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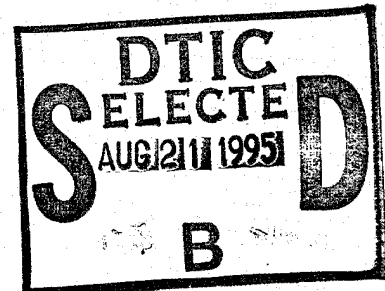
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## Contractor Report ARFSD-CR-95007

# XM1E5 ARTILLERY REARM MODULE FASTLOAD DEMONSTRATION

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## INTRODUCTION

This document is the Detailed Design Analysis Report for the XM1E5, 155mm Artillery Rearm Module, and it is based on the FASTLOAD DEMO Statement of Work (SOW). This program was awarded to Martin Marietta Armament Systems (MMAS), in Burlington, VT on August 31, 1994 by the U.S. Army ARDEC and is sponsored and managed by PMAMMOLOG, Picatinny Arsenal, NJ. as contract modification P00018 to DAAA21-91-C-0082.

The FASTLOAD DEMO Statement of Work consists of four major tasks ei. detailed design analysis of an objective system, design to cost (DTC) of an objective system, capability demonstration of an existing system and supporting data.

The first scheduled task was the design and fabrication of modifications needed to mount the existing ARM II/UNI (XM1E5) system on to an M977 cargo truck (M977 HEMTT). This effort extended from September 1994 through January 1995. The modified equipment was shipped to APG, MD on 2/2/95 for Government safety evaluation by TECOM prior to eventual shipment to Ft. Sill, OK for a capability demonstration/evaluation by TEXCOM in July.

Starting in November, 1994 effort was started to analyze the requirements of an objective system with respect to the draft prime item development specification included in the SOW. Major issues influencing the design of the objective system were outlined in the SOW and used as the primary focus of the design and analysis effort. The issue of electrical controls and software were also studied to provide a complete analysis.

The general approach for the design analysis was to build on past experience gained on the ARM I, ARM II/UNI, ARM II/LP and various IR&D studies. No attempt was made to design producibility improvements into proven designs such as magazine bucket carriers.

Since the main thrust of this effort was aimed at the design of a low cost automated projectile storage and handling system, considerable investigation was done to identify cost drivers and eliminate features not necessary to meet the minimum requirements of the draft prime item development specification. In some cases easing of the specification requirements could facilitate a lower cost system at little or no impact on performance or reliability.

## DESIGN REQUIREMENTS

During design analysis of the XM1E5 program, a list of system design requirements was derived from the SOW, the draft Prime Item Development Specification, prior ARM programs, customer requests and mission analysis. The system requirements were subsequently allocated to various subsystems and individual components through the process of functional decomposition. Near the end of the design analysis, the requirements list was translated into a formal system specification, (Martin Marietta Specification A10042), and will be submitted to as a separate data item to fulfill the requirements of the SOW paragraph 3.1.4.

The following is a summary of the XM1E5 system design requirements contained in the SOW. The complete system requirements specification is contained in the Prime Item Development Specification A10042.

### **XM1E5 System Definition**

The XM1E5 shall be a projectile and solid propellant storage module system for future field artillery rearm operations. The XM1E5 shall be capable of storing and transferring various 155 mm projectiles and fuzes as listed in the system specification.

In a projectile upload operation, projectiles are manually placed onto the XM1E5 transfer conveyor. The transfer conveyor shall carry the projectiles into the transfer unit where they shall be handed off to one of two projectile magazines. A hand held barcode reader will be used to scan palletized ammunition during upload of the XM1E5.

In the manual projectile download operation, projectiles shall be automatically handed off from the magazine through the handoff group to the handoff conveyor. The transfer conveyor shall bring the projectiles out of the XM1E5 for manual removal. In the automatic projectile transfer operation, the transfer conveyor shall deliver/accept 155 mm rounds to/from a manual load tray.

Uploading solid propellant onto the XM1E5 shall be accomplished by using an available crane or fork lift to transfer palletized containers from the resupply vehicle. Loose propellant containers will be manually transferred from the resupply vehicle to special racks equipped with straps to secure various types and quantities of propellant containers.

Downloading propellant containers shall be accomplished by manual operations in parallel with automated projectile download operations.

XM1E5 operation shall be under control of an electrical control group. The electrical control group shall also maintain onboard inventory information for projectiles, propellant and fuzes.

The XM1E5 shall utilize two projectile storage magazines mounted side by side at the forward end of the host vehicle cargo bed. The palletized propellant container storage shall be aft of the projectile storage module and loose propellant containers stored on top of the two projectile storage magazines.

The transfer conveyor shall be hinged at the forward end of the projectile storage module and shall unfold outward, perpendicular to the left side of the vehicle, during normal operation. The transfer conveyor shall be suspended by cables and provide a variable height adjustment for loading from the ground or truck platforms and downloading to various Howitzers. For transport, the transfer conveyor shall fold toward the XM1E5 and stow over the top of the handoff group.

Operator controls for the electrical XM1E5 components shall be accessible from the left hand side of the projectile magazine by crew standing on the ground. The electrical control group shall be located over the transfer unit with 24 vdc power receptacles on both sides of the system for easy access.

## **Environmental Requirements**

The XM1E5 shall be capable of meeting all operational performance requirements when parked on terrain with up to 20% side slope and 20% grade. In addition, the system shall be transportable over terrain with up to 40% side slope and 60% grade.

The XM1E5 shall meet all performance requirements with ambient temperatures ranging from -25°F to 125°F.

The XM1E5 shall be resistant to water spray, sand, dust, rain, humidity, vibration, shock, solar radiation and electromagnetic radiation, as detailed in Martin Marietta Specification #A10042.

## **Vehicle Interface Requirements**

Host vehicle #1 for XM1E5 shall be the M977 HEMTT truck. Host vehicle #2 shall be the M1074 PLS truck.

The XM1E5 shall mate with various existing cargo carriers and trucks, and the existing self propelled M109 series Howitzers for manual transfer and projectile upload operations.

Electrical input power shall be 24 vdc as supplied by the host vehicle auxiliary power subsystem.

## **Physical Requirements**

The XM1E5 empty weight shall not exceed 5700 pounds on the M977 HEMTT host vehicle. The XM1E5 empty weight shall not exceed **TBD** pounds on the M1074 PLS host vehicle.

The minimum storage capacity shall be 100, 155-mm projectiles with fuzes and 100 solid propellant containers on the M977 HEMTT host vehicle #1. The minimum storage capacity shall be 150, 155-mm projectiles with fuzes and 150 solid propellant containers on the M1074 PLS host vehicle #2.

Projectile orientation shall be such that they are delivered to the Howitzer nose first.

## **Functional Requirements**

The XM1E5 system shall be capable of simultaneously transferring both projectiles and Solid propellant to the Howitzer at the rates specified, under all specified environmental conditions.

The XM1E5 shall be capable of automatic identification of fuzes and projectiles, from bar-coded labels, and shall maintain an inventory of onboard propellant.

## **Performance Requirements**

Rearm time shall be **TBD**.

Projectile transfer rate shall be 20 per minute for a full load of one type, and 12 per minute for a full load of four mixed types.

The XM1E5 predicted mature system reliability shall be 8,000 mean rounds between failures (MRBF), minimum.

Scheduled maintenance shall be minimized. The design shall be modular and provide adequate access for replacement of worn or failed items.

### **Safety Requirements**

The operator/maintainer shall be protected from moving hardware, electric shock and pinch points.

The design shall be "fail safe" and shall provide built in test diagnostics to minimize secondary failures.

### **Human Factors Requirements**

The XM1E5 must be operable by a maximum of two MOS 13B cannon crew members.

Operational lifting requirements are not to exceed 100 pounds.

## **OBJECTIVE SYSTEM DESCRIPTION**

### **XM1E5 System Overview**

The XM1E5 system concept consists of four major groups; the conveyor group, the munition storage group, the hand-off group, and the electrical control group; and is designed to mount on the M977 HEMTT host vehicle (figure 1) or the M1074 PLS (figure 2).

The conveyor group consists of three conveyors to upload and download projectiles to and from the XM1E5 system. The outer and stub conveyors are suspended from the left forward corner of the left projectile magazine during ammunition transfer operations, and are folded 180° inboard to stow over the hand-off group during transport.

The munition storage group consists of two side by side projectile magazines positioned at the forward end of the cargo area, with the projectiles oriented horizontally and noses pointed towards the left side of the XM1E5. Propellant and fuze storage is also included in the munitions storage group.

The hand-off group transfers projectiles between the handoff conveyor and the projectile magazines is located directly in front of the projectile magazines. The hand-off group also provides the support for the conveyor in it's stowed position and includes the magazine drive motors and gearboxes.

The electrical control group controls all of the XM1E5 system operating functions. High and low level electronics units are located in an isolated compartment partially within the hand-off group structure, and interconnected with the host vehicle power supply, projectile magazines, and conveyor, via wiring harnesses.

All system components are mounted to a low profile pallet structure, enabling the entire system to be installed and removed as a single unit. A vehicle interface structure is nested over the cargo bed to mount the XM1E5 to the vehicle.

Projectile types and lot numbers are automatically identified using a hand held barcode scanner, that scans pallet bar-codes, and then uploaded by manually placing them onto the conveyor, that then carries them to the projectile transfer system where they are handed off into the two magazines.

Propellant charge canisters and fuzes in crates with bar-code labels are automatically identified by type and lot number using a hand held barcode scanner. If the barcode is missing or unreadable the alpha-numeric identification must be manually inserted using the key pad on the hand held barcode scanner. Loose propellant charge canisters and fuzes in cans are stored on special storage racks secured with straps and latches.

Due to the capacity requirements and the operational differences between the two host vehicles some physical differences were deemed necessary for the XM1E5 to meet the performance and human factors requirements. The most notable difference in the equipment design is the location and access to the operator control panel. The control panel for the XM1E5 on the M977 HEMTT is located on the lower left side of the magazine for easy access by the operator standing on the ground. The control panel for the XM1E5 on the M1074 PLS is located on the upper left side of the left side hand-off assembly for easy access by an operator standing on the M1074 PLS flatrack platform which could be resting on either the host vehicle or on the ground.

The entire XM1E5 system concept, as it existed at the end of this design and analysis study, is documented as an electronic CAD layout conceptual design drawings. No formal drawings were generated however figures 3 and 4 show the envelope dimensions of the XM1E5 when mounted on the M977 HEMTT and M1074 PLS host vehicles. Figure 5 depicts the planned drawing architecture for the baseline XM1E5 system.

### **Component Descriptions for the M977 HEMTT Host Vehicle**

**Conveyor Group.** The transfer conveyor system consists of three distinct interconnected conveyors (hand-off, stub and outer) which together provide the means to transport projectiles between the XM1E5 storage magazines and the Howitzer (figure 7). A folding load tray also enables the conveyor to upload and download between the ground or pallets, various trucks and other resupply vehicles, and the current M109 Howitzer. A suspension cable supports the cantilevered load and is positioned by the operator during deployment by remote control. The transfer conveyor system is powered by its own drive assembly.

**Hand-off Conveyor.** The hand-off conveyor has the longest fixed length of all of the conveyor segments and extends across the full width of the two side by side projectile magazines, passing through the hand-off units of both magazines. Its function for download is to accept munitions from the magazines and transport them to the remainder of the conveyor system. During upload, the hand-off conveyor carries projectiles into the magazines and positions them for controlled hand-off into the selected serpentine. Conveyor power is applied to the left end of the hand-off conveyor via a roller

chain driven by the drive assembly, and is then distributed to the remainder of the conveyor system by means of a gear mesh between the hand-off and stub conveyors.

**Stub Conveyor.** The stub conveyor is swung down approximately 120 degrees about its inboard hinge to deploy. The stub conveyor assembly provides the inboard end of the folding conveyor and contains all of the structural features needed to support the cantilevered weight of the outer conveyor, load tray and projectiles. The 120 degree deployment action is accomplished by activation of the operator controlled conveyor electric suspension hoist. A spring pushes the stub conveyor and attached outer conveyor out of the stowed position as the suspension cable is unreeled. Once the stub conveyor assembly is fully deployed, the crew rotates the outer conveyor approximately 120 degrees until the outer end rests on the ground or other platform. The outboard end of the stub conveyor contains the hinge for the folding outer conveyor which becomes cantilevered when fully deployed. (See figure 8).

The stub conveyor consists of a series of V-grooved friction rollers spaced approximately 5 inches apart. The V-grooved rollers support the weight of the projectiles and provide the traction needed to move them up and down the length of the conveyor. The power to drive the V-grooved rollers comes from a series of chains and sprockets connected to the conveyor drive gearbox and motor located in the projectile transfer assembly. (see figure 9).

**Outer Conveyor.** This conveyor section attaches to the aforementioned stub conveyor outboard hinge and is therefore free to rotate relative to the stub conveyor. The deployed outer conveyor is fixed in length and uses gravity to maintain a straight pathway when the deployed conveyor is suspended by the cable at a working height.

The outer conveyor consists of a fixed length structure and a series of V-grooved friction rollers spaced approximately 5 inches apart. The V-grooved rollers support the weight of the projectiles and provide the traction needed to move them up and down the length of the conveyor. The power to drive the V-grooved rollers comes from a series of chains and sprockets connected to the stub conveyor at the hinge joint. A sheet metal guard is provided to protect personnel from entanglement in the chains and sprockets. Provisions are also included for a linkage to actuate a collision avoidance switch located near the load tray on the outboard end of the structure.

**Load Tray.** The folding load tray is employed to facilitate the manual transfer of projectiles on or off of the conveyor. This tray attaches to the outer end of the outer conveyor structure and supports the weight of a projectile until it is either manually lifted off or slid onto the conveyor. (See figure 10). While a projectile is in the tray, a switch within the outer conveyor is automatically activated to prevent another projectile from exiting the docking head and colliding with the first. When not in use, the load tray is stowed on top of the outer conveyor and subsequently over the projectile transfer unit during transport.

**Conveyor Suspension .** The conveyor suspension assembly provides the structural components necessary to support the cantilevered conveyor assembly between the top of the stub conveyor structure and the extendible conveyor fixed section and thereby facilitate positioning of the docking arm.

**Conveyor Drive Assembly.** The transfer conveyor system is powered by an autonomous drive assembly consisting of a 5.0 HP, 28 volt DC electric motor coupled to a commercially available gear reducer. The reducer output drives the left end of the hand-off conveyor through a roller chain, and also drives the conveyor position encoder. The conveyor drive assembly mounts to the left side hand-off assembly structure.

### **Munition Storage Group**

The munition storage group consists of two projectile storage magazines and propellant storage components.

**Projectile Storage Group.** The projectile storage group consists of two projectile magazines that are independently mounted to the top of a structure assembly in a side by side arrangement (figure 6). Each magazine consists of a bucket carrier serpentine, a projectile magazine framework, and a drive assembly. Since each magazine is independently driven by its own mating hand-off assembly, one magazine is able to search for a desired projectile at high speed while the other is transferring a projectile to the hand-off conveyor.

Most of the ARM II/Uni magazine design was retained for XM1E5 and most parts are common. The fundamental difference is that the ARM II/Uni magazines are located end to end with a single hand-off/selector unit between them, while the XM1E5 magazines are side by side with each having a dedicated hand-off assembly.

**Bucket Carriers.** Each projectile serpentine consists of an endless chain of 50 bucket carriers, each carrier fully restraining the round under normal operating conditions to eliminate friction with guide surfaces within the magazine. Because of the side by side magazine arrangement, the two serpentes are identical, whereas in the ARM II/Uni magazines the forward serpentine is opposite hand from the aft serpentine. At the hand-off unit, projectiles are snapped into or out of the carriers.

**Propellant Storage.** The propellant storage equipment is divided into propellant container storage and fuze storage components. Figure 1 shows the general location of the propellant and fuze storage components.

**Cannister Tiedowns.** Cannister tiedown provisions consist of simple fabricated weldments that support loose propellant containers in a controlled manner similar to the method used on the Fastload demonstration system. Two identical racks are located on top of each projectile magazine in a convenient position to enable easy access by the crew standing on the cargo deck of the host vehicle. The loose containers are secured for transport by several adjustable ratchet straps commonly used for cargo tiedown.

Palletized propellant is tied down to the cargo bed of the host vehicle to the rear of the projectile magazines using existing tiedown anchor lugs and stable ratchet straps

**Fuze Storage.** The fuze storage components consist of enclosed metal boxes located on top of the projectile magazines between the propellant containers. Easy access for removal of metal fuze boxes is accomplished using a pull drawer that slides within an outer protective cover.

## **Handoff Group**

The two identical projectile hand-off mechanisms, one for each projectile magazine, are similar to the ARM II/LP hand-off-selector units except that a redefined interface with the magazines was created to establish a more practical modular design. The structure of the redesigned hand-off assemblies provides a housing for various electrical components and support for the transfer conveyor suspension assembly and stowage. Unlike the ARM II/UNI and ARM II/LP systems, however, the XM1E5 hand-off assemblies do not require any of the apparatus necessary to read ammunition ID labels.

All parts associated with the control of the projectiles have been rearranged from the ARM II/LP design to properly handle the left pointing projectile orientation. This approach facilitated the partial embedding of the stub conveyor within the hand-off assembly to achieve a compact system that fits within the 96 inch width envelope of the host vehicles. (See figure 11).

**Left Side Hand-off Assembly.** The left side hand-off assembly houses the high level electronics units and its related cooling components. The left side magazine drive motors and gear reduction drive train and position syncros are also housed in this assembly. This assembly provides support for the conveyor suspension system including its winch, pulley anchors, rollers and guides for its deployment and stowage. (See figure 12).

**Right Side Hand-off Assembly.** The right side hand-off assembly houses the low level electronics units and the control panel for the M1074 PLS configuration. The right side magazine drive motors and gear reduction drive train and position syncros are also housed in this assembly. The top of the structure supports the guides for the conveyor stowage.

**Magazine Drive Assembly.** The serpentine and hand-off mechanisms of each projectile magazine are driven by an identical, independently operated drive system consisting of a motor, speed reducer and gear train. This portion of the projectile storage system is similar to the ARM II/Uni drive system except for a more compact and efficient gearbox and mounting brackets.

Drive power is provided by a commonly used 28 volt DC electric motor, which can deliver 2.5 HP continuous at 5000 RPM with a 130 A current draw. This maximum speed will be applied for short duration high speed search, with a commercially available speed reducer providing the necessary reduction to drive the serpentine at 80 rounds per minute. Most of the time the drive motor will operate at 1250 RPM, corresponding to 20 rounds per minute.

**Structure Assembly.** The structure assembly includes all of the components necessary to support the XM1E5 system on the cargo bed of the host vehicle. Special mounting components will be used to adapt the magazines and hand-off assemblies to the cargo bed in order to secure the XM1E5 for transport loads.

## **Electrical Control Group**

The electrical control system is the set of electrical control boxes, motors, sensors, actuators, cables, human interface devices, and software required to provide an interface with the operator and to control the operation of the XM1E5 mechanism. The major components of the electrical control system are described below and their interconnection is illustrated in figure 13.

**Low Level Electronics Unit.** The low level electronics unit contains the system microprocessor and its interfaces to the rest of the control system.

The circuit cards within the low level electronics unit contain the microprocessor and its system interfaces, and the computer memory, including the read only memory (ROM) for program storage, the random access memory (RAM) for temporary storage, and the electrically erasable programmable read only memory (EEPROM) for non volatile data storage. Also included are the interfaces to discrete sensors and switches with on/off signals, the interfaces to discrete indicators and actuators, the interfaces to the magazine position resolvers, and the interfaces to the motor controls. Serial communications interfaces communicate with the control panel terminal and the barcode reader. The low power section of the motor control servo electronics is also packaged within this unit. This section receives motor rate and enable signals from the system microprocessor, and rate feedback signals from the motor tachometers and then provide control signals to the power drivers in the high level electronics unit.

**High Level Electronics Unit.** The High Level Electronics Unit controls the switching of power to the various system components, the sensing and interruption of overloads, and the interruption of high level power when an emergency stop switch is pressed. This unit also contains the motor control servo power Amplifiers. The motor control circuits take control signals from the low level electronics unit and provides the power control capability to drive the motors at the commanded speeds.

XM1E5 has four motors, each with a separate controller. There is one rate controlled motor for each projectile magazine and one for the conveyor drive. The conveyor suspension winch drive motor is forward/reverse controlled at a fixed speed.

The motor controls are packaged so as to survive in the environments which XM1E5 is expected to be subjected with special emphasis on temperature and heat dissipation.

**Ammunition Identification (Barcode Reader).** The barcode label reader utilizes existing LOGMARS technology used on the fielded ammunition packaging. The label reader is a hand held scanner which reads encoded labels on pallets of projectiles and propellant containers, or boxes of fuzes. Scanned projectile information is used by the automated projectile handling system to identify projectiles being loaded. Quantities are automatically counted as the projectiles are loaded and entered into inventory. Quantities of propellant and fuzes are manually entered and added to the scanned data in the electronic inventory system. The label reader is attached to the control panel and stored in a compartment within the control panel when not in use.

**Label Data.** The XM1E5 reads and uses the National Item Identification Number (NIIN) and the lot number from the standard LOGMARS barcode labels. Other information which may be coded on these labels such as quantities, Maintenance Due Date (MDD), and serial numbers is not used and is ignored by this system.

**Conveyor Sensors and Actuators.** In addition to the conveyor drive motor, the following sensors and actuators are included on the conveyor subsystem.

**Resolver.** The conveyor resolver provides absolute position of the conveyor which is utilized to control the positioning of projectiles in preparation for transfer to the projectile magazines.

**Initial Timing Sensor.** During an upload operation the initial timing sensor detects the presence of the projectile on the conveyor prior to its entering the magazine hand-off so that the conveyor and the projectile location can be synchronized with the conveyor resolver data. The conveyor and projectile can then be slowed to a stop in a controlled, rA down, manner to prevent over shooting the desired position. The initial timing sensor utilizes an optical beam technology.

**Projectile Position Limit Sensors.** The conveyor contains two pairs of limits switches (one pair for each magazine) which are used to ensure proper positioning of projectiles prior to transfer into either projectile magazine. These sensors are located one inch each side of the nominal position where the base of the projectile stops to transfer into the magazine so as to detect the proper positioning of a projectile base. For proper positioning, the base of the projectile must be covering the limit 1 sensor and not be past the limit 2 sensor. All limit sensors use optical beam sensor technology.

**Collision Avoidance and Load Tray Sensors.** During a download operation when a projectile is left on the conveyor load tray and another projectile is approaching on the conveyor, the conveyor will be stopped to prevent a collision between the two projectiles. To control this function a mechanical switch is built into the load tray support so that it is actuated when there is weight on the load tray. Another sensor is located on the conveyor between the conveyor belts to sense an approaching projectile. The collision avoidance sensor is a proximity switch sensing the metal surface of the projectile as it passes over the sensor. The conveyor will be stopped when a projectile is sensed at both of these sensors at the same time.

**Projectile Orientation Sensor.** During the upload operation, when projectiles are manually loaded on the conveyor, human error allows for the possibility that the projectiles will be loaded in the wrong orientation, nose first. vs. base first. A reversed projectile would not be sensed and positioned properly and could cause damage to the system or the projectile. The projectile orientation sensor is a proximity sensor located several inches ahead of the initial timing sensor. This sensor will sense the presence of a projectile when the projectile surface is approximately one half inch from the sensor, therefor the sensor will detect a projectile at a point closer to the base than to the nose. The orientation is determined by sensing the position of the conveyor when the projectile is sensed by this sensor compared to the conveyor position when the projectile is sensed by the initial timing sensor.

**Grommet Sensor.** The XM1E5 system is not capable of handling projectiles with grommets in place. To prevent damage due to operator error, the grommet sensor will detect the presence of grommets, halting the conveyor so the projectile can be removed and prepared for upload. The grommet sensor employs optical beam technology to detect the increased diameter of the projectile at the grommet.

**Conveyor Interlock Switch.** A switch is built into the conveyor deployment mechanism which is used to prohibit operation of the conveyor unless it is fully deployed.

**Emergency Stop Switches.** The emergency stop switches provide the crew with a means to stop the (motor/conveyor) system in the event of any immediate or potential hazard to personnel or system hardware. Actuation of the emergency stop requires only a simple depression which locks the switch in a depressed position. Restarting the system after an emergency stop can only be initiated by retracting the same emergency stop switch that created the stop, and requires additional protocols (procedural verification that conditions are safe to restart the system), which are implemented and

prompted via the control panel terminal. These safety switches are located at several convenient positions on the conveyor and one on the control panel.

**Projectile Magazine Sensors and Actuators.** In addition to the magazine drive motor, the following sensors and actuators are included on each projectile magazine or its associated transfer mechanism.

**Magazine Resolvers.** The magazine position is sensed by a resolver attached to each magazine in such a manner that it rotates through one revolution as a magazine element moves through one complete cycle of the serpentine loop. The resolver output is sent to the microprocessor through a resolver to digital converter and is used for magazine timing as well as identification of magazine elements for inventory control purposes.

**Empty Element Sensors.** The empty element sensor senses the presence of a projectile in a magazine element. It is used as a double check of the inventory information to prevent loading a projectile into an already full magazine element. For this purpose an inductive proximity switch is used. This sensor is located as close as possible to the projectile load position to minimize timing delays.

**Magazine Transfer Solenoid.** This actuator initiates the action of the magazine transfer forks and selector gate to load a projectile into or out of the magazine. The movement and timing of this transfer mechanism is mechanically controlled and driven from the magazine motion.

**Transfer Engaged Interlocks.** Transfer engaged interlock switches on each magazine transfer mechanism sense when the transfer mechanism is shifted into the engaged position where magazine motion will cause the transfer forks to move to transfer a projectile into or out of the magazine. This information is used to verify projectile transfers, and to control magazine timing.

**Control Panel.** The XM1E5 control panel (figure 14) provides the primary operator interface to the XM1E5 electrical system. The controls on this panel are grouped in the following categories.

#### **System Power**

**Power Switch.** Controls power to the XM1E5 system.

**Power Indicator.** Indicates when power is on.

#### **Manual Controls**

These controls are not intended for use during normal upload/download operations. The function of this set of controls is to facilitate certain maintenance operations and to coordinate certain degraded (download) mode operations where a transfer (or total) power loss has been experienced.

**Manual/Auto Mode Control.** This toggle switch will normally be in the AUTO position for routine system operation. In the MANUAL position, this control enables the remaining manual control functions.

**Magazine Select.** This three position rotary switch allows the selection of either of the two projectile magazines.

**Conveyor Enable.** This switch enables the conveyor and may be used along with the magazine select for simultaneous conveyor and magazine operation.

**Manual Direction.** This three-position toggle switch determines the direction of operation (upload, download, center off) of the conveyor and or selected magazine.

**Rate Control.** This rotary switch controls the system magazine and conveyor rates in the manual mode. A separate deck on this same switch sends rate signal to the system computer in the auto mode.

### **System Controls**

**Start Transfer Switch.** Initiates the transfer of projectiles into or out of the XM1E5 system.

**Transfer Complete Switch.** Signals the system that the transfer of projectiles is complete. Conveyor and magazines will then stop when any transfer in process is finished.

**Rate Control.** Located on the same switch as the manual rate control and controls conveyor and magazine rates and accelerations.

**Emergency Stop Switch.** Stops conveyor and magazine motion. Similar to emergency stop switches located on the conveyor.

**Conveyor Deploy Switches.** Two momentary switches which control the conveyor suspension winch to raise or lower the conveyor.

**Terminal Message Indicator.** Calls the attention of the operator that an error or informational message is displayed on the terminal screen.

### **Terminal**

The terminal is comprised of a menu display screen which is used to display menus and messages and a set of key switches listed below which are used to control and select from these screen messages to control the operational modes of the system and enter orders for transfer.

**Numeric Keyboard (0-9).** Used to enter quantities of ammunition to be transferred or carried.

**Enter Key.** Used to accept the displayed entry or to display a new menu as prompted by displayed messages.

**Clear Entry.** Used to discard current entry.

**Menu Key.** Used to move back to a higher menu level.

**Scroll Key.** Used to move cursor box up or down to make selection from a menu.

**Page Key.** Used to display a new page of selections on a menu.

The menu display area is formatted such that the arrangement of information is consistent, regardless of the application (upload, download, menu selections, etc.). The display arrangement shown in figures 15 and 16 is representative of all of the primary upload/download displays. The display areas common to all of these applications include (as a minimum):

- Menu or operational task title, centered at the top of the display.

- Menu options/data field area in the central area.
- Procedure/prompt/message area at the bottom.
- Single line cursor box to designate a selected menu option or a selected munition.

## **SYSTEM OPERATION**

### **XM1E5 System Deployment**

#### **Vehicle Positioning**

To transition the XM1E5 system from transport mode to upload or download operational modes, the XM1E5 vehicle must first be appropriately positioned in relation to the mating vehicle or munitions pallet. The most critical vehicle positioning is required when the conveyor is to be interfaced with the Howitzer. Once positioned, the XM1E5 vehicle is placed in neutral with the engine running and the brake set. If transfer operations are to begin immediately, system power can be turned ON at the system control panel on the left side of the XM1E5.

#### **Power Connections**

The XM1E5 requires the use of an electrical power cable to obtain power from the host vehicle for all electrical operations. The electrical power cable for primary XM1E5 operations is permanently attached to the left side of the high level electronics unit. An auxiliary power connector located on the right side of the XM1E5 high level electronics unit may also be used to obtain auxiliary power from other available 24 vdc power supplies equipped with a standard NATO connector and a suitable jumper cable.

#### **Conveyor Deployment**

The XM1E5 system is capable of interfacing with various vehicles, pallets and even projectiles on the ground. The following conveyor deployment procedure is applicable to the Howitzer upload mode of operation.

#### **Projectile Transfer**

**Upload.** Routine upload of projectiles to the XM1E5 will normally involve uploading projectiles from pallets placed on either a M1074 PLS flatrack on the ground or a truck bed. For this most common upload mode, the crew procedure consists of performing the following actions:

- Turn system power ON at the control panel. \*
- On the control panel terminal select UP LOAD from MAIN MENU and BARCODE IDENTIFICATION and PROJECTILES from the SELECT AMMUNITION FOR UPLOAD menu. Figure 15 shows the menus used for an upload projectile operation using the barcode reader.
- Scan barcode labels on projectile pallets and verify that the correct projectile type, description, and full lot number appears on the UPLOAD PROJECTILES menu.
- Press START TRANSFER switch on control panel to initiate conveyor motion.

- Place projectiles base first onto load tray and slide forward until picked up by the conveyor. Continue until all projectiles on the pallet are loaded.

- Once the above actions are performed, the system controls will coordinate conveyor and magazine motion automatically. System logic will determine which of the two magazines and which of the carriers in each magazine each projectile is destined, based upon minimizing upload time while distributing the projectile mass relatively evenly. The projectile will either stop for the left magazine or continue into the right magazine, as determined by the logic. When a projectile approaches its hand-off position, the entire conveyor quickly decelerates and stops, then restarts after the hand-off is complete.

- Press TRANSFER COMPLETE switch to stop conveyor when the last projectile has been transferred to the magazine.

- Use the same procedure to scan and load additional pallets until all pallets are loaded or all spaces in projectile magazines are filled.

**Download.** Routine download of projectiles from the XM1E5 system will normally occur with the conveyor load tray deployed near the ground or into the howitzer receiving the ammunition. In this case, projectiles are deposited onto the load tray where they must be removed manually. The crew procedure for this download mode consists of performing the following actions:

- Turn system power ON at the crew station in the vehicle cab.

- On the control panel terminal select DOWN LOAD from Main Menu and PROJECTILES from the Select Ammunition For Download menu. Figure 16 shows the menus used for a download projectile operation using the barcode reader.

- Choose the types and quantities of items to be downloaded from the Download Projectiles menu displaying the type description and full lot number of all projectiles in the onboard inventory.

- Press START TRANSFER switch on control panel terminal to initiate magazine and conveyor motion.

- Manually remove projectiles as they arrive at the load tray.

- Once the above actions are performed, the system controls will again coordinate conveyor and magazine motion automatically. System logic will determine the order that chosen items are delivered based upon minimizing download time. If a projectile is not removed from the load tray before the next projectile arrives the conveyor will stop until the projectile is removed.

- Press TRANSFER COMPLETE switch to stop conveyor when the last projectile has been transferred to the load tray.

- If projectile are required in a specific order individual orders should be placed for each projectile type. When all of one type of projectiles have been delivered an order for the next type can be placed and the same procedure used to deliver those projectiles.

### **Inventory of Manually Loaded Propellant and Fuzes**

Propellant canisters and fuzes are manually loaded onto the XM1E5 system, however the inventory of these item is maintained electronically and is entered and displayed using the barcode reader and the control panel terminal.

**Upload.** The crew procedure for entering into inventory the manually loaded propellant and fuzes consists of performing the following actions:

- Turn system power ON at the control panel
- On the control panel terminal select UP LOAD from Main Menu and BARCODE IDENTIFICATION and PROPELLANT or FUZES from the SELECT AMMUNITION FOR UPLOAD menu. Figures 17 and 18 show the menus used for an upload propellant or upload fuze operation using the barcode reader.
- Scan barcode labels on propellant pallet or fuze container and verify that the correct type, description, and full lot number appears on the control panel terminal menu.
- Enter the quantity of the selected type which have been loaded and press ENTER to modify inventory.
- Scan additional bar-codes and enter quantities to add additional items to inventory.

**Download.** The crew procedure for removing from inventory the manually delivered propellant and fuzes consists of performing the following actions:

- Turn system power ON at the control panel
- On the control panel terminal select DOWN LOAD from Main Menu and PROPELLANT or FUZES from the SELECT AMMUNITION FOR DOWNLOAD menu. Figures 19 and 20 show the menus used for a download propellant or download fuze operation.
- Choose the types and quantities of items to be downloaded from the DOWNLOAD PROPELLANT or DOWNLOAD FUZES menu displaying the type description and full lot number of
- Enter the quantity of the selected type which have been delivered and press ENTER to modify inventory.

#### **Auxiliary and Maintenance Functions**

The following auxiliary functions are available to aid in operation and maintenance of the projectile handling systems and to provide for degraded modes of operation.

#### **Manual Control.**

The projectile magazines and transfer conveyor can be controlled manually by using the control panel manual controls. This may be initiated to perform maintenance functions or to download the system in the event of computer failure, as exAles.

**Built-in Test.** Built-in test (BIT) functions are included in the system software to test the functions of its processor and its interfaces. One of the handset maintenance menus will display the results of these tests.

**System Status.** A control panel terminal menu is provided to display system usage data such as total hours of operation and total number of projectiles transferred.

## **XM1E5 HEMTT INSTALLATION CRITICAL DESIGN ISSUES**

The SOW requires a detailed evaluation of all aspects of installing and operating an XM1E5 on two candidate host vehicles. A significant aspect of the baseline design is the requirement to provide manual propellant handling. The following discussion provides an analysis of all of the design approaches considered to meet the draft prime item development specification and significant alternatives that were considered in the study.

The HEMTT installation was established by PMAMMOLOG as the baseline system for the design analysis effort. As such, the system general arrangement was driven by available floor space and human factors considerations. Accessibility by the crew to propellant and fuze storage were important considerations in the determination of the best operational configuration.

Figure 1 illustrates the general arrangement of the XM1E5 system installed on the M977 HEMTT truck in the transport mode.

The analysis of the HEMTT installation includes a number of specific issues defined in the SOW and several others found to be of significant importance to the baseline design.

### **Module to Vehicle interface (Specification Paragraph 3.1.2.1.1 and 3.1.2.1.2)**

An early assumption provided by PMAMMOLOG was a strong desire to mount the system on the bed of existing M977 vehicles with a minimum amount of modifications required to the truck. This direction was followed to the maximum extent practical without incurring excessive cost or performance compromises. This approach limits a number of attractive alternative approaches which will be discussed briefly later in this section.

The HEMTT cargo bed is a steel structure consisting of removable front and back panels, 6 fold down side panels (3 per side), and 22 swivel tie-downs as shown in figure 21. The overall width of the vehicle is 96 inches which is critical to the packaging of the entire system. The baseline approach to creating an interface between the vehicle and the system was to remove all of the panels and swivel tie-downs to gain the maximum width and provide a means to secure the system structure to the cargo bed.

A special adapter block (figure 22) was designed to mount on the existing studs of the tie-downs that would use the same nuts to secure the block and a surface to support the lower structural members of the projectile magazines. The adapter block also contains a threaded hole for fasteners to join the system structure to the blocks.

The structure under the projectile magazines will consist of 1 inch thick material rather than the I-beam structure typically found under previous ARM prototype designs that were fitted to track type vehicles with deep sections between the sponsons compared to a "flat" cargo bed surface. Observations

of actual HEMTT cargo beds suggest that a conformal shim may be required to achieve a flat mounting surface to join the rigid magazine structure and the lower cargo bed structure.

The only external electrical interface with the HEMTT will be at the existing NATO connector currently used for auxiliary power connections with other vehicles. To obtain power from various other host vehicles that are equipped with the common NATO connector and 24 vdc power a standard jumper cable or the main power cable may be used.

## **Electrical Controls and Software**

A number of critical design issues exist regarding the electrical controls and software that were not specifically addressed in the SOW. The following discussion covers those critical design issues.

### **Control Panel**

The remote handset of previous ARM systems has been eliminated, and its functions as primary operator interface as well as the functions of the maintenance control panel have been combined into a single fixed control panel. This control panel will be less susceptible to loss or damage than with a detachable handset, and will simplify the cables and minimizes the size of the cable which must be run through the flexible joints of the conveyor.

On the HEMTT the control panel will be located on the bottom left side of the magazines aft of the conveyor. It will fold down to a level below the bed of the vehicle so that it can be operated from the ground. When not in use it will fold up into a weather tight box.

The control panel display will be similar to the 40 character by 16 line display of the ARM II/Uni system's handset and will use similar menus to select operating modes and types and numbers of projectiles to be transferred. Menus will be provided for controlling the inventory of the manually loaded propellant and fuzes. Data read from bar-codes on pallets or fuze boxes will be displayed for verification, and means of manually selecting munitions type will be provided if bar-codes are not available.

To keep the control panel design as simple as possible no alpha-numeric keyboard has been provided that would allow the lot numbers to be manually entered. Menus of previously entered lot numbers could be displayed for selection. Since fuzed projectiles will not be carried in the XM1E5 projectile and fuze information does not need to be displayed simultaneously on the menu. This leaves room for the full 13 or 14 character lot numbers to be displayed.

### **Component Packaging**

The electrical controls are packaged in two boxes; the high level unit and the low level unit. This allows for the separation of the high current motor controls and power switching circuits which are generators of electrical noise, from the computer related circuits which are typically most sensitive to interference from this noise. Within these boxes the components will be mounted in such a way that heat generated from these components will be conducted to the outside of the box where it can be carried away by the heat dissipation system. The mounting position of the high level unit and low level unit take advantage of unused space above the transfer mechanisms. This position is also close to the motors and the vehicle power connector which will minimize the lengths of the high current cables.

## **Heat Dissipation**

The high level unit which contains the motor controls and high current switching signals will dissipate relatively large amounts of power which will be converted to heat. This heat must be removed from the system to prevent the electrical controls from overheating. The relatively small temperature difference between the maximum ambient air temperature in which a military vehicle must operate and the maximum operating temperature of the electrical components makes heat transfer systems less efficient, and precludes the use of a passive system based on natural convection or radiation for cooling.

A forced convection system similar to ARM II/Uni and ARM II/LP will be used in the XM1E5 electrical control high level unit. In this system all major heat producing components will be mounted inside a sealed enclosure on a heat conducting plate which forms one side of this enclosure. On the outside of this plate will be attached heat dissipating fins enclosed by ducts through which air will be forced to carry away the heat.

The low level unit which contains the computer system and low power controls also has power to be dissipated but at a much lower level. The low level unit may be cooled by natural convection if paths for natural air flow can be provided or may also be connected to the forced convection system.

## **Sensor Contamination**

Several optical beam type sensors are used to detect the position of projectiles as they are transferred to and from the magazines. The nature of the sensors makes them susceptible to possible contamination from sand and dust which could block the light beam and prevent the sensor from operating. No other sensor type has been found which would eliminate this problem and also provide the reliable accuracy necessary and not interfere with the transfer.

To minimize the contamination problem sensors have been selected which have high excess gain which will cause the beams to penetrate severe contamination. Sensors will be protected within the system as much as possible to prevent contamination, and easily removable access doors will be provided so that the sensors can be cleaned periodically.

While the system is transferring projectiles continuous checks will be made of the sensors operation by observing the sequence of sensor signals as projectiles are transferred. A sensor failure will cause the system to stop and display a message on the control panel identifying the faulty sensor which could then be cleaned if necessary.

## **Module Power Requirements (Specification Paragraph 3.1.2.1.3)**

A major concern of this study was minimizing the power consumption of the XM1E5 system in order to make it compatible with all of the expected mating vehicle 24 vdc power supplies. The following discussion addresses the power distribution, magnitude and potential electrical power supply requirements for the host vehicle or mating vehicles.

## **Power Distribution**

Experience gained through testing the ARM II/Uni and ARM II/LP prototype systems has identified the primary sources of power consumption in the current magazine and conveyor configurations. Electrical power supplied to the XM1E5 is divided into high and low level components. The high level power is further distributed to 4 motors that are used to activate the 2 projectile magazines, transfer conveyors and a winch to hoist the conveyor.

The load that the magazine drive motors must overcome is primarily the frictional drag of the bucket carriers and some work lifting projectiles in the magazines. A significant power drain is also attributable to losses through multiple gear passes in the drive train.

The largest single contributor to the drive train losses on early prototype systems was the main drive gearbox that was lubricated with oil. Low temperatures cause increased oil viscosity's and excessive power loss. During the ARM II/Uni development contract a series of tests were conducted on a typical commercial gearbox using different types of oil to determine the benefits of using synthetic lubricants. The results showed that significant improvements could be achieved, however a better approach would be needed to further reduce the main drive power losses.

A search was made of currently available commercial and military power transmission gearboxes in the capacity suited to the XM1E5 system requirements. The most promising candidate drives were found to be offered by Bayside Precision Gearheads located in Port Washington, NY. The gearhead designs offered by Bayside are high efficiency units with grease lubrication. A valuable feature of their standard design is the rated input speed capacity of up to 4,000 RPM. This allows higher motor speeds than most other commercial gearboxes with the benefit of keeping motor torque and current down.

The conveyor drive selected for the XM1E5 is a right angle gearhead design also offered by Bayside. Its compact size was needed to enable packaging it close to the conveyor components on the left side hand-off assembly structure.

## **Power Estimate**

A significant amount of actual test data has been gathered for the ARM II/Uni and ARM II/LP prototype systems that is available for analysis of power consumption. Rather than attempt to make a purely analytical estimate of the potential XM1E5 power consumption it was determined that extrapolation of empirical test data would produce the most accurate result.

The most recent and similar test data generated can be found in the ARM II/LP test report dated 5 May 1995. This report includes performance test results for a 64 projectile side-by-side magazine system with a magazine mechanism very similar to the XM1E5 design concept. A significant difference exists in the design and complexity of the conveyors, so a special effort was made to account for this and other known variables.

A power consumption estimate was made for peak power and average power of the ARM II/LP prototype system and then factored to suit the XM1E5 system capacity and expected conveyor differences. The resulting values were used to set the power supply requirements that were used in the Draft Prime Item Development Specification A10042.

## Peak Power

**ARM II/LP Test Data Analysis.** At the beginning of the ARM II/LP test, empty system power measurements were taken of the individual subsystems (conveyor and magazines). Later, once actual testing with projectiles began, all power data was taken at the total system level only. Therefore, to approximate subsystem power requirements when projectiles are in the system, the empty system test data is utilized to proportion the total power between the subsystems.

The following measured power consumption data for an empty system was extracted from the table on page 22 of the ARM II/LP test report.

Table 1. ARM II/LP peak power for an empty system.

Subsystem	Peak Start-Up	Less Power On	% Total Peak Start-Up
Power On	0.3 kW	-	2%
Conveyor Peak	8.5 kW	8.2 kW	57%
One Magazine Peak High Speed Search	3.2 kW	2.9 kW	
Two Magazine Peak High Speed Search		5.8 kW	41%

Since the conveyor and magazine peak power included "Power ON" drain, 0.3 kW was deducted from each subsystem. Since these values were for an empty system, it was assumed that the values for a full system would be proportional.

Maximum power consumption generally occurred for a loaded system during the upload operations. Figure 20 of the ARM II/LP test report shows an average peak power of 14.5 kW. Using the proportions from table 1, the maximum peak power was allocated as follows:

Power On	0.3 kW
Conveyor	8.3 kW
Magazines	<u>5.9 kW</u>
Total	14.5 kW

**XM1E5 Peak Current Estimate.** Scale factors were applied to the ARM II/LP test data in order to account for the differences in conveyor design and magazine capacity planned for the XM1E5 system. Since the conveyor is expected to be shorter and have significantly less frictional drag, a factor of 60% of the ARM II/LP test data was applied to the 8.3 kW peak power with the result of 5.0 kW. The scale factor for the magazines was estimated to vary as  $(N/64)^{1/2}$  where N= the magazine capacity, with the result of 7.4 kW for N = 100.

The total peak power estimate, including "Power On" for the 100 round XM1E5 system is 12.7 kW. This equates to 635 As. at the minimum supply voltage of 20 volts. In order to set a realistic value for the Draft Prime Item Development Specification, the 635 As was rounded to 640 As.

## Average Power

**ARM II/LP Test Data Analysis.** The method to estimate the average power draw for the XM1E5 was also based on empirical data from the ARM II/LP tests. Examination of the data indicated that the best operating scenario to use for this analysis were “uninterrupted” up and down load cases. This minimizes the effects of “Power On” losses and reduces the number of variables to take into account. The following table is based on data extracted from figure 23 of the ARM II/LP test report.

Table 2. ARM II/LP average download power consumption.

Test #	# Tests	# Rounds Downloaded	Average Power (kW)
81A - 98E	38	8	4.66
65A - 94C	14	16	4.44
80A - 98A	8	32	4.10
99A	1	64	3.71
99 (one upload)	1	64	4.22
	62		4.52 (weighted average)

Using the table on page 22 of the ARM II/LP test report for the steady state power of the conveyor and the magazines the following relationships were derived:

Table 3. ARM II/LP average power distribution for an empty system.

Subsystem	Average	Less Power On	Quantity	Net Average Steady State
Power On	0.3 kW	-		
Conveyor (full rate)	3.4 kW	3.1 kW	1	3.1 kW
Each Magazine (high speed search rate)	2.5 kW	2.2 kW	2	4.4 kW
Each Magazine (transfer rate)	0.9 kW	0.6 kW	2	1.2 kW

Based on typical operational scenarios observed in the ARM II/LP tests, it is assumed that the magazines are operating at the transfer speed 80% of the time and at high speed search 20% of the time. Thus the average power for the magazines is  $(4.4) 0.2 + 1.2 (0.8) = 1.84$  kW.

Table 4. Conveyor and the magazines power consumption ratio.

Subsystem	Average Power	% Calculated	% Rounded
Conveyor	3.1 kW	62	60
Magazines	1.84 kW	38	40

From table 2 above calculated average power of 4.52 kW, it can be assumed that the low level "Power On" will be a constant 0.3 Kw. The balance of the power was distributed as follows:

$$\text{Conveyor} = 0.6 (4.52 - 0.3) = 2.53 \text{ Kw}$$

$$\text{Magazines} = 0.4 (4.52 - 0.3) = 1.69 \text{ Kw}$$

Therefore, for the ARM II/LP tests, the average power is proportioned as follows:

Power On	0.30 kW
Conveyor	2.53 kW
Magazines	<u>1.69 kW</u>
Total	4.52 kW

**XM1E5 Average Current Estimate.** Based on the methodology and empirical data extracted from the ARM II/LP test results, the power for the XM1E5 was estimated as follows:

- Conveyor Average Power = 0.6 (ARM II/LP)  
= 1.52 Kw
- Magazines Average Power = ARM II/LP (N/64)<sup>.75</sup> (N = XM1E5 Payload)  
= 1.69(100/64)<sup>.75</sup>  
= 2.36 Kw
- Low level Power = 0.30 Kw
- Total Average Power = 4.18 Kw

The total average power estimate for the 100 round XM1E5 system is 4.18 Kw. This equates to an average current draw of 209 A at the minimum supply voltage of 20 volts. This is rounded to 210 As for the Draft Prime Item Development Specification.

### Power Supply Requirements

The M977 HEMTT host vehicle comes with a standard 24V start / 24V lighting electrical system powered by 4 - 12 volt 120 A-hour batteries and a 65 A alternator. An optional 200 A alternator package is available for certain HEMTT variants that would boost the recovery rate of the batteries.

The following analysis estimates the performance capability of the HEMTT battery / alternator system at three different temperatures given a typical field operating scenario with the 64 projectile XM1E5 system. In this case there are 4 batteries and 10 amps are used by the truck and are not available to power the XM1E5. The starting condition is with fully charged batteries and an empty 64

projectile magazine. Performance of the alternator and batteries was extracted from published technical data from equipment manufacturers .

Table 5. Battery / alternator performance of the baseline ARM II/Uni system on the standard M977 HEMTT truck.

Activity	Net Battery Charge (Amp - Min.) (1)		
	75 °F	32°F	- 20°F
<b>1) Upload 64 Projectiles at high idle (1400 RPM)</b> Generate (36 - 160) x 5 min.	-620	-620	-620
<b>2) Wait at low idle another 5 minutes to get stowed</b> Generate (46-10) x 5 min. 4 x 288 A-m absorbable at 75°F 4 x 96 A-m absorbable at 32°F 4 x 4 A-m absorbable at -20°F	180	180	16
<b>3) Drive for 15 minutes to delivery point</b> Generate (60-10) x15 min. 4 x 806 A-m absorbable at 75°F 4 x 288 A-m absorbable at 32°F 4 x 12 A-m absorbable at -20°F	825	825	48
<b>4) Stop #1 and deliver 20 rounds (2 min. high idle)</b> Generate (36 - 160) x 2 min.	-248	-248	-248
<b>5) Drive for 5 minutes</b> Generate (65-10) x 5 min.	275	275	16
<b>6) Stop #2 and deliver 20 rounds (high idle)</b> Generate (65-10) x 5 min.	-248	-248	-248
<b>7) Drive for 5 minutes</b> Generate (65-10) x 5 min.	275	275	16
<b>8) Stop #3 and deliver 24 rounds (high idle)</b> Generate (65-210) x 2.4 min.	-261	-261	-261
<b>9) Drive for 15 minutes to resupply point</b>	825	825	48
<b>10) Wait 10 minutes at idle before next upload</b> Generate (46-10) x10 min. 4 x 288 A-m absorbable at 75°F 4 x 96 A-m absorbable at 32°F 4 x 4 A-m absorbable at -20°F	360	360	32
<b>Scenario Totals (2)</b>	<b>1363</b>	<b>1363</b>	<b>-1201</b>

(1) Amp values are based on 20 vdc worst case due to battery load.  
 (2) Positive number means that batteries will stay charged.  
 Negative number means that batteries drain from mission.

The following analysis estimates the performance capability of the HEMTT battery / alternator system at three different temperatures given a typical field operating scenario with the 100 projectile XM1E5 system.

Starting Assumptions: 100 Amp alternator, 10 amps used by truck, there are four 12 V-120 A-h batteries, Idle speed produces 70 amps. The system starts empty but with fully charged batteries.

Table 6. Battery / alternator performance with the 100 round XM1E5 on the standard M977 HEMTT truck

Activity	Net Battery Charge (Amp - Min.) (1)		
	75 °F	32°F	- 20°F
<b>1) Upload 100 Projectiles at high idle (1400 RPM)</b> Generate (100-210) x 4.5 min.	-880	-880	-880
<b>2) Wait at low idle another 5 minutes to get stowed</b> Generate (70-10) x 5 min. 4 x 288 A-m absorbable at 75°F 4 x 96 A-m absorbable at 32°F 4 x 4 A-m absorbable at -20°F	300	300	16
<b>3) Drive for 15 minutes to delivery point</b> Generate (100-10) x15 min. 4 x 806 A-m absorbable at 75°F 4 x 288 A-m absorbable at 32°F 4 x 12 A-m absorbable at -20°F	1350	1152	48
<b>4) Stop #1 and deliver 25 rounds (high idle)</b> Generate (100-210) x 2 min.	-220	-220	-220
<b>5) Drive for 5 minutes</b> Generate (100-10) x 5 min.	450	384	16
<b>6) Stop #2 and deliver 50 rounds (high idle)</b> Generate (100 -210) x 4 min.	-440	-440	-440
<b>7) Drive for 5 minutes</b> Generate (100-10) x 5 min.	450	384	16
<b>8) Stop #3 and deliver 25 rounds (high idle)</b> Generate (100-210) x 2 min.	-220	-220	-220
<b>9) Drive for 15 minutes to resupply point</b>	1350	1152	48
<b>10) Wait 10 minutes at idle before next upload</b> Generate (70-10) x10 min. 4 x 518 A-m absorbable at 75°F 4 x 192 A-m absorbable at 32°F 4 x 8 A-m absorbable at -20°F	600	600	32
<b>Scenario Totals</b>	<b>2740</b>	<b>2212</b>	<b>-1584</b>

(1) Amp values are based on 20 vdc worst case due to battery load.  
(2) Positive number means that batteries will stay charged.  
Negative number means that batteries drain from mission.

## Module to Howitzer Interface (Specification Paragraph 3.1.2.1.3 & 3.1.2.2)

### Host vehicle attitude.

During rearm operations the M977 HEMTT host vehicle with the XM1E5 system must maneuver into a position to the rear of the Howitzer that will cause the conveyor to be aligned with the center of the rear door. Since the deployed conveyor has a fixed length, the distance between the vehicles must be closely controlled to minimize manual projectile handling while rearming the Howitzer. Figure 23 shows the proximity of the Howitzer and the XM1E5 host vehicles producing a conveyor angle of  $20^\circ$  on level ground. This angle places the center of the projectiles at a convenient height for crew lifting operations.

Figure 24 shows the conveyor alignment with the extreme heights encountered with the mating vehicles specified in the SOW. The greatest conveyor elevation required is to clear the side panels of the M977 HEMTT cargo bed producing an angle of  $+15^\circ$ . The lowest angle of depression is  $20^\circ$  when uploading from the M1077 flatrack on the ground and the center of the projectile on the load tray at 28.4 inches above the ground.

If the load tray were set on the top surface of the M1077 flatrack on the ground, the center of the projectile on the load tray would be at 17 inches above the ground creating a slope of  $29^\circ$  from the horizontal. (See figure 24a). A compromise angle of  $25^\circ$  will be used for the following discussion as a practical limit with both vehicles on level ground.

As the side slope roll angle of the mating vehicles goes to the  $\pm 20\%$  extremes specified in the SOW, see figure 25, the conveyor angle relative to gravity changes from  $11.3^\circ$  to  $36.3^\circ$ . It is anticipated that deployment of the conveyor at the specified host vehicle slope of  $20\%$  will not be achievable without adding excessive conveyor length to reduce the angle relative to gravity.

A more realistic side slope operating condition would be at  $10\%$  for both mating vehicles. At a  $\pm 10\%$  side slope roll angle of the mating vehicles, the conveyor angle relative to gravity changes from  $19.3^\circ$  to  $30.7^\circ$ . If local ground conditions exceed the  $10\%$  slope it is recommended that the vehicles move to a more suitable terrain for ammunition transfer operations.

### Alignment with mating vehicle

**Distance away from mating vehicle.** The distance between the mating vehicles varies as a function of the type of vehicle and the conveyor angle. A typical distance between the XM1E5 host vehicle left side and an M977 HEMTT or M1074 PLS cargo bed edge is 10 ft.  $\pm 1$  ft. The positioning of the XM1E5 host vehicle left side and the rear door of the M109A2/A3 and M109A4/A5 Howitzers will be 11 ft.  $\pm 1$  ft. The positioning of the XM1E5 host vehicle left side and the rear door of the M109A6 Howitzer will be 13 ft.  $\pm 1$  ft. Particular care will be required to avoid interference with the overhanging bustle on the M109A6 Howitzer during conveyor deployment.

**Lateral misalignment.** The specified lateral misalignment of  $\pm 1$  foot will be a factor in the initial vehicle positioning. Experience with the ARM II Uni prototype system indicates that vehicle drivers can easily learn to meet this requirement with or without a guide person. The M1074 PLS host vehicle is longer than the M977 HEMTT host vehicle and may require more practice to judge distance. A guide person may be required to help prevent lost time when aligning the vehicles.

**Angular misalignment.** The specified angular misalignment of  $\pm 10\%$  will not present any particular problems due to the fact that the final munitions transfer between vehicles will be a manual operation. Any variations in positioning of the end of the deployed conveyor will be compensated for by the crew.

### **Payload Capacity (Specification Paragraph 3.2.1.1)**

#### **Projectile Payload**

The specified capacity of 100 projectiles was achieved by creating a very compact and efficient use of the existing space on the bed of the M977 HEMTT. The side-by-side approach utilized in the ARM II/LP prototype system demonstrated the advantages of this packaging compared to the previously considered end-to-end configuration used in the ARM II/UNI system design. In order to minimize the technical risk of unknowns, a 4 row high arrangement similar to the ARM II/LP system was used. The overall length of the magazine was increased 34.2 inches in order to package the required 100 projectiles.

The resulting size of the projectile magazine and transfer unit provided a reasonable work area for the crew to safely work on the bed of the truck performing manual propellant and fuze handling operations. Figure 26 shows the space used by the XM1E5 on the M977 HEMTT cargo bed.

#### **Propellant Payload**

The specified propellant storage capacity of 100 propellant charge containers played a significant role in determining the available space for the projectile magazines and crew work area. Based on discussions with PMAMMOLOG the minimum 100 propellant charge capacity was expanded to permit storage of up to 111 containers. Space is available for 2 pallets of M13 or M14 containers secured by existing tie-downs and straps. Provisions for tie-down of another 11 loose propellant containers on top of the projectile magazines was also designed to increase the versatility of the XM1E5.

Provisions to store an unspecified quantity of fuze boxes was investigated in addition to the propellant storage. 16 boxes of fuzes were placed on top of the projectile magazines in a location that would permit easy access by the crew during resupply operations. The construction of the fuze storage racks will accommodate both tall and short boxes and have features to resist transport loads.

#### **HEMTT Load Handling System (LHS). Alternatives**

The HEMTT Load Handling System (LHS), see figures 27, 28 and 29 currently under development by Oshkosh Truck Inc. presents a viable alternative host vehicle for the XM1E5 system mounted on a basic flatrack. The primary payload limitation (with self recovery winch, w/o crane) is the 17,000 pound weight rather than flatrack floor space.

Three alternative overall system/host vehicle approaches are discussed below with their primary advantages and disadvantages. The payload capacity of the HEMTT LHS host vehicle can be approached by making a reduced 80 round HEMTT sized XM1E5, a 100 round HEMTT sized XM1E5 with a trailer or a partially filled 130 round PLS XM1E5.

**LHS With 80 Round Load.** Figures 30 and 31 show an 80 projectile XM1E5 system on the M1077 flatrack and HEMTT LHS host vehicle. This general arrangement provides ample work space for the

crew and storage space for other miscellaneous cargo, however, the weight limitation creates a smaller magazine and would reduce magazine structural commonalty with the 130 round PLS XM1E5.

**LHS With 100 Round Load and PLS M1076 Trailer.** Figures 32 and 33 show a more attractive alternative configuration uses the same basic 100 round HEMTT sized XM1E5 system as described for the M977 HEMTT host vehicle in conjunction with a PLS M1076 trailer dedicated to propellant and fuze storage. The truck/trailer approach increases the combined payload capacity to 100 complete rounds with room for extra propellant or miscellaneous cargo.

The PLS M1076 trailer has the capability/advantage of current Army inventory availability and the potential for loading propellant and fuzes at a different time and/or remote location. The 100 round HEMTT sized XM1E5 system would require unique mounting features for the M1077 flatrack interface and the control panel would have to be accessible by an operator standing on the cargo bed similar to the XM1E5 system for the M1074 PLS host vehicle and M1077 flatrack (described later).

The primary disadvantage of this approach is the vehicle positioning with respect to the Howitzer during rearm operations.

**LHS With 100 Round Load and HEMAT M989A1 Trailer.** Figures 34 and 35 show another alternative configuration using the same basic XM1E5 system as described for the M977 HEMTT host vehicle in conjunction with a HEMAT M989A1 trailer dedicated to propellant and fuze storage. This approach increases the combined HEMTT LHS / trailer payload capacity to 100 complete rounds with room for extra propellant or miscellaneous cargo.

The HEMAT M989A1 trailer has the capability/advantage of current Army inventory availability and the potential for loading propellant and fuzes at a different time and/or remote location. The 100 round HEMTT sized XM1E5 system would require unique mounting features for the M1077 flatrack interface and the control panel would have to be accessible by an operator standing on the cargo bed similar to the XM1E5 system for the M1074 PLS host vehicle and M1077 flatrack (described later).

The primary disadvantage of this approach is the vehicle positioning with respect to the Howitzer during rearm operations.

**LHS With Partial Load in 130 Round XM1E5.** Figure 36 shows a 130 projectile XM1E5 system on the M1077 flatrack and HEMTT LHS host vehicle. This general arrangement is identical to an XM1E5 system on the M1077 flatrack and M1074 PLS host vehicle (described later).

The primary advantage of this approach is the commonalty and inter-operability of the XM1E5 between two potential host vehicles.

The primary disadvantage of using this configuration is that the usable payload of the XM1E5 is only 73 complete rounds driven by the weight limitation of the HEMTT LHS.

#### **HEMTT with Two Row High Magazine**

Another concept was studied that consisted of a single loop magazine conveyor system. Figures 37, 38 and 39 show a 100 round magazine on the HEMTT cargo bed. This concept places the propellant on top of the projectile magazines for storage.

The advantage of this concept is the simplicity of the magazine design. The primary disadvantage is the platform height above the ground creating a potential safety hazard for crew members handling propellant.

### **Conveyor Layout (Specification Paragraph 3.2.1.2)**

The side-by-side projectile magazine arrangement created a serious need for a compact method to stow the conveyor within the vehicle envelope dimensions. A quick look at previous designs with swing out conveyors proved that they would exceed the envelope by as much as 24 inches on the left side of the vehicle.

#### **Projectile Re-orientation**

The most significant new design to evolve from this study was the fold out conveyor with a fixed extended length. In order to create the needed volume for the stowed conveyor the functional projectile guides and shifting forks in the left side hand-off assembly had to be moved approximately 10 inches to the right.

To accomplish this, the projectiles were re-oriented so as to point to the left side of the magazine i.e. 180° change from the ARM II/LP system. This orientation results in the delivery of projectiles nose first to the Howitzer as did the ARM I system. Figure 40 shows the space gained by re-orienting the projectiles in the left side hand-off assembly.

Another impact of the projectile re-orientation was the need to redesign the bucket carriers to create a mirror image of the clamping features similar to that of the ARM II/UNI forward magazine buckets.

#### **Fixed Length Conveyor**

The length of the conveyor was confined by the 96 inch width of the host vehicle envelope. A two section fold-out conveyor was designed to fit in the space envelope with special consideration given to the European tunnel and AC130 aircraft profiles. See figure 41.

Experience gained on the ARM II UNI and ARM II/LP prototype system development projects indicated that significant design complexity and cost are implicit in extendible conveyors. The approach for this study therefore concentrated on a fixed length conveyor that could adequately mate with each of the vehicles defined in the SOW.

The need for an exact location of the load tray was considered within vehicle positioning capability since the intended projectile transfer to or from the load tray of the XM1E5 system will always be handled by a crew person on foot.

#### **Conveyor Traction on Projectiles**

Based on the assumption that a fixed length conveyor will meet system requirements, the next critical design issue became that of generating adequate traction between the projectiles and the conveyor at the slopes required to mate with all of the mating vehicles.

**Design Constraints.** Experience gained on the ARM II UNI and ARM II/LP prototype systems indicate that dual gear belt conveyors with high traction surfaces work on slopes up to 25° when clean

and dry. After the traction surface becomes wet and/or covered with dirt the working slope typically was reduced to approximately 15°.

Observations of working ARM II UNI and ARM II/LP conveyors indicates that the "wedge angle" between the belts plays a significant role in adding to the effective coefficient of traction on the projectiles. Two negative factors result from increasing the wedge angle i.e. increased conveyor power consumption and increased complexity in the drive train.

Figure 24 shows that the extreme slope of the recommended conveyor would be as much as 20° with the host vehicle on a horizontal surface. As the relative angle of the mating vehicles worsens, so does the traction between the projectiles and the conveyor as shown in figure 24a.

**New V-groove Drive Elements.** A new design approach was needed to improve the high angle traction performance since the previously used conveyor designs failed to adequately grip the projectiles under adverse environmental conditions, Figure 9 shows a cross-section of a new design considered adequate to achieve the increased traction required.

The new design consists of a series of powered V-grooved elements with high traction rubber sleeves. By having two opposing deep V-groove traction elements mounted on the same driven shaft the wedging forces add to the apparent traction on the projectiles without adding the power consumption.

The issue of driving the V-groove elements significantly adds to the number of moving parts when compared to belts. A benefit of this approach is that each set of V-groove elements is identical and is suitable for cost effective high volume production methods.

Transferring the power through the folding hinge joint between the stub and outer conveyors was a special challenge of this design. Figure 42 shows how the conveyor chain drive is offset to a sprocket on the center of the conveyor hinge joint.

### **Load Tray**

The load tray concept designed for the XM1E5 system is a hinged configuration mounted on the end of the outer conveyor structure. The operational angle setting is achieved with an incremental adjustment of approximately 20° using the compression member located under the load tray frame. Figure 43 shows the adjustment extremes designed into the load tray support fittings.

When a projectile or other weight is added on the load tray, it is sensed by an elastomeric element that is forced to deflect in compression under load. A simple mechanical linkage (not shown) translates the deflection motion to an electrical switch located in the outer conveyor structure. This design approach was successfully tested on the ARM II/LP prototype system load tray.

### **Projectile Slope Transitions**

**Load Tray Transition.** A particular design issue arises at the slope transition of the projectile path from the load tray to the outer conveyor. Since the projectile nose points away from the XM1E5, a roller was added to prevent the corner of the projectile base from damaging the first conveyor traction element contacted. This design approach was successfully used on the FAASV conveyor to account for unknown human variables in launching of the projectiles onto the conveyor from the load tray.

As the projectile transitions from the outer conveyor to the load tray, its nose can contact the load tray liner surface. Assuming that the projectiles will not be fuzed at this time, sliding contact with the load tray liner should cause no damage and was deemed acceptable for this design approach.

When the conveyor is elevated to its maximum operational slope, a concern exists regarding the lateral control of the projectile. Figure 43 shows a potentially unstable condition unless side projectile guides are added to the lower end of the outer conveyor.

At some future time if fuzed projectiles were to be planned for use in the XM1E5 it would be advisable to change the design of the load tray to ease the potential for fuze damage by adding rollers or a non-powered belt.

#### **Stub Conveyor Transition.**

When the conveyor is depressed to its maximum operating slope, a similar condition to the elevated load tray transition exists at the stub conveyor interface to the hand-off conveyor. Figure 44 shows the extreme conditions of the transition and the apparent need for additional projectile guides on the side of the conveyor joint.

When the conveyor is elevated to its maximum operating slope, the projectile nose comes in contact with the traction elements. Figure 45 shows the close proximity between the projectile nose and the traction elements of the stub conveyor. Assuming that the projectiles will not be fuzed at this time, light contact with the rotating traction elements should cause no damage and was deemed acceptable for this design approach.

A roller similar to the one discussed at the load tray transition was considered but deemed unnecessary since the speed of the projectile is controlled by the mechanism rather than a human with unknown strength.

#### **Safety.**

In order to provide crew safety from moving parts, a protective chain guard is needed over the chains and sprockets exposed to operators during normal operations. At the hinge joint an overlapping surface may be used to prevent exposure during deployment and stowage of the conveyor if deemed a hazardous situation. The addition of such a cover over the hinge joint would likely add to the stowed width of the conveyor and create a problem with the envelope.

Emergency stop switches (E-stops) are needed along each side of the outer conveyor near the load tray to provide ready access to the operators

A potential hazard may exist during the manual deployment of the conveyor if the operator were to lose his footing causing the outer conveyor to fall to the ground by gravity. The best precaution for such a potential accident would be to use two operators during the deployment of the outer conveyor rather than designing a costly mechanism to limit its rate of fall.

## **Man-Machine Interface (Specification Paragraph 3.2.1.2, 3.2.1.3, 3.2.1.6 and 3.2.1.8)**

### **Deployment and Stowage (Specification Paragraph 3.2.1.2.1)**

The deployment and stowage of the transfer conveyor can be accomplished easily by two operators and by one under emergency conditions. One operator is needed to activate the electric winch while the second operator stands on the ground and unfolds the outer conveyor section during the deployment operation. Figures 46 - 52 show several stages of the conveyor deployment operation described below:

The electric winch when activated automatically causes deployment of the stub conveyor to an extreme down position, (figure 47). The initial force required to cause the stub conveyor to rotate away from the XM1E5 comes from stored energy in a spring. The extreme down position of the stub conveyor is intended to place the center of gravity of the outer conveyor and load tray as low as possible without danger of the outer conveyor accidentally going over center.

The outer conveyor is manually rotated approximately 155° down to the ground by one or two operators. (figures 48 - 51) The maximum effort to accomplish this task should not exceed the allowable human factors requirements since the estimated weight of the conveyor at the outer end of the grab bar is estimated to be ~ 65 pounds when the outer conveyor is in the horizontal position.

The final positioning of the outer end of the conveyor and load tray for the angle best suited for the mating vehicles is accomplished by a remote control for the electric winch and manual adjustment of the load tray support strut.

The operations needed to stow the conveyor are essentially the reverse of the deployment sequence.

### **Height Range (Specification Paragraph 3.2.1.2.2)**

The recommended operational height range for the center line of the projectile on the load tray ranges from 17 to 110 inches above the host vehicle ground plane in contrast to the 6 to 84 inch range specified.

Normally, operators prefer to carry heavy projectiles at arms length or at waist height from the working platform when not using a lifting hook. When using a lifting hook to transfer projectiles from a pallet to the load tray the lowest position usually results in the least amount of manual lifting.

For reasons discussed above in issue # 5 under "Design Constraints" it is important that the extreme conveyor slopes be minimized. Observations of operators up and down loading projectiles indicate that the 6 inch requirement is impractical from a human factors standpoint.

In a typical case of loading projectiles from the deck of a flatrack on the ground, the bed is 10 inches above the ground level placing the center of the projectiles on the load tray approximately 17 inches above the ground with a conveyor slope of 29°. (See figure 53). The practical upper limit occurs with the bottom of the load tray just clears the top of the HEMTT side panels during transfer of projectiles from the HEMTT cargo body. See figure 54.

### **Projectile Orientation (Specification Paragraph 3.2.1.3.2 and 3.2.1.6.1)**

For reasons stated above in issue # 5 under "projectile re-orientation" the planned XM1E5 system will accept projectiles with the base towards the XM1E5. PMAMMOLOG agreed that the requirement in the draft specification for projectile orientation was not absolutely fixed and that the recommended approach would not degrade operational performance.

### **Identification (Specification Paragraph 3.2.1.3.4)**

The use of a militarized barcode reader will be used to identify the projectile information contained on LOGMARS labels IAW Appendix G of MIL-STD-129L located on palletized unit loads. The information will be conveyed to the control system for building the inventory data base of the XM1E5.

One of the primary issues regarding the use of the barcode reader is how the data is transmitted to the system controller. If a wire cable is used for real time communications, then it must be long enough to reach all of the pallets being read. This long cable will also have to be stowed easily in a convenient location for easy access.

An alternative approach would be to store the data collected by the barcode reader that is self contained and later feed the data by a short cable to the system controller. This approach makes data collection easy but would complicate the inventory management of the controller since it needs to know what type of projectile is being loaded before it is placed into a magazine bucket carrier. A means would have to be devised to manually signal the controller that a new type of projectile is being loaded.

A better approach would be a barcode reader that could transmit a real time short range radio signal to the XM1E5 controller. This approach would eliminate the long cable and/or the manual sequencing required by the previously discussed methods. An new concern for the security of this approach would have to be investigated.

### **Upload Rate (Specification Paragraph 3.2.1.5.3)**

The mechanism planned for the XM1E5 will be capable of up load rates of up to 20 projectiles per minute. As a practical matter, the crew size, degree of fatigue and the environmental conditions will determine the actual upload rate. It is anticipated that a crew of 4 may be able to work at a rate of 10 projectiles per minute for 10 minutes.

### **Projectile Download (Specification Paragraph 3.2.1.6)**

All of the SOW requirements for this section will be met by the mechanism planned for the XM1E5. Experience with the ARM II/Uni and the ARM II/LP prototype systems indicates the equipment will meet or exceed these requirements.

### **Ammunition Inventory (Specification Paragraph 3.2.1.8)**

The ammunition inventory system will collect the data available on the barcode labels for projectiles and fuzes. The current projectile labels do not encode the weight of the individual projectiles and therefore would not be "automatically" recorded as required by the SOW. This information would best be acquired by the Howitzer crew as is currently done using the zone markings painted on the projectiles.

## Module Weight (Specification Paragraph 3.2.2.1)

The SOW draft specification requires a maximum empty weight of the XM1E5 of 5,700 pounds. The estimated weight for the empty XM1E5 is 5,461 pounds based on a 100 round system capacity. Table 7 provides a detailed estimate of the major component groups for the XM1E5. No attempt was made in this study to reduce the weight of the magazine structure or the bucket carriers. It is anticipated that the bucket carriers could be weight reduced for a production design.

Table 7. XM1E5 Weight estimates for alternative HEMTT capacities.

Description	M977 HEMTT (100 Rnds)						M977 HEMTT - LHS (82 Rnds)						M977 HEMTT - LHS (67 Rnds)					
	UNI Unit WT (lb)	Scale Factor	Qty	Sub Totals (lb)	Adjusted Wt. (lb)	pwr (a)	Scale Factor	Qty	Sub Totals (lb)	Adjusted Wt. (lb)	pwr (a)	Scale Factor	Qty	Sub Totals (lb)	Adjusted Wt. (lb)	pwr (a)		
XM1E5 (with payload)			1	19586				1	16282				1	16209				
XM1E5 (empty)			1	5461		39%		1	4707		41%		1	6716		71%		
XM1E5 (fixed)				1275					1275					1275				
XM1E5 (variable)				4186					3432					5441				
Munition Storage Group																		
Projectile Storage Unit (100 Projos.)			1	3736		(Var.)		1	3063		(Var.)		1	4856		(Var.)		
Structural Assembly	545	1.56	2		1704		0.82	2		1397		1.30	2		2215			
Drive Components (less motors)	230	1.56	2		719		0.82	2		590		1.30	2		935			
Serpentine Component List	420	1.56	2		1313		0.82	2		1077		1.30	2		1707			
Handoff Group			1	570		(fixed)		1	570		(fixed)		1	570		(fixed)		
RS Handoff Assy	260	1.00	1		260		1.00	1		260		1.00	1		260			
LS Handoff Assy	260	1.00	1		260		1.00	1		260		1.00	1		260			
Structure Assy					50					50					50			
Propellant Storage Assy			1	200		(Var.)		1	164		(Var.)		1	260		(Var.)		
Container Tie-down			1		125		0.82	1		103			1		163			
Fuze Storage			1		75		0.82	1		62			1		97			
Electrical Control System			1	425		(fixed)		1	425		(fixed)		1	425		(Var.)		
Hi-level Unit			1		120			1		120			1		120			
Low-level Unit					35					35					35			
Motor Magazine Drive	29	1.00	2		58		1.00	2		58		1.00	2		58			
Motor, Conveyor Drive	29	1.00	1		29		1.00	1		29		1.00	1		29			
Barcode Reader			1		5			1		5			1		5			
Control Panel			1		15			1		15			1		15			
Sensor List	3	1.00	1		3		1.00	1		3		1.00	1		3			
Actuator List	10	1.00	1		10		1.00	1		10		1.00	1		10			
Cable List	150	1.00	1		150		1.00	1		150		1.00	1		150			
Conveyor Group			1	280		(fixed)		1	280		(fixed)		1	280		(fixed)		
Handoff Conveyor	50	1.00	1		50		1.00	1		50		1.00	1		50			
Stub Conveyor & Support Assy			1		40			1		40			1		40			
Outer Conveyor			1		75			1		75			1		75			
Load Tray Assembly			1		25			1		25			1		25			
Conveyor Suspension Assy			1					1					1					
Winch Assy			1		20			1		20			1		20			
Hinge Assy			1		25			1		25			1		25			
Cable Components			1		25			1		25			1		25			
Drive Components (less motor)			1		20			1		20			1		20			
Pallet Structure (b)			1	250		(Var.)	0.82	1	205		(Var.)	1.30	1	325		(Var.)		
Payload			1	14125				1	11575				1	9493				
Projectile	100	1.00	100		10000		1.00	82		8200		1.00	67		6700			
Propellant (palletized)	35	1.00	110		3850		1.00	90		3150		1.00	74		2590			
Fuzes (boxed)	2.5	1.00	110		275		1.00	90		225		1.00	81		203			

(a) pwr = parasitic wgt ratio = (empty wgt) / (payload wgt)

Two alternative configurations are also shown in table 7 that indicate the weights for a fully loaded 82 round XM1E5 and a partially loaded 130 round XM1E5 on a LHS on a HEMTT host vehicle. The LHS has an 16,000 pound payload weight, 4,000 pounds lower than the basic HEMTT truck with a standard cargo platform due to the added weight of the mechanism needed to mount and load flatracks.

Many of the variable weights in the weight estimate were factored on a linear basis from the 64 projectile ARM II/Uni system to the size for each alternative configuration. The baseline 100 round XM1E5 was factored by  $100/64 = 1.56$ . The 82 round system was factored from the 100 round baseline by  $82/100 = 0.82$ . The 67 round system was based on a variable structure that was sized for the 130 round PLS system partially filled. The variable structure for the 130 round system was factored by  $130/100 = 1.30$ .

Where no scale factors appear in table 7 new estimates were generated due to significant differences in the planned design characteristics. The conveyor group of the XM1E5 will have a new construction approach and the new propellant storage assembly is unlike any previous designs.

### **Reliability (Specification Paragraph 3.2.3)**

The SOW draft XM1E5 Prime Item Development Specification provided no requirement for the objective XM1E5 system. No specific effort was expended in the study to analyze potential reliability characteristics of the XM1E5 system, however, recent reliability "goals" developed for the ARM II/LP system were examined for possible inclusion in the revised draft XM1E5 Prime Item Development Specification.

### **Future Capability Enhancements**

#### **XM1E5 with Wide and Narrow Magazines**

Since one of the over-riding design constraints is the width envelope of the host vehicles, many design options were explored for feasibility.

All of the design concepts studied in this analysis assume the use of currently available ammunition. A serious design problem would develop if the current "one size fits all" magazine concept were to be developed for production and the longer 155 mm projectiles currently under development actually enter the Army inventory.

As previously discussed above, the combined width of the side-by side magazines barely fits within the 96 inch envelope dimension for the XM1E5 system. A novel alternative to using the same size magazine approach would be to size one magazine for the short M107 projectiles (27.55 inches) and the other magazine to accept the longest proposed projectiles (~ 39.6 inches). By using this concept the combined width of two magazines could be reduced by 3.6 inches.

The number of common parts in the magazines would be reduced with this approach, however most of the different parts would be similar if not identical. The weight of the magazines would likely be a wash with one growing in width and the other reducing.

Figure 55 shows how more space efficient the wide and narrow magazine approach is when compared to the previously used concepts. It is conceivable that enough space could be gained to enable loading with the projectiles pointing toward the XM1E5 as with the ARM II UNI and ARM II/LP prototypes instead of being forced to re-orient the projectiles as discussed above.

## XM1E5 PLS INSTALLATION CRITICAL DESIGN ISSUES

The SOW requires a detailed evaluation of all aspects of installing and operating an XM1E5 on two candidate host vehicles. A significant aspect of the baseline design is the requirement to provide manual propellant handling. The following discussion provides an analysis of all of the design approaches considered to meet the draft prime item development specification and significant alternatives that were considered in the study.

The PLS installation was established by PMAMMOLOG as the alternate system for the design analysis effort. As such, the system general arrangement was driven by available floor space and human factors considerations. Accessibility by the crew to propellant and fuze storage were important considerations in the determination of the best operational configuration.

Figure 56 illustrates the general arrangement of the XM1E5 system installed on the M1074 PLS truck and M1077 flatrack in the transport mode.

The following discussion of the PLS installation includes a number of specific issues defined in the SOW and several others found to be of significant importance to the baseline design.

### **Module to Vehicle interface (Specification Paragraph 3.1.2.1.1 and 3.1.2.1.2)**

The primary vehicle interface design issue stems from the tradeoff of mounting the XM1E5 payload on top of an existing M1077 flatrack design vs. embedding flatrack features into the structure of the XM1E5 system. The baseline approach followed in this study uses the former option since it was considered to be the most cost effective and likely to be accepted by the logistics community.

The baseline approach can be further subdivided into two refinements i.e.. no modifications to the flatrack and minor mounting feature additions.

**No Flatrack Modifications.** The preferred approach for securing the XM1E5 system to the flatrack is by means of the existing standard ISO fittings that are part of each production flatrack. The preferred XM1E5 system will have standard ISO corner fittings welded to its support structure at locations that will meet the ISO standard dimensions for 8 by 20 foot containers. In order to provide adequate strength for handling and transport loads, substantial structural members will be required at each of the 4 corner tie-down locations of the XM1E5 system. The primary advantage of this approach is the use of established ISO tie down technology and simplicity of use in the field. Figure 57 shows the conceptual approach for the host vehicle interface.

Another approach to secure the XM1E5 system to the M1077 flatrack without special modifications would be to provide heavy duty blades that would engage the stake pockets that are located along the sides of the flatrack. The blades would be designed to resist the fore and aft and side loads and negative g loads would be resisted by standard straps and ratchet tensioners as are commonly used to tie down general purpose cargo loads.

**Customized Flatrack.** Another design approach for mounting the XM1E5 system to the modified M1077 flatrack would be to weld special fittings to the flatrack structure that would be used to resist transport loads. Oshkosh Truck Inc. engineers agree that this approach would make the best long term design. This approach would have the disadvantage of making the flatrack unique for this payload and the welded fittings would likely cause interference problems with general use cargo if the XM1E5 were removed for some reason.

**ISO Compatible Palletized Flatrack (IPF).** The IPF system offers another approach to mounting the XM1E5 system on a standardized platform currently being introduced into government inventory. The approach to secure the XM1E5 system to the IPF type M1 flatrack without special modifications would be to provide heavy duty blades that would engage the stake pockets that are located along the sides of the flatrack. The blades would be designed to resist the fore and aft and side loads and negative g loads would be resisted by standard straps and ratchet tensioners as are commonly used to tie down general purpose cargo loads.

The advantages of using the IPF type M1 flatrack include its ability to be stacked and its potential for adding a camouflage or environmental cover using the top ISO corner fittings. The primary disadvantages of using the IPF type M1 flatrack are its higher unit cost and reduced payload weight.

## **Electrical Controls and Software**

A number of critical design issues exist regarding the electrical controls and software that were not specifically addressed in the SOW. The following discussion covers those critical design issues for the PLS version of the XM1E5 not previously discussed in the HEMTT section.

### **Control Panel**

An XM1E5 system on a PLS is expected to be operated much of the time with the PLS flatrack setting on the ground. In this position the control panel as positioned on the HEMTT would be too low to be used conveniently. For the PLS version the control panel is located on the front of the magazines connected to the transfer mechanism and slides back into the transfer mechanism like a drawer when not in use. If the PLS pallet is on the ground the operator could easily walk onto the pallet to access the control panel. If the pallet is on the PLS vehicle the operator would be required to climb up to operate the system.

### **Module Power Requirements (Specification Paragraph 3.1.2.1.3)**

The method used to estimate the power consumption for the PLS version of the XM1E5 was the same as for the HEMTT version. The magnitude of the values was simply adjusted to reflect the 130 projectile magazine capacity.

### **XM1E5 Peak Current Estimate.**

Scale factors were applied to the ARM II/LP test data in order to account for the differences in conveyor design and magazine capacity planned for the XM1E5 system. Since the conveyor is expected to be shorter and have significantly less frictional drag, a factor of 60% of the ARM II/LP test data was applied to the 8.3 kW peak power with the result of 5.0 kW. The scale factor for the magazines was estimated to vary as  $(N/64)^{1/2}$  where N= the projectile magazine capacity with the result of 8.4 kW for N = 130.

The total peak power estimate, including "Power On" for the 130 round XM1E5 system is 13.7 kW. This equates to 685 As at the minimum supply voltage of 20 volts. In order to set a realistic value for the Draft Prime Item Development Specification, the 685 As was rounded to 690 As.

### **XM1E5 Average Current Estimate.**

Based on the methodology and empirical data extracted from the ARM II/LP test results, the power for the XM1E5 was estimated as follows:

- Conveyor Average Power = 0.6 (ARM II/LP)  
= 1.52 kW
- Magazines Average Power = ARM II/LP  $(N/64)^{.75}$  (N = XM1E5 Payload)  
= 1.69  $(130/64)^{.75}$   
= 2.88 kW
- Low level Power = 0.30 kW
- Total Average Power = 4.70 kW

The total average power estimate for the 130 round XM1E5 system is 4.70 Kw. This equates to an average current draw of 235 As at the minimum supply voltage of 20 volts. This is rounded to 240 As for the Draft Prime Item Development Specification.

### **130 Round XM1E5 Payload on M1077 Flatrack on the ground**

Starting Assumptions: The XM1E5 is delivered fully loaded by a PLS truck to a remote supply site and set on the ground without power from its prime mover. A 2.5 ton truck with a 60 A alternator and two 12 V - 120 Ah batteries drives up and is used to power the download cycle (worst case). Idle speed on the truck produces 40 A, 10 A are used by the truck, and it will take 8 minutes to download the 130 rounds.

In order to download 130 rounds in 10 minutes, the truck will provide 40 A and the batteries will supply the balance of the power. the average XM1E5 current draw is 240 A.

At 75°F: 35 minutes of 100 A discharge is available per battery .

Conclusion: at 75°F approximately 3 downloads are possible before the batteries are exhausted when assisted by truck alternator power.

At 32°F: 25 minutes of 100 A discharge is available per battery.

Conclusion: at 32°F approximately 2 downloads are possible before the batteries are exhausted when assisted by truck alternator power.

At -20°F: 10 minutes of 100 A discharge is available per battery .

Conclusion: at -20°F one download is possible before the batteries are exhausted when assisted by truck alternator power.

### **Module to Howitzer Interface (Specification Paragraph 3.1.2.2)**

#### **Host vehicle attitude.**

During rearm operations the M1074 PLS host vehicle with the XM1E5 system must maneuver into a position to the rear of the Howitzer that will cause the conveyor to be aligned with the center of the rear door. Since the deployed conveyor has a fixed length, the distance between the vehicles must be closely controlled to minimize manual projectile handling while rearming the Howitzer. Figure 23 shows the proximity of the mating vehicles on level ground producing a conveyor angle of 20°.

Figure 24 shows the conveyor alignment with the extreme heights encountered with the mating vehicles specified in the SOW. The greatest conveyor elevation required is to clear the side panels of the M977 HEMTT cargo bed producing an angle of +15°. The lowest angle of depression is 25° when unloading from the M1077 flatrack on the ground.

As the side slope roll angle of the mating vehicles goes to the  $\pm 20\%$  extremes specified in the SOW, see figure 25, the conveyor angle relative to gravity changes from 11.3° to 36.3°. It is anticipated that deployment of the conveyor at the specified host vehicle slope of 20% will not be achievable without adding excessive conveyor length to reduce the angle relative to gravity.

A more realistic side slope operating condition would be at 10% for both mating vehicles. At a  $\pm 10\%$  side slope roll angle of the mating vehicles, the conveyor angle relative to gravity changes from 19.3° to 30.7°. If local ground conditions exceed the 10% slope it is recommended that the vehicles move to a more suitable terrain for ammunition transfer operations.

#### **Alignment with mating vehicle**

**Distance away from mating vehicle.** The distance between the mating vehicles varies as a function of the type of vehicle and the conveyor angle. A typical distance between the XM1E5 host vehicle left side and an M977 HEMTT or M1074 PLS cargo bed edge is 10 ft.  $\pm 1$  ft. The positioning of the XM1E5 host vehicle left side and the rear door of the M109A2/A3 and M109A4/A5 Howitzers will be 11 ft.  $\pm 1$  ft. The positioning of the XM1E5 host vehicle left side and the rear door of the M109A6 Howitzer will be 13 ft.  $\pm 1$  ft. Particular care will be required to avoid interference with the overhanging bustle on the M109A6 Howitzer during conveyor deployment.

**Lateral misalignment.** The specified lateral misalignment of  $\pm 1$  foot will be a factor in the initial vehicle positioning. Experience with the ARM II Uni prototype system indicates that vehicle drivers can easily learn to meet this requirement with or without a guide person. The M1074 PLS host vehicle is longer than the M977 HEMTT host vehicle and may require more practice to judge distance. A guide person may be required to help prevent lost time when aligning the vehicles.

**Angular misalignment.** The specified angular misalignment of  $\pm 10\%$  will not present any particular problems due to the fact that the final munitions transfer between vehicles will be a manual operation. Any variations in positioning of the end of the deployed conveyor will be compensated for by the crew.

### **Payload Capacity (Specification Paragraph 3.2.1.1)**

The issue of payload capacity for the M1074 PLS host vehicle presents several areas of concern that require careful evaluation before settling on a preferred approach. Since the PLS has a 16.5 ton weight capacity, the limiting criteria for projectile capacity is floor area rather than weight. Several projectile magazine arrangements were studied to determine what configurations would yield the 150 projectile capacity specified in the SOW.

**150 Round Payload on M1077 Flatrack.** Figure 56 and 57 show a 4 row high arrangement with 150 projectiles. Inspection of the layout indicates that there is enough floor space available to store 150 propellant containers in pallets however there is no floor space available for the crew to access the control panel or fuzes stored on top of the magazines.

Figures 58 and 59 show a 6 row high configuration with 150 projectiles that adds more floor space for propellant storage but causes a very crowded work space for crew to access the control panel or fuzes stored on top of the magazines. This configuration meets the weight limitations of the host vehicle but creates a high center of gravity and potential interference with the European tunnel envelope and the AC130 aircraft envelope.

A limited analysis provided by the vehicle manufacturer, Oshkosh Truck Inc., indicates that this configuration could be a problem with 13 foot 6 inch (4 meter) overall height requirement. They also recommended that the propellant load be moved forward for vehicle mobility reasons which would reduce space for access to fuses and propellant stored on top of the projectile magazines.

**130 Round Payload on M1077 Flatrack.** Figures 60 and 61 show a 4 high projectile magazine configuration with 130 complete rounds on the PLS flatrack on the M1074 PLS host vehicle. Inspection of this layout indicates that it is possible to physically store the 130 projectiles on the cargo bed and still have adequate space for the crew to access the control panel or fuzes stored on top of the magazines. The exact position of the XM1E5 on the flatrack is subject to the final design details which will be influenced by the location of tie down features and human factors requirements.

**130 Round Payload on M1077 Flatrack with PLS M1076 Trailer.** Figures 62 and 63 show a 4 high projectile magazine configuration with 130 projectiles on the M1077 flatrack on the M1074 PLS host vehicle in conjunction with a PLS M1076 trailer dedicated to propellant and fuze storage. This optional configuration provides plenty of extra space for munitions storage with the capability/advantage of current Army inventory availability and the potential for loading propellant and fuzes at a different time and/or remote location.

**130 Round Payload on M1077 Flatrack with HEMAT M989A1 Trailer.** Figure 64 shows another alternative configuration using the same basic XM1E5 system as described for the M1077 flatrack on the M1074 PLS host vehicle in conjunction with a HEMAT M989A1 trailer dedicated to propellant and fuze storage.

The HEMAT M989A1 trailer has the capability/advantage of current Army inventory availability and the potential for loading propellant and fuzes at a different time and/or remote location. The primary disadvantage of this approach is the vehicle positioning with respect to the Howitzer during rearm operations.

### **Conveyor Layout (Specification Paragraph 3.2.1.2)**

The general arrangement of the conveyor layout is the same as previously described for the HEMTT version of the XM1E5. The primary difference between the two host vehicles is the height of the cargo bed.

Since the PLS flatrack cargo bed surface is 7 inches higher than the HEMTT, the angle of the conveyor when it is deployed to the lowest down operating position will develop a 31° angle with respect to gravity with the vehicle on a horizontal surface. As is the case with the HEMTT application, the slope of the ground is additive to the conveyor angle when the conveyor is deployed in a downhill attitude and subtractive when deployed in the uphill attitude. Figure 24 illustrates the effects of ground slope on conveyor angles.

Since the conveyor will have an upper functional limit on its angle, operations may have to plan on deploying the conveyor to the uphill side of the host vehicle when working in the extreme down position to prevent slippage of projectiles on the conveyor..

### **Man-Machine Interface (Specification Paragraph 3.2.1.2, 3.2.1.3, 3.2.1.6 and 3.2.1.8)**

#### **Deployment and Stowage (Specification Paragraph 3.2.1.2.1)**

The deployment and stowage of the transfer conveyor can be accomplished easily by two operators and by one under emergency conditions. One operator is needed to activate the electric winch while the second operator stands on the ground and unfolds the outer conveyor section during the deployment operation. Figures 46 - 52 show several stages of the conveyor deployment operation described below:

The electric winch is activated to cause the electric winch automatically deploys the stub conveyor to an extreme down position. (figure 47) The initial force required to cause the stub conveyor to rotate away from the XM1E5 comes from stored energy in a spring. The extreme down position of the stub conveyor is intended to place the center of gravity of the outer conveyor and load tray as low as possible without danger of the outer conveyor accidentally going over center.

The outer conveyor is manually rotated approximately 155° down to the ground by one or two operators. (figures 48 - 51) The maximum effort to accomplish this task should not exceed the allowable human factors requirements since the estimated weight of the conveyor at the outer end of the grab bar is estimated to be ~ 65 pounds when the outer conveyor is in the horizontal position.

The final positioning of the outer end of the conveyor and load tray for the angle best suited for the mating vehicles is accomplished by a remote control for the electric winch and manual adjustment of the load tray support strut.

The operations needed to stow the conveyor are essentially the reverse of the deployment sequence.

#### **Height Range (Specification Paragraph 3.2.1.2.2)**

The recommended operational height range for the center line of the projectile on the load tray ranges from 17 to 110 inches above the host vehicle ground plane in contrast to the 6 to 84 inch range specified.

Normally, operators prefer to carry heavy projectiles at arms length or at waist height from the working platform when not using a lifting hook. When using a lifting hook to transfer projectiles from a pallet to the load tray the lowest position usually results in the least amount of manual lifting.

For reasons discussed above in issue # 5 under "Design Constraints" it is important that the extreme conveyor slopes be minimized. Observations of operators up and down loading projectiles indicate that the 6 inch requirement is impractical from a human factors standpoint.

In a typical case of loading projectiles from the deck of a flatrack on the ground, the bed is 10 inches above the ground level placing the center of the projectiles on the load tray approximately 17 inches above the ground. (See figure 53). The practical upper limit occurs with the bottom of the load tray just clears the top of the HEMTT side panels during transfer of projectiles from the HEMTT cargo body. See figure 54.

#### **Projectile Orientation (Specification Paragraph 3.2.1.3.2 and 3.2.1.6.1)**

For reasons stated above in issue # 5 under "projectile re-orientation" the planned XM1E5 system will accept projectiles with the base towards the XM1E5. PMAMMOLOG agreed that the requirement in the draft specification for projectile orientation was not absolutely fixed and that the recommended approach would not degrade operational performance.

#### **Identification (Specification Paragraph 3.2.1.3.4)**

The use of a militarized barcode reader will be used to identify the projectile information contained on LOGMARS labels IAW Appendix G of MIL-STD-129L located on palletized unit loads. The information will be conveyed to the control system for building the inventory data base of the XM1E5.

One of the primary issues regarding the use of the barcode reader is how the data is transmitted to the system controller. If a wire cable is used for real time communications, then it must be long enough to reach all of the pallets being read. This long cable will also have to be stowed easily in a convenient location for easy access.

An alternative approach would be to store the data collected by the barcode reader that is self contained and later feed the data by a short cable to the system controller. This approach makes data collection easy but would complicate the inventory management of the controller since it needs to know what type of projectile is being loaded before it is placed into a magazine bucket carrier. A means would have to be devised to manually signal the controller that a new type of projectile is being loaded.

A better approach would be a barcode reader that could transmit a real time short range radio signal to the XM1E5 controller. This approach would eliminate the long cable and/or the manual

sequencing required by the previously discussed methods. An new concern for the security of this approach would have to be investigated.

**Upload Rate (Specification Paragraph 3.2.1.5.3)**

The mechanism planned for the XM1E5 will be capable of up load rates of up to 20 projectiles per minute. As a practical matter, the crew size, degree of fatigue and the environmental conditions will determine the actual upload rate. It is anticipated that a crew of 4 may be able to work at a rate of 10 projectiles per minute for 10 minutes.

**Projectile Download (Specification Paragraph 3.2.1.6)**

All of the SOW requirements for this section will be met by the mechanism planned for the XM1E5. Experience with the ARM II/Uni and the ARM II/LP prototype systems indicates the equipment will meet or exceed these requirements.

**Ammunition Inventory (Specification Paragraph 3.2.1.8)**

The ammunition inventory system will collect the data available on the barcode labels for projectiles and fuzes. The current projectile labels do not encode the weight of the individual projectiles and therefore would not be "automatically" recorded as required by the SOW. This information would best be acquired by the Howitzer crew as is currently done using the zone markings painted on the projectiles.

**Module Weight (Specification Paragraph 3.2.2.2)**

The SOW draft specification requires a maximum empty weight of the XM1E5 of **TBD** pounds. Based on a 150 round system configuration the estimated weight for the empty XM1E5 is 7553 pounds. The estimated weight for an empty XM1E5 is 6716 pounds for an alternative 130 round system configuration. No attempt was made in this study to reduce the weight of the magazine structure or the bucket carriers. It is anticipated that the bucket carriers could be weight reduced for a production design. Table 8 provides a detailed estimate of the major component groups for the 130 and 150 projectile XM1E5 systems.

Table 8. XM1E5 Weight estimates for alternative PLS capacities.

Description	UNI Unit WT (lb)	M1074 PLS (130 Rnds)					M1074 PLS (150 Rnds)				
		Scale Factor	Qty	Sub Totals (lb)	Adjusted Wt. (lb)	pwr(a)	Scale Factor	Qty	Sub Totals (lb)	Adjusted Wt. (lb)	pwr(a)
XM1E5 (with payload)			1	25079			1	28783			
XM1E5 (empty)			1	6716		37%	1	7553		36%	
XM1E5 (fixed)				1275				1275			
XM1E5 (variable)				5441				6278			
Munition Storage Group											
Projectile Storage Unit (100 Projos.)			1	4856		(Var.)	1	5603		(Var.)	
Structural Assembly	545	1.30	2		2215		1.50	2		2555.5	
Drive Components (less motors)	230	1.30	2		935		1.50	2		1078.5	
Serpentine Component List	420	1.30	2		1707		1.50	2		1969.4	
Handoff Group			1	570				570			
RS Handoff Assy	260	1.00	1		260		1.00	1		260	
LS Handoff Assy	260	1.00	1		260		1.00	1		260	
Structure Assy					50					50	
Propellant Storage Assy			1	260		(Var.)	1	300		(Var.)	
Container Tie-down		1.30	1		163		1.50	1		188	
Fuze Storage		1.30	1		98		1.50	1		113	
Electrical Control System			1	425		(fixed)	1	425		(fixed)	
Hi-level Unit			1		120		1			120	
Low-level Unit					35					35	
Motor Magazine Drive	29	1.00	2		58		1.00	2		58	
Motor, Conveyor Drive	29	1.00	1		29		1.00	1		29	
Barcode Reader			1		5			1		5	
Control Panel			1		15			1		15	
Sensor List	3	1.00	1		3		1.00	1		3	
Actuator List	10	1.00	1		10		1.00	1		10	
Cable List	150	1.00	1		150		1.00	1		150	
Conveyor Group			1	280		(fixed)	1	280		(fixed)	
Handoff Conveyor	50		1		50			1		50	
Stub Conveyor & Support Assy			1		40			1		40	
Outer Conveyor			1		75			1		75	
Load Tray Assembly			1		25			1		25	
Conveyor Suspension AssY			1					1			
Winch Assy			1		20			1		20	
Hinge Assy			1		25			1		25	
Cable Components			1		25			1		25	
Drive Components (less motor)			1		20			1		20	
Pallet Structure (b)		1.30	1	325		(Var.)	1.50	1	375	(Var.)	
Payload				18363				21230			
Projectile	100	1.00	130		13000		1.00	150		15000	
Propellant (palletized)	35	1.00	143		5005		1.00	165		5775	
Fuzes (boxed)	2.5	1.00	143		358		1.00	182		455	

(a) pwr = parasitic wgt ratio = (empty wgt) / (payload wgt)

The variable weights in the estimate were factored on a linear basis from the 64 projectile ARM II/Uni system to the size for each alternative configuration. The baseline 100 round XM1E5 was factored by  $100/64 = 1.56$ . The 130 round system was factored from the 100 round baseline by  $130/100 = 1.30$ . The variable structure for the 150 round system was factored by  $150/100 = 1.50$ .

Where no scale factors appear in table 1 new estimates were generated due to significant differences in the planned design characteristics. The conveyor group of the XM1E5 will have a new construction approach and the new propellant storage assembly is unlike any previous designs.

### **Reliability (Specification Paragraph 3.2.3)**

The SOW draft XM1E5 Prime Item Development Specification provided no requirement for the objective XM1E5 system. No specific effort was expended in the study to analyze potential reliability characteristics of the XM1E5 system, however, recent reliability "goals" developed for the ARM II/LP system were examined for possible inclusion in the revised draft XM1E5 Prime Item Development Specification.

### **Future Capability Enhancements**

#### **Remote Inventory Access**

A potentially useful enhancement to the XM1E5 system when mounted on the M1077 flatrack would be a means to remotely query the system controller to determine the ammunition payload inventory status. In this manner unmanned XM1E5 modules stored at ammunition transfer points or other locations could quickly be inventoried by a mobile command vehicle tied into the SINCARS battlefield communications network..

The remote radio systems such as the MITLA technology or another similar approach could be added to the XM1E5 and use available electronic data stored in it's system controller.

### **Conclusions**

Certain potential program/logistics advantages could be realized by maximizing common XM1E5 related equipment and moderating extreme specification requirements. This study attempted to comply with as many of the draft specification requirements as practical and explain the rationale for occasional exceptions.

**M977 HEMTT host vehicle.** The most attractive general arrangement for the XM1E5 on the M977 HEMTT host vehicle consists of a 100 round system with two 50 space side-by-side projectile magazines 4 rows high (similar to ARM II/LP) positioned at the forward end of the M977 HEMTT cargo body. (See figure 1). A new fixed length conveyor was designed with two folding sections that are suspended from cables controlled by an electric winch. The projectiles are oriented with the base toward the XM1E5 when down loading to a Howitzer as was done with the ARM I prototype system. Power to drive the whole system will be supplied by a host vehicle via a portable "jumper" cable permanently attached to the XM1E5 system.

**M1074 PLS host vehicle.** The most attractive general arrangement for the XM1E5 on the M1074 PLS host vehicle consists of a 130 round system with two 65 space side-by-side projectile magazines 4 rows high (similar to ARM II/LP) positioned on the M1077 flatrack. All features of the this system are

identical to the XM1E5 on the M977 HEMTT host vehicle except for the magazine length, control panel location and structural mounting details. This configuration has the added potential of being 100% interoperable (given a reduced payload) with the HEMTT LHS currently under development by Oshkosh Tuck Inc.

The primary difference from the HEMTT concept is the location of the operator controls over the hand-off assembly for ease of access when the flatrack is operated from the ground.

### **Recommendations**

The system approach evolving from this design and analysis study capitalizes on many of the lessons learned from prior development effort by MMAS on the ARM I, ARM II/UNI and ARM II/LP prototype contracts and related IR&D work.

Further effort should be directed towards the fabrication of a PLS version of the XM1E5. Specific areas that need further development include:

1. Develop a high traction conveyor that will reliably handle projectiles at up to 30° slopes under adverse environments.
2. Evaluate the operational issues regarding the folding conveyor concept and vehicle positioning requirements.
3. Further study technical issues regarding the best methods to handle inventory data acquisition, solid propellant handling and computer interfaces.

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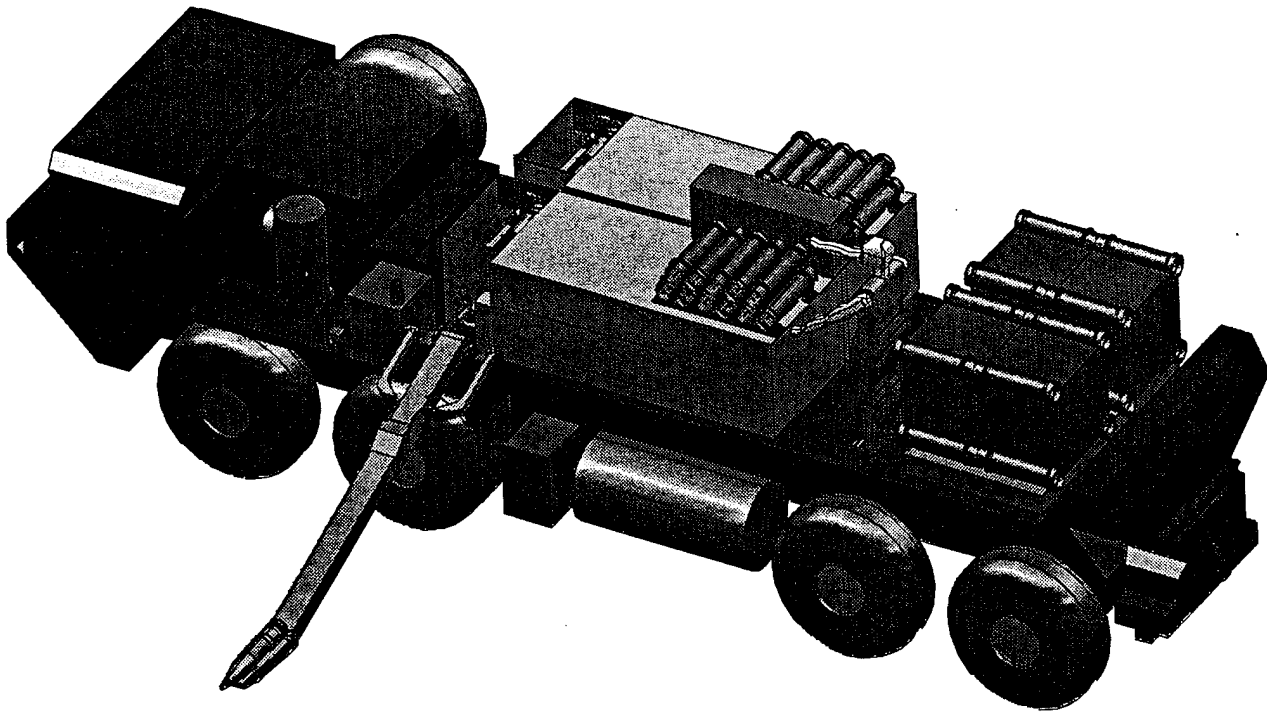


Figure 1. XM1E5 system installed on the M977 HEMTT host vehicle in the transport mode

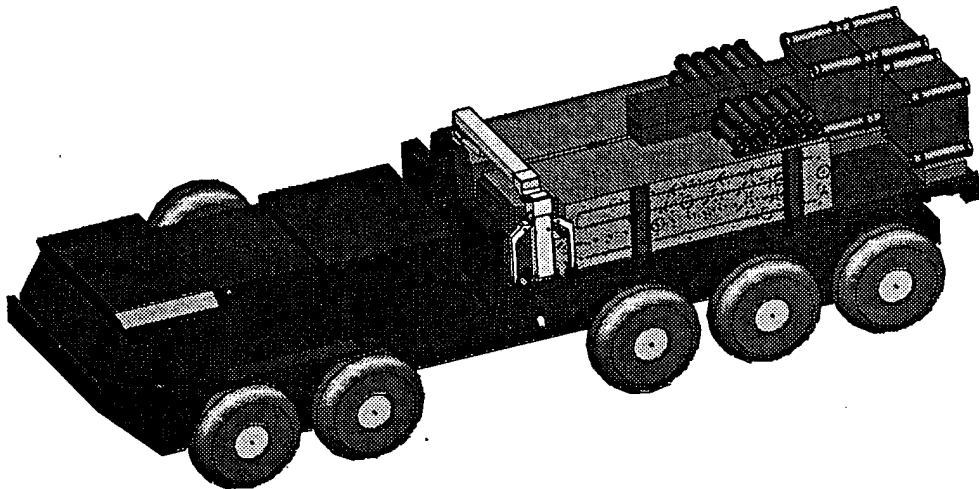


Figure 2. XM1E5 system installed on the M1074 PLS host vehicle in the transport mode

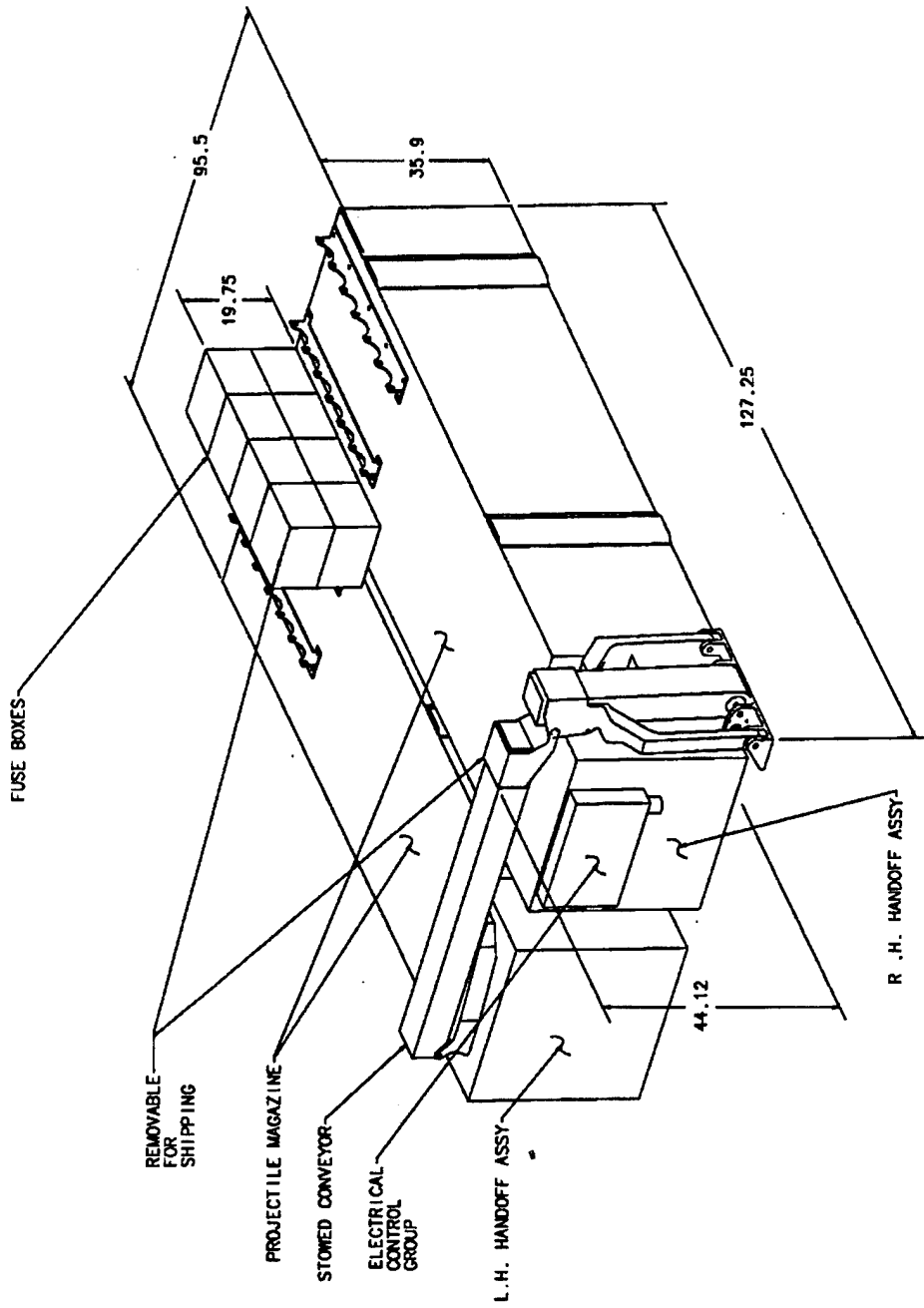


Figure 3. XM1E5 envelope dimensions on the M977 HEMTT host vehicle

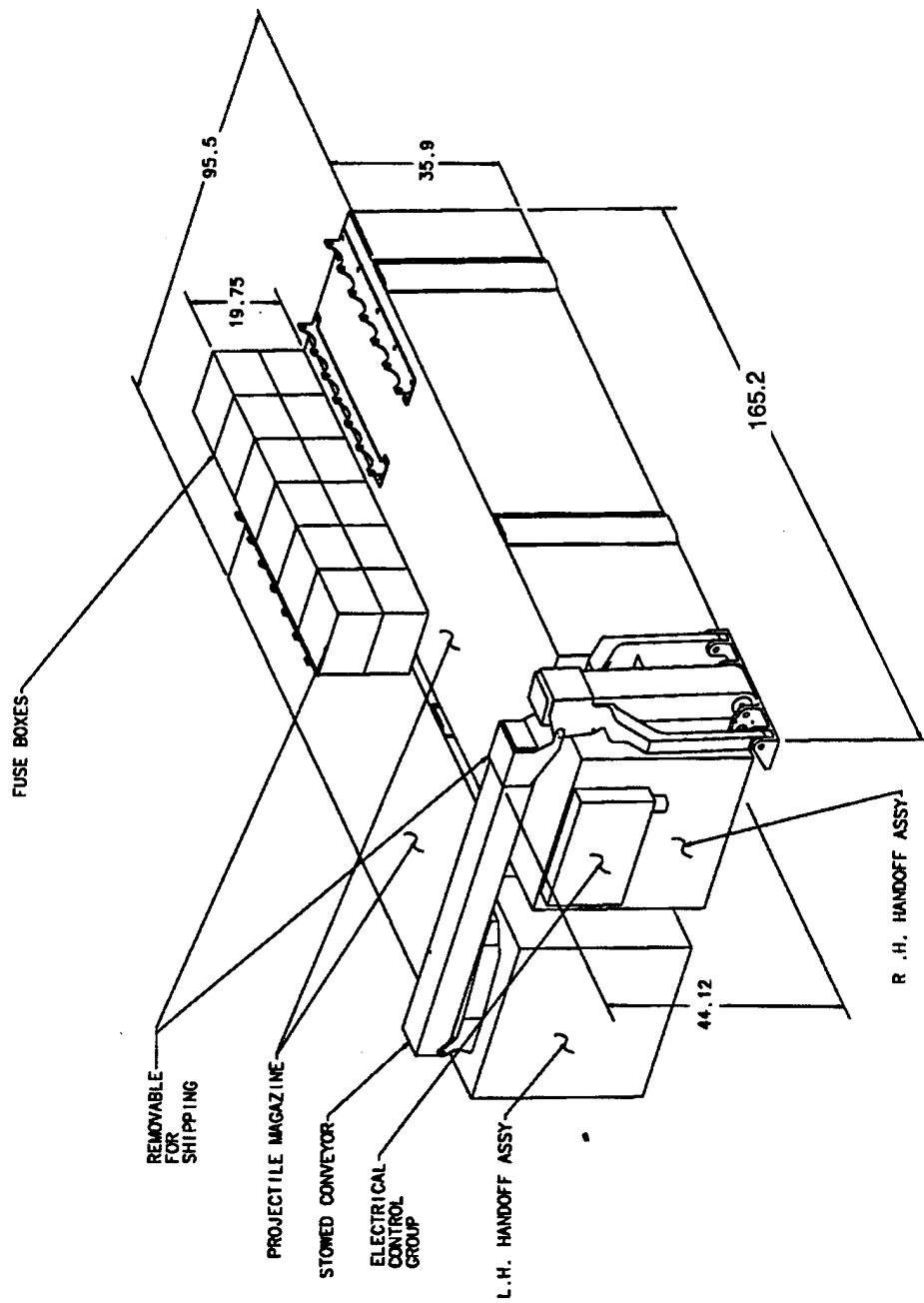


Figure 4. XM1E5 envelope dimensions on the M1074 PLS host vehicle

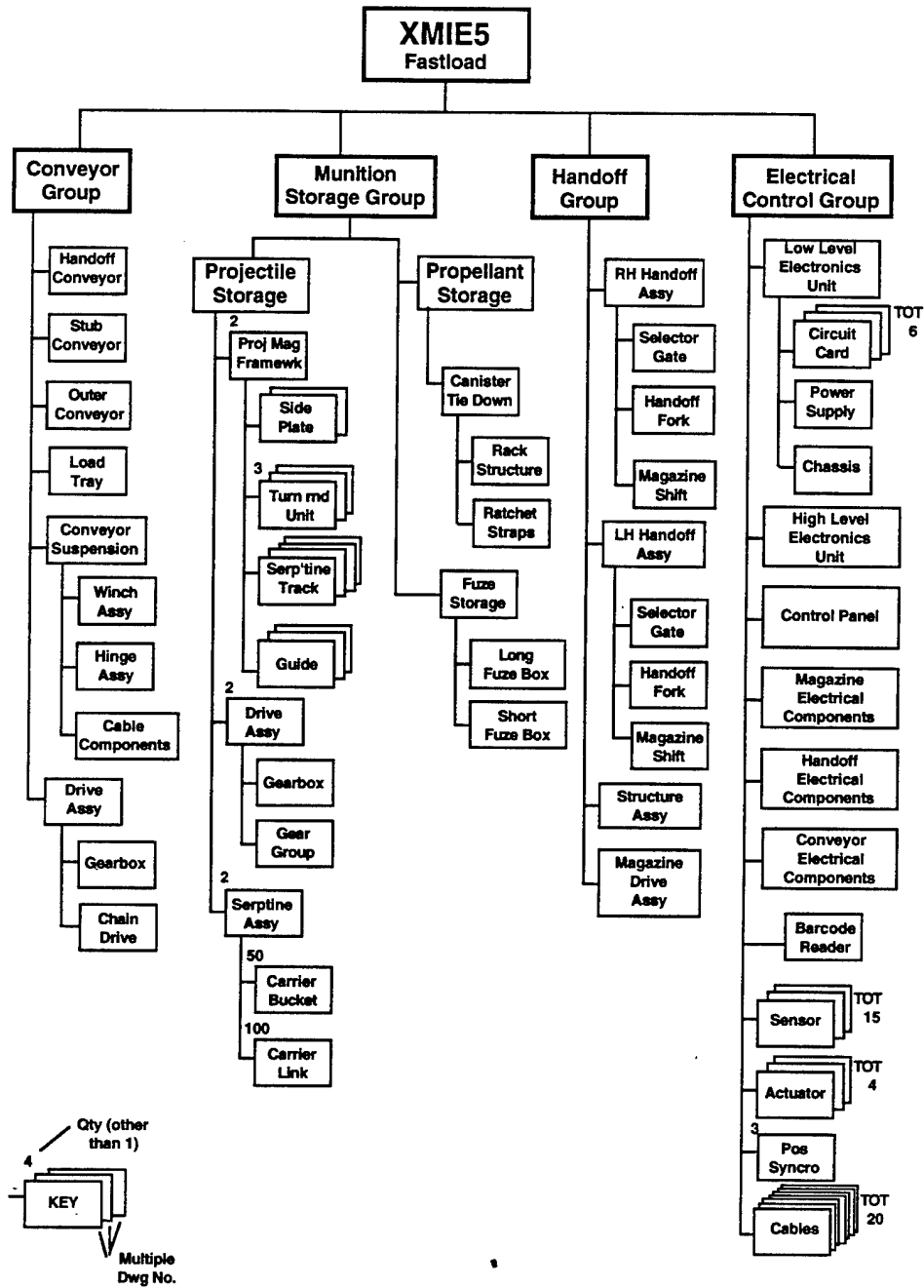


Figure 5. Planned XMIE5 drawing architecture for the baseline system

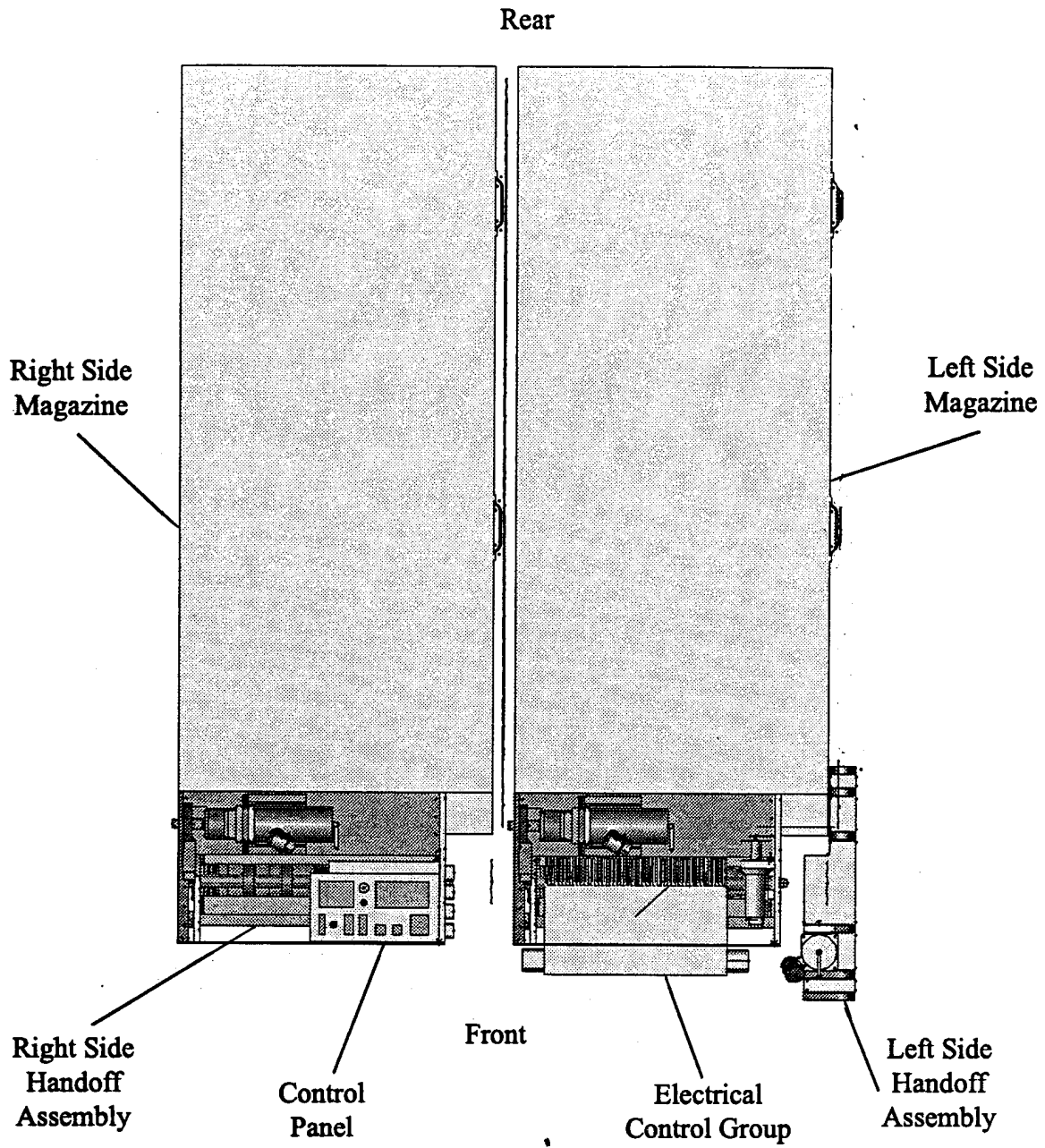


Figure 6. Side-by-side magazine arrangement maximizes the width of the host vehicle

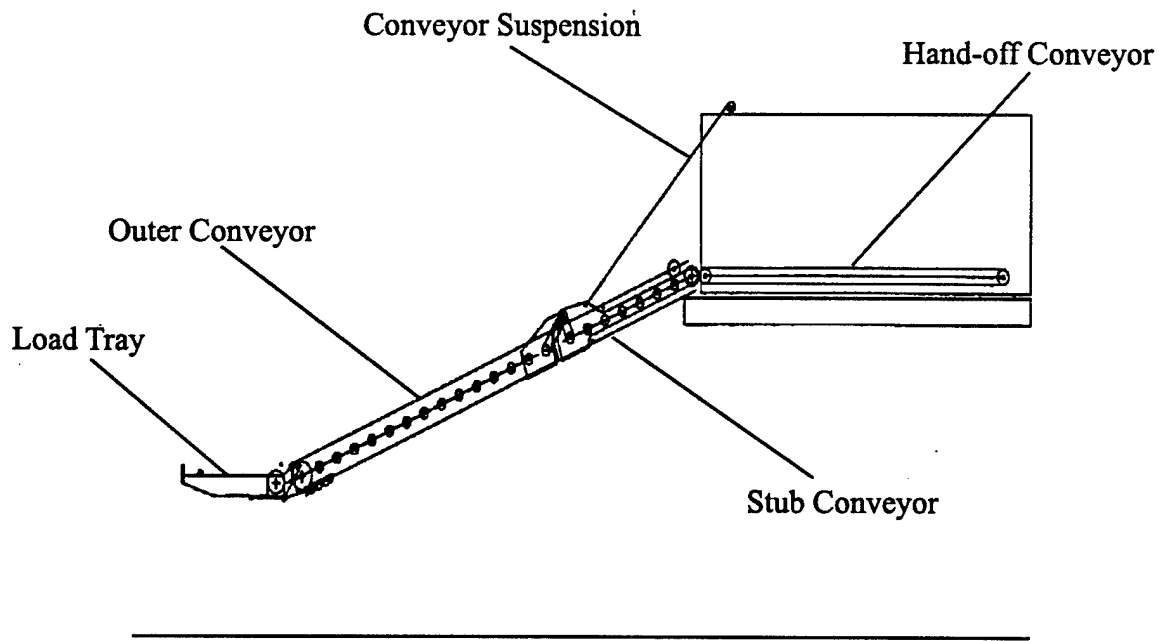


Figure 7. The transfer conveyor system consists of three distinct interconnected conveyors

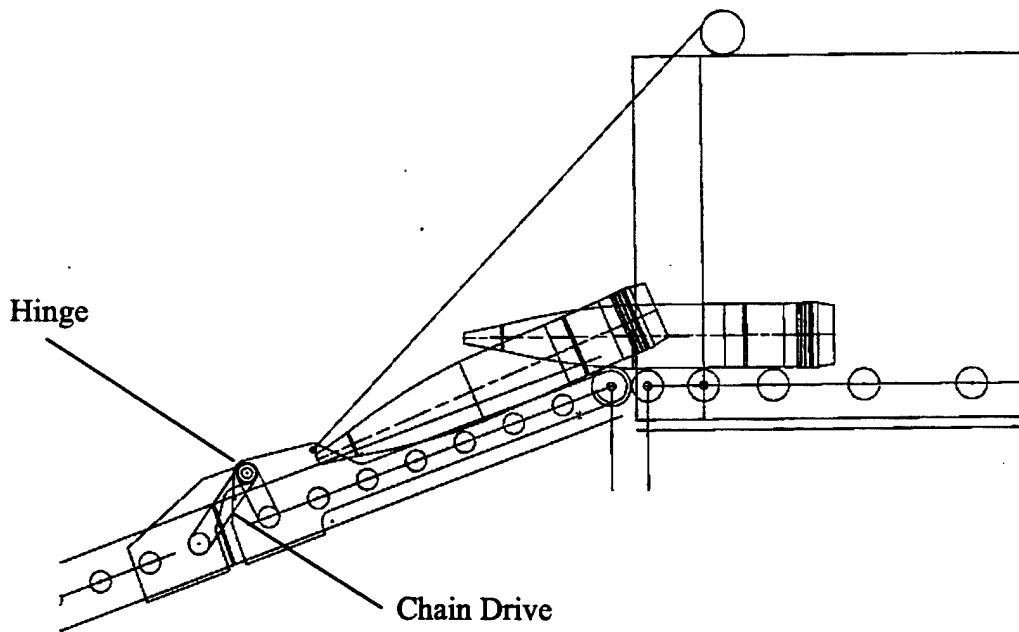


Figure 8. The stub conveyor contains the hinge for the folding outer conveyor

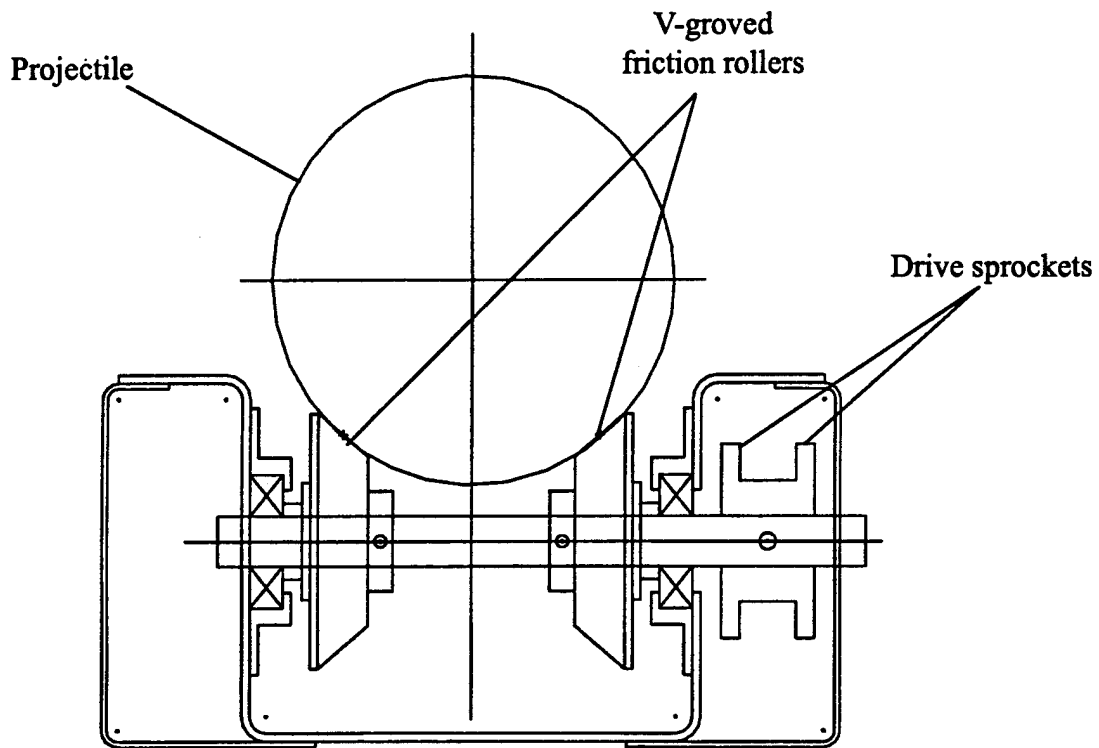


Figure 9. The Stub conveyor consists of a series of V-grooved friction rollers

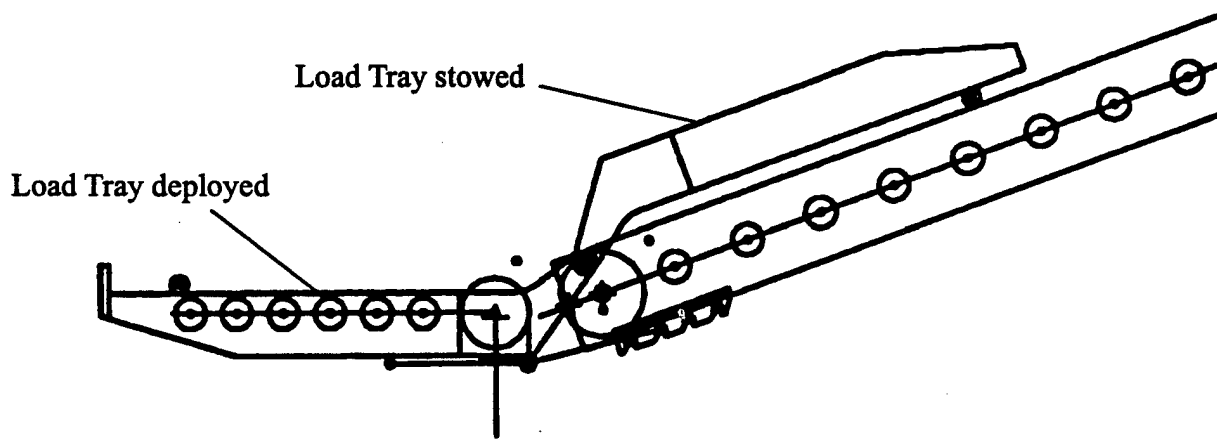


Figure 10. The folding Load Tray creates a compact volume for stowage

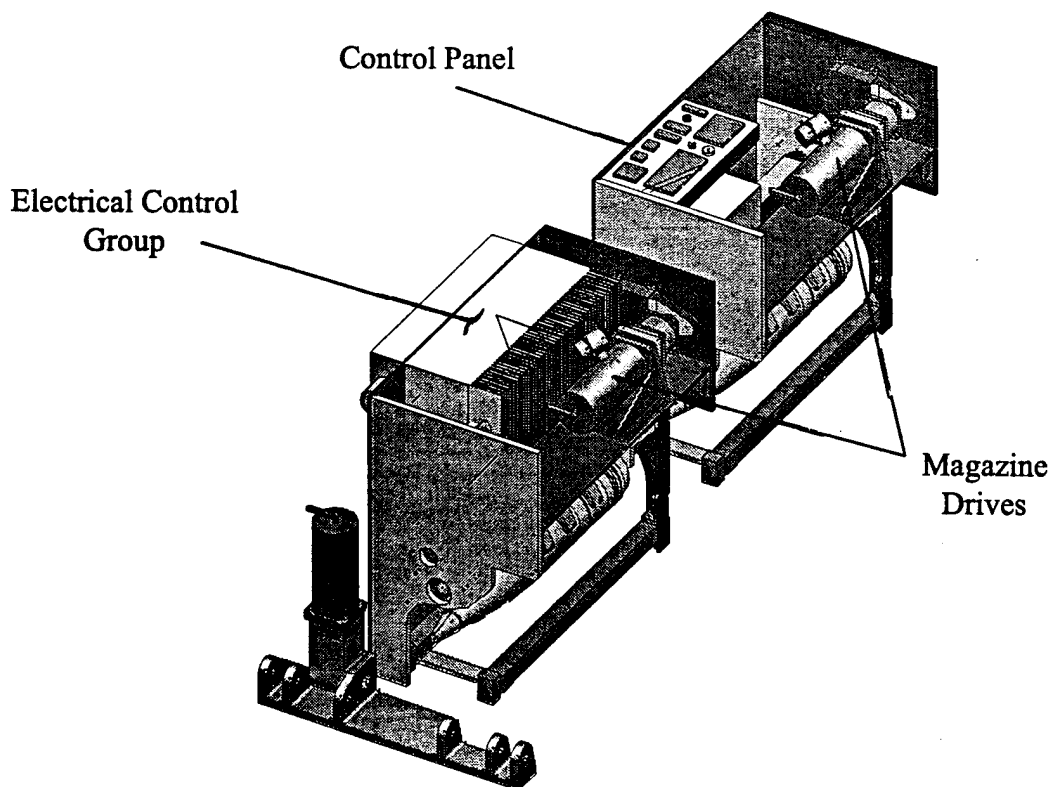


Figure 11. The Hand-off Group Houses the Handoff Assemblies, Handoff Conveyor, Control Panel and major Electrical Control Group components

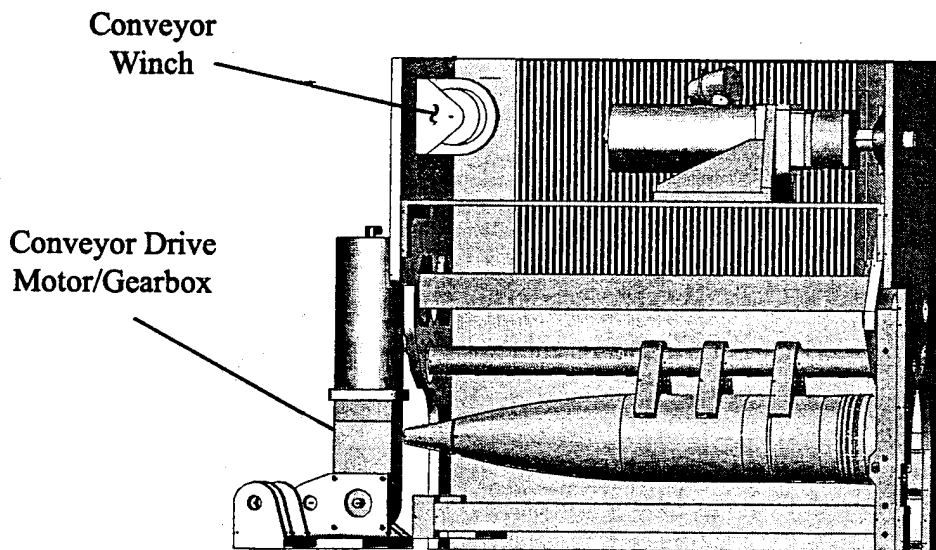


Figure 12. Power comes from a series of chains connected to the conveyor drive gearbox



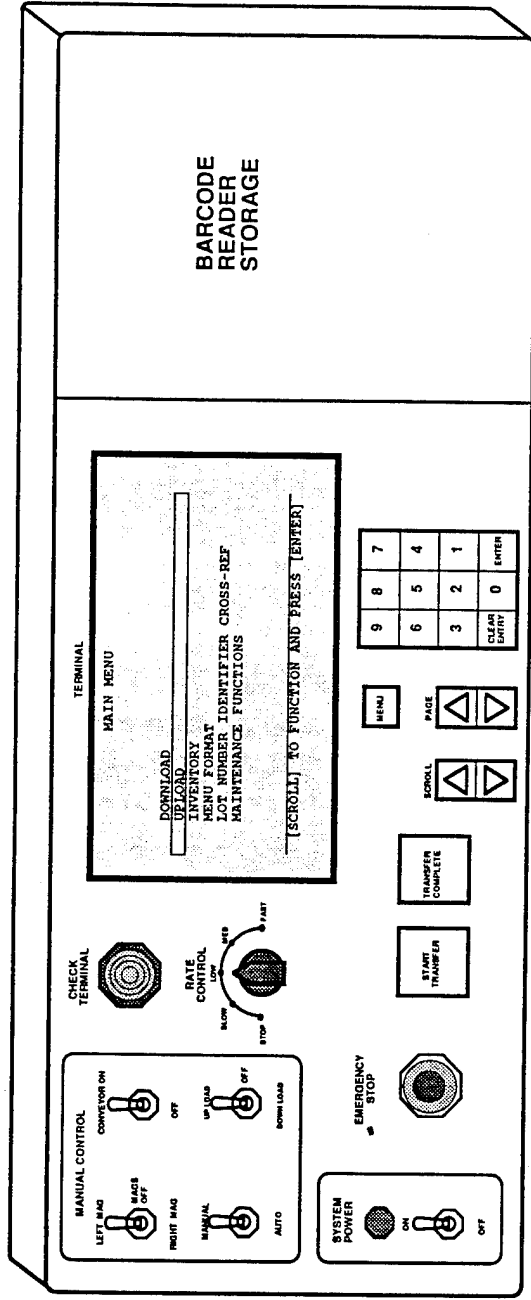


Figure 14. The control panel provides the primary operator interface to the XM1E5 electrical system

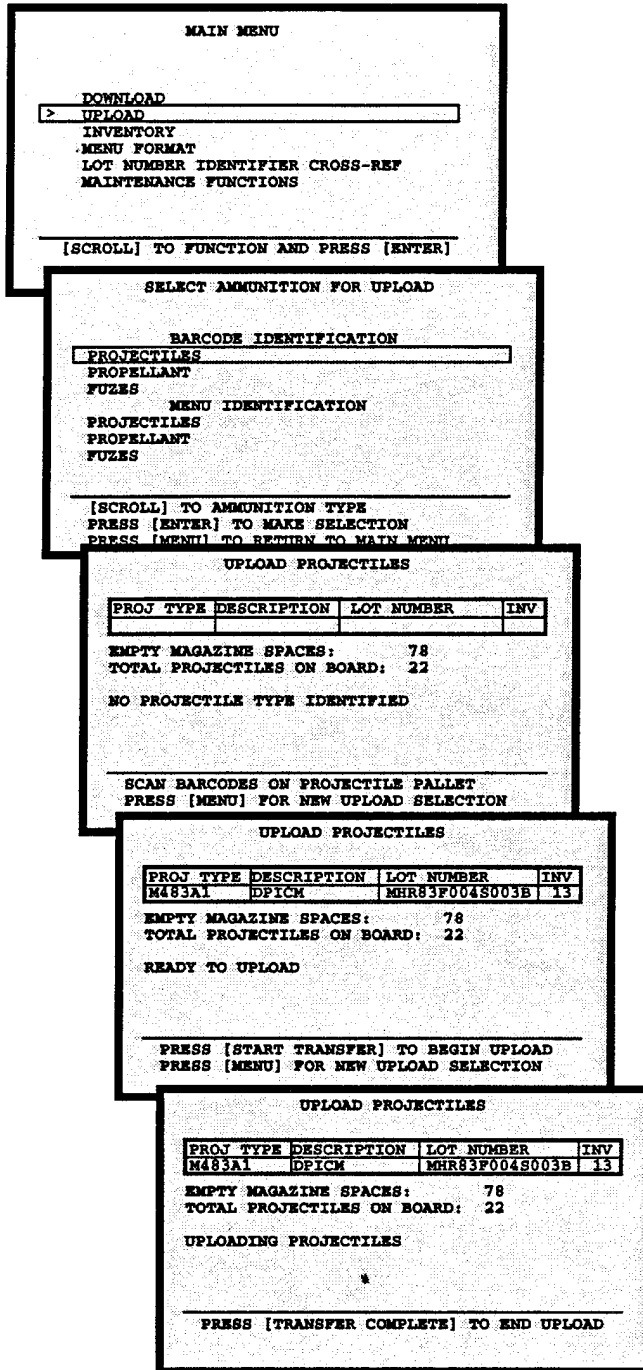


Figure 15. Projectile upload menus with barcode identification

MAIN MENU

---

DOWNLOAD  
 UPLOAD  
 INVENTORY  
 MENU FORMAT  
 LOT NUMBER IDENTIFIER CROSS-REF  
 MAINTENANCE FUNCTIONS

---

[SCROLL] TO FUNCTION AND PRESS [ENTER]

SELECT AMMUNITION FOR DOWNLOAD

---

PROJECTILES  
 PROPELLANT  
 FUZES

---

[SCROLL] TO AMMUNITION TYPE  
PRESS [ENTER] TO MAKE SELECTION  
PRESS [MENU] TO RETURN TO MAIN MENU

DOWNLOAD PROJECTILES PAGE 1 OF 1

PROJ TYPE	DESCR	LOT NUMBER	INV	ORD
M483A1	DPICM	MHR85F006-002	16	
M107	HE(DC)	JFR83F874-298	40	16
M549A1	RAP	ARF83F005-001	24	
M485A1	ILLUM	MHR83F004S003B	8	8
ANY PROJ			88	

---

[SCROLL] TO EACH ITEM, KEY IN QUANTITY  
PRESS [ENTER] TO ENTER ORDER  
PRESS [MENU] FOR NEW DOWNLOAD SELECTION

DOWNLOAD PROJECTILES

PROJ TYPE	DESCR	LOT NUMBER	INV	ORD
M107	HE(DC)	JFR83F874-298	40	16
M485A1	ILLUM	MHR83F004S003B	8	8

---

READY TO DOWNLOAD  
PRESS [START TRANSFER] TO BEGIN DOWNLOAD  
PRESS [ENTER] TO CHANGE ORDER  
PRESS [MENU] FOR NEW DOWNLOAD SELECTION

DOWNLOAD PROJECTILES

PROJ TYPE	DESCR	LOT NUMBER	INV	ORD
M107	HE(DC)	JFR83F874-298	40	16
M485A1	ILLUM	MHR83F004S003B	8	8

---

DOWNLOADING PROJECTILES  
PRESS [TRANSFER COMPLETE] TO END DOWNLOAD

Figure 16. Projectile download menus with barcode identification

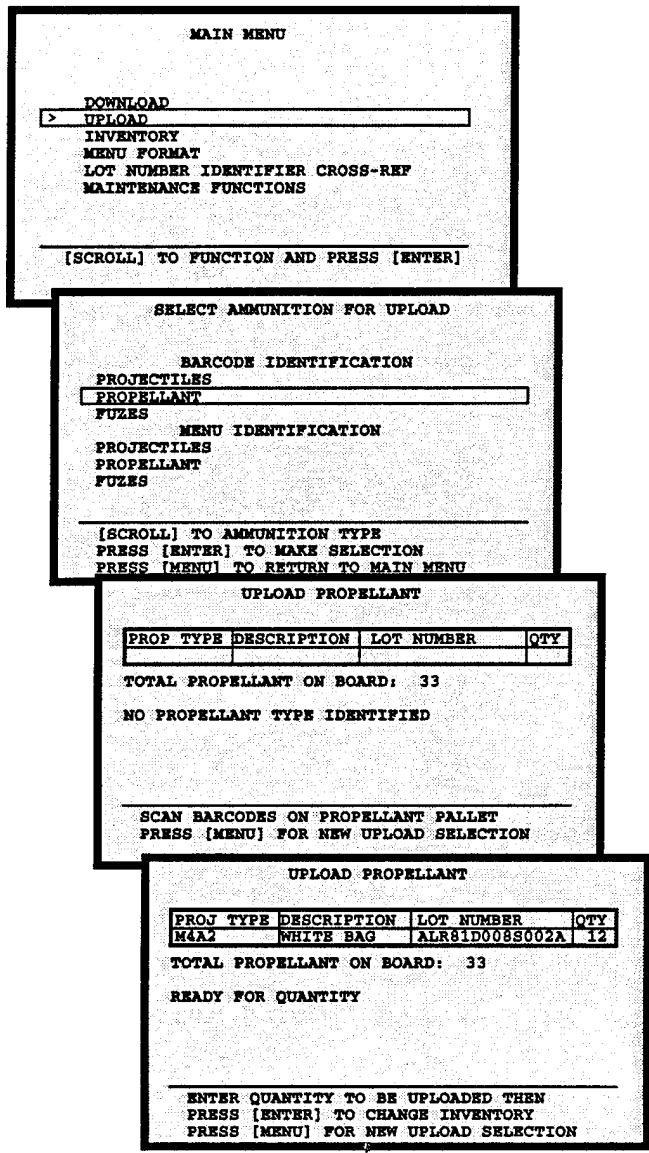


Figure 17. Menus used for a propellant upload operation using the barcode reader

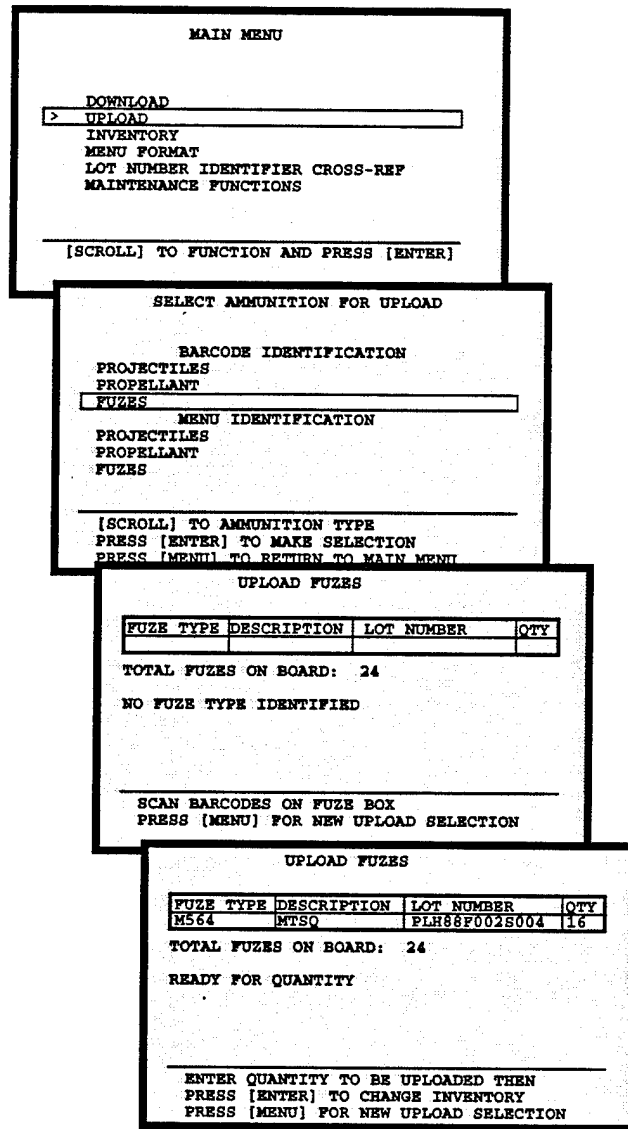


Figure 18. Menus used for a fuze upload operation using the barcode reader

MAIN MENU

UPLOAD  
 INVENTORY  
 MENU FORMAT  
 LOT NUMBER IDENTIFIER CROSS-REF  
 MAINTENANCE FUNCTIONS

[SCROLL] TO FUNCTION AND PRESS [ENTER]

---

SELECT AMMUNITION FOR UPLOAD

PROJECTILES  
  
 FUZES

[SCROLL] TO AMMUNITION TYPE  
 PRESS [ENTER] TO MAKE SELECTION  
 PRESS [MENU] TO RETURN TO MAIN MENU

---

DOWNLOAD PROPELLANT PAGE 1 OF 1

PROP TYPE	DESCR	LOT NUMBER	INV	ORD
W4A2	WHT BAG	ALR61D0088002A	16	
W4A1	GRN BAG	W4R21006-004	40	16

[SCROLL] TO EACH ITEM, KEY IN QUANTITY  
 PRESS [ENTER] TO ENTER ORDER  
 PRESS [MENU] FOR NEW DOWNLOAD SELECTION

Figure 19. Menus used for a propellant download operation using the barcode reader

MAIN MENU

UPLOAD  
 INVENTORY  
 MENU FORMAT  
 LOT NUMBER IDENTIFIER CROSS-REF  
 MAINTENANCE FUNCTIONS

[SCROLL] TO FUNCTION AND PRESS [ENTER]

---

SELECT AMMUNITION FOR DOWNLOAD

PROJECTILES  
 PROPELLANT

[SCROLL] TO AMMUNITION TYPE  
 PRESS [ENTER] TO MAKE SELECTION  
 PRESS [MENU] TO RETURN TO MAIN MENU

---

DOWNLOAD FUZES PAGE 1 OF 1

FUZE TYPE	DESCR	LOT NUMBER	INV	ORD
M557	FD	JAH85F006-002	24	
M548	MTBQ	AGV82D004-005	32	8

[SCROLL] TO EACH ITEM, KEY IN QUANTITY  
 PRESS [ENTER] TO ENTER ORDER  
 PRESS [MENU] FOR NEW DOWNLOAD SELECTION

Figure 20. Menus used for a fuze download operation using the barcode reader

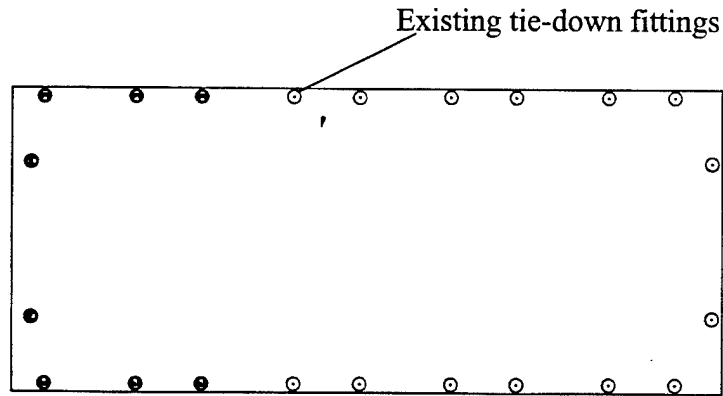


Figure 21. HEMTT cargo bed

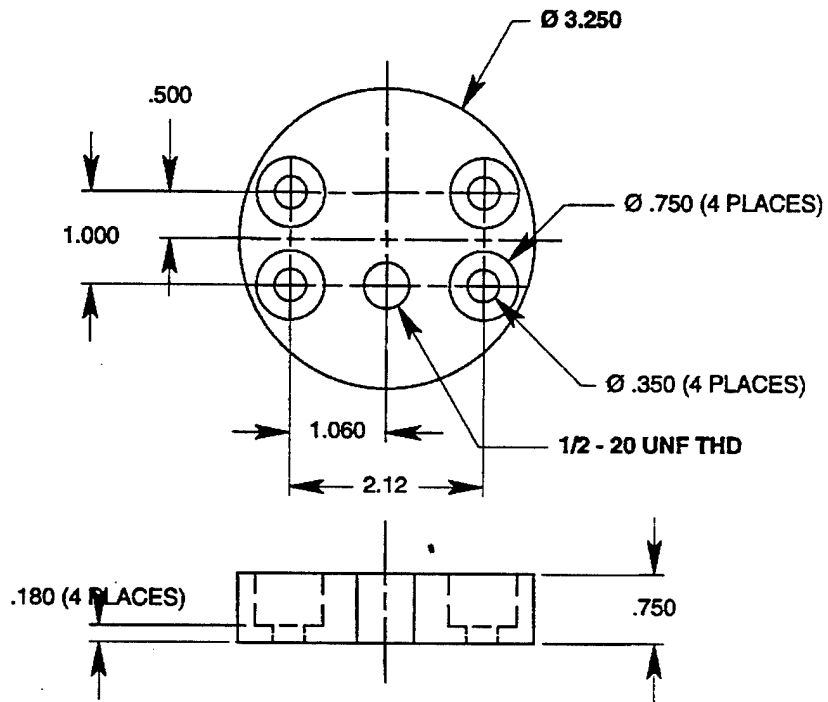


Figure 22. Adapter block designed to mount on the existing studs of the tie-downs

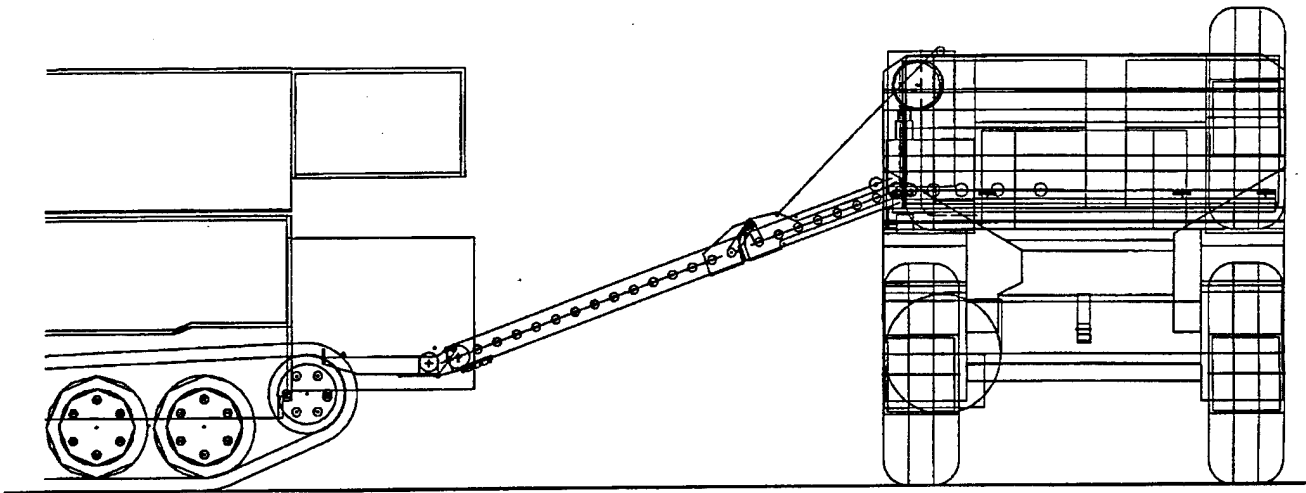


Figure 23. Mating vehicles on level ground produces a conveyor angle of 20°

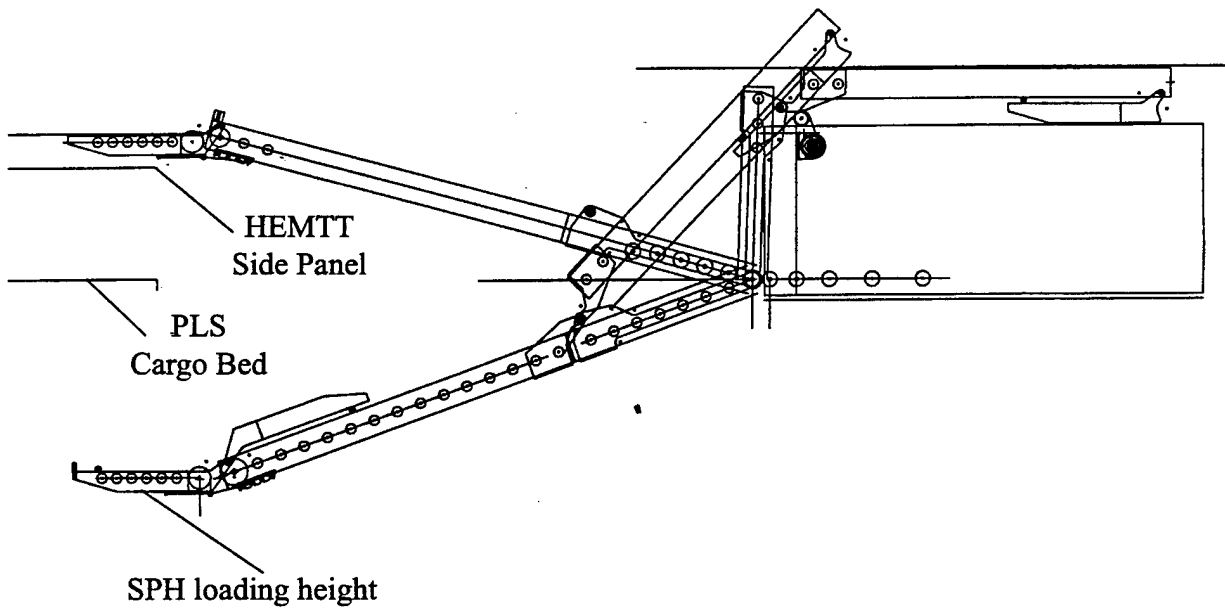


Figure 24. XM1E5 Conveyor alignment with mating vehicles

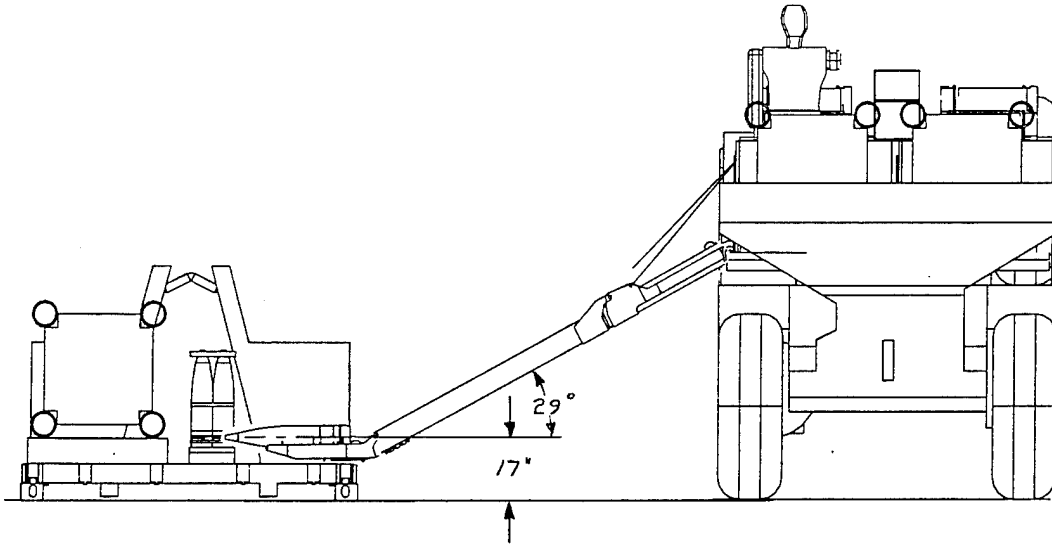


Figure 24a. XM1E5 Conveyor alignment with M1077 Flatrack on the ground

Given:

$$\alpha = 25^\circ \text{ Max.}$$

$$\theta_1 = 5.7^\circ \text{ (10\% slope)}$$

$$\theta_2 = 11.3^\circ \text{ (20\% slope)}$$

$$\begin{aligned} A_1 &= \alpha - \theta_1 \\ &= 25.0 - 5.7 \\ &= 19.3^\circ \end{aligned}$$

$$\begin{aligned} A_{1A} &= \alpha - \theta_2 \\ &= 25.0 - 11.3 \\ &= 13.7^\circ \end{aligned}$$

$$\begin{aligned} A_2 &= \alpha + \theta_1 \\ &= 25.0 + 5.7 \\ &= 30.7^\circ \end{aligned}$$

$$\begin{aligned} A_{2A} &= \alpha + \theta_2 \\ &= 25.0 + 11.3 \\ &= 36.3^\circ \end{aligned}$$

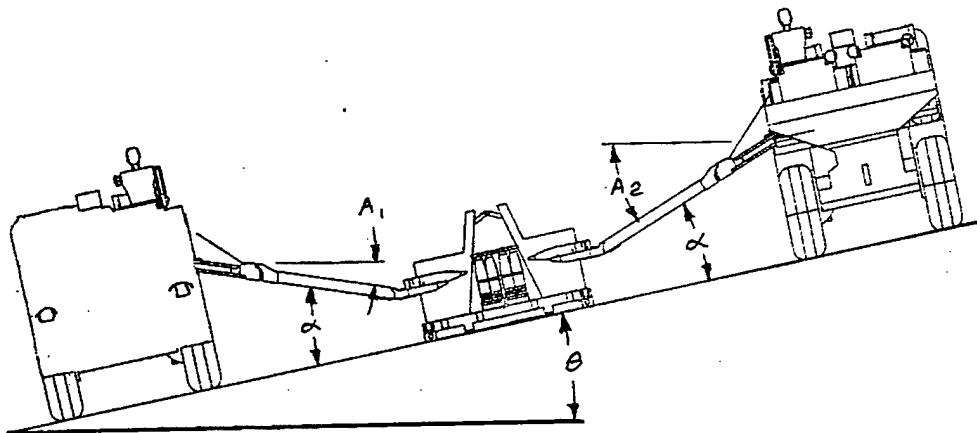


Figure 25. Side slope roll angle of the mating vehicles go to the  $\pm 20\%$  extremes

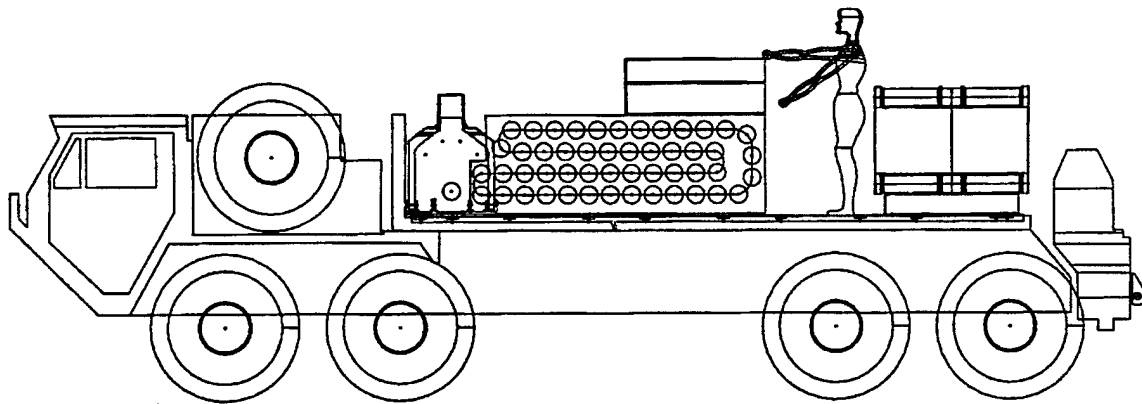
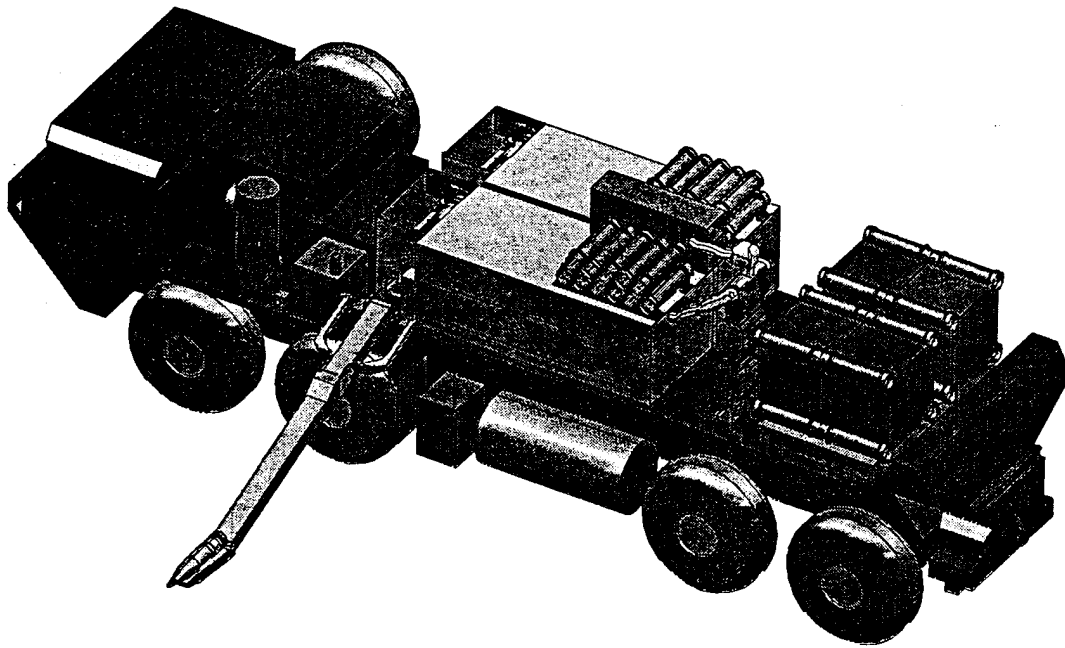


Figure 26. XM1E5 on the M977 HEMTT cargo bed

# HEMTT LHS

## HEAVY EXPANDED MOBILITY TACTICAL TRUCK LOAD HANDLING SYSTEM



### MORE OF A GOOD THING

The Desert Storm proven HEMTT has now been combined with a PLS proven Load Handling System to create a C130 air transportable HEMTT LHS with 8 ton payload capacity while using the new IPF (ISO Compatible Palletized Flatrack). This combination gives you HEMTT reliability and manpower efficiency with the addition of the PLS Load Handling System.

Parts commonality of this vehicle is virtually 100% with the current HEMTT and PLS making it the logistical choice in spare parts support and operation and maintenance training.

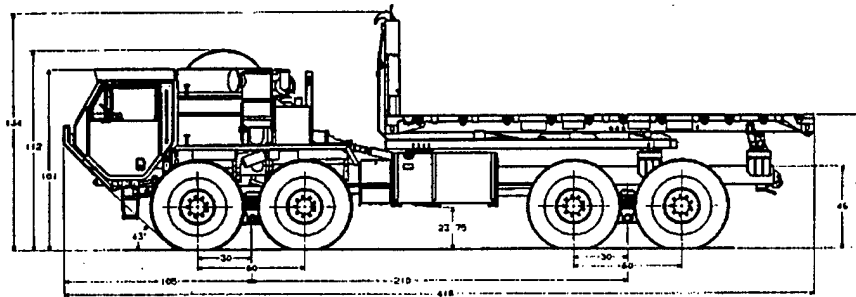
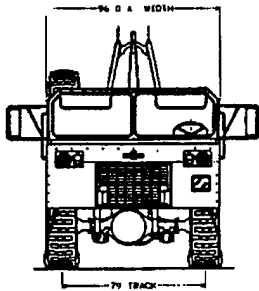
The Heavy Duty Specialist™



Figure 27. HEMTT Load Handling System (LHS) fact sheet 1

## HEMTT LHS FEATURES

- Interoperable with NATO standard flatracks
- Interoperable with PLS M1076 trailer
- C130 air transportable
- Virtually 100% parts commonality with HEMTT and PLS
- Payload capacity 8 ton using IPF (ISO Compatible Palletized Flatrack)
- No additional training necessary
- Can be ordered as new or remanufactured HEMTT option
- Other options
  - Material handling crane
  - CTIS
  - Independent suspension



For reference only. The addition of options will change the listed standard dimensions in some cases. For certified dimensions, consult Oshkosh Truck Corporation.

Specifications, descriptions and illustrations in this literature are as accurate as known at the time of publication but are subject to change without notice. Ratings are general guidelines. Actual ratings vary with application and duty cycle.

Illustrations may include optional equipment and accessories but may not include all standard equipment. Consult Oshkosh Truck Corporation for additional information.

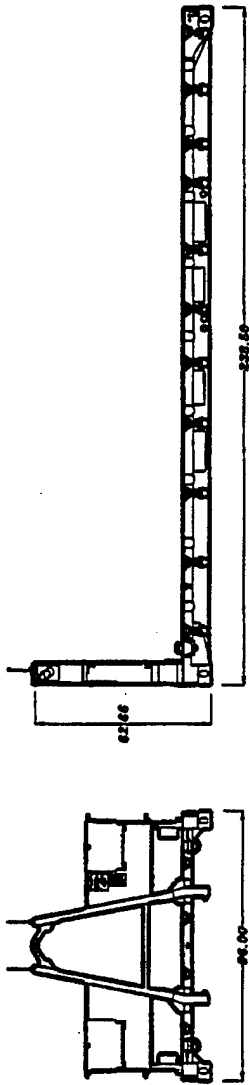
**OSHKOSH TRUCK CORPORATION**  
 P.O. Box 2566  
 Oshkosh, Wisconsin 54903-2566 • U.S.A.  
 (414) 235-9150 FAX (414) 233-9540

Figure 28. HEMTT Load Handling System (LHS) fact sheet 2



PALLETIZED LOAD SYSTEM - TYPE M1077 AND TYPE M1 FLATRACKS

THE GENERAL PURPOSE A-FRAME FLATRACK TYPE M1077



THE ISO COMPATIBLE PALLETIZED FLATRACK (IPF) TYPE M1

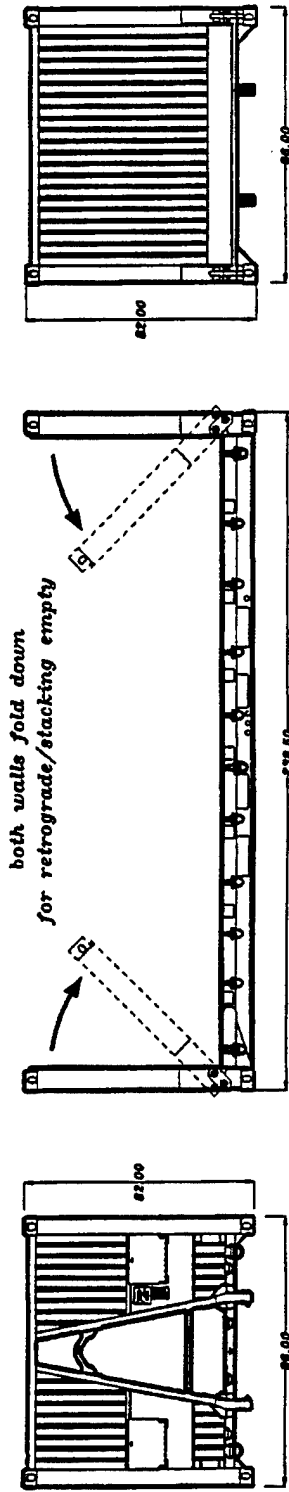


Figure 29. Type M1077 and M1 flatrack envelope dimensions

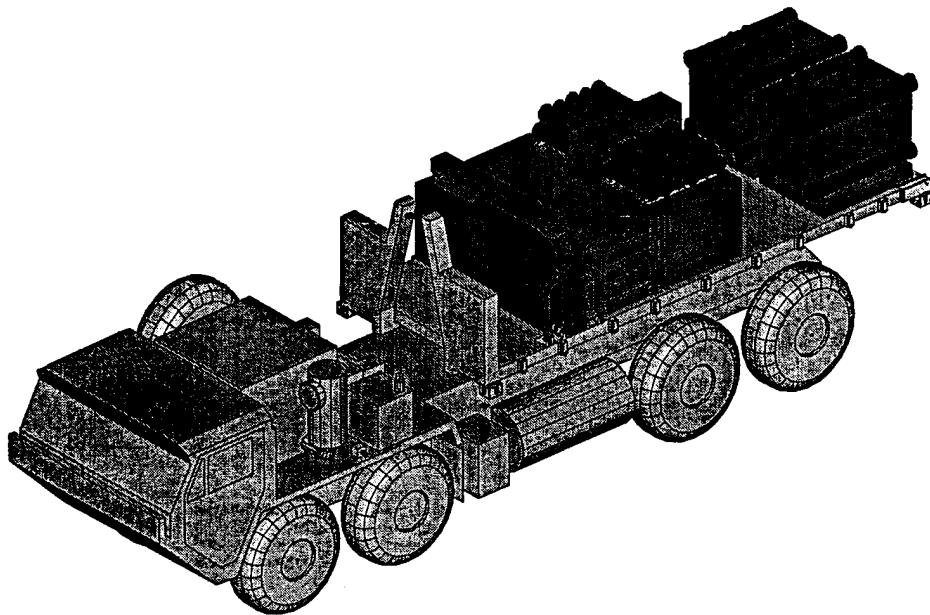


Figure 30. 80 projectile XM1E5 system on the M1077 flatrack and HEMTT LHS host vehicle

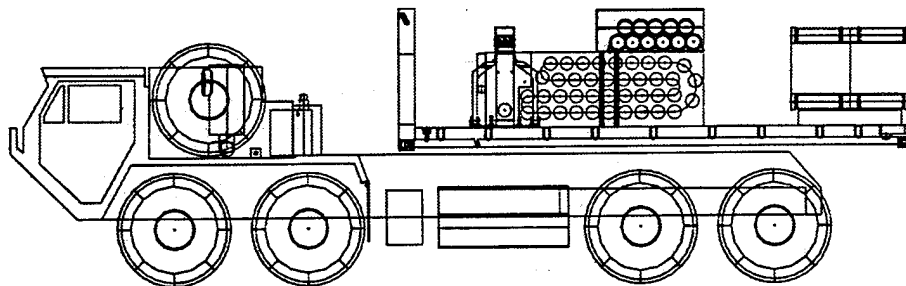


Figure 31. 80 projectile XM1E5 system on the M1077 flatrack and HEMTT LHS host vehicle  
(side view)

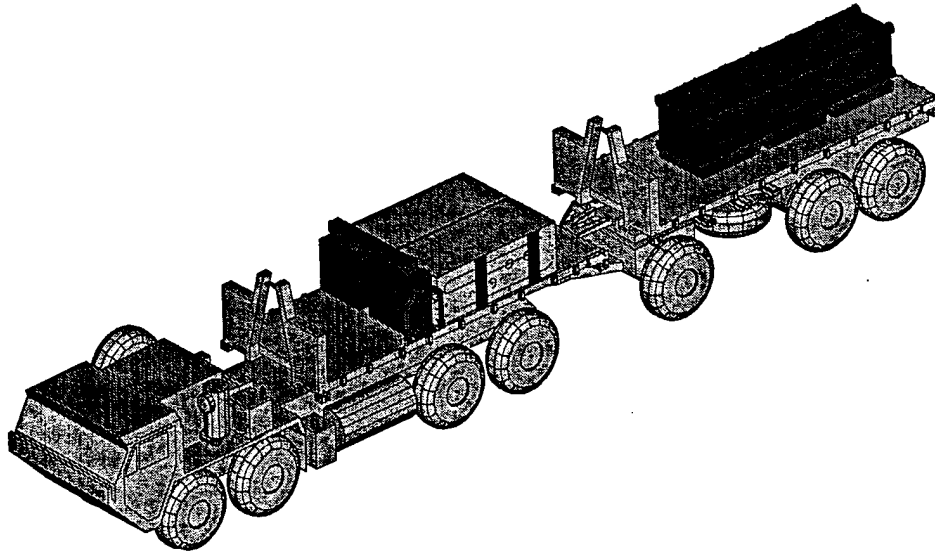


Figure 32. 100 round XM1E5 system on the M977 HEMTT with a PLS M1076 trailer for propellant and fuzes

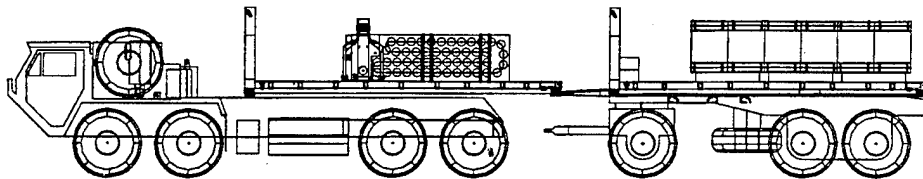


Figure 33. 100 round XM1E5 system on the M977 HEMTT with a PLS M1076 trailer for propellant and fuzes (Side view)

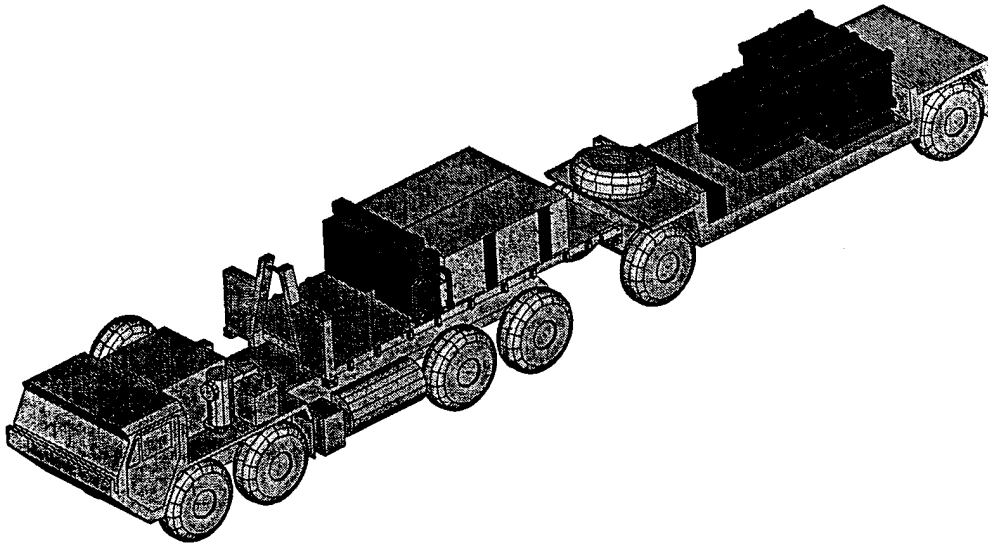


Figure 34. XM1E5 on the M977 HEMTT with a HEMAT M989A1 trailer for propellant and fuzes

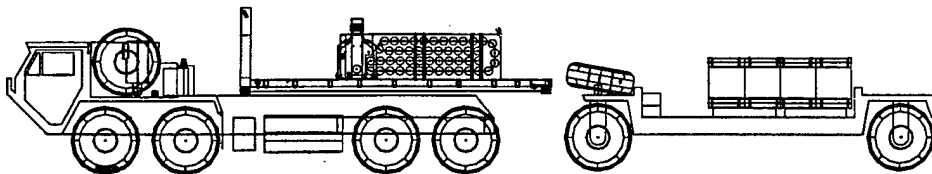


Figure 35. XM1E5 on the M977 HEMTT with a HEMAT M989A1 trailer for propellant and fuzes (Side view)

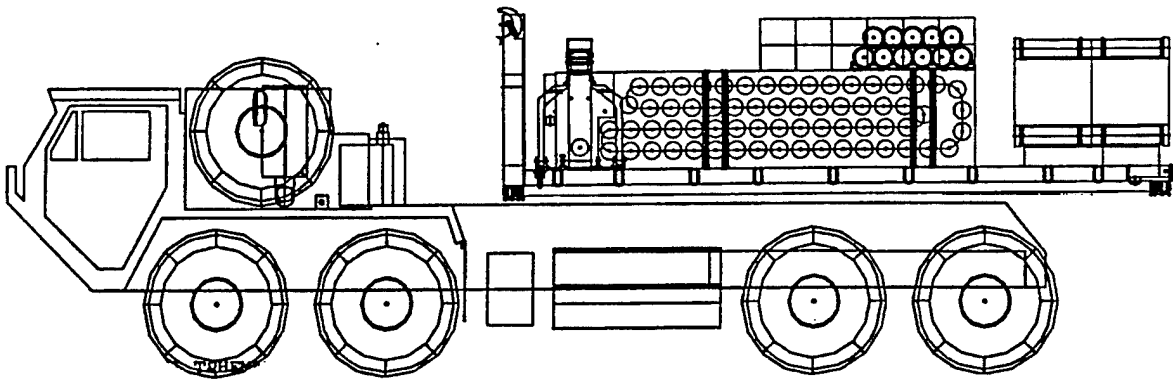


Figure 36. A 130 projectile XM1E5 system on the M1077 flatrack and HEMTT LHS host vehicle

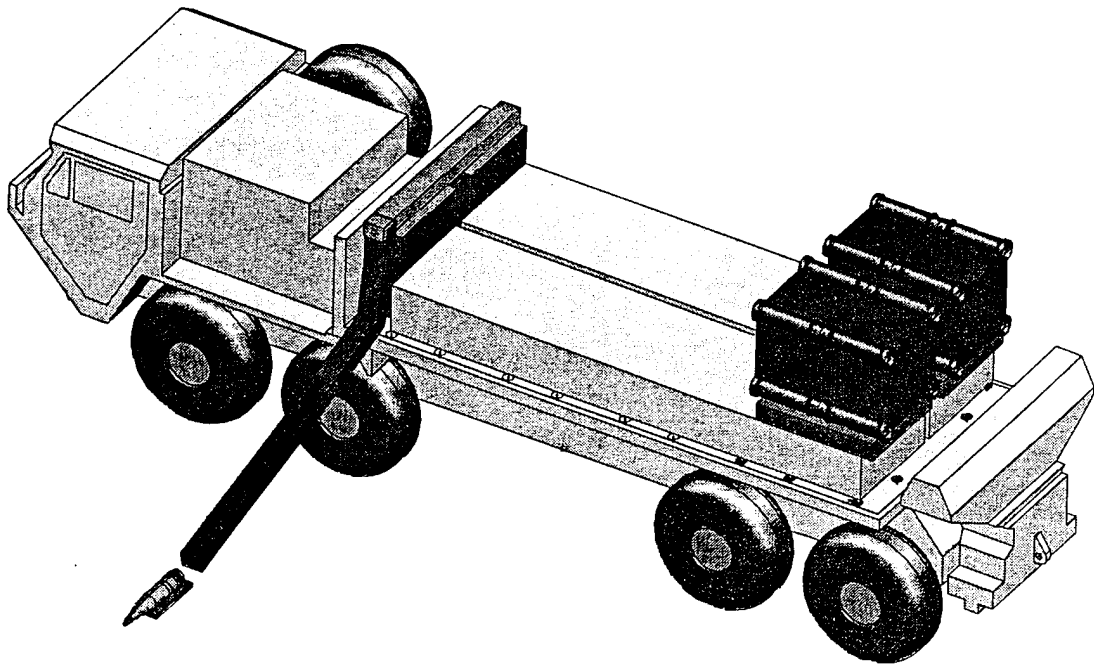


Figure 37. A single loop magazine conveyor concept on the M977 HEMTT host vehicle

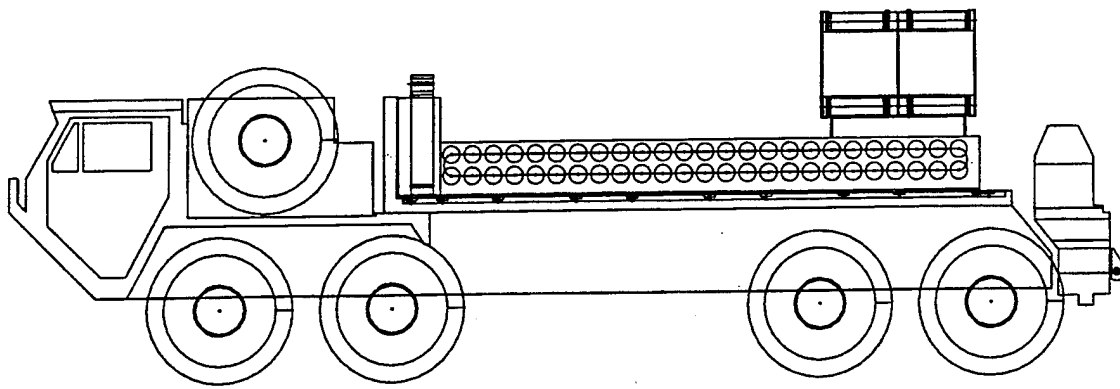


Figure 38. A single loop magazine conveyor concept on the M977 HEMTT host vehicle (side view)

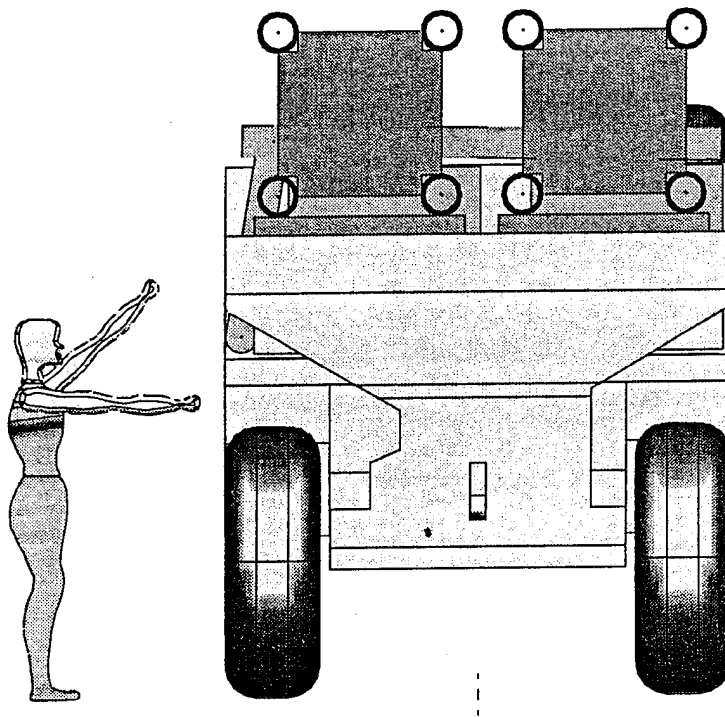


Figure 39. A single loop magazine conveyor concept on the M977 HEMTT host vehicle (rear view)

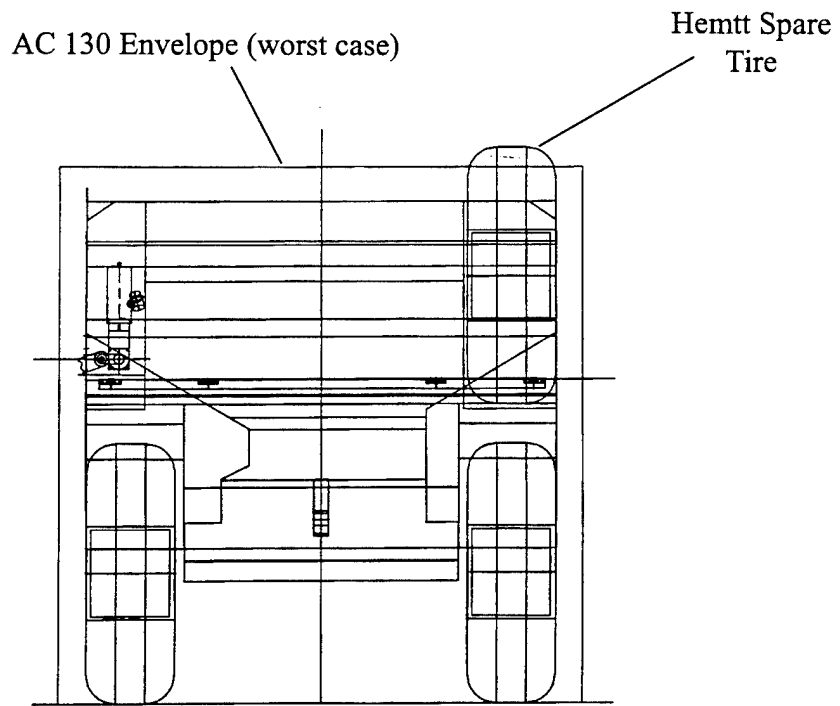


Figure 40. The AC130 aircraft profile requires that the HEMTT spare tire be removed for transport

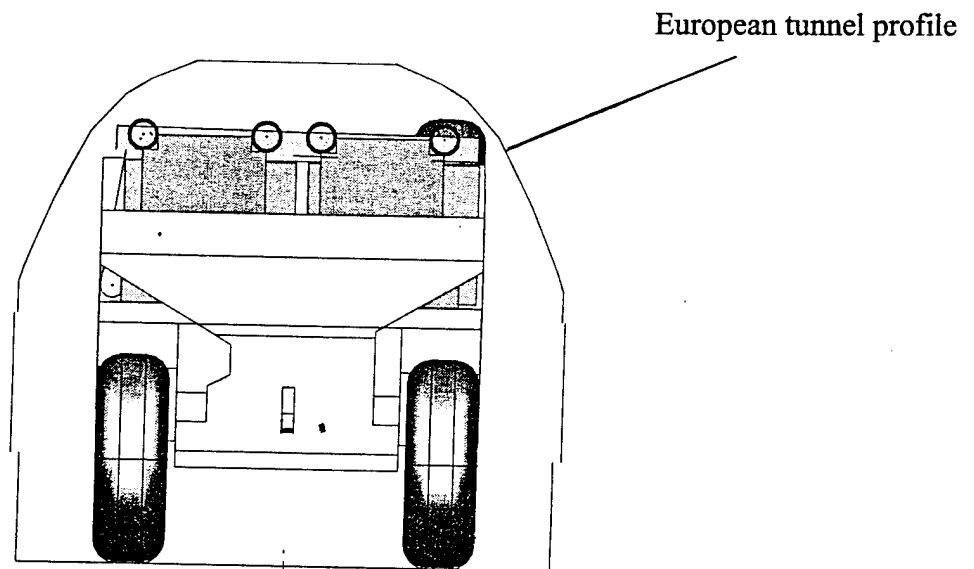


Figure 41. The XM1E5 on the HEMTT fits within the European tunnel profile without modification

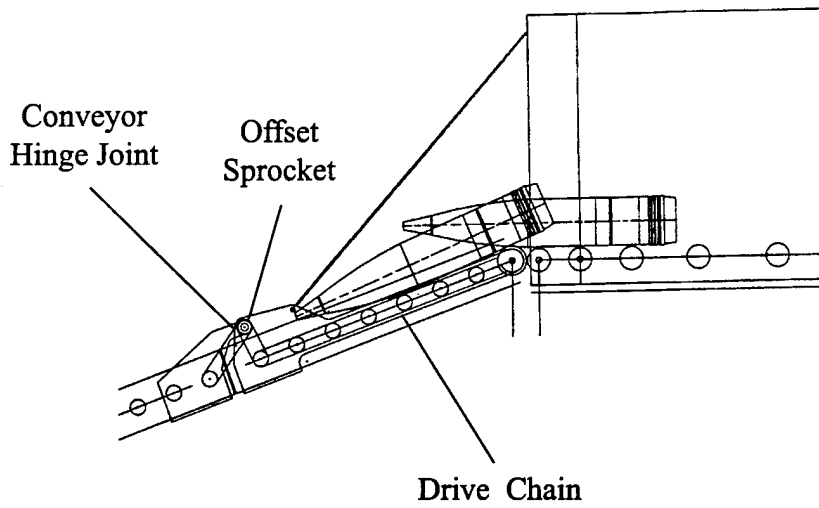


Figure 42. The conveyor chain drive is offset to a sprocket on the center of the conveyor hinge joint

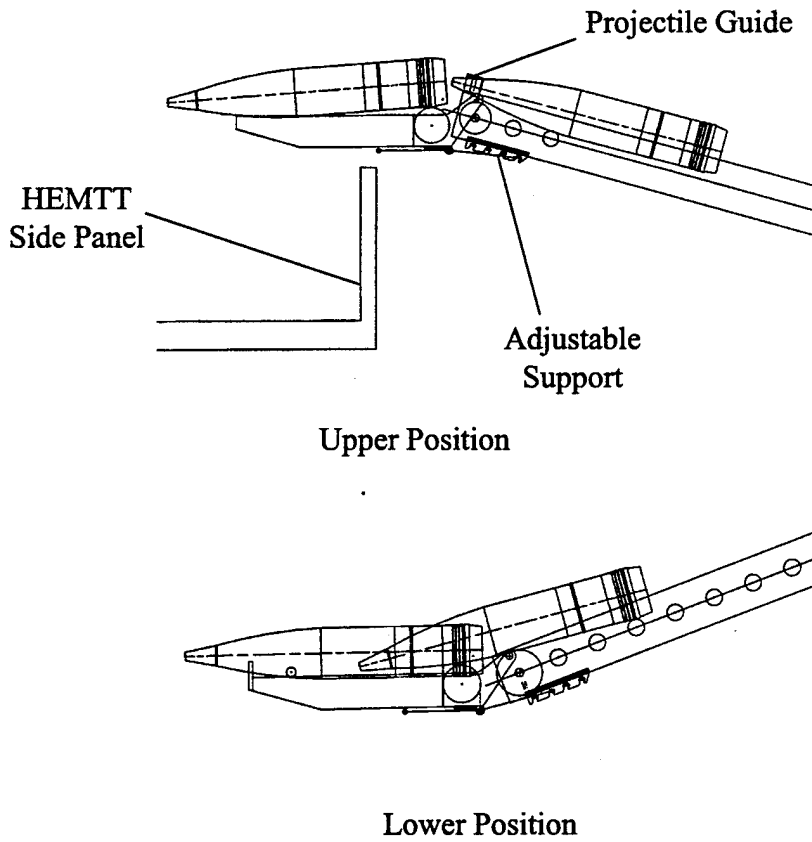


Figure 43. Adjustment extremes designed into the load tray support fittings

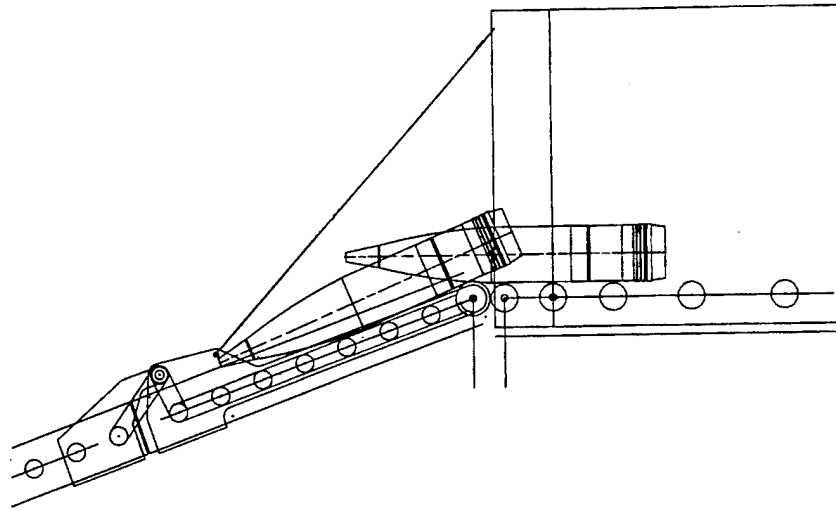


Figure 44. Stub conveyor interface to the hand-off conveyor at a 20° depressed operating condition

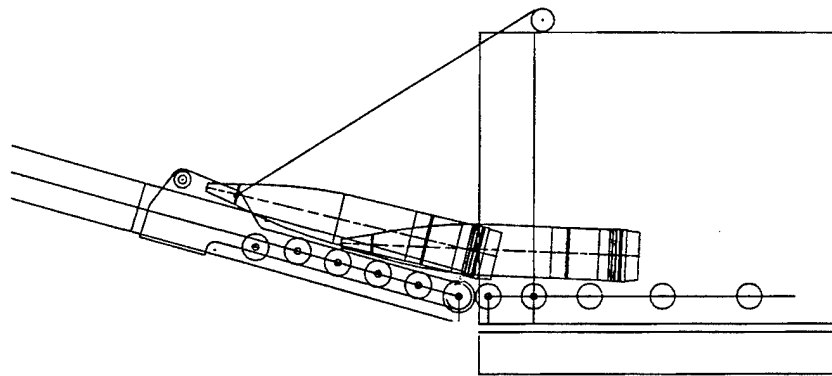


Figure 45. Close proximity between the projectile nose and the traction elements of the stub conveyor at a 15° elevated operating condition

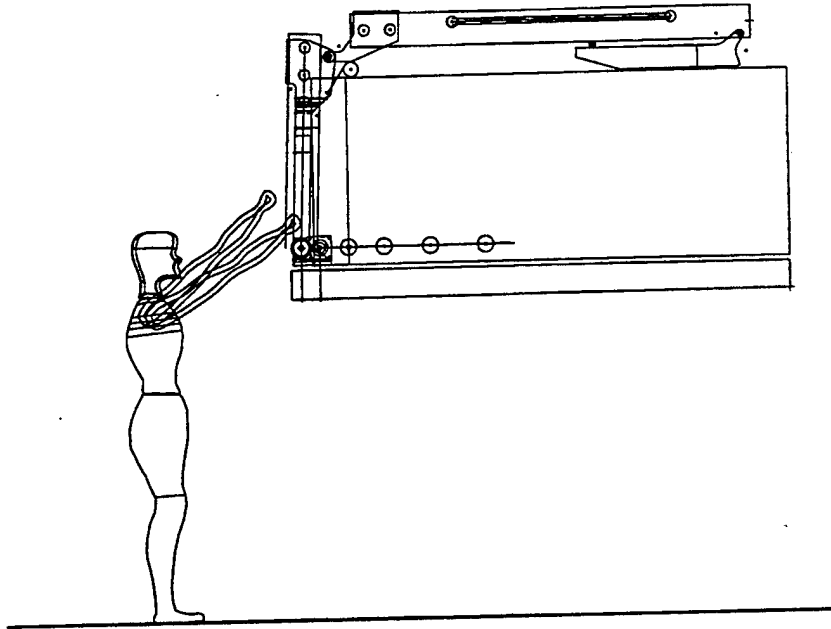


Figure 46. Conveyor in the stowed position with 95% man

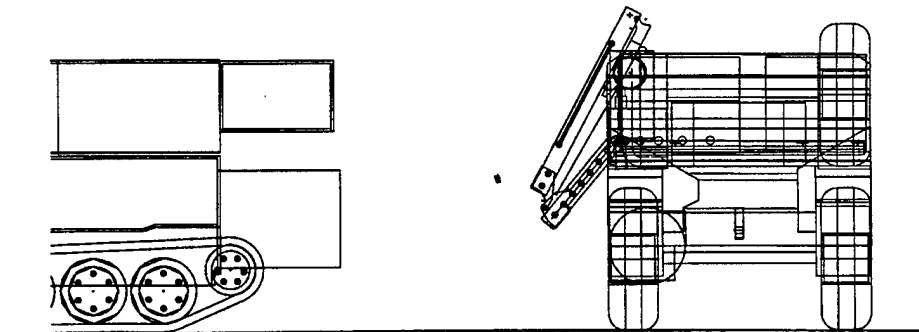


Figure 47. The electric winch automatically deploys the stub conveyor to an extreme down position

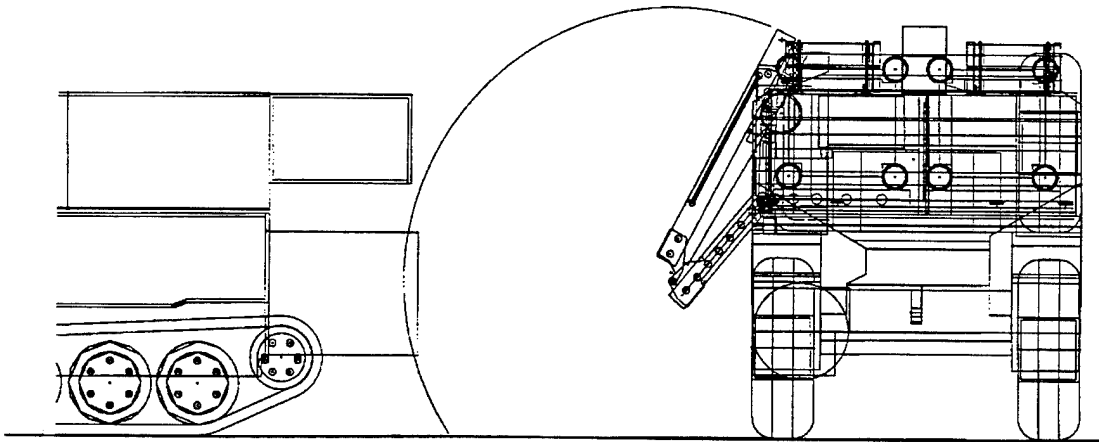


Figure 48. Outer conveyor ready to rotate with clearance from mating M109A6 Howitzer

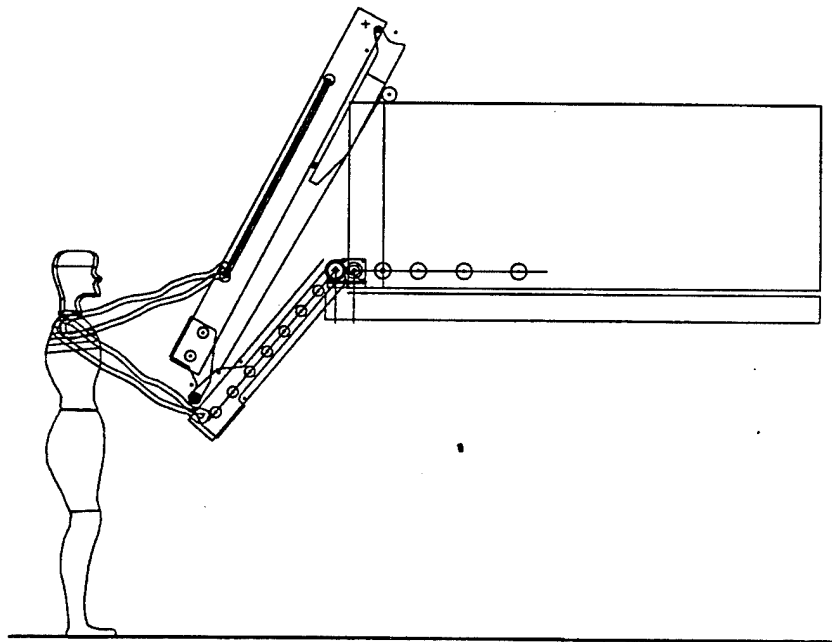


Figure 49. Start of manual rotation of outer conveyor

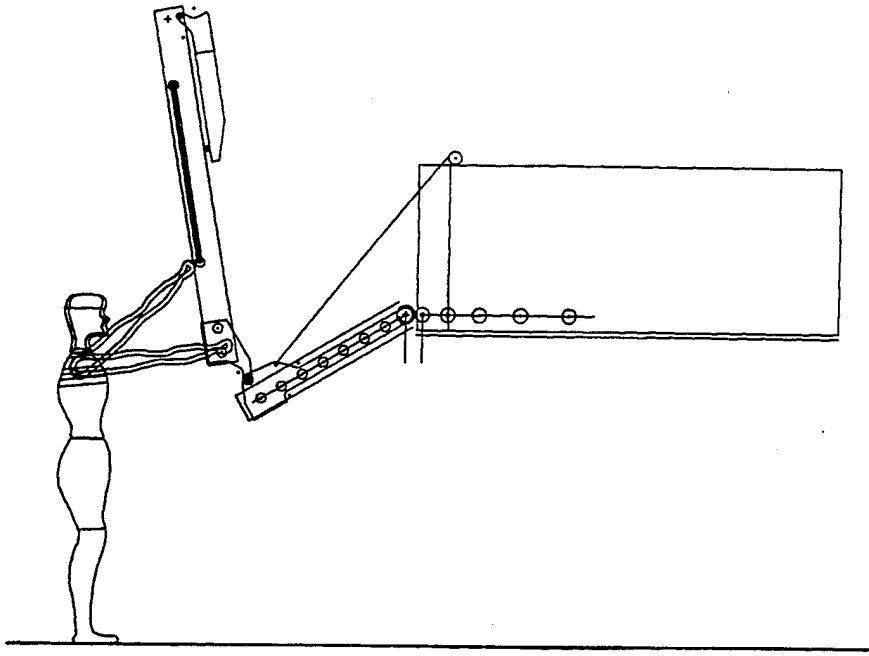


Figure 50. Over center rotation of outer conveyoyr

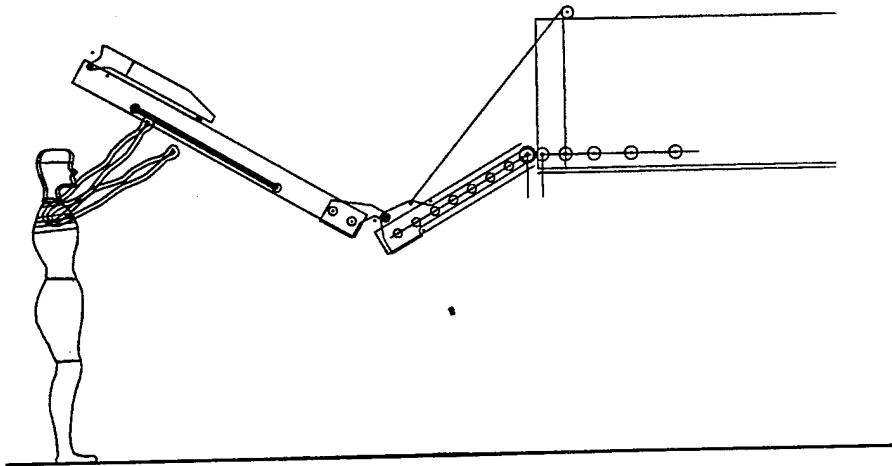


Figure 51. 75% rotation of outer conveyoyr

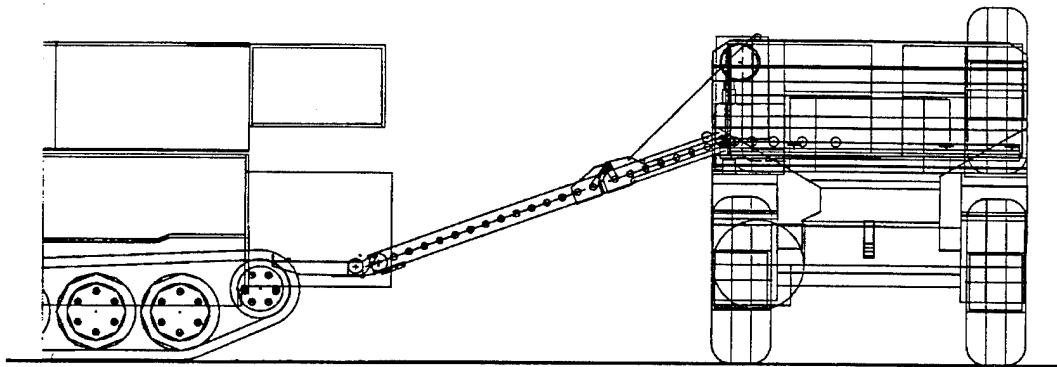


Figure 52. Fully deployed conveyor mated with the M109A6 Self Propelled Howitzer

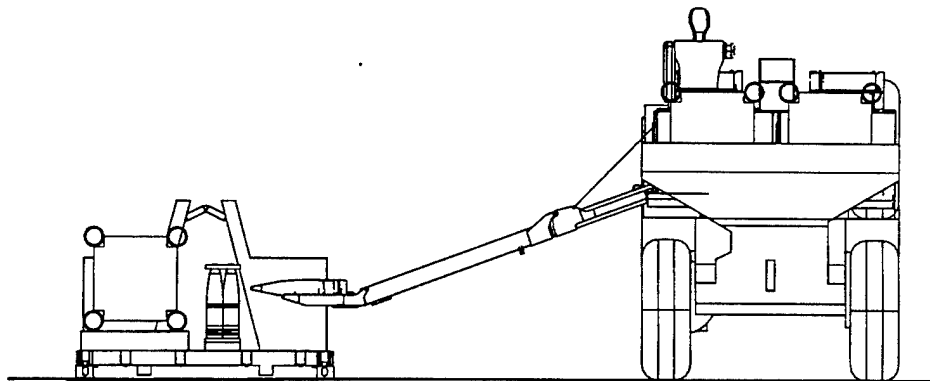


Figure 53. Loading projectiles to the XM1E5 from the deck of a flatrack on the ground

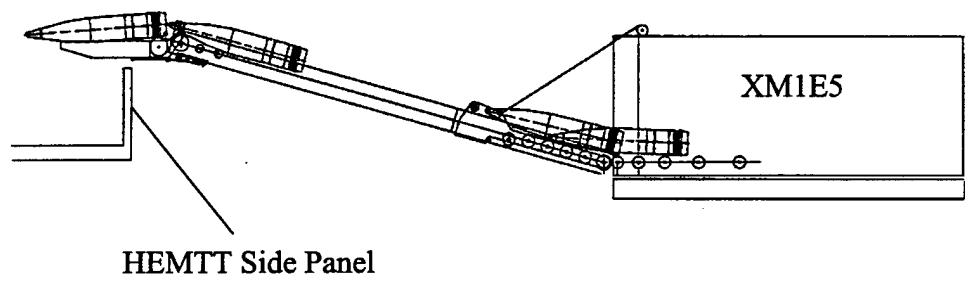


Figure 54. Conveyor deployed over the M977 HEMTT cargo bed side panel

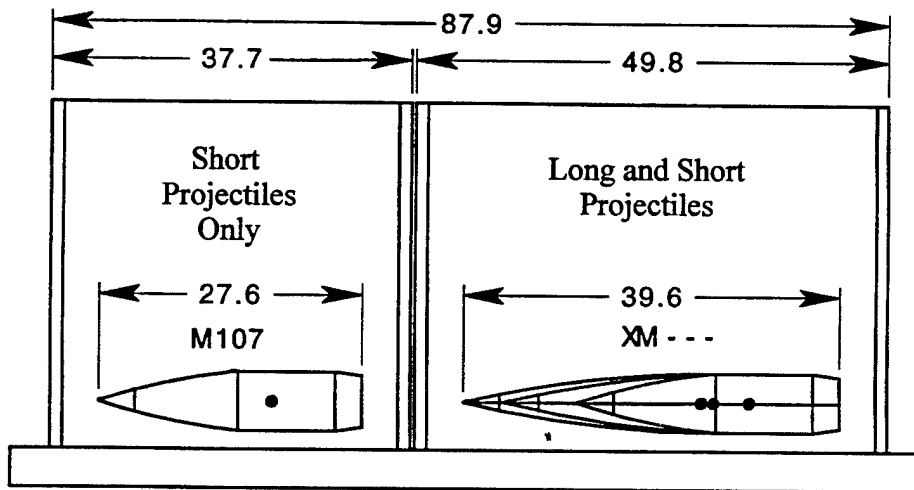
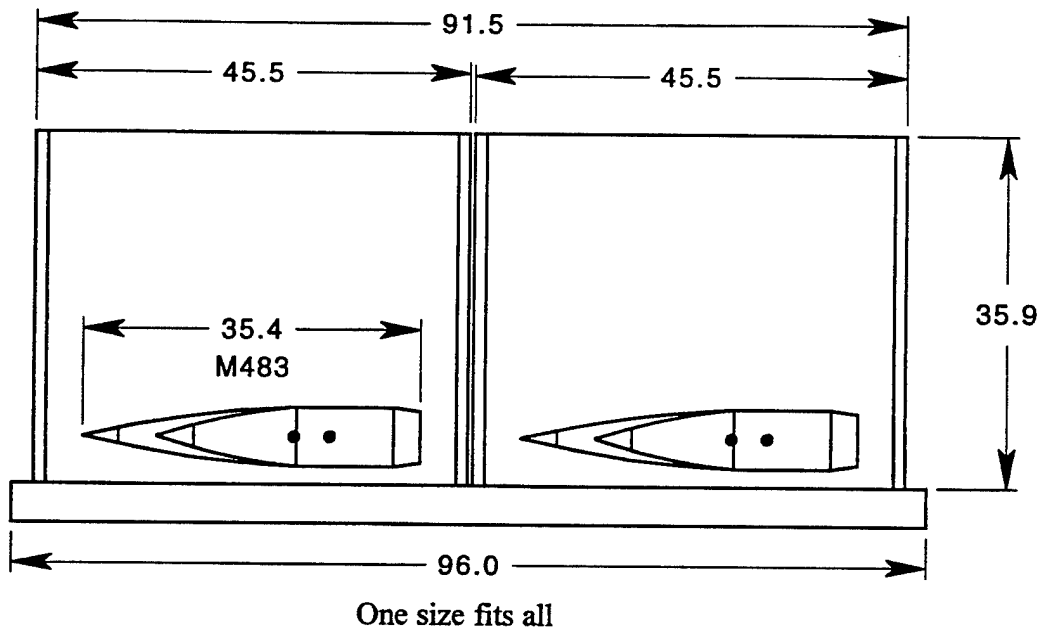


Figure 55. A space efficient the wide and narrow magazine approach

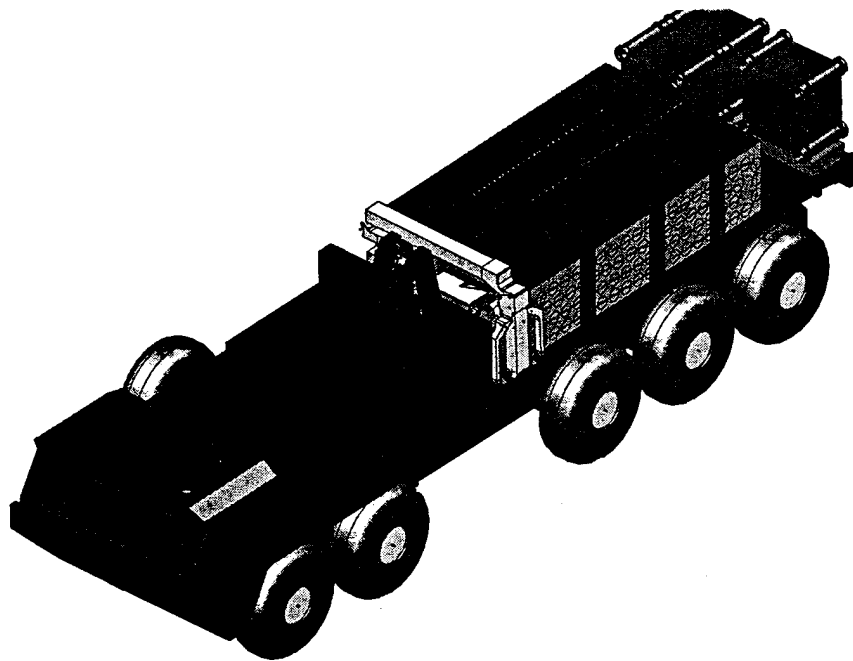


Figure 56. A 4 row high configuration with 150 projectiles in the XM1E5 system installed on the M1074 PLS truck and M1077 flatrack in the transport mode

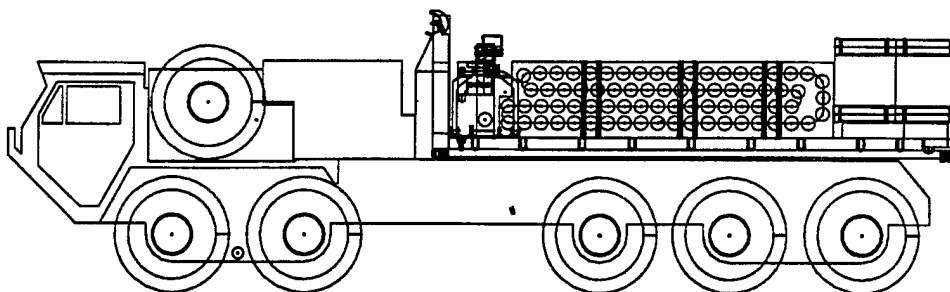


Figure 57. A 4 row high configuration with 150 projectiles in the XM1E5 system installed on the M1074 PLS truck and M1077 flatrack in the transport mode (side view)

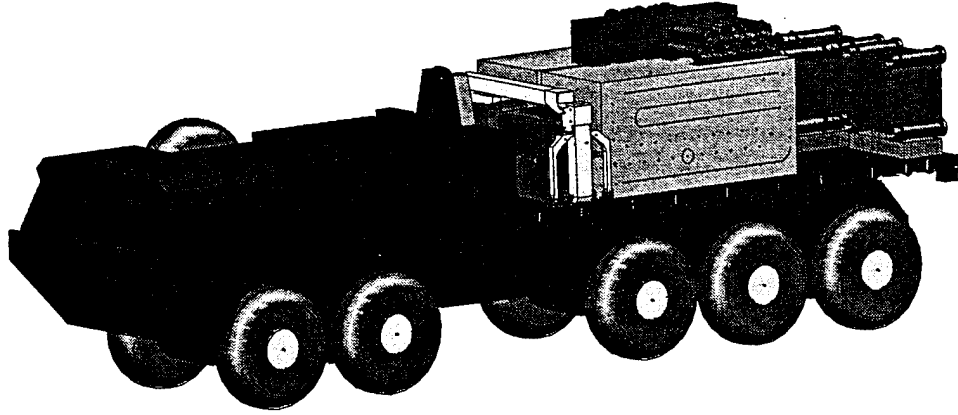


Figure 58. A 6 row high configuration with 150 projectiles that adds more floor space

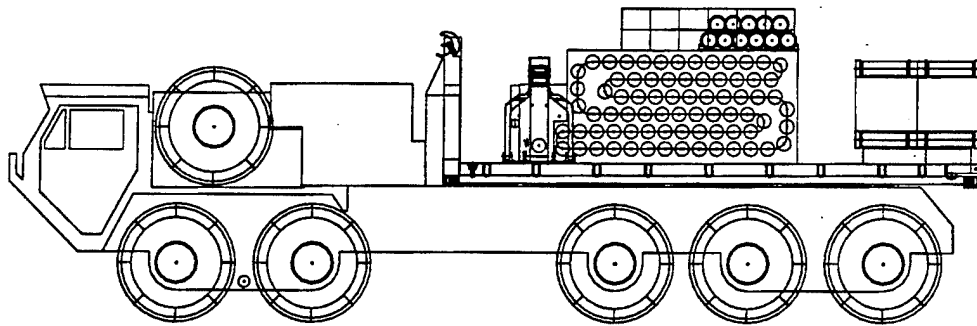


Figure 59. A 6 row high configuration with 150 projectiles that adds more floor space  
(Side view)

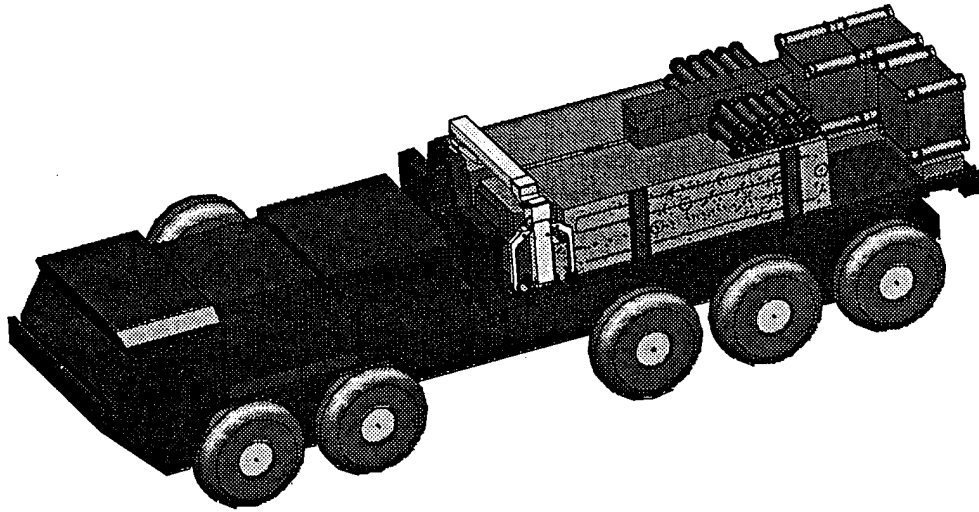


Figure 60. 130 complete rounds on the PLS flatrack on the M1074 PLS host vehicle

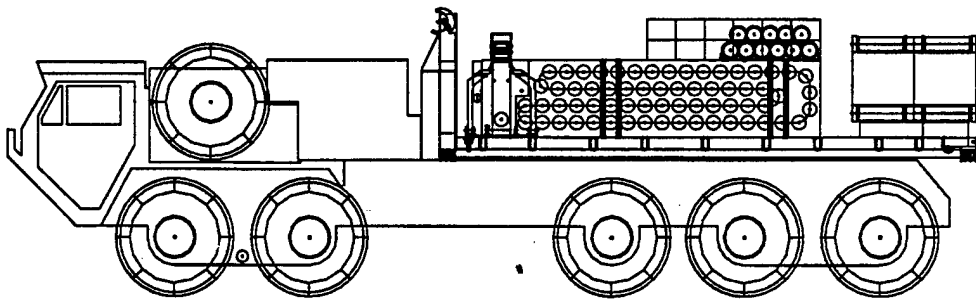


Figure 61. 130 complete rounds on the PLS flatrack on the M1074 PLS host vehicle. (Side view)

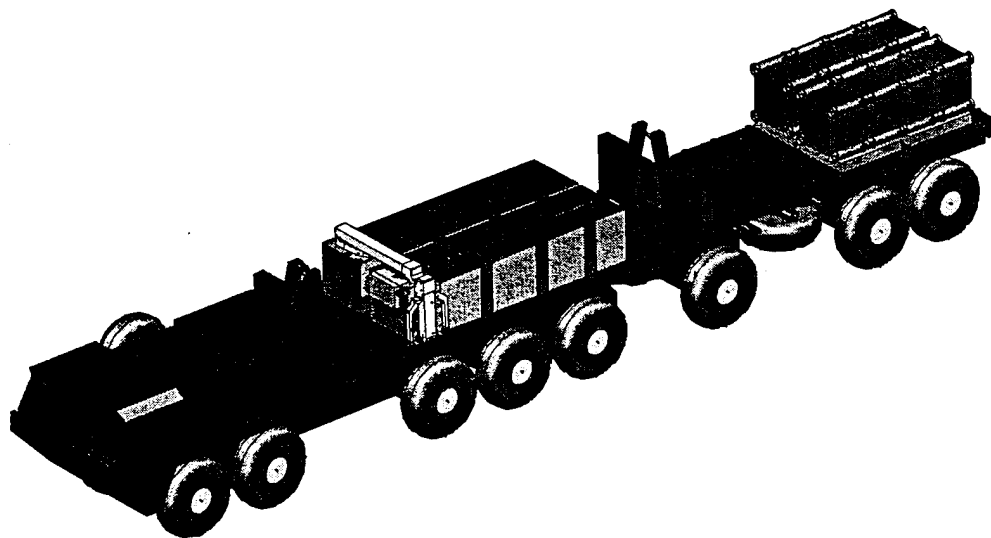


Figure 62. 150 Round Payload on M1077 Flatrack with PLS M1076 trailer for propellant and fuzes

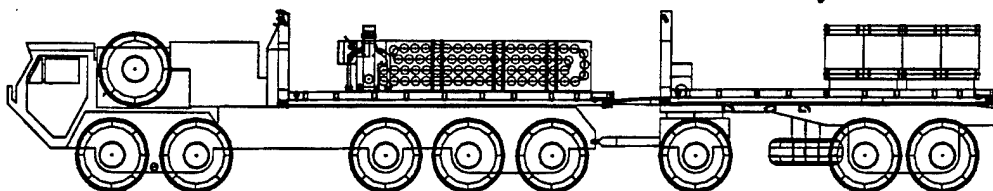


Figure 63. 150 Round Payload on M1077 Flatrack with PLS M1076 trailer for propellant and fuzes (Side view)

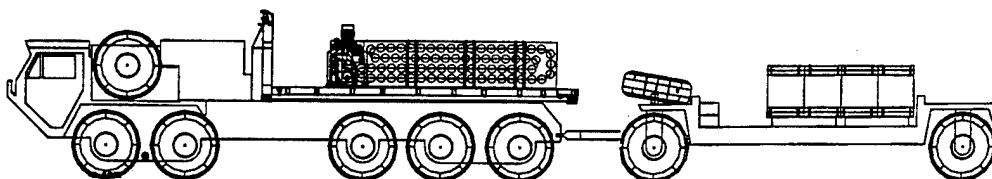


Figure 64. 150 Round Payload on M1077 Flatrack with a HEMAT M989A1 trailer for propellant and fuzes (Side view)

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- 2 Saganich, Richard, et al., "155-mm ARTILLERY REARM MODULE WITH LIQUID PROPELLANT, PHASE 1", Contractor Report ARFSD-CR-94001, ARDEC, Picatinny Arsenal, NJ, June 1994.
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