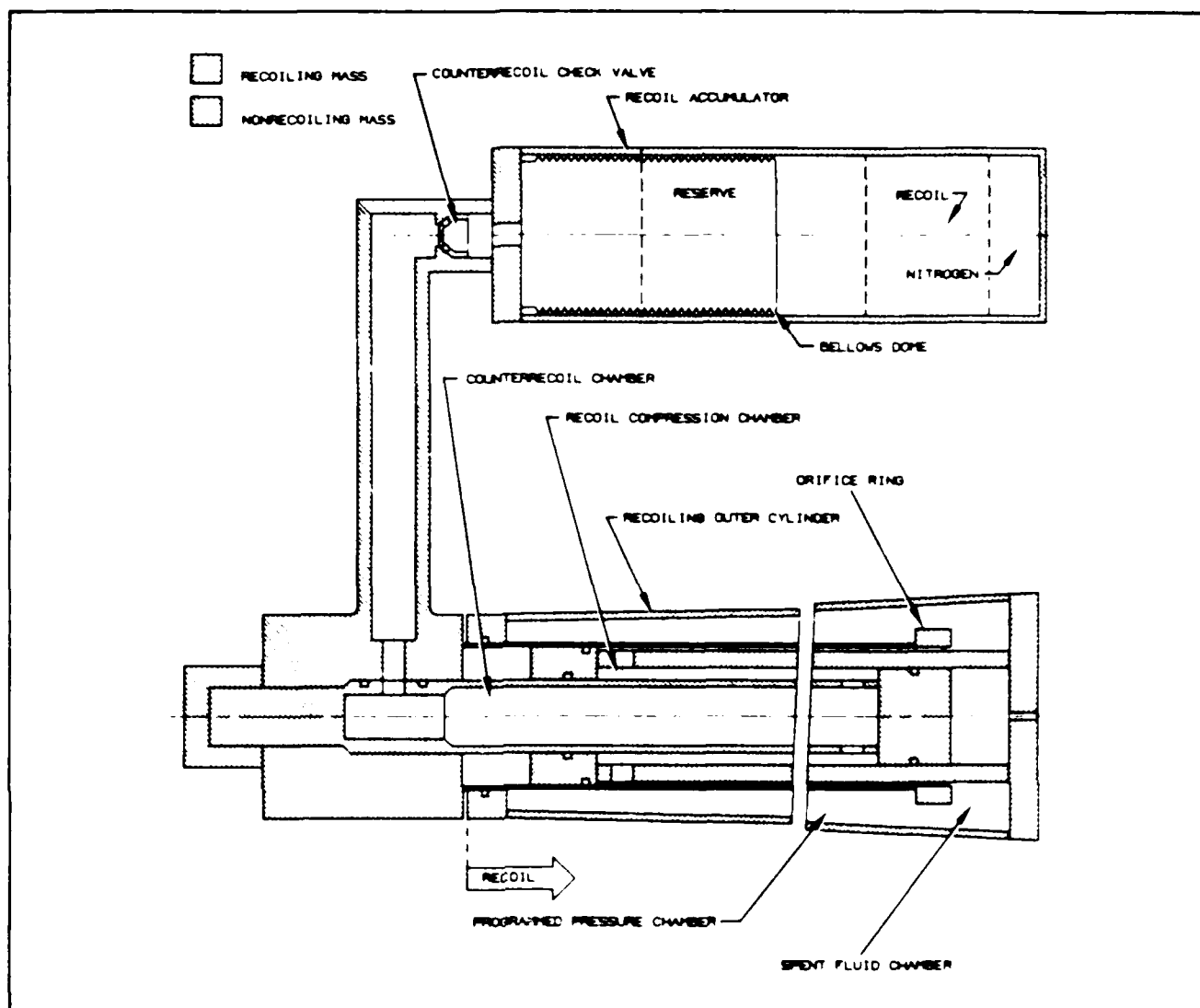


Figure 3-38. THE FMC LTHD RECOIL CYLINDERS improve RAM-D by orificing against the outer wall (reducing sensitivity to outside damage) and bellows accumulators (reducing sensitivity to outside damage and eliminating nitrogen maintenance).

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

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 pre-charge 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:

<u>Function</u>	<u>Paragraph</u>
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

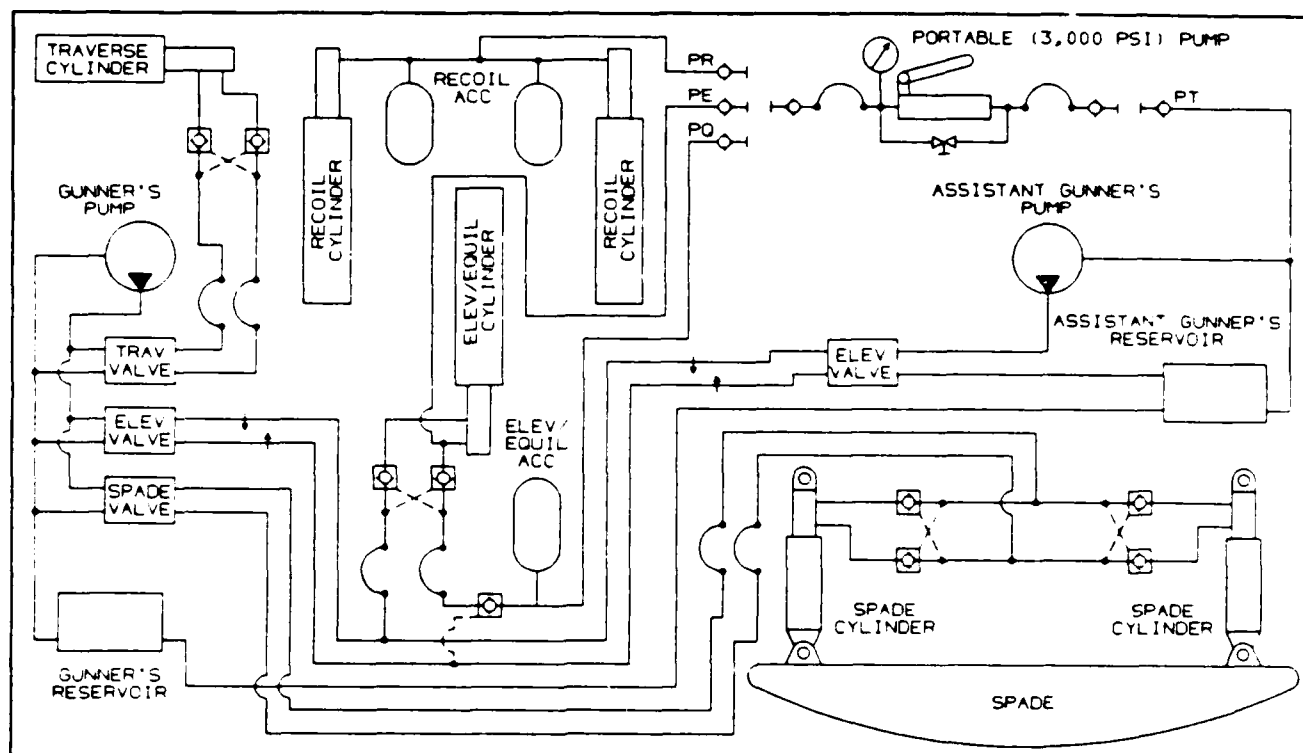


Figure 3-39. CENTRALIZATION OF THE HYDRAULIC SYSTEM reduces weight; controls at the gunner and assistant gunner positions provide for flexibility and degraded operations.

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.

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.

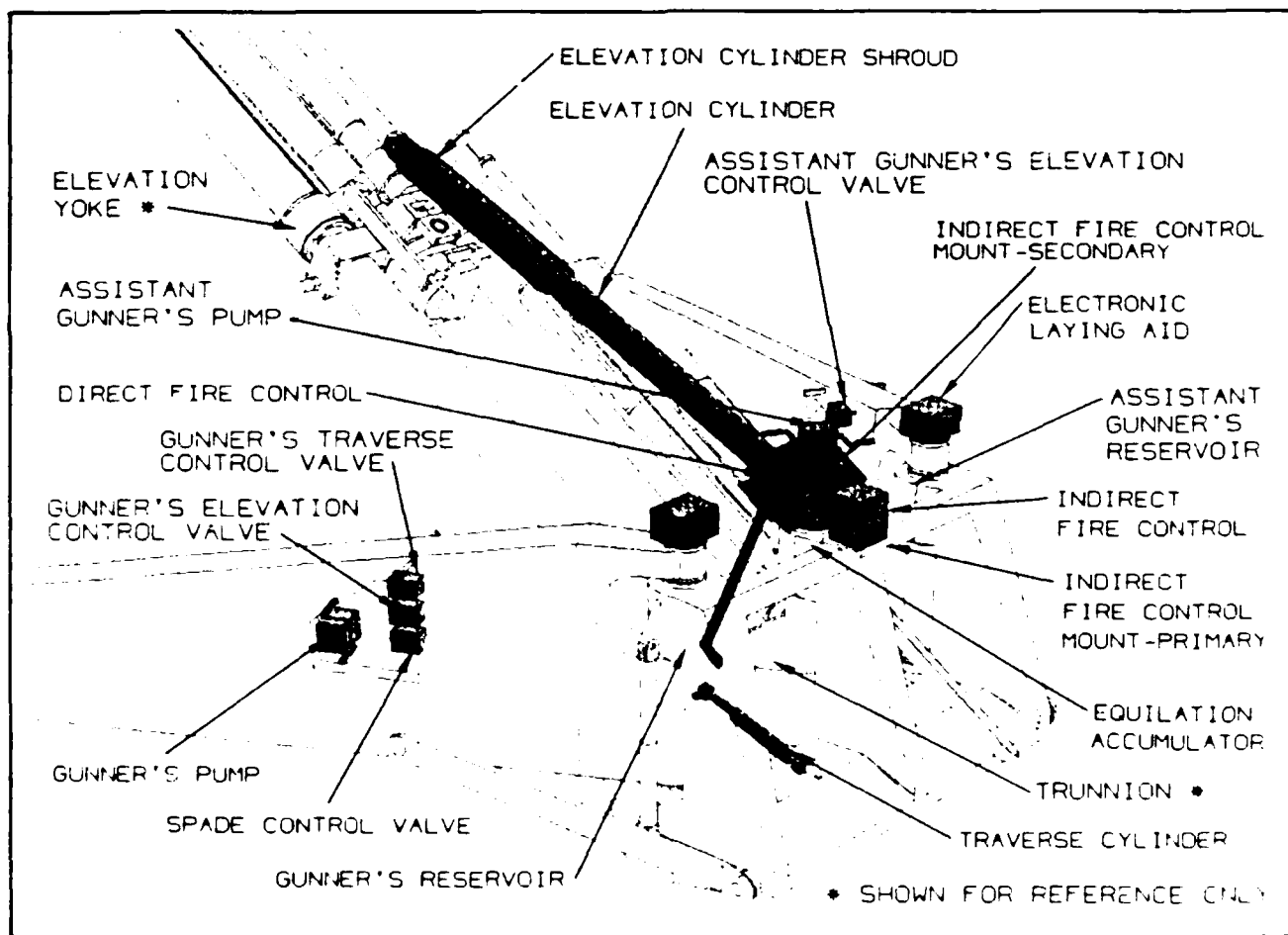


Figure 3-40. FIRE CONTROL SYSTEM WEIGHT is reduced through a single elevation cylinder; RAM-D is improved with a bellows accumulator (reducing sensitivity to outside damage and eliminating nitrogen maintenance).

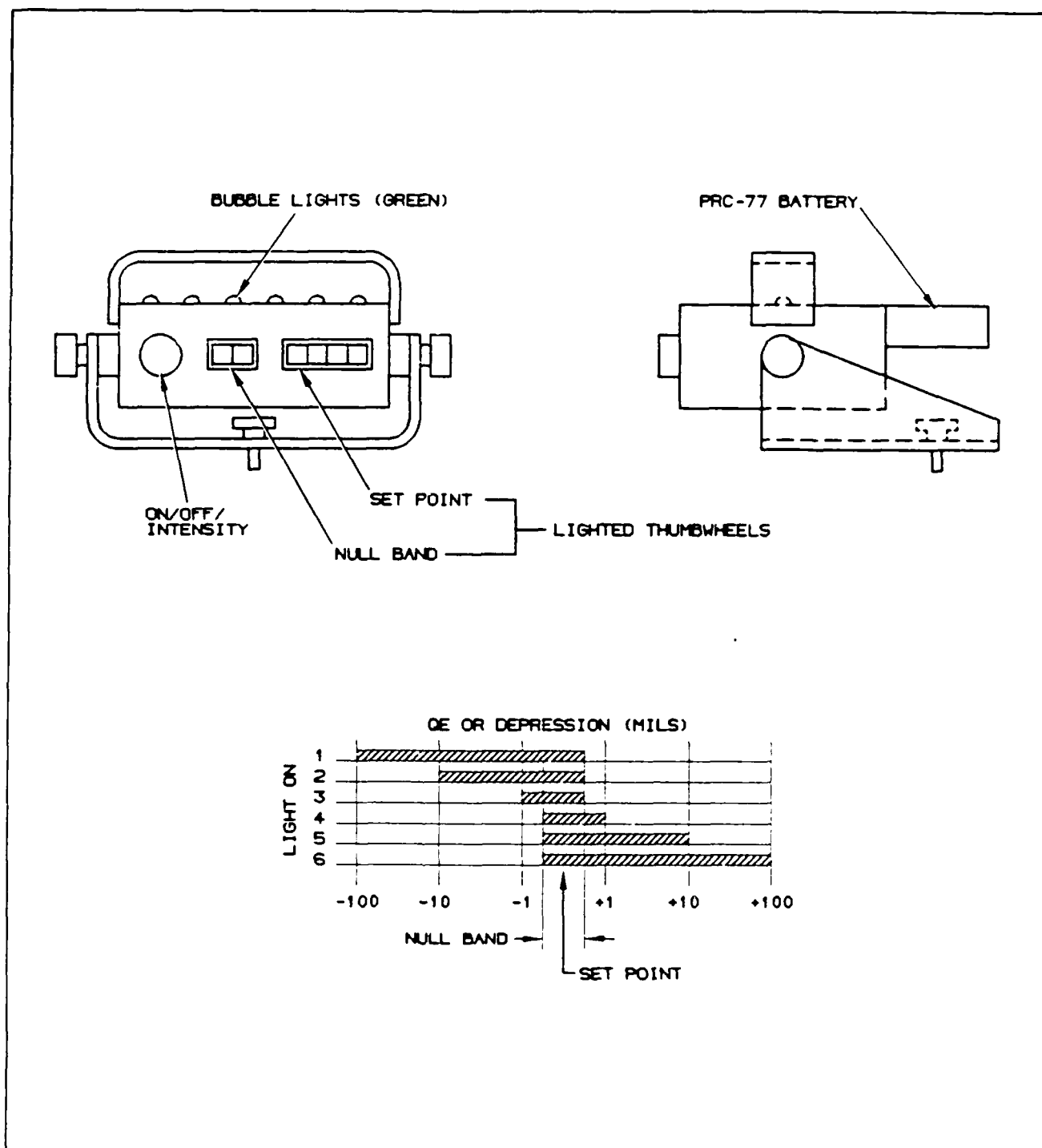


Figure 3-41. THE ELECTRONIC LAYING AIDS reduce the time required to set lay while accommodating the FMC LTHD low trunnion height and stationary platform.

In the event of an electronic failure, the IFC 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)

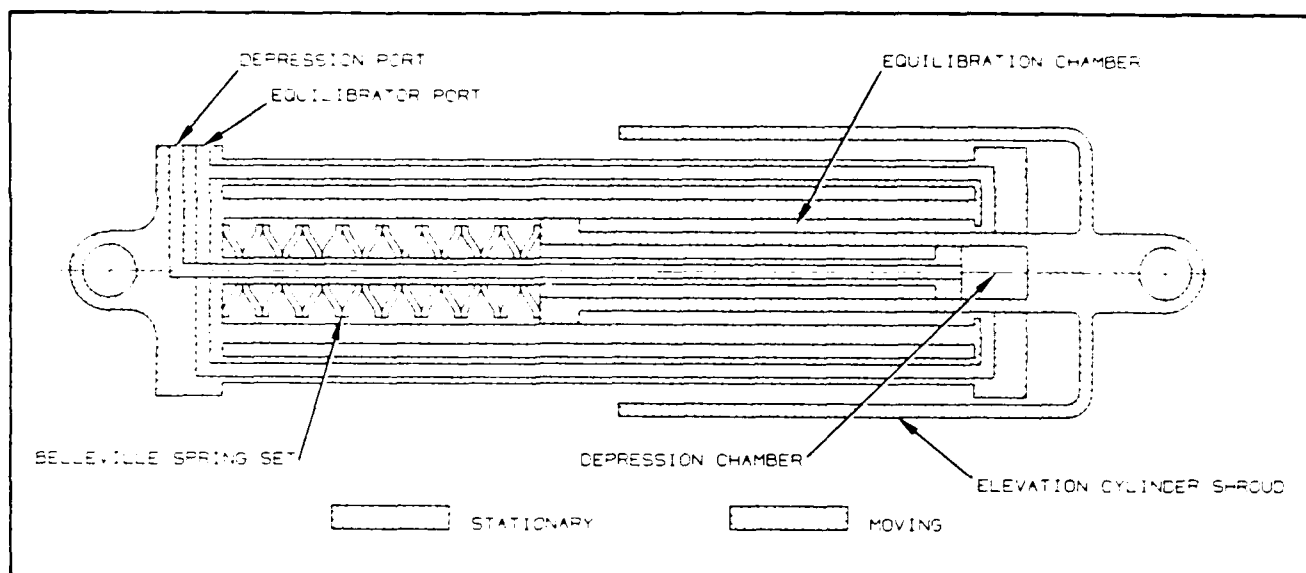


Figure 3-42. THE ELEVATION CYLINDER employs a simple, two-chamber design with integral equilibrator to minimize weight and reduce friction.

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
Innovative Recoil Mechanism

H
R

Second Letter:

Technical Issues
Management Issues
Cost Issues

T
M
C

Numerical:

Issue Number

Numeric

Pages, figures, and tables are sequentially identified with dashed numerics, and appendices are sequentially identified with dashed alphabets 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.



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.

HT1-1

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.

HT1-2

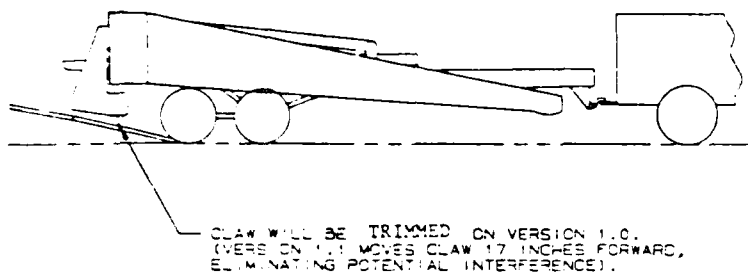


FIGURE HT1-1.
LOADING INTO C130E; FIRST
POTENTIAL INTERFERENCE POINT

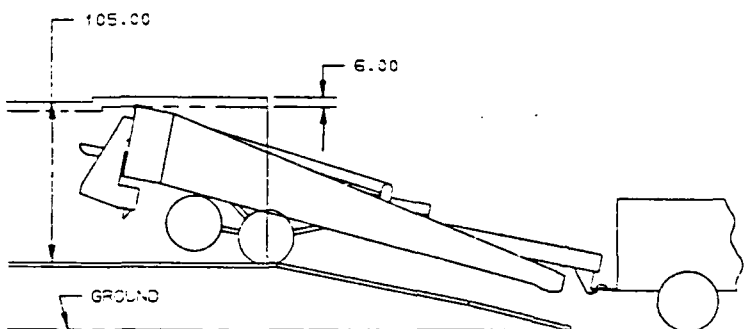


FIGURE HT1-2.
LOADING INTO C130E; SECOND
POTENTIAL INTERFERENCE POINT

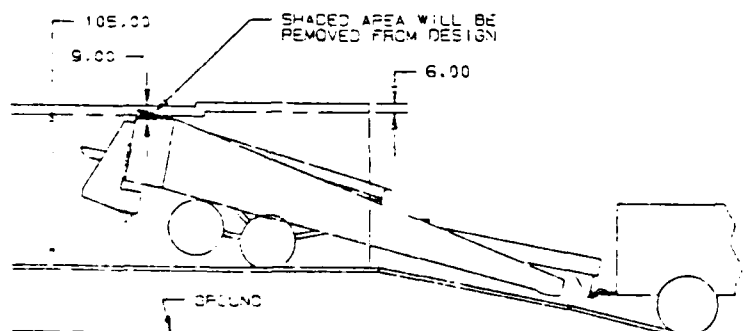
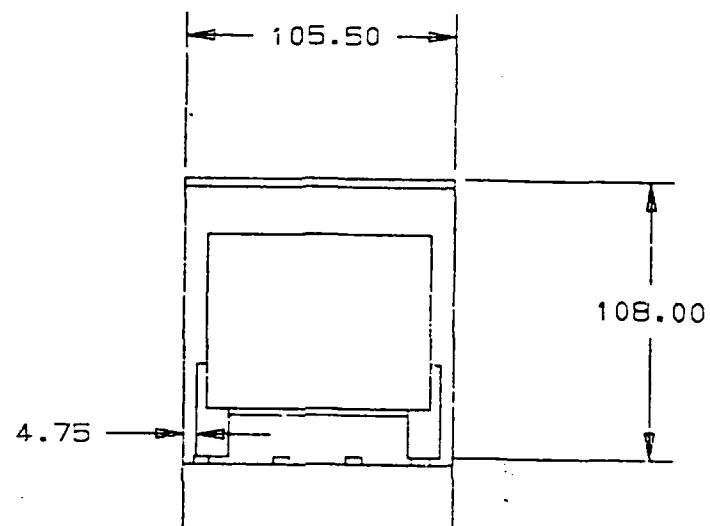


FIGURE HT1-3.
LOADING INTO C130E; THIRD
(AND FINAL) POTENTIAL
INTERFERENCE POINT.

HT1-3



END VIEW

Figure HT1-4.

Loading Into C130E;
End View

HT1-4

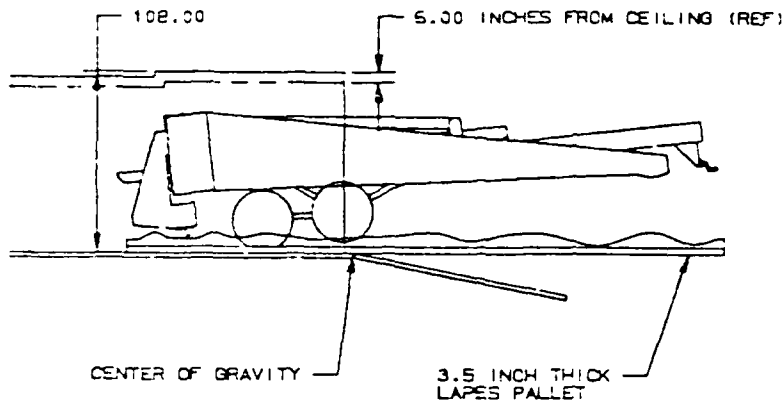


FIGURE HT1-5.
PARACHUTE EXTRACTION FROM
C130E; JUST PRIOR TO
TIPPING AT RAMP HINGE.

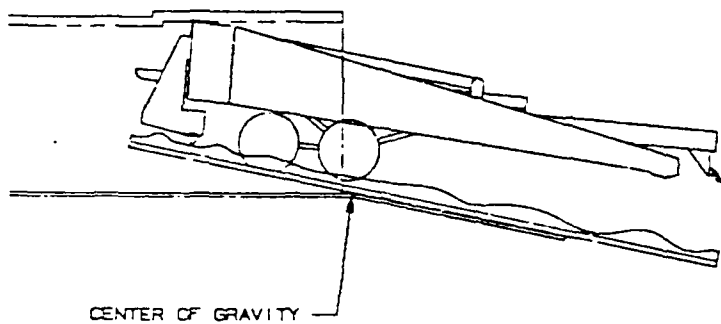


FIGURE HT1-6.
PARACHUTE EXTRACTION FROM
C130E; JUST AFTER
TIPPING AT RAMP HINGE.

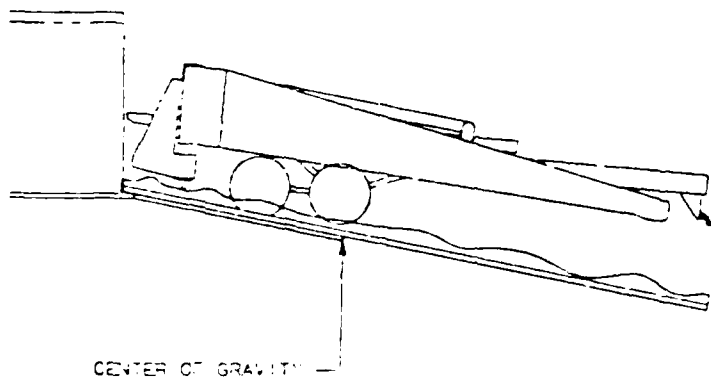


FIGURE HT1-7.
PARACHUTE EXTRACTION FROM
C130E; CENTER OF GRAVITY
AT END OF RAMP.

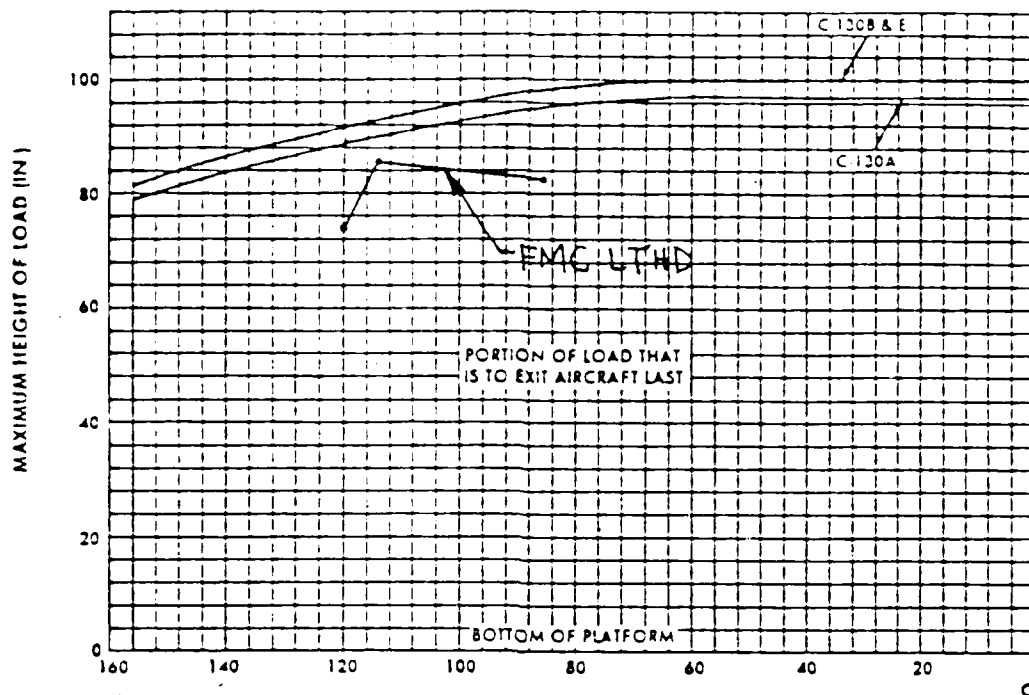


Figure HT1-8. Relationship of FMC LTHD on 3.5 inch pallet to C130 tip off curves (from AFSC Design Handbook 1-11).

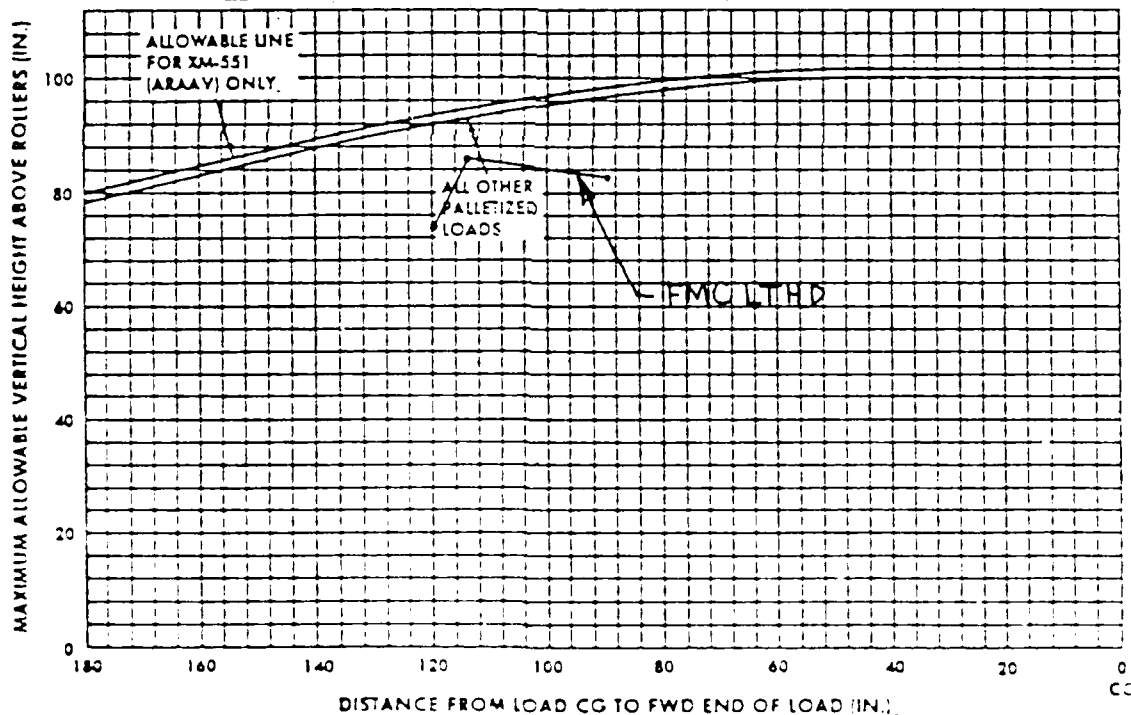


Figure HT1-9. Relationship of FMC LTHD on 3.5 inch pallet to C141 tip off curves (from AFSC Design Handbook 1-11).

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.

HT2-1

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

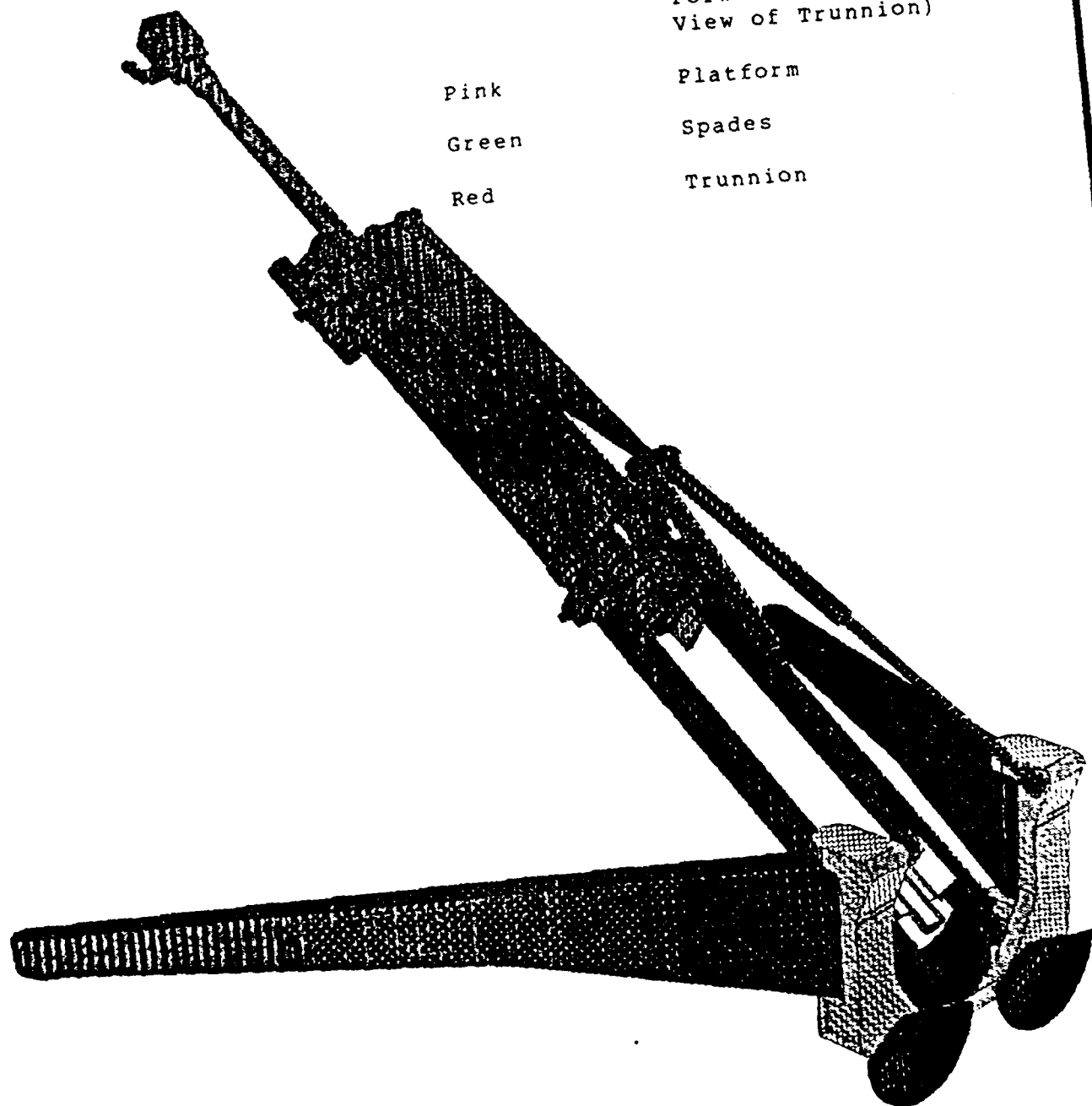


Figure HT2-1. FMC LTHD Version 1.1.

HT2-2

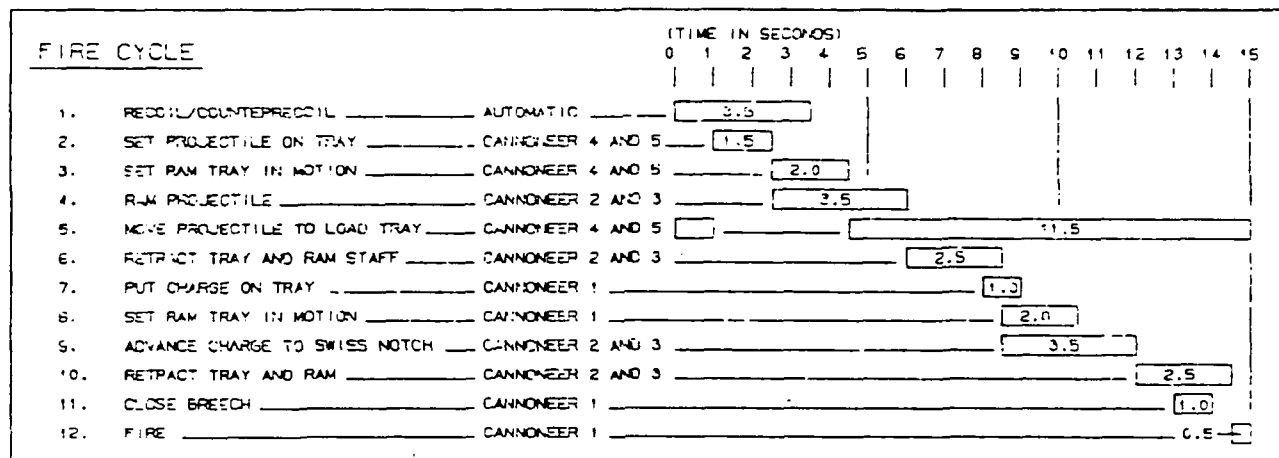


Figure HT2-2. Firing Time Line for FMC LTHT
Version 1.1

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LIGHTWEIGHT TOWED HOWITZER DEMONSTRATOR PHASE 1 AND
PARTIAL PHASE 2 VOLUM (U) FMC CORP MINNEAPOLIS MINN
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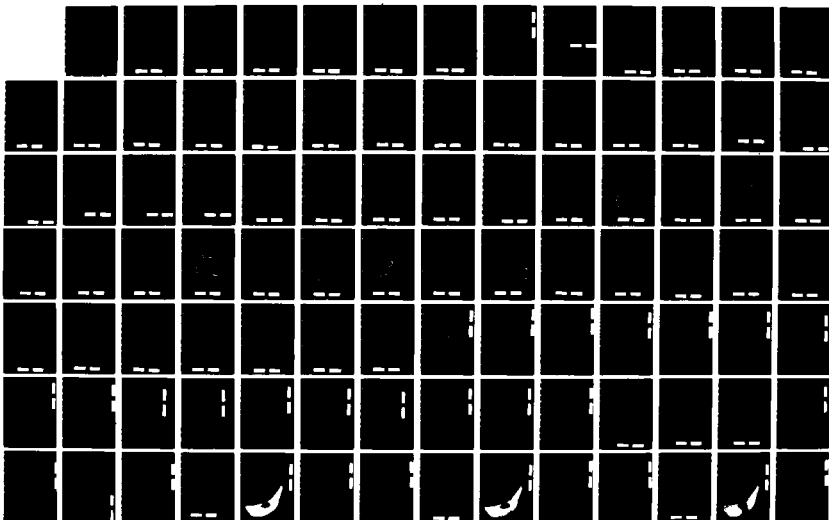
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MICROCOPY RESOLUTION TEST CHART

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. Bellville springs eliminated due to elimination of the need to elevate/depress for each round at high QE. Adds 115 pounds.

HT2-A1

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 Hydraulic 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.

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.

HT2-A3

Negotiation Issues

FMC

155MM LIGHTWEIGHT HOWITZER DEMONSTRATOR

Technical Issues:

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).

HT3-1

Negotiation Issues

FMC

155MM LIGHTWEIGHT . 762MM 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.

HT4-1

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 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 Bellville 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 lbf weight, assuming similar rod pulls, has a "QE safety margin" of only 3.5 degrees.

HT4-2

RAMMING FORCE SUMMARY

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

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:

$$F1 = (104 \text{ LBM}) * (\sin QE)$$

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

$$((15 \text{ FPS} ** 2) / (2 * 4.73 \text{ ft})) / 32.2 * 104 = 76.82 \text{ LBF}$$

Total ramming force per cannoneer (2 assumed):

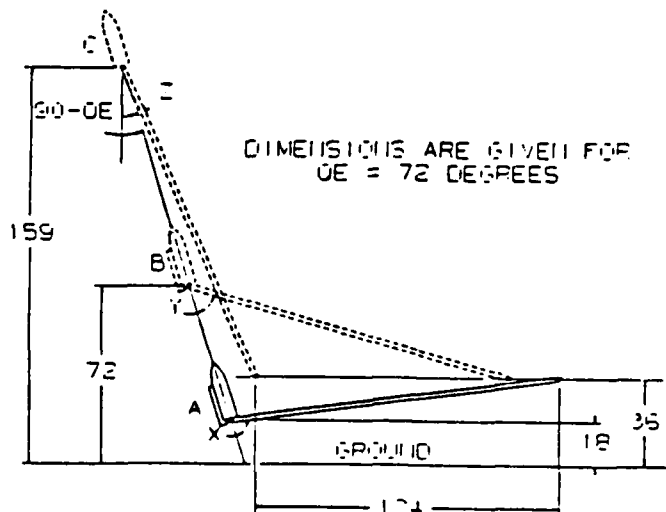
$$FR = (F1 + 76.82) / 2$$

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

HT4-A1

Appendix HT4-A. Ramming Force Analysis (sheet 2)

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:

$$\text{Point A: } 40 \text{ LBF} * \cos (72 - 79.5) = 39.7$$

$$\text{Point B: } 40 \text{ LBF} * \cos (72 - 56.5) = 38.5$$

$$\text{Average: } 39.1 \text{ LBF}$$

Vertical Components:

$$\text{Point A: } 40 \text{ LBF} * \sin (72 - 79.5) = -5.2$$

$$\text{Point B: } 40 \text{ LBF} * \sin (72 - 56.5) = 10.7$$

$$\text{Average: } 2.75$$

Appendix HT4-A. Ramming Force Analysis (sheet 3)

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:

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

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

$$\text{Average FR}_{BC} = (\text{FRB} + \text{FRC}) / 2$$

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

$$\text{Point B} = \text{FHB} = (\text{FR}_{BC}) * \cos (QE - Y)$$

$$\text{Point C} = \text{FHC} = (\text{FR}_{BC}) * \cos (QE - Z)$$

$$\text{Average} = \text{FH}_{BC} = (\text{FHB} + \text{FHC}) / 2$$

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

$$\text{Point B} = \text{FVB} = (\text{FR}_{BC}) * \sin (QE - Y)$$

$$\text{Point C} = \text{FVC} = (\text{FR}_{BC}) * \sin (QE - Z)$$

$$\text{Average} = \text{FV}_{BC} = (\text{FVB} + \text{FVC}) / 2$$

Moving A to C at 0° QE

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

HT4-A3

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.

HT5-1

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.)

HT5-A1

- 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.

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.

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.

HT5-C1

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	140587.1	-3.849308E-02		140587.1
.00168	234.3119				
	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	77235.21	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	9810.656	16.35106
8.749561	198.4625	137286.3	127491.1	9795.188	16.32531
9.573839	198.0128	136975.3	127169.5	9805.833	16.34306

HT5-D1

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

10.39788	197.5634	136664.5	126778	9886.511	16.4775
11.2212	197.1144	136353.9	126378.9	9974.958	16.6249
12.04332	196.6661	136043.8	125894.5	10149.22	16.9153
12.86364	196.2187	135734.3	125398.3	10335.94	17.2265
13.68168	195.7726	135425.7	124870.1	10555.61	17.5926
14.49696	195.328	135118.1	124225.8	10892.26	18.1537
15.30888	194.8852	134811.8	123567.1	11244.75	18.7412
16.11696	194.4444	134506.9	122764.4	11742.51	19.5708
16.92072	194.0062	134203.7	121872.9	12330.81	20.5513
17.71968	193.5704	133902.3	121053	12849.38	21.4156
18.51372	193.1374	133602.8	120393.1	13209.63	22.0160
19.30284	192.707	133305.1	119822.8	13482.29	22.4704
20.08704	192.2794	133009.2	119325.6	13683.64	22.8060
20.86632	191.8544	132715.3	118866.9	13848.32	23.0805
21.64068	191.4321	132423.1	118440.4	13982.68	23.3044
22.41024	191.0124	132132.8	118106.5	14026.25	23.3770
23.17488	190.5954	131844.4	117762.8	14081.58	23.4693
23.93472	190.181	131557.7	117507.3	14050.44	23.4174
24.68976	189.7693	131272.9	117206	14066.86	23.4447
25.44	189.3601	130989.8	116962.9	14026.88	23.3781
26.18532	188.9536	130708.7	116754.4	13954.21	23.2570
26.92596	188.5497	130429.2	116548.5	13880.73	23.1345
27.6618	188.1484	130151.6	116329	13822.61	23.0377
28.39284	187.7498	129875.9	116083.3	13792.59	22.9876
29.1192	187.3536	129601.9	115829.6	13772.25	22.9537
29.84064	186.9602	129329.7	115609.2	13720.51	22.8675
30.5574	186.5693	129059.3	115402.8	13656.52	22.7608
31.26948	186.181	128790.7	115111.9	13678.79	22.7979
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	22.5964
34.0704	184.6535	127734	114193.3	13540.67	22.5677
34.75896	184.278	127474.2	113971.1	13503.18	22.5053
35.44272	183.9051	127216.3	113757.7	13458.61	22.4310

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	13235.33	22.05874
54.36972	173.5831	120076	106840.2	13235.78	22.05966

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	13235.25	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	13675.61	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	23.0511
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

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
73.35896	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	95679.32	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	93065.98	17842.64	29.73789
78.97476	160.1646	110793.2	92770.62	18022.62	30.03786
79.27151	160.0028	110681.3	92520.4	18161.2	30.26883
79.56444	159.843	110570.8	92240.81	18229.95	30.38542

HT5-D5

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

79.85352	159.6854	110461.7	92057.85	18403.84	30.67326
80.10876	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	110140	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	34.92831
83.50931	157.6917	109082.3	87905.26	21177.07	35.2954
83.74296	157.5642	108994.2	87615.09	21381.09	35.65543
83.973	157.4388	108907.4	87303.06	21604.29	36.00745
84.19944	157.3150	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	23218.40	38.69777
85.6854	156.5049	108261.2	84794.47	23466.71	39.11157
85.88364	156.3968	108186.4	84469.02	23717.06	39.52934
86.0784	156.2906	108112.9	84158.61	23954.27	39.9242
86.2698	156.1862	108040.7	83845.20	24195.42	40.32612
86.45761	156.0838	107969.8	83528.08	24441.71	40.73663
86.64204	155.9832	107900.2	83198.25	24701.90	41.17034

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
87.51536	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	74046.82	32393.55	53.9903
90.47088	153.8931	106454.8	73792.2	32662.64	54.43881
90.56184	153.8435	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

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

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:

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

HT6-1

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

LINE	DESCRIPTION	STRESS ANALYSIS			PLAN	TOTAL FOR QTY					L
		Q	T	Y		MATERIAL	PROBA-	DENSITY	VOLUME	WEIGHT	
		MTHD	ACCUR				BILITY	(#/IN3)	(IN3)	(LBM)	
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 muzz 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 pltfm)	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, battery					20	4
F1700	Elev XDCR: IFC-pltfm	1				60				5	4
F1750	Elev XDCR: pltfm-cannon	1								5	4
F1800	Elect laying aid (AZ)	1			CF/E box, elect, battery	60				20	4
F1850	Trav XDCR: IFC-pltfm	1								5	4
F1900	Trav XDCR: pltfm-cannon	1								5	4

FIELD EXPLANATIONS AND ABBREVIATIONS EXPLAINED ON LAST SHEET

HT6-2

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

HT6-3

Figure HT6-1. FMC LTHD Component Breakdown (Sheet 3)

62650	...Platform & trunnion assy	1						392	3
62700	Platform	1	TRAD	See Appendix HT7-A	60			210	4
62750	Claw--primary	1		Ti	50	0.16	63	10	4
62800	Claw--secondary	2		Ti	20	0.16	125	20	4
62850	Traverse bearings	3	PUBL	5	Purchased			15	4
62900	Trunnion	1						60	4
62920	Spaceframe	1	TRAD	Ti	80	0.16	188	30	5
62930	Panels	1		Fiberglass	60	0.07	429	30	5
62950	Trunnion bearing	2	PUBL	5	Torrington 27SFL44			11	4
62975	Trunnion pins	2		Steel	80	0.28	54	15	4
63000	Spade mounting shafts	2		Ti	60	0.16	119	19	4
63050	Traverse cylinder	1	TRAD	30				32	4
63100	Piston and rod	1						5	5
63120	Piston	1		Al 7075-T6	90	0.10	10	1	6
63130	Rod	1		Ti	90	0.16	25	4	6
63150	Cylinder	1		Al 7075-T6	90	0.10	160	16	5
63200	Front end cap	1		Al 7075-T6	90	0.10	40	4	5
63250	Rear end cap	1		Al 7075-T6	90	0.10	50	5	5
63300	Tie rods	4		Steel	90	0.28	7	2	5
63350	...Trails (set of)	1						356	3
63400	Trail positioning link	2						36	4
63420	Ends	1		Ti	60	0.16	75	12	5
63430	Tube	1		CF/E	60	0.057	105	6	5
63450	Trail w integral brg-LH	1	TRAD	See Appendix HT7-A	60			140	4
63500	Trail w integral brg-RH	1	TRAD	See Appendix HT7-A	60			140	4
63550	Trav lock to elev yoke	2		Ti	60	0.16	125	20	4
63600	Skid plates	2						20	4
63620	Outer shell set	1		Fiberglass	70	0.07	129	9	5
63630	Inner core	1		Foam	90	0.006	167	1	5
63650	...Spade assembly	1						285	3
63700	Spade	1	FEA	10	See Appendix HT7-A	50		210	4
63750	Spade bearing	2	PUBL	5	Torrington 27SFL44	50		11	4
63800	Spade cylinder	2	TRAD	30				64	4
63850	Piston and rod	1						5	5
63870	Piston	1		Al 7075-T6	90	0.10	10	1	6
63880	Rod	1		Ti	90	0.16	25	4	6
63900	Cylinder	1		Al 7075-T6	90	0.10	160	16	5
63950	Front end cap	1		Al 7075-T6	90	0.10	40	4	5
64000	Rear end cap	1		Al 7075-T6	90	0.10	50	5	5
64050	Tie rods	4		Steel	90	0.28	7	2	5
64100	...Hydraulic system	1						327	3
64150	Gunner's hardware							94	4
64200	Elev ctrl valve	1		Purchased	90			3	5
64250	Pump	1		Purchased	90			20	5
64300	Reservoir	1		Al	60	0.10	500	50	5
64350	Spade ctrl valve	1		Purchased	90			8	5

FIELD EXPLANATIONS AND ABBREVIATIONS EXPLAINED ON LAST SHEET

HT6-4

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

FIELD EXPLANATIONS AND ABBREVIATIONS EXPLAINED ON LAST SHEET

HT6-5

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 accumultr 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

FIELD EXPLANATIONS AND ABBREVIATIONS EXPLAINED ON LAST SHEET

HT6-6

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).

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.

HT7-1

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 control, 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.

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.

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 assess 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.

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 lightweight 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 1) 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. Taylor 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 125 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 lower

APPENDIX HT7 - B2

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.

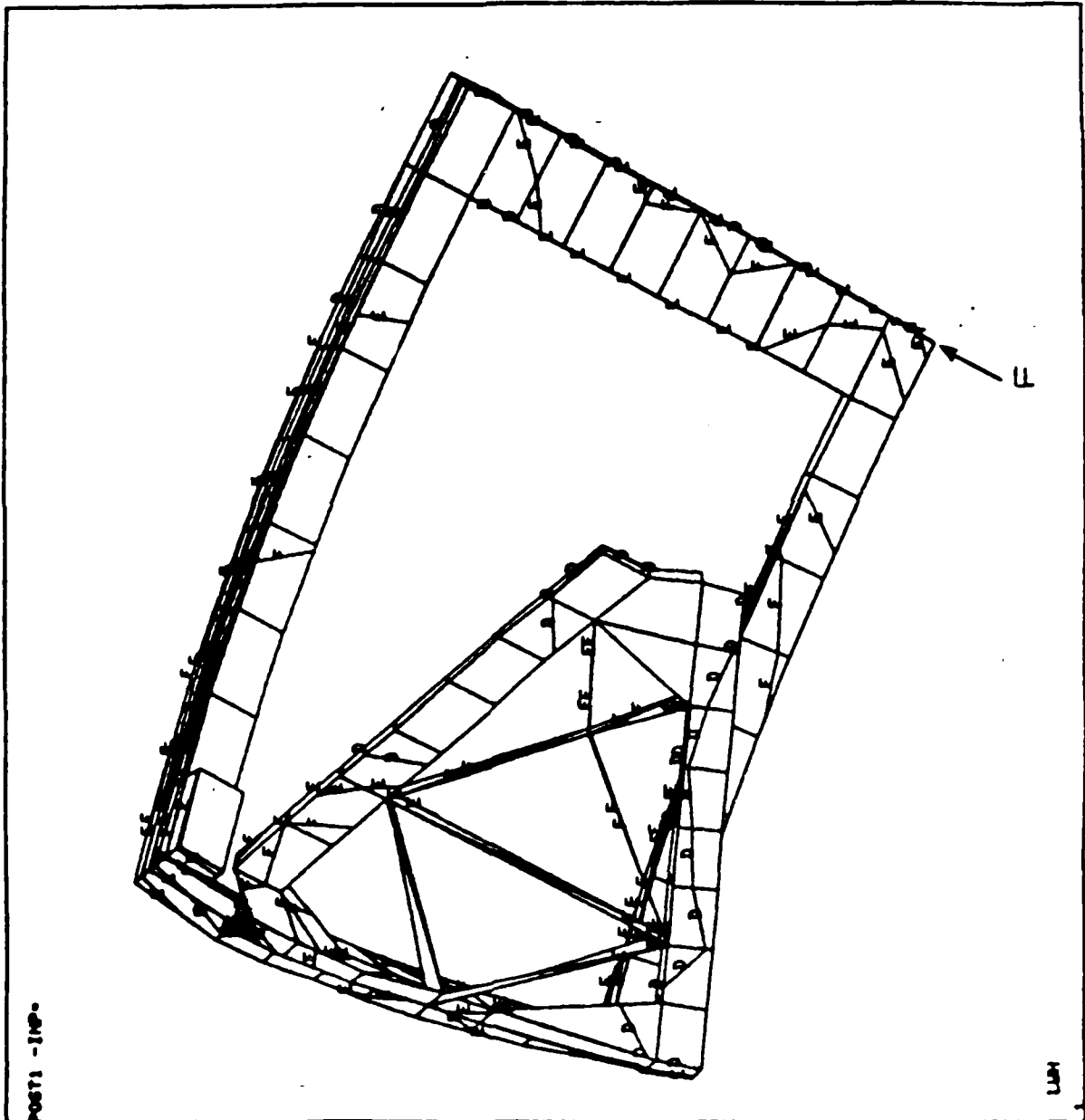
CROTH

C.R. Ortloff

ja

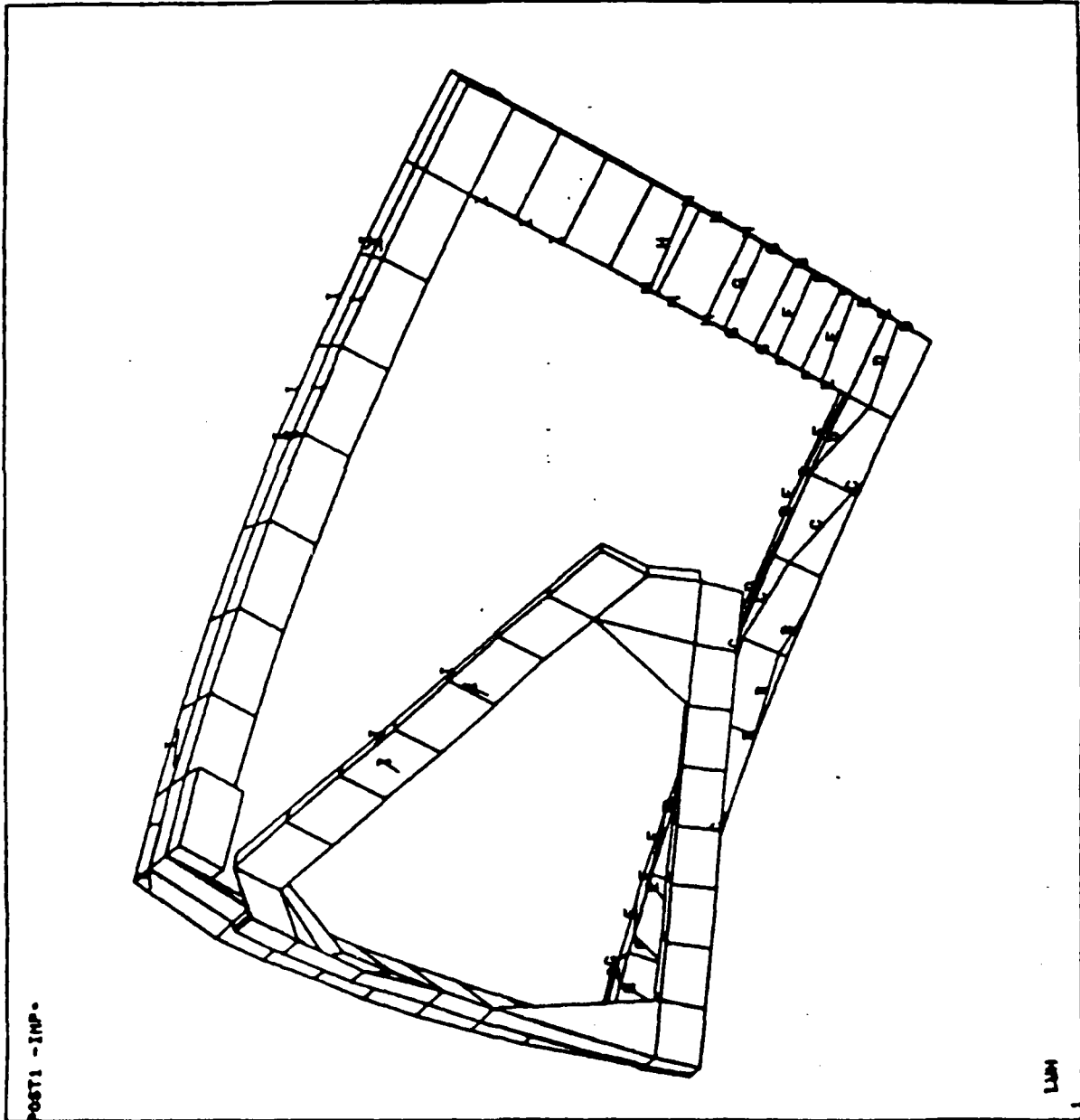
APPENDIX HT7 - B3

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 ZU=-.7
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 WF=15
 ZF=5.55
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 F=24000
 G=20000
 H=40000
 I=40000

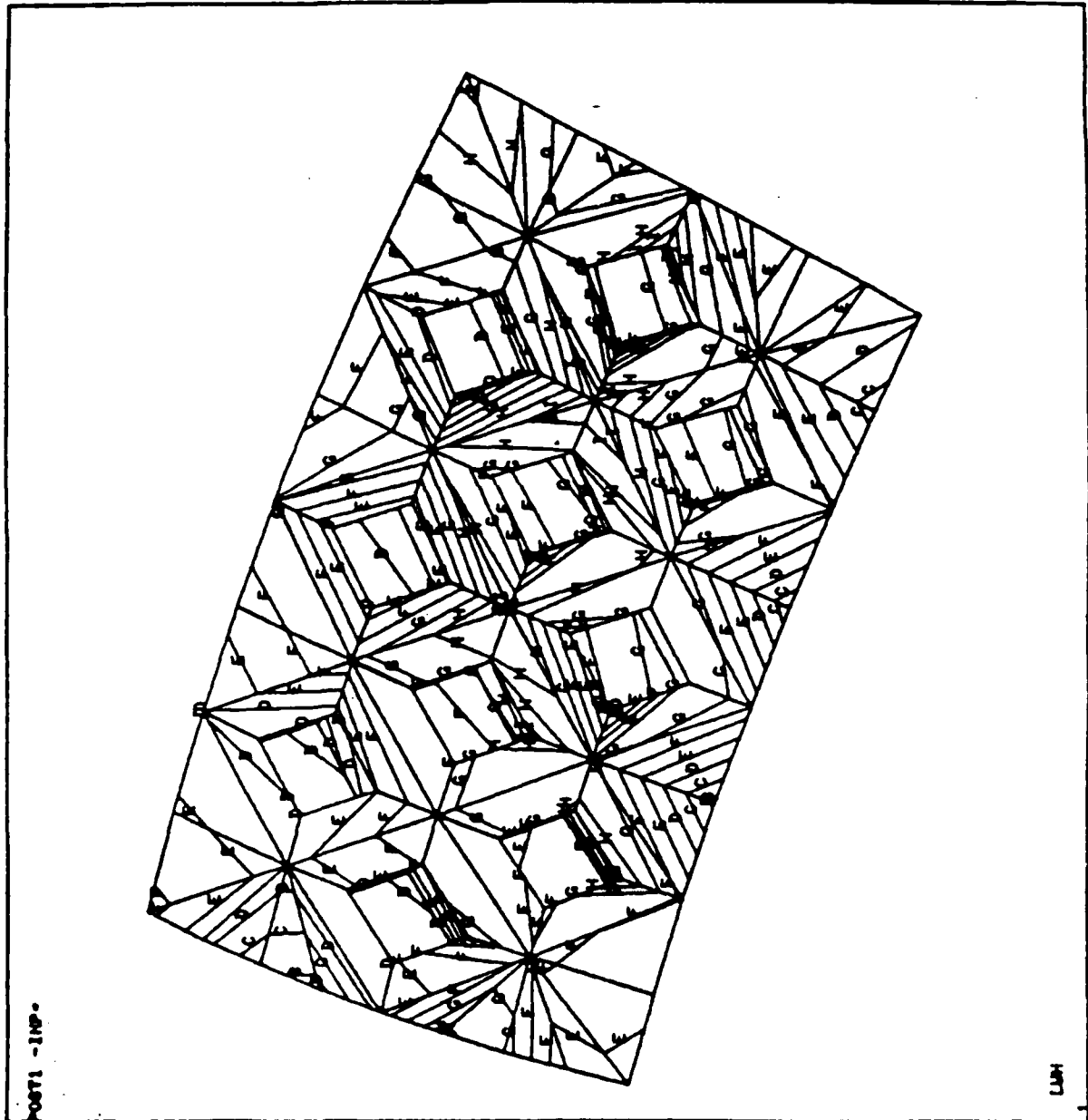


APPENDIX HT7 - B4

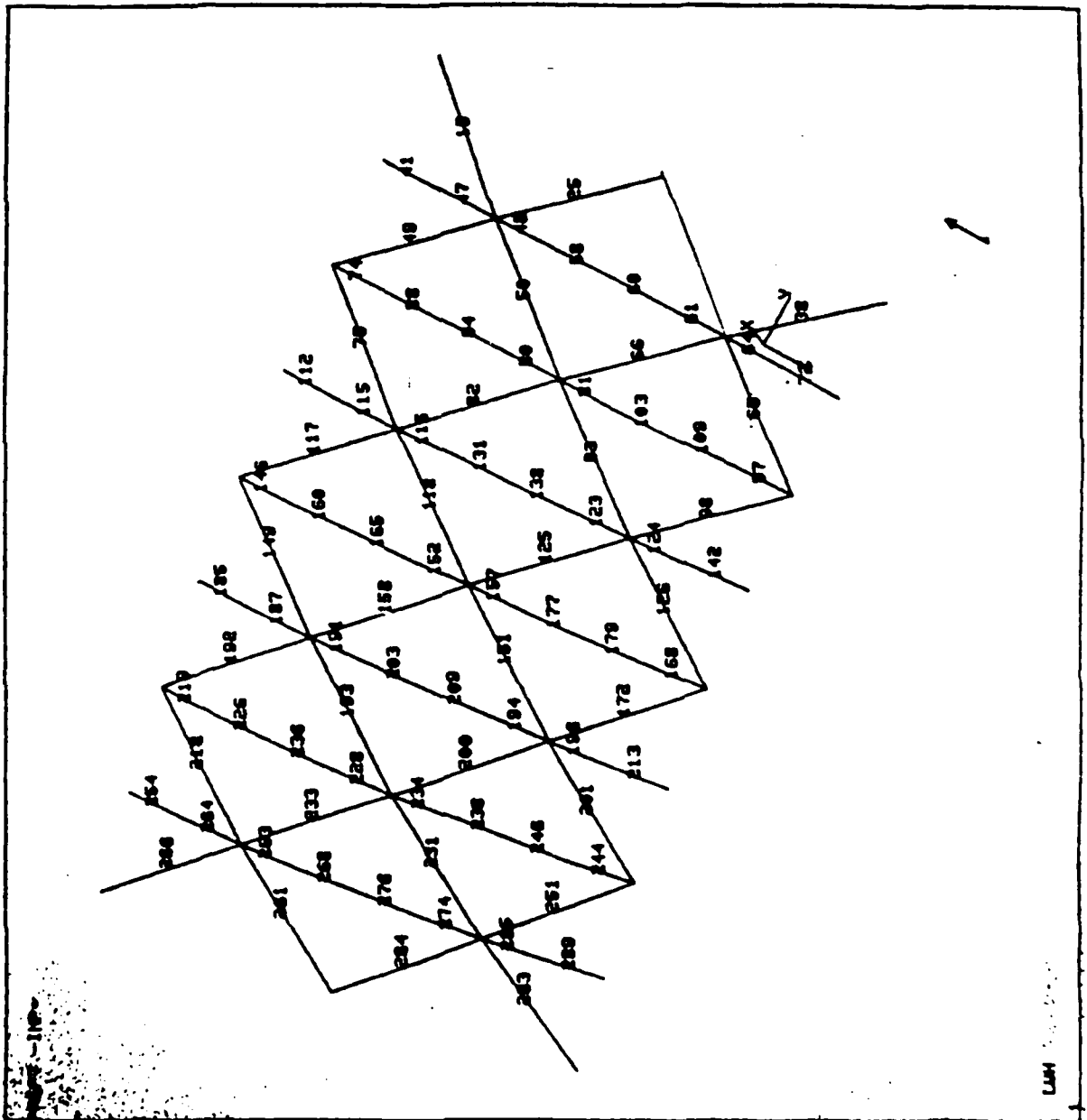
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STRESS PLOT
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AUTO SCALING
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ZU=-.7
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XF=31.4
YF=-15
ZF=5.55
ANGL=-120
HIDDEN
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PRN=-.072
D=-.07
C=-.06
D=-.06
E=-.04
F=-.03
G=-.02
H=-.01
I=0



ANSYS
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 ITER=1
 STRESS PLOT
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 TOP
 AUTO SCALING
 KU=-2
 VU=.3
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 HIDDEN
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 G=8750
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ANSYS
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 FBC=1
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 XU=-2
 YU=-3
 ZU=-.7
 DIST=21
 XF=47.6
 YF=-18.3
 ZF=13.3
 ANGL=-120



POSTR.1.1.8

PRINT ELEMENT STRESS ITEMS PER ELEMENT

88888 POST1 ELEMENT STRESS LISTING 88888

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

ELEM	SDIR	SBZ	SBV	SIG1	SIG2
15	-1805.0	878.28	1820.2	201.46	-3091.5
26	3765.8	-329.28	-89.327	4166.2	-3777.0
38	-1653.8	79.014	478.46	-1046.3	-2121.2
41	2476.6	-194.88	160.11	2831.5	2181.7
47	2473.3	-804.31	62.478	3339.1	1695.5
48	4934.7	-222.12	670.88	5827.7	4041.7
49	3109.5	-144.96	786.45	440.9	2178.1
50	-1214.6	-558.06	-753.28	96.767	-2525.9
58	431.09	926.23	-246.89	1803.2	-741.03
60	429.22	1364.0	43.406	1836.6	-978.17
61	4431.3	6640.7	-473.33	11545.	-2682.7
64	2821.0	2993.2	827.84	6042.9	-399.17
65	1600.7	1633.0	2179.1	5412.8	-2211.5
68	-1187.0	-778.97	29.080	-389.82	-1993.0

MORE (YES, NO OR CONTINUOUS).

C

88888 POST1 ELEMENT STRESS LISTING 88888

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

ELEM	SDIR	SBZ	SBV	SIG1	SIG2
72	8225.9	255.14	128.32	3220.3	2433.4
74	3164.0	-255.16	0.15005E-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	-301.50	-260.61	1346.8	204.57
82	-8011.9	467.09	928.06	-616.72	-3407.0
83	-3067.7	620.00	-768.91	-1678.2	-467.2
88	-823.88	-41.818	71.457	-570.71	-787.26
94	-889.36	359.06	38.742	-201.66	-1087.1
97	2431.3	6734.4	160.08	9325.8	-4463.3
98	-3428.7	-1704.6	-2615.3	891.03	-7748.4
103	-1169.8	8069.3	-460.76	1342.3	-3679.9
109	-1189.1	2332.8	40.365	1206.2	-3541.4
118	-992.66	-1172.8	-83.104	853.04	-2248.7

88888 POST1 ELEMENT STRESS LISTING 88888

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

ELEM	SDIR	SBZ	SBV	SIG1	SIG2
115	-994.79	-184.19	-89.311	-781.29	-1898.3
116	871.04	-836.36	144.48	1261.6	-708.17
117	-2570.3	808.18	2487.8	426.39	-9166.1
118	-1009.4	-289.03	581.82		

H77-11

222.2 -3553.6

----- POST1 ELEMENT STRESS LISTING -----

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

ELEM.	SDIR	SDZ	SDY	SIG1	SIG2
152	-902.04	6405.9	836.27	8340.1	-8324.2
157	768.53	213.08	-88.421	1070.8	466.25
158	-2877.1	1110.7	2297.2	530.75	-6284.9
160	-1473.1	-152.76	343.00	-977.36	-1868.9
165	-1478.7	1841.1	-3.7700	468.24	-3421.6
168	2313.7	7088.1	12.230	8488.0	-4789.7
172	-1840.7	-746.00	-785.02	232.22	-2713.6
177	-1112.3	1880.7	187.54	955.94	-3180.8
179	-1118.4	2322.5	3.8343	1280.0	-3604.8
185	-1894.7	-1407.3	-95.142	-382.30	-3397.1
187	-1800.8	874.20	-45.780	-820.75	-2020.8
191	-278.04	78.173	551.85	348.40	-905.47
192	-1872.1	869.42	2023.5	269.84	-4614.0
193	-1066.8	721.73	-887.41	642.95	-2776.3

----- POST1 ELEMENT STRESS LISTING -----

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TIME- 0.00000E+00 LOAD CASE- 1

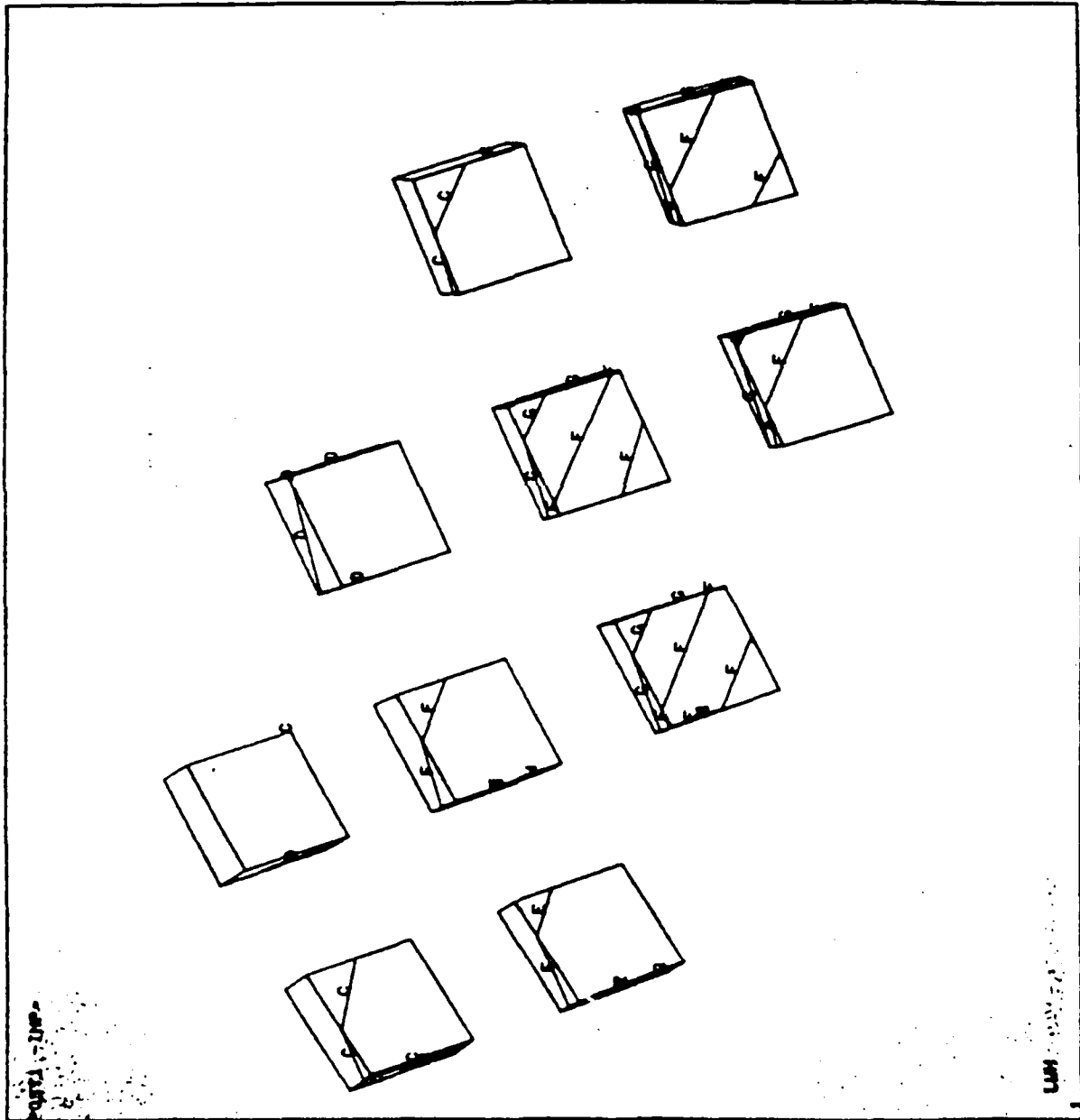
ELEM.	SDIR	SDZ	SDY	SIG1	SIG2
184	-429.50	8561.1	282.38	8523.0	-8354.0
196	1526.3	2804.9	-183.21	4313.4	-1852.9
200	-2274.3	879.59	-2574.5	1879.8	-6828.4
201	-3738.9	-2033.7	2723.6	1018.3	-8406.1
203	-1894.1	2314.4	490.02	1000.2	-4608.5
208	-1805.0	3255.0	17.787	1488.8	-5978.7
213	1530.7	187.61	-27.806	1748.2	1315.2
218	-2370.4	-400.81	-1276.8	-687.78	-4053.1
219	-1302.1	438.24	55.173	-888.79	-1855.5
225	-1427.0	1157.8	346.76	77.544	-2931.5
228	-205.13	6200.5	185.57	6237.0	-6449.8
231	-208.00	-1417.3	-1831.7	2340.1	-4348.8
233	-430.00	305.41	-887.6	844.0	-3722.1
234	1308.5	180.73	880.01	2300.8	208.73

----- POST1 ELEMENT STRESS LISTING -----

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

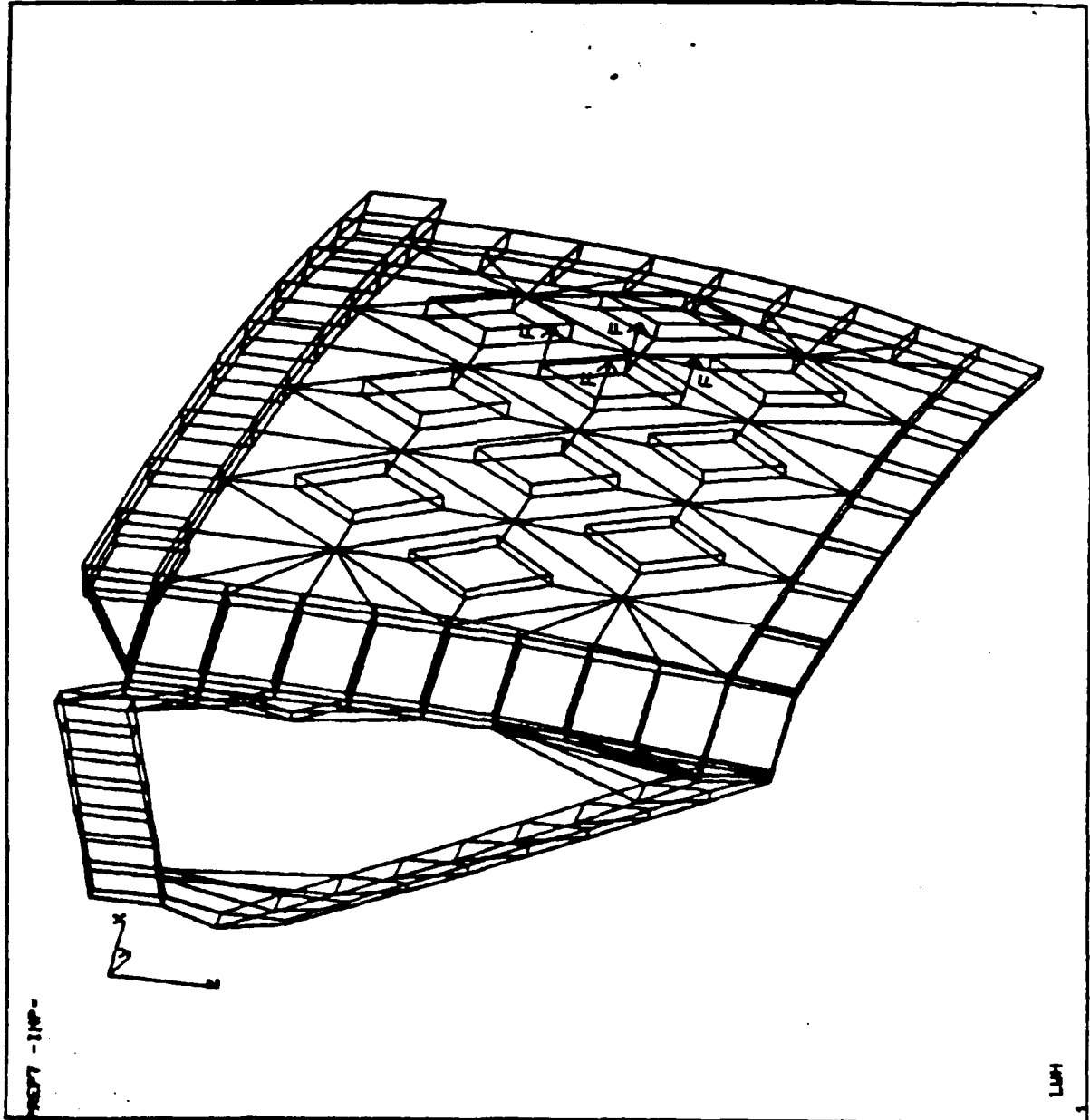
ELEM.	SDIR	SDZ	SDY	SIG1	SIG2
236	-1489.3	8191.8	25.538	778.39	-2036.1
238	-404.65	1788.8	1380.3	2581.9	-2611.0

ANSYS
 4/11/85
 15.7731
 POST1
 STEP=1
 ITER=1
 STRESS PLOT
 SIZE
 TOP
 AUTO SCALING
 XU=-2
 YU=.3
 ZU=-.7
 DIST=15.2
 XF=49.9
 YF=-21
 ZF=11.8
 ANGL=-180
 HIDDEN
 RX=1327
 RN=436
 C=500
 D=825
 E=750
 F=875
 G=1000
 H=1125
 I=1250

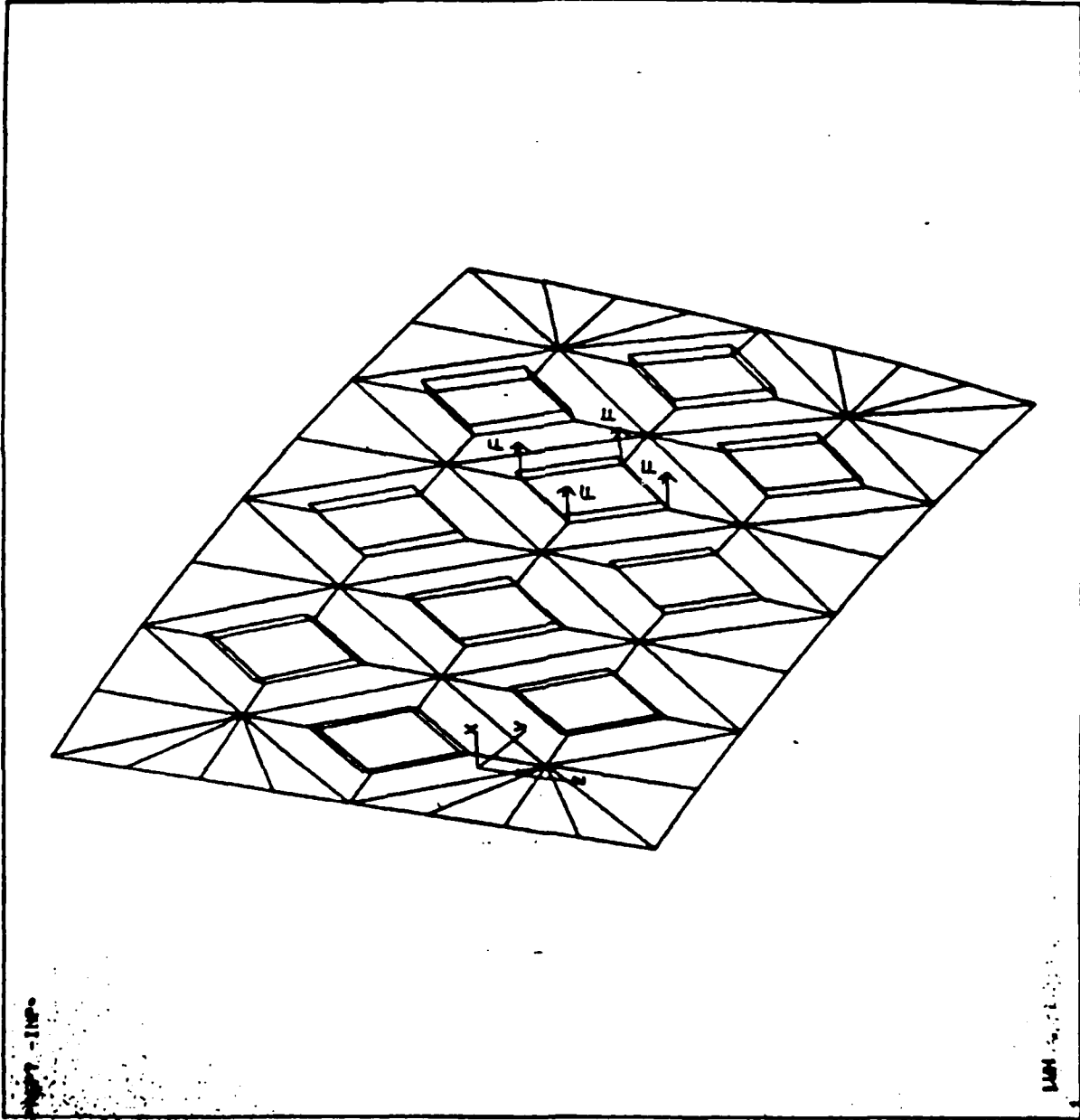


APPENDIX HT7 - B10

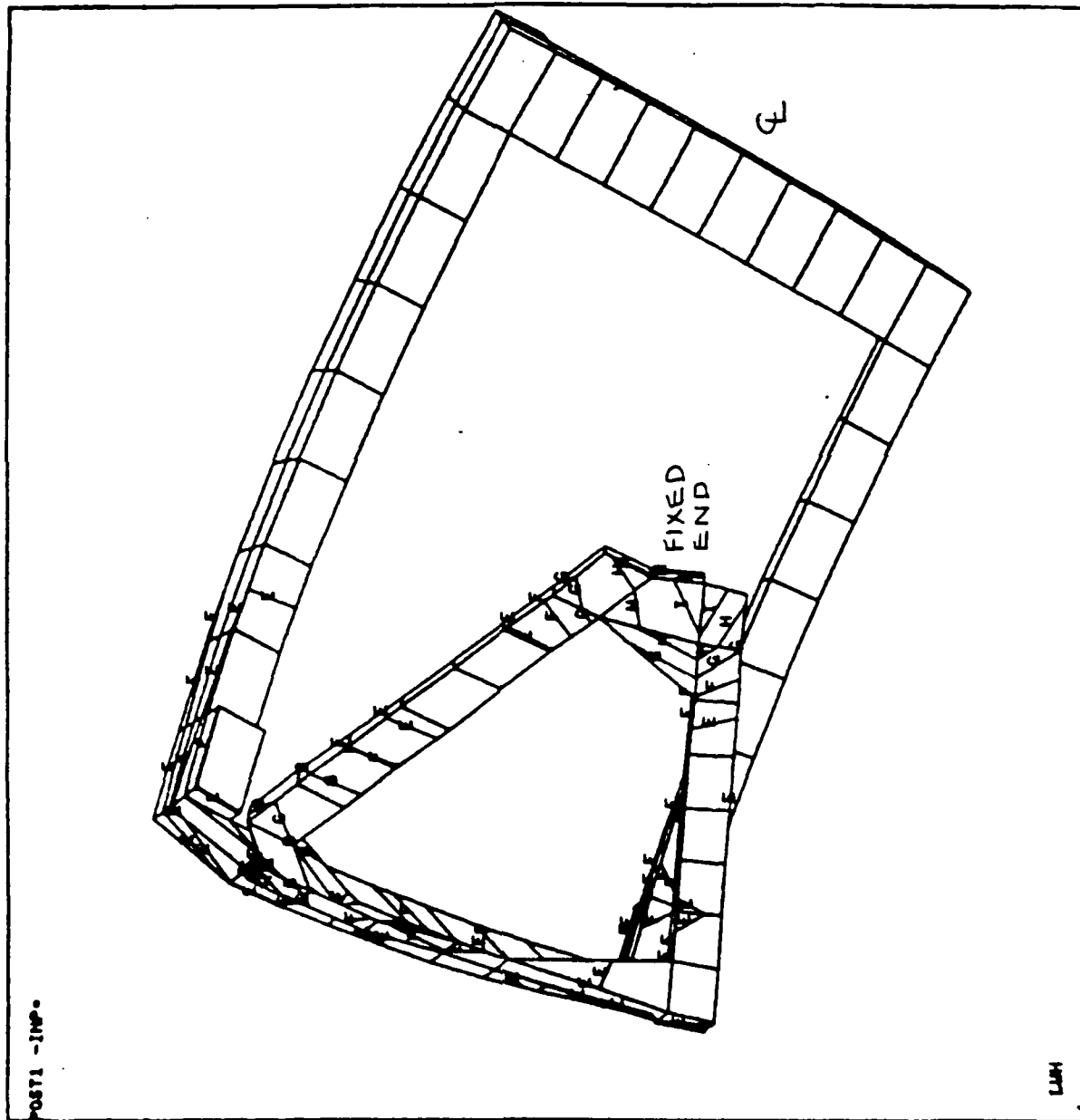
ANSYS
 4/11/85
 16.5-400
 PREP7 ELEMENTS
 MESH
 FBC-1
 AUTO SCALING
 ZOOM
 XU--8
 YU-5
 ZU--.7
 DIST-38.2
 XF-30.9
 VF--16.7
 ZF-12.3
 ANGL--120
 VRT0-2.13



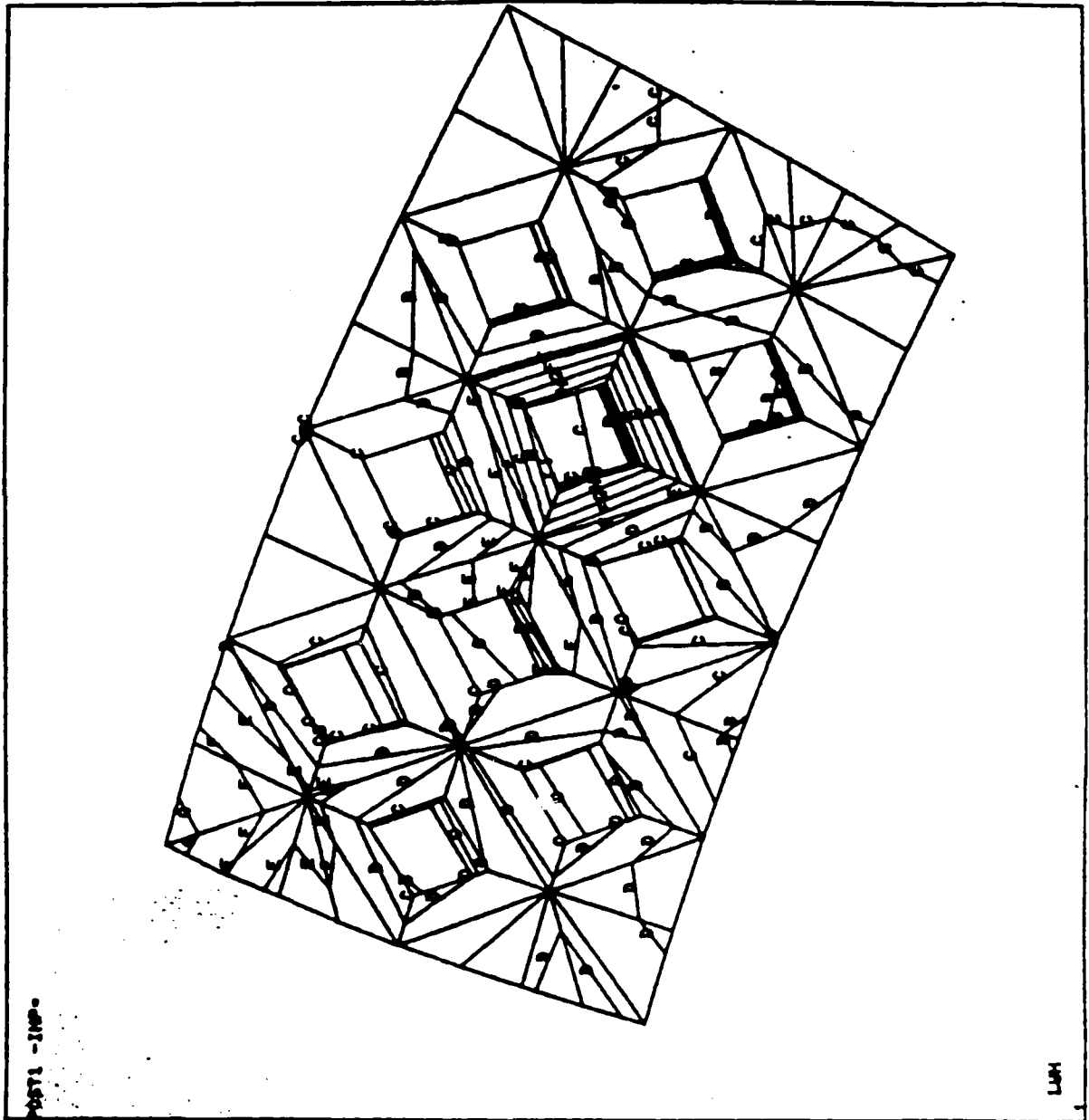
ANSYS
 4/11/85
 15.5213
 PREP7 ELEMENTS
 MSET
 FBC=1
 AUTO SCALING
 ZOOM
 XU=-2
 YU=1.5
 ZU=-.7
 DIST=26.1
 XF=48.8
 YF=-19.8
 ZF=11.8
 ANGL=-120
 VETO=8.13



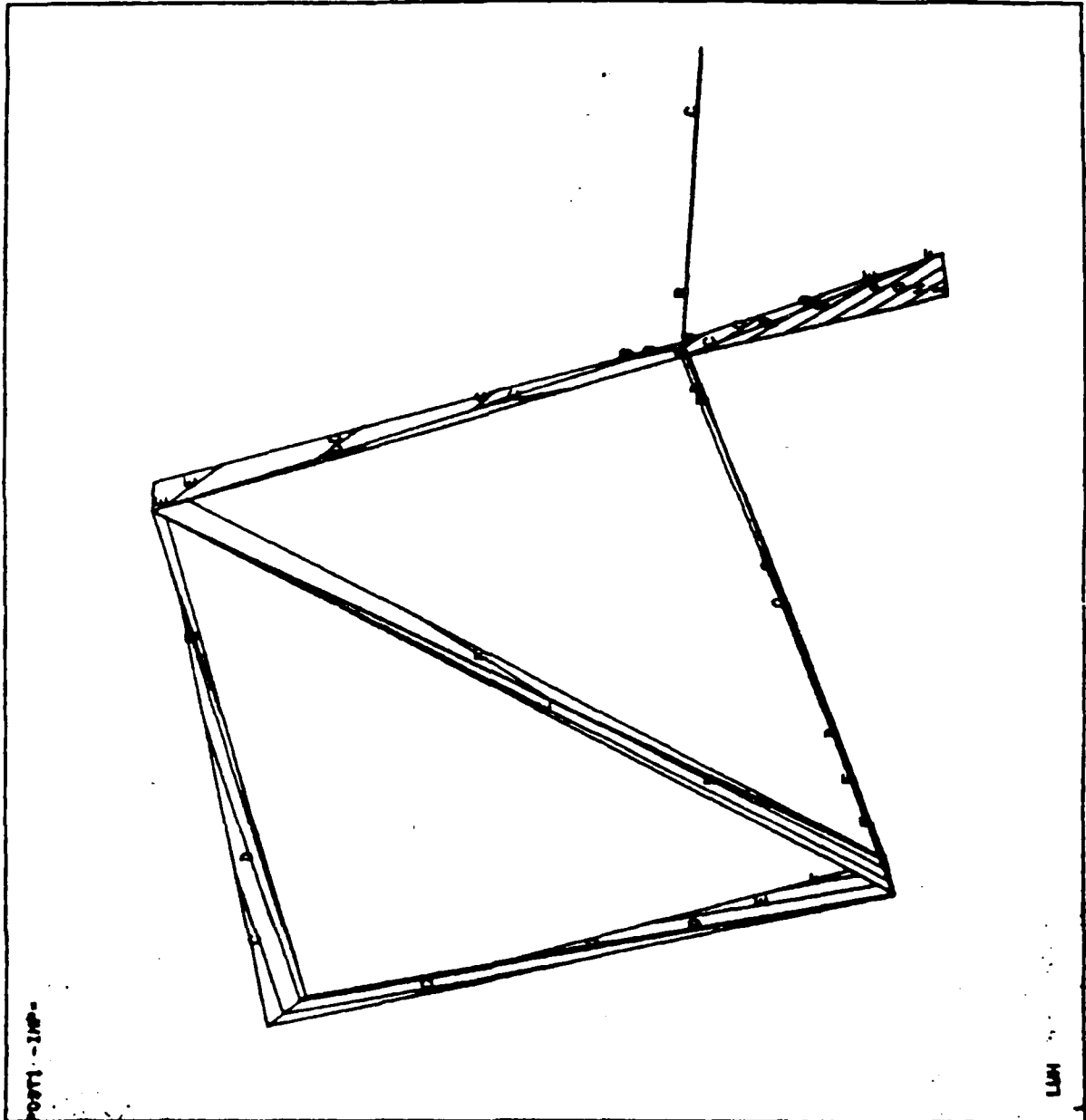
ANSYS
4/11/85
15.1548
POST1
STEP=1
ITER=1
STRESS PLOT
SIZE
TOP
AUTO SCALING
XU=-2
YU=.3
ZU=-.7
DIST=85.1
XF=31.4
YF=-15
ZF=6.55
ANGL=-180
HIDDEN
RX=479582
RY=2532
E=80000
F=160000
G=240000
H=320000
I=400000



ANSYS
 4/11/85
 15.1046
 POST1
 STEP=1
 ITER=1
 STRESS PLOT
 SIZE
 TOP
 AUTO SCALING
 NU=2
 W=3
 BU=-.7
 DIST=81
 WF=48.5
 WF=-19.4
 WF=11.8
 ANGL=-180
 HIDDEN
 RM=104283
 RM=5321
 D=12500
 C=25000
 D=37500
 E=50000
 F=62500
 G=75000
 H=87500
 I=100000



ANSYS
 4/11/85
 15.8485
 POST1
 STEP=1
 ITER=1
 STRSS PLOT
 SIZE
 TOP
 AUTO SCALING
 NU=-2
 VU=.3
 ZU=-.7
 B157=9.41
 XF=24
 YF=-23.8
 ZF=8.33
 ANGL=-180
 HIDDEN
 RM=178344
 RM=82862
 D=87500
 C=100000
 B=118500
 E=185000
 F=137500
 G=100000
 H=108500
 I=175000



POSTN.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	SBV	SIG1	SIG3
15	14885.	-184.87	-8758.9	21767.	7883.1
26	-18788.	3804.8	3588.8	-8308.7	-83276.
38	8866.4	-8866.4	-10381.	86439.	-8937.7
41	-4034.7	-1848.6	-348.86	-8083.3	-6886.2
47	-4028.0	-428.69	16.118	-3681.1	-4466.7
48	-10720.	3818.9	-734.25	-8185.6	-16274.
49	-80821.	8882.8	3231.0	-14707.	-85335.
50	18123.	-8748.6	-645.76	21511.	14735.
58	-11581.	-832.88	-2186.8	-8180.9	-13889.
60	-11679.	3737.8	-671.87	-7189.6	-16089.
61	-8328.6	3343.8	-1767.2	-3217.4	-13440.
64	-8497.7	-5883.3	613.35	3888.8	-8104.3
65	-11861.	3376.4	7095.8	-1180.6	-82132.
66	18806.	-3888.5	6449.8	23034.	8768.9

NONE (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	SDZ	SBV	SIG1	SIG3
72	-8413.8	-2183.8	-100.83	-200.84	-4627.4
74	-868.87	-4138.7	8038.1	9900.6	-18446.
76	18848.	1741.7	-4548.3	86236.	18658.
80	7455.3	18469.	6348.7	86264.	-11364.
81	8188.8	12891.	-854.2	20118.	-13784.
82	-1842.1	6521.8	16629.	21308.	-85183.
83	3634.0	8456.4	-17640.	87630.	-20662.
88	1443.6	-2089.1	2518.7	7871.3	-4884.3
94	1425.8	1888.0	13.412	3328.2	-476.37
97	885.84	-8233.0	-6342.6	8221.4	-7849.7
98	11488.	-7877.7	-8548.1	87589.	-4854.4
103	8724.8	18634.	-2846.8	17804.	-11766.
108	8761.6	1381.1	-550.67	4693.3	889.72
118	10408.	1868.8	-41.216	18307.	8608.6

----- POST1 ELEMENT STRESS LISTING -----

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

ELEM	SDIR	SDZ	SBV	SIG1	SIG3
116	10488.	-8289.6	-11.609	18788.	8163
118	11746.	-7183.4	-48.87	18778.	2044.4
117	8828.6	1888.2	805.53	8888.7	2013.5
118	8863.5	8888.8	8888.8	8888.8	8887.8
123	17887.	47788.	-788.48	88888.	-83173.
124	16173.	-8788.6	888.88	88888.	-88368.
126	-8881.0	8188.8	-11888.	11107.	7884.8
126	88771.	-1288.4	-1881.6	84881.	-16111.

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

ELEM	911R	912	91V	9101	9103
154	8018.0	8267.7	-5181.0	30000.0	-60220.0
157	8000.1	13077.7	6170.1	8001.3	-13483.0
160	11604.1	3317.6	603.04	15616.0	7678.6
163	-1223.3	-3558.8	-8994.8	330.00	-18777.0
165	-3242.0	8001.1	-120.63	760.65	-13053.0
168	8100.1	8341.0	4810.5	16467.0	-12005.0
172	8100.1	-3002.8	-8750.8	-18187.0	-31705.0
177	-1000.8	10078.0	-3070.8	14354.0	-17760.0
179	-1073.0	6175.3	107.84	4006.3	-8043.0
185	-13476.0	-4068.0	86.010	-8710.8	-18240.0
187	-13403.0	7074.3	-819.43	-8707.0	-20707.0
191	-10003.0	4330.0	100.30	-15530.0	-24454.0
198	11003.0	800.30	4000.0	10104.0	5001.0
199	-10001.0	8401.0	-6317.4	-10104.0	-34000.0

----- POST1 ELEMENT STRESS LISTING -----

LOAD STEP: 1 ITERATION: 1 SECTION: 1

TIME: 0.00000E+00 LOAD CASE: 1

ELEM	911R	912	91V	9101	9103
154	-13014.0	80448.0	-604.06	15130.0	-48767.0
157	3700.0	8002.0	120.60	11000.0	-4374.6
160	-7078.0	-4345.0	-3411.0	-818.87	-15733.0
163	4030.0	-1030.8	-121.71	6002.0	8005.0
165	-83056.0	3041.0	-476.74	-10030.0	-80073.0
168	-83001.0	14003.0	300.15	-8707.5	-20624.0
172	3770.0	1774.4	-122.00	5007.3	1074.3
177	-37000.0	-3040.0	8015.1	-31040.0	-43058.0
179	-27720.0	2007.1	-3300.1	-17304.0	-20100.0
185	-17040.0	4140.3	143.00	-13000.0	-80224.0
187	-13012.0	8240.1	-4250.8	13100.0	-40023.0
191	-10300.0	-8000.0	819.34	-4411.0	-14000.0
198	10000.0	100.10	-6000.0	81400.0	8002.3
199	-6310.1	8077.4	1001.4	-10104.0	-10017.0

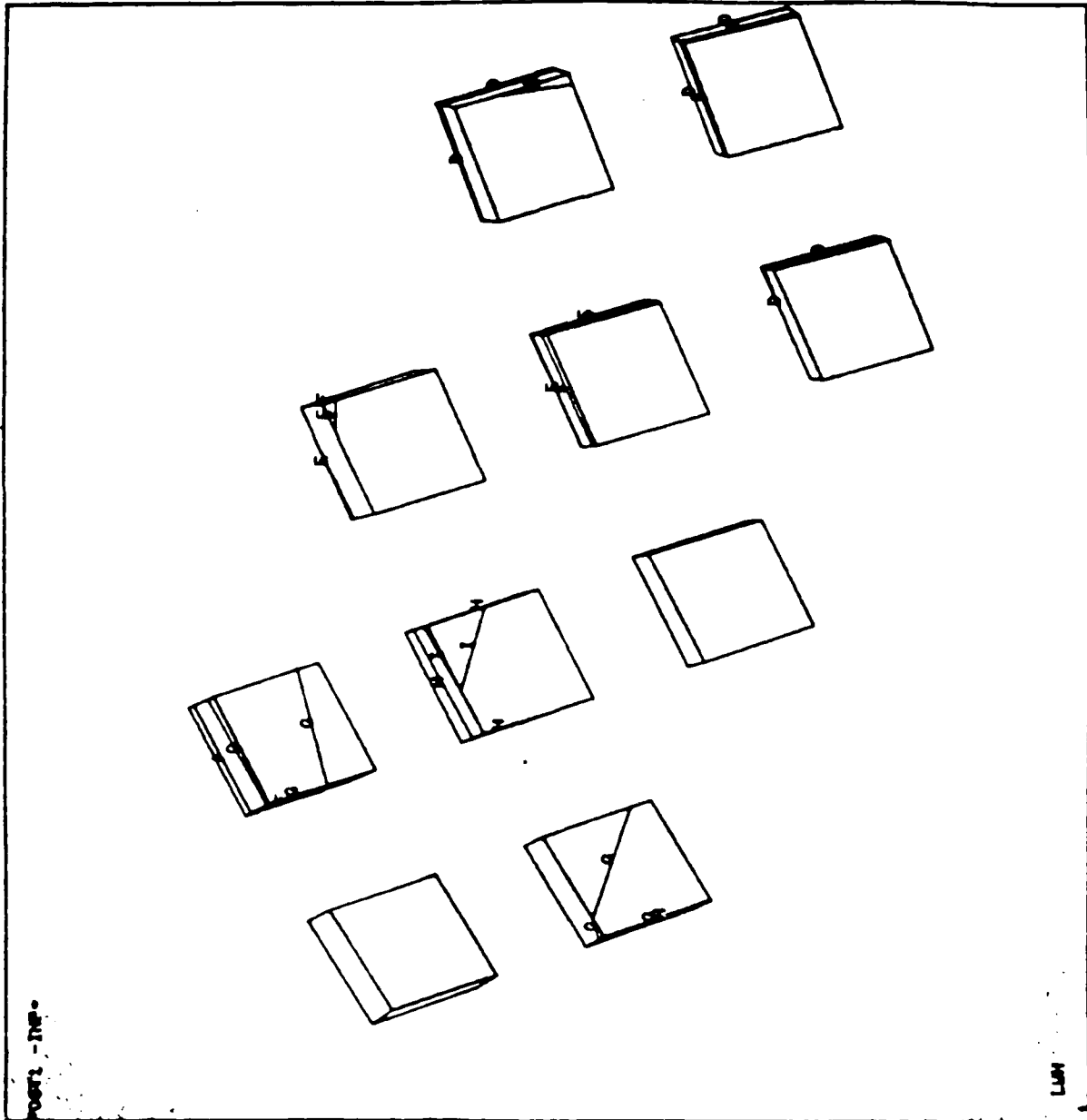
----- POST1 ELEMENT STRESS LISTING -----

LOAD STEP: 1 ITERATION: 1 SECTION: 1

TIME: 0.00000E+00 LOAD CASE: 1

ELEM	911R	912	91V	9101	9103
154	-17044.0	10490.0	100.31	-7330.1	-80540.0
157	-10910.0	8040.0	-400.00	-4000.0	-17430.0
160	-8070.3	87000.0	8100.0	87000.0	-30100.0
163	-10003.0	10000.0			

ANSYS
 4/11/85
 15.2403
 POST1
 STEP=1
 ITER=1
 STRESS PLOT
 SIZE
 TOP
 AUTO SCALING
 XU=-8
 YU=.3
 ZU=-.7
 DIST=15.8
 XF=48.8
 YF=-21
 ZF=11.8
 ANGLE=120
 HIDDEN
 MX=5126
 MY=282
 D=800
 E=1600
 F=2400
 G=3200
 H=4000
 I=4800



FMC Corporation
Central Engineering Laboratories

Interoffice

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?

Bart Anderson

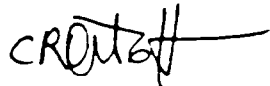
April 1, 1985

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:PORTLOFF.ABX7LWH.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.



C. R. Ortloff

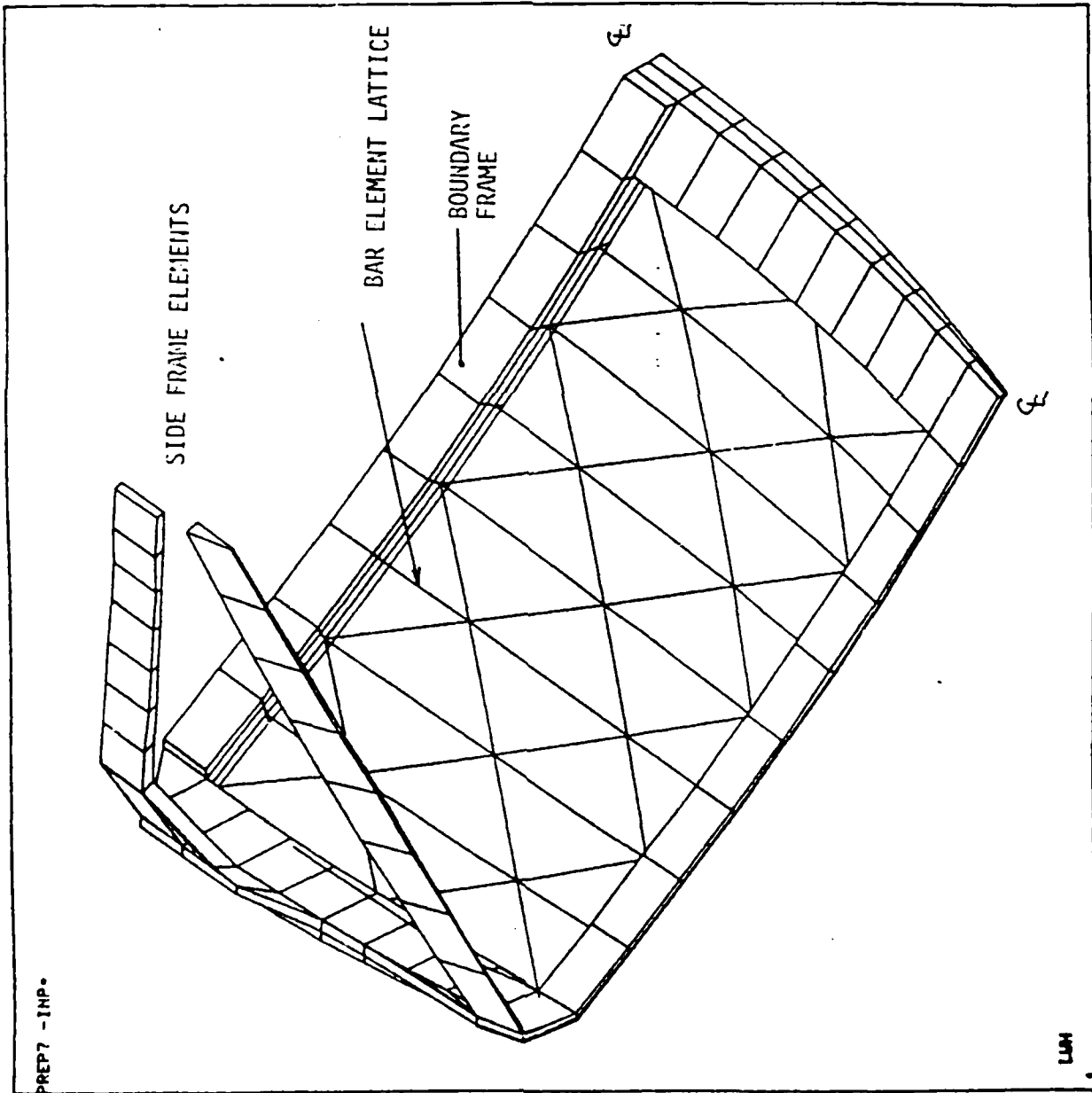
ja

HT7-23

ANSYS
3/26/85
10.3145
PREP7 ELEMENTS
HSET

AUTO SCALING
XU=-2
YU=1
ZU=.5
DIST=25.1
XF=35.2
VF=-12.4
ZF=13
ANGL=-120
HIDDEN

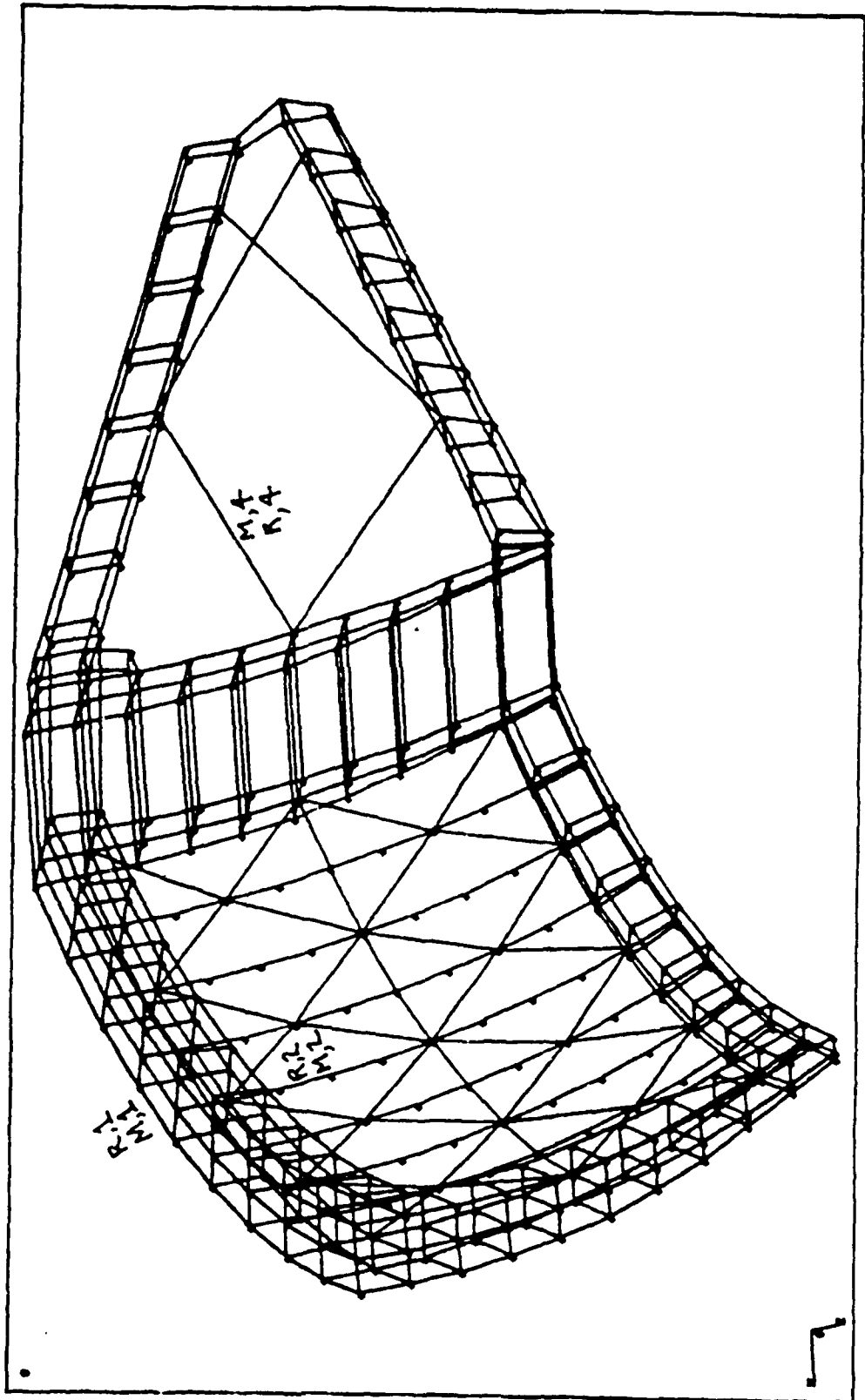
COMPOSITE SPADE
(HALF SECTION)



20-MAR-85 14:30:49

MODEL_CREATION

LUH



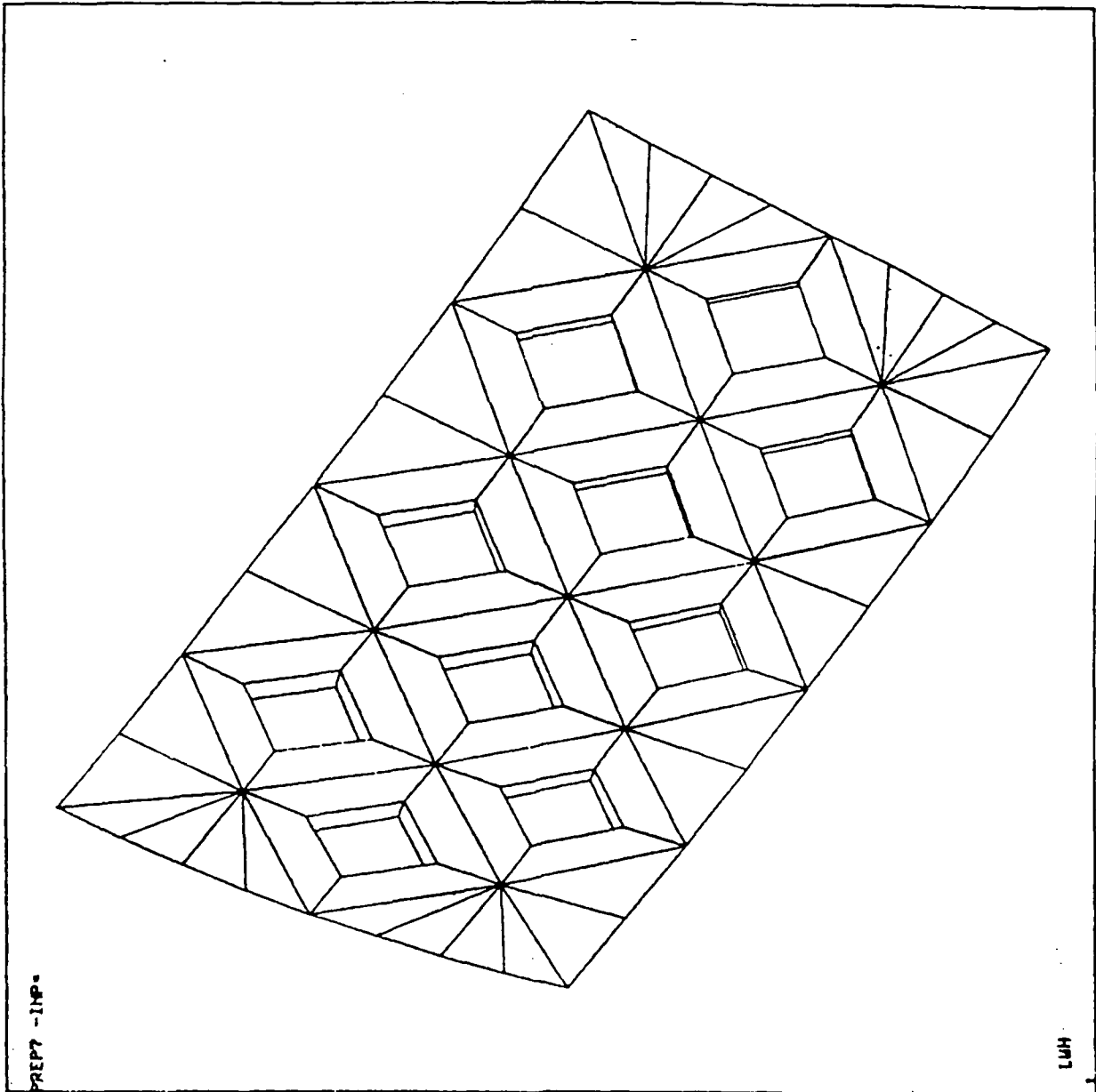
SCHEMATIC OF THE COMPOSITE SPADE DESIGN

HT7-25

APPENDIX HT7 - C5

COMPOSITE WAFFLE PLATE
M,3
R,3

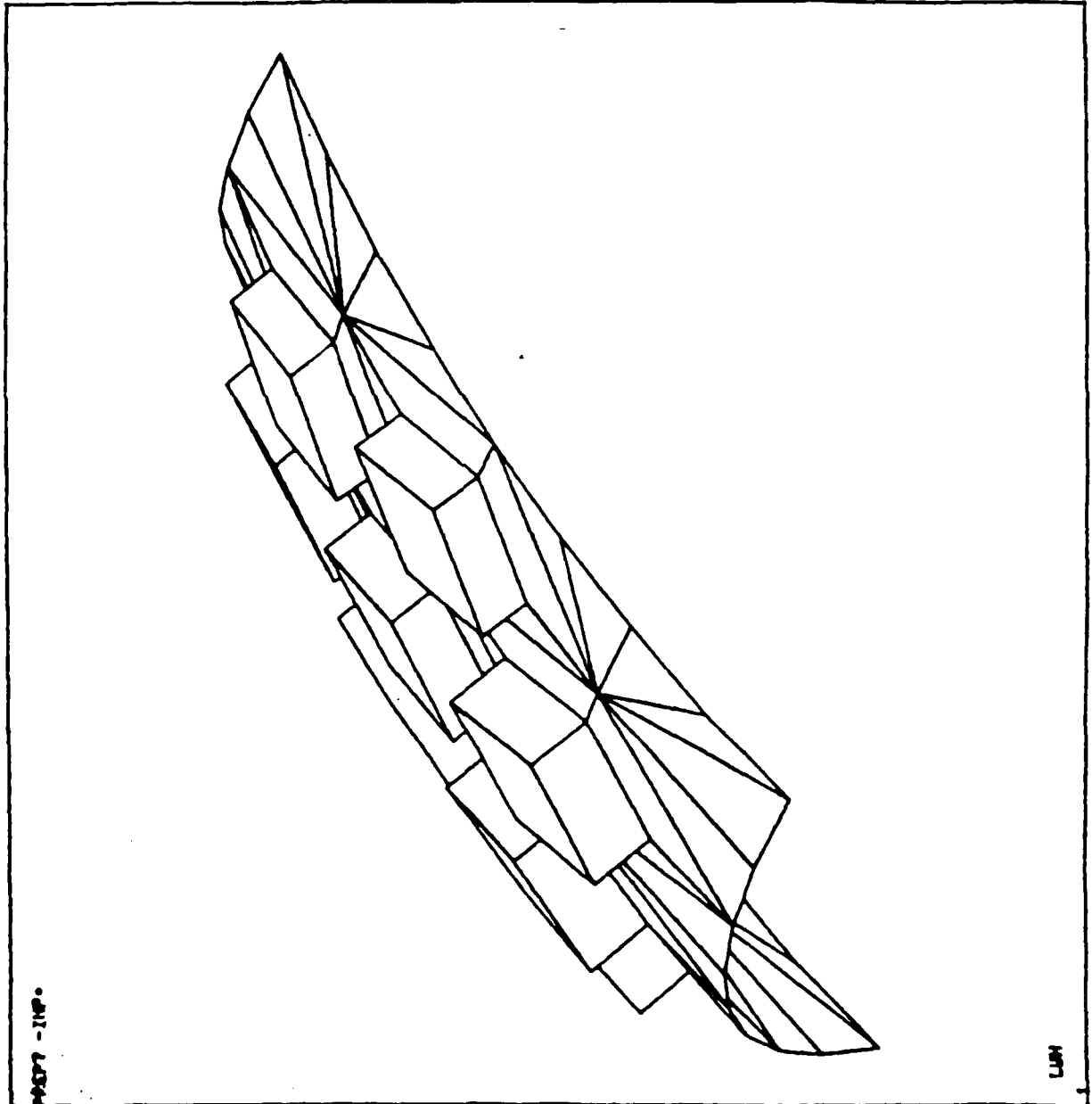
ANSYS
3/26/85
9.5165
PREP7 ELEMENTS
MSET
ENM=1
NNUM=1
AUTO SCALING
ZOOM
XU=.3
YU=.2
ZU=.4
DIST=46.1
XF=48
YF=-19.5
ZF=11.5
ANGL=-120
XRT0=2.13
YRT0=2.46
HIDDEN



ANSYS
 1/26/88
 9.3837
 PREP7 ELEMENTS
 NSET
 ENUR=1
 AUTO SCALING
 ZOOM
 XU=.3
 YU=.6
 ZU=-.1
 DIST=88
 XF=48.6
 VF=-19.4
 ZF=12.2
 ANGL=-120
 XRT0=2.13
 YRT0=2.46
 HIDDEN

COMPOSITE WAFFLE PLATE

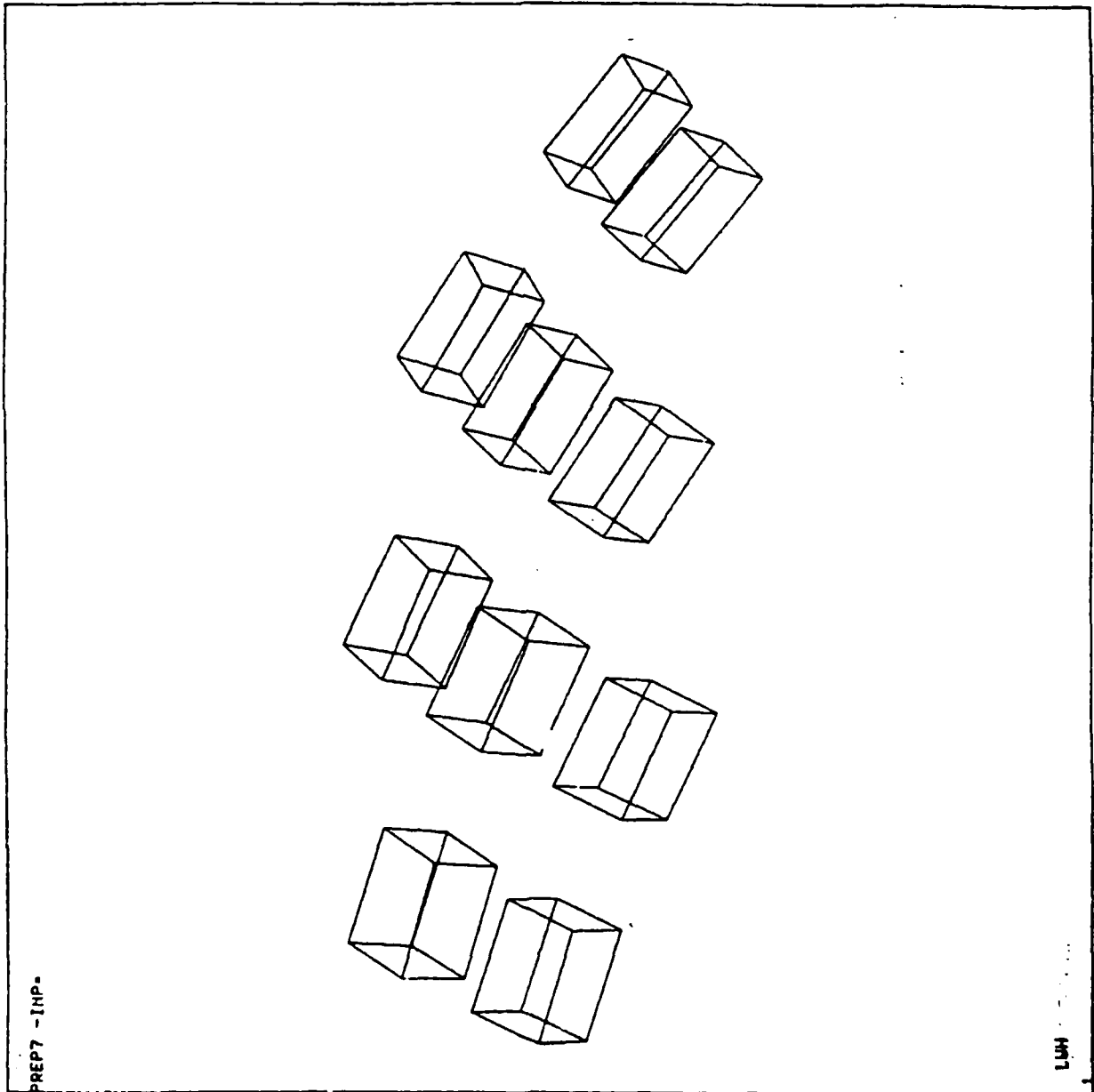
M,3
 R,3



APPENDIX HT7 - C7

ANSYS
3/25/85
17.9197
PREP7 ELEMENTS
MSET
AUTO SCALING
ZOOM
YU=.3
ZU=-.5
DIST=31.5
XF=50.7
YF=-21
ZF=12.1
ANGL=-120
XRT0=2.13
YRT0=2.46

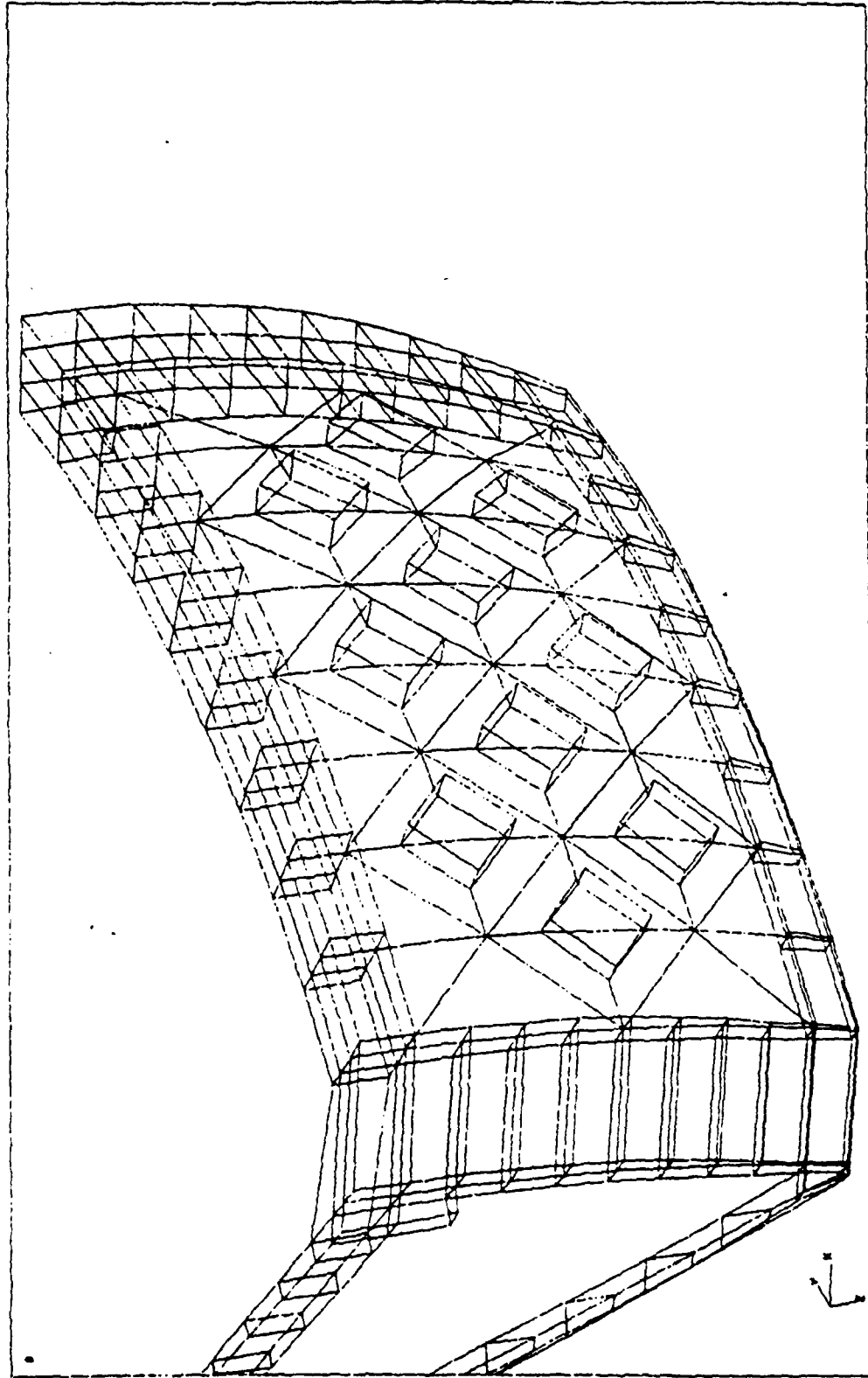
URETHANE FILLER PLUGS
(JIAFFLE PLATE INSERTS)
M,5
R,5



21-MAR-85 08:58:59

MODEL_CREATION

LWH



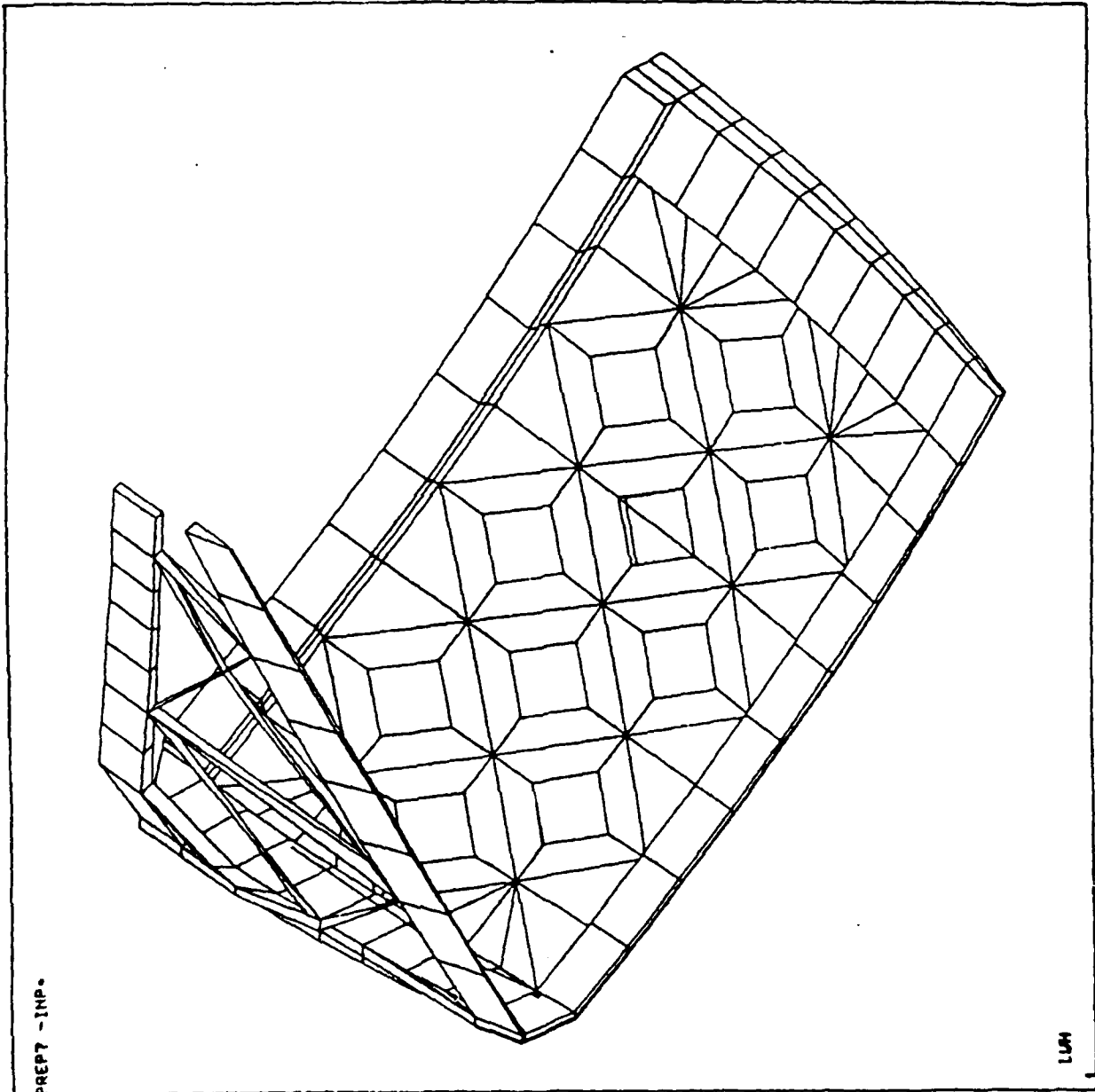
ASSEMBLED VIEW OF THE COMPOSITE LIGHTWEIGHT HOWITZER SPADE

HT7-29

APPENDIX HT7 - C9

ANSYS
3/26/85
10.3499
PREP7 ELEMENTS
MSET

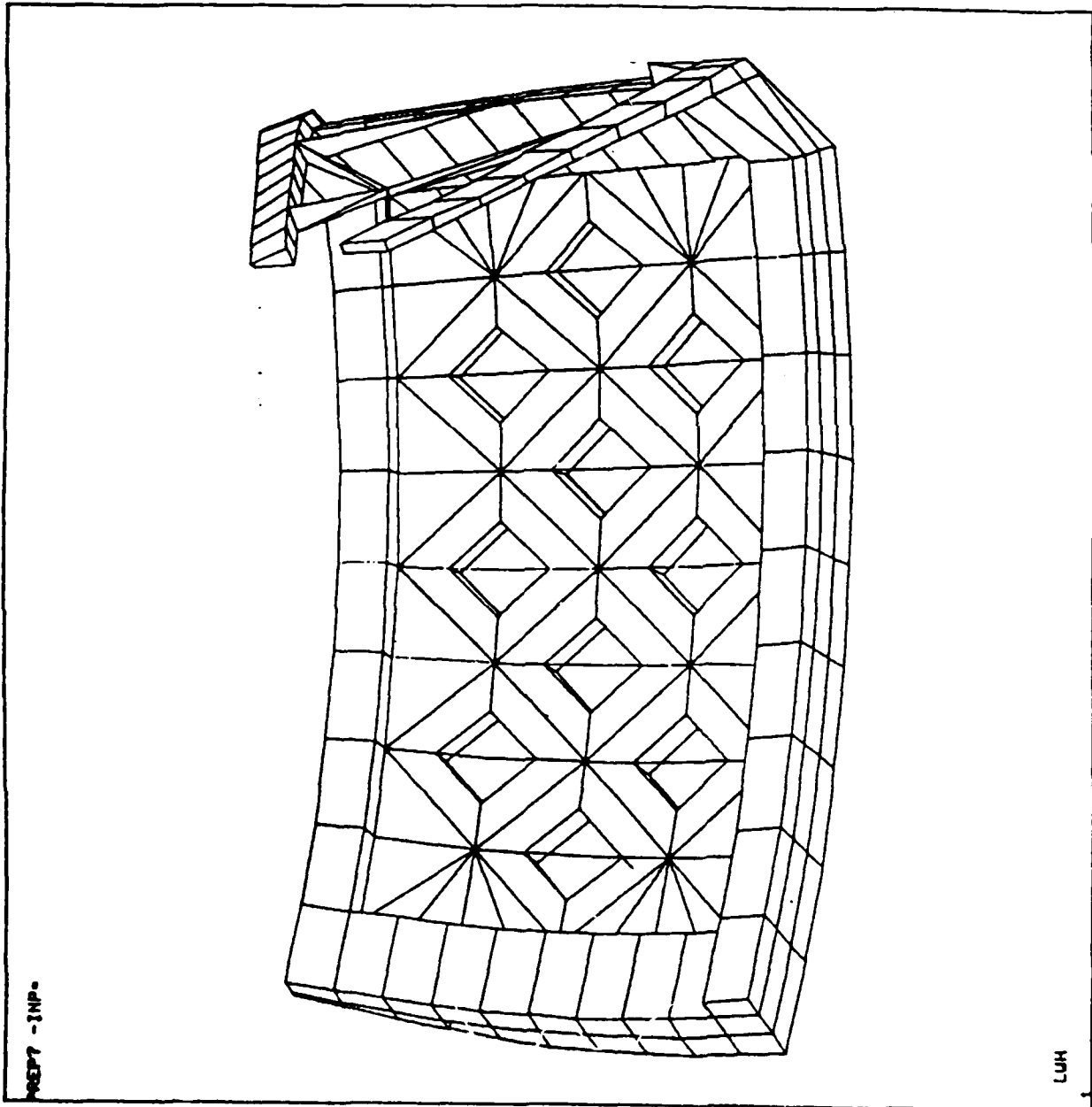
AUTO SCALING
XU=-2
YU=1
ZU=.5
DIST=25.1
XF=35.2
YF=-12.4
ZF=13
ANGL=-120
HIDDEN



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

APPENDIX HT7 - C10

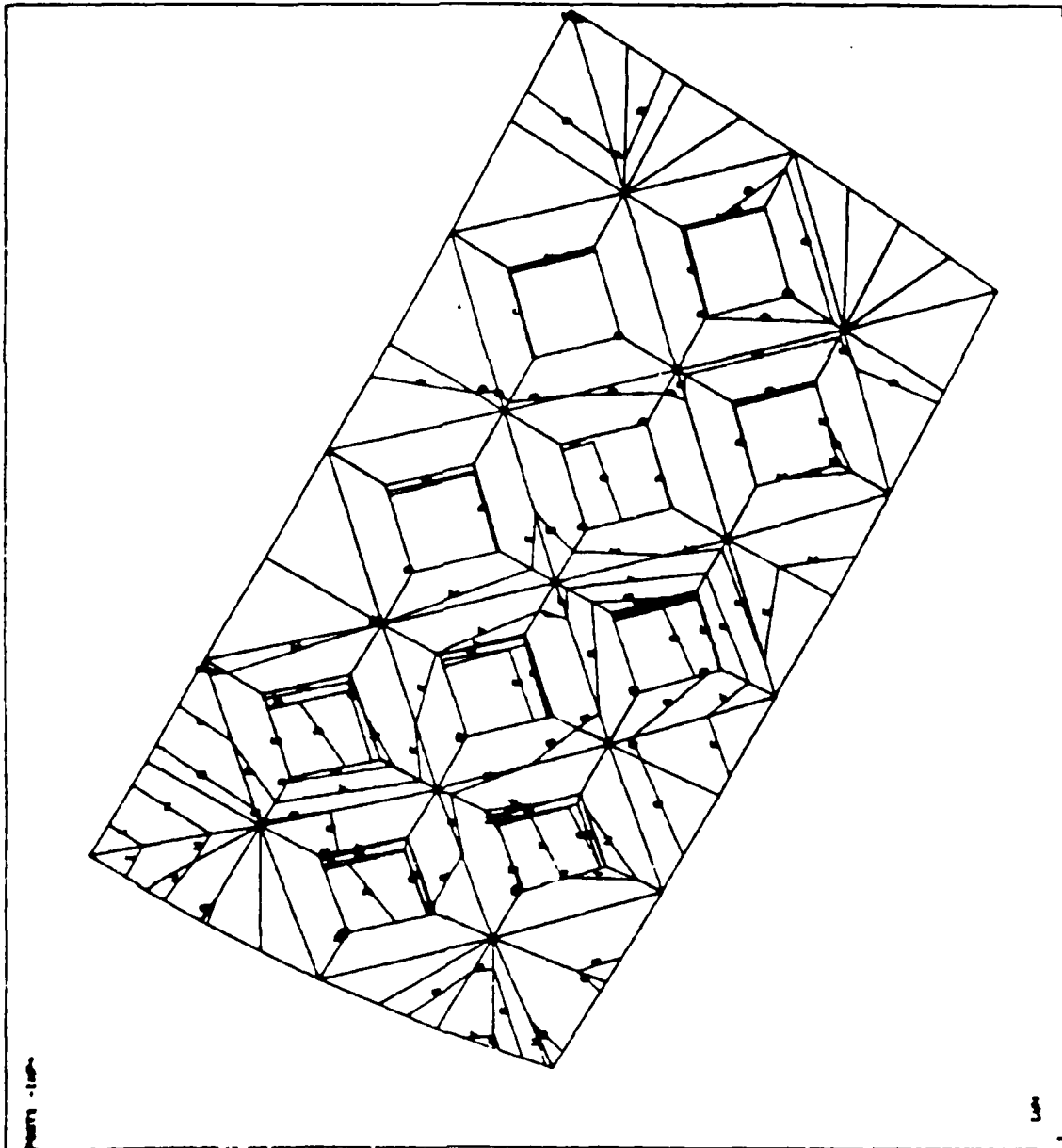
ANSYS
3/21/85
14.4273
PREP7 ELEMENTS
TSET
AUTO SCALING
ZOOM
XU=-1
YU=.7
ZU=-.7
DIST=69.1
XF=36.4
YF=-11.8
ZF=4.99
ANGL=75
XRT0=2.91
YRT0=2.59
HIDDEN



HIDDEN LINE VIEW OF THE COMPOSITE SPADE

COMPOSITE WAFFLE PLATE^e

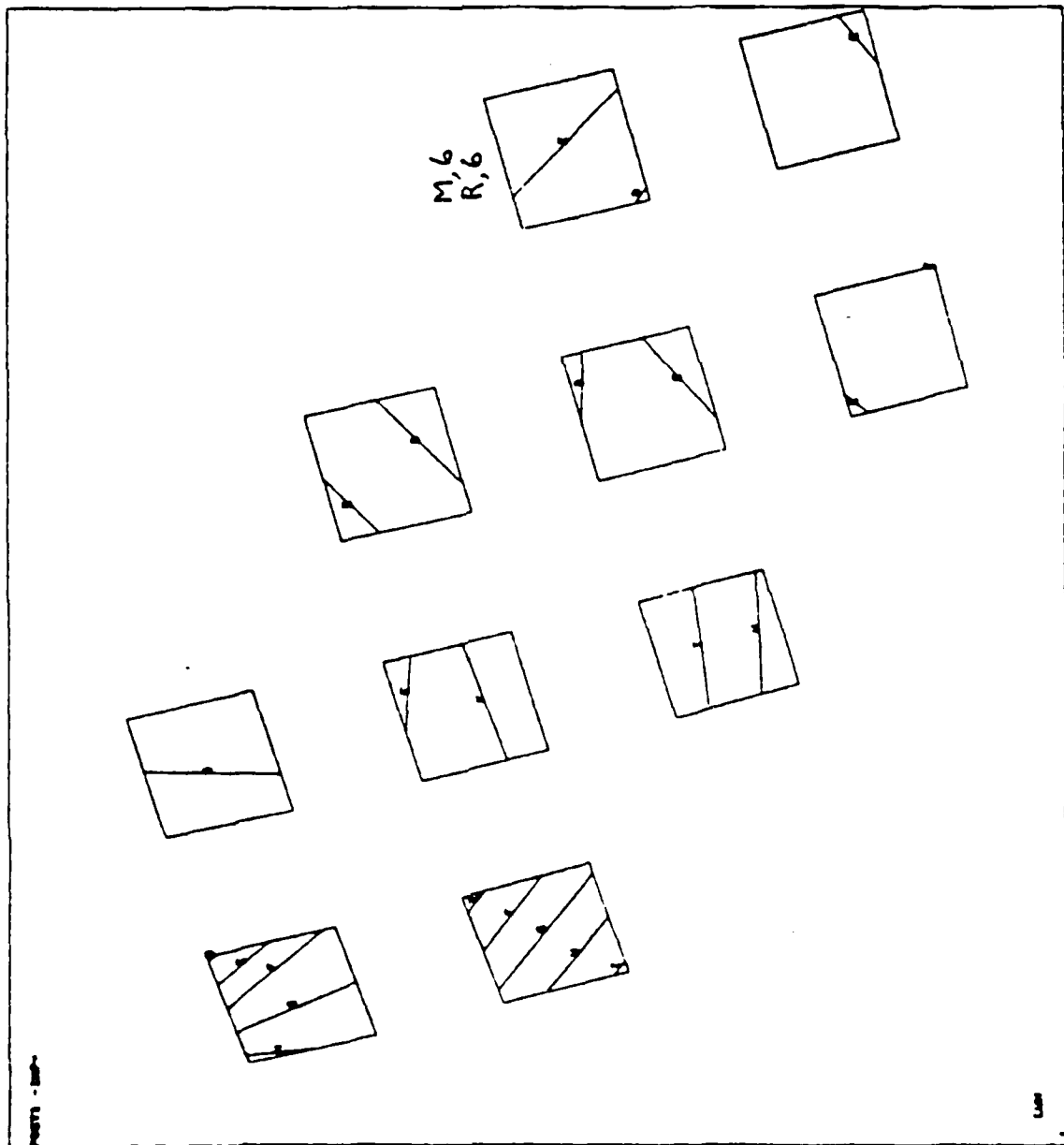
200000
 100000
 50000
 25000
 12500
 6250
 3125
 1562
 781
 390
 195
 97
 48
 24
 12
 6
 3
 1
 0

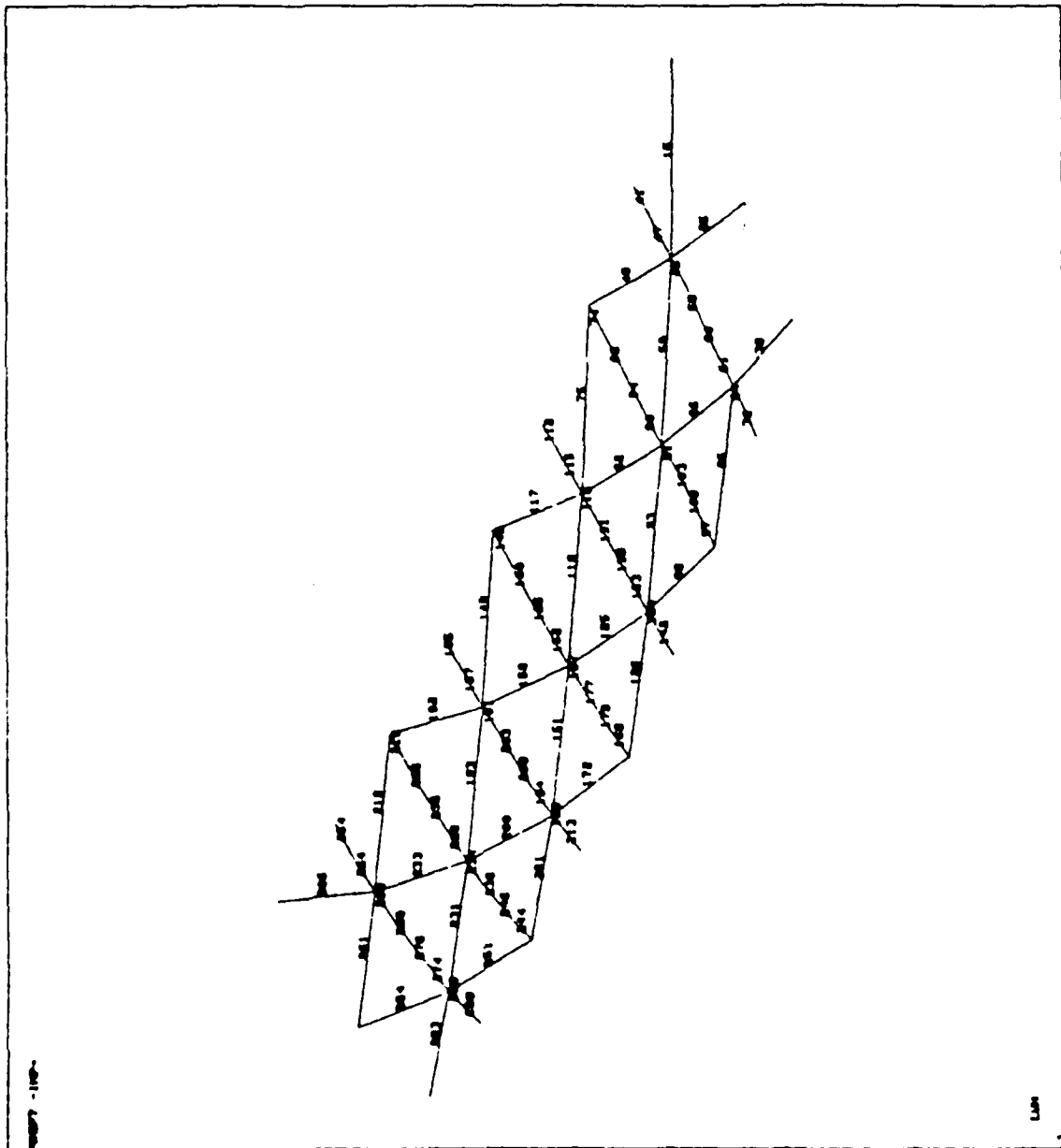


SEGMENTS OF THE OUTER COVER SHEET

DATE
↓ 1-68
11-1937
PORT
STD-1
STD-2
STANDARD PLOT
SIZE
YDR

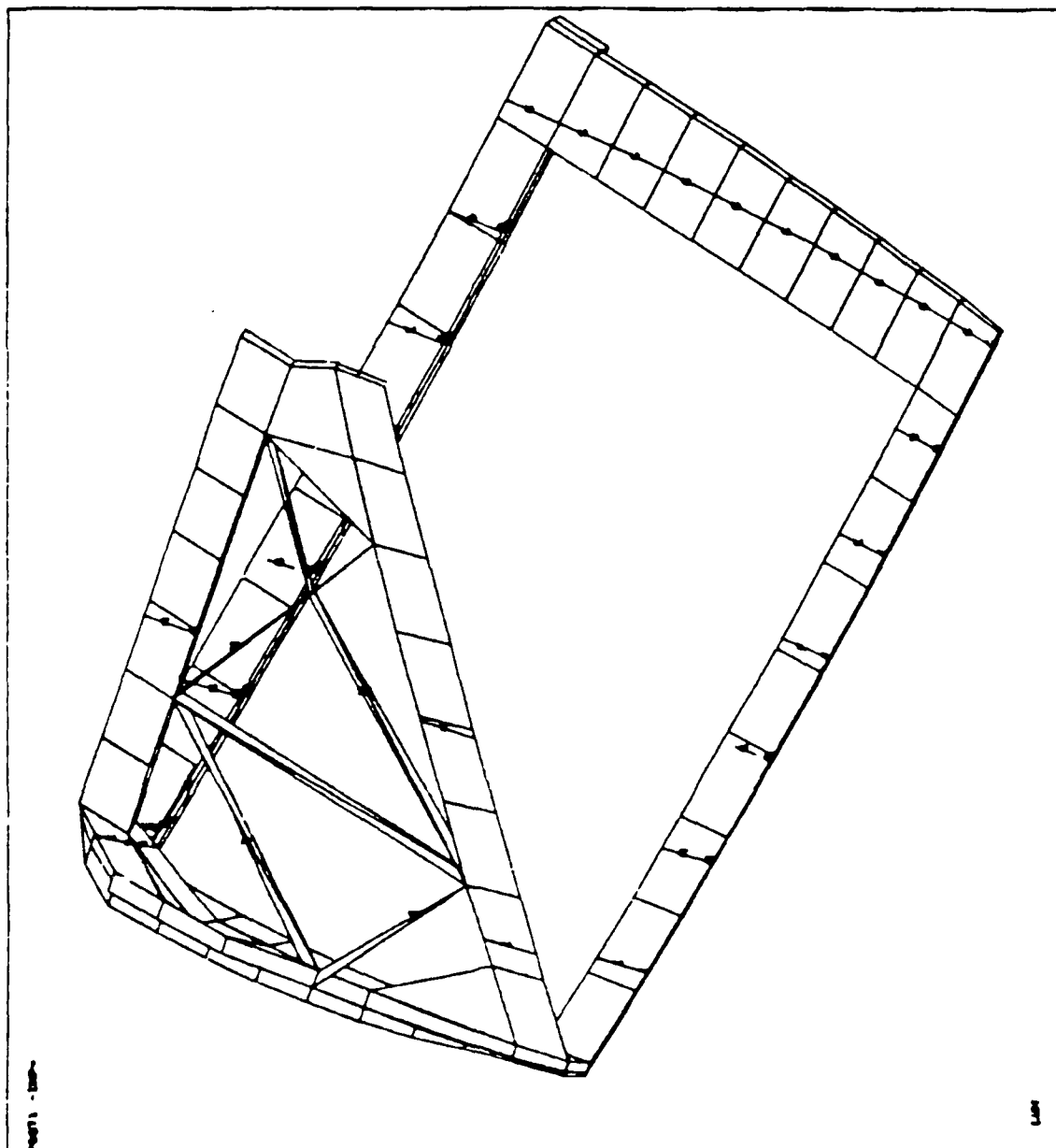
AUTO SOL MD
MD-3
VDR-4
ZDR-4
DRT-12.0
W-SD
WR-SR.0
ZF-12
ANAL--LDB
MIDBEN
NS-CJMS
MR-11.0
S-LMBN
E-SMBN
F-ZMBN
G-MBN
H-MBN
I-MBN



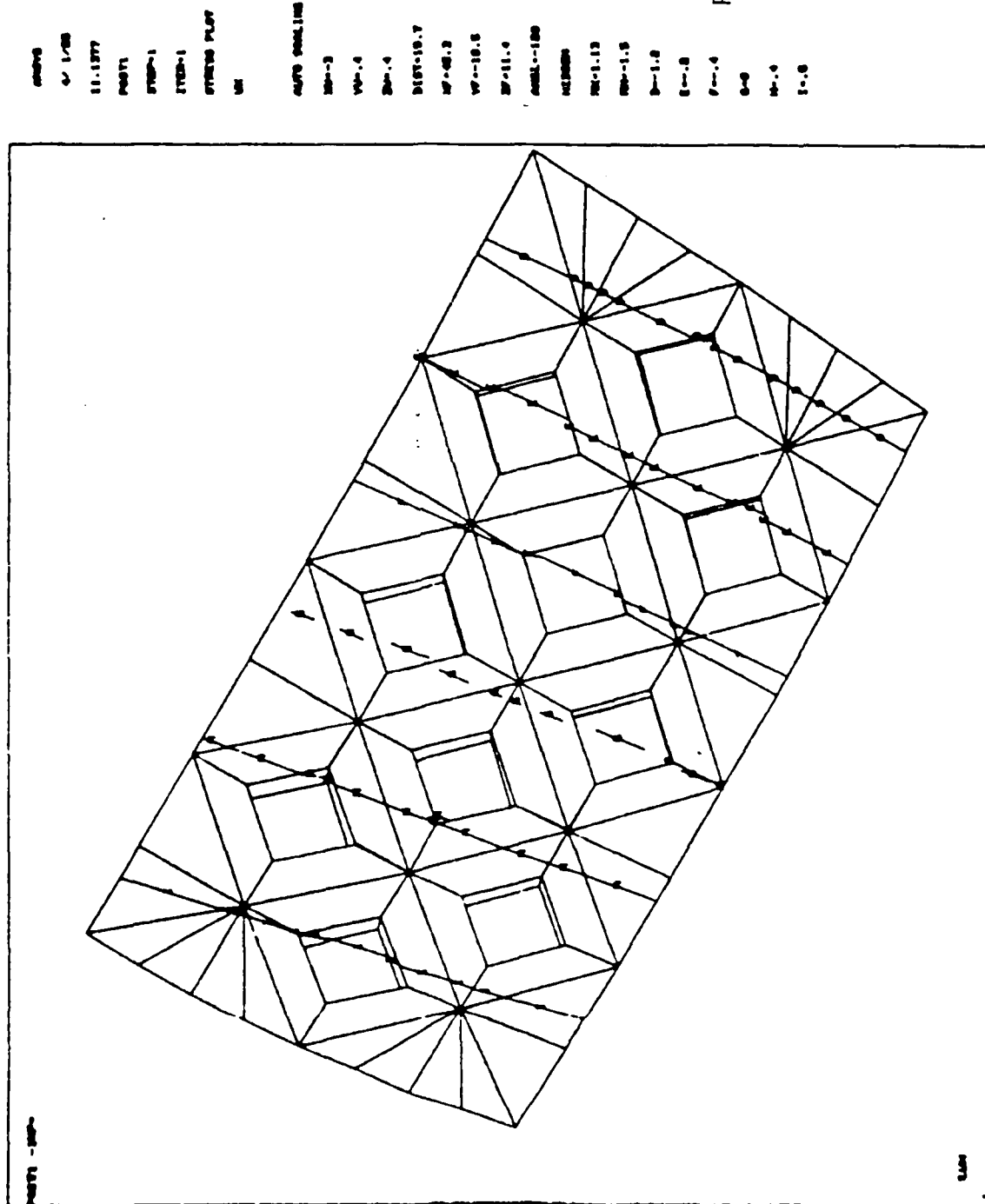


BAR ELEMENT STRESSES

0000-0
 01-1-00
 11-1111
 0000
 0000-1
 1000-1
 00000 0000
 000
 0000 0000 0000
 000-2
 000-4
 000-4
 000-4
 0000-0000
 00-20-3
 00-10-3
 00-10-0
 0000-1-00
 000000
 00-1-10
 000-1-00
 00-1-0
 00-1-0
 00-0
 00-4
 1-0



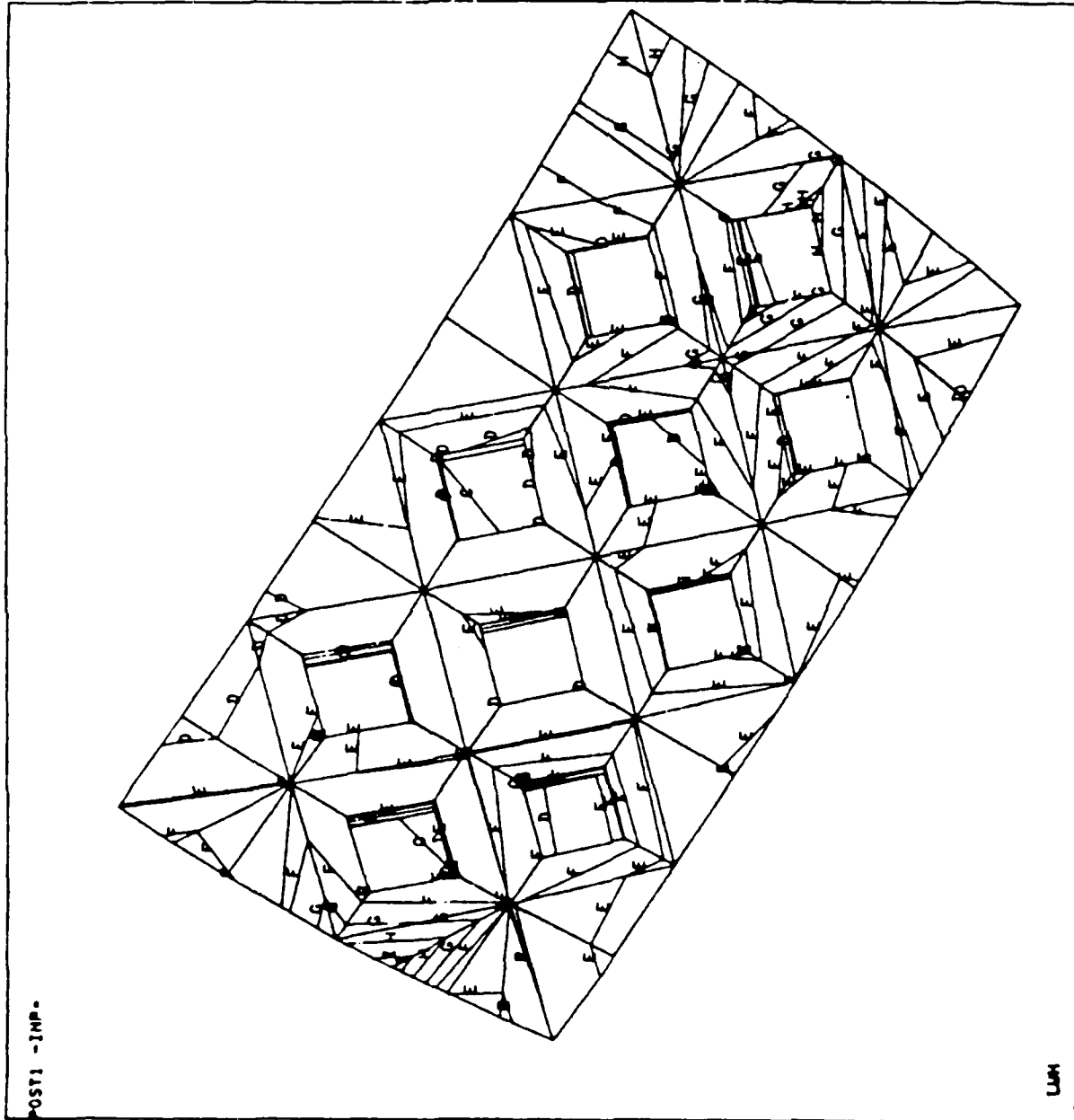
RADIAL DEFLECTION



HT7-41

[illegible]

ANSYS
 4/ 1/85
 14.7272
 POST1
 STEP=1
 ITER=1
 STRESS PLOT
 SICE
 TOP
 AUTO SCALING
 XU=-2
 VU=.55
 ZU=.35
 DIST=20.4
 XF=48.7
 VF=-19.8
 ZF=11.3
 ANGL=-120
 HIDDEN
 RX=6121
 MN=201
 C=800
 D=1500
 E=2400
 F=3200
 G=4000
 H=4800
 I=5600



HT7-43

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	SDZ	SDY	SIG1	SIG2	SIG3
15	-1703.1	-7.0446	438.51	-1257.5	-2148.6	-2148.6
25	1946.6	-74.032	-197.39	2212.0	1669.2	1669.2
38	-244.59	203.72	797.89	847.91	-1336.2	-1336.2
41	-164.84	-719.39	48.844	604.00	-932.48	-932.48
47	-165.82	-301.67	16.684	152.54	-484.17	-484.17
48	250.12	-14.431	236.00	500.55	-0.30662	-0.30662
49	1189.1	-50.091	115.83	1365.0	1012.2	1012.2
50	-1614.3	-545.35	-649.10	-419.80	-2808.7	-2808.7
58	-1088.3	66.436	92.241	-930.23	-1247.6	-1247.6
60	-1089.3	618.19	25.517	-445.64	-1733.1	-1733.1
61	-222.56	1881.1	-230.04	1808.6	-2333.7	-2333.7
64	-342.38	1332.7	142.40	1032.8	-1717.4	-1717.4
65	-712.93	45.152	214.47	-453.31	-972.56	-972.56
66	8.3367	-143.85	-283.89	436.07	-419.40	-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	SDZ	SDY	SIG1	SIG2	SIG3
72	-339.45	339.88	100.02	100.45	-779.36	-779.36
74	-233.50	-326.65	-33.864	127.01	-594.02	-594.02
75	-315.24	-401.38	-1516.4	1602.5	-2233.0	-2233.0
80	-1709.2	809.45	17.960	-800.70	-2617.6	-2617.6
81	-1582.5	-381.44	-103.09	-1178.0	-1087.0	-1087.0
82	-537.10	219.69	368.12	50.618	-1125.0	-1125.0
83	-2410.5	260.31	77.251	-2073.0	-2748.1	-2748.1
88	-1318.4	287.86	114.08	-916.43	-1720.3	-1720.3
94	-1321.7	-112.01	15.143	-1194.6	-1448.9	-1448.9
97	-1004.8	1744.8	-29.542	769.58	-2779.2	-2779.2
98	-687.70	-215.55	-432.75	-39.484	-1336.1	-1336.1
103	-1606.8	257.62	141.05	-1208.2	-2005.5	-2005.5
109	-1607.0	982.14	32.757	-592.12	-2621.9	-2621.9
112	-1289.4	-1019.0	-45.338	-224.21	-2354.6	-2354.6

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

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

ELEM	SDIR	SDZ	SDY	SIG1	SIG2	SIG3
115	-1200.1	-115.98	-37.918	-1135.2	-1444.0	-1444.0
116	-1304.8	62.198	-18.142	-1230.4	-1375.1	-1375.1
117	-1116.0	254.88	640.44	-311.93	-1920.0	-1920.0
118	-930.95	-822.63	277.66	-439.65	-1440.0	-1440.0
123	-1886.1	1409.8	-130.16	-266.35	-3514.8	-3514.8
124	-1669.4	-41.863	18.311	-1499.8	-1618.9	-1618.9
126	-448.01	77.743	-325.64	-44.624	-851.40	-851.40
184	-1008.0	-594.18	1837.8	-71.885	-3734.0	-3734.0
131	-1018.4	430.18	83.640	-1102.8	-8130.1	-8130.1

138	-1616.3	902.85	-16.301	-607.15	-2625.6	-2625.6
142	-1657.0	-27.467	35.523	-1495.0	-1620.9	-1620.9
146	-661.80	-353.86	20.878	-287.16	-1036.6	-1036.6
149	879.16	-131.68	-697.16	1708.0	60.332	60.332
151	-745.58	-135.66	520.40	-89.441	-1401.7	-1401.7

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

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

ELEM	SDIR	SDZ	SDY	SIG1	SIG2	SIG3
152	-1499.1	1813.0	229.54	543.44	-3541.7	-3541.7
157	-1289.3	-19.901	148.96	-1120.4	-1458.3	-1458.3
158	-1071.1	416.54	640.66	-13.923	-2128.3	-2128.3
160	-946.03	-420.41	147.65	-368.97	-1523.1	-1523.1
165	-947.77	614.32	-6.6396	-326.74	-1568.7	-1568.7
168	-1468.6	-16.345	-28.349	-1423.9	-1513.3	-1513.3
172	304.08	220.53	230.32	754.92	-146.76	-146.76
177	-1349.7	-314.14	446.82	-588.75	-2110.7	-2110.7
179	-1349.7	248.25	12.200	-1089.2	-1610.1	-1610.1
185	-679.03	-835.35	-39.774	196.09	-1554.2	-1554.2
187	-681.52	76.451	-29.689	-575.38	-787.66	-787.66
191	-777.53	790.39	271.19	284.05	-1839.1	-1839.1
192	-1087.0	227.76	482.03	-377.15	-1796.7	-1796.7
193	355.98	215.40	-559.28	1130.7	-418.70	-418.70

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

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

ELEM	SDIR	SDZ	SDY	SIG1	SIG2	SIG3
194	-1199.7	188.08	313.97	-697.67	-1701.8	-1701.8
196	-1470.4	-893.98	-171.30	-405.16	-2535.7	-2535.7
200	-848.17	564.66	-1085.4	702.02	-2599.3	-2599.3
201	-1126					

HT7-44

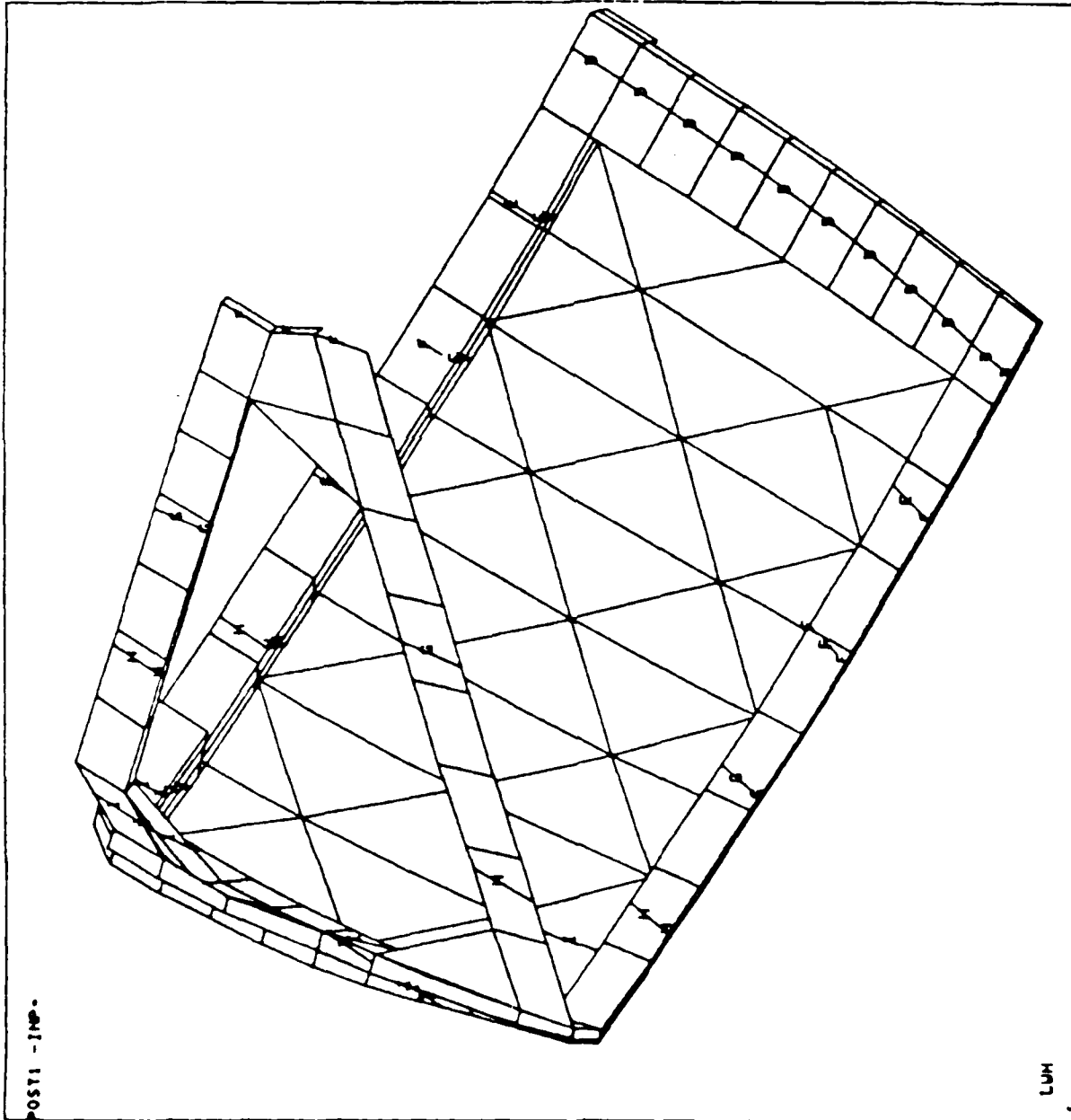
238	8.49	594.93	10.081	186.52	-1023.5	-1363.4
244	-646.76	-218.75	537.86	149.85	-3818.0	-1060.1
246	-1531.6	-2208.9	77.524	754.85	-1329.6	-325.85
251	-105.10	-452.48	-2.4914	-150.14	-1744.3	-137.69
254	827.71	322.32	179.54	1329.6	-2332.3	-1010.9
261	-908.18	-835.65	-0.43088	-72.008	-1812.9	-1631.2
263	846.29	-60.211	748.38	1754.9	-2722.7	-1335.4
264	-1626.3	341.46	364.51	-920.38	-743.54	
266	-909.87	52.197	48.802	-808.87		
268	-1596.8	-139.86	-176.10	-1200.7		
274	-1187.7	253.93	189.64	744.10		
276	-1236.0	-1012.0	473.79	250.71		
283	-1185.9	138.54	10.983	-1036.3		
	-134.28	-218.53	390.72	474.08		

3333 POST1 ELEMENT STRESS LISTING 3333

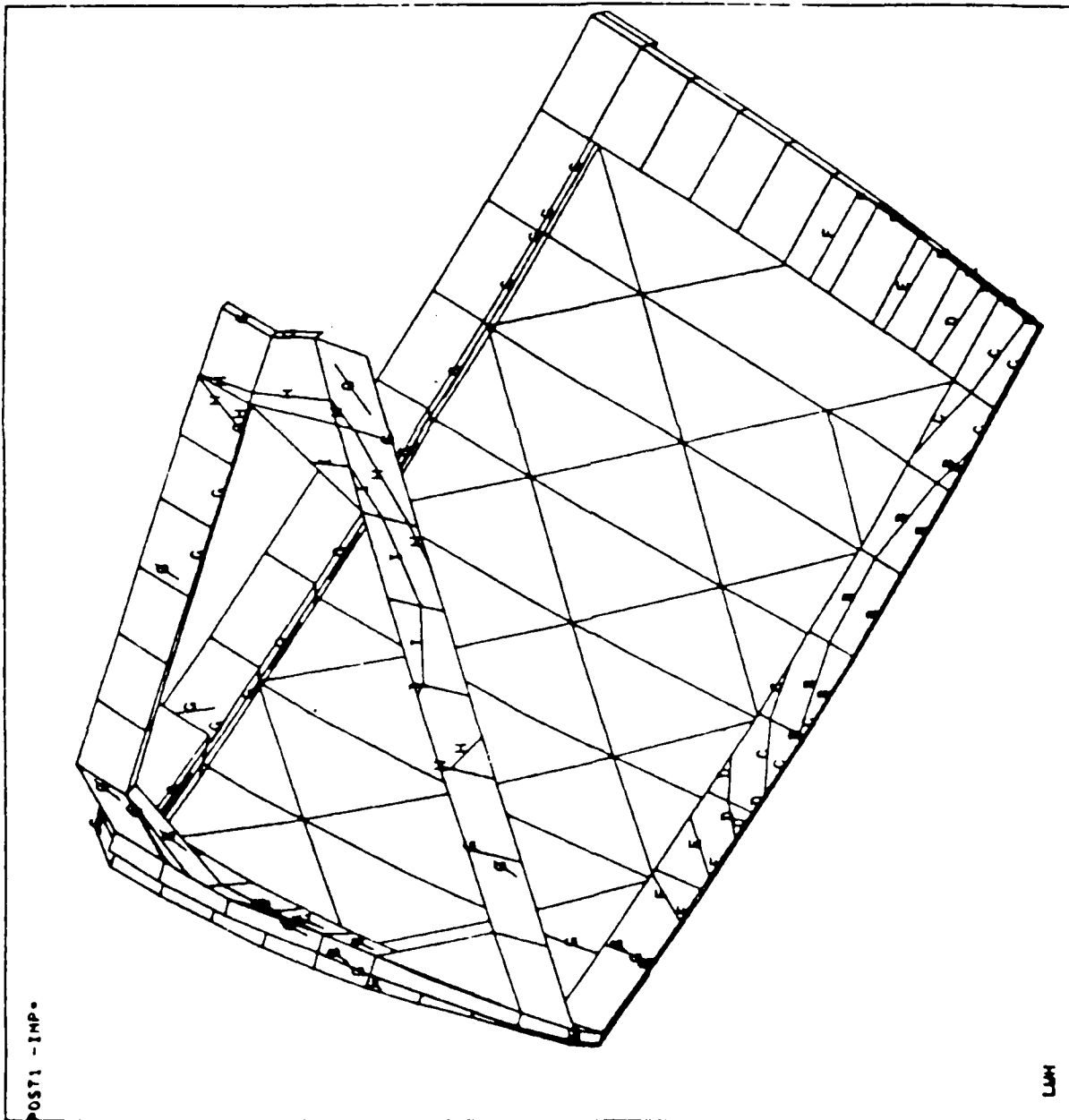
LOAD STEP	1	ITERATION	1	SECTION	1
TIME	0.00000E+00	LOAD CASE	1		
ELEM	SD1A	SB2	SBV	SIG1	SIG3
284	-828.94	149.99	5.6855	-682.27	-975.62
285	-2044.2	-2025.8	-108.82	90.454	-4178.8
289	-2046.2	-630.17	-43.189	-1372.8	-2719.5
POST1	-1MP.				

APPENDIX HT7 - C25

ANSYS
4/ 1/85
14.6510
POST1
STEP=1
ITER=1
STRESS PLOT
UX
AUTO SCALING
XU=-3
YU=.4
ZU=.5
DIST=22.8
XF=33.7
YF=-15.4
ZF=13.1
ANGL=-120
HIDDEN
MX=1.39
MY=-.95
D=-.8
E=-.4
F=0
G=.4
H=.8
I=1.2

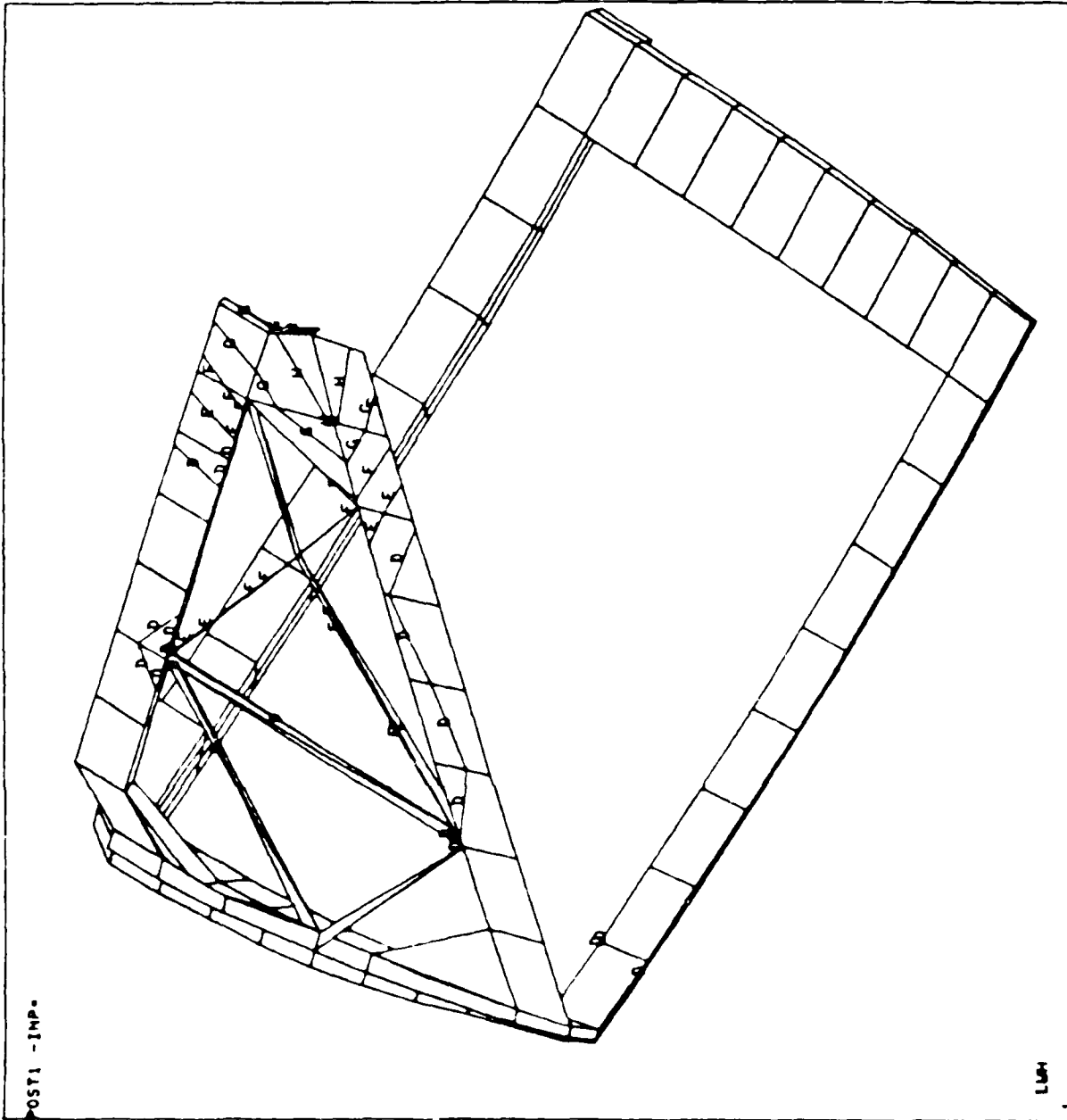


ANSYS
 4/ 1/85
 14.6802
 POST1
 STEP=1
 ITER=1
 STRESS PLOT
 UZ
 AUTO SCALING
 XU=-3
 YU=.4
 ZU=.5
 DIST=22.8
 XF=33.7
 YF=-15.4
 ZF=13.1
 ANGL=-120
 HIDDEN
 RX=.0146
 RY=-.0299
 B=-.025
 C=-.02
 D=-.015
 E=-.01
 F=-.005
 G=0
 H=-.005
 I=-.01



HT7-47

ANSYS
4 / 1/85
14.5825
POST1
STEP=1
ITER=1
STRESS PLOT
SIZE
TOP
AUTO SCALING
XU=-3
YU=.4
ZU=.5
DIST=22.8
XF=33.7
YF=-15.4
ZF=13.1
AMCL=-120
HIDDEN
RX=120113
RY=466
D=20000
E=40000
F=60000
G=80000
H=100000
I=120000



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

FMC Corporation
Central Engineering Laboratories

APPENDIX HT7 - D1

INTEROFFICE

TO: C. Orloff DATE: March 27, 1985

FROM: Michael Coulter cc: E. Thuse
R. Kazares

SUBJECT: Lightweight Howitzer - Spade Analysis
Preliminary Stress Calculations (Static & Dynamic)
on All-Metal (Steel, Titanium) & FG/EP
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 4500 psi results from this loading. Deflection and stress contour plots are shown in Attachment E.

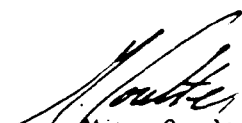
[REDACTED] [REDACTED]

HT7-45

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



HT7-50

APPENDIX HT7 - D3

TABLE 1

LOAD CASE SUMMARY

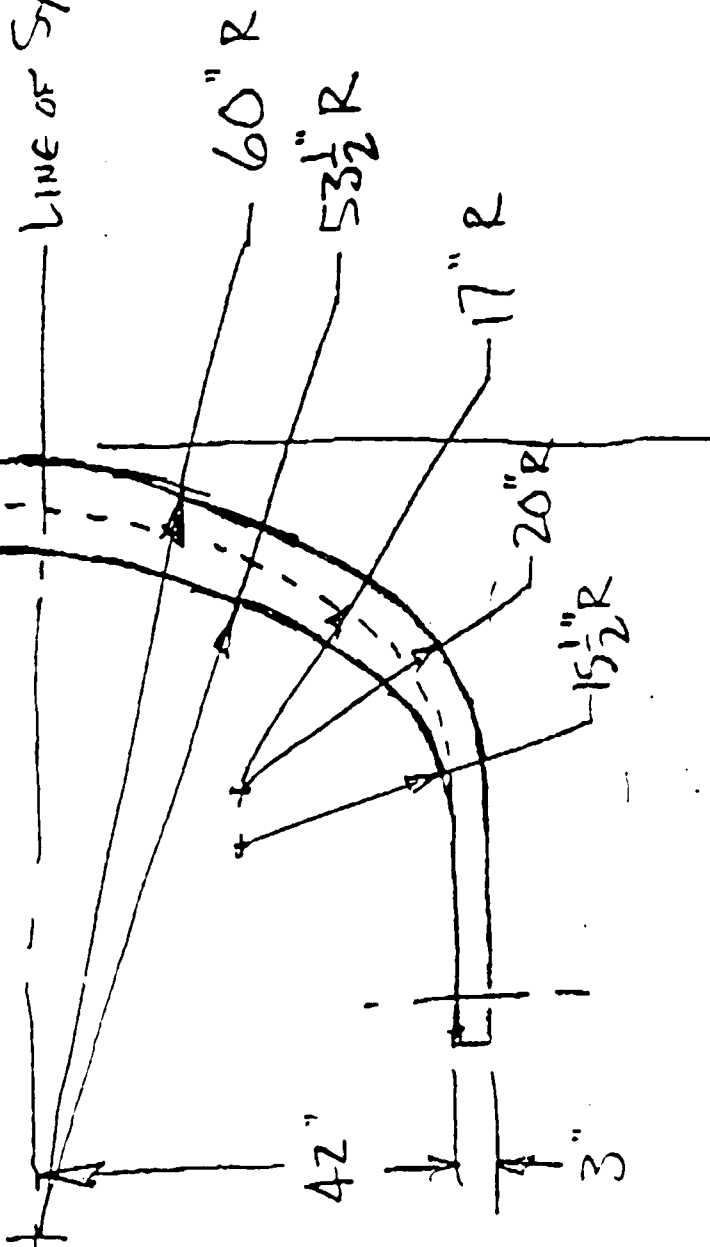
<u>MATERIAL</u>	<u>TOTAL WEIGHT</u>	<u>MAX. DEFLECTION</u>	<u>MAX STRESS ON PRESSURE SURFACE</u>
STEEL	2300 lb.	0.15 in.	8000 psi.
TITANIUM	1300 lb.	0.27 in.	8000 psi.
FIBERGLASS	800 lb.	1.25 in.	8000 psi.

MATERIAL PROPERTIES

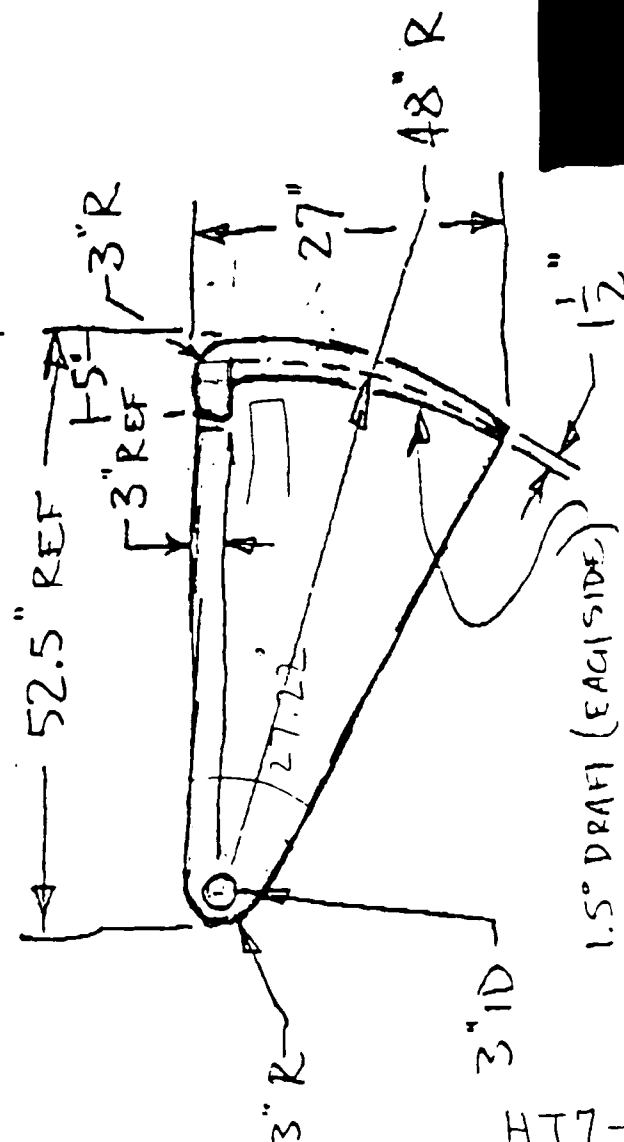
<u>MATERIAL</u>	<u>YOUNGS MODULUS</u>	<u>POISSON RATIO</u>	<u>DENSITY</u>
STEEL	$30 \times 10^6 \text{ lb/in}^2$	0.3	0.283 lb/in^3
TITANIUM	$17 \times 10^6 \text{ lb/in}^2$	0.33	0.161 lb/in^3
FIBERGLASS*	$5 \times 10^6 \text{ lb/in}^2$	0.20	0.10 lb/in^3

* $G_{XY} = G_{XZ} = G_{YZ} = 6 \times 10^5 \text{ lb/in}^2$

LINE OF SYMMETRY



SPADE
No REV



HT7-52

FIGURE 1

ANSYS
3/18/85
14.5400
PREP7 ELEMENTS
TNUM=1
TDBC=1
PRBC=1
AUTO SCALING
XU=-1
YU=1
ZU=1
DIST=35
XF=31.4
YF=-25.6
ZF=-10.7

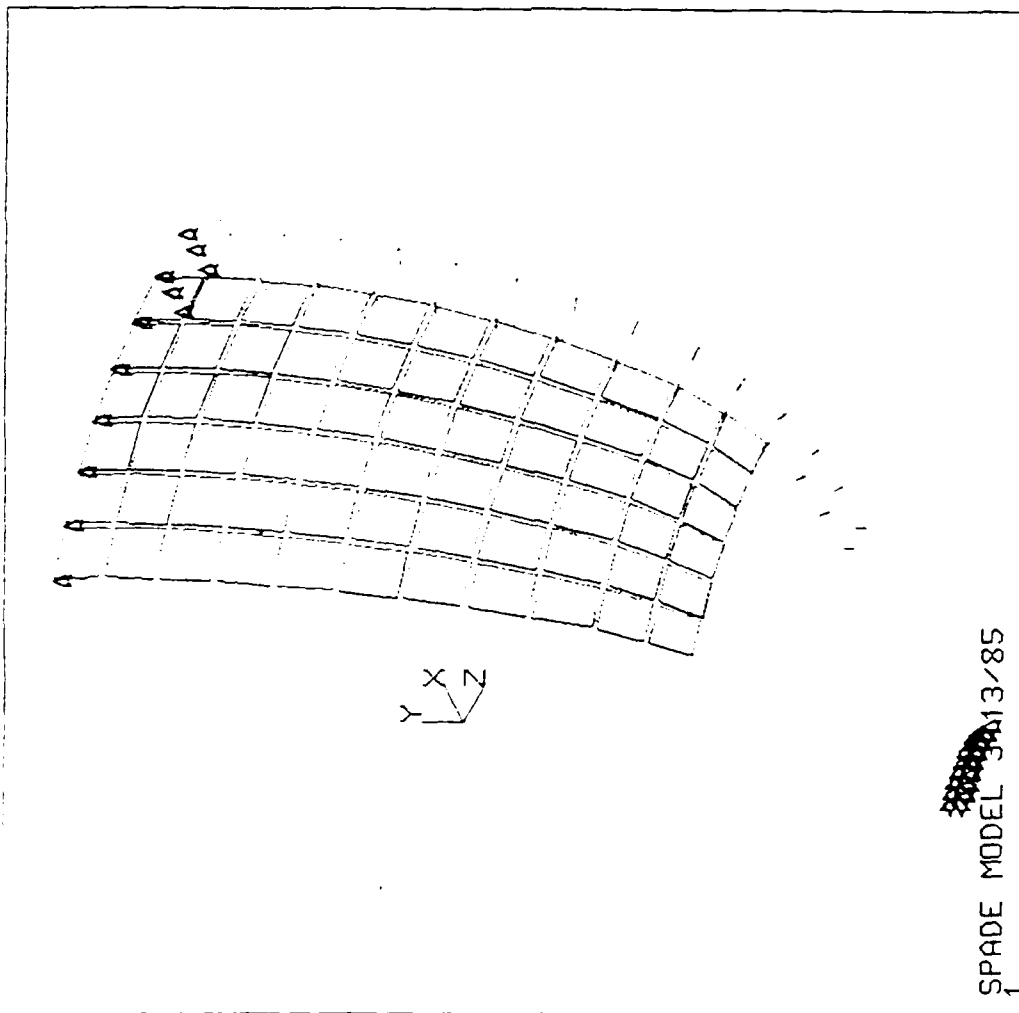
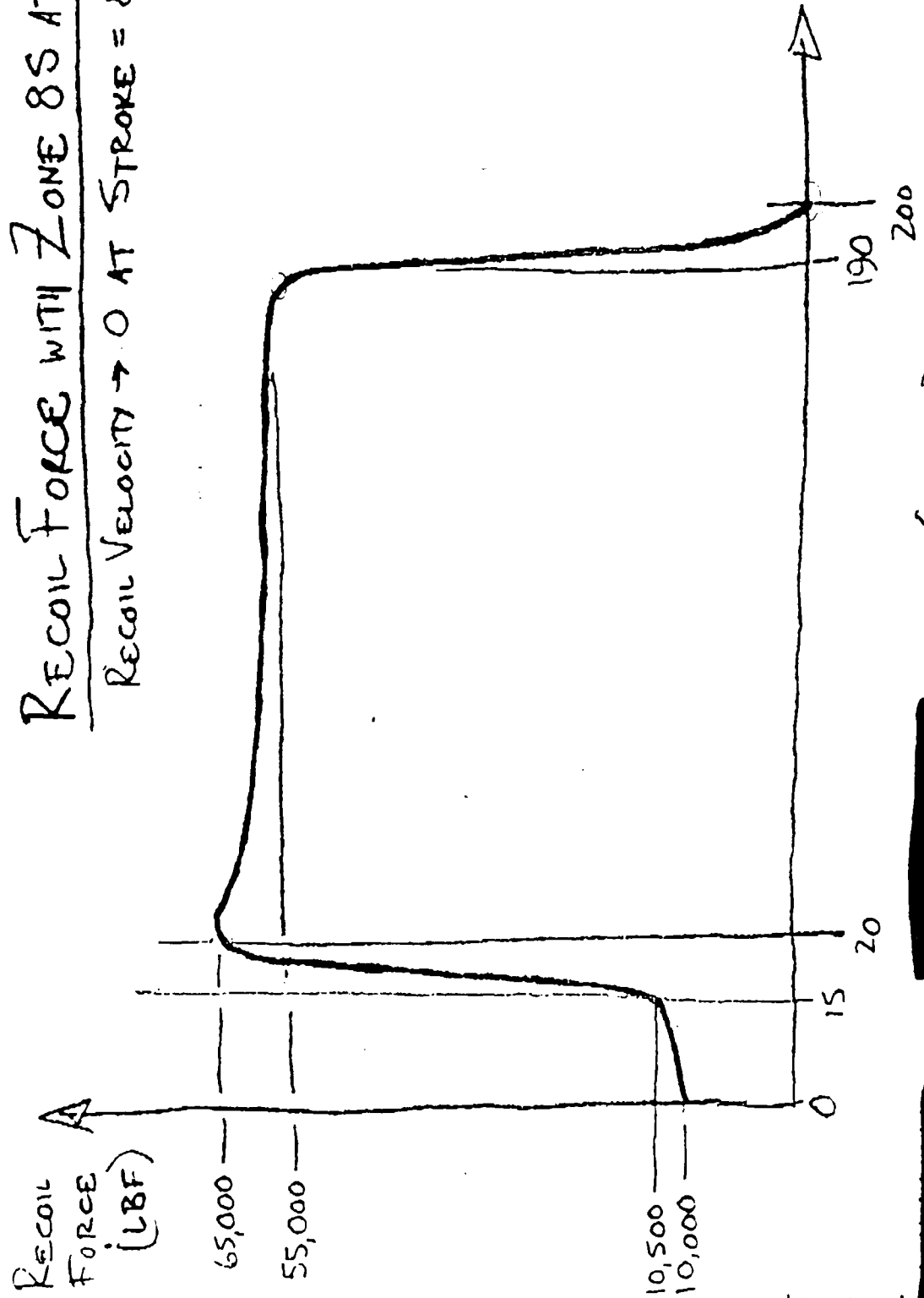


FIGURE 2
FINITE ELEMENT MODEL WITH PRESSURE LOAD & DISPLACEMENT CONSTRAINTS

RECOIL FORCE WITH ZONE 8S AT 15°
 Recoil Velocity $\rightarrow$ 0 AT STROKE = 84.5".



TIME (MSEC)

FIGURE 3

HT7-54

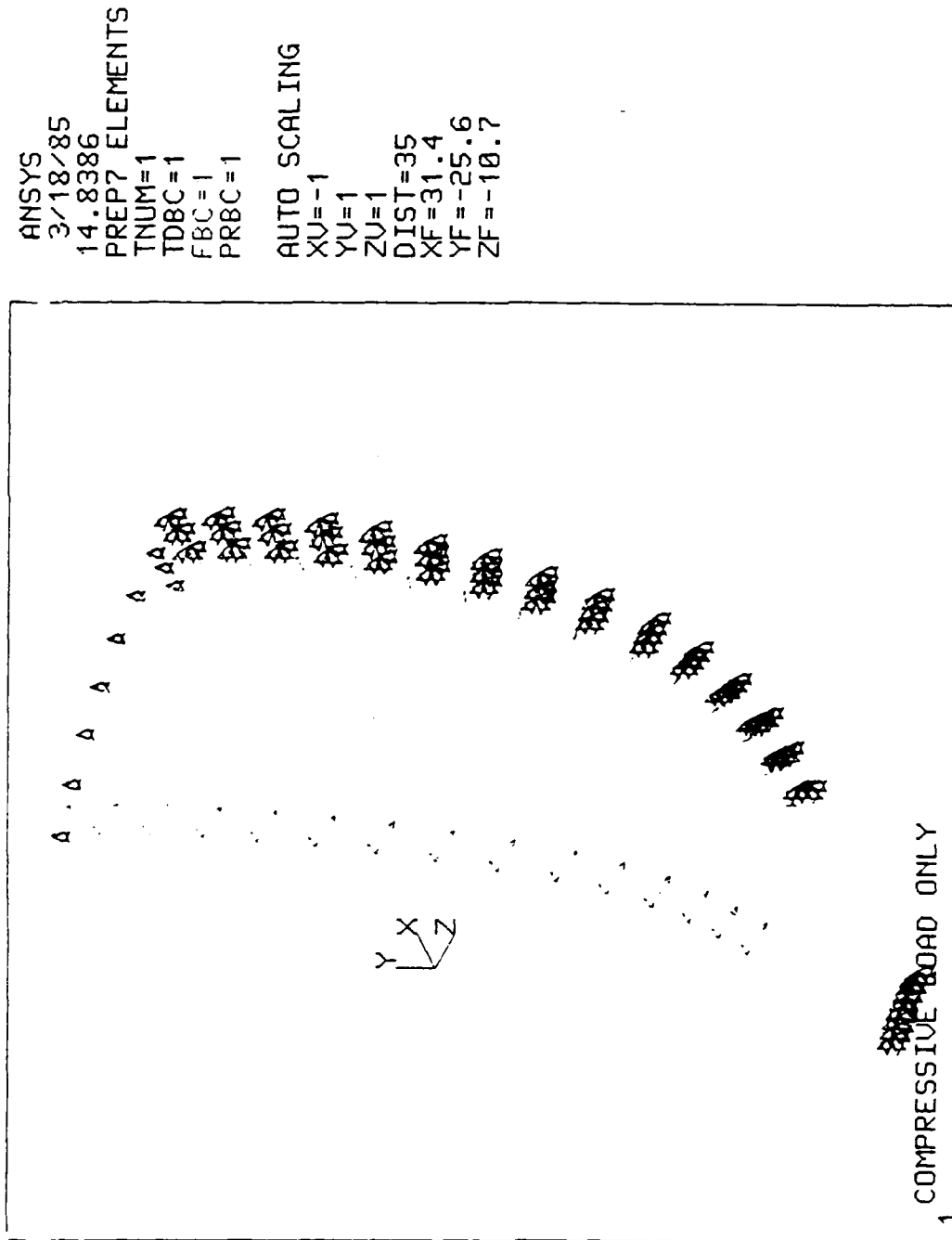


FIGURE 4
DESCRIPTION OF COMPRESSIVE LOAD CASE

APPENDIX HT7 - D8

ATTACHMENT A

Displacement and Stress Contour Plots - Steel Spade

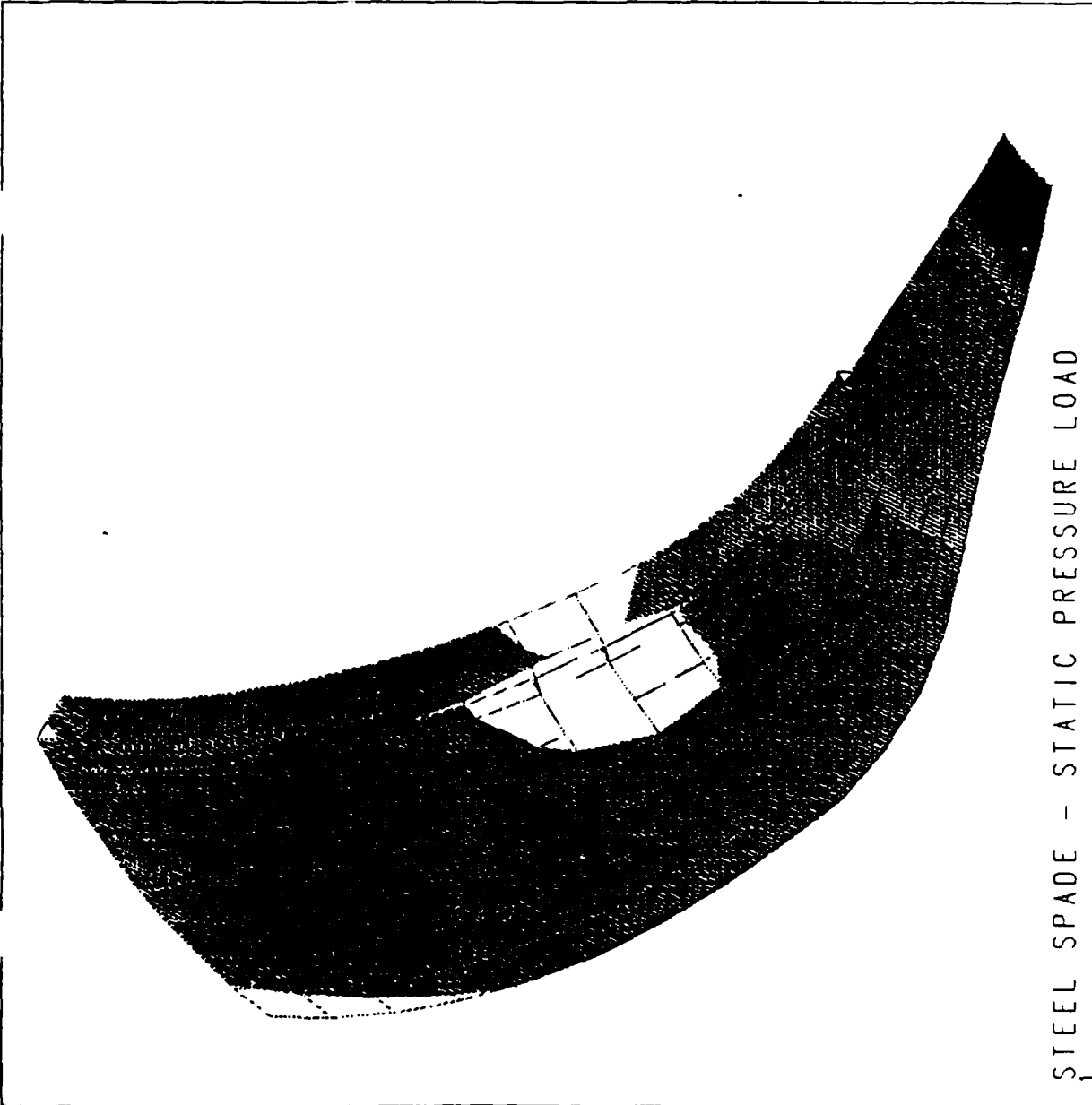


```

ANSYS
3/28/85
8.3764
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=25945
MN=322

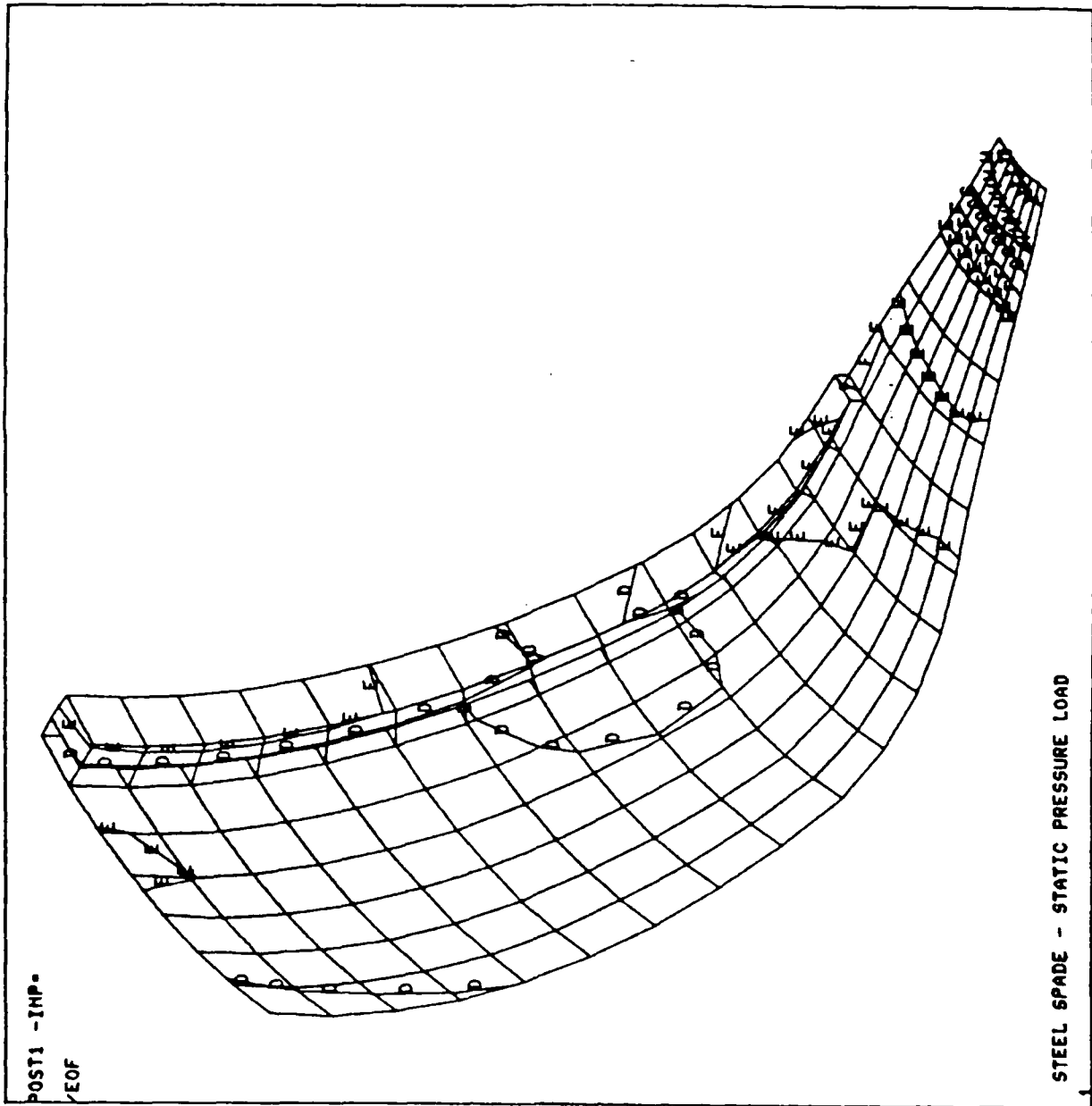
5000
10000
15000
20000
24000
28000
    
```



HT7-57

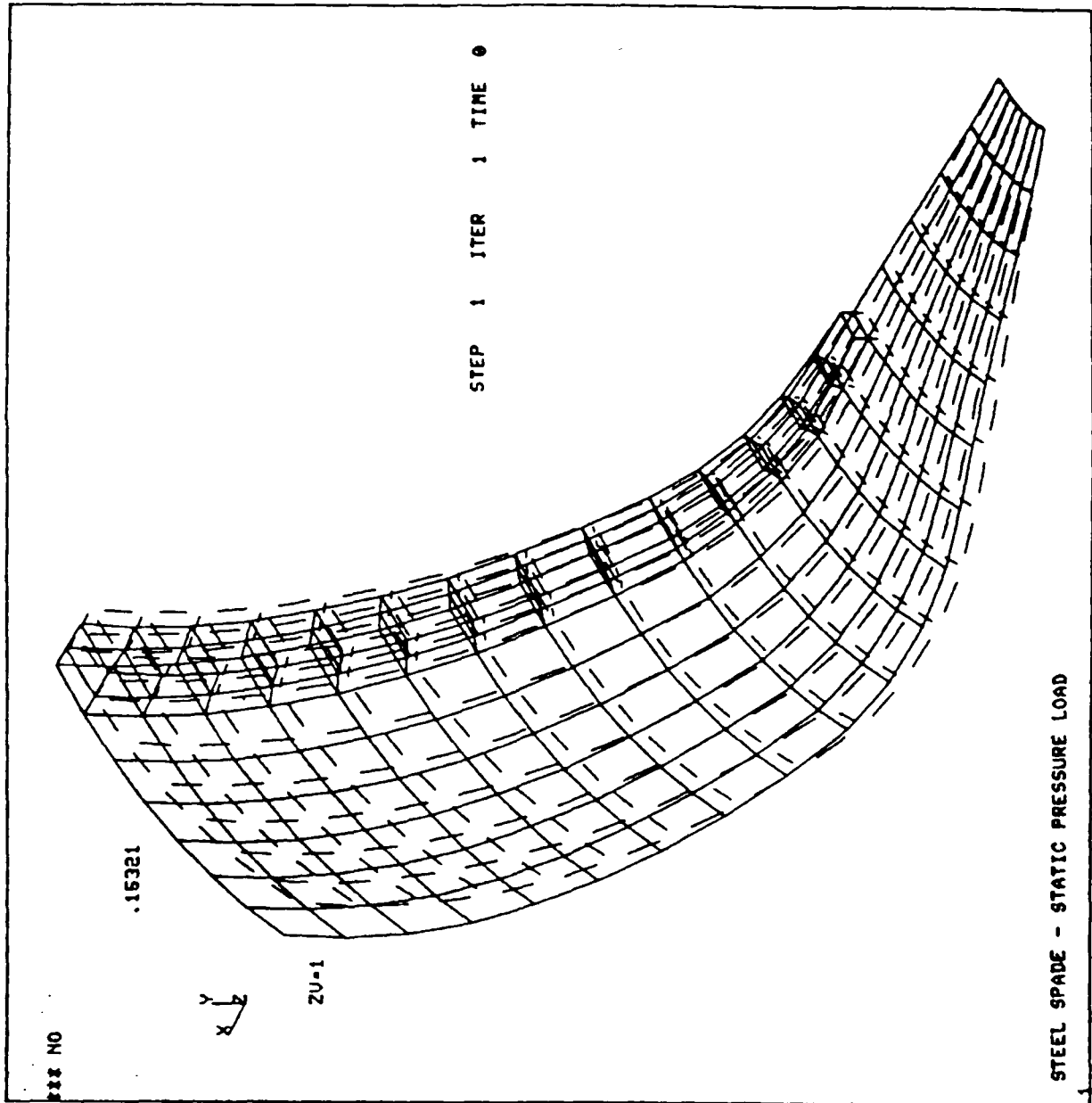
APPENDIX HT7 - D10

ANSYS
3/28/86
8.0558
POST1
STEP=1
ITER=1
STRESS PLOT
SIGE
TOP
AUTO SCALING
XU=-1
VU=1
ZU=-1
DIST=31.8
XF=28.3
YF=-22.5
ZF=-6.26
HIDDEN
MX=25945
MN=322
D=4000
E=8000
F=12000
G=16000
H=20000
I=24000



APPENDIX HT7 - D11

ANSYS
3/28/85
8.1041
C
POST22
DISPLACEMENT
AUTO SCALING
XU=-1
YU=-1
ZU=-1
DIST=5.42
XF=4.84
YF=5.57
ZF=2.55



APPENDIX HT7 - D12

ATTACHMENT B

Displacement and Stress Contour Plots - Titanium Spade



HT7-6c

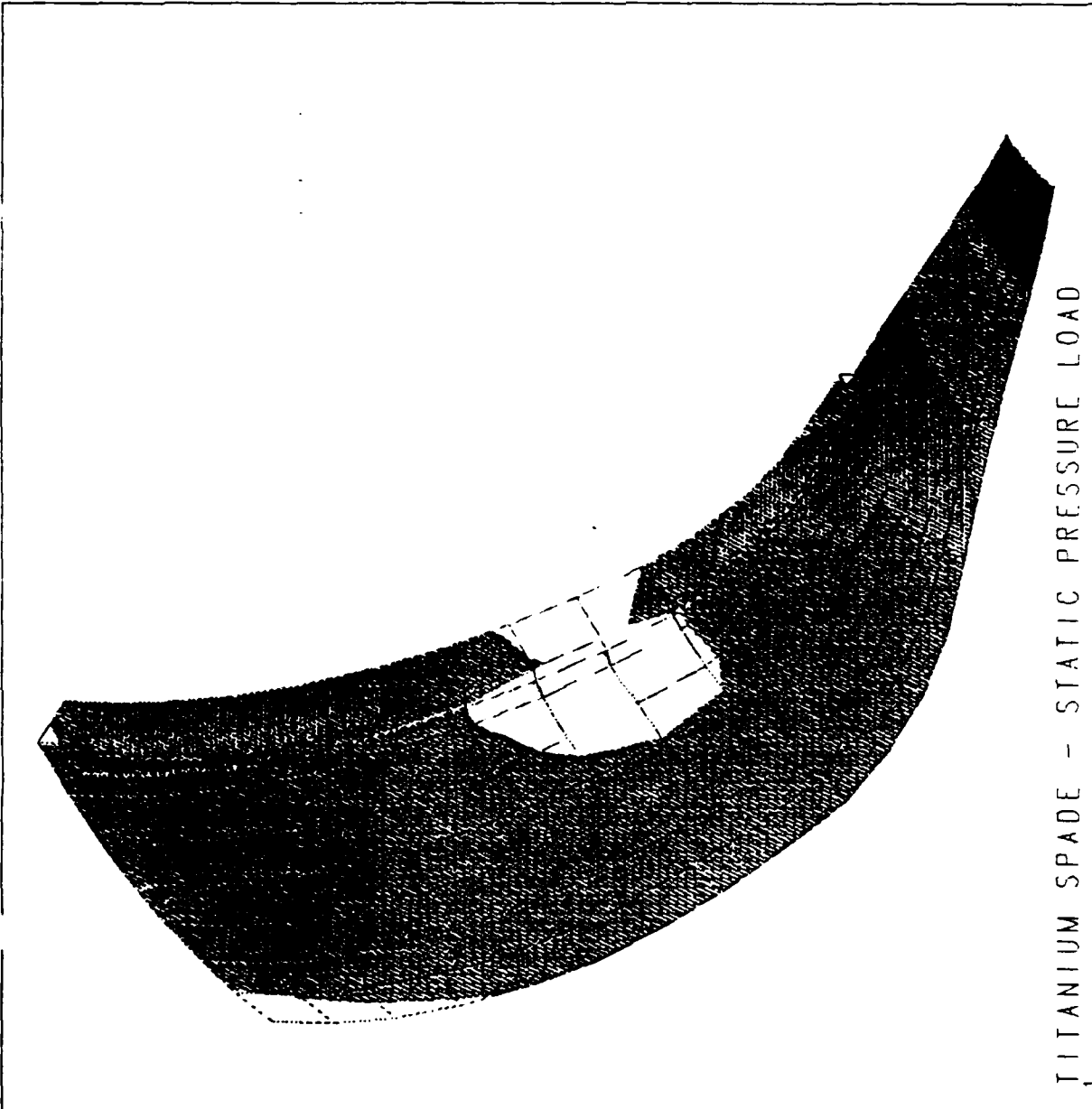
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ANSYS
3/28/85
8.5543
POST1
STEP=1
ITER=1
STRESS PLOT
SICE
TOP

AUTO SCALING
XV=-1
YV=1
ZV=-1
DIST=31.8
XF=28.3
YF=-22.5
ZF=-6.26
HIDDEN
MX=26127
MN=305

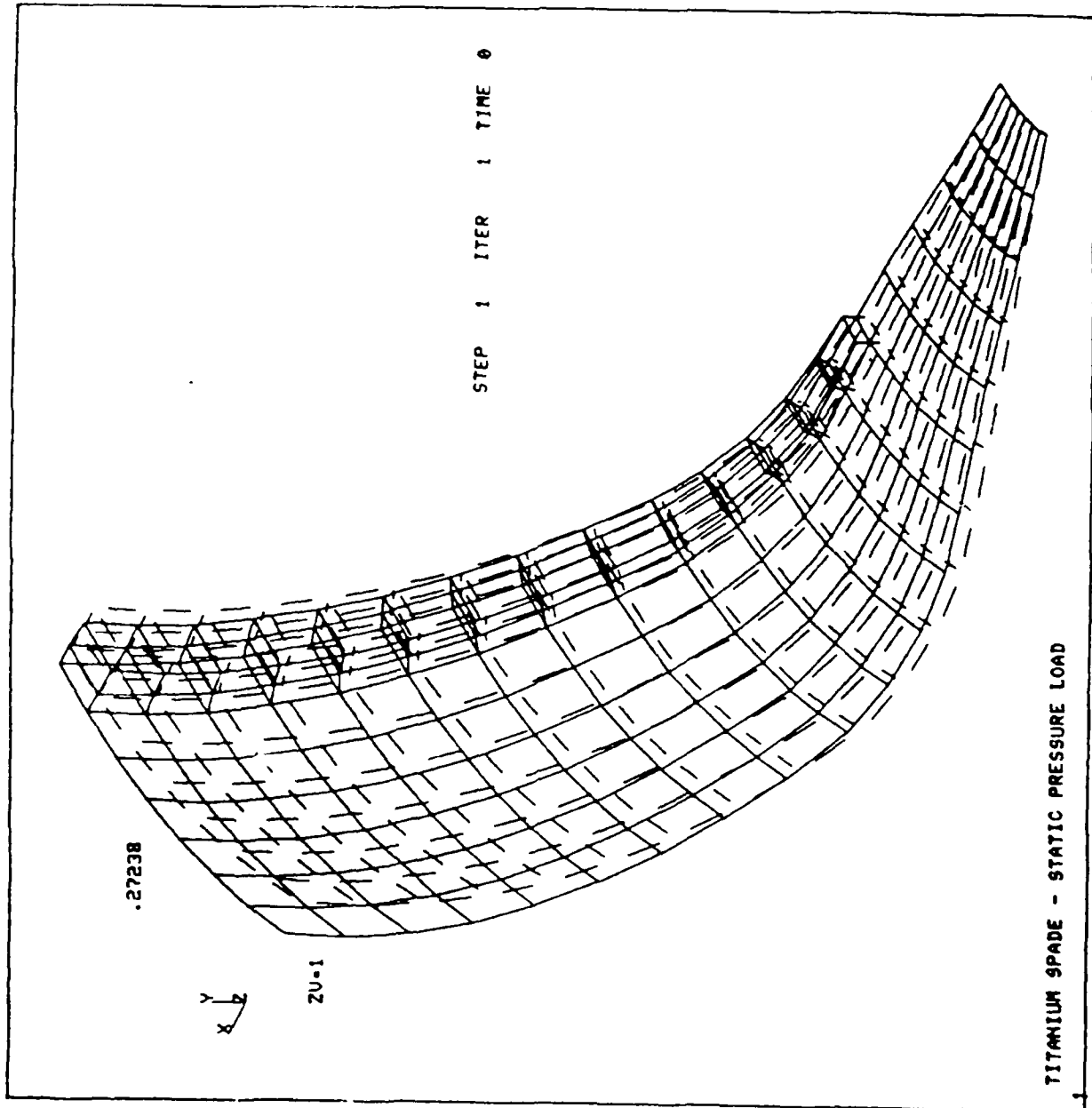
3100
3000
2000
24000
28000

```



APPENDIX HT7 - D14

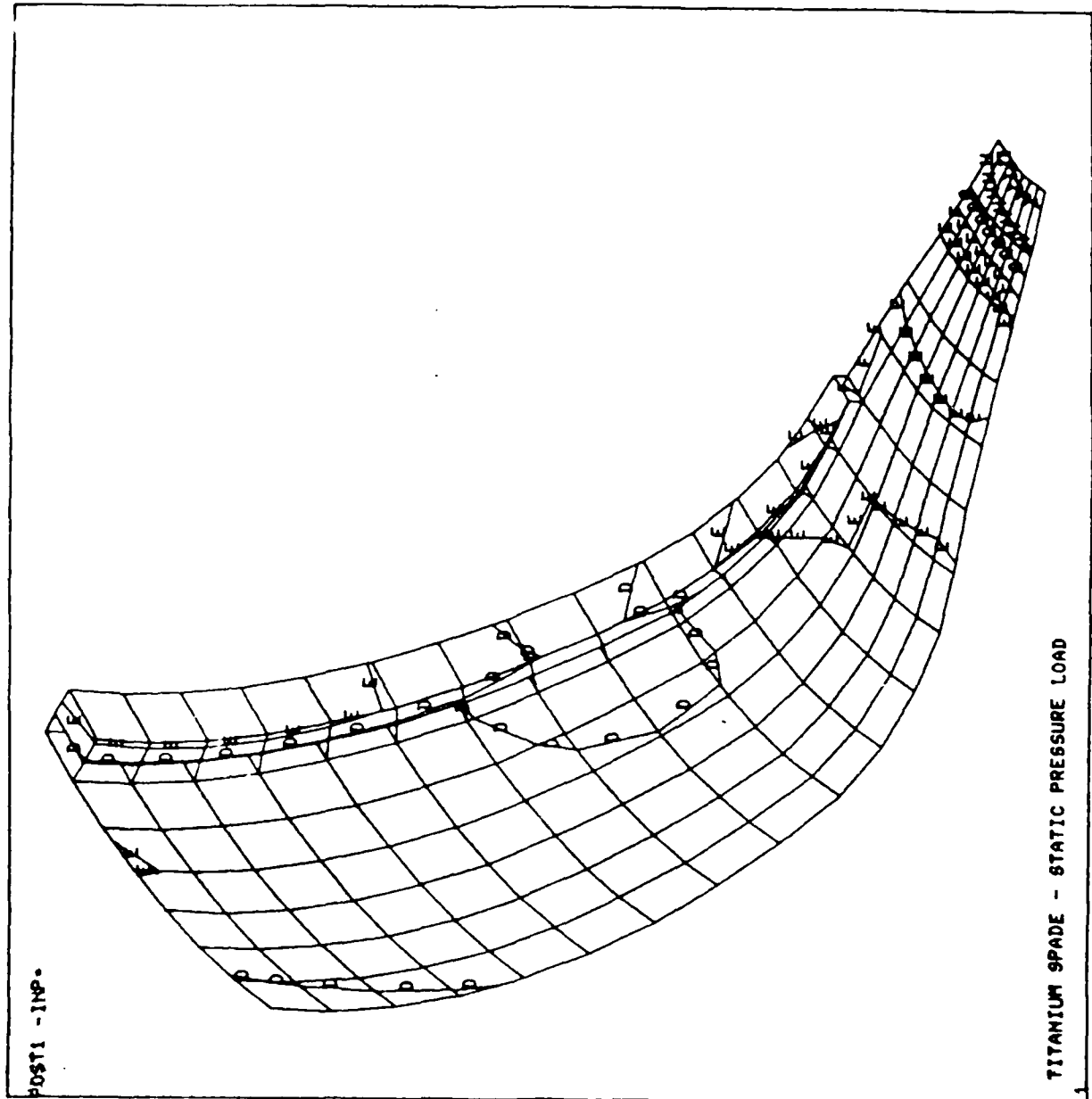
ANSYS
3/28/85
8.1520
C
POST22
DISPLACEMENT
AUTO SCALING
XU=-1
YU=-1
ZU=-1
DIST=5.42
XF=4.84



HT7-62

APPENDIX HT7 - D15

ANSYS
3/28/85
8.1372
POST1
STEP=1
ITER=1
STRESS PLOT
SIGE
TOP
AUTO SCALING
XU=-1
YU=-1
ZU=-1
DIST=31.8
XF=28.3
YF=-22.5
ZF=-6.26
HIDDEN
MM=305
MX=26127
D=4000
E=8000
F=12000
G=16000
H=20000
I=24000



HT7-63

APPENDIX HT7 - D16

ATTACHMENT C

Displacement and Stress Contour Plots - Fiberglass Spade



HT7-64

APPENDIX HT7 - D17

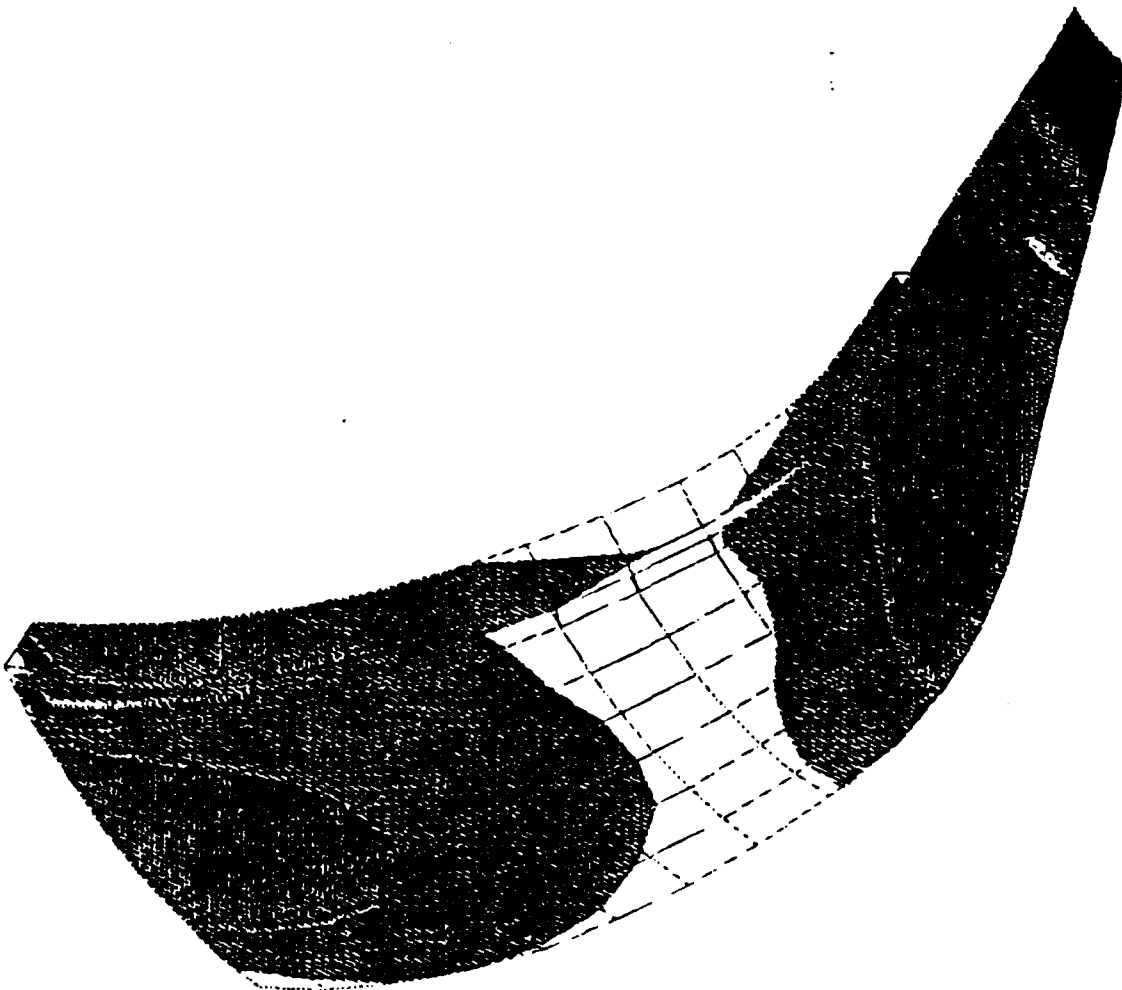
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ANSYS
3/28/85
11.1023
POST1
STEP=1
ITER=1
STRESS PLOT
SICE
TOP

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

      0.000
      1.000
      1.000
      2.000
      2.000
      2.000

```



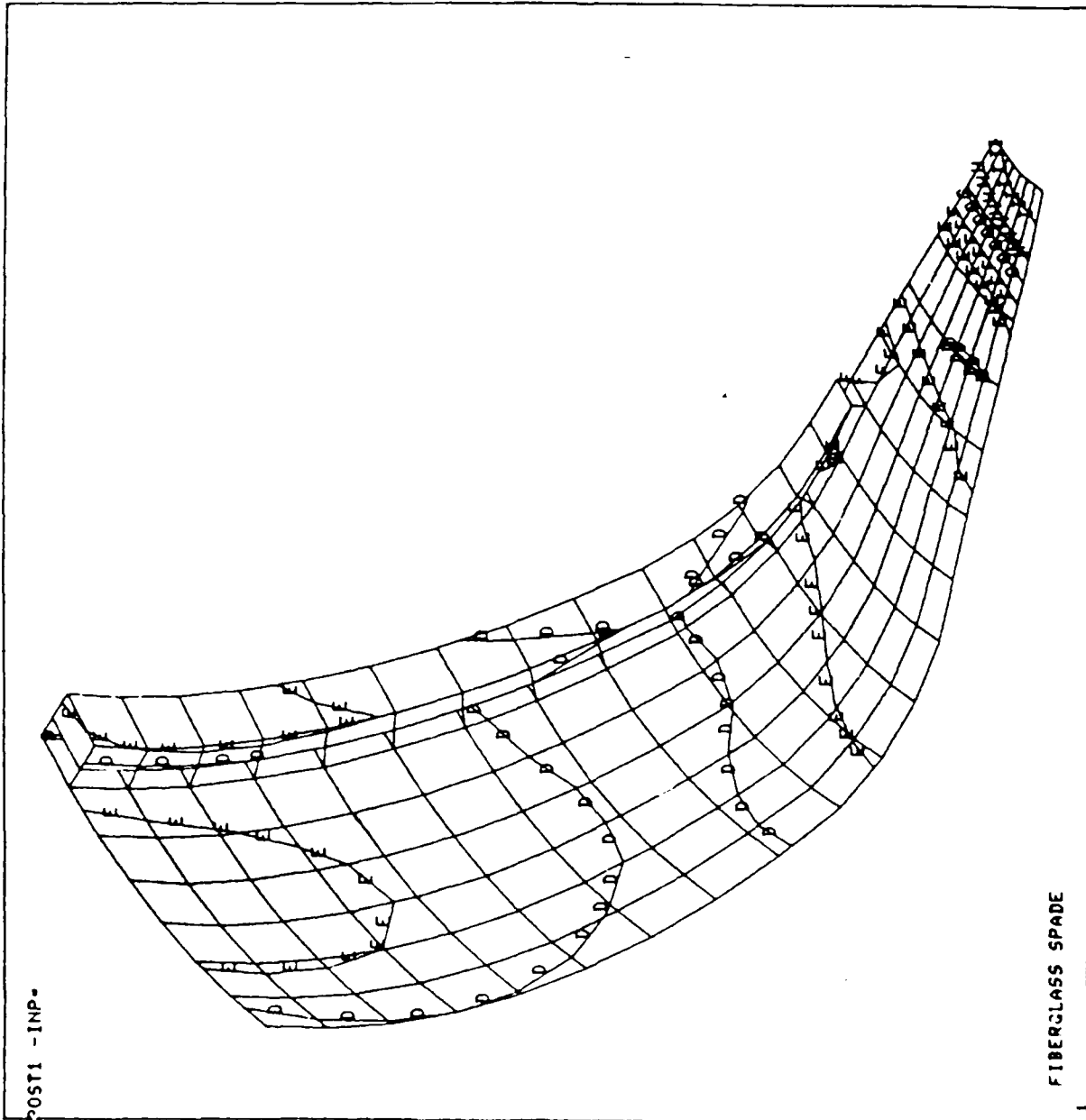
FIBERGLASS SPADE

HT7-65

APPENDIX HT7 - D18

ANSYS
3/28/85
10.9977
POST1
STEP=1
ITER=1
STRESS PLOT
SIGE
TOP

AUTO SCALING
XU=1
YU=1
ZU=1
DIST=31.8
XF=28.3
YF=-22.5
ZF=-6.26
HIDDEN
MX=27388
MY=1243
D=4000
E=8000
F=12000
G=16000
H=20000
I=24000



AD-A183 983

LIGHTWEIGHT TOWED HOWITZER DEMONSTRATOR PHASE 1 AND
PARTIAL PHASE 2 VOLUM (U) FNC CORP MINNEAPOLIS MINN
NORTHERN ORDNANCE DIV R RATHE ET AL APR 87

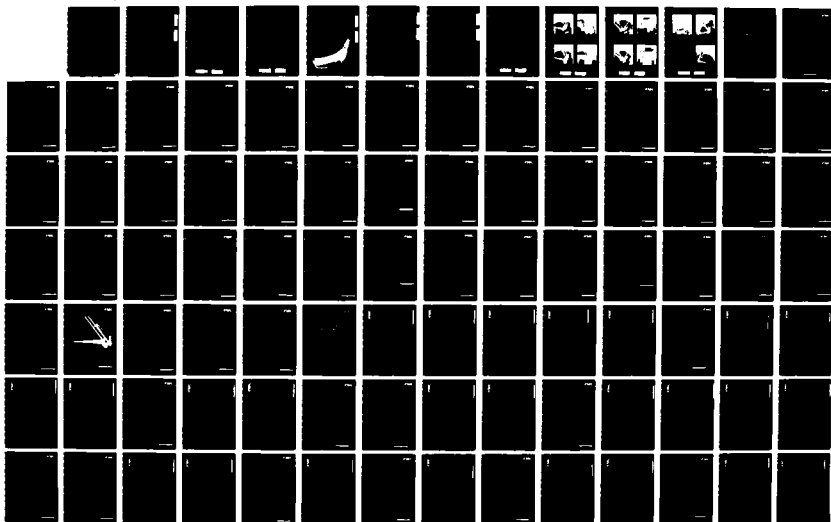
374

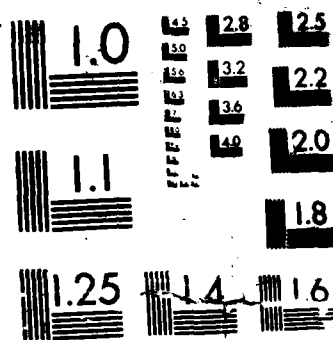
UNCLASSIFIED

FNC-E-3841-VOL-B-PT-1 DAAA21-86-C-0047

F/G 19/6

NL

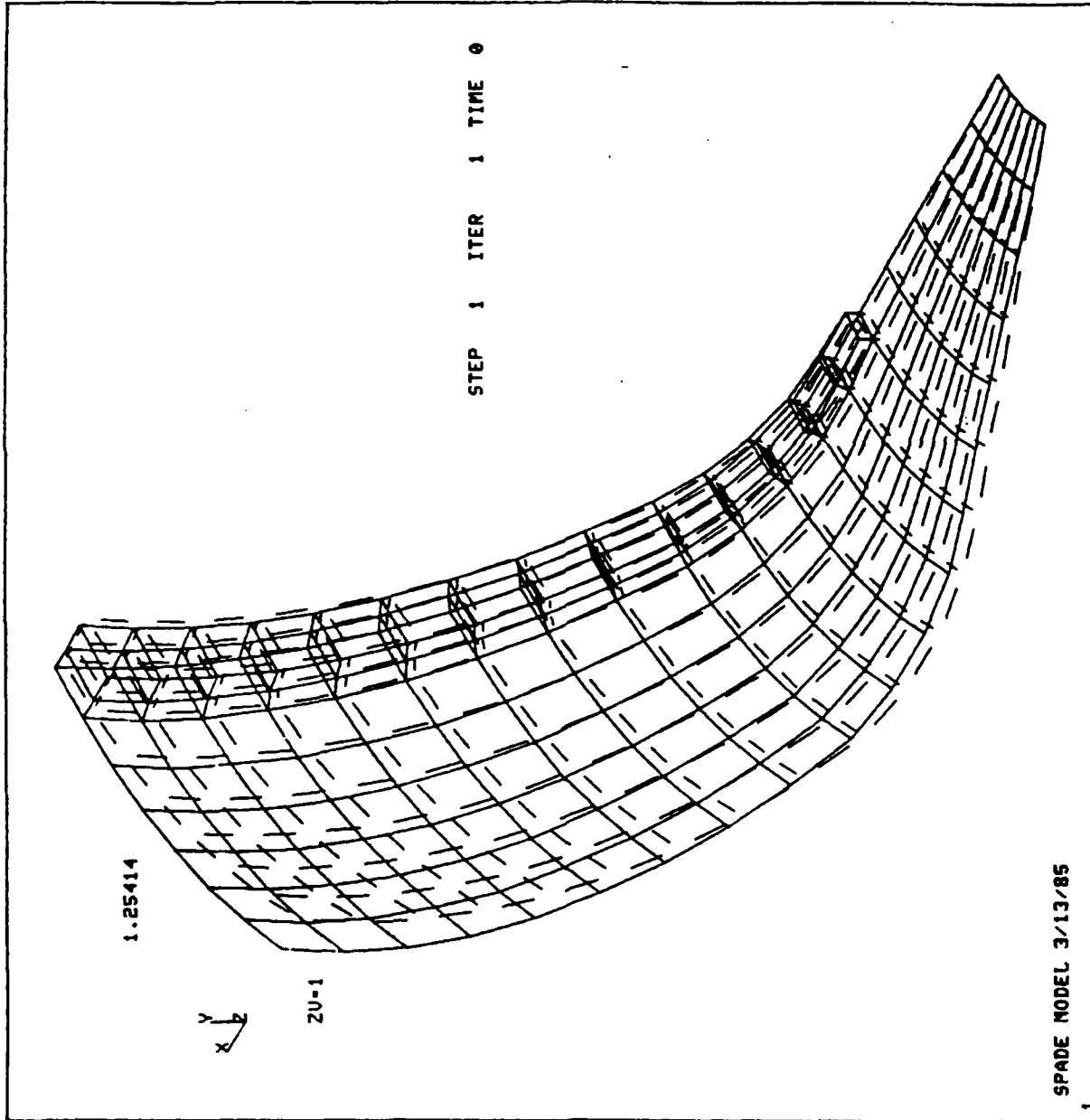




MICROCOPY RESOLUTION TEST CHART

APPENDIX HT7 - D19

ANSYS
3/28/85
11.0170
C
POST22
DISPLACEMENT
AUTO SCALING
XU=-1
YU=1
ZU=-1
DIST=5.41



HT7-67

APPENDIX HT7 - D20

ATTACHMENT D

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



APPENDIX HT7 - D21

ATTACHMENT E

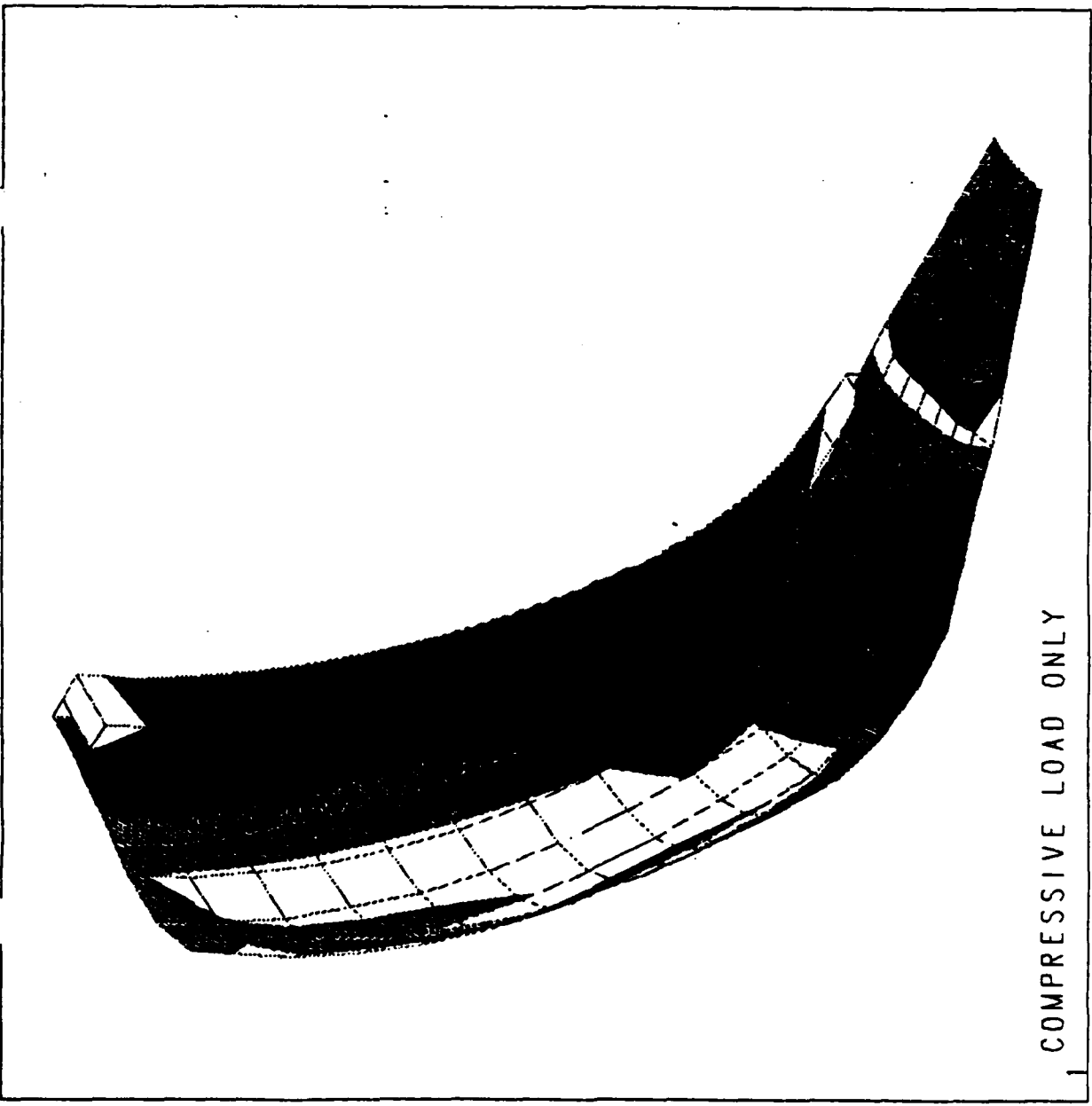
Displacement and Stress Contour Plots - Steel Spade
Compressive Load Case Results



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

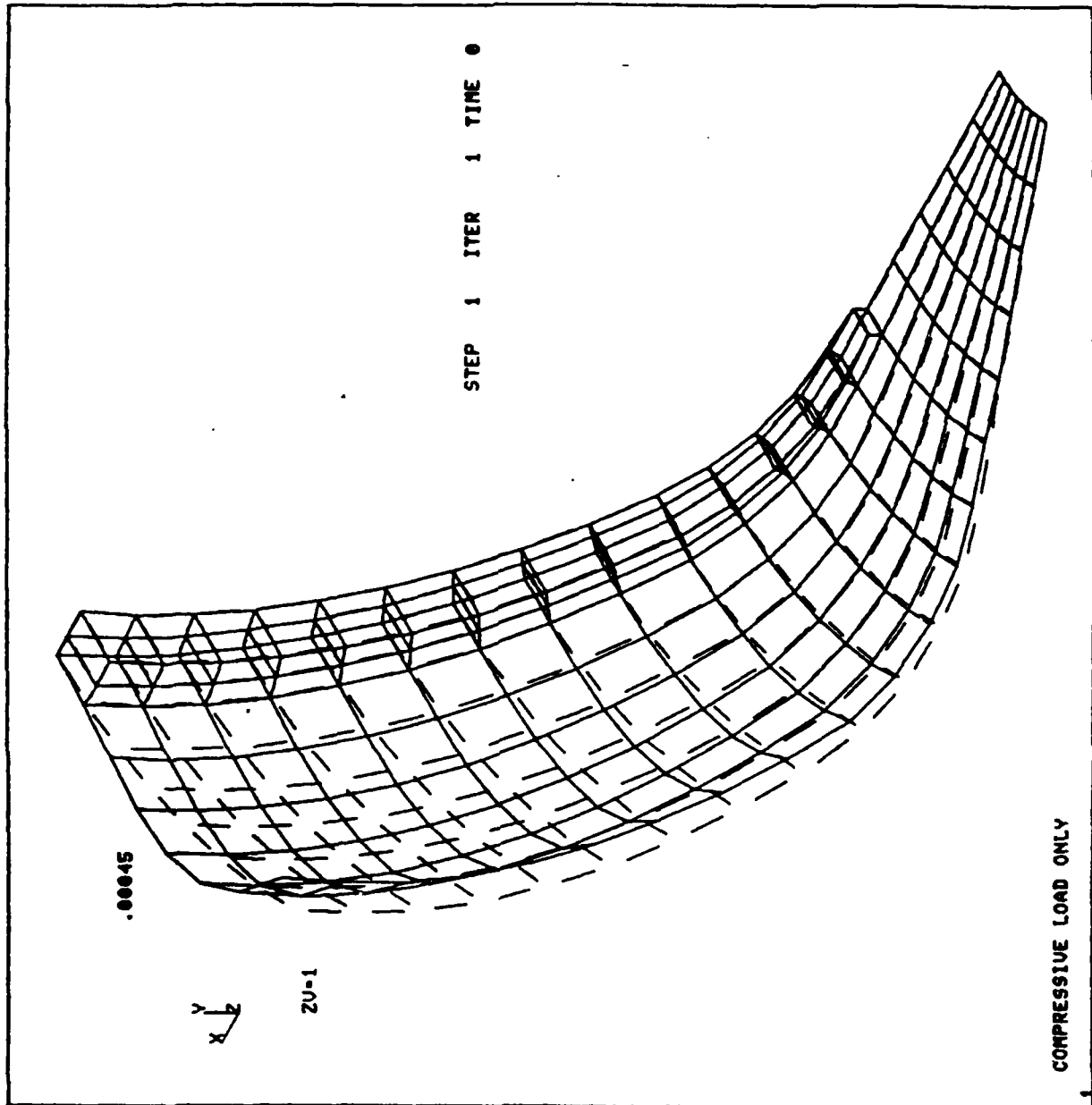
100
200
250
300
350
400
450



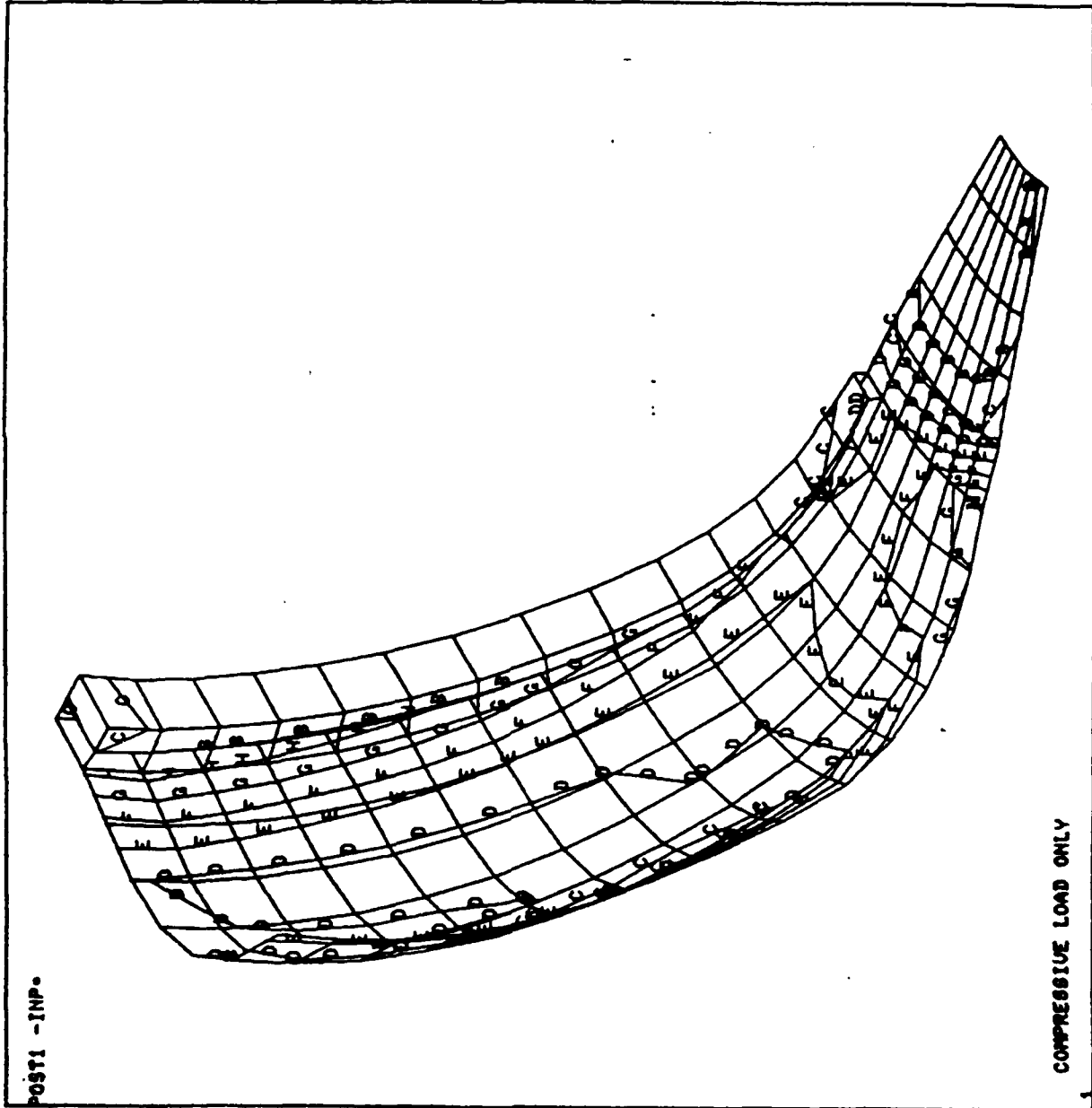
COMPRESSIVE LOAD ONLY

APPENDIX HT7 - D23

ANSYS
3/28/85
8.2836
C
POST22
DISPLACEMENT
AUTO SCALING
XU--1
YU--1
ZU--1



ANSYS
3/28/86
8.2675
POST1
STEP=1
ITER=1
STRESS PLOT
SIZE
TOP
AUTO SCALING
XU=-1
YU=1
ZU=-1
DIST=31.8
XF=28.3
VF=22.5
ZF=-6.26
HIDDEN
MX=437
MY=7.92
B=50
C=100
D=150
E=200
F=250
G=300
H=350
I=400



Negotiation Issues

FMC

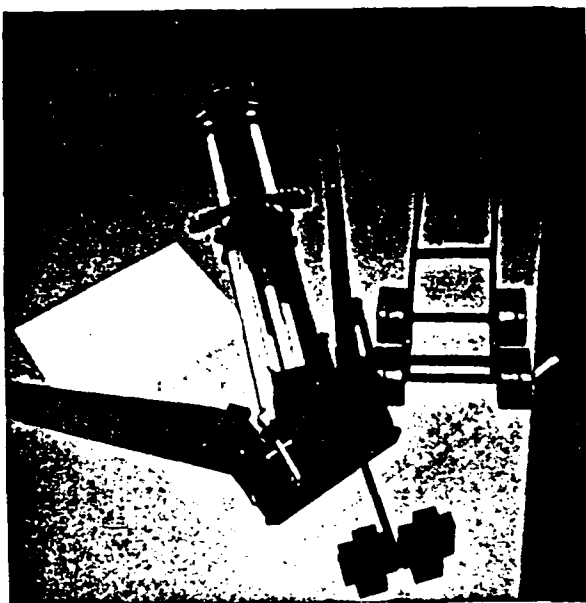
155MM LIGHTWEIGHT HOWITZER DEMONSTRATOR

Technical Issues:

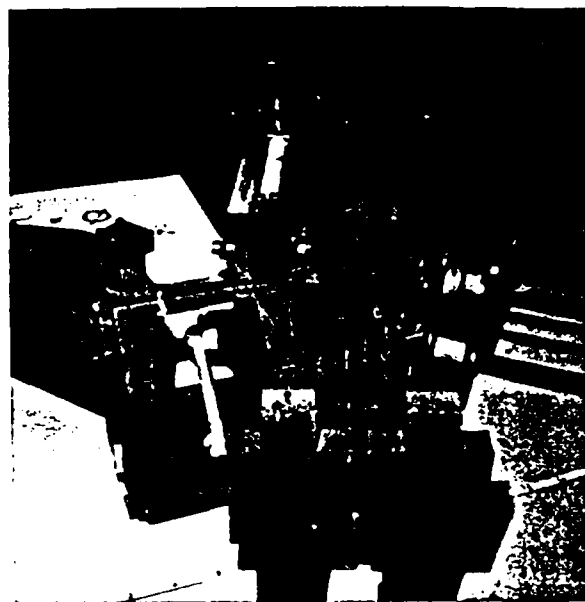
Issue 8. Provide additional detail to illustrate the operation of key subsystems; i.e., traverse mechanism operation and load tray interference at various traverse positions.

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.

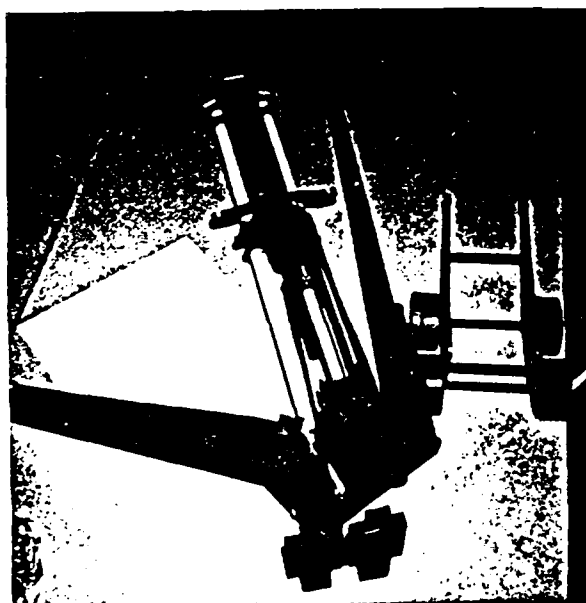
HT8-1



Loading



Loading Close-Up



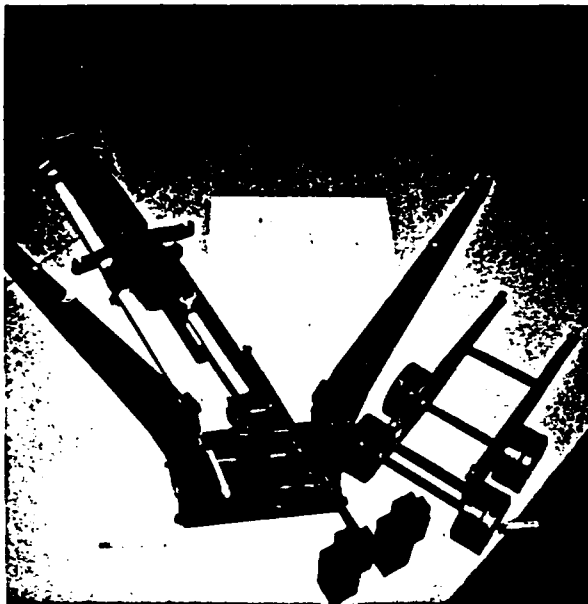
Ramming



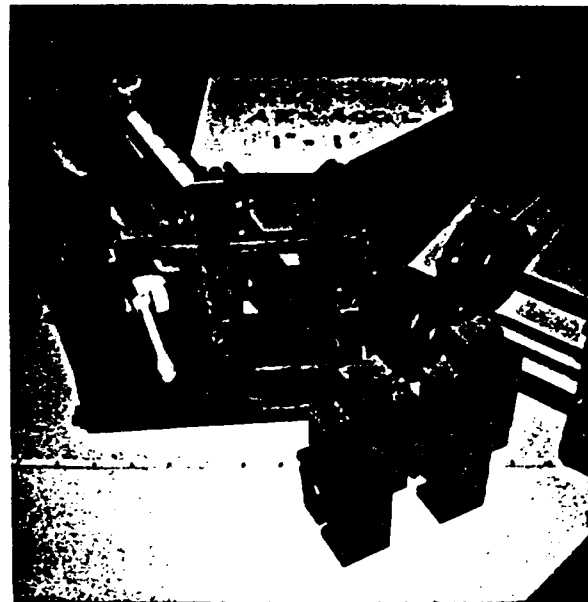
Ramming Close-Up

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

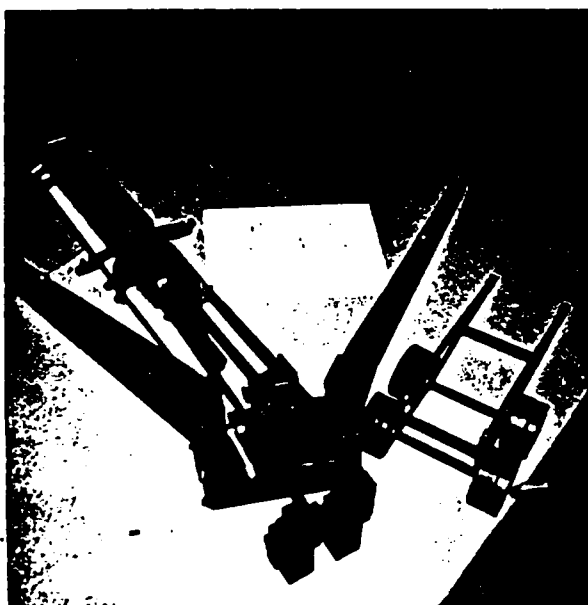
HT8-2



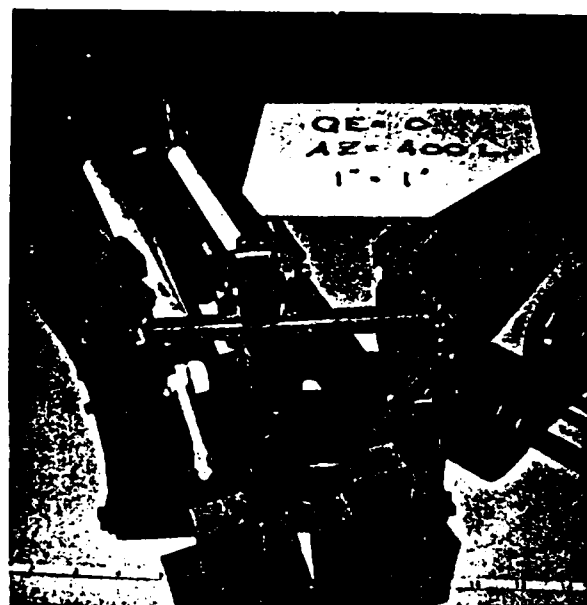
Loading



Loading Close-Up



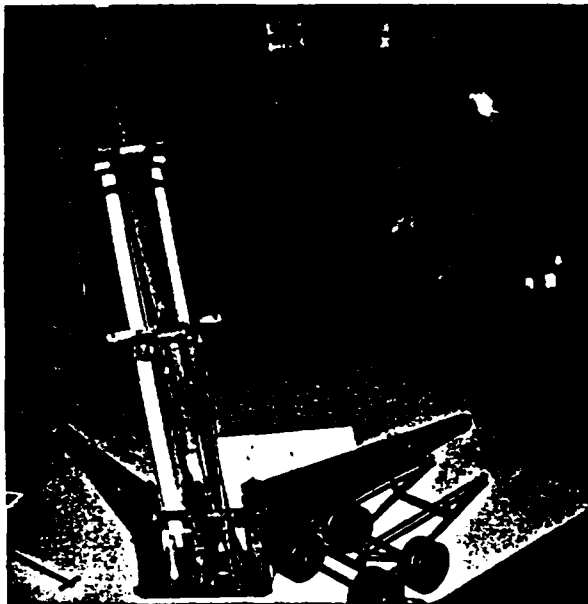
Ramming



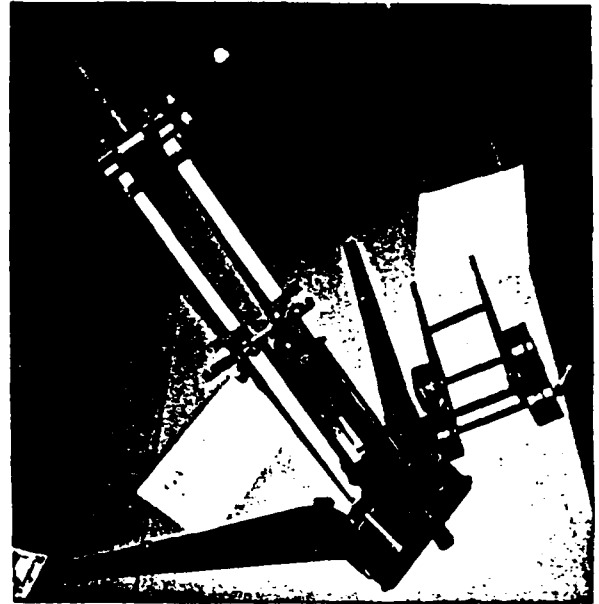
Ramming Close-Up

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

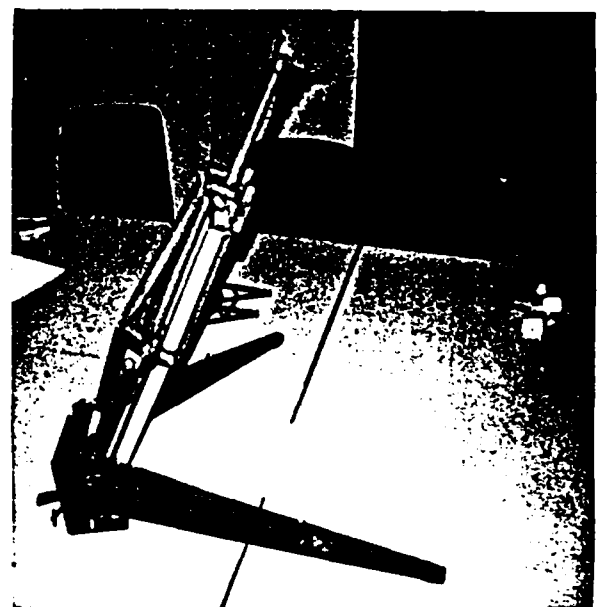
HT8-3



400 Mils Left



400 Mils Right



Side View

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

HT8-4

B/300

04 MAR 86

TECHNICAL
PRESENTATION
PHASE I

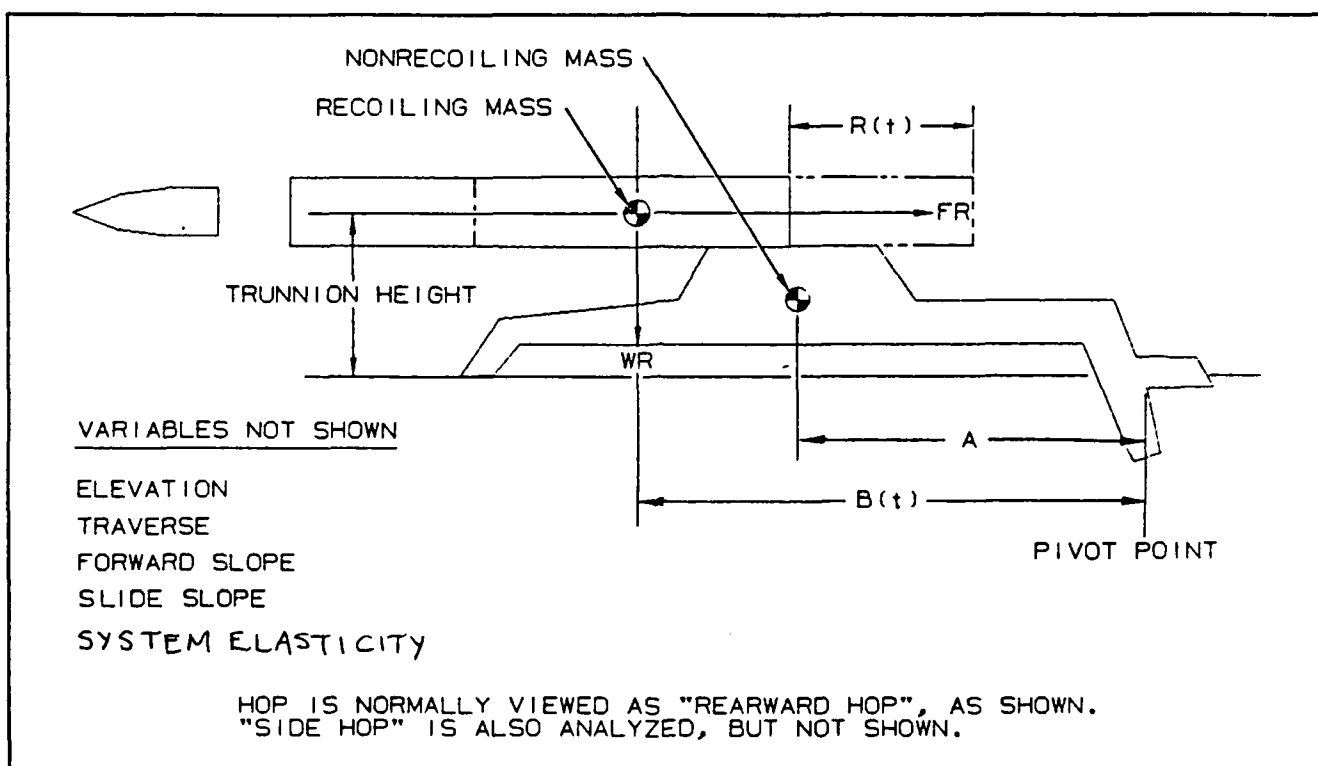
FMC LTHD DESIGN REVIEW

4 MARCH 1986

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THE WEIGHT-STABILITY RELATIONSHIP



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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 SUBSYSTEM 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 INSTEAD 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 CLOSSES, 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

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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)

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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

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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)

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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 Do
What will Do.

LTHD

ANALYSIS AND DESIGN

1. BALLISTICS

BL
Worst case
Zone 1

2. FIRING STABILITY

Recoil

R.C. Design

Chce.

3. TOWING STABILITY

St

Dyn.

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SD

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BALLISTICS

- . BARREL LENGTH
- . ZONE 8S
- . ZONE 1

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LTHD BARREL LENGTH TO MAINTAIN M198 RANGE

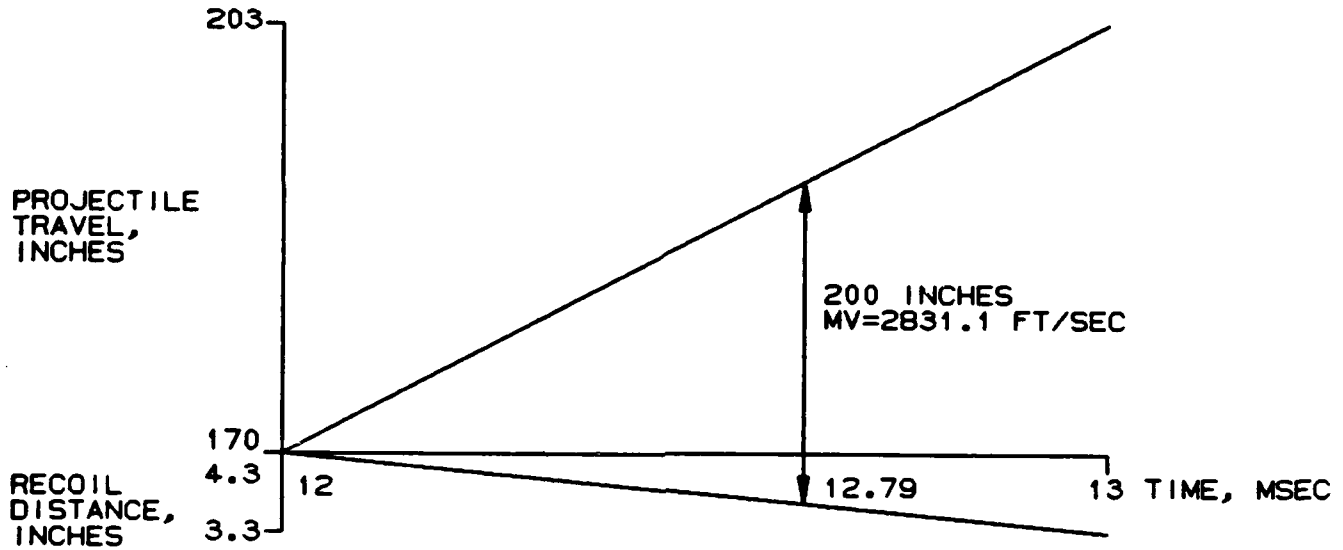
	M198 ----	LTHD ----
RECOIL COMPONENT WEIGHT, LBS	7258	4611
RECOIL COMPONENT MASS, SLUGS	225	143
TIME PROJECTILE IS IN BARREL, MILLISECONDS	12.79	12.74
MUZZLE VELOCITY WITH RESPECT TO GROUND, FT/SEC	2831.1	2825.6
RANGE, METERS	24309	25252

LTHD BARREL LENGTH = M198 BARREL LENGTH + 1.8 INCHES

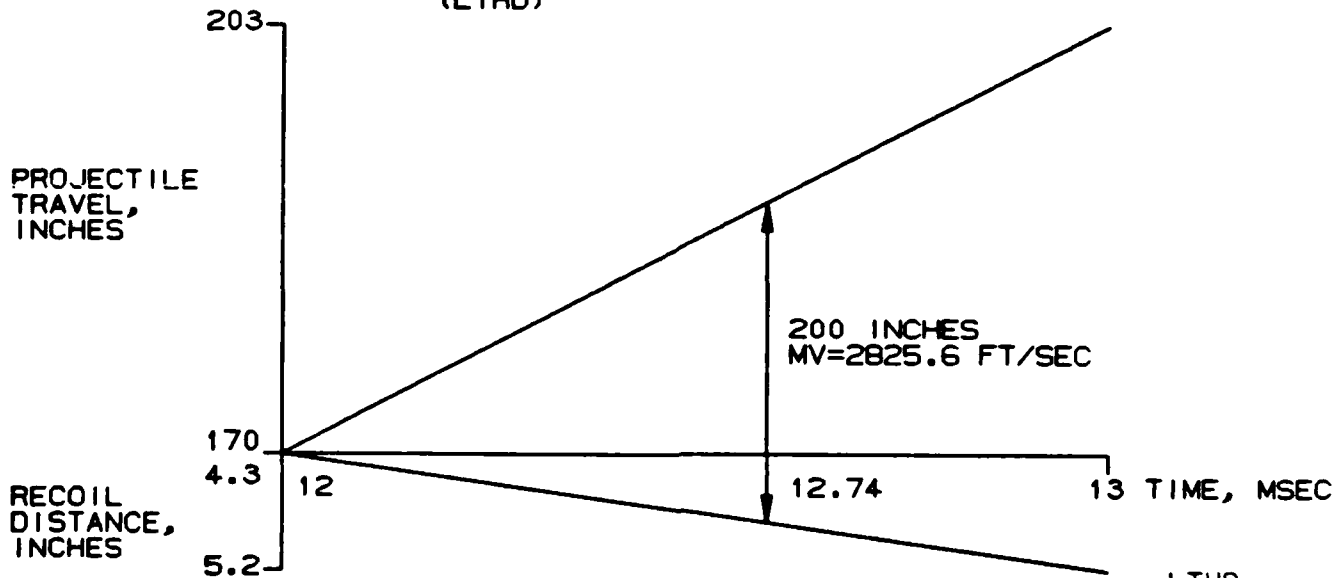
LTHD
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RECOILING MASS=225 SLUGS (7258 LBS)
(M198)



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



LTHD

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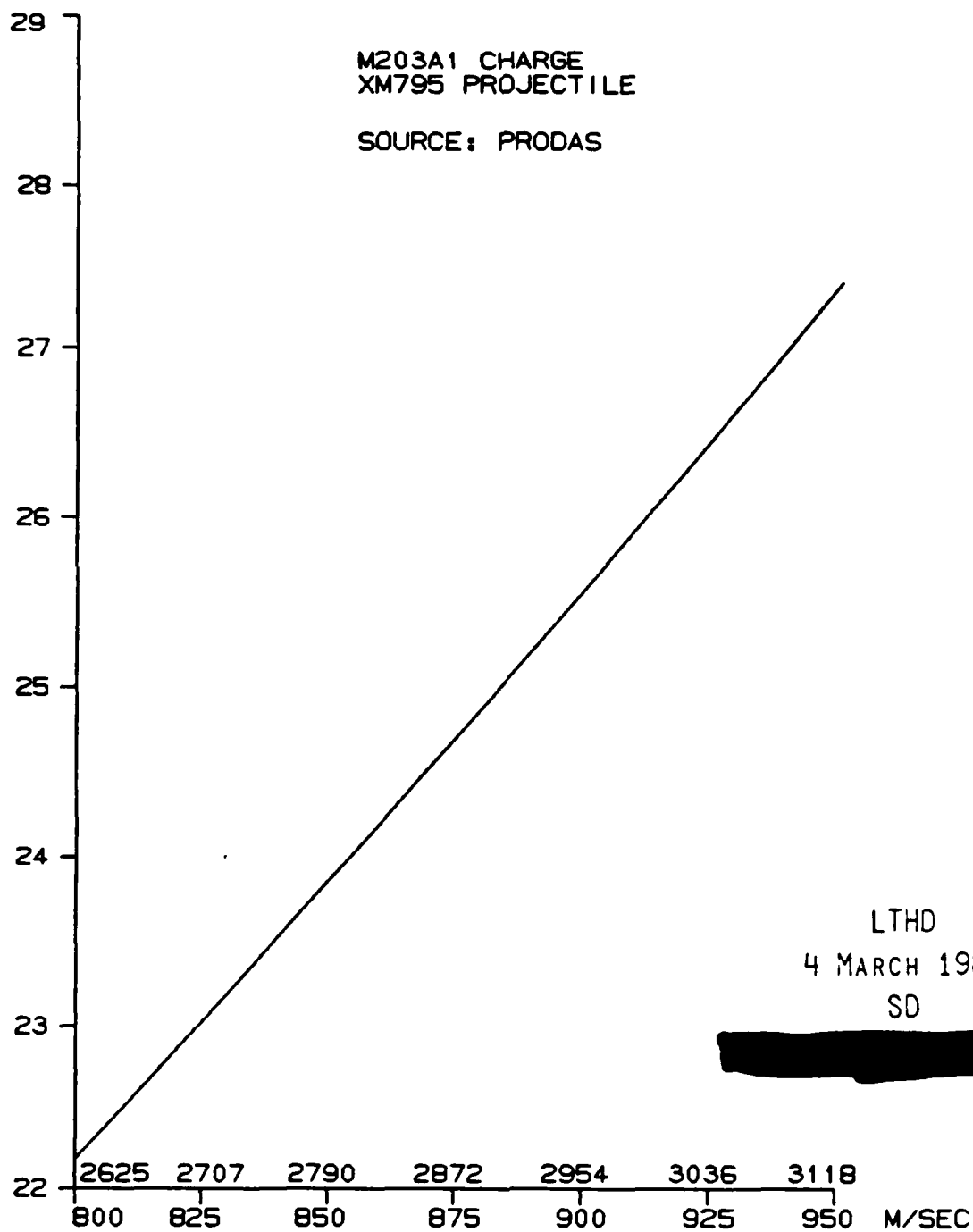
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MUZZLE VELOCITY VS RANGE

M203A1 CHARGE
XM795 PROJECTILE

SOURCE: PRODAS



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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)

LTHD

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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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SD



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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	54400
(145 DEG F)	
MUZZLE VELOCITY, FT/SEC	2843

LTHD
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SD

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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

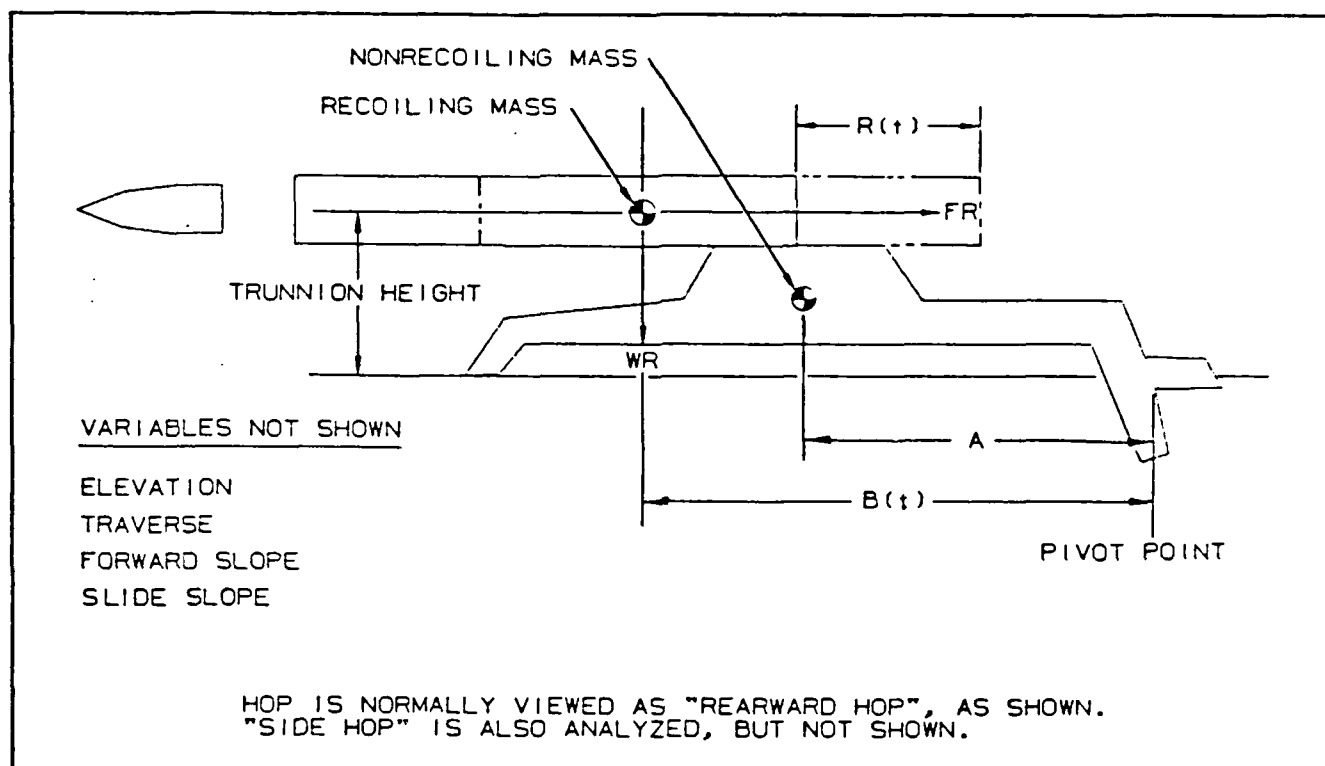
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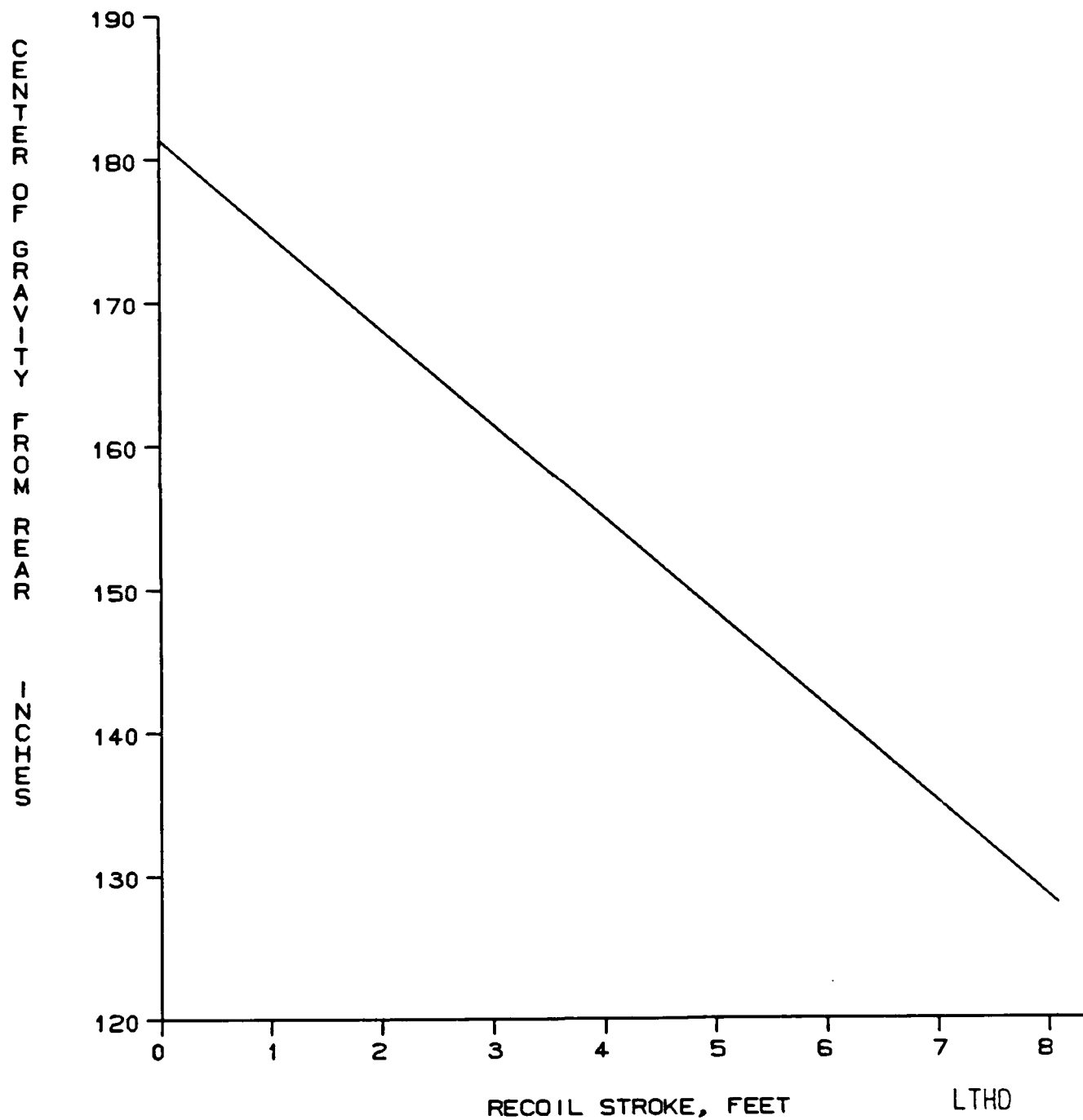
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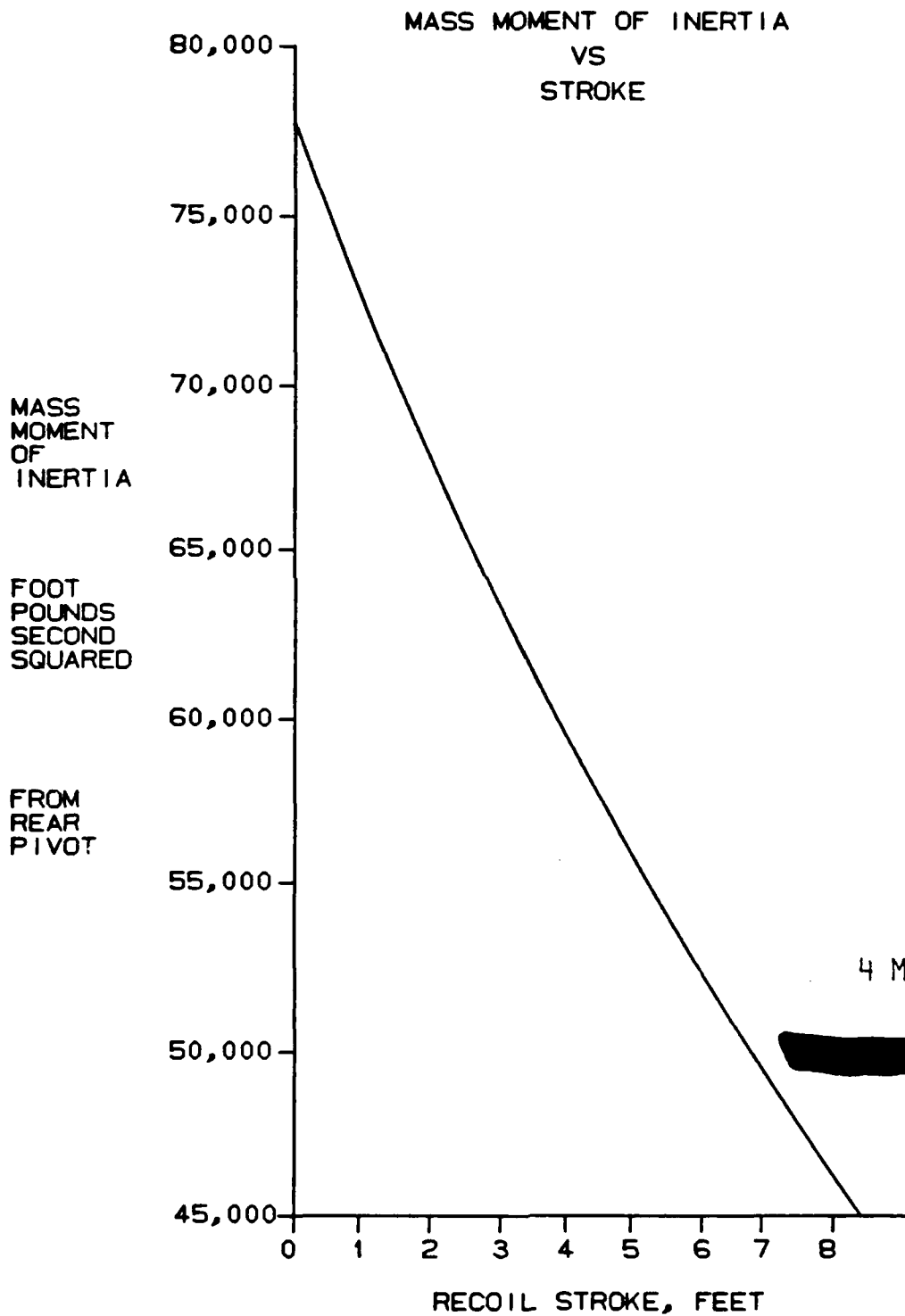
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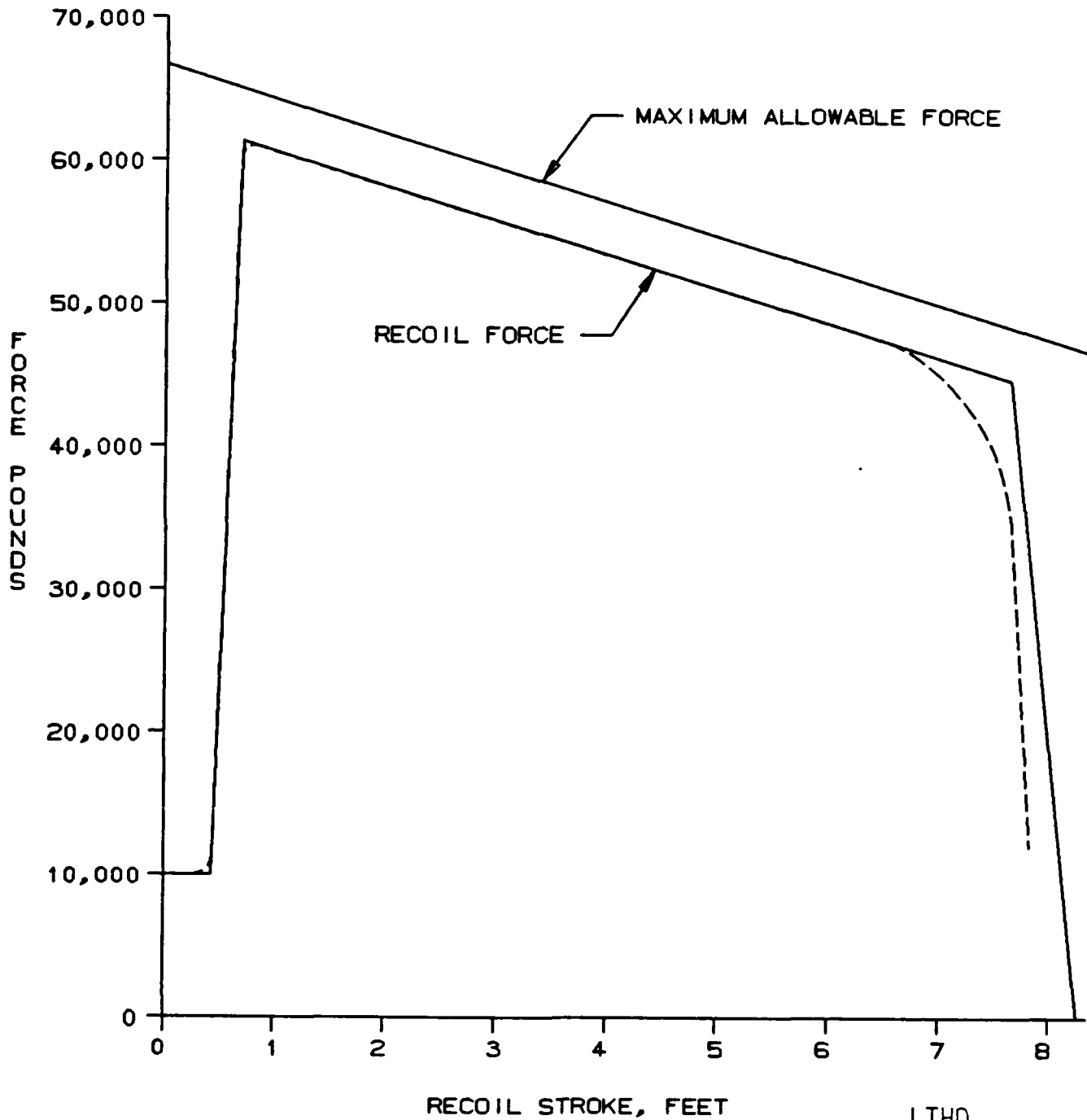
CENTER OF GRAVITY VS STROKE



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FMCRECOIL FORCE VS STROKE
WORST CASELTHD
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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

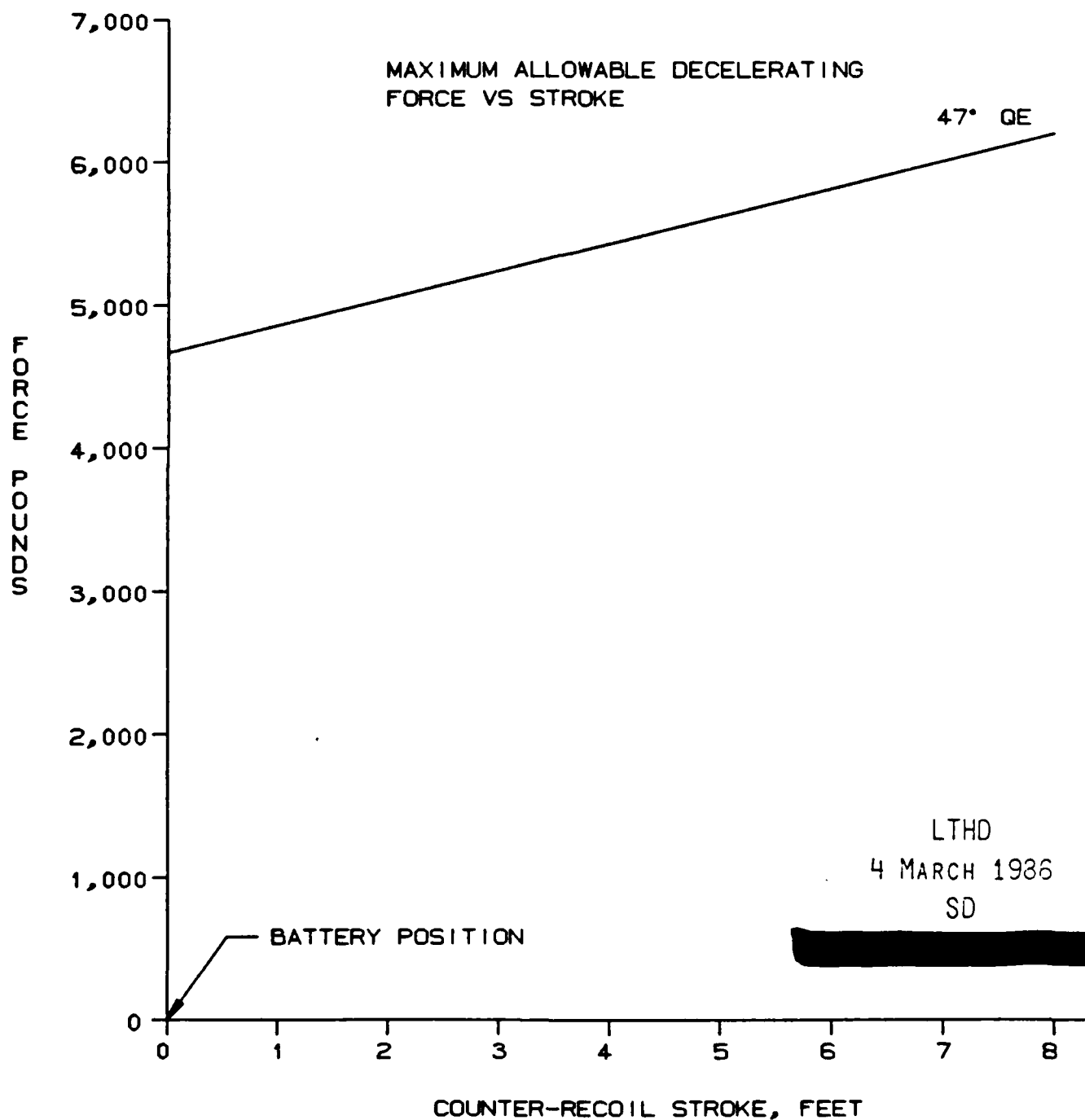
OTHER COMPONENTS:

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-SEC ²	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

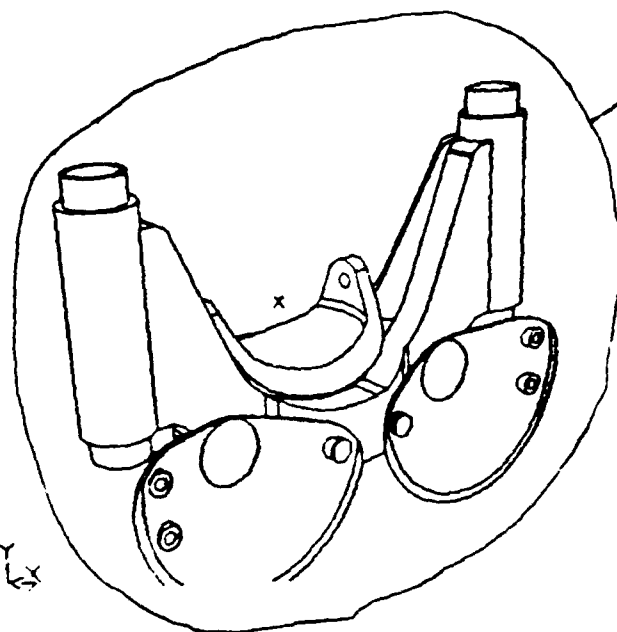
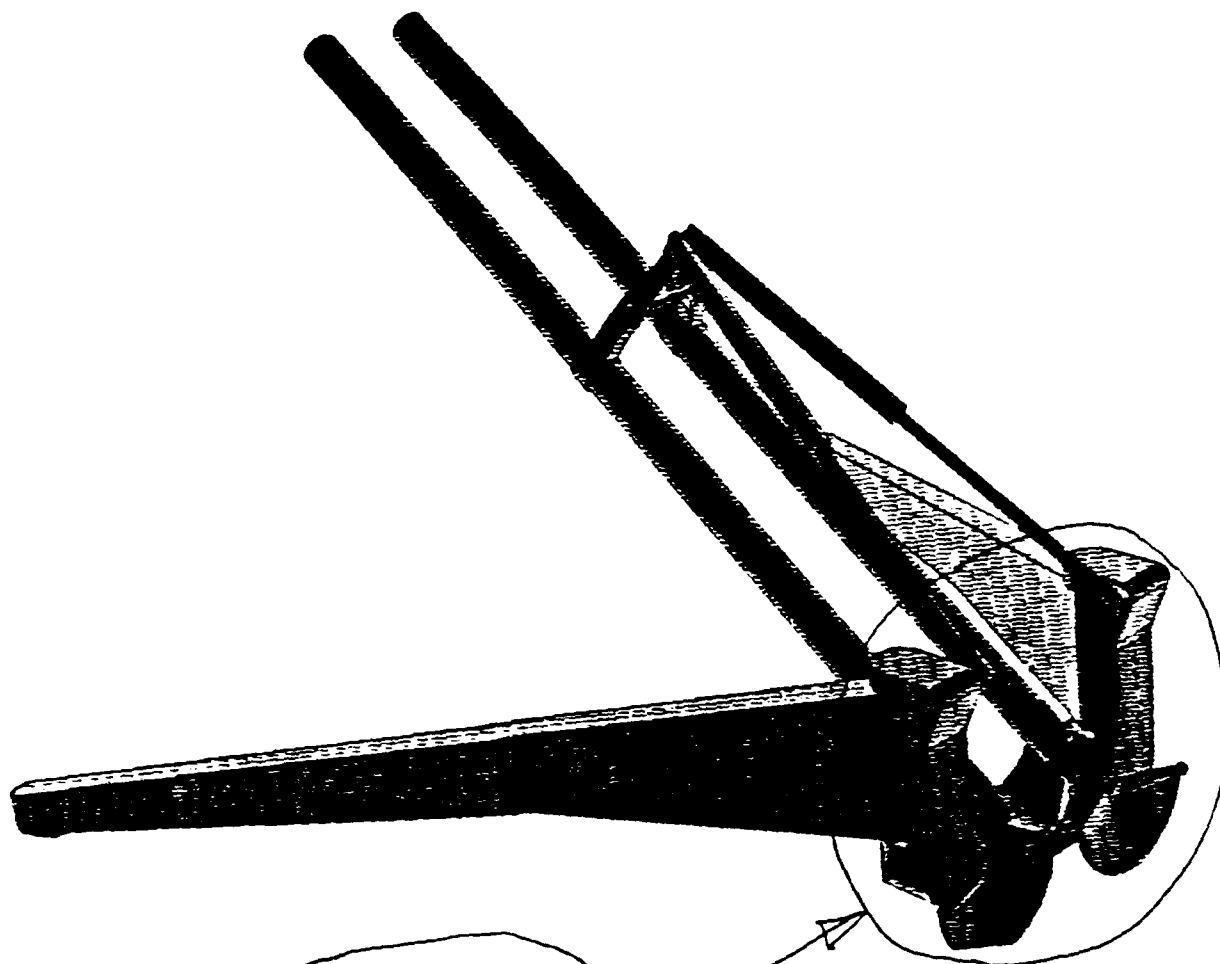
1. CONFIGURATION CANDIDATES
2. BETTER WEIGHT AND COST ESTIMATES
3. A MEASURE OF STRUCTURAL ELASTICITY
 - WHICH WILL IMPACT FIRING STABILITY ANALYSIS
 - FEASIBILITY OF QE/AZ CYLINDER ANCHORS NEAR TRAILS

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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 ACCEPTABLE?
 - (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

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Since the Mar 4 Design Review....	4-5

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Hangfires.....	4-14
Stickers.....	4-15
Cookoff.....	4-16
Speedshift.....	4-17
Displacement.....	4-18

Component Viewpoint

Cannon.....	4-19
Recoil System.....	4-20
Carriage.....	4-22
Hydraulic Controls.....	4-23
Fire Control.....	4-24
Ground Engagement.....	4-25
Dolly.....	4-26

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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

- 0 2,700 LB VERSION OF M199 BARREL
WITH M185 STYLE BREECH AND M198 MUZZLE BRAKE WITH INTEGRAL LUNETTE
- 0 SUPER LONG RECOIL (TO MINIMIZE RECOIL FORCE)
- 0 LOW TRUNNION HEIGHT (TO MINIMIZE OVERTURNING MOMENT)
- 0 FORWARD POINTING TRAILS (PROVIDING BALANCED WEIGHT DISTRIBUTION)
- 0 ACCESS TO BREECH VIA A LOADING TRAY (TO KEEP CREW AWAY FROM LONG RECOIL STROKE)
- 0 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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4-4

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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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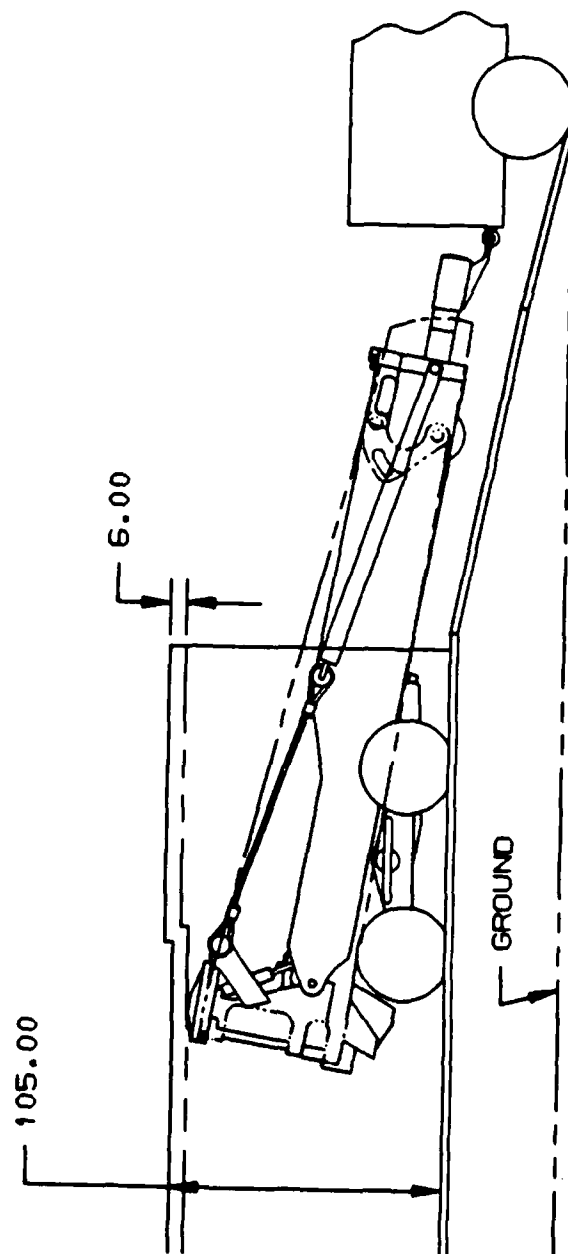
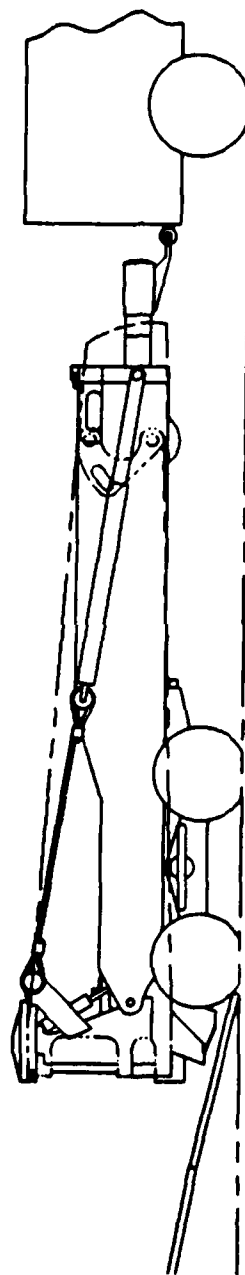
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OPERATIONAL VIEWPOINT
C130E DEPLOYMENT

LOADING FMC LTHD INTO A C130



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TOWING

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4-8

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.

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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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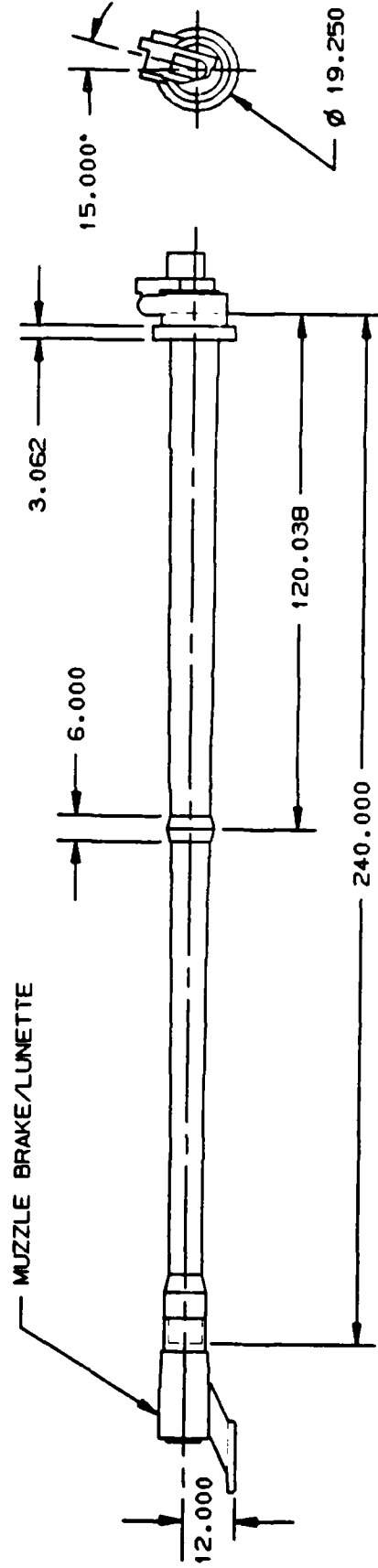
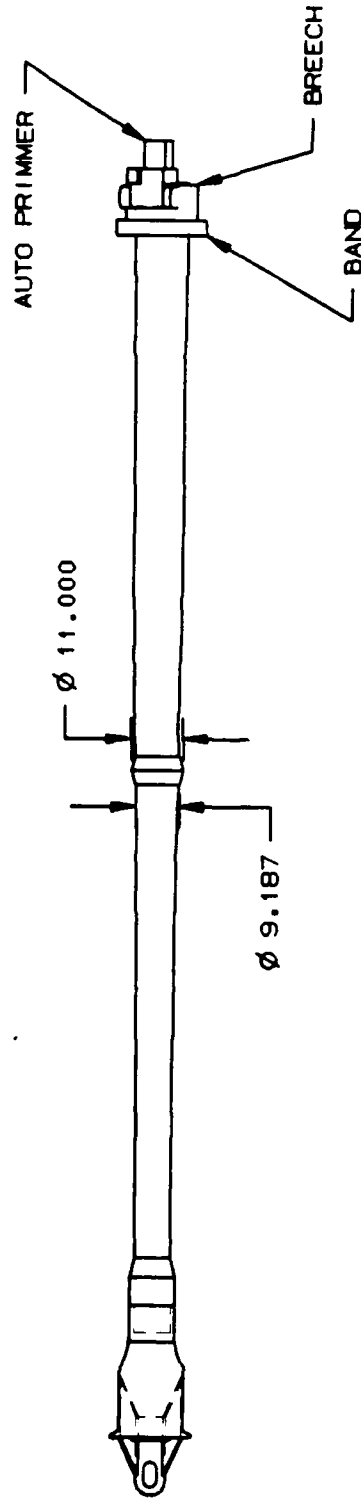
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CANNON ASSEMBLY



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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

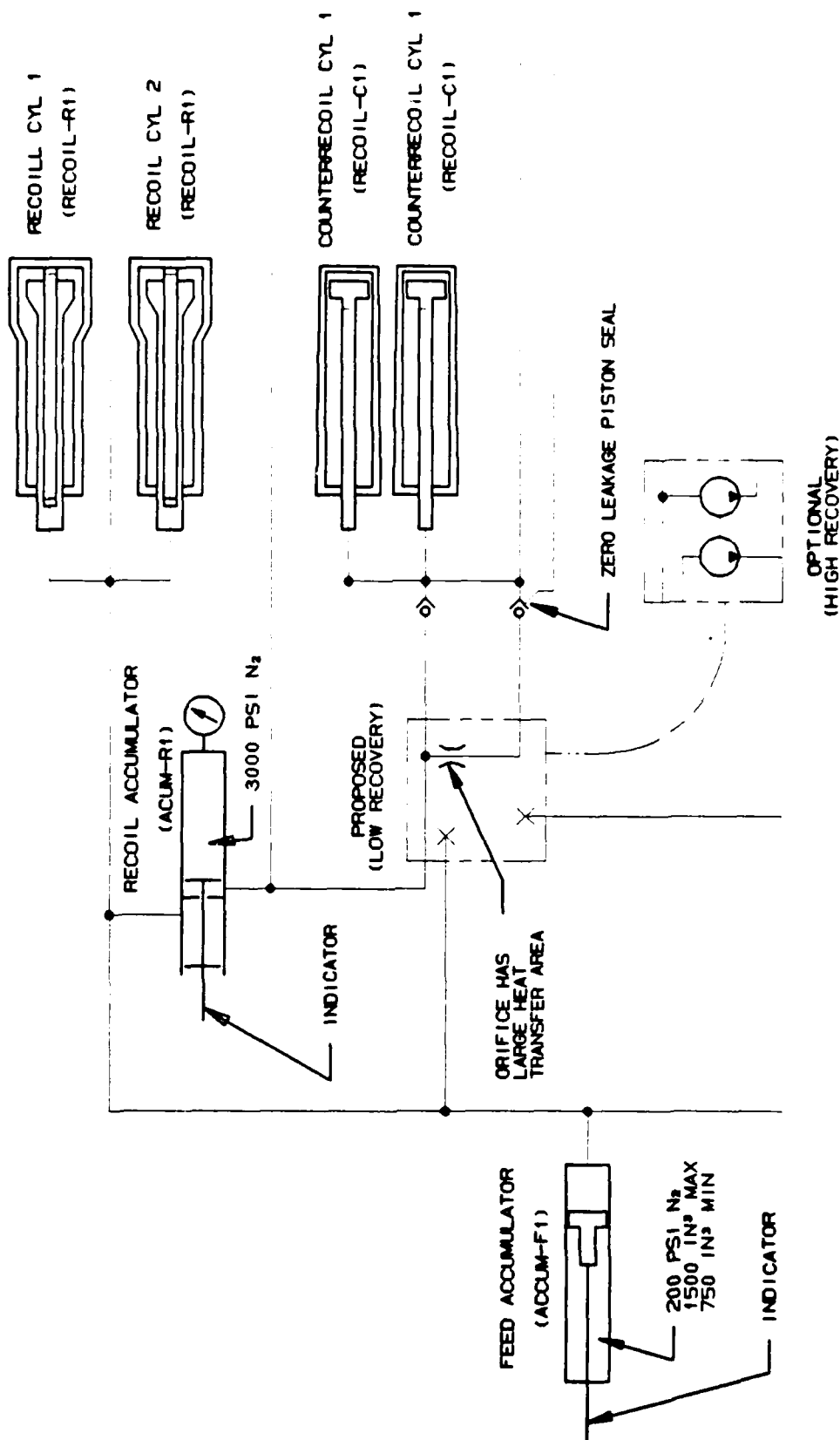
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RECOIL SYSTEM



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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)

TRAVERSE.....(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 HMMJV TIRES PROPOSED MAY BE NEEDED TO RETAIN M198
STABILITY IN TURNS

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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

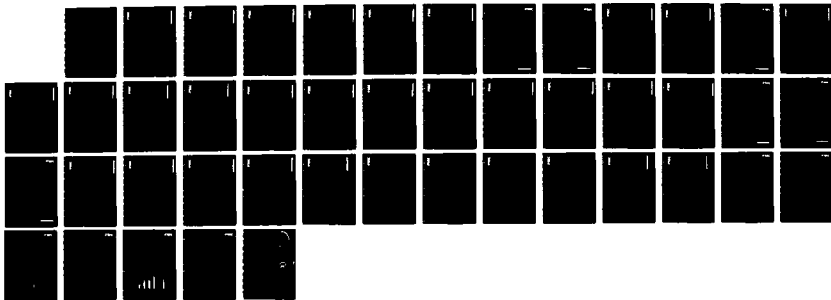
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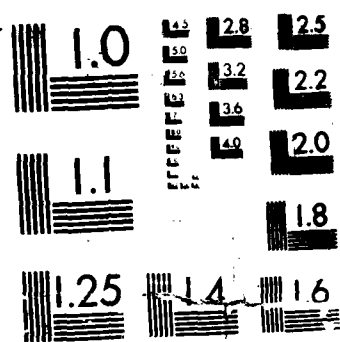
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MICROCOPY RESOLUTION TEST CHART

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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FMC

VARIATION IN IMPULSE CALCULATIONS

CONDITIONS:

M203 CHARGE (8S) AT 145 DEGREES F

M549 PROJECTILE

MUZZLE BRAKE		IMPULSE (LB-SEC)	
MOMENTUM			
INDEX	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

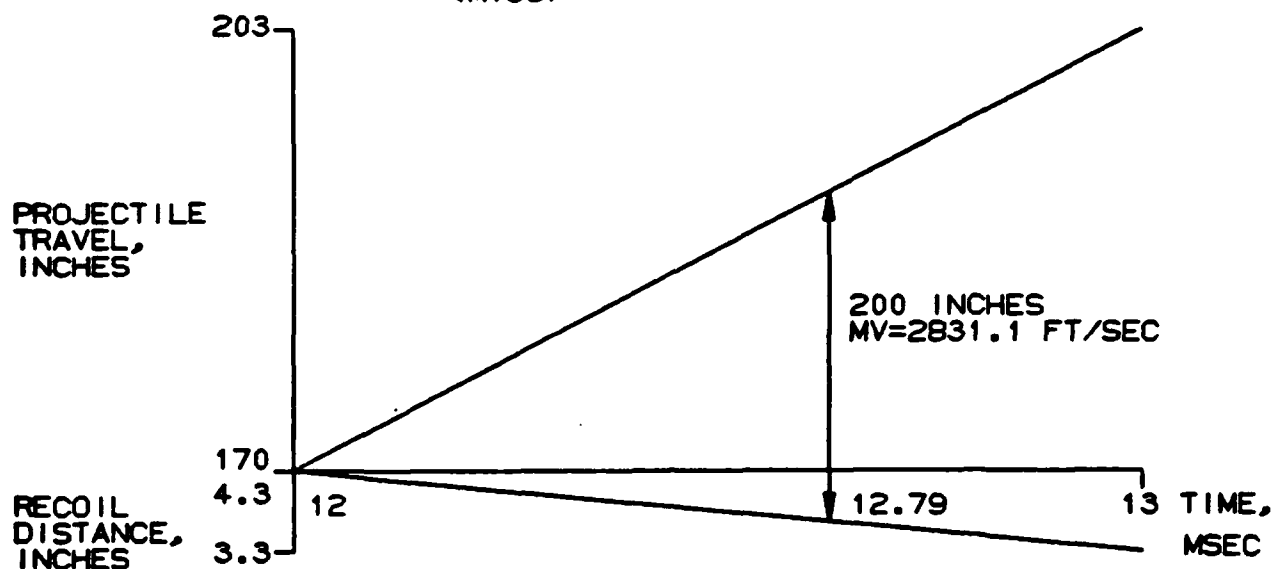
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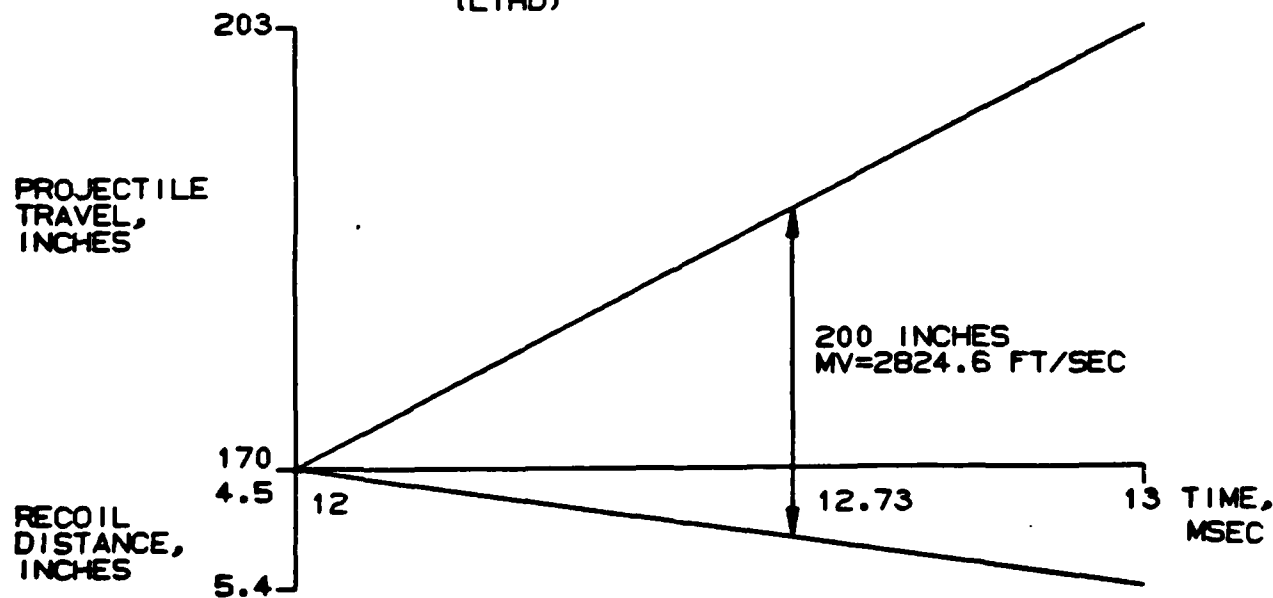
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RECOILING MASS=225 SLUGS (7258 LBS)
(M198)



RECOILING MASS=131.3 SLUGS (4228 LBS)
(LTHD)



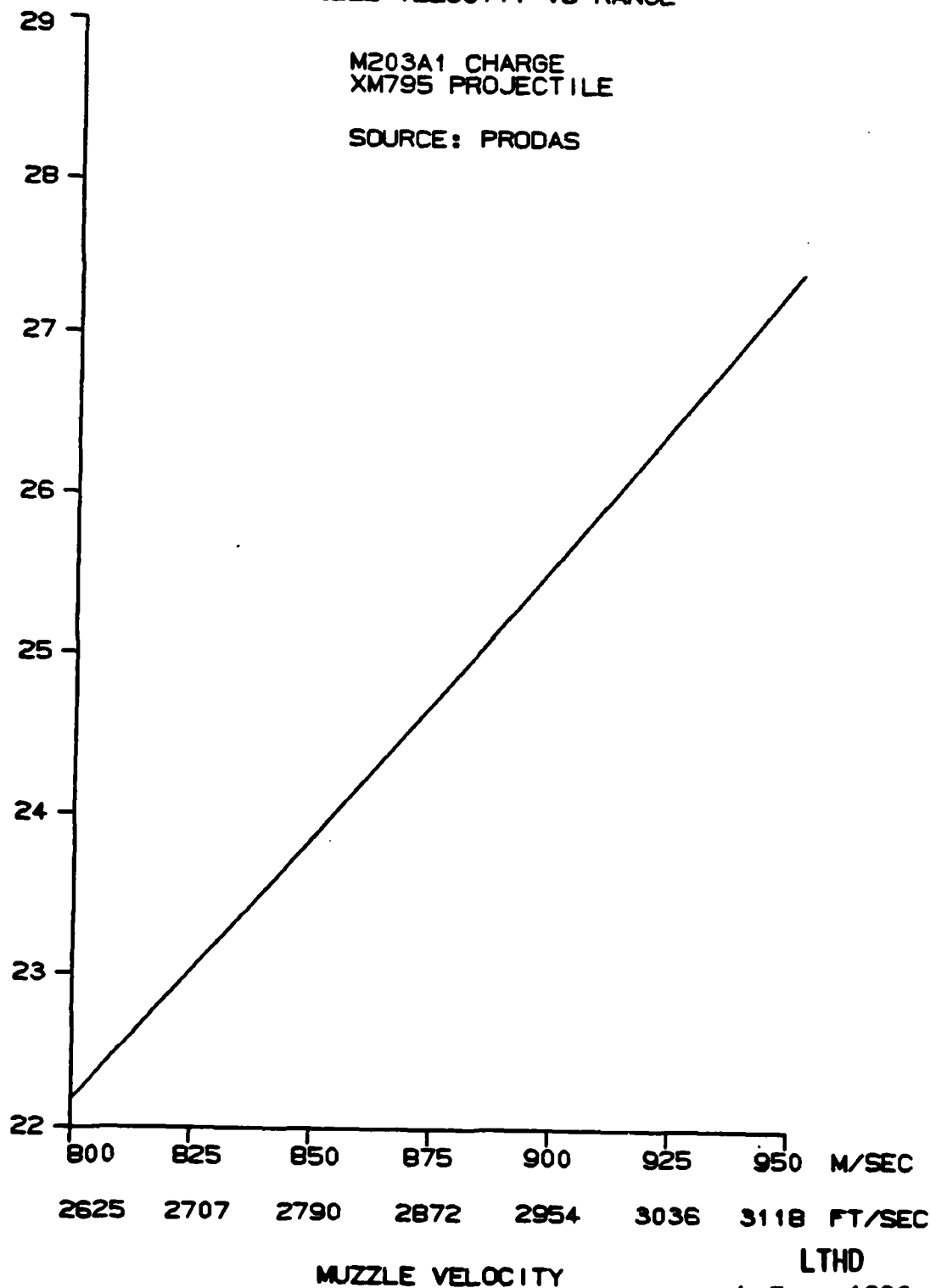
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MUZZLE VELOCITY VS RANGE

M203A1 CHARGE
XM795 PROJECTILE

SOURCE: PRODAS

RANGE
KM



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RECOIL ANALYSES

RECOIL MOTION

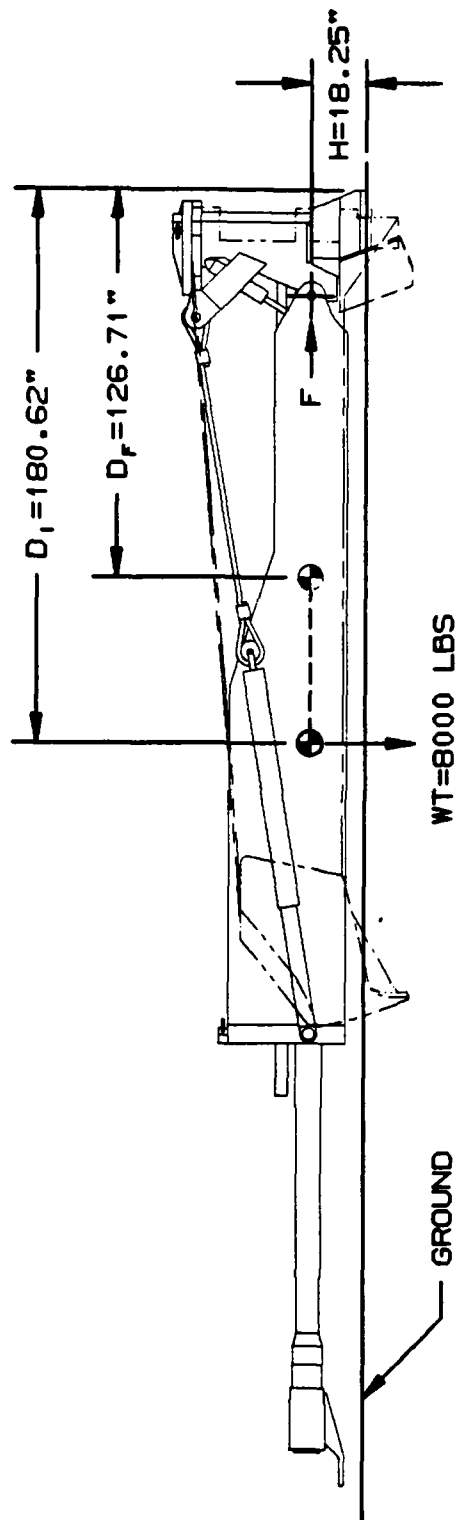
COUNTER-RECOIL MOTION

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FMC

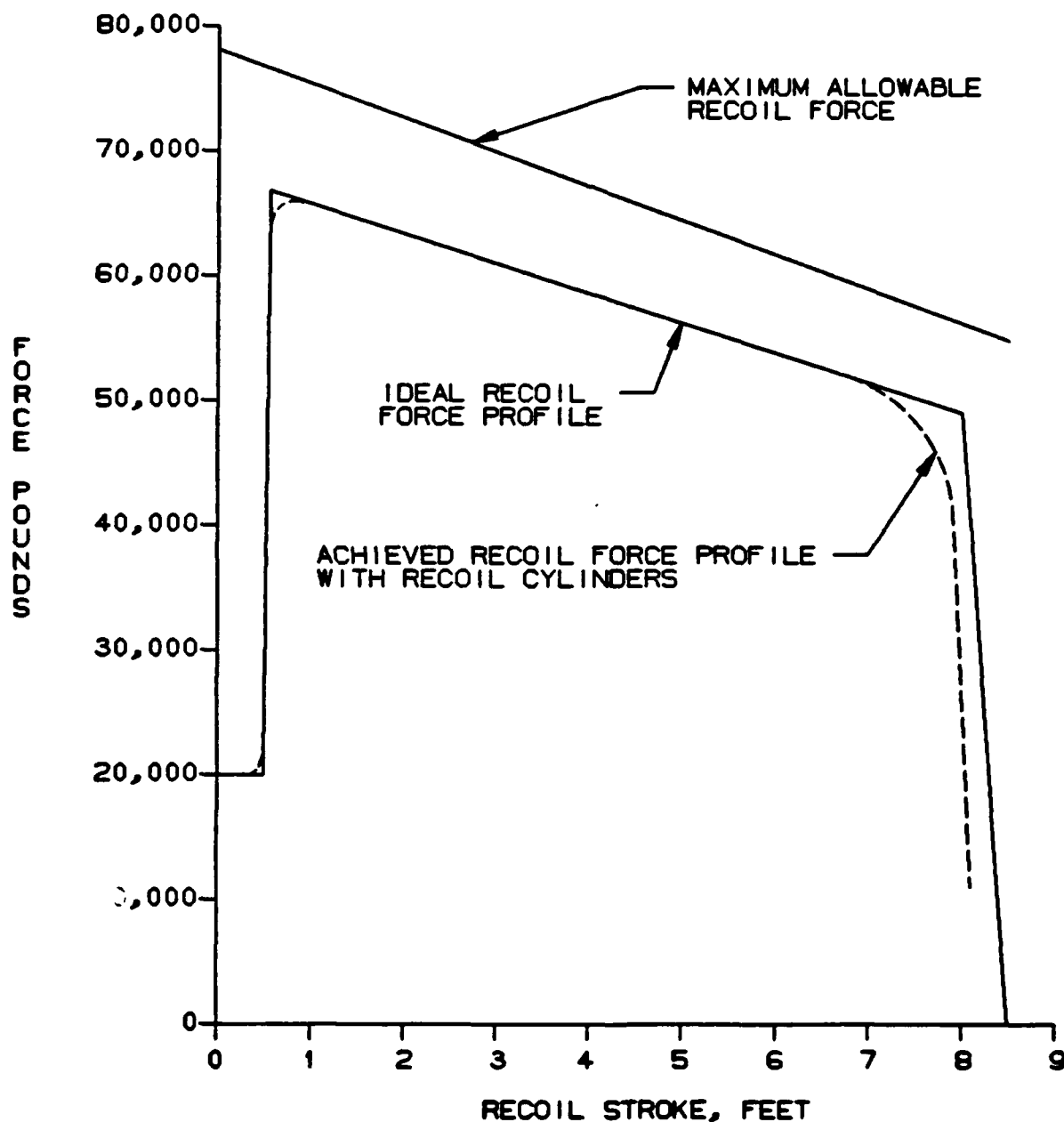
FMC LTHD - BATTERY POSITION, 0° QE



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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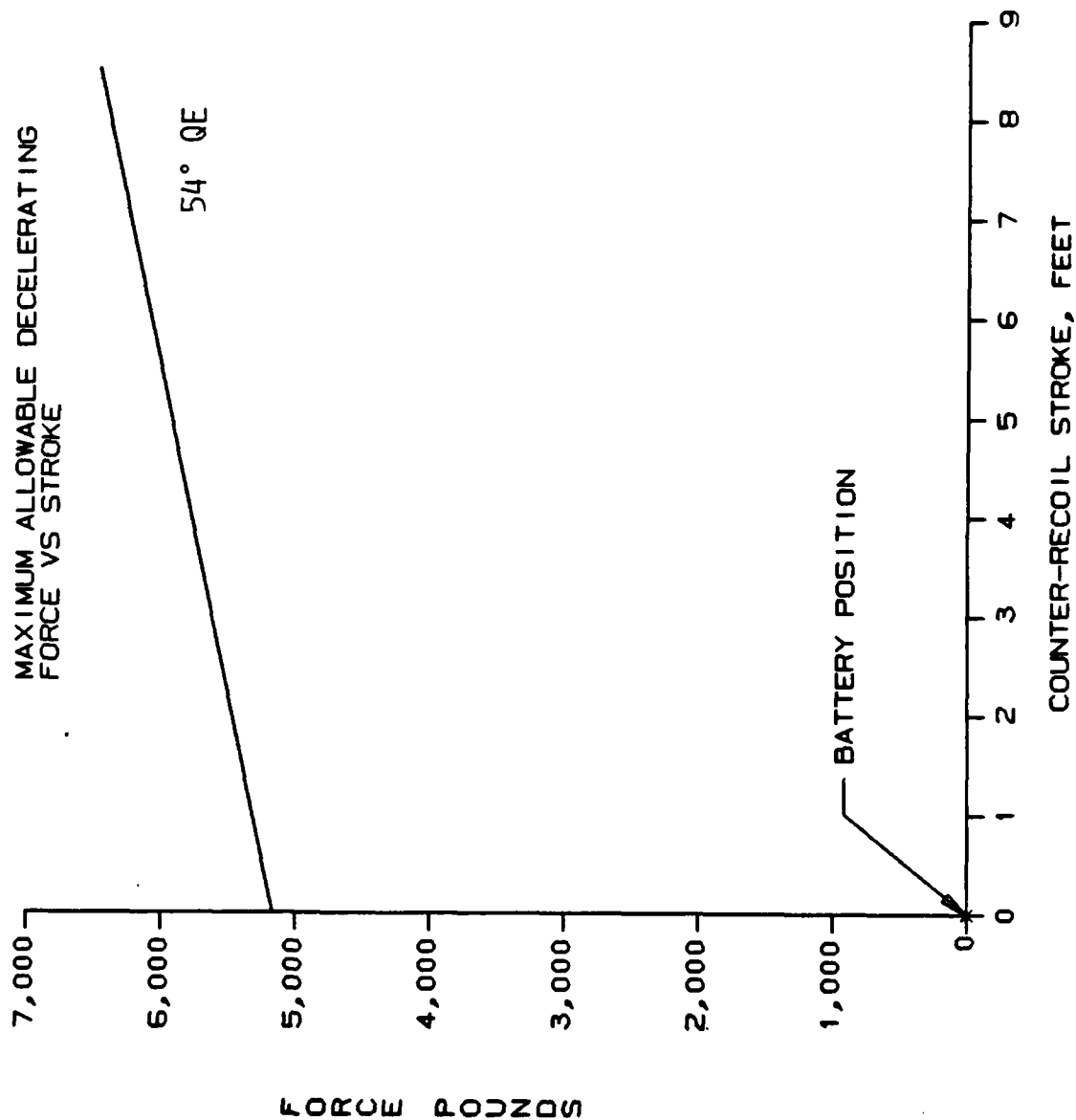
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COUNTER-RECOIL CUSHION



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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 0 DEGREES TRAVERSE
- 0 NO SKID
- 0 ZONE 8S, HOT (13,200 LB-SEC IMPULSE)
- 0 TRAIL SPRING CONSTANT OF 3000 LB/IN EACH
- 0 NO DAMPING IN TRAILS
- 0 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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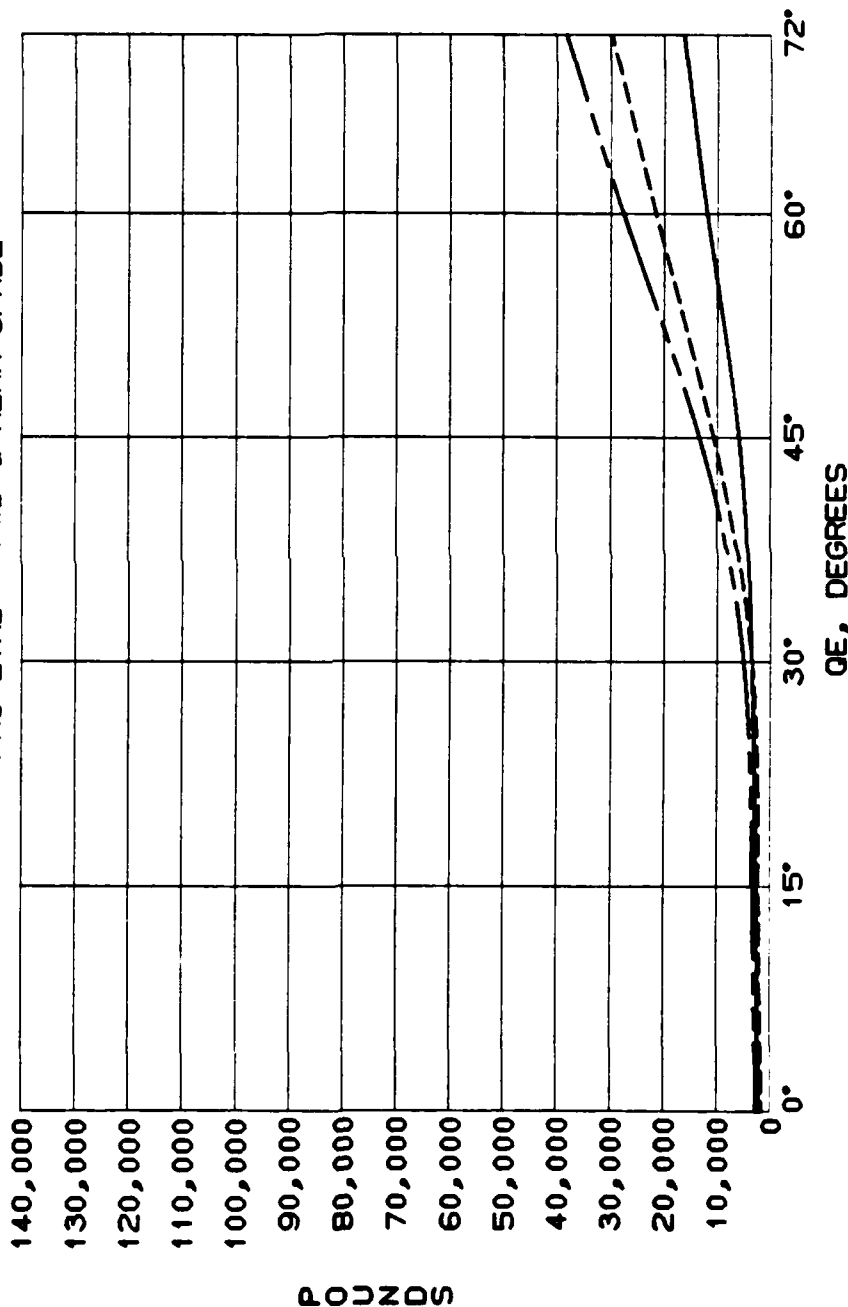
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FMC LTHD & M198 SPADE LOAD HOLDING CAPACITY IN CLAY

— M198
--- FMC LTHD - REAR SPADE ONLY
--- FMC LTHD - FWD & REAR SPADE



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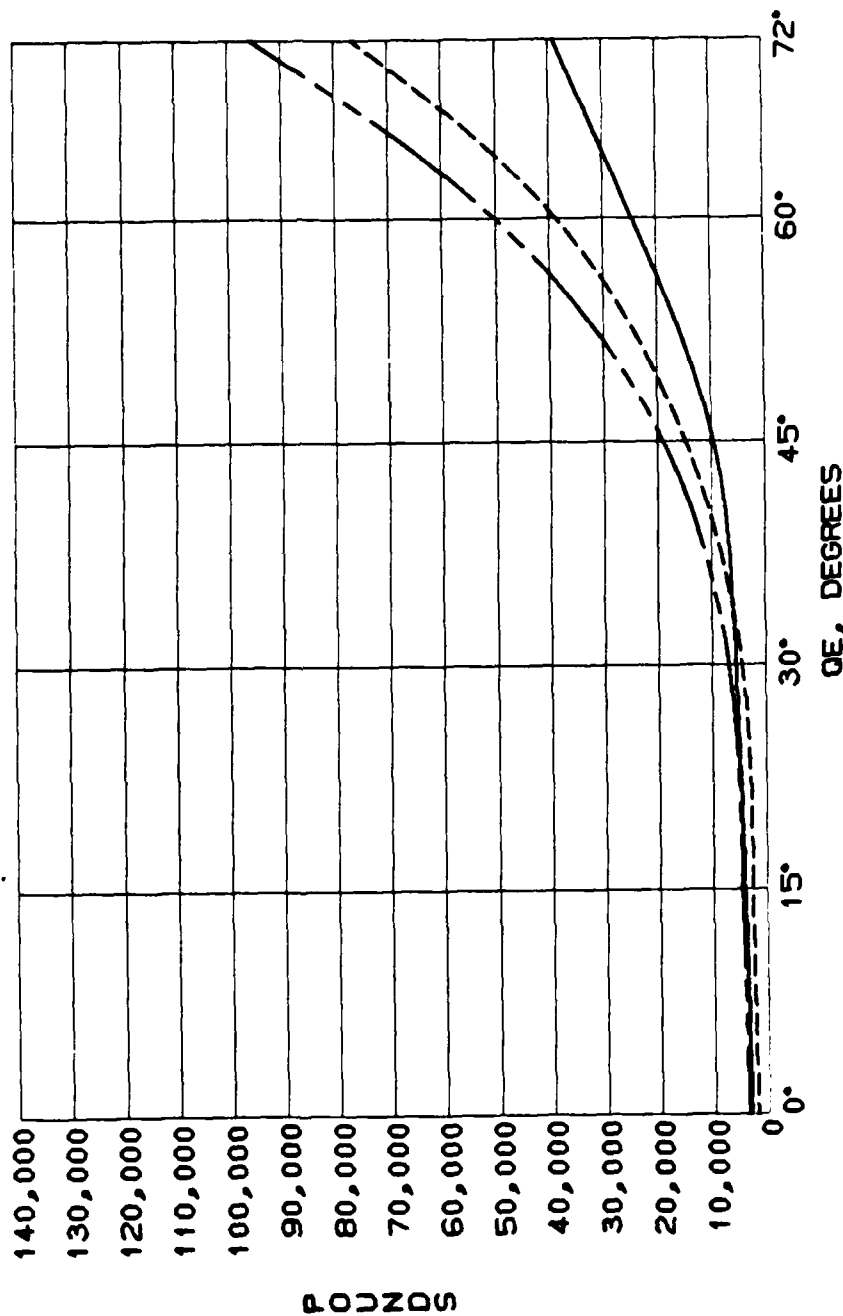
5-20

CLAY PROPERTIES
c : 6° c : 201.6 LB/FT² G : 95.73 LB/FT²

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FMC LTHD & M198 SPADE LOAD HOLDING CAPACITY IN LOAM

— M198
 - - - FMC LTHD - REAR SPADE ONLY
 - - - FMC LTHD - FWD & REAR SPADE

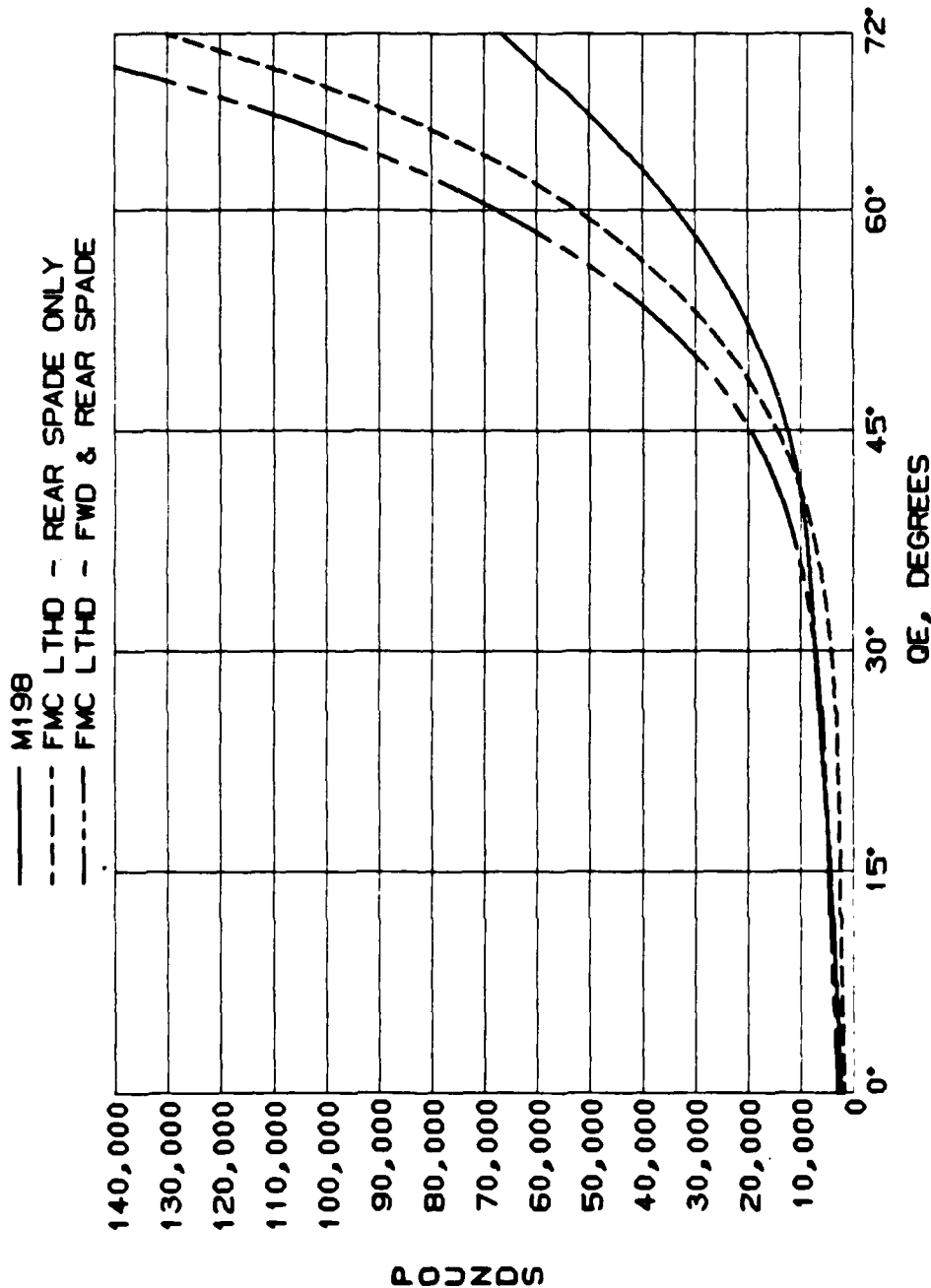


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LOAM PROPERTIES
 c : 28° c : 57.6 LB/FT² G : 102.3 LB/FT³

FMC

FMC LTHD & M198 SPADE LOAD HOLDING CAPACITY IN SAND



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SAND PROPERTIES
φ : 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 CLAY & HARD

SAND LOAM CLAY

0 DEG'S OE FMC LTHD 10.38 8.68 7.09

M198 8.27 6.92 5.65

45 DEG'S OE FMC LTHD 4.18 3.50 2.87

M198 5.53 5.17 3.80

72 DEG'S OE FMC LTHD 0.57 0.48 0.39

M198 2.24 1.88 1.55

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FMC

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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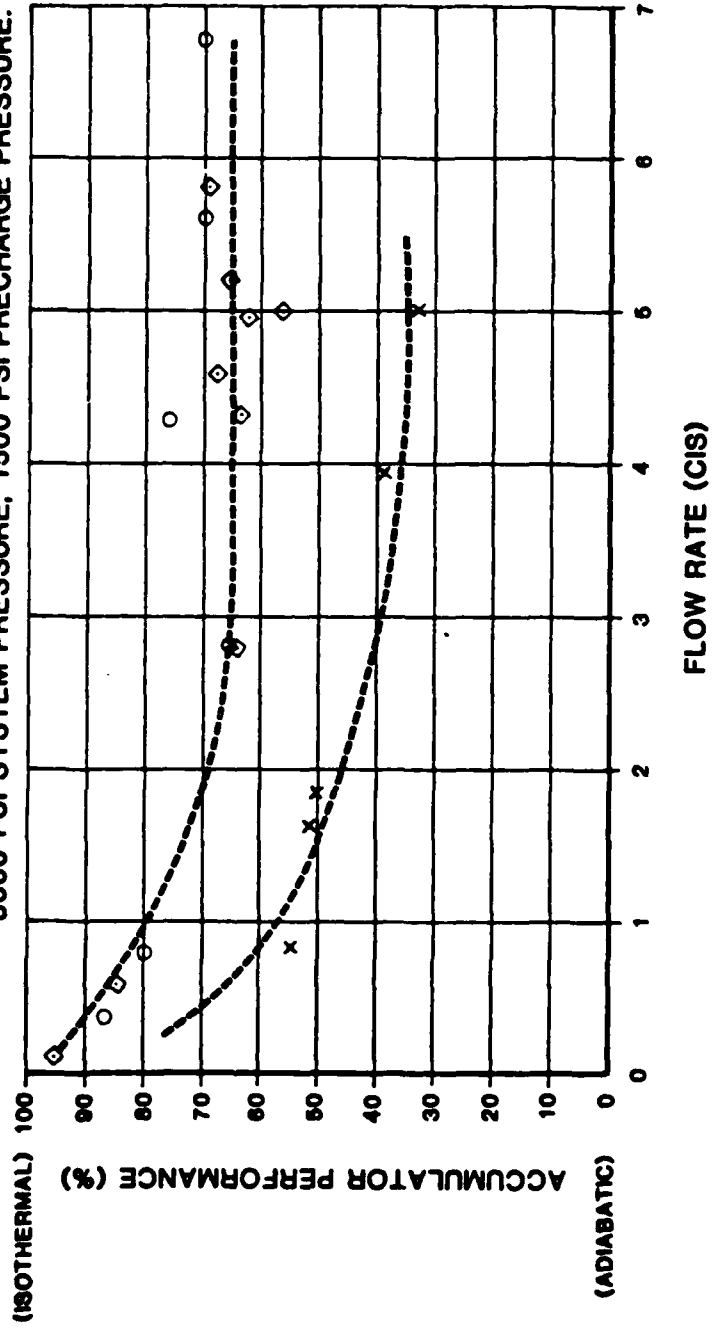
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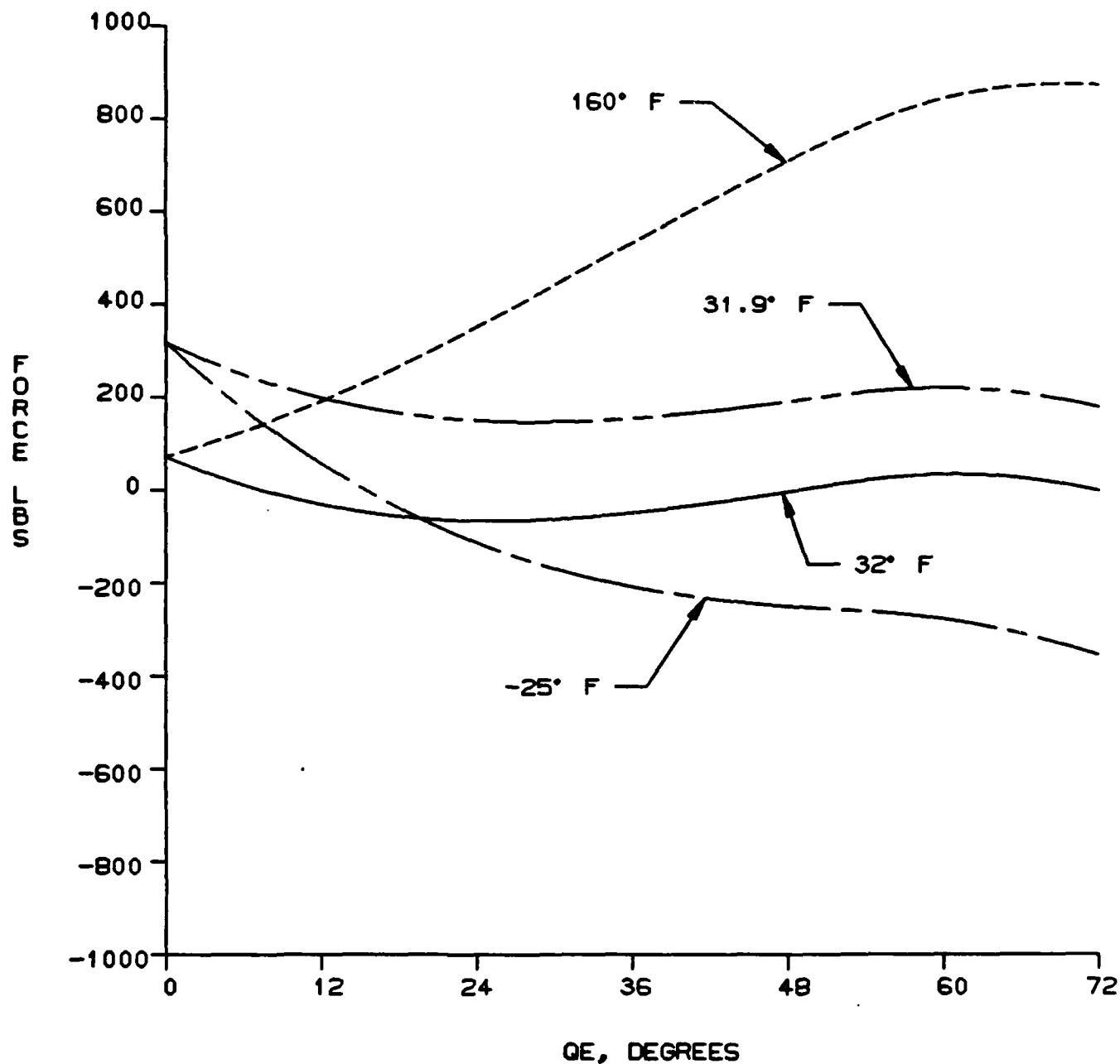
- x PISTON ACCUMULATOR, 100 IN³ PRECHARGE VOLUME,
6000 PSI SYSTEM PRESSURE, 3000 PSI PRECHARGE PRESSURE.
- o BELLOWS ACCUMULATOR, 100 IN³ PRECHARGE VOLUME,
6000 PSI SYSTEM PRESSURE, 3000 PSI PRECHARGE PRESSURE.
- ◇ BELLOWS ACCUMULATOR, 100 IN³ PRECHARGE VOLUME,
3000 PSI SYSTEM PRESSURE, 1500 PSI PRECHARGE PRESSURE.



Performance Efficiency Curves -
HIPRES Bellows vs Piston Accumulator

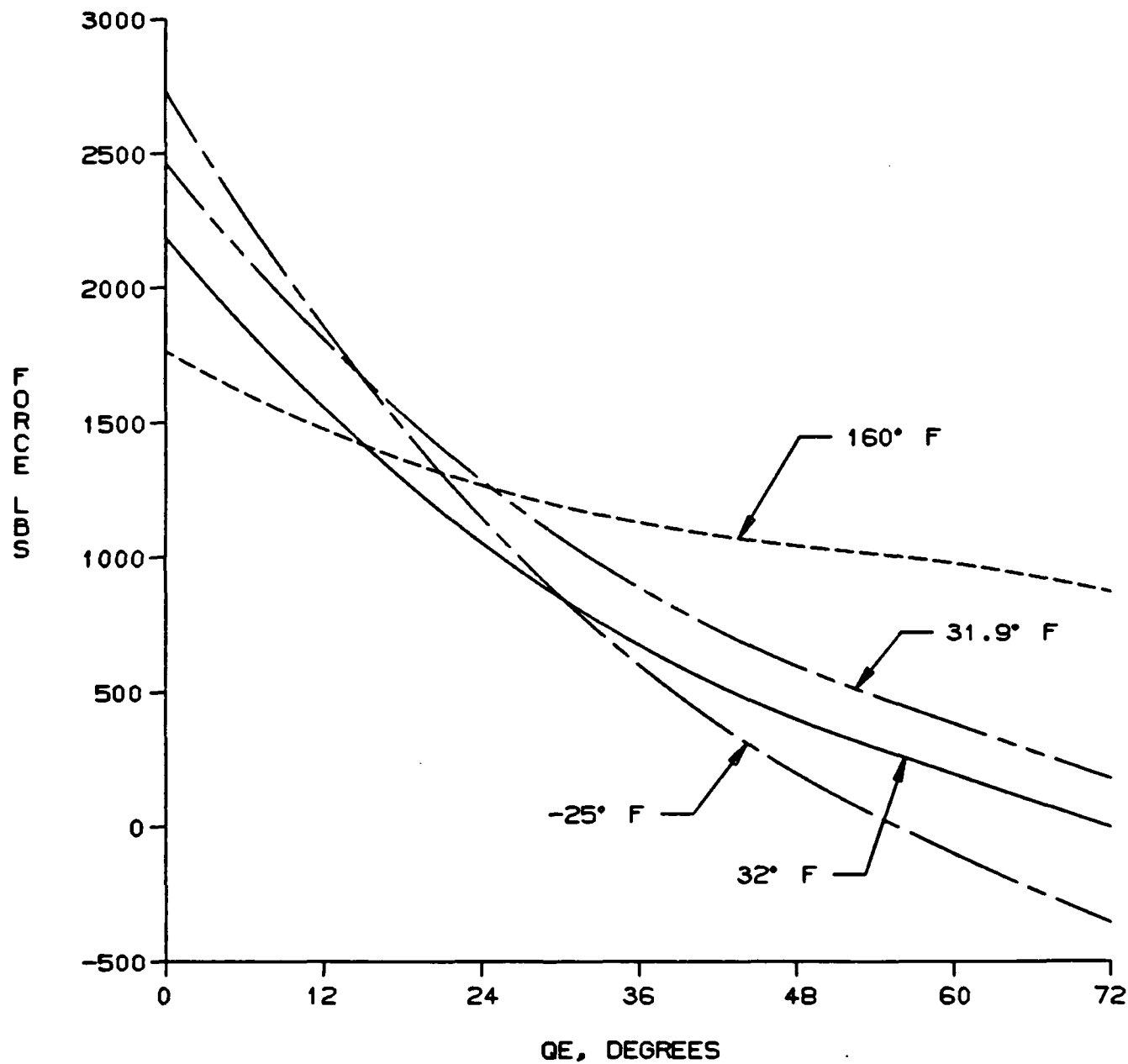
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EQUILIBRATION FORCE MATCH : EQUILIBRATORS-CABLE ISOTHERMAL CONDITIONS - N₂ OR He



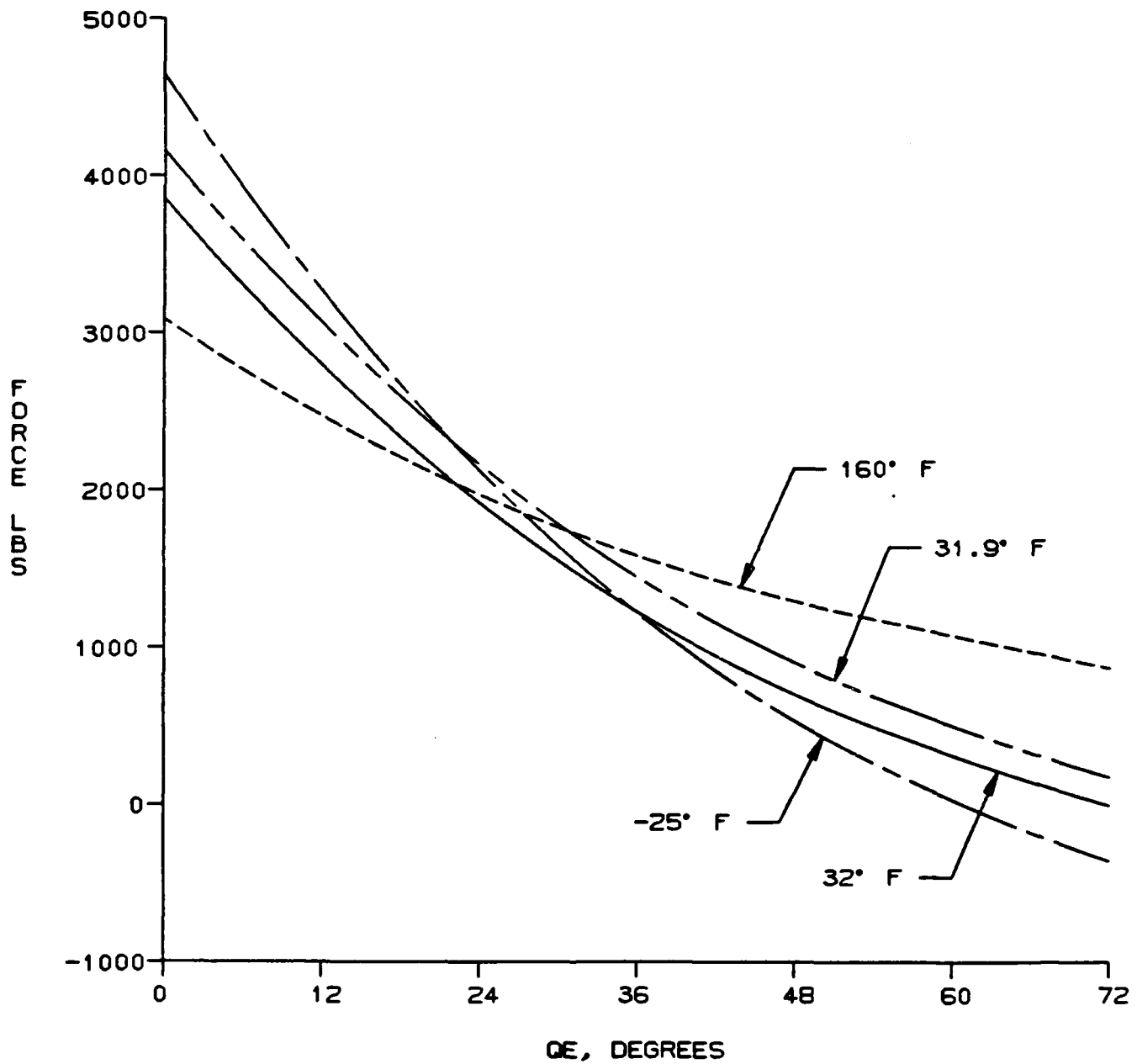
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SD

EQUILIBRATION FORCE MATCH : EQUILIBRATORS-CABLE ADIABATIC CONDITIONS - N₂



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EQUILIBRATION FORCE MATCH : EQUILIBRATORS-CABLE ADIABATIC CONDITIONS - He



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FMC

LOADING AND HUMAN FACTORS

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SD

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FMC

TOWING STABILITY

STATIC

DYNAMIC: RESPONSE TO ROAD CONDITIONS

LTHD

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SD

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FMC

TOWING STABILITY - STATIC

M198		
TOW	LTHD	
----	----	
53.84	48.29	
C.G. HEIGHT, IN.		
DIST. BETW. WHEELS		
CENTERS, IN	93.0	73.0
TIPPING ANGLE, DEG'S	40.8	37.1

LTHD

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SD

b-33

FMC

TOWING STABILITY - DYNAMIC

M198	
TOW	LTHD
----	----
TIRE SPRING CONSTANT, LB/IN	4.507 1.312
DAMPING COEFFICIENT ROLLING: NEGLIGIBLE	.019 .019
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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FMC

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.
- o STRUCK BY RECOILING ELEMENTS.
- o BREECH CLOSED ON HAND.
- o FIRE CONTROL ERROR PLACES ROUND IN FRIENDLY TROOP AREA.

TYPICAL SLING LOAD ACCIDENTS

- o 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.

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
CREW POSITION		X			X	X		X

PHA SUMMARY

CATEGORY I	CATOSTROPHIC	22
CATEGORY II	CRITICAL	10
CATEGORY III	MARGINAL	7
CATEGORY IV	NEGLEGIBLE	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, NRC, 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
NEGLECTIBLE	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.

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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.

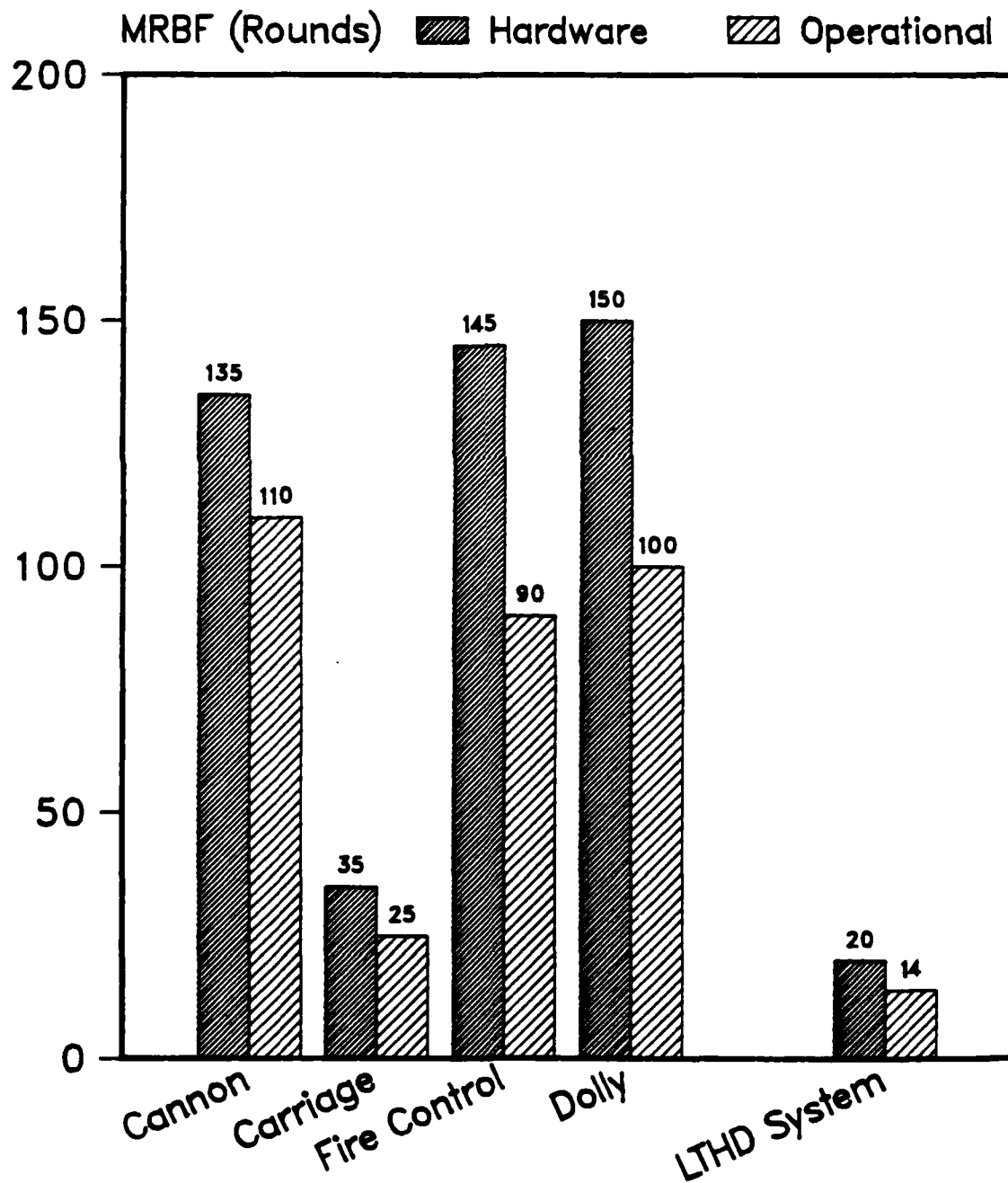
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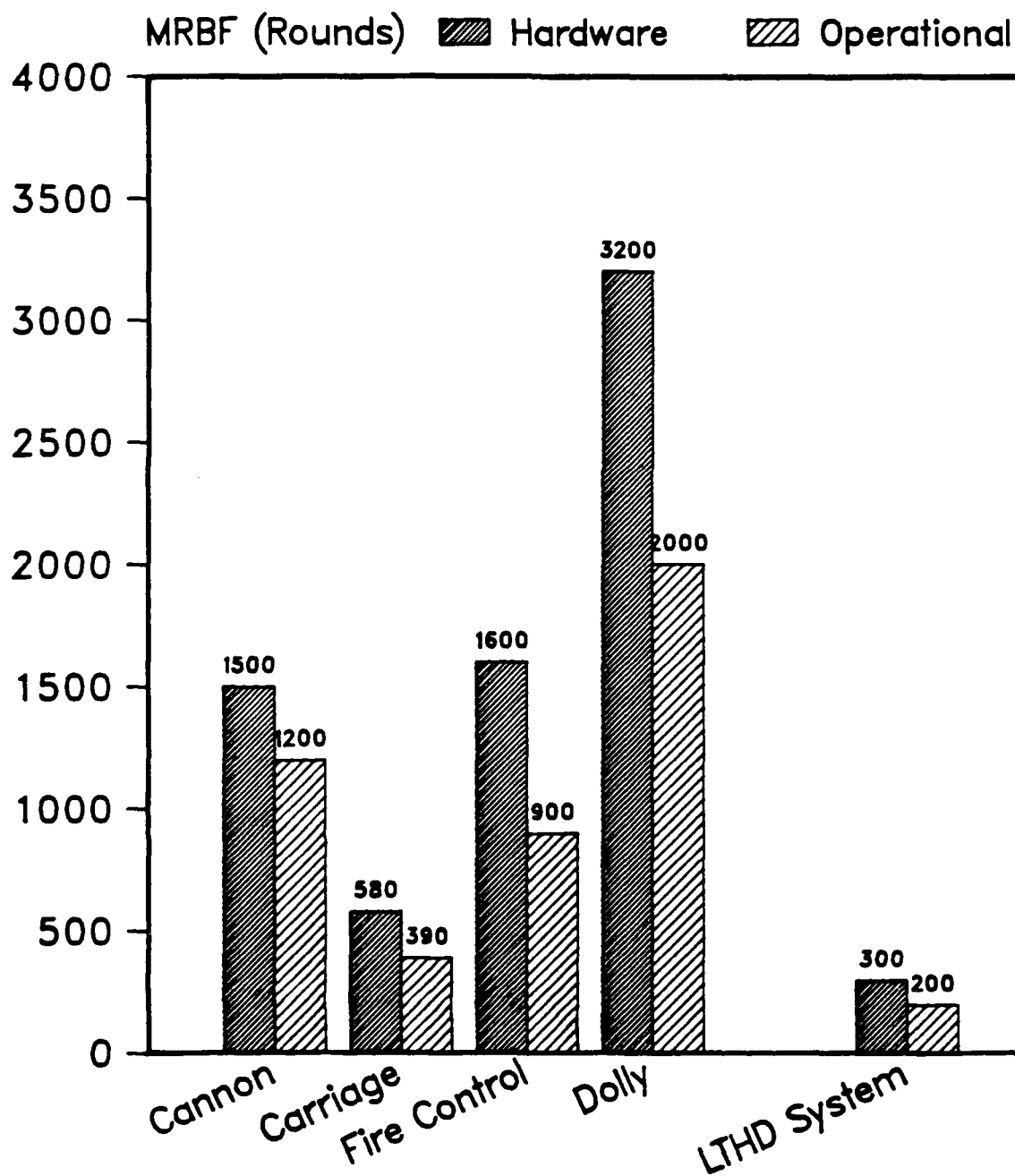
LTHD Reliability Goals Based on M198 Howitzer Performance Data (Corrective Maintenance Failures)



**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

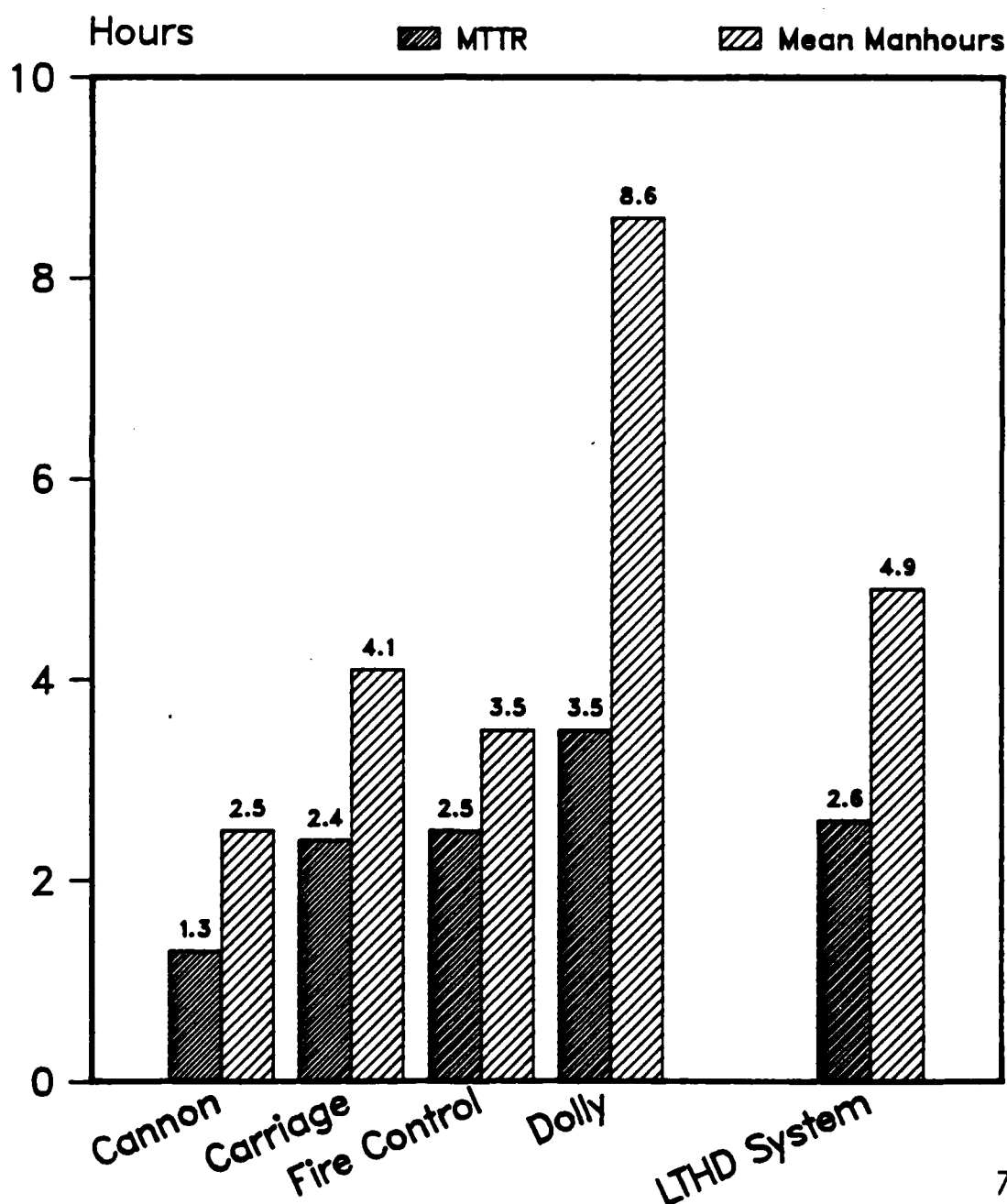
LTHD Reliability Goals Based on M198 Howitzer Performance Data (Combat Abort Failures)



**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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