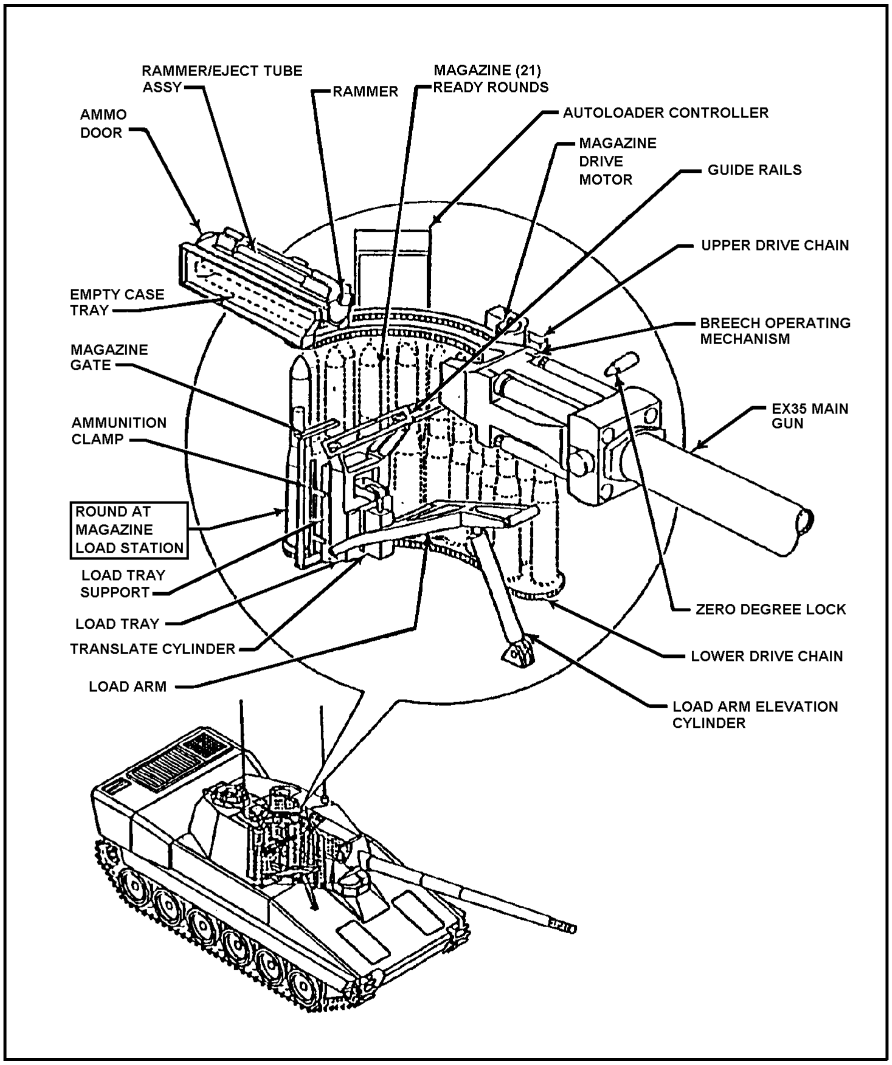
The Armored Gun System (AGS) Autoloader

by Lieutenant Colonel George E. Mauser

A recent article ("Ammunition Loading Systems for Future Tanks" by Sharoni and Bacon, *ARMOR* March-April 1995) clearly outlined many of the issues associated with automated loading systems and reduced crews in combat tanks, as well as providing an informative survey of recent U.S. autoloading concepts and engineering demonstrators. The following additional information discusses the related subject of the Armored Gun System (AGS) autoloader (A/L) which will be the first production autoloader for a large caliber direct fire weapon system to be fielded by the U.S. Army.

Let us remember that the interest in autoloaders is a natural progression flowing from the steady trend toward crew reduction throughout the history of armored fighting vehicles. During WWI, the British Mark I Male tank had a crew of eight, while the German A7V carried 18 men. WWII and the Korean War-era tanks had five-man crews. Remember the bow gunner? Those now on active duty or with recent tanker experience know the close knit teamwork of the four that crew M48s, M60s, Sheridans, and Abrams. Now, we are at the point of serious investigation and adoption of automated ammunition handling and loading capabilities in future large caliber weapons systems with crews of three and possibly two members.



As a strategically deployable system for use by early entry and contingency forces, the AGS has specialized air transportability requirements for delivery by airlanding and Low Velocity Air Drop (LVAD) (parachute delivery). Note that air transportability considerations tend to drive designs to be "small" and "light," which is in direct competition with the tendency to build armored vehicles "big" and "heavy." So, while being small and light, the AGS must be reliable and robust enough to operate in the severe ground combat environment, as well as support the weight and firing shock of a high-pressure 105mm cannon. An autoloading system was selected for use in the AGS, based on the need to build AGS within the weight and size envelopes dictated by the capabilities of available USAF tactical transport aircraft.

Design specifications for the AGS autoloader essentially describe a mechanical assistant to the gunner and commander that provides capabilities far exceeding the physical performance of a human loader. An autoloader offers the sustained rate of fire and system flexibility permitting a reduced crew of three to successfully adapt to and fight in rapidly changing battlefield conditions at least as well as a four-man crew. A collateral result is that smaller crews minimize the number of personnel placed in harm's way, reducing potential casualties.

Replacing the fourth crew member with an autoloader provided opportunities to optimize the system for rapid, flexible rates of fire. AGS will be one of the deadliest armored vehicles for its size, because it can load, fire, and reload more quickly, over harsher terrain at higher speeds for a longer period than vehicles that depend on human loaders. This gives the AGS commander the tactical agility to acquire, engage, and defeat multiple targets very quickly while stationary or on the move.

Significantly, the space needed for the autoloader is much less than that of a fourth crewman, thus the interior protected volume is less. Consequently, less structure and ballistic protection is required to protect the autoloader mechanism than would be required to protect a crewman. Another advantage is the ability to allocate conserved space and weight to increased armor and on-board ammunition or other stores. The AGS autoloader provides a weight savings to the total design of about 1500 lbs. In terms of volume, the autoloader, with 21 ready rounds is equal to a crewman, all of his equipment, and only nine ready rounds.

The autoloader — the "robotic crew member" — is capable of maintaining the desired 12-rounds-per-minute rate of fire and allows the commander and/or gunner to rapidly select the appropriate round for the identified target from the mix of standard 105mm munitions loaded in the magazine. The AGS has demonstrated sustained rates of fire of 12 rounds per minute. (Practical limitations on rates of fire will still be dictated by crew target acquisition and engagement skills, target obscuration and the need to follow basic principles — mutual support, overwatch, disciplined fire distribution, ammunition conservation, and use of good terrain movement techniques, including use of cover and concealment, as well as alternate and supplemental positions.)

The autoloader control system in the AGS provides the crew full flexibility to select a round from the magazine, load it, unload it, re-stow it as a ready round, and select another in less time than it takes to describe. Ammunition selection, loading, firing, and ejection commands can be ordered at both the commander's and gunner's weapons control panels, with the commander having the option of final override on all actions from his control panel. Upon firing, the autoloader ejects the spent casing from the vehicle and can load the next round automatically or on command. Should a misfire occur, the autoloader extracts and ejects the misfired round to prepare the gun for another round, or extracts and presents the round for re-stowage, if desired. Under normal engagement conditions, the crew does not handle ammunition or empty cases.

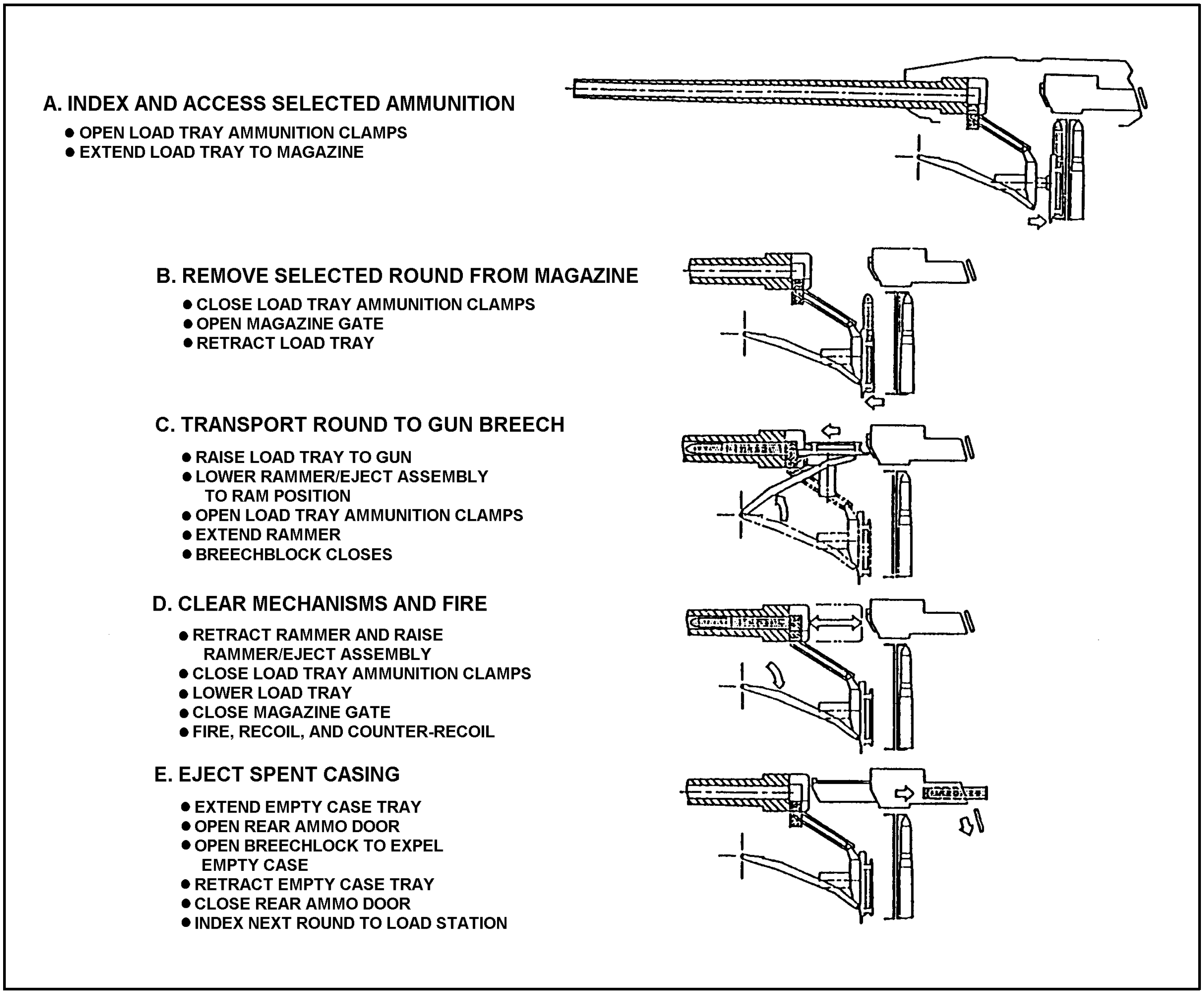
Should the autoloader fail, a crew member can easily get into the autoloader compartment and manually load from inside the turret. Manual loading under armor provides the crew redundant capabilities and reinforces their confidence that they will always have a means of self protection. A positive lock-out at the access door shuts off hydraulic power so that the autoloader and main gun drive mechanism won't operate while the crew member is in the compartment. The door is part of a bulkhead that segregates the autoloader, magazine, and gun from the crew compartment as an added measure of protection for the crew if there is a threat penetration and a subsequent ammunition detonation or fire. This compartmentalization is a proven technology feature modeled upon that used in the Abrams tank.

The AGS carries thirty 105mm rounds — 21 ready rounds in the autoloader magazine and nine more in hull stowage below the turret ring. Each ready round is inventoried and its type and magazine location registered in the autoloader controller and displayed on the computer control panel during autoloader replenishment. If necessary, the inventory function can be reviewed during operations to confirm the type and location of each ready round or to account for rounds manually replenished. During a replenishment function, the autoloader control system indexes the magazine by evenly distributing the rounds of each type to ensure a maximum firing rate. A byproduct of this indexing is maintenance of an optimum spacing of like rounds to improve survivability and evenly distribute the weight of rounds. Replenishment of the autoloader magazine with a full complement of 21 rounds, including inventory entry and verification, has been regularly accomplished in less than two minutes.

Autoloader status is reported to the gunner's computer control panel at power-up and during operations by a Built-In Test (BIT) capability through the autoloader computer controller. Autoloader status is constantly reported in a message cue at the computer control panel. Fault messages notify the crew to initiate isolation via on-board diagnostics to determine whether a system fault can be corrected in the turret or if it will affect the mission.

The primary software development challenge for the management and control of the autoloader was its proper integration with the total vehicle system under all combat and training conditions, in conjunction with providing on-board diagnostic capabilities.

Design of the autoloader to withstand LVAD without excessive weight presented some very unique challenges. To be immediately combat-ready once on the ground, the autoloader structure had to be capable of surviving LVAD landing forces with up to 10 rounds of 105mm ammunition loaded in the magazine. The loading system components had to be robust enough to handle the stresses of parachute landing and yet function reliably. To accomplish this, all autoloader components are designed for, and have demonstrated survival of, a 15G vertical shock — the damped loading imparted to the autoloader upon parachute landing. The design underwent extensive stress analysis to ensure maximum performance at minimum weight. This resulted in numerous structural design changes for strength and weight reduction and judicious selection of materials best suited to the task such as stainless steel, titanium, and composites. An autoloader unit alone and also one mounted in an AGS have undergone static drops to replicate airdrop shock. On both occasions, the autoloader units functioned correctly immediately after the drops. Automated functions used after LVAD include control and meas-



urement of the autoloader hardware interfaces, system monitoring through BIT, automatic recalibration of the mechanism without intervention by the crew, and the ability to step-function the system to aid system diagnostics. A demonstration of LVAD with an actual AGS was conducted in June of last year as part of the Early User Test and Evaluation.

The autoloader also had to be designed to interface with the government-provided XM35 gun. This 105mm gun, designed by the U.S. Army's Benet Laboratories for use in lightweight vehicle applications, but not specifically for use in the AGS, has to be effectively serviced by the autoloader without overstressing it. A prime concern was the gun/autoloader interface, in which the autoloader pushes against the gun breech operating mechanism to open the breech and expel the spent case or unload a full round. Autoloader actions had to be tempered to protect the breech mechanism from excessive forces while still providing consistent operation over many thousands of operating cycles. This was accomplished by analyzing and tailoring the hydraulic forces and accelerations applied to the breech and modifying the gun with a positive breech stop.

Additionally, the gun and autoloader combination had to accommodate a wide range of available 105mm ammunition types with significant variations in trunnion forces produced, weights, overall lengths, structural robustness and centers of gravity. The gun and autoloader combination had to consider many variations in ammunition components, such as fuzes, primers, warheads, propellants, and metal cases. For safety, positive control of the munitions must be maintained by the autoloader during all phases of ammunition handling. As the 105mm ammunition family has been designed over almost a 40 year span, there is a wide variation in case materials and projectile designs. Case crimp design, and, most critically, wide variations in the case crimp yield strength, became a significant factor during development of the autoloader. Traditional ammunition design guidelines had never envisioned the forces that high rate automatic loading would generate when compared to forces produced by manual loading.

The autoloader incorporates a wide variety of common and innovative technologies. The turret electrical control box provides the autoloader with 28 volts DC power to the autoloader controller (ALC). The ALC is programmed to safely control the loader's ammunition handling and inventory functions. The ALC receives and transmits all communications from and to the fire control computer (FCC) and

	Use	Model	Type
Group A	Training	M490A1 M724A1	TP-T TPDS-T
Group B	Primary War Fighting	M900 M833 M456A2	APFSDS APFSDS HEAT-T
Group C	Special Purpose	M393A1 M393A2 M416 M456A2	HEP-T (Training) HEP-T (Service) WP-T APERS-T

105mm munitions undergoing qualification for use in AGS.

the computer control panel (CCP). The autoloader software currently has 12,785 lines of code and has 97.7 percent Ada language content.

The AGS autoloader is powered by a hydraulic system that incorporates features such as linear actuators, a servo-controlled actuator, and solenoid-controlled valve blocks found in state-of-the-art hydraulic systems.

All ammunition transfers (magazine-to-breech or breech-to-magazine) are accomplished via linear actuators. Each linear actuator is designed to control both the acceleration and the deceleration of the mechanism in motion. Additionally, the start and end position of each mechanism is exactly the same for each actuation/de-actuation cycle. The actuators are sized for the heaviest load, which compensates for variations due to round size, round weight, shock, vibration, and changes in environmental conditions. This approach ensures round-to-round repeatability and high reliability.

The autoloader magazine drive design incorporates a servo-controlled actuator. The servo-controlled design incorporates a servo valve, electrical feedback circuits, and software to control the acceleration, deceleration, velocity, and position of the magazine. This approach was selected to achieve high performance in positioning the desired round to the load station from any position in the magazine. The current design permits magazine rotation in either direction and for any distance or duration.

The solenoid control valve blocks incorporate individual solenoid valves and "shuttle valves" to transition low-level electrical control signals to high power hydraulic output drive signals. Each linear actuator and servo actuator are controlled through these valve blocks. Safety is provided and maintained by a fail-safe design approach on the main control valve block, which incorporates a solenoid that returns to an "Off" or "No Hydraulic Pressure Applied" condition upon loss of either hydraulic pressure or electrical power.

The design approach selected for the sensors was to use Hall Effect proximity switches and magnet combinations for sensing critical positions of the autoloader mechanisms. The magnet's field is sensed by a proximity switch when the two items are aligned within a specified gap/distance. This approach was selected because of the high reliability of proximity switches and improved service life gained by eliminating physical contact to actuate the switch. This feature makes the switch largely insensitive to external contamination from dust, dirt, and moisture. It is much more reliable than a standard contact switch or optical sensor. Additionally, since there are no moving parts internal to the proximity switch, reliability is enhanced. Proximity switches are also fail-safe since they do not fail in an "On" position. A disconnected switch is sensed electrically as a switch out of proximity, signals the electronic controller that an unusual condition exists, and halts operations for safety.

The autoloader hydraulic actuators and servo magazine motors are safety sequenced through logic and timers internal to the autoloader controller. Ammunition can be transferred from the magazine to the breech and from the breech to the magazine. This is possible because none of the mechanisms are mechanically linked to the next sequence, but are software-sequence linked to a specific operation. Sequence diagrams were developed for each desired operation (load, unload, eject) and the logic was programmed in software to achieve that result.

This feature of sequencing or synchronizing mechanisms to operations provides for an extremely fast loading rate as it allows for simultaneous operations. For instance, load tray and empty case tray motions can occur at the same time. This feature also provides for optimization of parts and multi-function of assemblies. The multi-function approach lowers weight and heightens reliability as it results in fewer parts, and the complexity of the system is reduced. A prime example of a multi-functional assembly is the Rammer/Empty Case Tray. This assembly actually performs three functions:

- Ramming the round to the breech during load operations
- Extending the empty case tray for ejecting cases or misfired rounds
- Buffering the round during an unload operation

The autoloader electronic controller sequences the autoloader mechanisms as described above, interfaces to the CCP and FCC, maintains inventory, and performs BITs on the autoloader.

While the controller manipulates the system, it also runs ALC background BIT, operational BIT, and operator requested BIT. The background BIT is active whenever electrical power is applied to the ALC and no autoloader motion is requested. Examples of this BIT are internal circuit board tests, cable connection tests, and power supply checks. Any faults found are sent over the 1553 data bus and displayed on the computer control panel.

The operational BIT is active whenever an autoloader operation is requested. Examples of this BIT are "autoloader stowed" as a condition to start, ammunition inventory checks as a condition to perform the desired operation, and proximity switch and solenoid safety interlock checks as a condition to complete the requested operation.

The operator-requested BIT is active or available for fault isolation and corrective action. Autoloader information available to the operator includes motion timing, fault history, cycle history, switch status, and solenoid status. The ALC also contains electrical and hydromechanical BIT tests that can be requested by the operator to help identify a problem, or determine the current status of the system. Options that can be operator-requested include:

- Electrical test — a test to see if the system's electronics are receiving messages and power.

- System test — a test to see if the system mechanical interfaces are operating in sequence and unison.
- Ammo hatch door test — a test to see if the door functions as programmed.

BIT is an integral part of the autoloading safety and self-protection system. If the software determines the condition detected by BIT to be dangerous to either ammunition, equipment, or personnel, the solenoids will be held in their last condition and hydraulic pressure is automatically removed from the autoloader. The unsafe condition must be corrected and the autoloader brought to a stowable condition before continuing operation. Immediate action drills have been developed, similar in concept to those used on automatic weapons such as machine guns, to facilitate quick recovery to full fightable condition if stoppages do occur.

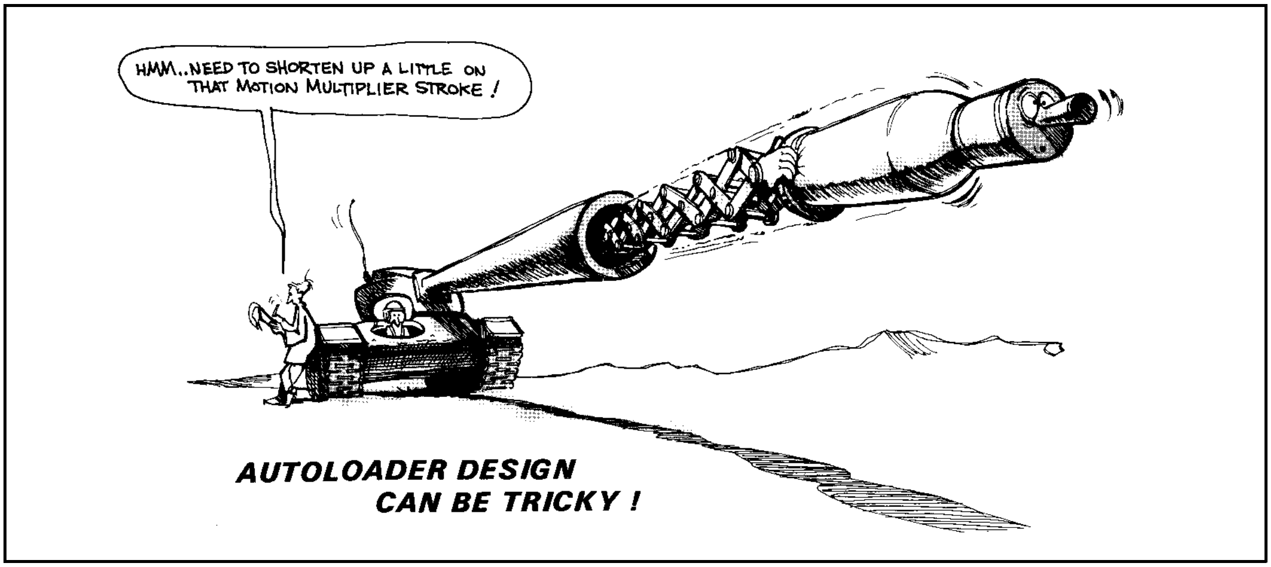
The functional design of the autoloader is complete and the contractor has delivered eight prototypes. The first two prototype autoloaders were delivered as qualification units. One was retained by the contractor for component/environmental qualification tests and the other was sent to Aberdeen Proving Ground to support ammunition qualification. The remaining six prototype autoloaders were delivered to United Defense Limited Partnership (UDLP) and are now installed in the six pre-production vehicles undergoing government technical and operational test.

The AGS autoloader environmental/component qualification test ended successfully in March 1994. Tests evaluated autoloader performance against parameters in the AGS program's Critical Item Development Specifications (CIDS) to establish the operational and survivability characteristics of the autoloader when subjected to external environmental conditions. The scope of tests performed consisted of operations under high temperatures, low temperatures, thermal shock, humidity, blowing dust, cleaning water spray, slope, random vibration, operational/non-operational shock, and air drop shock. Testing replicated the most severe field conditions, including heavy dust, mud, and moisture contamination, and was very successful. Any shortcomings discovered during the test resulted in component changes for subsequent application to the autoloader assembly and re-testing.

The second qualification autoloader is currently at Aberdeen Proving Ground (APG), Maryland, and is being used to support ammunition qualification testing. The ammunition qualification test is designed to determine the compatibility between the AGS and currently fielded 105mm ammunition types. Qualification testing consists of six subtests:

- Autoloader function
- Autoloader cycle
- Autoloader vibration
- Sequential life-cycle
- Sequential rough handling
- Ammunition airdrop

Each subtest is being conducted on each ammunition type to be fired by the AGS. In addition, each qualification autoloader is used to evaluate any design changes and their impact on ammunition handling. The autoloader undergoing government test at Aberdeen Proving Ground has completed over 16,000 cycles (vs. 10,000 cycle design life) with no major failures or overhaul. Like the Energizer Bunny, "it just keeps going and going." Indications are that the AGS autoloader system will exceed its original design life by a wide margin. Testing will continue through FY96.



The Lighter Side of Autoloaders

Larry Bacon, Director of Graphic Arts at Western Design, a California firm that develops autoloaders and ammunition-handling systems, amuses co-workers and customers with his cartoons when he isn't designing serious stuff like rammer assemblies and feed chutes. This one is from a humorous briefing entitled "Ammunition Handling Through the Ages."

The six pre-production vehicles (PV) are currently being used for technical testing, operational experimentation, and logistics demonstrations. Fully functional autoloaders are in each of these vehicles. One PV has completed the contractor 4,000 mile durability test, which includes autoloader cycling and live ammunition firing. Two PVs are at APG undergoing government performance and reliability testing. Another two PVs are being evaluated at Early User Test and Experimentation (EUT&E) now in progress at Ft. Pickett, Va. During these tests, the total requirements for the AGS are being evaluated. The remaining PV is currently at United Defense Limited Partnership (UDLP), the prime system contractor, and is being used for logistics demonstrations and engineering evaluations.

Informal observations shared by the ever-expanding population of those with exposure to the AGS autoloader are providing insight into its characteristics and suitability. Emerging information substantially supports the view that soldiers can be easily trained to operate the autoloader. It is simple and safe to operate; positively controls and safeguards ammunition; aids crew interactions; is robust, reliable, repeatable, and repairable; and meets its specified requirements. Definitive judgment about the autoloader and the AGS must await technical and operational test outcomes and official assessment by the appropriate independent evaluation agencies.

The AGS autoloader, designed and built by United Defense Limited Partnership, Armament Systems Division (UDLP-ASD) of Minneapolis, Minnesota, is supplied to United Defense Limited Partnership, Ground Systems Division (UDLP-GSD), San Jose, California, for AGS system integration.

Although not a main battle tank, the AGS will be the first U.S. production tank-like system with a reduced crew of three (commander, gunner, and driver) and an automatic loading system (the "robotic" crew member) in place of the traditional fourth crewman. AGS will provide the Army its first experiences in the transition from four-man crews. As such, the AGS will be the precursor of those future systems described by the recent article.

AGS is leading the practical adaptations to our operational and logistics support doctrine (as well as our Armor culture) and will influence future tactical operations with crews of less than the accustomed four members. This process has already started with the exposure of Armor soldiers and organizational mechanics from the 3rd Battalion, 73rd Armor, XVIII Corps. Hands-on experiences with production-like hardware have occurred during logistics demonstrations conducted over the last two years by soldier crews conducting technical testing at Aberdeen Proving Grounds, Md., and at tactical and gunnery testing now ongoing.

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Lieutenant Colonel George E. Mauser was commissioned in Armor in 1974 from Virginia Polytechnic Institute and has a masters degree from the University of Redlands, California. He has served in a variety of assignments in cavalry, armor, and mechanized infantry units in CONUS and Europe, as well as positions as a test director at Aberdeen Proving Grounds, Observer-Controller at the NTC, and on HQ AMC and DA ODCSOPS staffs. He was recently the Product Manager, AGS Main Armaments, and is currently attending the Army War College.