Ammunition Logistics Program

DEVELOPMENT OF AN AUTOMATED AMMUNITION PROCESSING SYSTEM FOR BATTLEFIELD USE*

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DISCLAIMER

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ABSTRACT

The Future Armored Resupply Vehicle (FARV) will be the companion ammunition resupply vehicle to the Advanced Field Artillery System (AFAS). These systems are currently being investigated by the U.S. Army for future acquisition. The FARV will sustain the AFAS with ammunition and fuel and will significantly increase capabilities over current resupply vehicles. Currently ammunition is transferred to field artillery almost entirely by hand. The level of automation to be included into the FARV is still under consideration. At the request of the U.S. Army's Project Manager, AFAS/FARV, Oak Ridge National Laboratory (ORNL) identified and evaluated various concepts for the automated upload, processing, storage, and delivery equipment for the FARV. ORNL, working with the sponsor, established basic requirements and assumptions for concept development and the methodology for concept selection. A preliminary concept has been selected, and the associated critical technologies have been identified. ORNL has provided technology demonstrations of many of these critical technologies. A technology demonstrator which incorporates all individual components into a total process demonstration is planned for late FY 1995.

INTRODUCTION

The Advanced Field Artillery System (AFAS), the Army's next generation artillery system, will be a 155mm self-propelled howitzer with significantly increased capabilities over the current M109-series fleet. It is intended to be a more lethal, more survivable, longer-range, and less manpower-intensive cannon. The AFAS requires a companion vehicle with similar mobility and survivability capabilities so that it can be resupplied with ammunition and fuel throughout the battlefield in, or very near, its firing position. This companion vehicle, or the Future Armored Resupply Vehicle (FARV), must be able to carry 130 rounds and associated liquid propellant (LP), as well as fuel. It must transfer supplies to the AFAS while the crew is protected inside the vehicle.

Ammunition processing consists of removing the lifting eyes, fuzing, weighing, and marking. Once processed, the projectiles must be stored until ready for transfer to the AFAS. On current systems, projectiles are processed manually. This manual processing is labor intensive and fails to meet the time constraint of 130 rounds in 65 min. At the request of the U.S. Army's Project Manager, AFAS/FARV, Oak Ridge National Laboratory's (ORNL) Robotics and Process Systems

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Division has been investigating several methods of reducing the artillery ammunition processing times. These range from the addition of improved tools and data entry/management systems to complete automation of the upload, handling, and processing operations. This paper will deal exclusively with the efforts directed at the fully automated approach.

BASIC ASSUMPTIONS AND REQUIREMENTS

The original project task consisted of developing alternative concepts which satisfied the basic requirements of the FARV, while incorporating passive ammunition storage and state-of-the-art robotics and automation technology. To limit the number of possible concepts, assumptions were made with the requirements as the primary driver. All processing and storage equipment, as well as a minimum of 130 complete rounds, had to be contained in a rectangular envelope approximately 130 × 168 × 65 in. The system required a minimum upload and processing rate of 130 rounds in 65 min. The AFAS chassis was assumed as the FARV platform since it was the leading candidate being considered. The configuration of the space available on the AFAS chassis then led to a storage orientation with the projectiles horizontal and parallel to the direction of travel.

CONCEPT SELECTION

The initial objective of the project was to develop alternative upload and processing concepts which satisfied the basic assumptions and requirements. All of the FARV subsystems were subjectively considered by individual team members. Various approaches for each subsystem were considered, and the advantages and disadvantages of each were identified. After the subsystem evaluation, the preferred subsystem approaches were integrated into complete concepts. A formalized decision analysis technique was then used to systematically evaluate each of the concepts. Figure 1 shows the concept selected for further consideration.

CONCEPT DESCRIPTION

Upload of the FARV will take place from a combat configured load on a palletized load system flatrack containing projectiles, fuzes, and containers of LP. In this concept, the FARV is uploaded with unprocessed projectiles through an articulated boom which is also used to transfer processed projectiles, LP, and fuel to the AFAS. Before each projectile is loaded, a protective grommet is manually removed from its rotating band. The types of projectiles and fuzes and their lot numbers are input into the FARV control system computer during upload. Fuel, both for the FARV and for eventual transfer to the AFAS, is also taken on during the upload process.

Projectiles are processed within the dry and secure interior of the vehicle. Once inside the vehicle, the projectiles are removed from the boom conveyor by a pick-and-place robot and placed into the first processing station. (Should conditions warrant, the rounds could be placed immediately into storage for later processing allowing rapid upload). For this concept, an automated processing system is provided which consists of a process transfer system (PTS) and four

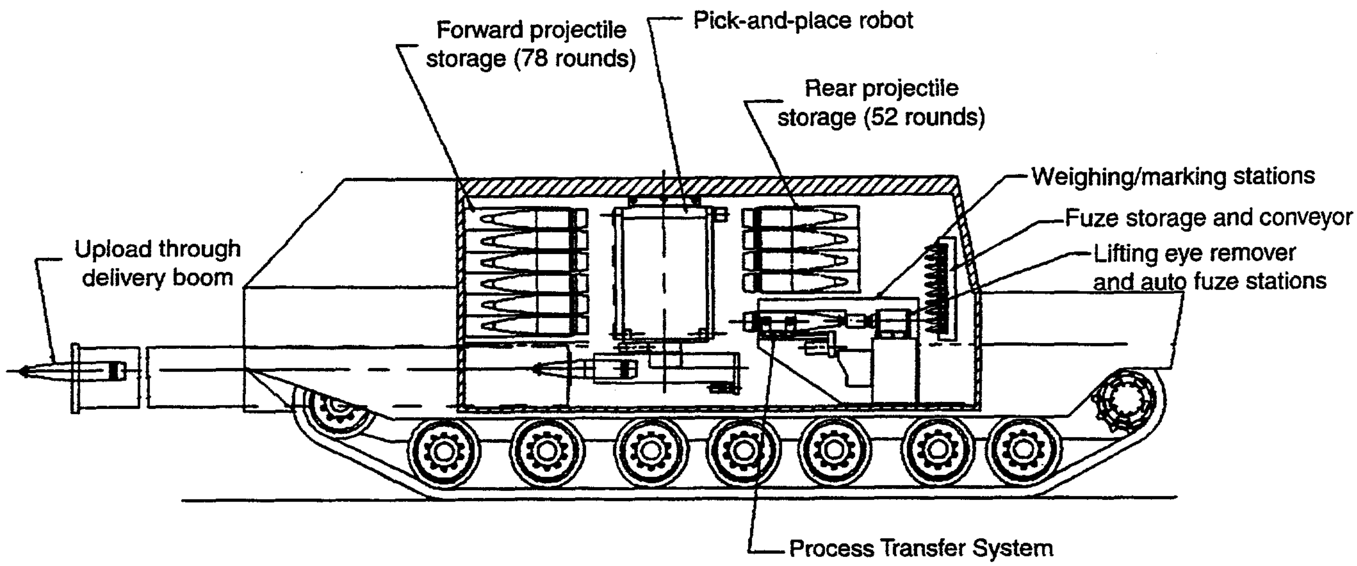

Figure 1. Selected concept.

processing stations. The PTS is an overhead shuttle device that moves each projectile successively through each of the processing stations. The processing stations include lifting eye removal, appropriate fuze selection and insertion, weighing, and marking (which indicates the projectile's weight, type, and lot number by machine-readable code on the projectile's exterior). The same pick-and-place robot removes the processed projectile from the last processing station and moves it to a storage cell for later delivery to the AFAS. The projectiles are stored horizontally and parallel to the direction of vehicle travel. When the FARV reaches the AFAS, the delivery conveyor boom mates to the AFAS vehicle. The projectiles are removed from their storage cells by the transfer robot and placed onto the delivery conveyor. An inventory management system tracks the storage locations of the assembled rounds (projectile and fuze assembly) and ensures delivery of the correct rounds to the AFAS.

TECHNOLOGY DEVELOPMENT

The following sections describe critical technology operations which are planned or have been demonstrated. The concerns and/or issues associated with each technology and the test stands provided for demonstrating them are described. When all demonstrations are complete the Army will evaluate each of the technologies for incorporation into the FARV. The pick-and-place robot is being developed by another organization and will not be addressed in this paper.

Upload/Delivery Conveyor

To accommodate ammunition transfer, the vehicles must be able to dock in various battlefield conditions and terrain. Based on direction from the project sponsor, the terrain to be considered results in vehicle mismatch of ±10° in pitch, roll, and yaw. Further restraints include delivery of the projectiles coaxial to the AFAS and at a height no greater than 4 ft above the ground. The approach taken to meet the requirements of projectile transfer was to develop a three-section, 6-D.F. articulated conveyor that is fully extendible and retractable. Although this approach has the highest technical risk, it was selected to meet the requirement that the FARV accommodate all the degrees of freedom required for docking.

One of the main concerns for a device of this size is weight. Section 1, which stays inside the vehicle during docking, weighs approximately 1000 lb. Sections 2 and 3, which are cantilevered during docking, weigh a combined 1050 lb, meaning the pitch actuator at the shoulder must be able to support the moment created by their combined masses. For the technology demonstrator, sections 2 and 3 were fabricated out of 2219 aluminum to take advantage of its high strength-to-weight ratio.

The arm is currently being fabricated and will be evaluated during the integrated testing planned for late FY 1995; however, in order to validate the design, a conveyor test stand was fabricated for preliminary testing. This test stand allowed verification of the conveyor belt design approach (V-configuration) as a workable concept. It also ensured that all projectile types could transition from one section to another at angles of ±20° pitch and yaw at speeds up to 40 ips. The arm and the conveyor test stand are more thoroughly described in another paper.[1]

Lifting Eye Removal and Fuzing

Automation of the lifting eye removal is relatively straightforward. A demonstration of automated lifting eye removal was conducted for the sponsor, using the fuzing test stand and control system with minor modifications. No technical issues were identified.

One problem with automating the fuzing operation was that the fuzes and shells could not be modified. Typically, when an assembly process is automated the parts are modified for ease of assembly. Due to the large inventory of existing ammunition stocks, modifications to either fuzes or projectiles were not practical. An additional constraint on the fuzing design was vehicle space limitations, which dictated that the design be capable of processing the projectiles in a horizontal position. This introduces potential alignment problems. Proper insertion and thread mating is a concern because of misalignment between the fuze centerline and projectile centerline. The centerline misalignment can be both angular and lateral and can occur because of fuze and projectile dimensional variance and fuzing equipment misalignment.

A tolerance study was completed to determine the maximum misalignment caused by dimensional variances since all the projectile and fuze combinations must be fuzed using the same equipment. Additionally, an analytical study was conducted to determine the parameters necessary for successful fuzing. This study led to the selection of a remote compliance center (RCC) to compensate for misalignment between the fuze and projectile centerlines. The RCC introduces a known compliance into the fuzing system, and provided the fuze contacts the shell within the chamfer on the shell, compensates for misalignments by ensuring that the fuze correctly enters the fuze well.

A fuzing test stand was designed and fabricated to verify information obtained in the analytical study, including confirmation of the appropriate RCC and determination of the angular and lateral misalignment the system could tolerate. The analysis leading to the design of the test stand and the fuzing test results are presented in another paper.[2] The fuzing stand is shown in Figure 2.

ORNL PHOTO 5590-94

Figure 2. Fuzing testing stand.

Weighing

It is necessary for the FARV to accurately weigh projectiles so that the howitzer may adjust its fire to compensate for varying projectile mass. The accuracy required for the weighing system was specified as $\pm$ 0.1 lb. This requires a scale to be accurate to within roughly 0.1%, which is well within the capability of commercial weighing systems. The fact that the weighing system would be mounted on a military vehicle, however, introduced additional requirements which could not be satisfied by an off-the-shelf system. These requirements include weighing accurately on slopes of up to 10°, accommodating projectiles of different lengths and center of gravity locations, functioning with vehicle vibration, and withstanding the abuse of military operation.

Several concepts were considered to meet these requirements including dynamic weighing methods and various load cell types. The system chosen for development was composed of a commercial load cell combined with a computer system and an inclinometer to compensate the load cell output.

The load cell chosen was a cantilever beam type as used in bench scales. This load cell is very accurate and durable. It also reads only the normal force applied to the end of the beam and is insensitive to side loading, moments, and load position. This is essential to the application as these effects are produced when the vehicle must operate on sloping surfaces and as the load position varies on the scale due to different projectile sizes. If the scale assembly is at some orientation other than horizontal, the normal force to the load cell will no longer line up with the weight vector. The normal force applied to the load cell will be roughly equal to the weight of the projectile multiplied by the cosine of the angle of inclination.

A dual-axis inclinometer mounted to the weighing system is used to measure the angles of inclination, which are then fed into the computer. The computer calculates a compensation factor for each of the two inclination angles from preprogrammed angular compensation algorithms. The normal force, or raw weight, as measured by the load cell is then multiplied by these compensation factors to obtain a correct weight for each projectile.

To evaluate this method a test stand, as shown in Figure 3, was built which incorporates a base mounted on adjustable legs which allow the whole unit to be tilted. The inclinometer and load cell are mounted to the base plate. In turn, a special tray is mounted to the load cell to hold projectiles. A computer screen displays the inclinometer output voltages, the angles of inclination, and the raw and corrected weight.

A calibration and test program was conducted using this test stand. First the load cell was calibrated. Next, using a projectile of known weight, the repeatability of the load cell was tested. The load cell was then verified to be insensitive to various load positions such those expected due to the different size projectiles.

The angular compensation routines were then developed. Using a sine plate and traceable standards, the inclinometer was calibrated in both axes over a ±15° range. With this done, single-axis curves of raw weight vs angle of inclination were constructed by measuring the raw weight of the projectile at every degree of rotation about that axis from −15 to +15°. These curves were then programmed into the weighing system computer to calculate a compensation factor for each axis.

The effectiveness of the compensation routines was tested by checking the corrected weight values first for single-axis rotations and then for compound angles of up to 15° in both axes. When the routines were working correctly, testing was performed with the system mounted on a military vehicle to determine the combined effects of vibration, compound angles, and varying the load position on the tray. Data points were taken at every 5° throughout the range of inclination with the vehicle idling and with the load placed in the center of the tray and 2.5 in. to either side. Successful completion of this testing verified that the weighing system was capable of providing accurate data while mounted on a military vehicle.

ORNL PHOTO 3900-94

Figure 3. Weighing test stand.

Automated Ammunition Identification and Marking

To permit the high rates of fire proposed for the AFAS, the Army is developing an automatic reload system that removes the gun crew from the process. To ensure that the correct ammunition is being loaded, without human intervention, a method for automatically identifying ammunition is required. One proposed approach employs machine-readable matrix symbols on each projectile to convey important data such as projectile and fuze types, lot numbers, and total weight. Figure 4 shows an example of matrix symbols encoding the necessary data. These function like a bar code and have several advantages. Matrix symbols have a higher data capacity and offer error correction capabilities that traditional bar codes do not. Also, unlike bar codes that are decoded with a laser scanner, matrix symbols are decoded with a small video camera. This type scanner allows matrix symbols in any orientation to be decoded, even if they are moving. The video scanner can also decode matrix symbols with low contrast or poor image quality, which is difficult for regular bar code scanners.

The key technology needed for the proposed approach is an acceptable method for placing the matrix symbols on artillery projectiles. Tests were conducted to evaluate two methods for marking artillery ammunition with machine-readable symbols. The first method uses ink-jet printing directly onto projectiles, and the second uses thermal-transfer printing onto self-adhesive labels that are subsequently applied automatically to projectiles.

The ink-jet tests demonstrated that small printing head misalignments will not adversely affect the readability of

Figure 4. Matrix symbols.

printed symbols and that symbols can be printed at high speed on either vertical or horizontal surfaces. Existing water-based black inks provide adequate contrast for reading symbols from olive-drab projectiles but are nonpermanent on projectile surfaces. The printer manufacturer is currently developing a permanent ink for nonporous surfaces, but a sample was not yet available for the tests described in this paper.

Label printing and application tests demonstrated the importance of proper media selection and system alignment to successfully attach self-adhesive labels to projectiles. Given the unpredictable nature of environmental conditions on the battlefield and the importance of system alignment for proper label application, labeling systems are not recommended for marking projectiles.

Results of testing both systems indicate that projectiles must be clean and dry before marking with either method. This places a requirement on soldiers or an automated system that may be difficult to achieve under extreme battlefield conditions.

Process Transfer System

All the automated processing operations in the selected concept take place within the PTS (see Figure 5). The PTS was designed and fabricated to allow the integration of all the automated processing operations previously described. The overhead shuttle assembly parts are pneumatically actuated and are constructed of commercially available hardware. The grippers are specially designed to fit the contour of the projectiles and are rubber lined to provide friction for gripping, as well as protecting, the projectile's exterior.

The equipment to be mounted opposite the four processing stations shown in the figure consists of manipulators to remove the lifting eye and fuze the projectile, a conveyor to provide fuzes to the fuze manipulator, a load cell to weigh the projectiles, and equipment to mark the exterior of the projectiles.

The PTS begins operation when the first projectile uploaded into the FARV is inserted into the lifting eye removal station by the pick-and-place robot. To provide support and

ORNL PHOTO 4995-94

Figure 5. Process Transfer System.

allow insertion of the projectile, the cradle in this station consists of polyurethane wheels mounted in a V-configuration. After insertion, the shuttle device is lowered and gripper 1 is engaged to hold the projectile while the manipulator removes the lifting eye. The projectile is then transferred into the fuzing station where a steel V-block cradle provides precise alignment with the fuzing manipulator. During this move another projectile is inserted into the lifting eye removal station.

To avoid introducing misalignment during fuzing, a vertically mounted pneumatic clamp adjacent to gripper 2 is used to push down and hold the projectile into the V-block rather than the gripper itself. The two projectiles in the system are then moved by the shuttle device to the weighing and fuzing stations, respectively, while a third projectile is inserted. The weighing station consists of a contoured cradle with a load cell mounted underneath for performing the actual weighing. The final move operation (involving three projectiles) transfers the initial projectile from the weighing station into the marking station. Here, the cradle consists of several transfer balls mounted in a V-configuration to allow rotation of the projectile for marking purposes and also extraction by the transfer robot. A pneumatic three-jaw chuck is driven over the nose of the projectile and then closed. The marking is applied to the exterior of the projectile as it is rotated by the chuck. At this point the projectile is ready to be removed from the PTS and taken to a storage cell. This operating sequence continues until all projectiles have been completely processed and stored.

Control System

A critical technology area not previously discussed is the control philosophy adopted and implemented. Certain basic principles guided the development and implementation of the control architecture. Key among these was the concept of a control architecture that supports all of the discrete demonstrations and can be easily enhanced to facilitate an integrated demonstration of the various subsystems. A different, but related, objective was to maximize the reuse of software between subsystems.

The control system was designed so that hardware dependency was minimized. During the early stages of design and development, detailed knowledge of the hardware was not available. Because of the relatively fast-paced development effort undertaken, the control system had to be developed in parallel with the system hardware design and fabrication.

A system monitoring and debugging capability was integrated into the control system. The monitoring capability permits the system developers and integrators to verify the correct operation of the various low-level control signals in a nonintrusive manner during operation of the equipment. The debugging capability permits modification of system parameters and direct entry of low-level commands.

The control system is a hierarchical system built on a multiprocessor, network-based architecture which provides significant benefits in the development, implementation, and integration of the control system. The modular and hierarchical nature of the hardware/software architecture facilitated development of certain portions of the control system in the absence of accurate or complete information on the hardware to be controlled. It also provided a convenient method to integrate and test the system as various hardware components are completed.

The VxWorks operating system was used throughout the control system except in the operator interface CPU, which runs OS/9, in order to leverage some previously developed operator interface experience. A UNIX (SunOS) host machine provides a development environment for all of the software running on the VxWorks target machines.

All control systems software was written in C and C++. Where practical, object-oriented design practices were used in conjunction with the C++ language to produce reusable modules which encapsulated their data.

INTEGRATED PROCESS DEMONSTRATION

Future plans include integrating all the various discrete processing and projectile handling equipment into a single test stand, as shown in Figure 6. The upload/delivery boom will be situated beneath a 5-ft-high mezzanine structure on which the processing equipment will be mounted. Delivery of projectiles between the conveyor and the processing equipment will be via a lift table. Since the actual pick-and-place robot will not be available for integrated testing, ORNL has designed an ammunition transfer device (ATD) that will simulate its operation. For simplification, the ATD will operate in only one plane to transfer projectiles among the processing stations, storage cells, and lift table. Also, rather than using a complex cam and latch arrangement, as proposed for the actual robot, the ATD will simply grasp the projectiles by a pneumatic gripper similar to those used in the PTS. Capability for 180° rotation of projectiles will be maintained.

Two racks of four storage cells each will be used to simulate the 130 cells that will be onboard an actual vehicle. These cells have been designed to interface with the ATD and the projectiles in place. The locking requirement is due to the operating conditions of the FARV, which call for cross-country transport over rough terrain. The PTS will be situated on the test stand as shown and will operate as described earlier.

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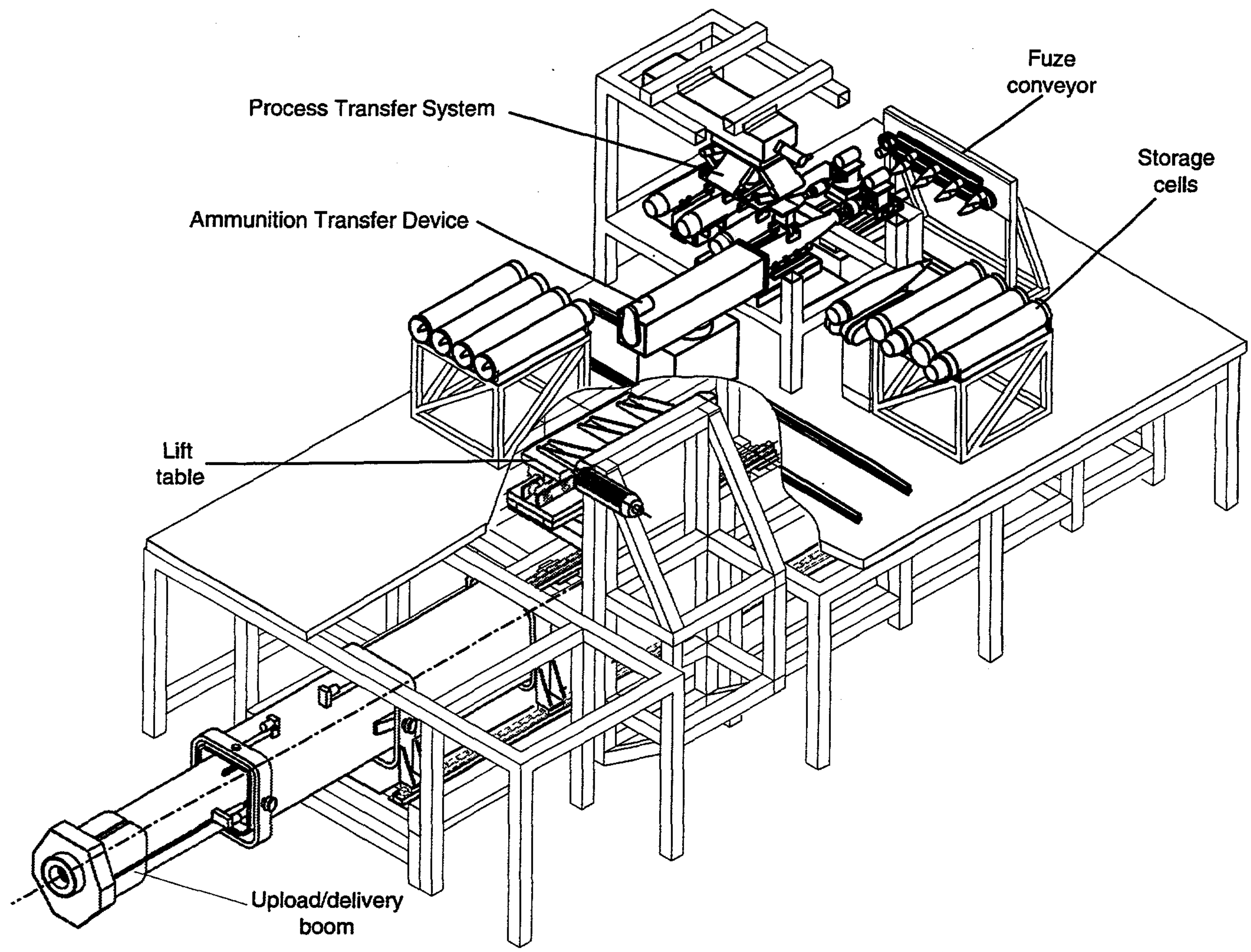

Figure 6. Integrated test stand.

The integrated process demonstration, scheduled for August 1995, will provide the Army with the data necessary to make informed decisions as to the extent of automation desirable in the final FARV system.

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