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Ammunition Logistics Program

**ROBOTIC CONVEYANCE OF ARTILLERY PROJECTILES FOR REMOTE
AMMUNITION RESUPPLY OPERATIONS***

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ABSTRACT

The U.S. Army's Project Manager, Advanced Field Artillery System/Future Armored Resupply Vehicle has given Oak Ridge National Laboratory the task of developing a robotic conveyance system which will provide automated artillery ammunition transfer. This technology is currently being developed and will be demonstrated in the summer of 1995. This paper describes the development of an ammunition transfer arm to date. The arm consists of three sections and 6 D.F. which will allow the Future Armored Resupply Vehicle to dock and mate with the Advanced Field Artillery System on terrain varying from $\pm 10^\circ$ in pitch, yaw, and roll and will allow for alignment of the fuel and propellant transfer ports. This arm will deliver the ammunition to the AFAS, where it will be received by an automatic handling and storage system inside the AFAS.

INTRODUCTION

During Operation Desert Storm the U.S. Army required an extremely mobile team of armor and artillery systems. An important factor in this type operation is the Army's field artillery system, which prepares the way for the combined arms team. It must supply firepower with accuracy, speed, and persistence to allow the front line of forces to press on toward the target or to provide cover to allow the troops to retreat if necessary.

This need to strike with speed and persistence is not adequately met by the current fleet of field artillery vehicles. Therefore the Army shifted emphasis in the weapons modernization program to the artillery systems and the development of the next generation field artillery. This new system will be known as the Advanced Field Artillery System (AFAS). The AFAS will be a 155mm self-propelled howitzer with significantly increased capabilities over the current M109 series fleet. The AFAS will provide increased lethality, allowing more flexibility for employment in pairs, platoons, batteries, and battalions, as well as the added capability for independent mission execution.

The AFAS will require a resupply vehicle which will have the ability to not only keep pace with the AFAS but to also supply the ammunition required with speed, accuracy, and safety in an environment consisting of fire/counterfire, directed at the AFAS or itself, and possibly nuclear, biological and chemical (NBC) threats. This resupply vehicle will be the Future Armored Resupply Vehicle (FARV). It will be armored and able to accompany the AFAS as far forward as the firing line and will allow the two to operate in a decentralized and independent manner. It will also be able to resupply the AFAS with ammunition, propellant, and fuel on any terrain encountered on the battlefield.

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Existing Methodology

Current technology requires that once the 155mm self-propelled howitzer exhausts its supply of ammunition, a resupply vehicle is dispatched to a rendezvous location to refresh the howitzer's supply of ammunition and propellant charges. This resupply vehicle, called the Field Artillery Ammunition Supply Vehicle (FAAS-V), contains racks of ammunition with a manually deployable conveyor to transfer the ammunition from the racks to the ground outside the FAAS-V. A soldier takes a projectile out of the storage rack and places it onto the conveyor, which in turn delivers the projectile to a soldier waiting outside. This soldier then carries the projectile to the howitzer to be put into storage by another soldier inside the howitzer, while other soldiers transfer propellant charges to the howitzer. This is a lengthy process, and the crews of both the howitzer and the resupply vehicle must leave their vehicles open during this transfer operation. This exposes the crews of both vehicles to the counterfire threats and the possible NBC environment.

Next Generation Methodology

The new technology will allow the crews of both the AFAS and the FARV to remain sealed inside their armored vehicles and transfer the ammunition through an articulated conveyor system. The FARV will also be able to supply fuel and propellant to the AFAS while the ammunition is being transferred, thereby ensuring the atmospheric integrity of both vehicles.

In a typical AFAS/FARV scenario, the units will be deployed together to a firing location. The AFAS will fire its missions, and depending on the threat, will then either move to a new location or wait upon further fire missions where it is located. When its ammunition supply is running low, the AFAS will request that the FARV dock to it and replenish its supply of ammunition, propellant, and fuel. At this point the FARV will move into docking range and deploy the ammunition transfer device, in this case, an articulated conveyor. Once the FARV is docked, the AFAS will request an inventory of the FARV's ammunition. It will then create a request for ammunition compatible with that inventory and the threat it is firing against. The ammunition will then be transferred through the articulated conveyor and into the AFAS, where it will be stored by an automated loader. At the same time, both fuel and propellant will be transferred to complete the AFAS request.

DESIGN REQUIREMENTS

To accommodate ammunition transfer, the vehicles must be able to dock in various battlefield conditions and terrain. From requirements documents and direction given Oak Ridge

National Laboratory (ORNL) from the project sponsor, the terrain to be considered results in vehicle mismatch of $\pm 10^\circ$ 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.

Once the FARV and AFAS are within 25 ft of each other and the respective docking ports are facing each other, the FARV must also be able to dock and resupply the AFAS with 60 complete projectiles, in any operational condition, in less than 12 min. This time limit must be kept to a minimum in order to return the AFAS to the firing line as quickly as possible. Other requirements include the FARV being a slave to the AFAS once the two vehicles are docked together and the ability to effect a quick disconnect (less than 10 s) with no damage to components, no loss of projectiles, and minimal spillage of fuel and liquid propellant.

The family of 155mm projectiles which the AFAS will be firing is quite extensive; therefore the ORNL system was limited to considering only four representative projectiles: the M864, the M483, the M549, and the M107. Figure 1 shows three of the four projectiles as well as an additional practice projectile which ORNL's system was designed to work with.

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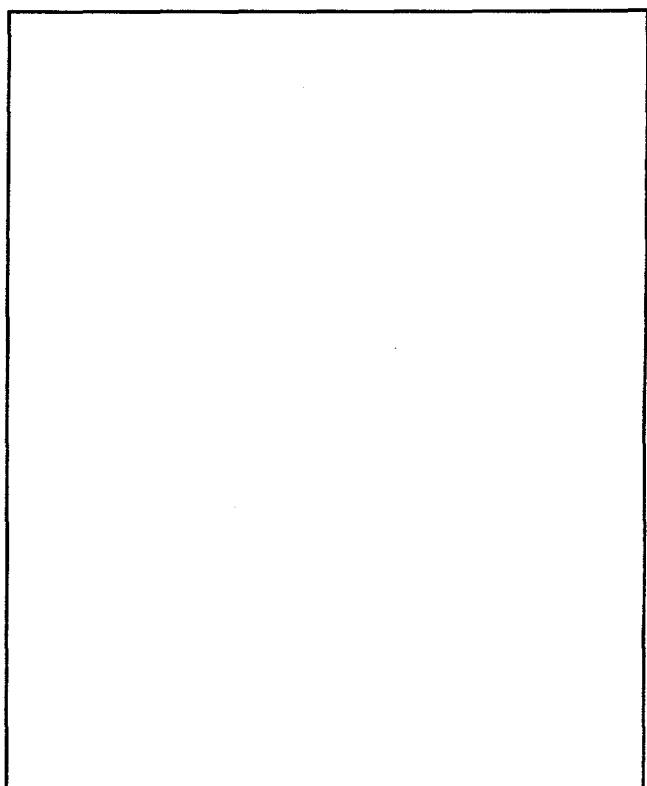


Fig. 1. Representative 155mm projectiles.

DESIGN APPROACH

The Robotics and Process Systems Division (RPSD) at ORNL had addressed ammunition resupply of tank systems with the Future Armor Rerarm System (FARS),¹ shown in Fig. 2, and therefore had this background to draw on in the design of the ammunition transfer system for the FARV. The FARS conveyance system utilized a 4- D.F. hydraulically actuated arm which housed a flat conveyor system and a passive set of side guides to keep the projectile centered during transfer. This resulted in a large and bulky transfer arm, as seen in Fig. 3, which had a cross-sectional area approximately 48 by 48 in.

The approach taken to meet the requirements of an ammunition transfer device was to develop an articulated conveyor system. This approach was taken in response to the project sponsor's desire that ORNL look at the FARV as having to accommodate all degrees of freedom required for docking. This approach resulted in ORNL addressing the highest technical risk system required for ammunition resupply. The result is a three-section, 6-D.F. articulated conveyor, as seen in Fig. 4.

The articulated conveyor, or ammunition transfer arm, retracts into the vehicle for storage and extends to dock with the AFAS for ammunition resupply or upload to the FARV. The first arm section remains inside the vehicle and is attached to the track which the arm rides on to extend and retract. The second and third arm sections make up the 6-D.F. jointed arm.

The joint (shoulder) between the first and second sections has $\pm 20^\circ$ pitch and yaw motions (D.F. 1 and 2). The joint (elbow) between the second and third sections has $\pm 18^\circ$ pitch and yaw motions (D.F. 3 and 4). The third section contains an 18-in. extension (D.F. 5) and also houses the docking port which incorporates a roll joint of $\pm 10^\circ$ (D.F. 6). The docking port requires the roll joint to accommodate the alignment and mating of the fuel and liquid propellant ports on the AFAS.

Mechanical Considerations

A cross-sectional arm smaller than that of FARS was desired for the FARV. To achieve a smaller cross section, a new conveyor configuration was required. Instead of a flat

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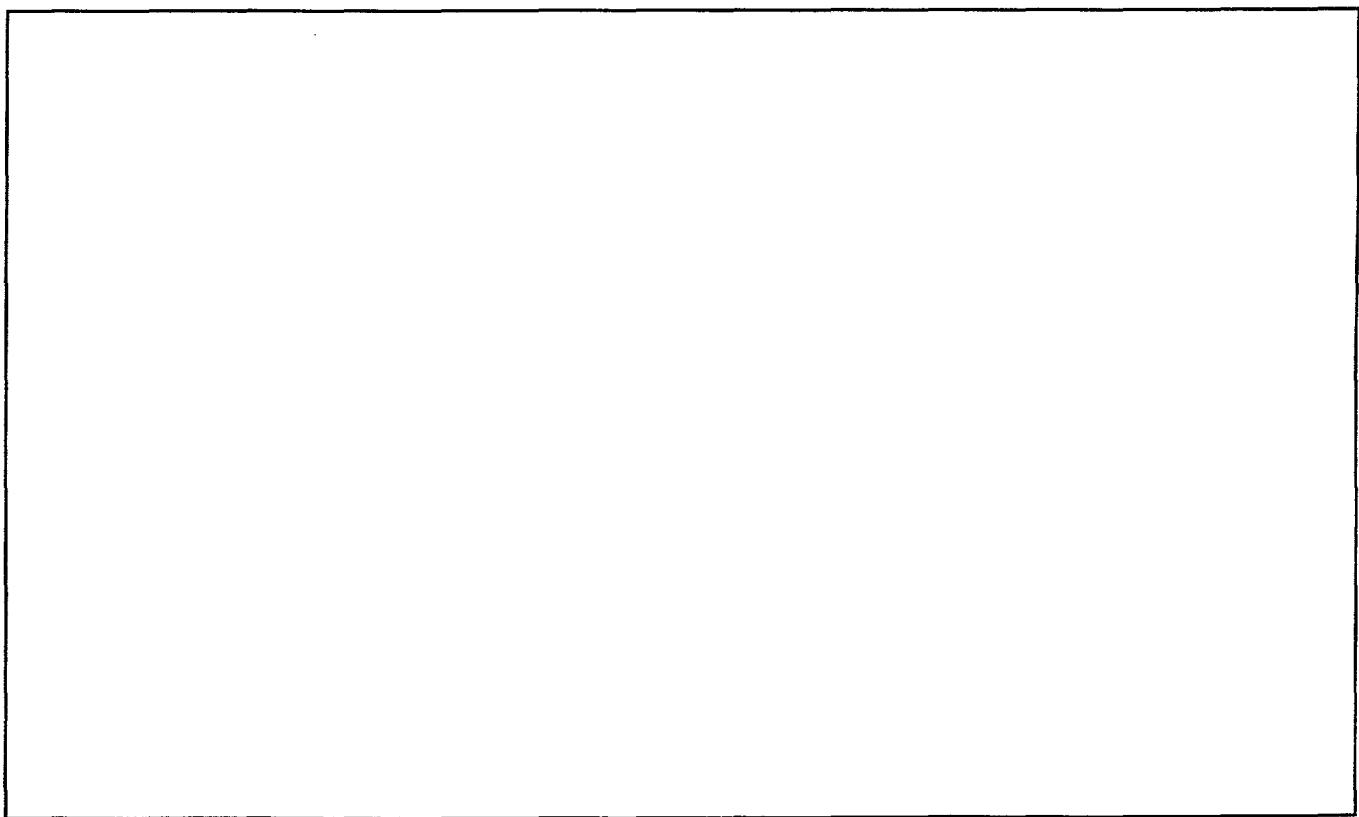


Fig. 2. FARS meeting with tank.

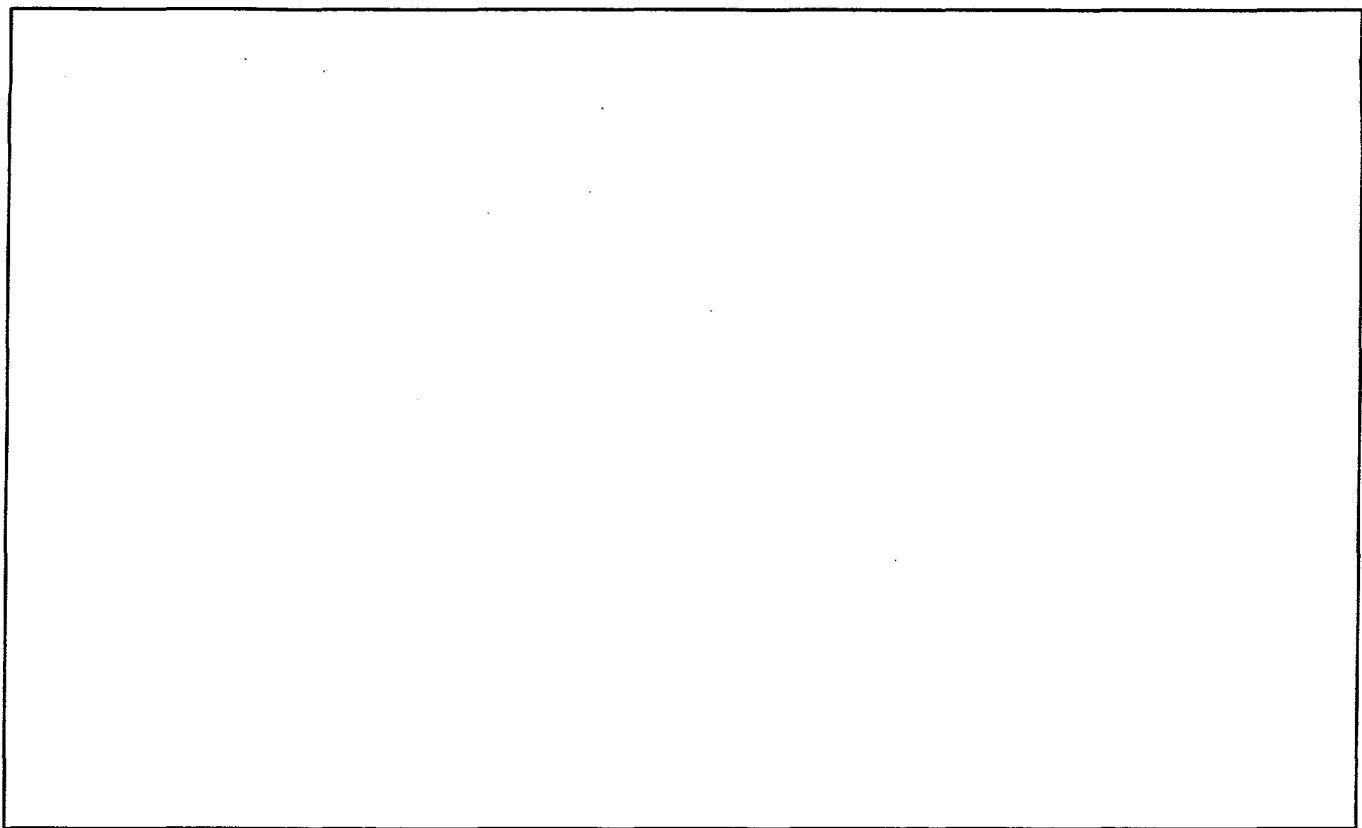


Fig. 3. Hydraulically actuated transfer arm.

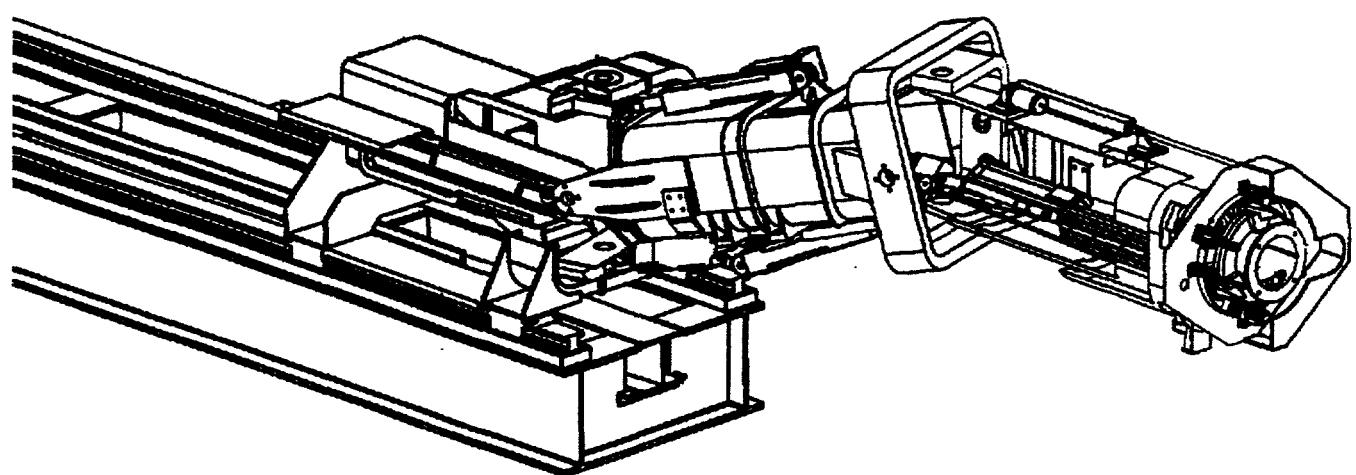


Fig. 4. Articulated conveyor.

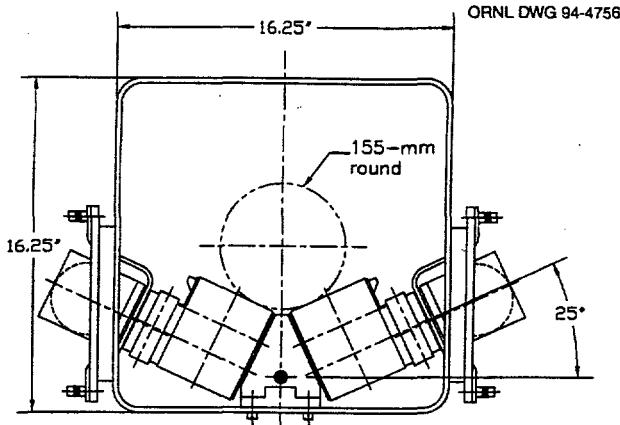


Fig. 5. End view of the V-configuration conveyor.

belt design, a V-configuration was designed which eliminated the need for side guides. The configuration, shown in Fig. 5, has a 25° trough to keep the projectile centered. The belts maintain a 15° trough when the FARV is on the worst-case side slope of 10°, thereby preventing the projectile from rolling out. Eliminating the side guides reduces the interior cross section of the arm; however, the interior cross section is limited in the amount it can be reduced. As seen in Fig. 6, the longest projectile requires 10.63 in. of clearance just to be able to sweep through a 10° pitch or yaw angle. Once the conveyance system is put into place, the resulting cross-sectional area for the conveyor housing is roughly 18 by 16 in. The size of the gimbal rings is governed by the size of the housing and the required angles which the arm must be capable of maneuvering through. For a housing of this size and the angles of $\pm 20^\circ$, the resulting outer gimbal ring size is ~31 in., as seen in Fig. 7. This cross-sectional area allows the projectile to pass through the joints at the worst case angle (20°) and speed (40 ips) without impacting the housing. It is important that the projectile not impact the housing to prevent damage to the fuze, which, if damaged, would affect flight ballistics and could possibly cause the projectile to detonate prematurely or fail to detonate at all.

One of the main concerns for a device of this size is weight. Section 1 is 51 in. long and weighs approximately 1000 lb, section 2 is 67 in. long and weighs approximately 650 lb, and section 3 varies in length from 72 to 90 in. and weighs approximately 400 lb. Section 1 remains inside the vehicle during docking; however, sections 2 and 3 are cantilevered, and therefore the pitch actuator at the shoulder must be able to support the moment arm created by the combined mass of sections 2 and 3. For this technology demonstrator, the sections 2 and 3 were fabricated out of 2219 aluminum to take advantage of its high strength-to-weight ratio. Gas springs were used on section 2 to counteract the load seen by the pitch actuators due to the weight of sections

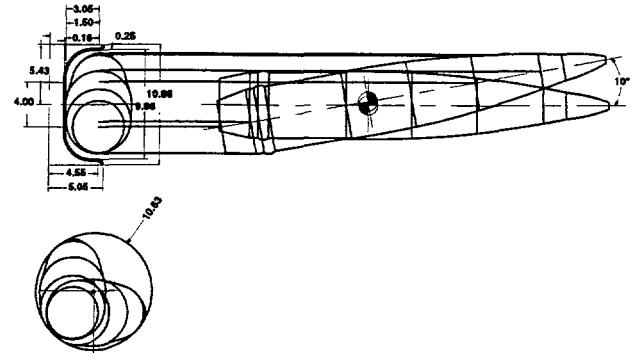


Fig. 6. Swept area of M864 projectile.

2 and 3. These springs were designed such that no load would be seen by the pitch actuators when the arm joint angles were at 0°. These steps ensured that commercial actuators could be used for each of the joints.

Controls Considerations

To achieve a more precise level of control than that of the FARS arm, linear thrust actuators driven by an electric servo motor were chosen for joint control instead of hydraulics. The linear motion of the actuators is converted into joint angle motion by a lever arm formed by the two pitch/yaw joint gimbal assemblies. The extension joint has linear motion, and its actuator moves the extension directly. The docking port roll is similar to the pitch/yaw actuator.

Ball screw actuators were chosen for the two yaws and the extension degrees of freedom, while acme screw actuators were chosen for the two pitch actuators. The ball screws reduce the arm stresses by allowing the joints to backdrive during the clamping together of the docking and resupply ports by the docking clamp latches, while the acme screws prevent undesirable backdrive in the pitch planes. An absolute position sensor was mounted to each actuator to ensure that joint position is always known. These sensors provide the feedback necessary for both manual and computer-aided docking.

To accomplish manual docking, a control scheme was used which will "fly" the head (docking port) to the location desired, normally the AFAS resupply port. The operator moves the head in three directions (up/down, right/left, and forward/back) relative to the current docking port axes. These commands must be corrected to be referenced to the base coordinate frame, which is located at the center of the shoulder pitch/yaw joint. Axis +X points straight out of the vehicle's front and is parallel to the vehicle's tracks. Axis +Y points straight out of the vehicle's left side. Axis +Z points straight out of the vehicle's top. The operator controls the arm by

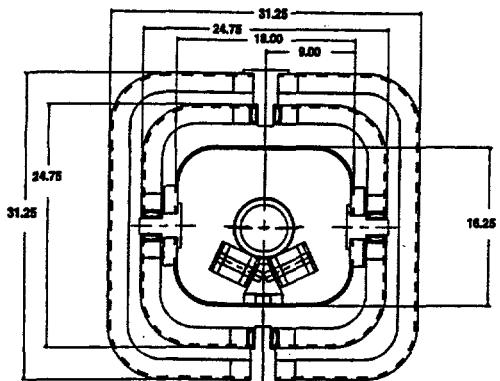


Fig. 7. Cross-sectional area with conveyor installed.

controlling the velocities in each of the three directions. Using the arm's Jacobian, the individual joint velocities can be found and used to control the arm joints.

The kinematics equations and arm end point and orientation angles are all based on the base coordinate frame. Forward kinematics produce the arm end point and orientation

angles when given the joint angles and extensions. Inverse kinematics produce the required joint angles and extensions for a desired arm end point and orientation. The kinematics equations used for the arm are based on a yaw-pitch, pitch-yaw configuration and are a special version because they do not deal with the docking port roll, as full 6-D.F. kinematics equations would. The docking port roll is considered independent and is handled separately, making the kinematics equations simpler.

The docking port orientation when docking with the AFAS is determined and corrected by the docking port sensors and the computer. Thus the operator is concerned only with moving the docking port to the resupply port or any other location desired; the orientation will be correct. The operator can turn off/on the orientation correction as required for operations. The operator moves the arm into position with the aid of a camera located in the center of the docking port. Once the docking port is within the range of the sensors located on its periphery, the computer takes over to control the final docking maneuver. Once the arm is docked and the clamps are latched, the camera is deployed to a storage position to allow passage of the ammunition.

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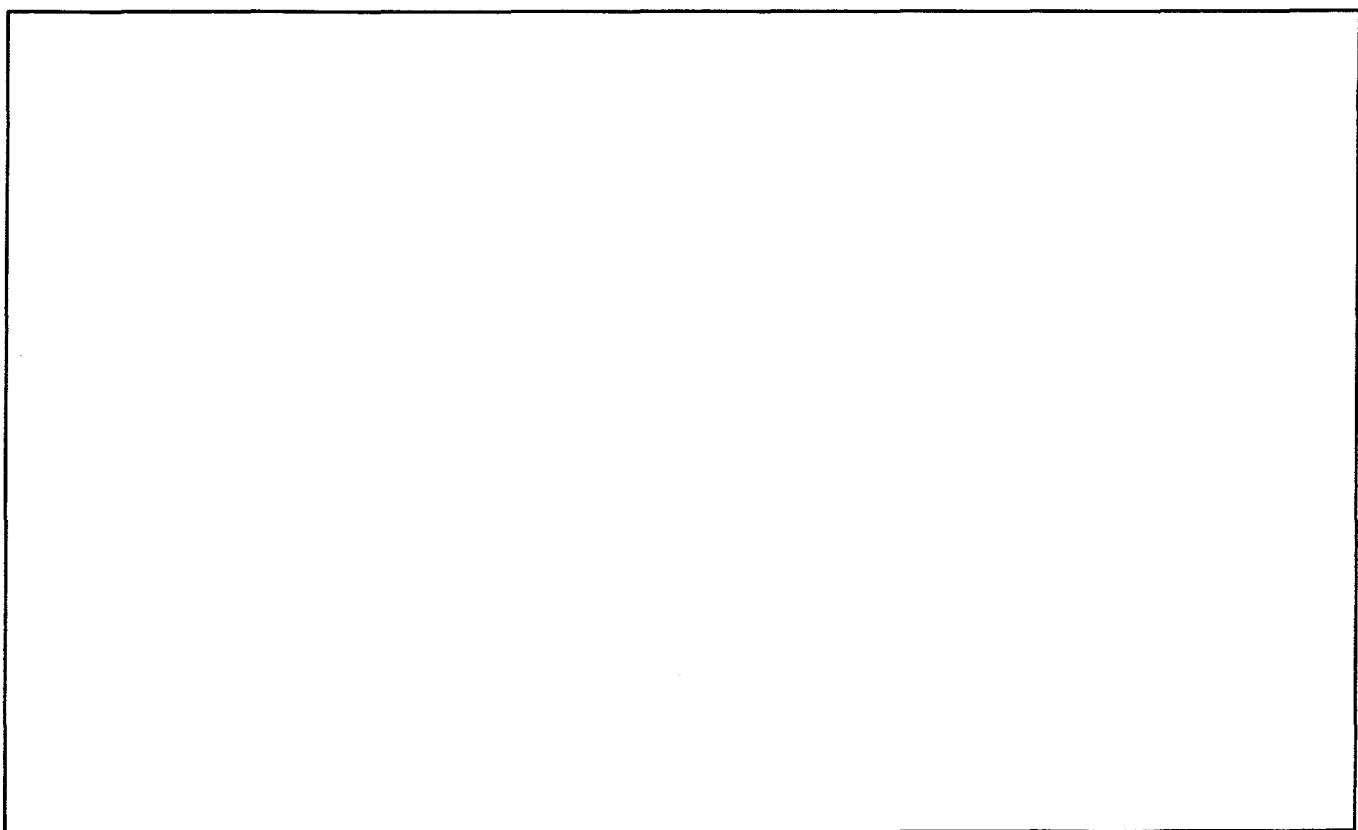


Fig. 8. Conveyor test stand.

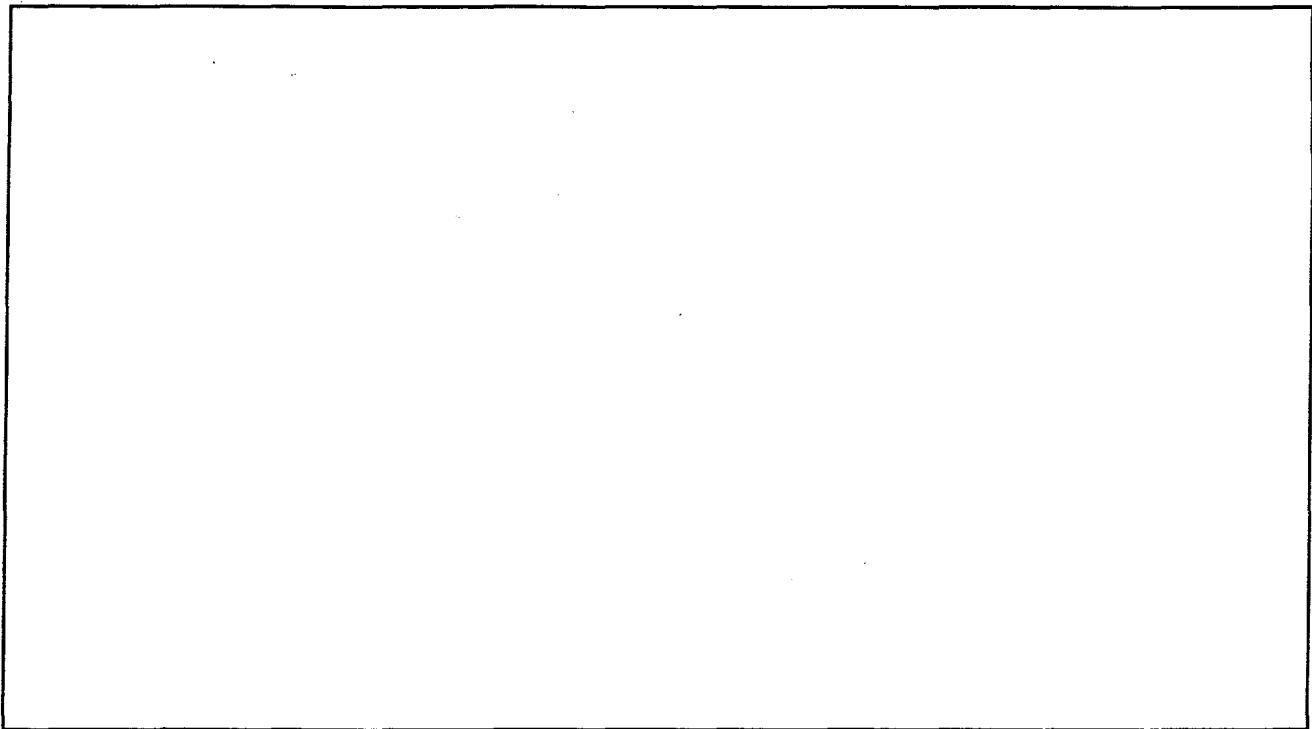


Fig. 9. M107 projectile tipping in the joint.

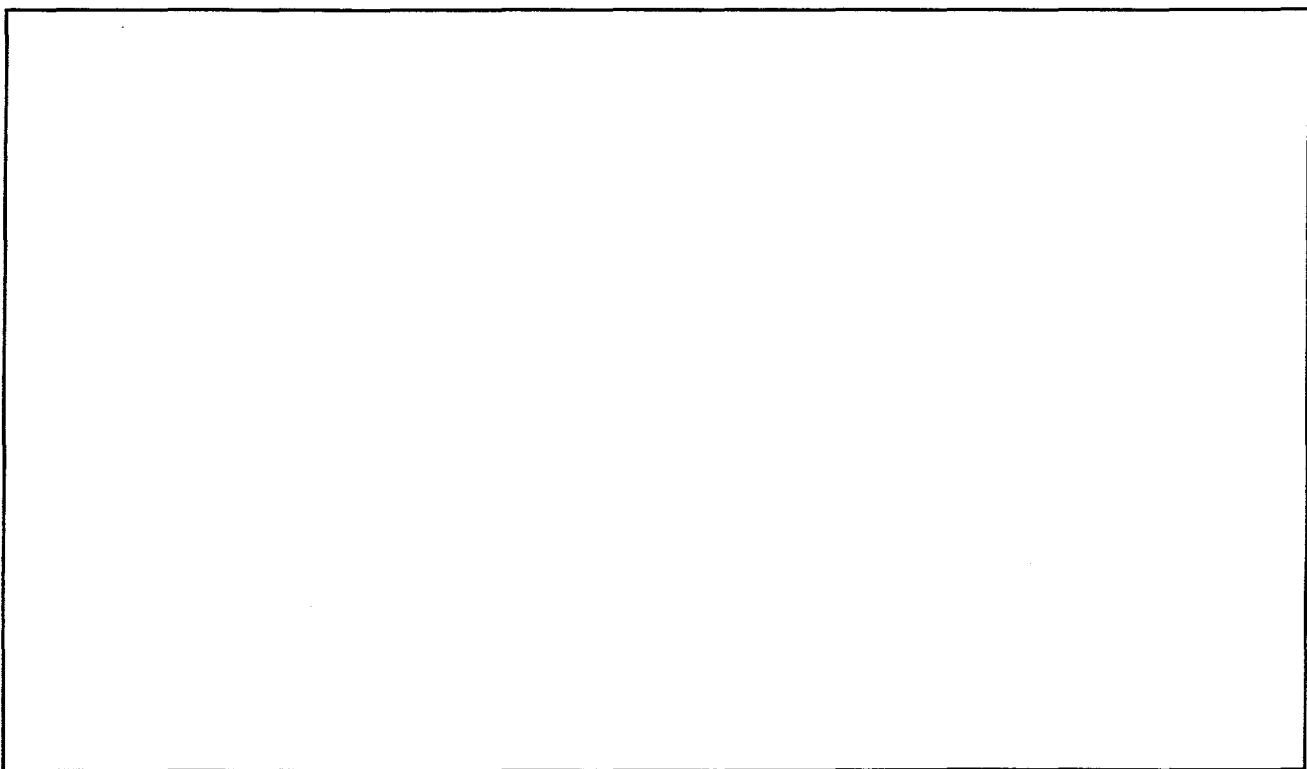


Fig. 10. M107 projectile with intermediate support roller.

In other efforts to decrease the docking time and thereby allow more time for ammunition resupply, a separate scheme for computer-aided docking is being developed. This scheme determines the position and orientation of an uncooperative object, in this case the AFAS docking port, in a world-coordinated frame based solely on visual cues. This vision system will provide destination coordinates for the ammunition transfer arm and allow the computer to control the docking of the arm. This work is presented in a separate paper.²

Concept Validation

To validate the conveyor design, a conveyor test stand was designed and fabricated. Testing of this equipment, shown in Fig. 8, verified the V-configuration as a workable concept. The projectile did not roll out of the trough at any of the angles, $\pm 20^\circ$ pitch and yaw, or speeds, 0–40 ips. The housing size was also shown to require at least 16 in. of clearance in both the horizontal and vertical planes to prevent the fuze from impacting the sides at the extreme angles of $\pm 20^\circ$ in pitch and yaw. The conveyor test stand successfully transferred each of the four projectiles, but the M107, the shortest of the projectiles, required an intermediate roller in the joints to provide support as it was transferred through the positive pitch angles. This was required due to the spacing between the rollers of each conveyor section, while they were

configured in a positive pitch angle, being greater than the distance from the base of the projectile to its center of gravity. In the negative pitch angles the conveyor sections are closer together and the support roller is not required. The M107 projectile is shown tipping in the joint in Fig. 9, and with an intermediate support roller installed in Fig. 10.

Current Status

The 6-D.F. ammunition transfer arm is currently being fabricated at ORNL. It is due to be completed in March 1995, and integration of the hardware and controls will continue through the summer. A technology demonstration is scheduled for August 1995, which will show the docking and transfer of ammunition to a simulated AFAS.

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