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Technology Demonstration for Automated Ammunition Reloading of Heavy Armored Systems

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AMMUNITION
LOGISTICS
PROGRAM

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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Ammunition Logistics Program

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EXECUTIVE SUMMARY

Presently, the world's most lethal battle tank, the M1A1 Abrams, must be rearmed with main gun ammunition one piece at a time through the tank's hatch. Under the best conditions, this procedure is a tiresome task; under battlefield conditions, it is also a dangerous task because the crew and equipment are exposed to deadly weapon fire and nuclear, biological, and chemical agents. Ammunition reloading for heavy armored systems has been a proven logistical problem with the Army's armored systems.

The U.S. Army's Project Manager for Ammunition Logistics (PM-AMMOLOG) assembled a national team to develop critical technology for automated reloading of armored vehicles to improve the safety and efficiency of this essential element of armored warfare. This technology was demonstrated with the Future Armor Rearm System (FARS).

FARS consists of a tracked, armored chassis, a 5-degree-of-freedom teleoperated ammunition transfer arm, and a specialized mission module. This mission module houses the systems that store ammunition and transfer it into the tank. The automated systems allow the soldier to remain safe under sealed and armored protection while remotely loading ammunition from the FARS into the tank storage system. Automated reloading not only eases the manual burden on the soldier but also provides a safer, faster, and more efficient means of reloading heavy armored systems.

This activity was sponsored by PM-AMMOLOG and the U.S. Army's Project Manager for Tank Main Armament Systems. Team members included Oak Ridge National Laboratory (ORNL), Human Engineering Laboratory (HEL), Tooele Army Depot, and Benet Weapons Laboratory.

HEL and Tooele Army Depot performed modifications on the FARS chassis. These included modifications to the power distribution systems and the addition of hydraulics to the vehicle. Tooele also fabricated the floor module and a portion of the ammunition transfer hardware.

Benet Weapons Laboratory developed an automatic loading system for the M1A1 tank, which interfaced with FARS. This autoloader mechanism, termed the XM-91 Autoloader, is a complimentary element to the XM-291 Tank Main Armament System. It provides ready rounds directly to the main gun of the tank. Benet Weapons Laboratory provided additional mechanisms which would accommodate the FARS systems and worked with ORNL to establish a communications protocol between the FARS and tank systems.

ORNL fabricated the ammunition storage system and integrated all the systems onto the floor module of the vehicle. The FARS controls architecture was developed and implemented by ORNL, and a Technology Demonstration was performed at ORNL in January 1993.

1. INTRODUCTION TO AUTOMATED RELOADING

1.1 CURRENT METHOD OF AMMUNITION RELOADING

Ammunition reloading for tanks is a proven logistical problem within the U.S. Army's armored systems. At the present time, tanks are manually reloaded. This manual reloading is aided by a Heavy Enhanced Mobility Tactical Truck (HEMTT), a wheeled, lightly armored vehicle used for a variety of army operations. For ammunition reloading, the HEMTT carries ammunition stored in metal cans which are strapped onto pallets that sit on the bed of the HEMTT.

When a tank is running low on ammunition, the Tank Commander (TC) communicates with the base and a HEMTT is discharged to meet with the tank at a safe place, well behind the fighting line. When the tank and HEMTT meet, the tank hatch is opened, the HEMTT and tank crews dismount, and ammunition reloading begins. A soldier removes each round from the storage cans and passes them to another soldier standing on top of the tank. This second soldier passes them to a third soldier inside the tank who places the ammunition into the storage tank honeycombs. Under the best conditions, this is a tiresome task; under battlefield conditions, it is also a dangerous task because both the crew and equipment are exposed to weapon fire and nuclear, biological, and chemical (NBC) agents.

1.2 TECHNOLOGY FOR AUTOMATED RELOADING

Automated reloading not only eases the manual burden on the soldier but also provides a safer, faster, and more efficient means of reloading heavy armored systems. The Future Armor Rearm System (FARS) technology demonstrates the ability to transfer ammunition to an automatic reloader in a tank. The use of automated systems eliminates the need for manual intervention in the reloading and firing operations. The scenario for the FARS operation is described in the following paragraphs.

When the tank is running low on ammunition, the TC will communicate with the base and a FARS will be discharged to meet with the tank, as shown in Fig. 1. The FARS will be on a tracked, armored chassis which will enable it to access the same areas as the tanks. Armored protection will allow the FARS to meet the tank closer to the fighting line than the HEMTT. The FARS will approach the tank, and the FARS operator will dock the transfer arm with the port located on the tank bustle, as shown in Fig. 2. This docking operation will be performed from inside the FARS cab. Once docking is completed, the connection between the tank and the FARS will be purged to maintain complete NBC protection during reloading. Communications will indicate a ready mode, and the ammunition transfer will begin.

Ammunition will be housed in individual storage cells inside the FARS. These cells will be mounted in a rotating carousel to allow access to any desired type and sequence of ammunition. The TC will specify the desired combination of ammunition, and the FARS will send the ammunition from the carousels to a 2-degree-of-freedom (D.F.) lift table and through the transfer arm into the bustle of the tank. Once inside the tank, a receiver mechanism will take the round and transfer it into an

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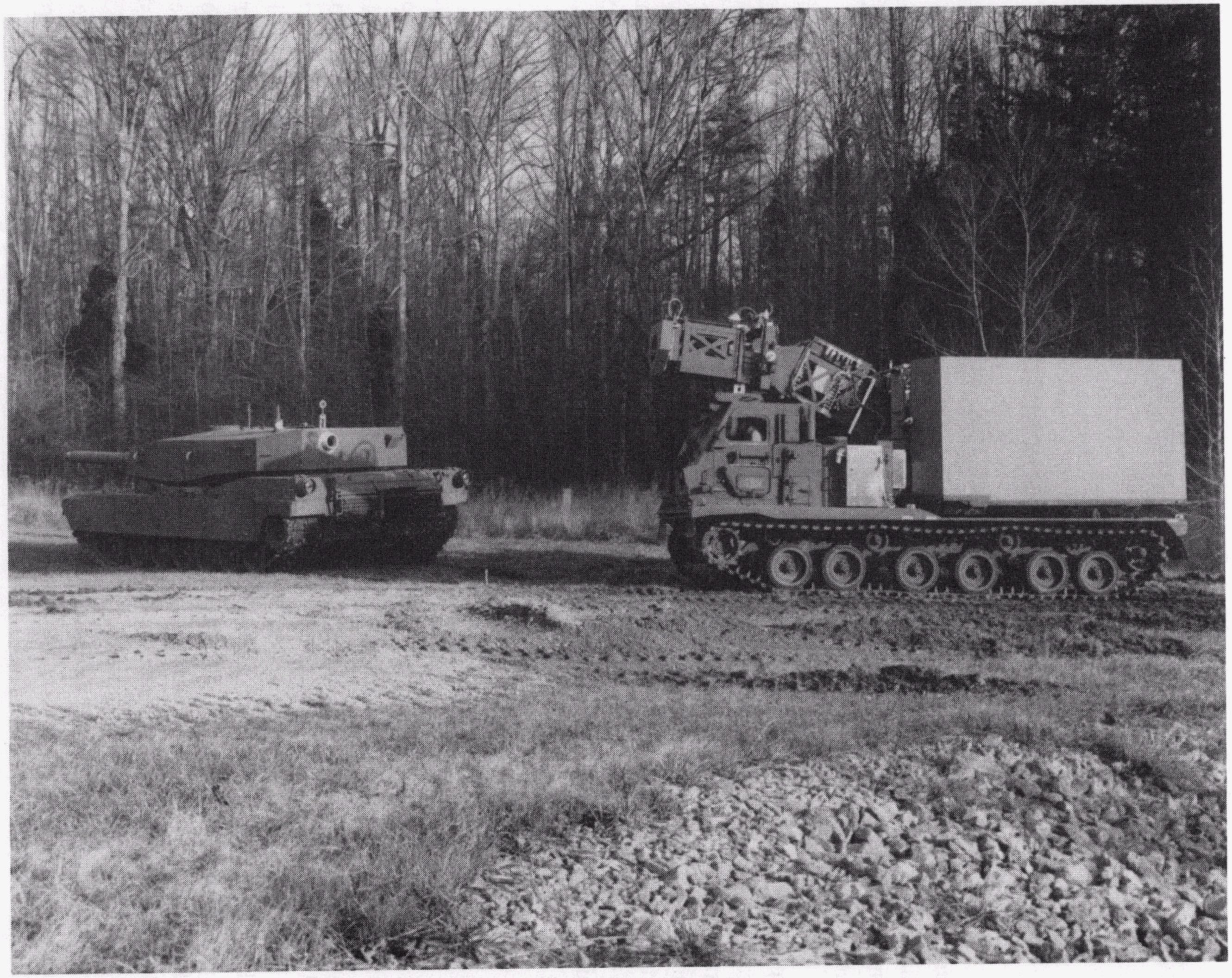

Fig. 1. FARS meeting with tank.

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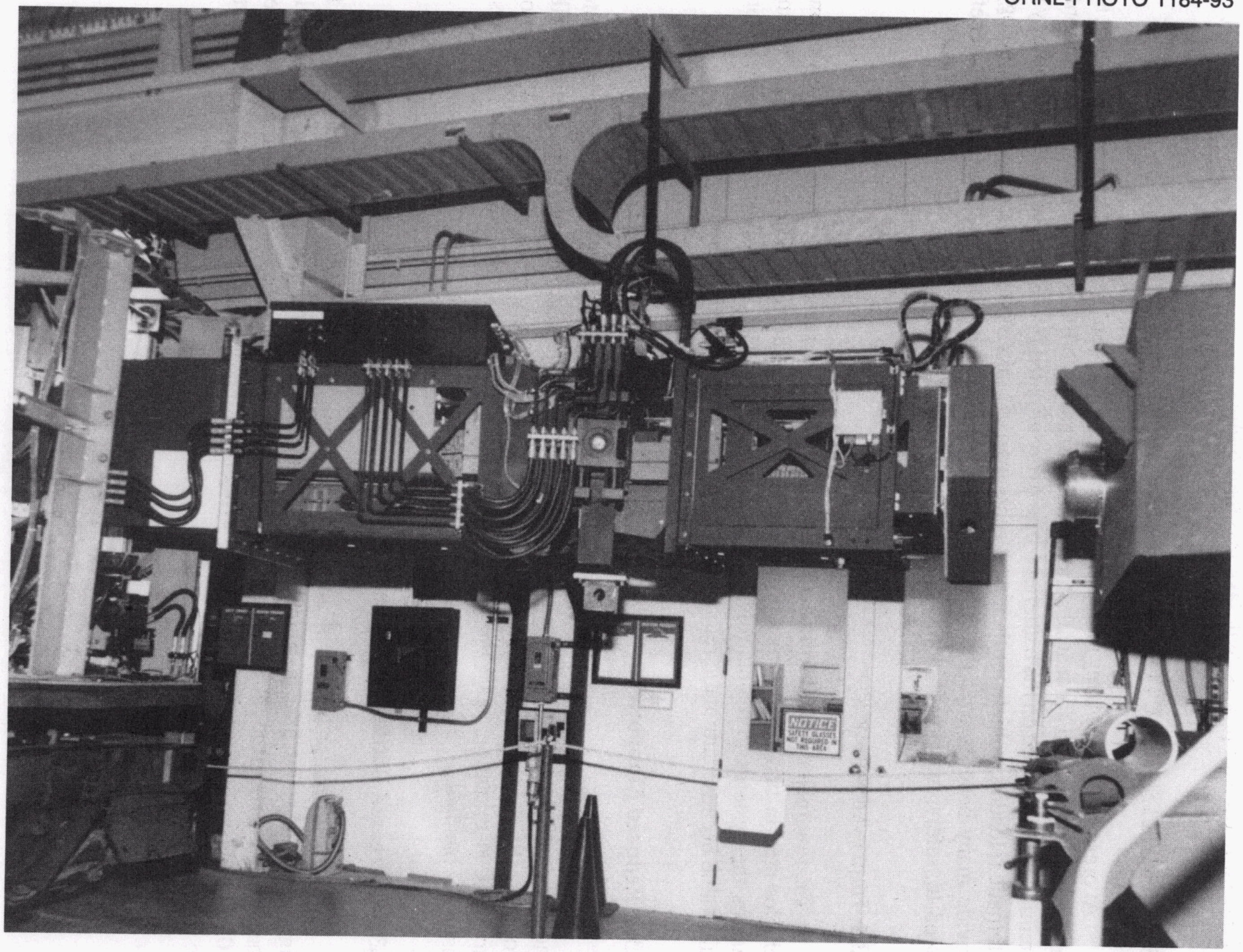

Fig. 2. Transfer arm docking with port on tank bustle.

autoloader carousel inside the tank. This autoloader mechanism will store the ammunition in the tank bustle and feed it into the main gun.

The goal was to perform the entire reloading process, including docking and ammunition transfer, in 10 min or less. We estimate that the docking operation will take approximately 2 min and that the entire transfer process will take less than 8 min.

1.3 BENEFITS OF AUTOMATED RELOADING

At present the U.S. Army reloads tanks manually, using soldiers to handle rounds one at a time. This is slow, at best, and is not at all suited for the hazardous NBC environment and conventional fire potentially encountered on the battlefield. The Army initiated FARS to develop the technology for an automatic reloading vehicle for their next generation of tanks. Automated reloading technology will provide many benefits over the current manual method. The major areas which will benefit are threefold: safety, manpower, and battlefield availability.

1.3.1 Improved Safety

The first major benefit from automated reloading is increased soldier safety. Crews from both vehicles remain under full armor protection during the entire reloading process. This technology enables the systems to maintain NBC-sealed conditions. Also, the soldiers and vehicles are less vulnerable because automatic reloading is faster than the current method.

1.3.2 Reduced Manpower

The second major area to benefit is manpower reduction. The current method is labor intensive and lengthy. Soldiers from both crews must dismount and handle the ammunition from the HEMTT storage cells, to the tank, down the hatch, and into the tank storage system. With automated ammunition reloading, once the FARS leaves the supply base, the ammunition never has to be manually handled.

1.3.3 Increased Battlefield Availability

The third major benefit of automated reloading is increased battlefield availability for the fighting vehicles. Because the automated reloading vehicle is armored and tracked, it can go closer to the fighting line than the current reloading vehicle. With the entire automated reloading sequence taking 10 min or less, there is a significant time savings over the current manual method, which can take up to 30 min.

2. AMMUNITION RELOADING TECHNOLOGY DEMONSTRATION

A Technology Demonstration was performed at Oak Ridge National Laboratory (ORNL) in January 1993 with the FARS/Autoloader systems which demonstrated the transfer of ammunition from a reloading vehicle into a tank without manual intervention. Although the concepts developed apply to the complete fielded rearm vehicle, the Technology Demonstration focused on critical features to ensure the most efficient use of resources. Objectives and information on this demonstration are outlined in the following subsections. The following subsections also describe the full FARS/Autoloader systems and, where applicable, outline limitations for the Technology Demonstration. Appendix A contains a glossary of terms which are used throughout this report.

2.1 OBJECTIVES FOR TECHNOLOGY DEMONSTRATION

The automatic reloading technology demonstrated by the FARS/Autoloader systems was designed to meet many objectives. The main objective of FARS was to develop systems which would allow closed-hatch rearming under armored protection. The FARS development effort produced systems which can handle main gun ammunition and expand to other types of ammunition or supplies.

For the fielded FARS, plans are to have two operators stationed in the vehicle cab. The FARS operator will be able to perform all reloading functions from control panels located in the vehicle cab. For the Technology Demonstration, the operator control station for the system was located on the floor of the module to allow easier troubleshooting and a more efficient use of resources.

The relative pitch and yaw between the reloading vehicle and the tank can be as much as 10°. The vehicles must be able to reload where the longitudinal and/or lateral slope of the terrain is as great as 20% (where 45° = 100%). The system was designed to meet these requirements, but the Technology Demonstration was held on level terrain inside the high bay of Building 7603.

The reloading vehicle requires the ability to quickly break away from the tank in emergency situations. This allows for either the FARS or the tank to quickly escape. This capability was also demonstrated at the Technology Demonstration. A set of simplified global requirements is presented in Table 1.

2.2 DEVELOPMENT TEAMS

The organization chart for the FARS/Autoloader teams is shown in Fig. 3. The sponsor for the FARS Project was the Project Manager for Ammunition Logistics (PM-AMMOLOG), located at the Picatinny Arsenal. PM-AMMOLOG has as its charter the challenge of identifying logistics problems in the ammunition chain and finding solutions. PM-AMMOLOG assembled a team consisting of three government agencies to develop and demonstrate the FARS technology. This team included ORNL in Oak Ridge, Tennessee; the Human Engineering Laboratory (HEL) at Aberdeen Proving Ground, Maryland; and the Tooele Army Depot (TeAD) at Tooele, Utah. The sponsor for the XM-91

Table 1. Global design requirements for the FARS/Autoloader systems

Item	Requirement
Ammunition:	
140-mm front end: projectile of round	27.2-kg, 1.07-m-long, 140-mm-diam
140-mm rear end: propellant of round	18.1-kg, 0.53-m-long, 140-mm-diam
120-mm one-piece round	25-kg, 0.99-m-long, 120-mm-diam
Relative misalignment between FARS and tank	±10° in pitch (see Fig. 4) ±10° in roll ±1 ft from docking port centerlines (see Fig. 5)
Terrain	Operational up to a 20% slope
Separation between FARS and tank	3.7-m maximum
Docking	≤2 min and capable of quick breakaway
Feed rate	8 pieces/min[a] in any arbitrary order[b]
Reverse operation	Able to unload tank (no time limit)
Crew	2 persons: 1 person in emergency
Light	None to full daylight
Temperature	−18 to 49°C

[a]This would allow for a complete load of 39 rounds to be transferred in 10 min.
[b]The transfer rate for the Technology Demonstration was 4 pieces/min.

Autoloader was the Project Manager for Tank Main Armament Systems (PM-TMAS), also at the Picatinny Arsenal. The XM-91 Project falls under the Advanced Tank Cannon (ATAC) System with the U.S. Army Armament Munitions and Chemical Command. The development team is from Benet Weapons Laboratory in Watervliet, New York.

2.3 DEMONSTRATION SCOPE

The Technology Demonstration consisted of docking the transfer arm to the tank and transferring ammunition from the FARS carousel to the lift table, through the transfer arm to the receiver, and into the Autoloader. Downloading of that same ammunition was also demonstrated. Additional information on the demonstration is outlined in the following paragraphs.

FARS was developed to handle either the 120-mm one-piece ammunition or the 140-mm two-piece ammunition; both types of ammunition were transferred in the Technology Demonstration. Dummy samples of both types of ammunition are shown in Fig 6.

The 140-mm family of ammunition which was simulated in the Technology Demonstration consists of three cartridges for both combat rounds: a kinetic energy cartridge, a chemical energy cartridge, and a training cartridge. Each cartridge consists of a forward and rear component. The rear component, or prop charge, is identical for all three cartridges. It consists of a stub base and primer assembly, a combustible side wall, an ignition system, and propellant. The forward component, or projectile, houses the appropriate projectile and propellant in a combustible cartridge case. The case also contains a relay charge at its base to transfer ignition from the rear component. A snap joint joins

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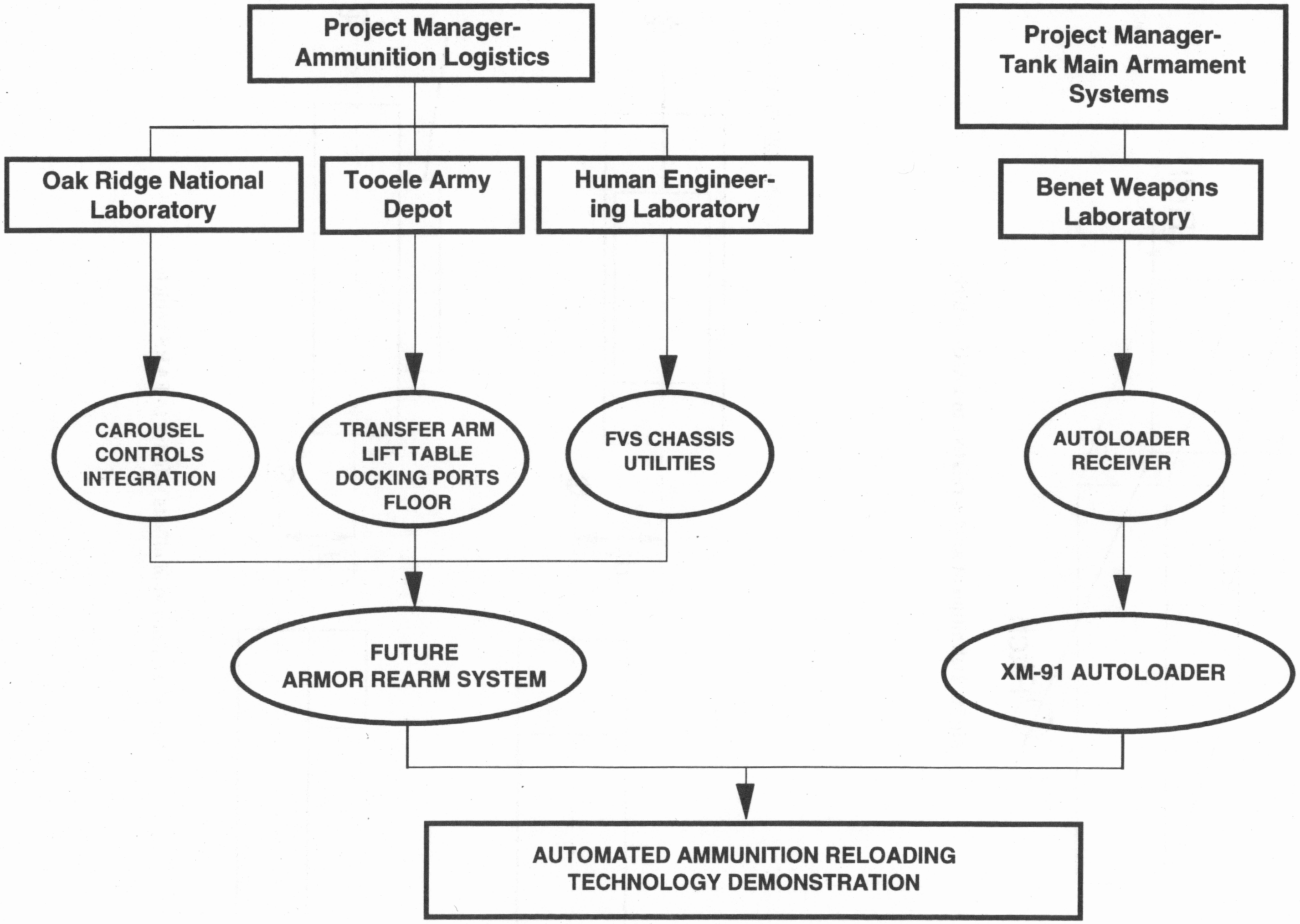

Fig. 3 Organization chart for FARS/Autoloader teams

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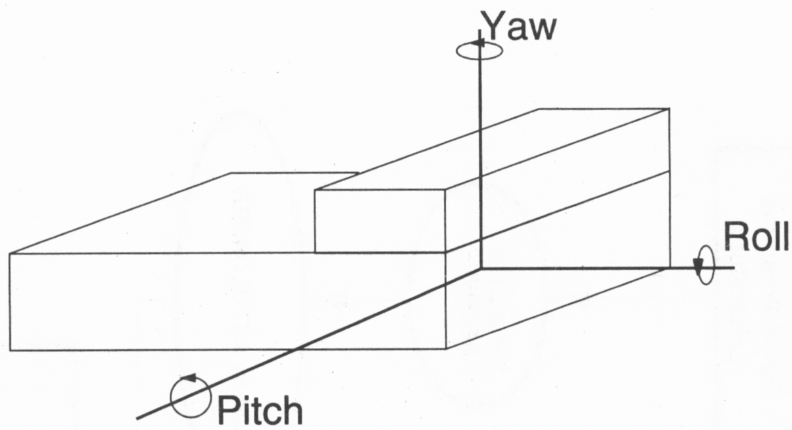

Fig. 4. Definition of angles relative to FARS vehicle.

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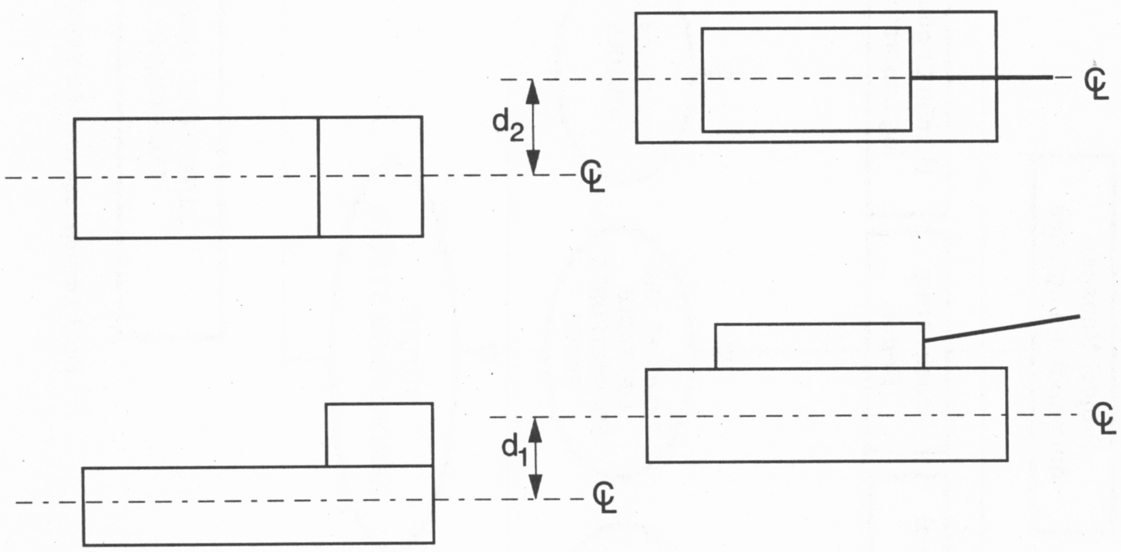

Fig. 5. Definition of offsets relative to FARS vehicle.

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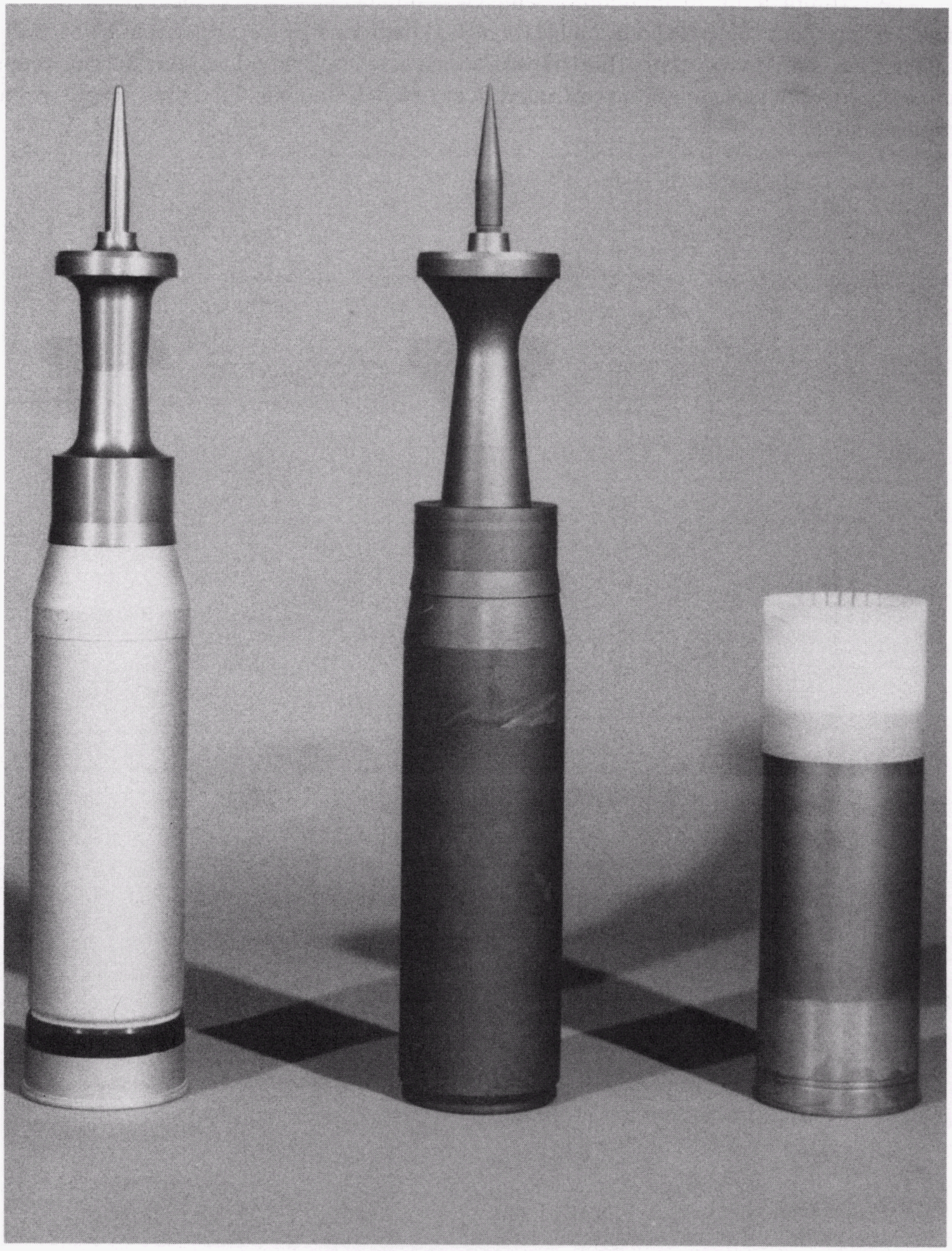

Fig. 6. 120- and 140-mm ammunition.

the two components, allowing cartridge removal from the breech of the gun. The 140-mm round offers a muzzle energy that is double that of the standard 120-mm round. A generic dummy round was used in the Technology Demonstration to simulate the 140-mm rounds; however, the FARS/Autoloader systems were developed to handle all three types of rounds.

The 120-mm family of ammunition which was simulated in the Technical Demonstration also consists of three cartridges for both combat rounds: a kinetic energy cartridge, a HEAT cartridge, and a training cartridge. It consists of a stub base and primer assembly, a combustible side wall, propellant, and the appropriate projectile. Dummy rounds were used to simulate the rounds in the Technology Demonstration.

3. HARDWARE INFORMATION

The technology for automated ammunition resupply can be broken down into several major subsystems that work together to form the total FARS/Autoloader system: (1) the articulated transfer arm and docking port with internal conveyor connects with the tank and transfers rounds from the FARS vehicle to the tank, (2) the carousel stores and selects rounds, (3) the lift table aligns and transfers between the carousel and the transfer arm, (4) the receiving mechanism receives the rounds inside the tank, and (5) the Autoloader stores ammunition in the tank and feeds it into the gun. With the exception of docking with the articulated transfer arm, which is done first, the carousel, lift table, transfer arm conveyors, receiving mechanism, and Autoloader systems must act together as a coordinated system. Specifically, this requires that (1) transferring a round from one system implies receipt of the round by another system, (2) transferring rounds between systems must be at matching speeds, and (3) the average rate of transfer through each of the systems must be equal.

3.1 FARS SYSTEMS

The FARS systems and dimensions are shown in Fig. 7. The FARS systems are located in the module, as shown in Fig 8. For the Technology Demonstration, a single six-cell carousel which holds three projectile cells, two prop charge cells, and one dummy cell was used. A single-cell test simulated the rear carousel, and a powered roller set simulated a top carousel. All other FARS systems were developed as shown and are outlined in the following sections.

3.1.1 FARS Floor

The FARS systems are mounted on a floor which is attached to a 45-in. rotating bearing. Two hydraulically driven motors rotate the floor 360°. Hydraulic and electric power is passed through the floor via a slip ring attached to the chassis. The structure of the floor is shown in Fig. 9, and the layout of equipment on the floor is shown in Fig. 10. The single-cell test stand was used for the bottom aft carousel, and the six-cell carousel was used for the bottom forward carousel. The powered roller set was used as the top forward carousel and was mounted directly over the bottom forward carousel. The man-machine interface (MMI) was located on the floor next to the single-cell test stand. The MMI is described in Sect 5.1.

3.1.2 Carousel

The FARS ammunition modules consist of a horizontally oriented, chain-driven carousel magazine equipped with 20 ammunition cells capable of bidirectional rotation. Ammunition is stored in the carousels in individual storage cells. Each cell is equipped with warhead supports released only

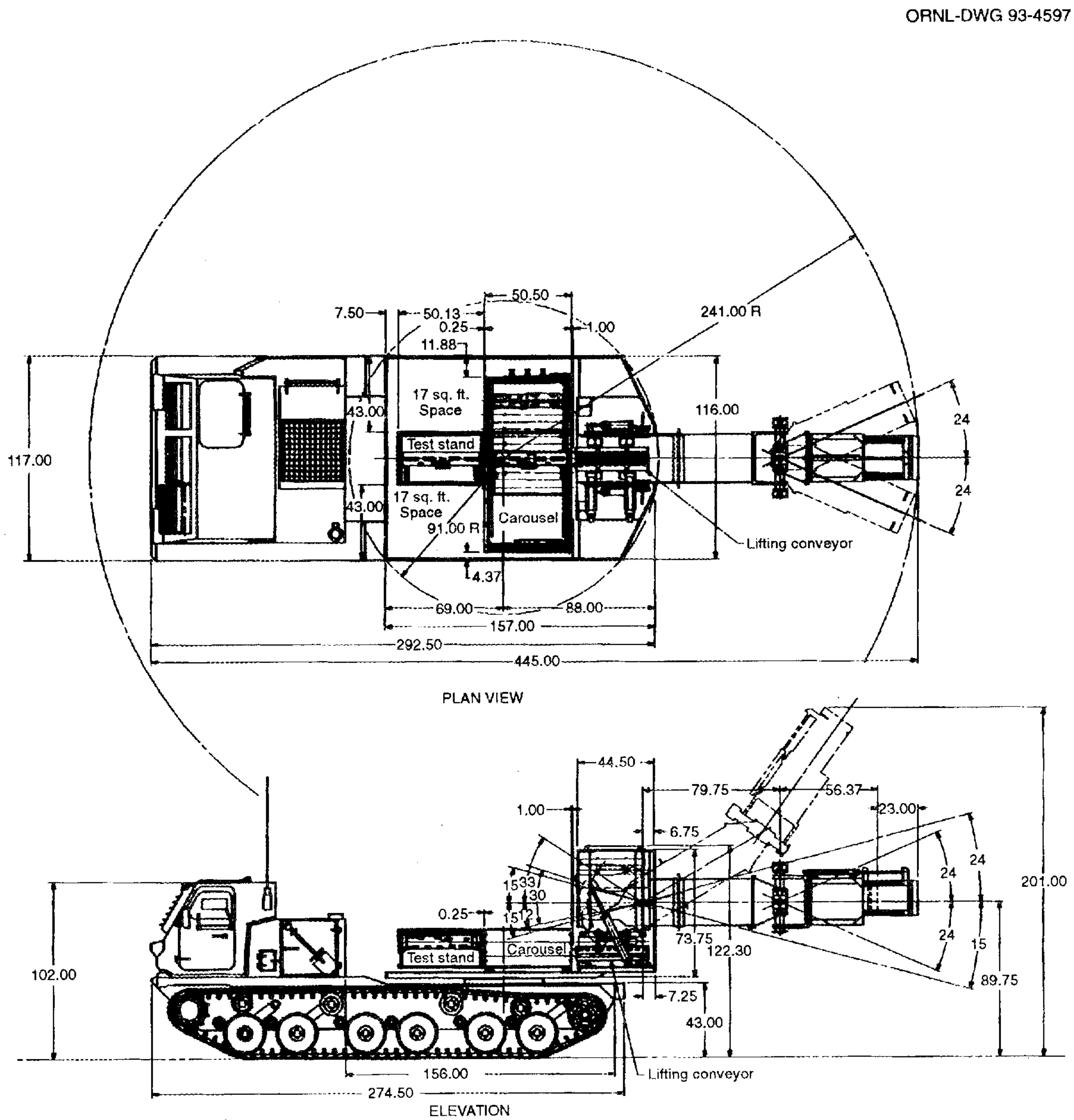

Fig. 7. FARS systems and dimensions.

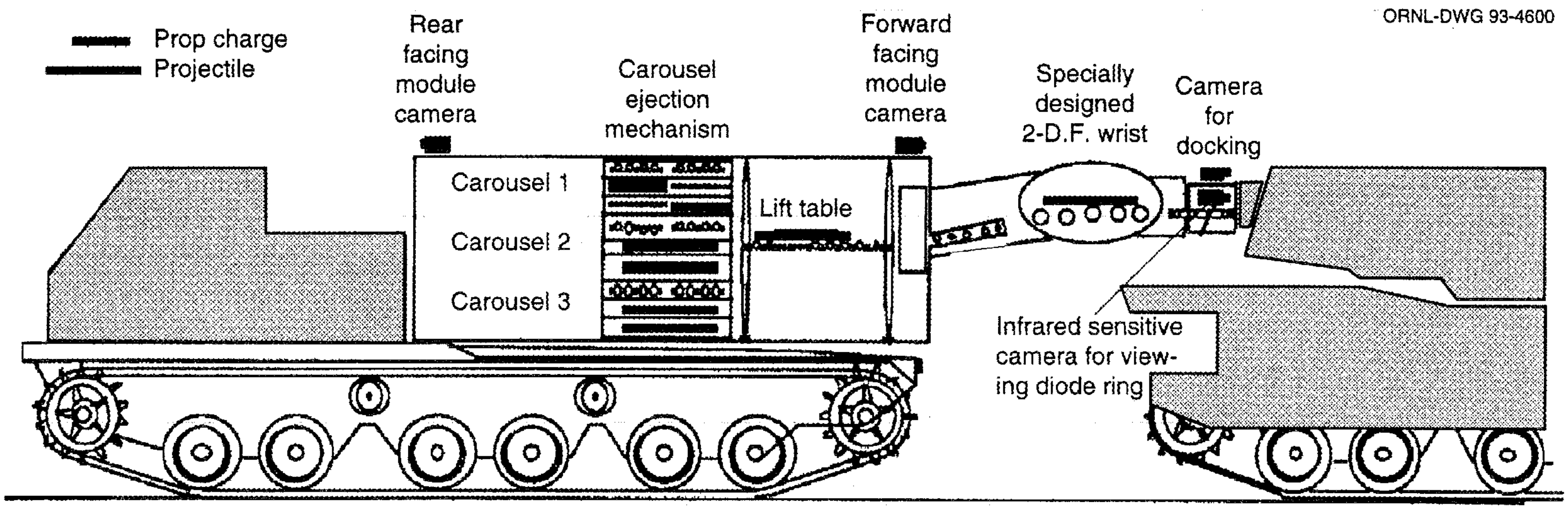

Fig. 8. Schematic diagram of FARS vehicle and tank.

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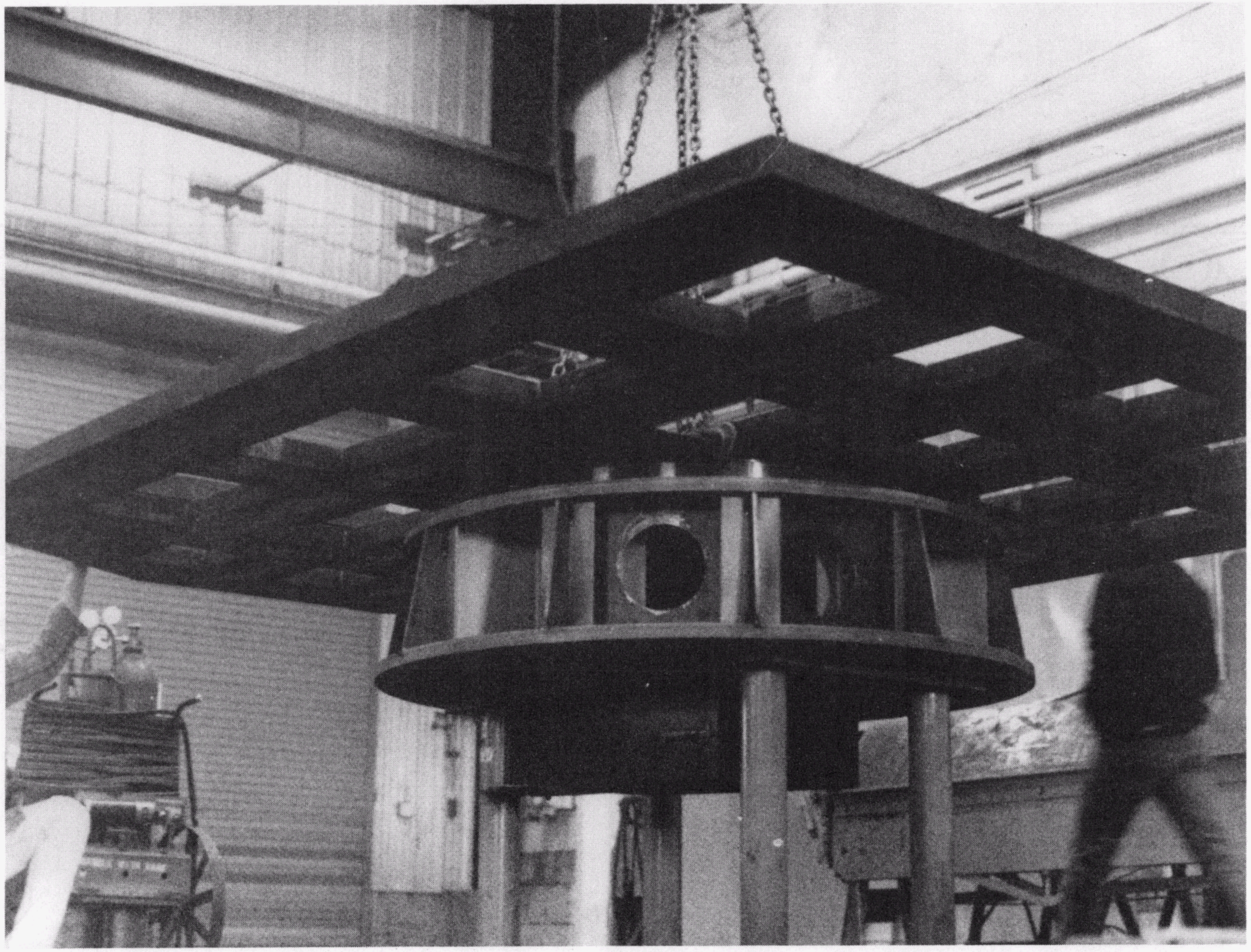

Fig. 9. Structure of FARS floor.

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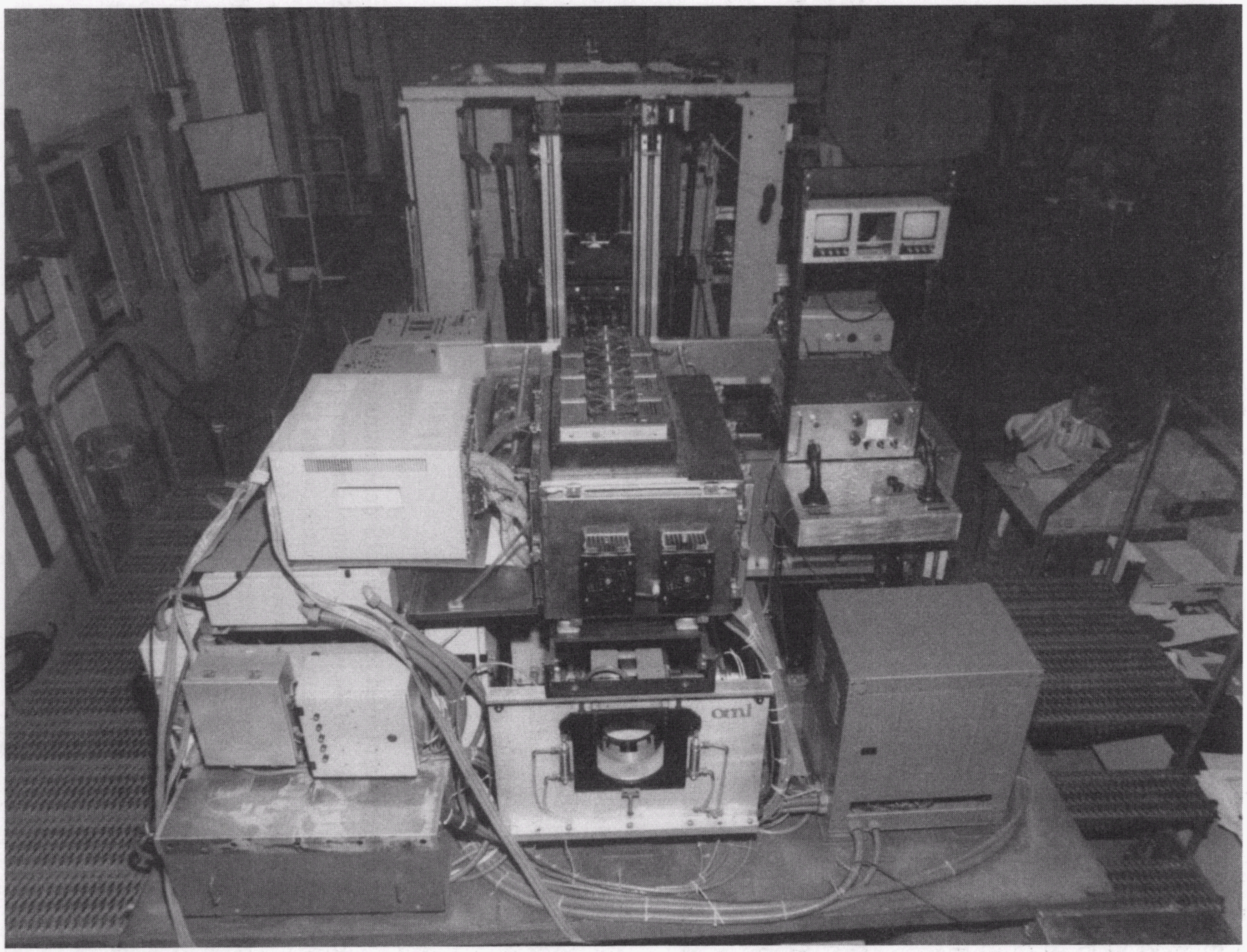

Fig. 10. Layout of equipment on FARS floor.

during ammunition transfer into or out of a cell. As stated earlier, the demonstrator carousel contained only six cells. For the carousel operation, the transfer process proceeds as follows:

1. Lower ejector.
2. Release sear.
3. Retract nose support.
4. Release rim latch.
5. Eject ammunition from cell.
6. Activate rim latch.
7. Activate sear.
8. Activate nose support.
9. Raise ejector.
10. Index carousel to next piece of ammunition.
11. Repeat steps 1–10.

The download process follows the same steps, omitting step 4 only. The design for the FARS carousel is shown in Fig. 11. The FARS vehicle will house six carousel modules. The carousels will be stacked three high and two deep to allow storage of 120 120-mm rounds or 80 140-mm rounds. Different cells for the prop charge and the projectile pieces will be used to store and handle the 140-mm rounds.

3.1.3 Lift Table

The lift table interfaces with the carousel and the transfer arm. The lift table can access each of the three carousels. It receives the round from the carousel cell, moves it to the proper elevation and pitch to align with the transfer arm, and ejects it onto the transfer arm conveyor. The lift table consists of a set of powered rollers and is attached to four columns which allow it to match the angle and elevation of the transfer arm. The lift table is shown in Fig. 12.

3.1.4 Transfer Arm and Conveyors

The delivery arm used for the FARS demonstrator has 4 D.F.: (1) shoulder pitch, (2) elbow pitch, (3) elbow yaw, and (4) wrist extension. One remaining degree of freedom for the FARS came from the rotation of the entire FARS module, which gives a total of 5 D.F.

The FARS transfer arm was hydraulically operated using two joystick controllers with rotary actuators controlling the elbow movements and linear actuators controlling the shoulder pitch and the wrist extension. Integral to the FARS transfer arm are two sets of conveyors. The conveyor set which receives the round from the lift table is a multibelt conveyor. The forearm conveyor is a single flat-belt conveyor. This configuration was chosen to reduce gap sizes when the elbow is yawed to the right or left. Passive guide rollers are used along the sides of the conveyors to assist in centering the round as it travels through the arm. The transfer arm is shown in Fig. 13.

3.1.5 FARS Docking Port

The docking system locks the transfer arm to the tank. The female port is located on the end of the FARS transfer arm, and the mating port is mounted on the tank bustle, as seen in Fig. 14. A noncontacting infrared communication system is integral to the docking port system (see Sect. 4). Long- and short-range sensors are used to aid in docking with the tank. The long-range sensor is an

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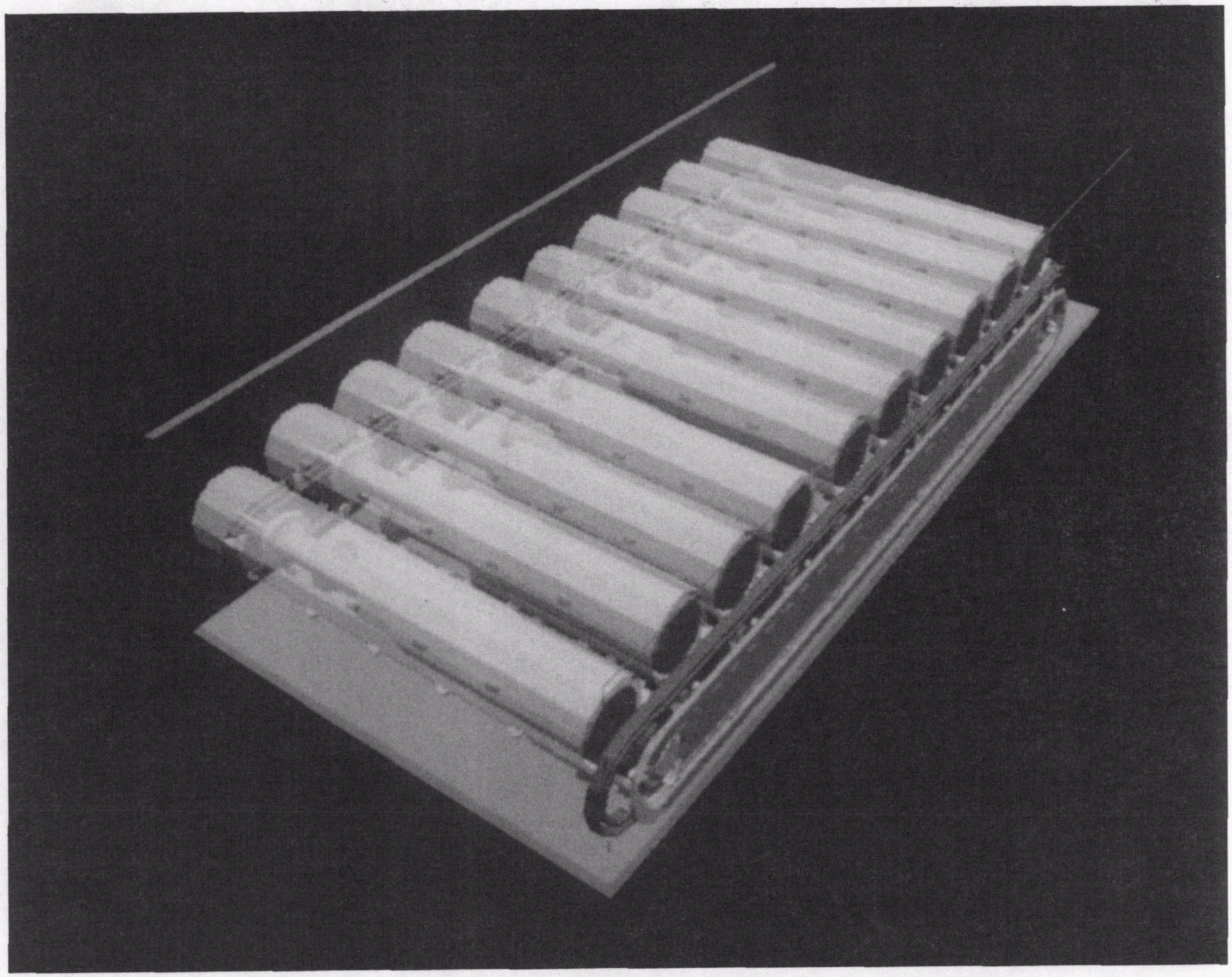

Fig. 11. Design for FARS carousel.

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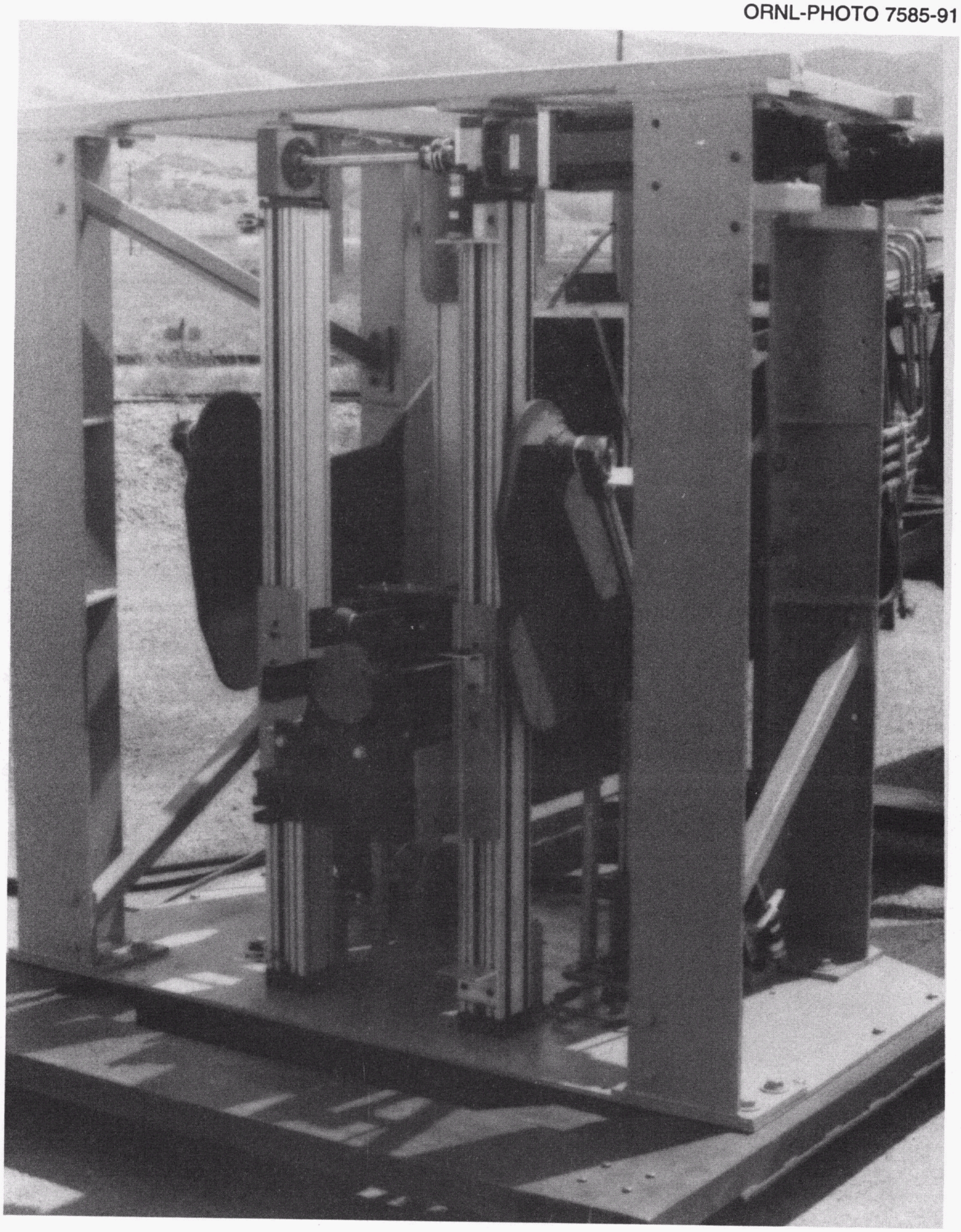

Fig. 12. Lift table.

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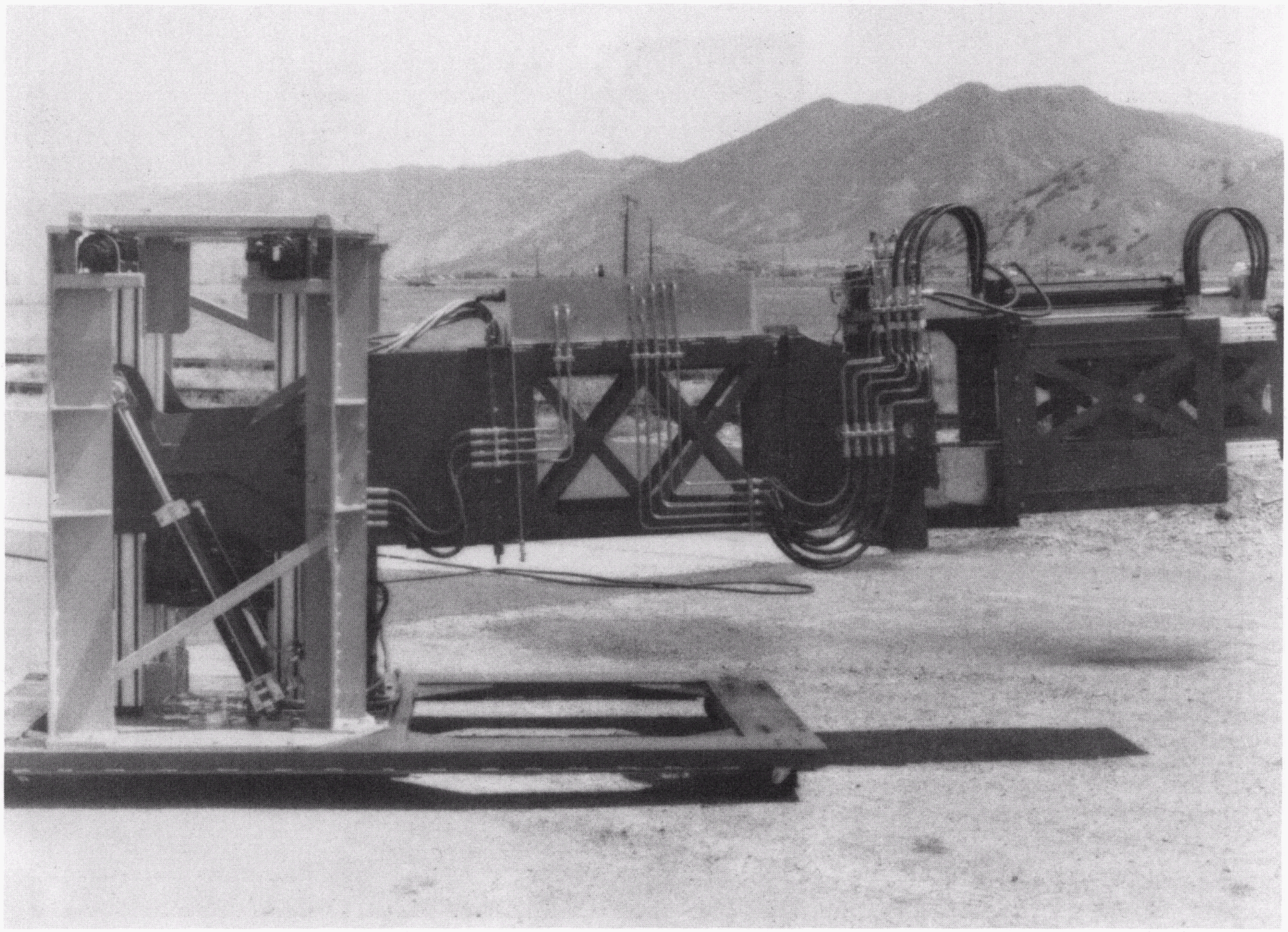

Fig. 13. Transfer arm.

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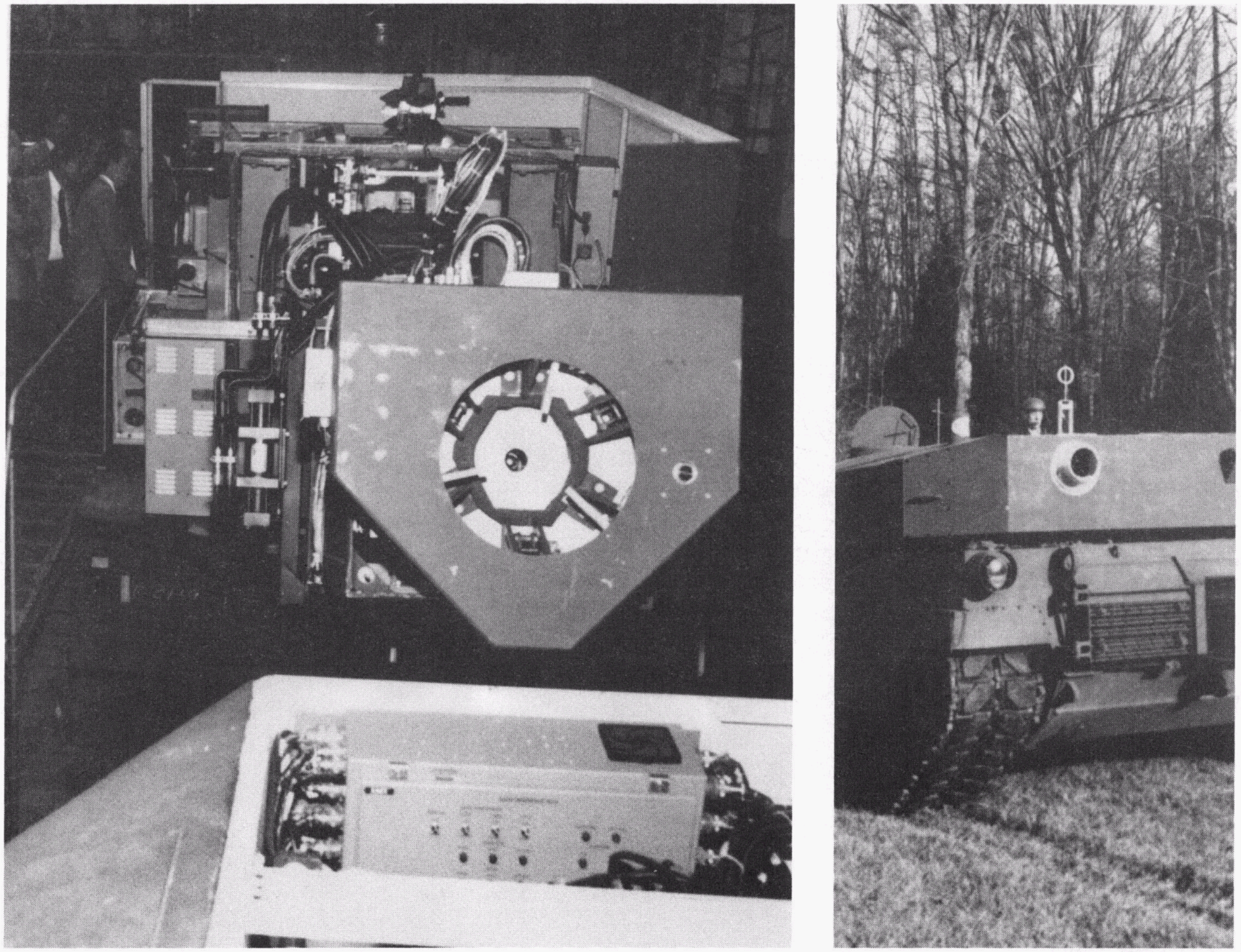

Fig. 14. Female docking port (left) and male mating port (right).

ultrasonic device used to measure distances of 24 to 4 in. between the FARS and the tank. Three short-range sensor probes around the docking port door opening measure the docking port separation of 4 to 0 in. from the tank. The docking ports have doors to isolate the interior of both vehicles from the outside environment. Integral to the FARS door is an infrared camera which views a set of infrared light-emitting diodes embedded in the outer ring of the tank docking port. This camera aids in the final positioning of the transfer arm.

3.2 TANK SYSTEMS

3.2.1 Tank Docking Port

The tank docking port is mounted on the bustle of the turret and mates with the docking port on the FARS transfer arm. The tank docking port is fitted with a ring of infrared lights to aid the FARS operator with docking.

3.2.2 Receiver

The receiver mechanism is a set of powered rollers which receives rounds through the tank docking port. It takes the rounds from the FARS transfer arm and pulls them into the tank bustle. It aligns with the Autoloader and passes the ammunition into the Autoloader cells.

3.2.3 Autoloader

The Autoloader receives the rounds from the tank receiver. The ATAC ready-round Autoloader has been optimized for the 140-mm international harmonized two-piece ammunition but can accommodate the standard 120-mm fixed ammunition. It consists of a horizontally oriented, chain-driven carousel magazine equipped with 17 ammunition cells capable of bidirectional rotation and precise positioning. Each cell is equipped with warhead supports released only during round transfer into or ramming out of a cell. The ammunition cell also contains an inner tube which extends and retracts in concert with the rammer to provide support and guidance for the round during loading. The magazine is also capable of unloading a round from the gun and returning it to an empty cell. The Autoloader is shown in Fig. 15.

3.3 VEHICLES

3.3.1 FARS Chassis

For the Technology Demonstration, the FARS systems were mounted on the U.S. Army's Fighting Vehicle System (FVS) armored carrier (see Fig. 16). This carrier is designed as a universal carrier that can satisfy a wide variety of military missions, depending upon the design of the enclosure mounted on the cargo area. The payload area is behind the engine compartment. The FVS carried a center-mounted bearing and rotating module. These are outlined in Sect. 3.3.2.

The FVS carrier has a cab-over-power-train arrangement. The FVS cab seats three crewmembers. Armor protection is provided by the aluminum cab and ballistic front windows. Fold-down covers and an overhead hatch provide added visibility and additional crew ventilation during nontactical situations. The cab also has an over-pressure ventilation system and noise attenuation materials.

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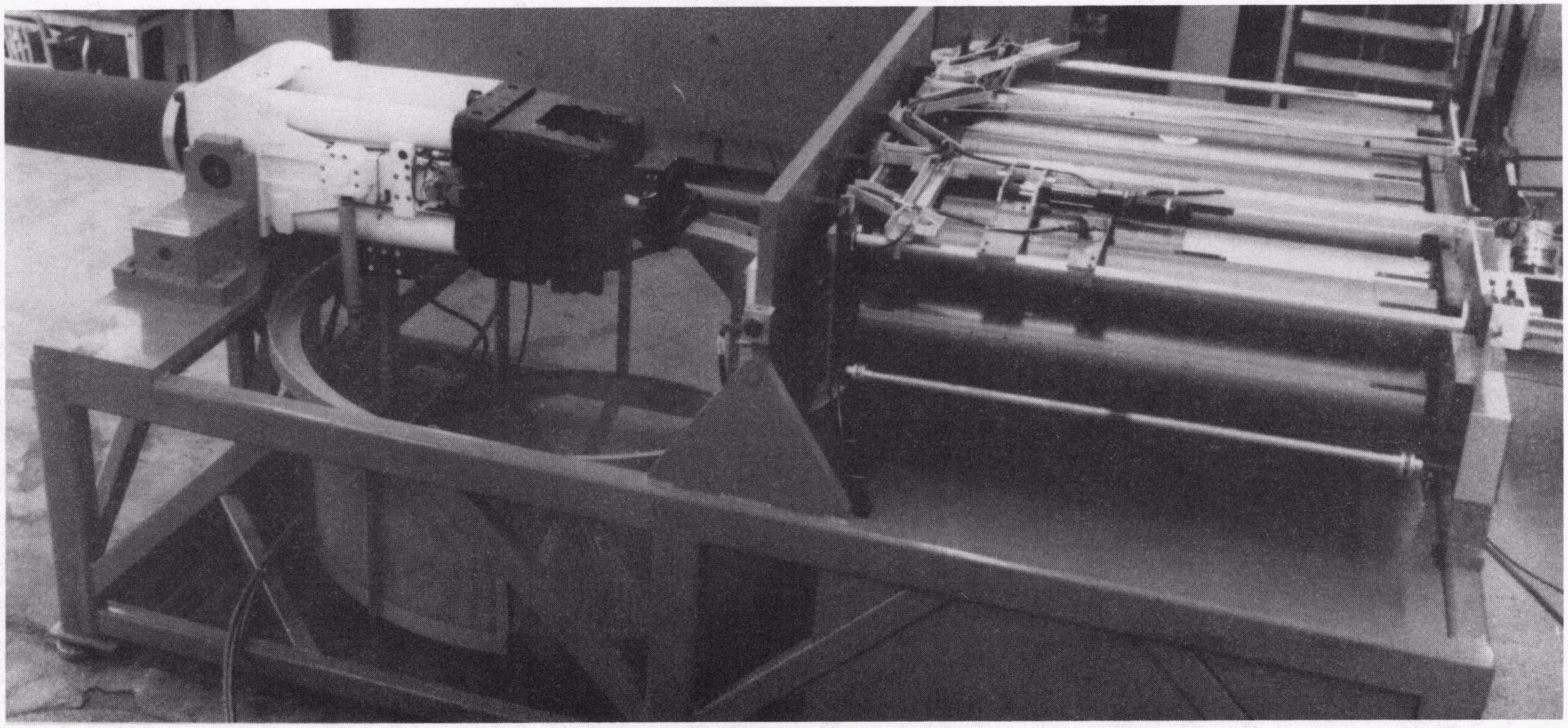

Fig. 15. Autoloader.

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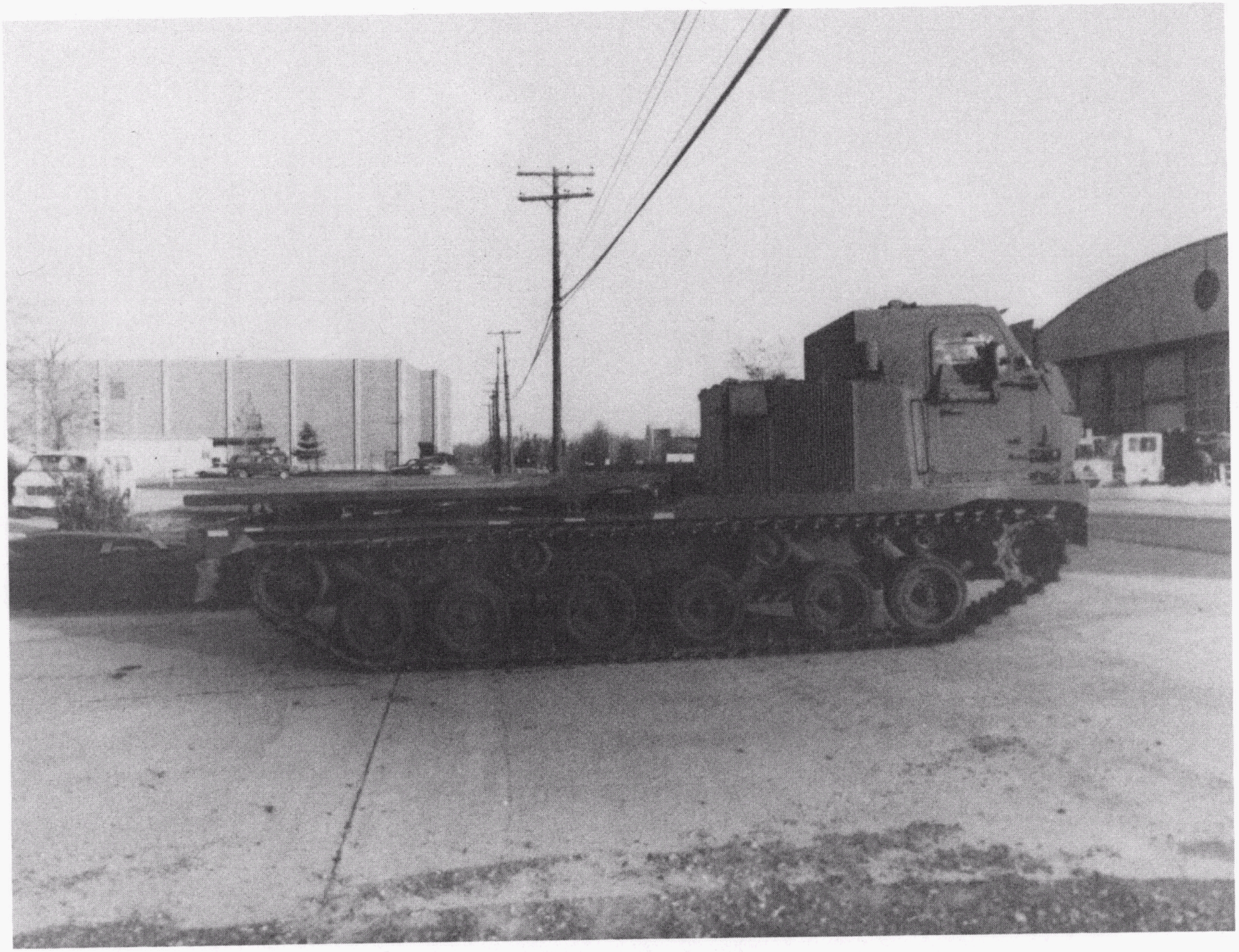

Fig. 16. FVS armored carrier.

3.3.2 Tank Test Bed

For the automatic reloading demonstration, the Thumper modified M1A1 test tank was used as a demonstrator vehicle. The XM-91 Autoloader was mounted in the tank bustle, and the bustle was equipped with a rearm port to allow the FARS vehicle to reload the Autoloader from the rear of the turret.

4. COMMUNICATIONS

This section describes the communications protocol between the FARS and the XM-91 Autoloader in the M1A1 tank. Amplifying information is available in Appendixes B and C. The primary means of communications between the TC and the FARS operator before the FARS and the tank are docked will be via VHF-FM voice radio. This capability was assumed and was not a part of the FARS Technology Demonstration.

While the FARS and the tank are docked, data communications between the two vehicles' computer systems will be the principle means of communications. This data link will operate in a half-duplex mode over an RS-232 serial data link at 2400 baud. Connectivity between the two systems is provided with a noncontacting infrared communications device, the Photoport, developed by Cariger, Inc. While higher data rates would provide for more rapid transmission of data between the two systems, the Photoport only supports data rates up to 2400 baud. This is not considered a significant limitation since the communications protocol was designed to eliminate the requirement for frequent or lengthy messages between the systems.

4.1 MESSAGE DEFINITION

Messages between the two systems are "packaged" to facilitate transmission over the data link. Each message package is composed of six sections: (1) header, (2) byte count, (3) command, (4) data, (5) sumcheck, and (6) end-of-file mark.

1. The header is the same for all messages and is used to mark the start of each message. A received signal that is not prefaced by the correct header is treated as an invalid message. The header is a single byte and is defined to be the ASCII character S.

2. The count section immediately follows the header section and is 1 byte long. The count is the total number of bytes in the message (i.e., the sum of bytes of the header, count, command, data, and sumcheck). The end-of-file character, which is a single byte, is not included in this sum. As a 1-byte unsigned integer, the count may have a value between 0 and 255. However, since the smallest message package is 5 bytes long, the count will have valid values between 5 and 255. The longest message package is 255 bytes. The count section is used to verify the integrity of received messages. If a message is received with a count that does not agree with the message length, the message will be treated as invalid.

3. Two ASCII characters comprise each command section. These two bytes immediately follow the count section. Table 2 is a summary of these commands; definitions are provided in Appendix B.

Table 2. Summary of command definitions

Command	Name	Sender
BA	BreakAway	Both
CC	Command Complete	Both
CE	Command Error	Both
CR	Command Receive	FARS
CS	Command Stop	Tank
DL	DownLoad	Tank
DR	Download Ready	FARS
FE	FARS Error	FARS
FH	FARS Here	FARS
GO	Give One	Tank
GI	Give Item	Both
GR	Give Round	Both
RI	Request Inventory	Tank
SI	Ship Individual	Tank
SO	Shipping Order	Tank
SV	Shipping Void	FARS
TE	Tank Error	Tank
TH	Tank Here	Tank
TF	TransFer	Tank
TR	Transfer Ready	FARS
UD	UnDock	Both
UR	Undock Request	Both
VI	Vehicle Inventory	FARS

4. The data section immediately follows the command section. Not all commands will have a data section. If the message command contains a data section, the data may be from 1 to 250 bytes long. The length depends on the required data to be sent (see Appendix C).

5. The sumcheck section immediately follows the command or data section and is 1 byte long. The sumcheck is the sum of the header, count, command, and data bytes of the message, truncated

to 1 byte. Sumcheck considers each byte to be an unsigned integer value. This value may be used to check for errors when a message is received; if a message is received with a sumcheck that does not agree with the sum of the message bytes, the message will be treated as invalid.

6. The end-of-file section immediately follows the sumcheck section and is 1 byte long. The end-of-file marks the end of the message. The end-of-file character is the null character (hex 00). The end-of-file byte is not considered in count or sumcheck calculations. The message format is shown in Fig. 17.

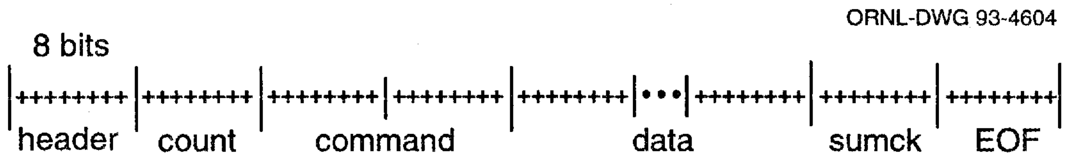

Fig. 17. Message format.

4.2 COMMAND DEFINITIONS

The command section of each message is comprised of two ASCII characters (each ASCII character is a single data byte). The commands listed in Table 2 provide a minimally capable communications system. Additional commands should be provided to enhance the functionality, flexibility, and robustness of the data link. Definitions of each of the commands are provided in Appendix B.

4.3 DATA DEFINITIONS

Only three of the messages defined in Table 2 have a data section. The TC uses the Ship Individual (SI) message during transfer or download operations to request a single piece of ammunition. The SI message has a single data byte that defines the type of piece (e.g., KE-140, Prop, or HE-120) that the TC wants. Shipping Order (SO) messages are similar but allow the TC to request multiple pieces of ammunition during a single download or transfer operation. Sequential bytes in the variable length data section of the SO message describe the type of ammunition and the order that it is expected by the Autoloader. Since each SO data byte defines a single piece of the shipping order, the maximum allowable shipping order is 250 pieces long, more than sufficient to handle the maximum capacity of the FARS (160 pieces). The Vehicle Inventory (VI) message is sent by the FARS in response to a Request Inventory (RI) from the TC. The VI message has eight data bytes; the first five each contain the number of pieces that the FARS has available for transfer. The quantity of each type of ammunition is represented by a single byte. Similarly, each of the other three data bytes describe the number of storage locations available for download operations for a particular type of ammunition.

Each of the data bytes in the VI message are interpreted and treated as unsigned integers in the range of 1 to 254. To avoid conflicts with the end of message byte, defined as the null character (0x00), zero values in the VI message are represented by the hexadecimal number 0xff. Data bytes in the SI and SO messages are interpreted as hexadecimal numbers (0x00 - 0xff), where the following hexadecimal values are defined:

null/stop/end	0x00	140-mm HE	0x08
120-mm KE	0x01	Prop charge	0x40
120-mm HE	0x02	Reserved (future)	All others
140-mm KE	0x04		

4.4 OPERATIONS

4.4.1 Message Sequences

Sample message sequences are provided in Appendix B.

4.4.2 FARS Communications Operations

FARS communications operations are controlled by the communication manager, a real-time process operating on processor 1. The manager is divided into two sections: sending and receiving.

4.4.2.1 Sending

The sending section of the communications manager is functionally divided into two sections: a control function and a code and send function.

Send control function

To send a message, a manager (equipment, function, system, etc.) writes an event to the communication manager. The control function uses a look-up table and the event number to define the command section of the message buffer. Once the command section is defined, the controller calls the code and send function.

Message code and send function

The code and send function uses a character array data buffer to construct the message. The header and end-of-file sections, which are constants, are filled in. If the message requires data, the coder gets the data from the data base and places it in the correct buffer locations. The message coder then counts the number of bytes in the message buffer and places the result in the count byte of the message buffer. The coder also determines the value of the sumcheck byte and places it in the message buffer. Finally, the function uses an OS-9 function to write the contents of the message buffer to the serial data path. The path is an RS-232 port that is connected to the infrared communications device. The function notifies the operator manager when the message is sent.

4.4.2.2 Receiving

The receiving section is divided into three basic functions: a receive function, a message check function, and a decode/control function.

Receive function

The receiver uses an OS-9 function to check the RS-232 port on the processor card for incoming data. When data is detected, the receive function places the data in a message buffer and calls the message checker to determine whether the received data is a valid message. If the message checker reports that the data is a valid message, the receiver passes control to the decode/control function.

Message check function

The message checker makes three checks to verify the validity and integrity of the received data: (1) It verifies that the header section in the message buffer is correct. (2) It counts the number of bytes in the message buffer and compares the count to the value in the count section of the message. (3) It sums up the message bytes and compares the sum to the value in the sumcheck byte. If any of the three checks is incorrect, the message checker will issue an event to the send portion of the communication manager that will cause a Command Error (CE) message to be sent to the tank. Upon receipt of a CE from the FARS, the tank will resend its last nonCE message. Upon completion, the message check function will pass control back to the receive function with a report indicating whether or not the data represent a valid message.

Decode/control function

The decoder extracts the command information from the message buffer and uses a look-up table to determine the appropriate action(s) to take. Depending on the command, the decode/control function might issue an event token, send a return message to the tank, and/or update the data base. If there are data in the message, the controller gets the data from the message buffer and places it in the message data buffer in the common data base for use by a manager.

4.4.2.3 Data Messages

Three messages have an associated data section: SI, SO, and VI. The VI message sends information from the FARS to the tank, while the SI and SO messages send information from the tank to the FARS. The data needed to construct the VI message are kept in the common data base and are available to the communication manager as required. The data received from the tank in the SI and SO messages describe the ammunition type and the order in which the pieces are to be sent. The decode function of the communication manager transfers the information from the data sections of these messages to the FARS common data base, where it is available for use by either the transfer or the download function managers.

5. OPERATOR CONTROL STATION

The operator controls and monitors the FARS from the operator control station. The operator uses joysticks to provide command signals to the transfer arm and a camera system to provide video feedback to monitors at the operator control station. The operator also has panic switches that provide immediate and safe shutdown of the system in the event of an emergency. An MMI provides a graphics display/mouse-controlled interface between the operator and the computer system.

For the fielded system, plans are to have the operator control station located inside the vehicle cab. To permit maximum design flexibility for the proof-of-principle system, however, the control station was mounted on the module floor. This enabled more rapid development and troubleshooting of the control station. No attempt was made to meet MIL-STDs in this area. The control station was intended for proof of principle only; a fielded system will require further study.

5.1 MMI

The FARS operator can monitor system status from the MMI's computer color graphics display. The MMI also provides a point-and-click menu and a mouse for the operator to command system operations and to provide user input during certain operations.

The MMI displays the following information: (1) a list of FARS operating commands for the operator to select from, (2) computer communication messages between the FARS and the tank, (3) system error messages, (4) the location of ammunition as it moves through the system, and (5) docking door and docking latch status. During certain operations, additional information is displayed to assist the operator such as range measurements between the end of the FARS arm and the tank (displayed during docking operations) and system inventory (displayed upon operator request and after any inventory operation). The control system also seeks operator input during some of the more hazardous operations (e.g., arm movement, docking, and undocking). These safety precautions were intended to ensure operator involvement during system testing and could be removed in the future to provide a more autonomous and responsive system.

5.2 JOYSTICKS

The control station has two joysticks that the operator uses to provide command signals to the transfer arm. The joysticks are equipped with deadman switches that must be closed before the joystick's output signal will be recognized by the control system; the operator closes the deadman switches when he grasps the joysticks. When the operator releases the joystick, all functions controlled by that joystick are put in a safe condition. The deadman switch operates independently of the computer system by controlling a relay between the computer control signal and the arm joint actuators.

The left joystick controls floor rotation, floor brakes, the arm shoulder joint, and floor rotational speed mode (slow or fast). The right joystick controls the arm knuckle pitch and yaw and arm extension. The floor rotation and arm joint velocities are proportional to the displacement of the joystick.

5.3 TV MONITORS

Black-and-white monitors display video images from four cameras mounted on the rotating platform. One camera is mounted on each side of the FARS module at the level of the shoulder joint; these cameras provide information about the position and orientation of the arm relative to the workspace. A third camera is mounted on the top of the elbow joint and is aimed along the axis of the extension joint. This camera, combined with a course sighting system mounted on the tank, provides the primary means of aligning the arm with the tank during docking evolutions. The fourth camera is mounted at the end of the arm with a view through the center of the docking door. The FARS has a monitor for each camera, but video switches were installed to reduce the number of monitors.

5.4 SAFETY CONTROLS

The operator control station has two hard-wired panic switches for emergency stop. One emergency stop switch causes the computer to stop operations and locks all motors; the other emergency stop switch performs the same action but will also turn off all ac and dc power to the floor module. Batteries provide dc power to the computer and sensors in the event of an emergency shutdown. Emergency breakaway from the tank can be performed either by pushing a panic switch or by selecting the Emergency Breakaway icon on the MMI screen. This icon appears on the MMI screen when any of the docking latches are in the latched position.

A push-pull switch on the operator control station allows the FARS to single-step through its operation. For normal operation the switch is pulled out. If the switch is pushed in while a function manager is running, the function manager will wait for any previously commanded actions to be completed but will stop before issuing any other commands. The Halt/Resume icon on the MMI allows the operator to resume operations, but the function manager will only proceed through one state at a time as long as the single-step switch on the control station is pushed in. When the switch is pulled back out, the FARS operator may resume normal operation by selecting the Halt/Resume icon; function manager operations will resume at the point where they were stopped.

6. CONTROL SYSTEM

The FARS control system consists of the following subsystems: (1) computer, (2) computer hardware interface, (3) sensors, (4) motors, and (5) actuators. The computer system consists of both hardware and software. Figure 18 provides an overview of the FARS control system components and their configuration.

6.1 COMPUTER SOFTWARE

6.1.1 Operating System

The operating and development system for FARS, OS-9, is a commercial package by Microware, Inc. OS-9 is a real-time, multiuser, and multiprocessing kernel with disk and Ethernet support. OS-9 runs on one VME single-board computer (SBC) card. The FARS uses two SBCs that each serve as both host and target computer. A host computer is used for software development, while a target computer actually runs the developed software. Many other operating and development systems require the host to be a different computer system (e.g., Sun, IBM, or DEC) than the target computer. With the host and target being the same computer, the FARS contains its own development platform and does not require an outside computer system.

6.1.2 Language

To reduce software development costs, the source code for FARS was written in C, instead of Ada. The software written did not use any special "tricks" or operating system commands that cannot be reproduced in Ada.

6.1.3 Software Architecture

A brief description of the software architecture is given in this report. A complete description of the architecture used on the FARS can be found in ORNL/TM-12364, the FARS Software Architecture Specification.[1]

The software is divided into four sections: system support managers, function managers, equipment managers, and real-time handlers. The system support managers, function managers, and equipment managers operate on an SBC (also referred to as the first SBC) in a multiprocessing, asynchronous mode. The real-time handlers operate synchronously at 100 Hz on the second SBC in the VME system (see Sect. 6.2 for a complete description). Equipment managers and the real-time handlers communicate using flags and data in a common data base on a memory card shared by both SBCs.

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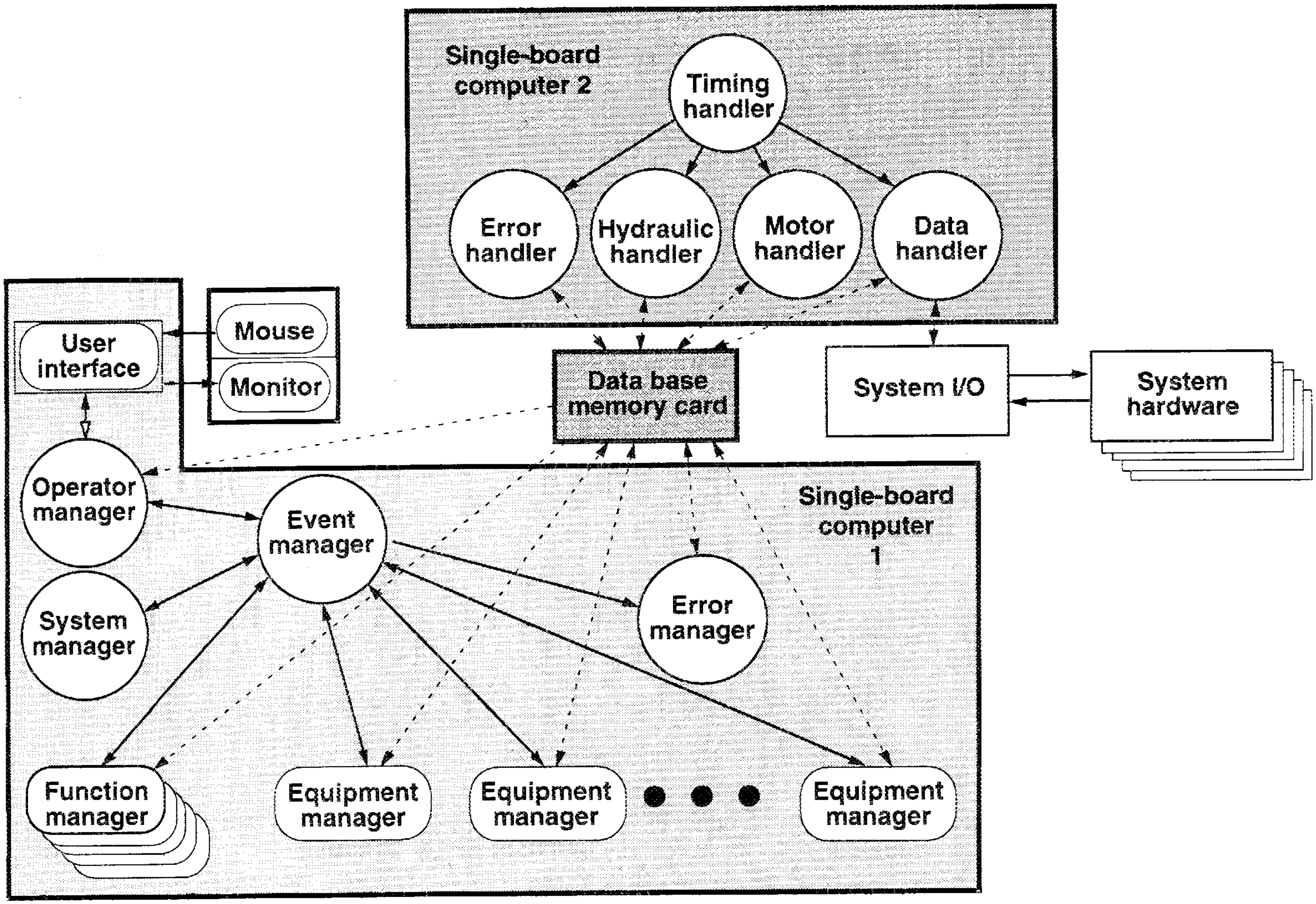

Fig. 18. FARS control system components and configuration.

The managers communicate with event tokens. Each manager has two event queues—one queue for normal or operational events and a second queue for emergency events. Emergency queues are always checked for pending events before the normal queues are checked. Events are read from the queues in a first-in-first-out manner; after the manager reads an event from one of its queues, it performs the action required by the event. The event manager, described in Sect. 6.1.3.1, acts like a post office and is the only manager permitted to write an event to another manager's queue. All managers are permitted to write events, but the events must always be sent to the event manager, where they are rewritten to the appropriate manager's queue.

6.1.3.1 System Support Managers

The system support managers consist of the system manager, operator manager, error manager, communication manager, and event manager.

System manager

The system manager controls the waking and sleeping of the function and equipment managers. It is always in operation (i.e., awake) and is used to wake the function and equipment managers needed to perform tasks requested by the FARS operator or the TC. The system manager also puts the function and equipment managers back to sleep when the task is completed or in the event of an error.

Operator manager

The operator manager is the interface between the MMI and the computer. It is always in operation. It controls the MMI screens and responds to operator input. The MMI screens are updated by the operator manager as it detects changes in the information stored in the data base.

Error manager

The error manager handles FARS errors. The error manager monitors the common data base for errors from the real-time error handler. When an error occurs it also coordinates with the system manager to ensure that the function and equipment managers are put to sleep.

Communication manager

The communication manager handles all communication with the tank computer. It is described in detail in Sect. 4.

Event manager

The event manager receives and passes event tokens between all of the managers on the first SBC. Any manager may write events to the event manager's normal queue or emergency queue. The event manager always checks the emergency queue first. If there is an event in the emergency queue, the event manager will read and write that event to the emergency queue of every awake manager. If the emergency queue is empty, then the event manager will check its normal queue. If the normal queue has an event in it, the event manager will read the event, determine which manager(s) the event is intended for, and write the event into the normal queue(s) of the correct manager(s). Write control flags are used to prevent two managers from writing to the event manager 's queues simultaneously.

6.1.3.2 Function Managers

The function managers control and coordinate the operation of multiple equipment managers in order to accomplish a given task from the FARS operator or the TC. The function managers were developed using state-based logic and were designed to be as independent of the actual hardware as possible. There are dedicated function managers for unstowing the arm, docking, inventory, transfer, download, breakaway, undocking, and stowing the arm. All function managers are in a sleep mode until the system manager wakes one of them to perform a specific task; only one function manager is permitted to be awake at a time. The function managers control the sequence of equipment operation by sending events to the equipment managers. As a function manager enters each new state, it sends events to the equipment managers. These events indicate specific tasks that the equipment manager must perform. The function manager waits until it has received return or finished event(s) from the equipment managers before it proceeds to the next state.

6.1.3.3 Equipment Managers

The equipment managers are the interface between the function managers' state-based logic and the real-time handlers that actually control the FARS equipment. The equipment managers communicate with the real-time handlers by setting flags and data in the common data base shared by the two SBCs. There are separate equipment managers for the lift table, the arm conveyors, the arm joint control, and each carousel. Equipment managers can respond to only one event at a time, and they remain asleep until the system manager wakes them as needed. Equipment managers can be used by any one of the function managers.

6.1.3.4 Real-Time Handlers

The real-time handlers operate as a single process on the second SBC and consist of a data handler, an error handler, a motor handler, an arm joint handler, and a timing handler. The timing handler runs at 100 Hz and controls the operation of the other handlers. The handlers use both the common data base on the memory card and a local data base on the second SBC.

Data handler

The data handler reads the computer I/O hardware interface cards for equipment status. It also collects, processes, and stores the data in the data bases. The data handler also tracks the movement of ammunition through the FARS. Commands from the equipment managers are decoded and converted to commands for equipment control. The data handler also records the number of operations or cycles a piece of equipment operates. Each piece of equipment in FARS (i.e., carousels, lift table, arm conveyors, arm joints, and floor) has a separate module in the data handler that performs the equipment-specific data handling functions.

Error handler

The error handler checks for proper operation of the equipment. If the error handler detects an error condition, it will stop all equipment, lock the motor brakes, and disable the motors. An error condition code unique to the error that was detected will be sent to the other SBC for processing by the error manager. The error handler monitors the MMI emergency switches and compares various data base entries for combinations that would indicate improper system operation.

Motor handler

The motor handler controls the FARS motors. There is a motor handler module for each motor on FARS. Each module is enabled only when its associated motor amplifier controller is enabled; otherwise, the module is disabled. All motors start, accelerate, and decelerate with an S velocity profile to minimize equipment jerk (the derivative of acceleration) on start and stop operations. A motor is stopped when the equipment the motor is moving reaches the proper location as determined by sensors. A motor's operating parameters can be changed when required for an operation. The parameters include motor direction, speed, S velocity profile gains, and stopping conditions. An equipment manager sets new operating parameter values in the common data base. The data handler moves the new parameters from the common data base to the local data base on the SBC running the motor handler. The motor handler uses the local data base for its operation.

Arm joint handler

The arm joint handler, which controls the FARS arm, is made up of eight modules that control each of the FARS hydraulic joints (floor rotation, shoulder pitch, knuckle pitch, knuckle yaw, wrist extension, and clam shell), the docking door, and the docking latches. Each module is enabled only when movement of its associated joint is required; otherwise, the module is disabled.

6.1.3.5 Data Bases

The two SBCs share a common data base which contains information describing the status of the FARS equipment at any moment in time. Since the data base resides on a battery-backed memory card, on startup the computer system always knows the equipment status for the entire system. Write permission to the data base is restricted; only the data handler on SBC 2 can write equipment status information, and only the equipment manager and handlers associated with a given piece of equipment can set parameters and flags for that equipment's operation. All managers and handlers are permitted to read from the shared data base.

A local data base on the second SBC is provided for the real-time handler's use only. The information in this data base is used for local (i.e., SBC 2) processing only. Since the handlers are not required to access the VME bus to retrieve information from the common data base, the processing rate is increased and VME bus traffic is reduced. Managers on SBC 1 cannot directly access or change the information in this data base.

6.1.3.4 Data Flow

Once the system is initialized, the system manager puts to sleep all of the function managers and equipment managers on SBC 1. The operator manager, event manager, system manager and error manager on SBC 1, and the real-time process on SBC 2 remain awake at all times during system operation.

Tasks may be initiated in two basic ways. The FARS operator can initiate a task (e.g., conduct an inventory, unstow the arm, and dock with a tank) by selecting the appropriate task from a menu on his MMI. In this case, the operator manager sends an event to the system manager that describes the task to be performed. Alternately, if the FARS is docked with a tank and data communications have been initiated, the TC can initiate a task (e.g., transfer ammunition to the tank or download ammunition from the tank) by sending the appropriate command to the FARS communication manager. In this case, the communication manager sends an event describing the TC's task to the system manager. In either case the system manager responds by waking the function manager and equipment managers required to perform the task.

Once all of the necessary managers have reported their awake status to the system manager, the system manager sends an event to the function manager that initiates the actual task. From this point until the function manager reports completion of the task, events that command specific equipment operations are sent by the function manager to the equipment managers.

Upon receiving an event from the function manager, the equipment manager sets the required flags and data in the common data base and then waits until the real-time handler completes the commanded operation. When finished, the handler resets the common data base flags, which signal the equipment manager that the desired operation has been completed. The appropriate equipment manager sends a return event to the function manager as each operation is completed.

Once all of the commanded events in a given state have been reported as complete, the function manager moves to its next state. Upon task completion, the function manager sends an event to the system manager, reporting the completion; the system manager, in turn, puts the function manager and each of the equipment managers back to sleep. During the entire process the operator manager and error manager monitor the event flow and the common data base for information and errors.

6.2 COMPUTER HARDWARE

The computer hardware system consists of computer cards and bus, interface hardware, sensors, and actuators. The interface hardware, sensors, and actuators are included as part of the computer hardware because this hardware is such an integral part of the computer-based control system design.

6.2.1 Computer Bus

The VME computer bus standard was chosen for FARS. The VME bus standard system is widely supported with commercial hardware and is widely used in the military. The VME computer bus uses plug-in cards that permit off-the-shelf parts to be combined into a custom-built computer system designed to meet a specific set of requirements. Figure 19 depicts the configuration of the various computer cards on the VME bus.

6.2.2 Computer Cards

The FARS computer system used SBCs, computer support cards, and dedicated input/output (I/O) cards for the hardware interface.

6.2.2.1 SBC

The FARS computer system used two Motorola MVME147 SBCs with a 68030 microprocessor with a 25-MHz clock and floating-point math chip support. The 147 has 4 MB of memory with small computer standard interface (SCSI) and Ethernet interfaces built in. The SBC running the system support, function, and equipment managers was connected to Ethernet and served as the VME bus master. The SBC running the real-time handlers was not supported by Ethernet. Both SBC cards were connected to a common hard disk drive with the SCSI interface. The disk was used for computer boot, program development, and program storage. Each SBC operates as if it is the only computer board on the VME bus, and neither SBC has knowledge about the other.

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Computer card
Graphics card
Memory card
Computer card
Digital I/O card
Digital I/O card
Digital I/O card
Digital/analog card
Digital/analog card
Encoder card
Analog/digital card
Resolver card

Fig. 19. Computer card installation.

6.2.2.2 Memory Card

The memory card contains 2 MB of static random access memory with battery backup support when computer power is turned off. The common data base resides on this card. Because of the battery backup, the data base remains intact when computer power is turned off and data are immediately available on computer startup.

6.2.2.3 Graphics Card

The MMI graphics are generated with the Gespac, Inc., GESVIG-4VME graphics card. The color monitor, keyboard, and mouse plug directly into the card. The operator manager provides the necessary interface between SBC 1 and the graphics card.

6.2.2.4 I/O Card

The computer system has three digital I/O cards. The cards are Datel DVME-660. Each card has 48 I/O points arranged in six groups of eight. Each group can be defined as either an input group or an output group. These cards provide the computer's interface to the switch-type sensor inputs (e.g., break beam switches and proximity switches) and the on/off-type actuators (e.g., relays and solenoids).

6.2.2.5 Analog-to-Digital (A/D) Conversion Card

The computer system has one Datel DVME-612 A/D card. The DVME-612 card is capable of providing either 32 single-channel inputs or 16 differential-channel inputs to a 12-bit A/D converter. The card uses the differential input capability to provide computer input from the linear position sensors and the joysticks. The card also provides two digital-to-analog (D/A) channels, but this feature was not used for the FARS control system.

6.2.2.6 D/A Conversion Card

The computer system has two VME Microsystems International Corporation VMIVME-4100 D/A cards. The VMIVME-4100 card is a 12-bit D/A converter with 16 channels of output. The D/A card is used for motor drive control and arm joint control signals from SBC 2.

6.2.2.7 Encoder-to-Digital Counter Card

A single Compcontrol CC133 encoder counter card provides nine encoder channels. Each channel has a 32-bit up/down counter that accepts standard A and B phase signals from an optical encoder. Each channel counter can be preloaded with a known count. The encoder card, in conjunction with the motor encoders, provides motor position data to the motor handler modules running as part of the synchronous process on SBC 2.

6.2.2.8 Resolver-to-Digital Counter Card

The computer system has one VME Microsystems International Corporation VMIVME-4941 resolver card. The card has four channels, and each channel has a 16-bit counter. The channels accept the standard resolver sine, cosine, and reference phase signals. The card is provided for the resolvers on each of the arm joints but is not presently used in the FARS.

6.2.3 Computer Hardware Interface

The carousels, lift table, arm conveyor, and arm control systems each have their own computer hardware interface. Each interface serves as a central collection and distribution point for all of the sensor and actuator signals between the computer and the associated hardware subsystem. Opto 22-type input and output modules in each of the interface boxes change sensor switch signals from 24 to 5 Vdc and convert on/off actuator signals from 5 to 24 Vdc. These modules also isolate the computer I/O lines from power voltages used by the actuators and switches.

Analog voltage sensors and digital encoders send their signals to the interface where the signals are routed to the correct computer input line. Motor control signals from the computer are sent to the interface for connection to the motor power amplifiers. The computer provides a single analog voltage that ranges between −10 and +10 Vdc as the arm joint control signal for each joint. The signals are sent to the hydraulic control interface, which maps the control signals to values that are compatible with the hydraulic valve actuators. Figure 20 depicts the control system mapping that the hydraulic control interface performs.

Each interface can be switched to permit either manual or computer control of the associated hardware subsystem. In the manual mode, control panels allow an operator to directly control the equipment without the computer system. This was very important during system development, testing, and integration. In the computer mode, lights on the control panels display sensor signal outputs but control signals from the manual control stations are disabled.

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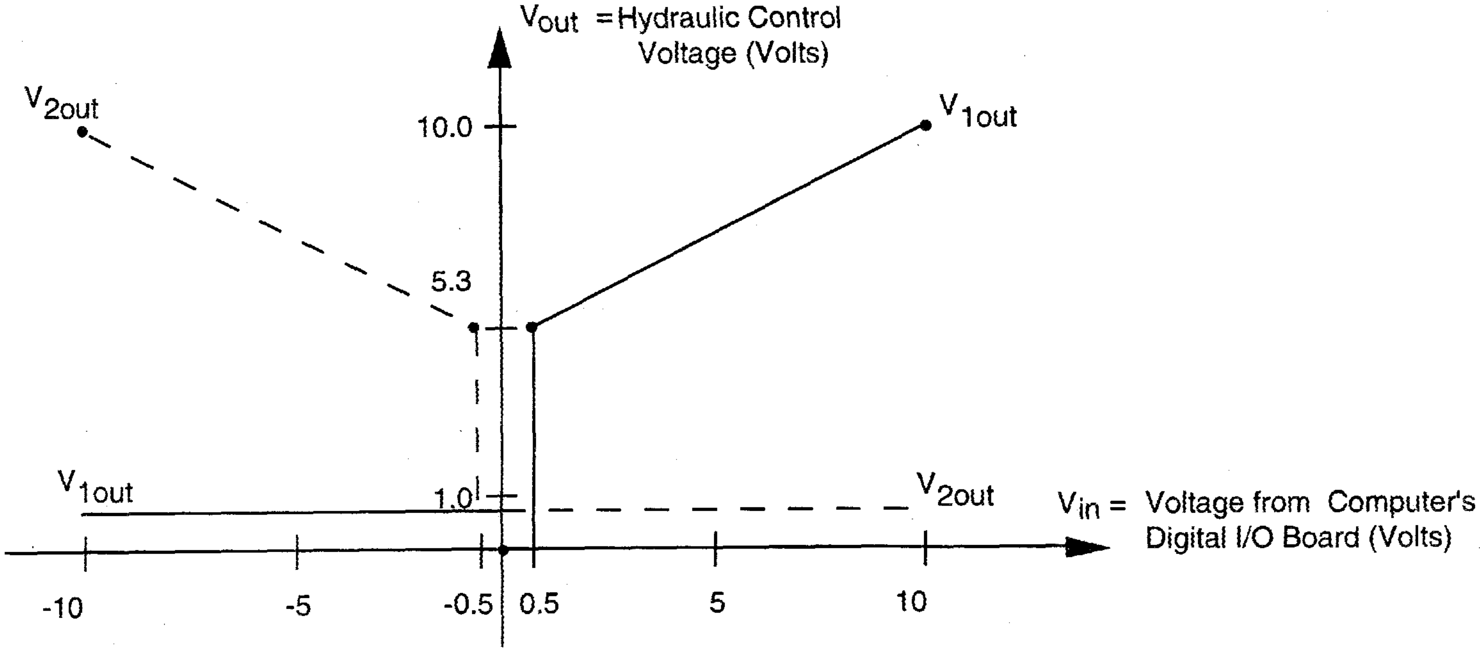

Fig. 20. Voltage mapping for the hydraulic control signal.

6.2.4 Sensors

6.2.4.1 Optical Sensors

Optical sensors are used to monitor the location of ammunition within the FARS and the status of equipment during operation. Optical sensors are used on the carousels, lift table, docking door, and docking port area.

The optical sensor system consists of the Banner Micro-Amp amplifier (MA3-4P) and either the break beam optical sensor pair (LR250 and PT250) or a diffuse mode (proximity) sensor (SP320D). The Banner sensors and amplifiers were selected because of their miniature size and because the gain of the sensor-amplifier pair was adjustable. The amplifier power and output signal are both 24 Vdc.

6.2.4.2 Linear Position Sensor

Linear position sensors are used to measure the lift table position and angle and the arm shoulder joint angle. The lift table has forward and aft sensors. The arm shoulder joint sensor is mounted so that the joint angle can be calculated from the sensor output value.

The linear position sensor used is the Balluff BTL linear displacement transducer (BTL-A16-1250-Z-S32). The sensing element is mounted inside a rugged stainless steel tube, and a passive magnetic position ring travels along the outside of the tube. The passive magnetic position ring is attached to the equipment in motion. The output signal of the transducer is directly proportional to the distance from a null point (zero displacement) on the tube to the magnetic position ring.

6.2.4.3 Joint Position Resolvers

Resolvers are mounted on the knuckle pitch and yaw joints and on the extension joint. The resolvers used are Clifton Precision Model 11-BHW-36F. The rotor frequency is 2500 Hz at 11.8 V, and the stator is two phase at 11.8 V. The resolvers are fully installed but presently are not in use.

6.2.4.4 Position Encoders

The carousel index motor and the two lift motors on the lift table use incremental encoders to measure motor shaft position. The optical encoders were supplied with the motors. The carousel index motor encoder is used to measure cell travel. The aft and forward lift table lift motor encoders are used to measure the lift table motion.

6.2.4.5 Arm Switches

The arm has position switches mounted above its conveyors to monitor the location of ammunition as it moves through the arm. Each switch is closed as ammunition displaces a whip-type actuator in the arm conveyor path.

6.2.4.6 Joysticks

Two joysticks were purchased from J. R. Merritt Company. Each joystick has X and Y motion, a deadman switch, and four push buttons on top of the joystick. Figure 21 depicts the joysticks and the system control functions that they control.

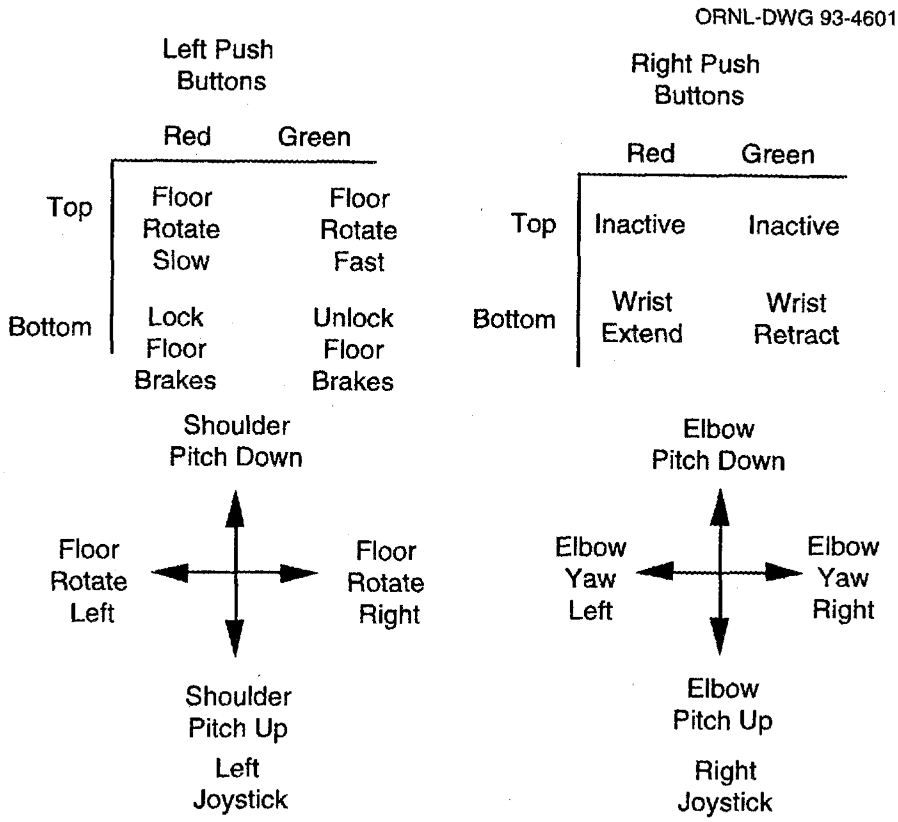

Fig. 21. Joystick controls.

6.2.5 Actuators

6.2.5.1 Pneumatic Valves

The carousel actuators are pneumatic-operated pistons. The pneumatic pistons are controlled with pneumatic valves which are controlled with 24-Vdc solenoids. The solenoids are connected to Opto 22 output modules. The control signals of the Opto 22 output modules are the output signals of the digital I/O cards.

6.2.5.2 Relays

Relays are used to control carousel index motor brakes, lift table lift motor brakes, motor amplifier enable commands, ac power control system, arm control, and manual control system. Relays used are the Potter and Brumfield Model KHS17D11-24, a four-pole, double-throw configuration with a 24-Vdc coil and Models T82N11D114-24 and T82N11D114-5, two-pole, double-throw configurations with 24- and 5-Vdc coils respectively.

6.2.5.3 Motors

The motors used on the carousel, lift table, and arm conveyors were manufactured by Rexroth Indramat. The motors are ac, three-phase, brushless servo motors which produce constant torque over their entire speed range. Each motor has a built-in tachometer which supplies motor velocity signals to the motor amplifier. The motor velocity feedback loop is closed locally via the motor amplifier; thus the computer is not required for velocity control. The carousel index motor and the two lift motors on the lift table have factory-installed optical shaft encoders. A computer-controlled position + position derivative servo controller combined with the encoders provides precise motor position control for the carousel index motor and the lift table lift motors. The carousel index motor and the lift motors on the lift table are equipped with fail-safe brakes.

Motor amplifiers

Each motor has its own controller amplifier with motor enable and drive command signals. The enable and drive signals are generated by the computer. The amplifier enable signal is a relay-switched 15-Vdc signal supplied by the amplifier. The motor amplifier is disabled when the relay is deenergized and enabled when the relay is energized. The motor drive signal is a ±10-Vdc signal supplied by the computer D/A card. Motor direction is set by drive signal parity, and motor speed is proportional to the drive signal magnitude.

Each motor amplifier is equipped with a plug-in motor personality module. The personality module sets the amplifier to the characteristic parameters of that motor. Amplifier operation depends on the type of motor being controlled. The motor velocity and motor commutation (position) signals are supplied to the amplifier for motor control.

The amplifier accepts regenerative power from the motor during motor deceleration. The regenerative power is put back onto the power supply bus, which increases bus voltage. The regenerative power can be used by another motor amplifier connected to the bus or, if the bus voltage rises above a preset voltage, the power supply will convert the power to heat.

Motor amplifier power supply

Two power supplies provide power for all of the motor amplifiers. Each power supply provides 25 A continuously and 150 A peak to the motor amplifiers at a bus voltage of 300 Vdc. One power supply provides power to the carousel motor amplifiers, and the other provides power for the lift table and arm conveyor motor amplifiers. The input voltage for each power supply is 208-Vac three-phase, which is provided by a generator on the FARS vehicle chassis. The controller supplying the 208 Vac to the power supplies is equipped with a current limiting circuit to reduce the in-rush current to the power supplies.

The power supplies accept regenerative power as an increase of bus voltage from the motors during motor deceleration. The regenerative power may be used by another motor amplifier attached to the power supply. If the bus voltage reaches a preset bus voltage, the extra bus power can be converted to heat by connecting the bus to a bleeder power resistor. The bleeder power resistor can be disconnected when the bus voltage is reduced to normal values.

6.2.5.4 Hydraulics

Hydraulic controller

The arm hydraulic controller and valves used on FARS were manufactured by Monsun-Tison. The controller has four channels; each channel is dedicated to control a specific arm joint (shoulder pitch, knuckle pitch, knuckle yaw, and wrist extension). Each controller channel requires two voltages, depending on the required motion. For no motion, both voltages are zero. For proportional motion in one direction, one voltage is zero and the other voltage ranges from 5.3 to 8.0 Vdc. For proportional motion in the other direction, one voltage ranges from 5.3 to 8.0 Vdc and the other voltage is zero. The hydraulic interface for the computer converts the ±10 Vdc from the computer D/A card into the proper signals for the controller.

The hydraulic controller and valves for the rotating floor module and floor brakes were supplied by Rexroth. The Rexroth controller accepts a ±10-Vdc signal directly from the computer D/A card. Floor direction is set by drive signal parity, and floor speed is proportional to the drive signal magnitude. The floor brake is controlled by a solenoid-operated hydraulic valve. The solenoid is operated by a relay controlled by the computer digital I/O signal.

The docking latches are controlled by a solenoid-operated hydraulic valve. This solenoid is also operated by a relay controlled by the computer digital I/O signal. The docking door is controlled by a solenoid-operated pneumatic valve. This solenoid is also operated by a relay controlled by the computer digital I/O signal.

Hydraulic power and ac power

The hydraulic pump and the 208-V three-phase ac generator may be powered by either a 25-hp electric motor or the vehicle's diesel engine. The electric motor is used for testing indoors, and the diesel engine is used for mobile testing and operations outdoors. The FARS has operated successfully under both conditions.

6.3 COMPUTER POWER SYSTEM

The computer system may be powered from any one of three 24-Vdc sources: the engine generator, an ac power supply, or the vehicle batteries. The engine generator, rated at 2400 W at 28 Vdc, was used for outside tests, and the ac power supply was used for indoor testing. The ac power supply converts 480 Vac three phase into 25 Vdc rated at 2400 W. In the event of an emergency shutdown, the engine generators and ac power supplies are shut down as a safety precaution. To preclude the loss of power to the computer and system sensors, vehicle batteries provide emergency power. The batteries are used only for emergency computer and sensor power and cannot drive the motors. The FARS power system is equipped with an interlock to prevent both the engine generator and the ac power supplies from supplying dc power in parallel.

REFERENCE

1. R. L. Glassell and P. D. Lloyd, *Future Armor Rearm System (FARS) Software Architecture Specifications (SAS)*, ORNL/TM-12364, Martin Marietta Energy Systems Inc., Oak Ridge Natl. Lab., to be published.

APPENDIX A
GLOSSARY OF TERMS

Autoloading mechanism
Automated ammunition handling system on the new M1A1 tank.

Transfer arm
Physical connecting link between the FARS and the tank.

Transfer arm extension
Last degree of freedom on the transfer arm. The extension makes the final connection between the FARS vehicle and the tank.

Lower transfer arm
Transfer arm portion below the wrist which attaches to the tank.

Upper transfer arm
Transfer arm portion above the wrist which attaches to the FARS vehicle.

Transfer arm conveyor mechanism
Mechanical conveyor which moves ammunition through the transfer arm from the lift table to the Autoloader.

Carousel
Device which holds the rounds within the FARS vehicle.

Carousel ejection mechanism
Mechanical device which moves rounds out of the carousel and onto the lift table.

Docking port
The mechanical connectors, controls, and sensors used for docking and connecting the transfer arm to the tank.

Drive mechanism
Actuator on a particular system (e.g., the actuator(s) on the carousel, the lift table on the transfer arm conveyor, etc.).

Hydraulic system
Hydraulic system to supply power to drive the transfer arm.

Joints

Moveable joints of the transfer arm.

Lift table

Mechanism which aligns and transfers between the carousel and the transfer arm conveyor.

Lift table ejection mechanism

Mechanical device which moves rounds off the lift table onto the upper transfer arm conveyor.

Links

Connections between the joints of the transfer arm.

Module

Part of the FARS vehicle which holds the carousel, lift table, and ammunition.

Rotating base

Rotating base for the module. This is the first degree of freedom for the connection between the FARS and the tank.

Wrist

Last pitch/yaw joint in the transfer arm.

APPENDIX B
FARS/TANK COMMAND DEFINITIONS

The command section of each message is comprised of two ASCII characters (each ASCII character is a single data byte). The commands listed in Table 2 in Sect. 4.1 provide for a minimumally capable communications system. Additional commands should be provided to enhance the functionality, flexibility, and robustness of the data link.

This appendix consists of definitions for each of the valid commands. The following format is used for each command definition.

Command:	**XX**
Name:	Command XX
Length:	$5 \leq n \leq 255$ bytes
Sum:	TBD
Description:	Description of the command XX
Data format:	Description of the data format, if applicable
Who sends:	FARS and/or tank authorized to send the command
Who receives:	FARS and/or tank authorized to receive the command
Tank action:	Description of tank action associated with the command XX
FARS action:	Description of FARS action associated with the command XX

Command:	**BA**
Name:	BreakAway
Length:	5 bytes
Sum:	TBD
Description:	Either vehicle, tank or FARS, is ordering a breakaway from the other.
Data format:	None
Who sends:	Tank/FARS
Who receives:	FARS/Tank
Tank action:	Send the breakaway message to the FARS if the tank is commencing the breakaway. Commence to store items away and break from FARS. The tank monitors the tank docking port proximity switch (if installed). If the switch detects breakaway, the tank will send the breakaway message to FARS and commence to store items away.
FARS action:	Send the breakaway message to the tank if FARS is commencing the breakaway. Commence to store items away and break from tank. Stop all piece motion. Stop the current running function manager, and start the breakaway function manager. The breakaway function manager will break from the tank as soon as the port is cleared and then stow away all pieces. FARS responds with a BA message to the tank after it receives a BA from the tank. The communication manager monitors the FARS docking port proximity switch (if installed). If the switch detects breakaway, the communication manager will send the breakaway message to the tank and issue the breakaway command to the FARS.

Command:	**CC**
Name:	Command Complete
Length:	5 bytes
Sum:	TBD
Description:	Used by FARS to inform the tank that the last operation, transfer or download, using the Shipping Order (SO) message was completed. Used by the tank to inform FARS that the last operation, transfer or download, using the Ship Individual (SI) message was completed.
Data format:	None
Who sends:	FARS/Tank
Who receives:	Tank/FARS
Tank action:	After receiving the CC from FARS, the tank may go to next desired action. Tank sends a CC message when done with transfer or download operations using SI messages.
FARS action:	Upon completing transfer or download operations with data from an SO message, the function manager will issue a CC message and end itself. During transfer or download operations with data from an SI message, the tank sends a CC message when the operation is completed. After receiving the CC message, the function manager will then end itself.

Command:	**CE**
Name:	Command Error
Length:	5 bytes
Sum:	TBD
Description:	The last message received had an error.
Data format:	None
Who sends:	Tank/FARS
Who receives:	FARS/Tank
Tank action:	Resend the last message that was not a CE message.
FARS action:	Resend the last message that was not a CE message.

Command:	**CR**
Name:	Command Receive
Length:	5 bytes
Sum:	TBD
Description:	Responds to the following messages: Transfer and Download.
Data format:	None
Who sends:	FARS
Who receives:	Tank
Tank action:	Continue to the next command.
FARS action:	Sends the message after the required transfer or download function manager is awaken and operating and ready for the next message. FARS will not send the CR message until it has cleared the lift table and arm of any pieces that might be left on the conveyors.

Command:	**CS**
Name:	Command Stop
Length:	5 bytes
Sum:	TBD
Description:	Used by the tank to cancel a Download or Transfer Command.
Data format:	None
Who sends:	Tank
Who receives:	FARS
Tank action:	Tank sends a CS message when the tank wishes to cancel a transfer or download operation.
FARS action:	After receiving the CS message, the operating function manager will then end itself. The operating equipment will stop, and any pieces that are on the lift table or on the arm conveyors will be restored in the carousels.

Command:	**DL**
Name: Length: Sum:	DownLoad 5 bytes TBD
Description:	Command from the tank to request the downloading of the tank.
Data format:	None
Who sends:	Tank
Who receives:	FARS
Tank action:	Requests to begin the downloading of the tank.
FARS action:	The system manager will begin the download function manager. The function manager, after starting, will respond with a CR message and wait for the shipping order, either SO or SI message, from the tank.

Command:	**DR**
Name: Length: Sum:	Download Ready 5 bytes TBD
Description:	Shipping order from the tank is acceptable. FARS is ready to accept the desired items from the tank.
Data format:	None
Who sends:	FARS
Who receives:	Tank
Tank action:	Begin the downloading of the tank.
FARS action:	The download function manager begins its state diagram to move the desired pieces received from the tank into the carousel cells.

Command:	**FE**
Name:	FARS Error
Length:	5 bytes[a]
Sum:	TBD
Description:	If during operations the FARS cannot continue with the desired operation, then the FARS will send this message.
Data format:	None[a]
Who sends:	FARS
Who receives:	Tank
Tank action:	TBD Once the error is corrected, the tank may resume/start desired operations by sending an RI, TF, or DL message.
FARS action:	If during operations the FARS cannot continue with the desired operation, then the FARS will send this message. Once the problem is corrected, the FARS operator will notify the tank operator that it is ready to resume normal operations.

[a]The existing system does not provide for any detailed data exchange between the two systems when an error occurs. However, by defining this message to be 6 bytes long, a single data byte could be used to pass an unsigned integer ($0 \leq n \leq 255$) that would define the FARS error condition for the TC.

Command:	**FH**
Name:	FARS Here
Length:	5 bytes
Sum:	TBD
Description:	After docking with the tank, FARS sends this message to the tank to begin the communications link.
Data format:	None
Who sends:	FARS
Who receives:	Tank
Tank action:	Responds with a Tank Here message.
FARS action:	After docking, the docking function manager will begin sending the FH message. The message will be sent at periodic intervals until the communications manager receives a TH message. At that time the communications manager will report to the operator manager that the link has been established, and FARS waits for a tank command (e.g., RI, TF, DL).

Command:	**GO**
Name:	Give One
Length:	5 bytes
Sum:	TBD
Description:	Tank command to FARS to give the next two pieces in the FARS queue. This should be a front and a rear end, and in that order.
Data format:	None
Who sends:	Tank
Who receives:	FARS
Tank action:	Ready to accept a front end (shell) and a rear end (prop charge).
FARS action:	If a piece is waiting in the boom at the docking port, that piece will be driven into the tank and the piece on the lift table will be driven into the tank without stopping inside the boom. If the GO message is received before the first piece leaves the lift table, the FARS will drive the piece into the tank without stopping. The second piece will follow without stopping.

Command:	**GI**
Name:	Give Item
Length:	5 bytes
Sum:	TBD
Description:	Tank command to FARS to transfer the next piece in the FARS queue. FARS command to the tank to download the next piece in the tank. This would either be a front or rear piece.
Data format:	None
Who sends:	Tank/FARS
Who receives:	FARS/Tank
Tank action:	During transfer, ready to accept the next piece from FARS. During download, send the next piece into the FARS.
FARS action:	During transfer, if a piece is waiting in the boom at the docking port, that piece will be driven into the tank. If the GI message is received before the piece leaves the lift table, the FARS will drive the piece into the tank without stopping. During download, FARS is ready for the next piece from the tank and will drive the piece onto the lift table. Once the lift table is cleared and repositioned in line with the shoulder conveyor, the next GI will be issued.

Command: **GR**

Name: Give Round
Length: 5 bytes
Sum: TBD

Description: Tank command to FARS to transfer the next 120-mm round in the FARS queue. FARS command to the tank to download the next 120-mm round in the tank.

Data format: None

Who sends: Tank/FARS

Who receives: FARS/Tank

Tank action: During transfer, ready to accept the next 120-mm round from FARS. During download, send the next 120-mm round into the FARS.

FARS action: During transfer, if a 120-mm round is waiting in the boom at the docking port, that round will be driven into the tank. If the GR message is received before the round leaves the lift table, the FARS will drive the round into the tank without stopping.

During download, FARS is ready for the next 120-mm round from the tank and will drive the piece onto the lift table. Once the lift table is cleared and repositioned in line with the shoulder conveyor, the next GI will be issued.

Command: **RI**

Name: Request Inventory
Length: 5 bytes
Sum: TBD

Description: Tank command to FARS to give number of different pieces to the tank.

Data format: None

Who sends: Tank

Who receives: FARS

Tank action: Ready to accept the VI message.

FARS action: Will respond with a VI message.

Command:	**SI**
Name:	Ship Individual
Length:	6 bytes
Sum:	TBD
Description:	The tank wants to receive/send a single piece from/to FARS. The message contains the piece identification.
Data format:	Single hex byte data. See Data Definitions for piece-type definitions.
Who sends:	Tank
Who receives:	FARS
Tank action:	Ready to accept the piece by sending a GI or GR message. Send the piece upon receiving a GI or GR message.
FARS action:	During transfer: Upon receiving the SI message, the communication manager will enter the data into a buffer. The transfer function manager will use this data to find a carousel/cell with the desired item and enter this information into a shipping order array. The transfer function manager will commence to perform the state diagram to get the desired piece up to the docking port and wait for the GI or GR message from the tank. FARS inventory will be updated. During download: Upon receiving the SI message, the communication manager will enter the data into a buffer. The download function manager will use this data to find an empty carousel/cell for the desired item and enter this information into a shipping order array. The download function manager will commence to perform the state diagram to get the desired piece from the tank and into the selected empty carousel cell. FARS inventory will be updated.

Command:	**SO**
Name:	Shipping Order
Length:	5+ data bytes
Sum:	TBD
Description:	The tank wants to receive/send pieces from/to FARS. The message contains the piece identification.
Data format:	Single hex byte data. See Sect. 4.3 for piece-type definitions. data byte 1 = desired piece type 1 data byte 2 = desired piece type 2 data byte 3 = desired piece type 3 data byte 4 = desired piece type 4 data byte 5 = desired piece type 5 as many pieces as required
Who sends:	Tank
Who receives:	FARS
Tank action:	Ready to accept the piece from FARS by sending a GI, GR, or GO message. Send the piece to FARS upon receiving a GI or GO message from FARS.
FARS action:	During transfer: Upon receiving the SO message, the communication manager will enter the data into a buffer. The transfer function manager will use this data to find carousels/cells with the desired items in the list and enter this information into a shipping order array. The transfer function manager will commence to perform the state diagram to get the desired pieces up to the docking port and wait for the GI, GR, or GO messages. FARS inventory will be updated. During download: Upon receiving the SO message, the communication manager will enter the data into a buffer. The download function manager will use this data to find empty carousels/cells for the desired item and enter this information into a shipping order array. The download function manager will commence to perform the state diagram to get the desired pieces from the tank and into the carousel cells. FARS inventory will be updated.

Command:	**SV**
Name:	Shipping Void
Length:	5 bytes
Sum:	TBD
Description:	The shipping order from the tank could not be filled. FARS does not have either the items or the empty cells required.
Data format:	None
Who sends:	FARS
Who receives:	Tank
Tank action:	Inform the TC. The TC may request an RI command.
FARS action:	If the tank's shipping order cannot be performed, the function manager will send the SV and wait for a new SO or SI (or an RI) message.

Command:	**TE**
Name:	Tank Error
Length:	5 bytes[a]
Sum:	TBD
Description:	If during operations the tank cannot continue with the desired operation, then the Tank will send this message.
Data format:	None[a]
Who sends:	Tank
Who receives:	FARS
Tank action:	If during operations the tank cannot continue with the desired operation, then the tank will send this message.
FARS action:	Operations will stop, and the function manager will inform the FARS operator. Any pieces that are on the lift table or the arm conveyors will be stowed in the carousel before the function manager ends itself. In order to resume operations, a message such as RI, DL, or TF will be required from the tank.

[a]The existing system does not provide for any detailed data exchange between the two systems when an error occurs. However, by defining this message to be 6 bytes long, a single data byte could be used to pass an unsigned integer ($0 \leq n \leq 255$) that would define the tank error condition for the FARS operator.

Command:	**TH**
Name:	Tank Here
Length:	5 bytes
Sum:	TBD
Description:	After receiving the FH message from FARS, the tank sends this message to begin the communications link.
Data format:	None
Who sends:	Tank
Who receives:	FARS
Tank action:	Responds with a TH message after receiving the FH message. See Note in FH message.
FARS action:	After receiving the TH message, the communications manager reports to the operator manager that the link has been established.

Command:	**TF**
Name:	TransFer
Length:	5 bytes
Sum:	TBD
Description:	Command from the tank to FARS to request the transfer of shells to the tank.
Data format:	None
Who sends:	Tank
Who receives:	FARS
Tank action:	Requests to begin the rearming of the tank.
FARS action:	The system manager will begin the transfer function manager. The function manager will respond with a CR message and wait for the shipping order, either SO or SI message, from the tank.

Command:	**TR**
Name:	Transfer Ready
Length:	5 bytes
Sum:	TBD
Description:	Shipping order from tank is acceptable. FARS is ready to send the desired items to the tank.
Data format:	None
Who sends:	FARS
Who receives:	Tank
Tank action:	Begin rearming the tank.
FARS action:	The transfer function manager begins the state diagram to move the desired pieces into the tank.

Command:	**UD**
Name:	UnDock
Length:	5 bytes
Sum:	TBD
Description:	Sender is responding to a UR message from the other vehicle. This message has the effect of authorizing the requested undocking to take place.
Data format:	None
Who sends:	Tank/FARS
Who receives:	FARS/Tank
Tank action:	Upon receipt of a UR message, send the UD message to FARS. Close the tank docking port door within 5 s of sending the UD message. The UR message may be ignored if an ammunition transfer or download operation is in progress.
FARS action:	Upon receipt of a UR message, send the UD message to the tank. Close the FARS docking port door and release the docking latches. FARS will allow at least 5 s after transmitting the UD message to the tank before releasing the latches. The UR message may be ignored if any function manager is awake.

Command:	**UR**
Name:	Undock Request
Length:	5 bytes
Sum:	TBD
Description:	Sender is requesting to undock from the other vehicle.
Data format:	None
Who sends:	Tank/FARS
Who receives:	FARS/Tank
Tank action:	Send the UR message to the FARS to request undocking. Do not begin undocking until receipt of the UD message from the FARS. Upon receipt of a UR message, send the UD message to the FARS to authorize the undock operation. The UR message may be ignored if an ammunition transfer or download operation is in progress.
FARS action:	Send the UR message to the tank to request undocking. Do not begin undocking until receipt of the UD message from the tank. Upon receipt of a UR message, send the UD message to the tank to authorize the undock operation. The UR message may be ignored if any function manager is awake.

Command:	**VI**
Name:	Vehicle Inventory
Length:	13 bytes
Sum:	TBD
Description:	Tells the tank the number of each type of piece the FARS has on board.
Data format:	data byte 1 = number of 140-mm KE data byte 2 = number of 140-mm HE data byte 3 = number of 120-mm KE data byte 4 = number of 120-mm HE data byte 5 = number of prop charges data byte 6 = number of empty 140-mm shell spaces data byte 7 = number of empty 120-mm round spaces data byte 8 = number of empty prop charge spaces **(If data byte is zero, send a hex 0xff)**
Who sends:	FARS
Who receives:	Tank
Tank action:	Displays information
FARS action:	Upon receiving the RI message, the communication manager will read the data base to get the inventory and then send the VI message.

APPENDIX C
FARS/TANK MESSAGE SEQUENCE EXAMPLES

This appendix contains message sequence examples that represent the message patterns that occur between the tank and the FARS during various types of operations. The examples are not intended to be all inclusive, but a number of different scenarios are presented in order to demonstrate the general usage of the messages defined by the FARS/Tank Communications Protocol developed for the FARS Project.

The two ASCII characters from the command section of each message are used to indicate the message being sent. The letters "T" (for tank) and "F" (for FARS) separated by a "->" indicate the sender and the receiver of the message. For example, FH F -> T, means that a FARS Here message is sent by the FARS to the tank.

I. Dock and transfer a multiple-piece shipping order. Tank requests to undock.

DOCK		
FH	F -> T	
FH	F -> T	
•		
•		every two seconds until the tank responds
•		
TH	T -> F	comm link is established
RI	T -> F	request inventory
VI	F -> T	send inventory
TF	T -> F	request transfer
CR	F -> T	transfer operation is ready
SO	T -> F	desired shipping order
TR	F -> T	shipping order is ok, FARS begins operation
GO	T -> F	send front end and prop to tank
GO	T -> F	send front end and prop to tank
•		
•		continues as long as the shipping order is not complete
•		
GO	T -> F	send front end and prop to tank, done
CC	F -> T	shipping order complete, transfer is completed by FARS
UR	T -> F	tank requests to undock
UD	F -> T	FARS acknowledges the undock request; FARS and tank initiate undocking sequence

II. Dock and transfer two items, requested one at a time. FARS request to undock.

DOCK		
FH	F -> T	
FH	F -> T	
•		
•		every two seconds until the tank responds
•		
TH	T -> F	comm link is established
RI	T -> F	request inventory
VI	F -> T	send inventory
TF	T -> F	request transfer
CR	F -> T	transfer operation is ready
SI	T -> F	request a single piece
TR	F -> T	shipping order is ok, FARS begins operation
GI	T -> F	send item to tank
SI	T -> F	request a single piece
TR	F -> T	shipping order is ok, FARS begins operation
GI	T -> F	send item to tank
CC	T -> F	shipping order complete, transfer is completed by the tank
UR	F -> T	FARS requests to undock
UD	T -> F	tank acknowledges the undock request; FARS and tank initiate undocking sequence

III. Dock and download a multiple-piece shipping order.

DOCK		
FH	F -> T	
FH	F -> T	
•		
•		every two seconds until the tank responds
•		
TH	T -> F	comm link is established
RI	T -> F	request inventory
VI	F -> T	send inventory
DL	T -> F	request download
CR	F -> T	download operation is ready
SO	T -> F	desired shipping order
DR	F -> T	shipping order is ok, FARS begins operation
GI	F -> T	send item to FARS
GI	F -> T	send item to FARS
•		
•		continues as long as the shipping order is not complete
•		
GI	F -> T	send item to FARS, done
CC	F -> T	shipping order complete, download is completed by FARS

IV. Dock and download two items, requested one at a time.

DOCK		
FH	F -> T	
FH	F -> T	
•		
•		every two seconds until the tank responds
•		
TH	T -> F	comm link is established
RI	T -> F	request inventory
VI	F -> T	send inventory
DL	T -> F	request download
CR	F -> T	download operation is ready
SI	T -> F	request a single piece
DR	F -> T	shipping order is ok, FARS begins operation
GI	F -> T	send item to FARS
SI	T -> F	request a single piece
DR	F -> T	shipping order is ok, FARS begins operation
GI	F -> T	send item to FARS
CC	T -> F	shipping order complete, download is completed by the tank

V. Dock, request to transfer a multiple-piece shipping order that the FARS cannot provide, modify request, transfer ammunition to satisfy the modified request.

DOCK		
FH	F -> T	
FH	F -> T	
•		
•		every two seconds until the tank responds
•		
TH	T -> F	comm link is established
TF	T -> F	request transfer
CR	F -> T	transfer operation is ready
SO	T -> F	desired shipping order
SV	F -> T	order is not ok, FARS waits
RI	T -> F	request inventory
VI	F -> T	send inventory
SO	T -> F	modified shipping order
TR	F -> T	shipping order is ok, FARS begins operation
GO	T -> F	send front end and prop to tank
GI	T -> F	send next piece in shipping order to tank
GR	T -> F	send next piece in shipping order (120-mm round) to tank
•		
•		continues as long as the shipping order is not
•		complete
GO	T -> F	send front end and prop to tank
CC	F -> T	shipping order complete, transfer is completed by the FARS

VI. Dock, request to download a multiple-piece shipping order that the FARS cannot store, modify request, download ammunition to satisfy the modified request.

DOCK		
FH	F -> T	
FH	F -> T	
•		
•		every two seconds until the tank responds
•		
TH	T -> F	comm link is established
RI	T -> F	request inventory
VI	F -> T	send inventory
DL	T -> F	request download
CR	F -> T	download operation is ready
SO	T -> F	desired shipping order
SV	F -> T	shipping order is not ok, FARS does not begin operation
SO	T -> F	modified shipping order (could ask for another RI)
DR	F -> T	shipping order is ok, FARS begins operation
GI	F -> T	send item to FARS
•		
•		continues as long as the shipping order is not complete
•		
GI	F -> T	send item to FARS, done
CC	F -> T	shipping order complete, download is completed by FARS

VII. Dock, initiate a multiple-piece transfer, but terminate the transfer due to a FARS error condition.

DOCK		
FH	F -> T	
FH	F -> T	
•		
•		every two seconds until the tank responds
•		
TH	T -> F	comm link is established
RI	T -> F	request inventory
VI	F -> T	send inventory
TF	T -> F	request transfer
CR	F -> T	transfer operation is ready
SO	T -> F	desired shipping order
TR	F -> T	shipping order is ok, FARS begins operation
GO	T -> F	send front end and prop to tank
•		
•		continues as long as the shipping order is not complete
•		
GO	T -> F	send front end and prop to tank
FE	F -> T	FARS error, operation stop

VIII. Dock, initiate a multiple-piece transfer, but terminate the transfer due to a tank error condition.

DOCK		
FH	F -> T	
FH	F -> T	
•		
•		every two seconds until the tank responds
•		
TH	T -> F	comm link is established
RI	T -> F	request inventory
VI	F -> T	send inventory
TF	T -> F	request transfer
CR	F -> T	transfer operation is ready
SO	T -> F	desired shipping order
TR	F -> T	shipping order is ok, FARS begins operation
GO	T -> F	send front end and prop to tank
•		
•		continues as long as the shipping order is not
•		complete
GO	T -> F	send front end and prop to tank
TE	T -> F	tank error, operation stop

IX. Dock and initiate a multiple-piece transfer, but terminate the transfer due to an emergency breakaway request from the tank.

DOCK		
FH	F -> T	
FH	F -> T	
•		
•		every two seconds until the tank responds
•		
TH	T -> F	comm link is established
RI	T -> F	request inventory
VI	F -> T	send inventory
TF	T -> F	request transfer
CR	F -> T	transfer operation is ready
SO	T -> F	desired shipping order
TR	F -> T	shipping order is ok, FARS begins operation
GO	T -> F	send front end and prop to tank
•		
•		continues as long as the shipping order is not
•		complete
GO	T -> F	send front end and prop to tank
BA	T -> F	breakaway
BA	F -> T	breakaway, FARS and tank initiate emergency breakaway sequences

X. Dock and start a transfer but terminate prematurely due to a tank-ordered stop.

FH	F -> T	
FH	F -> T	
•		
•		every two seconds until the tank responds
•		
TH	T -> F	comm link is established
RI	T -> F	request inventory
VI	F -> T	send inventory
DL	T -> F	request download
CR	F -> T	download operation is ready by FARS
CS	T -> F	download is aborted by tank
TF	T -> F	request transfer
CR	F -> T	transfer operation is ready
SO	T -> F	desired shipping order
TR	F -> T	shipping order is ok, FARS begins operation
GO	T -> F	send front end and prop to tank
GO	T -> F	send front end and prop to tank
•		
•		continues as long as the shipping order is not
•		complete
GO	T -> F	send front end and prop to tank
GO	T -> F	send front end and prop to tank
CS	T -> F	transfer is aborted by tank

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