AD-A110 386

AD A-110386

AD-E400 749

CONTRACTOR REPORT ARLCD-CR-81053

DEMONSTRATION PROTOTYPE AUTOMATED AMMUNITION HANDLING AND LOADING SYSTEM FOR A 155-mm SELF-PROPELLED HOWITZER TEST BED

JOHN J. SCHEURICH
GARY J. NELSON
FMC CORPORATION
NORTHERN ORDNANCE DIVISION
4800 EAST RIVER ROAD
MINNEAPOLIS, MN 55421

STEPHEN G. FLOROFF
PROJECT ENGINEER
ARRADCOM

DECEMBER 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Contractor Report ARLCD-CR-81053	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): DEMONSTRATION PROTOTYPE AUTOMATED AMMUNITION HANDLING AND LOADING SYSTEM FOR A 155-mm SELF-PROPELLED HOWITZER TEST BED	5. TYPE OF REPORT & PERIOD COVERED: Final 10 Aug 79 - 10 Apr 80
	6. PERFORMING ORG. REPORT NUMBER: FMC/NOD TR/E-1856
7. AUTHOR(s): John J. Scheurich and Gary J. Nelson, FMC; Stephen G. Floroff, Project Engineer, ARRADCOM	8. CONTRACT OR GRANT NUMBER(s): DAAK10-79-C-0188
9. PERFORMING ORGANIZATION NAME AND ADDRESS: FMC Corporation, Northern Ordnance Division, 4800 East River Road, Minneapolis, MN 55421	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: ARRADCOM, TSD, STINFO Div (DRDAR-TSS), Dover, NJ 07801	12. REPORT DATE: December 1981
	13. NUMBER OF PAGES: 85
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): ARRADCOM, LCWSL, Weapons Div (DRDAR-LCW-E), Dover, NJ 07801	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This study is a continuation of previous work performed by FMC under the provisions of the Independent Research and Development/Bidding and Proposal Advanced Agreements for CY 1978 and 1979.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Automated loading
155-mm self-propelled howitzer
Howitzer test bed
Ammunition handling
Self-propelled howitzer

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
A design concept for a fully automatic loading and handling system for use as a demonstration prototype is presented. A sustained rate-of-fire of 10 rounds per minute, fast response, and simplified man-machine interface are achieved with the use of technology proven in automatic naval guns. A detailed description of the system concept and the discussion of the major influences driving the design of such systems is included, as well as control system, shock, and vibration considerations.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I INTRODUCTION AND SUMMARY

The application of automated handling and loading to the U.S. Army's present and next generation 155 mm self-propelled howitzers can provide significant improvements in overall artillery system performance. When properly integrated into an overall cannon system, automated ammunition handling and loading will—increase both the burst and sustained rate of fire, sharply reduce reaction time, reduce crew size, and simplify field operations.

FMC/Northern Ordnance Division has conducted the design study reported herein concerning the preliminary design for a demonstration prototype automatic ammunition handling and loading system for a 155 mm self-propelled howitzer test bed.

This FMC/NOD technical approach to autoloading can provide self propelled howitzers with the firepower and responsiveness needed to effectively wage the artillery battle, survive, and win. A single crewman can automatically select any of the available projectile types and propelling charge zones and fire them at a sustained rate-of-fire of 10 rounds per minute. A capability for real time response to a firing mission is now possible. Interactive automatic control concepts and modular componetry provide a simplified man-machine interface. Ease of operation and simplified maintenance procedures are the result. Reliable performance is achieved by the innovative application of proven technology to the development of this high performance system.

FMC/NOD's approach to the solution of the problems associated with the development of a practical automated ammunition handling and loading system for 155 mm self-propelled artillery—has been to apply the techniques, concepts and mechanisms which have been proven in the other numerous operational medium and large caliber automatic gun mounts and automatic guided missile launching systems, which have been designed and developed by FMC/NOD for Naval use. While the so generated design concepts are revolutionary to the field artillery community, they are evolutionary when viewed from the generalized perspective of large caliber automatic ordnance technology as pioneered by FMC/NOD.

The major activity of the study has been the generation of a preliminary design for a demonstration prototype for an SPH test bed application. Preliminary design layouts have been prepared for all the major system components and mechanisms. Each component drive mechanism design was supported by dynamic analysis to define parameters and ensure the achievability of the desired performance.

These efforts are summarized in this final report. First, the scope of the study is delineated in terms of goals and objectives, previous FMC/NOD studies and system requirements and constraints. This is followed by a discussion of the driving relationships between the overall design concept and those requirements and constraints. Then, a detailed description of both the overall mechanical and the control system concept for the demonstration prototype autoloading system is presented together with an operational description. Quantitive characteristice of the system—operating time cycle, weight and power requirements are estimated. Finally, views and recommendations on overall system issues which have an impact on autoloader system design are discussed. These issues include: resupply concepts, manual backups, requirements for other related weapon system components, and the design of equipment to withstand shock and vibration.

TABLE I

SUMMARY OF CHARACTERISTICS

- Rate of Fire
  Burst Rate—3 rounds in 10 seconds
  Maximum Sustained Rate—10 rounds per minute

- Responsive
  Full selectivity of projectiles and propelling charges
  Load and fire at all angles of elevation and azimuth

- Ammunition
  Handles all current and developmental ballistic projectiles

- Operation
  One crewman can fire the entire ready ammunition load without assistance

- Ready Ammunition Storage
  Capacity—18 ballistic projectiles and 18 propelling charges

- Weight
  Weight without ammunition tray (dry)—5105 pounds
  Weight with 18 rounds (dry)—7517 pounds

- Hydraulic Power Requirements
  Continuous fire (engine driven pump/accumulator)—15.4 hp

- Space Envelope
  The system is designed to fit within the general layout of an M109A1 SPH based test bed.

Figure 1. Summary of Characteristics

II DESIGN STUDY DEFINITION

Over a period of several years as part of its Independent Research and Development/Bidding and Proposal Program, FMC/NOD has investigated the problems associated with the application of automated ammunition handling and loading to Field Artillery Cannons. In particular, the automation of the U.S. Armys next generation 155mm self-propelled howitzer has been considered. This effort has involved: visits to Fort Sill, including attendance at HELBAT 7, as well as visits to Camp Roberts in California and Camp McCoy, Sparta, Wisconsin, to witness weapon handling, loading and firing operations of M109, M109A2 and M110 self-propelled howitzers—review of documentation covering the operation and limitations of the existing ammunition handling equipment—attendance at the QRI and other field artillery system related briefings—as well as conferences with representatives of the LCWSL/ARRADCOM Dover, New Jersey. Based on this initial effort, FMC/NOD concluded that the automation of ammunition handling and loading for 155mm self-propelled howitzers would be feasible by the application of the technology, concepts and mechanisms proven in the numerous medium and large caliber automatic naval gun mounts and guided missile launching systems developed by FMC/NOD over the past 30 plus years.

A preliminary conceptual design for a practical SPH autoloader system which could achieve or exceed the stated goals was generated by FMC/NOD and was initially submitted to the U.S. Army Armament Research and Development Command in a proposal in response to QRI ARRAD-004 on 17 April 1978 and subsequently resubmitted in a second proposal on 4 January 1979.

As a result of continuing IR&D effort by FMC/NOD and the more concentrated effort during this design study, the details have been changed and refined into the demonstration prototype automated ammunition handling and loading system for a 155mm self-propelled howitzer test bed (HTB) as herein described.

- SYSTEM REQUIREMENTS AND CONSTRAINTS

The important specific requirements as defined in the contract include:

- Capability to automatically load and fire the standard family of ballistic projectiles weighing approximately 100 pounds and a rigid cased propelling charge weighing approximately 30 pounds.

- The system shall be designed to fit within the general layout of the present M109A1 turret and hull.

- Ability to achieve a "burst" rate of fire of 3 rounds in 10 seconds at all quadrant elevations from 0° to 75°.

- Ability to achieve at a minimum, a sustained rate of fire of 2 rounds per minute.

- At a minimum—full automatic selection of pre-zoned propelling charges and pre-fuzed projectiles is required.

- The autoloader shall not impede 0° to 75° QE movement or 360° traverse of the cannon tube and/or turret.

- The autoloader shall be designed to interface with a recoil—counter recoil cycle of 500 milliseconds duration.

- The autoloader shall be capable of manual operation and parallel hydraulic electrical or mechanical backup systems shall be provided for critical operations.

- DESIGN STUDY OBJECTIVE

In general, it has been the intent of this study effort to establish realistic design approaches to the solution of the major problems associated with the application of the aforementioned automated ammunition handling technology to the special problem of 155mm self-propelled artillery.

As directed by the contract, the autoloader system must provide; on-board ready magazine storage for pre-fuzed projectiles and pre-zoned propelling charges, automatic selection of any combination of those two ammunition components, and subsequent automatic transfer to the cannon chamber/breech for firing.

Due to the time and funding constraints of the contract and the requirements for detailed design layouts, this study concentrated primarily upon the mechanization of the initial concept and the application of automated ammunition technology for a SPH test bed application. A full system study of control consoles, safety issues (misfire, etc.) resupply, and interface with an ARSV or similar vehicle was not undertaken.

It was, however, anticipated that the study would identify interface problem areas and provide definition of the configuration and performance characteristics required from other portions of the cannon system to properly support an SPH automatic ammunition loading system for the SPH test bed application.

The major activity of this study has thus been the generation of a preliminary design for a 155mm self-propelled howitzer automated ammunition handling and loading system demonstration prototype. Preliminary design layouts have been prepared for all the major components to identify and resolve significant problem areas. Hydraulic/mechanical schematics were prepared for each of the major component drive mechanisms. The design of each component drive mechanism is supported by dynamic analysis to define actuator parameters, the necessary hydraulic control approaches, and to ensure that the desired performance is in fact achievable. These efforts thus form a firm basis for the quantitative system performance and physical characteristics which are presented in section VI.

This design concept for a demonstration prototype 155-mm SPH automatic handling/loading system meets or exceeds the system requirements and constraints outlined in the foregoing.

As designed, the concept system:

- Provides a burst rate of fire of 3 rounds in 10 seconds and a sustained rate of fire of 10 rounds per minute.

- Provides the above rate of fire performance at all quadrant elevations from 0° to 75°. Note that the 60° elevation limit shown in Figure 2 (page 3-3) applies only to an installation of this system concept in an M109 SPH chassis as a demonstration prototype. This limitation is a limitation evoked by the floor to trunnion height of approximately 59.0 inches of the current M109. This is not a limitation of the design concept. Given an increase of 4.5 inches in the floor to trunnion centerline distance to 63.5 inches, the concept will fully meet the requirement to load and fire at all quadrant elevations from 0° to 75°.

- Provides the ability to automatically load and fire the standard family of ballistic projectiles. (The M107 family, the M483 family and the XM862 extended range/base bleed projectile family.) This design is based on a new full length combustible case propelling charge.

- Provides full selectivity of pre-fuzed projectiles and pre-zoned propelling charges.

- The demonstration prototype version of this concept has been designed to fit within the general layout of the present M109A1 turret and hull.

- Does not impede 0^{o} to 75^{o} QE movement of the cannon tube in elevation or 360^{o} traverse of the turret. Note, that even in the demonstration prototype version for an M109 SPH based test bed, the 60^{o} elevation limitation for automatic load does not prevent the gun tube from being elevated to and fired at any angle above 60^{o} and up to 75^{o} QE.

- Has been designed to interface with a recoil/counter-recoil cycle of 500 milliseconds duration.

III SYSTEM CONCEPT

At the outset it is important to understand how the system requirements identified in section II as well as other constraints, tend to drive the design for an ammunition handling system. Some of these major driving influences and their resulting impact include the following:

Combustible Cased Propelling Charge

The requirement for automated handling of the propelling charge indicated the need for a rigid combustible cased propelling charge. Although it might be possible to place bagged charges in metal containers while in the handling system, (and subsequently drive the charge out of the container and into the chamber during ram, thus allowing reuse of the container in the automatic loader) such concepts appear to be too complex mechanically to achieve satisfactory RAM-D as well as the fact that they tend to present some time consuming reload procedures.

The combustable cased charge greatly simplifies the basic handling problem. This will be true not only in the SPH but also wherever else this charge is being handled by mechanical equipment.

Ramming

Although not a contract requirement, the issue of fling vs positive ram is an important one. With the availability of a combustible case, positive ram using the case as a spacing element between the projectile and the rammer head is possible. This is the approach which has been used with brass cased two-piece naval ammunition for many years. It is also the approach used in the French

AMX/GCT system. Positive ram provides the best insurance that projectile seating is uniform, thus affording consistent muzzle velocity performance and minimizing fall-back problems. The system as presently configured is based on positive ram.

Round Selectivity

The requirement for full selectivity of any of the projectiles and propelling charges in the ready ammunition load indicated that the ammunition stowage would employ either rotating drums or an X-Y scanner type of storage. The rotating drum was selected because of its inherent simplicity and thus potentially higher RAM-D.

Projectile/Propelling Charge Size

The close similarity in physical size of the projectiles and the rigid cased propelling charge suggested that the ready ammunition drums might be essentially identical and in fact employ modular components.

Firing Rate

The requirement to achieve a burst rate of 3 rounds in 10 seconds indicated either a system which could continuously load the gun at all angles of elevation or one which could load 3 rounds onto the elevating carriage at a fixed QE and then carry the 3 rounds to the selected firing QE for subsequent automatic loading. The former approach of continuous feed at any QE was selected as the least complex mechanically. Again, the selection was made for reasons of simplicity and potentially higher RAM-D.

Having made this selection, the burst rate of fire and the continuous rate of fire became essentially identical, and the overall performance is thus substantially greater than that which would l e obtainable from the latter approach.

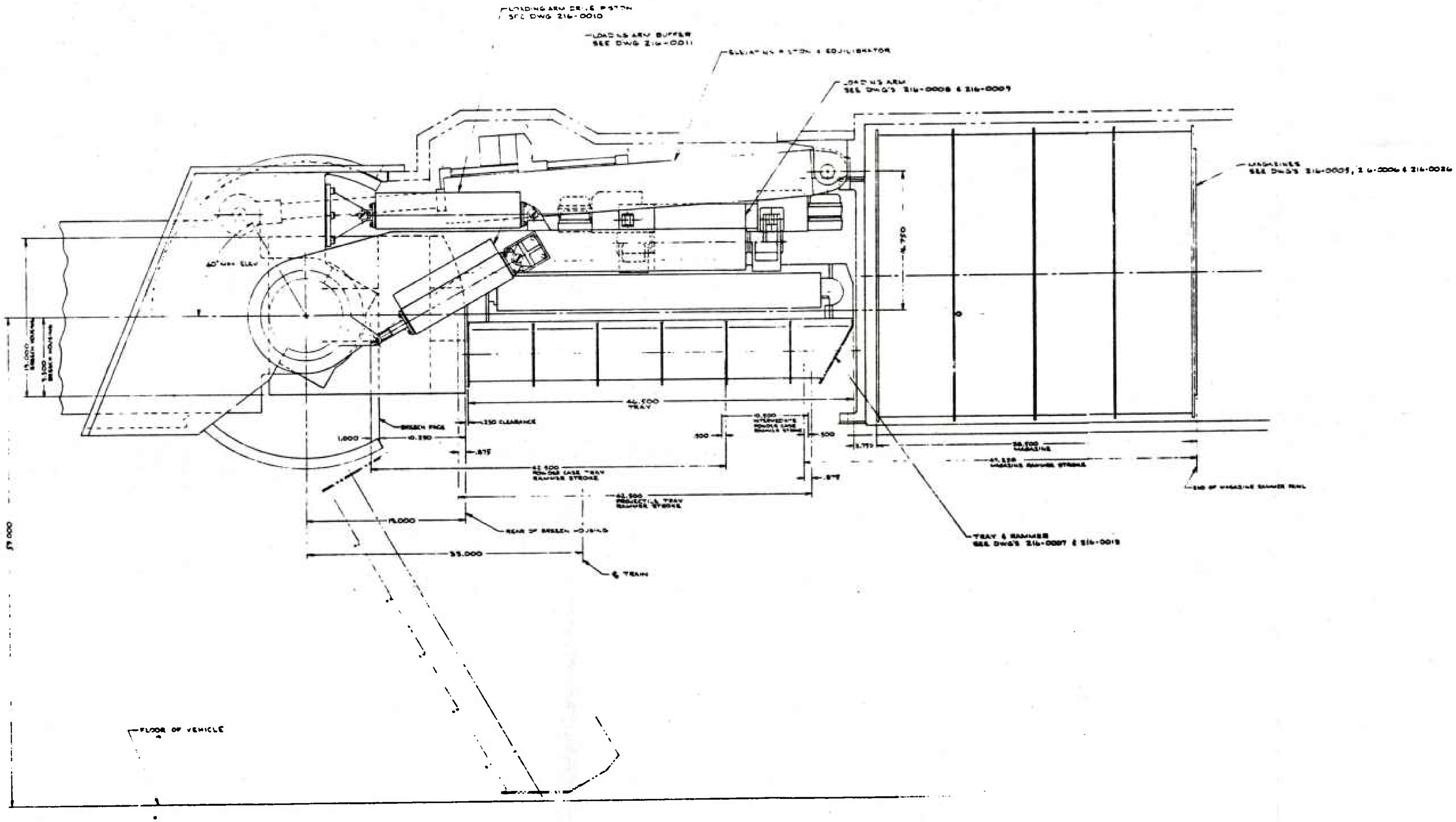

Figure 2. Auto-Loader Systems General Arrangement–Side View

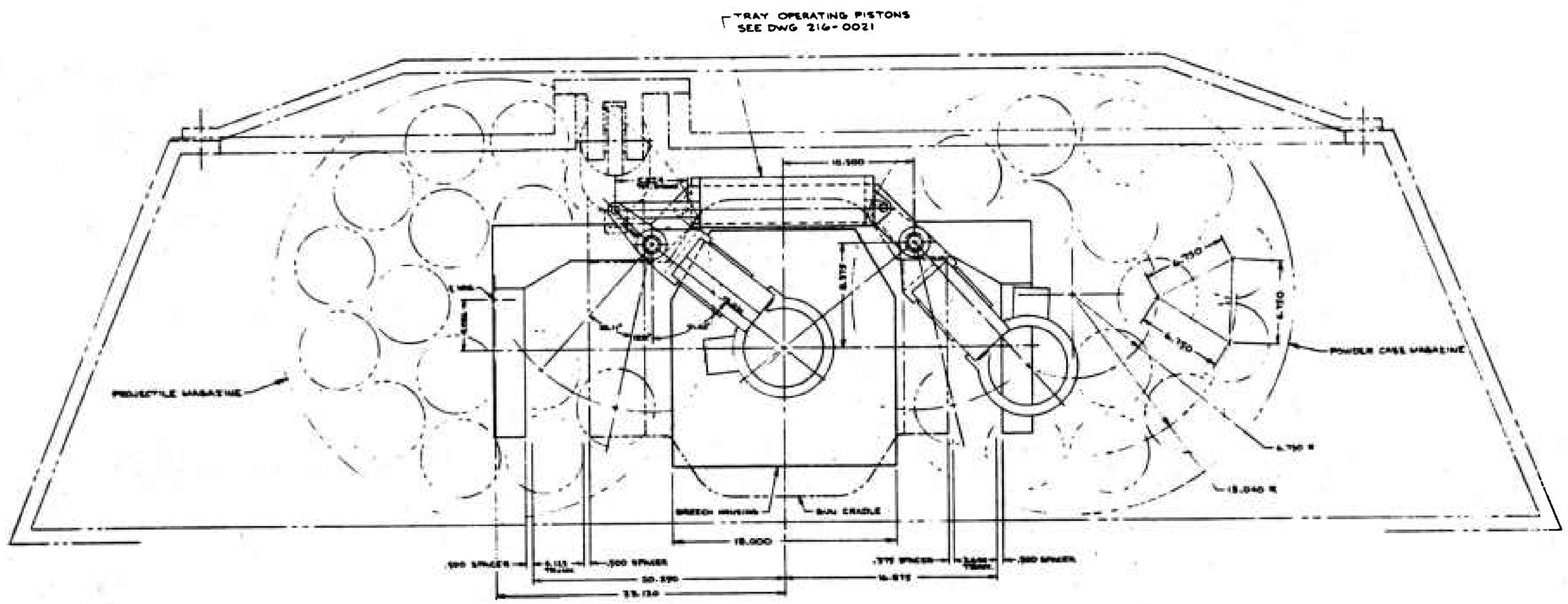

Figure 3. Auto-Loader Systems General Arrangement—End View (Looking Forward)

Turreted Vehicle

The requirement to fit the system concept into the general layout of the turreted M109 SPH obviously tends to drive the basic arrangement of the system. It also places limitations on the possible ready ammunition drum diameter due to the available distance between the turret ring gear/bearing and the roof. An 18 round drum layout was selected as a reasonable capacity to demonstrate the basic concept. It can be fitted to an M109 SPH based test bed with relatively minor revision to the turret. Turreted vehicles with the turret support ring lowered, i.e. a higher ratio of turret height to overall vehicle height, or non-turreted casemate vehicles will provide for substantially larger drums.

The requirement to adapt to a 360° traverse turret configuration together with the firing rate requirements tend to dictate concepts which are completely contained in the turret, to avoid mechanized transfer of ammunition from the fixed hull onto the moving turret.

Positive Ammunition Restraint

The shock and vibration environment of tracked vehicles while moving indicates that ammunition must be positively restrained when in stowage. The reaction of an SPH during and immediately subsequent to firing dictates that all ammunition transfer be under control, thus requiring positive handling techniques which are not dependent upon the gravity field.

• PHYSICAL DESCRIPTION

The FMC/NOD 155mm handling and loading system demonstration prototype concept employs two ready service magazine storage drums—one for projectile storage and one for propelling charge storage. Projectiles and propelling charges can be automatically

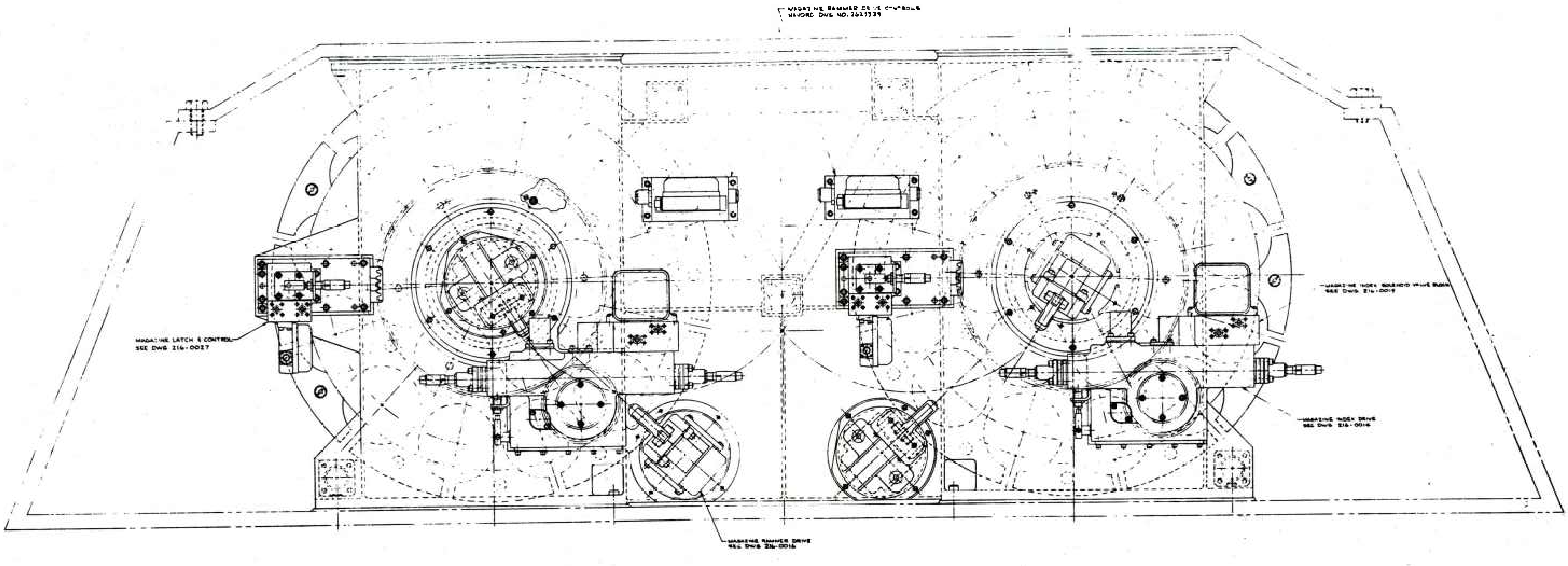

Figure 4. Ready Ammunition Drums/Transfer Drives—View at Aft End

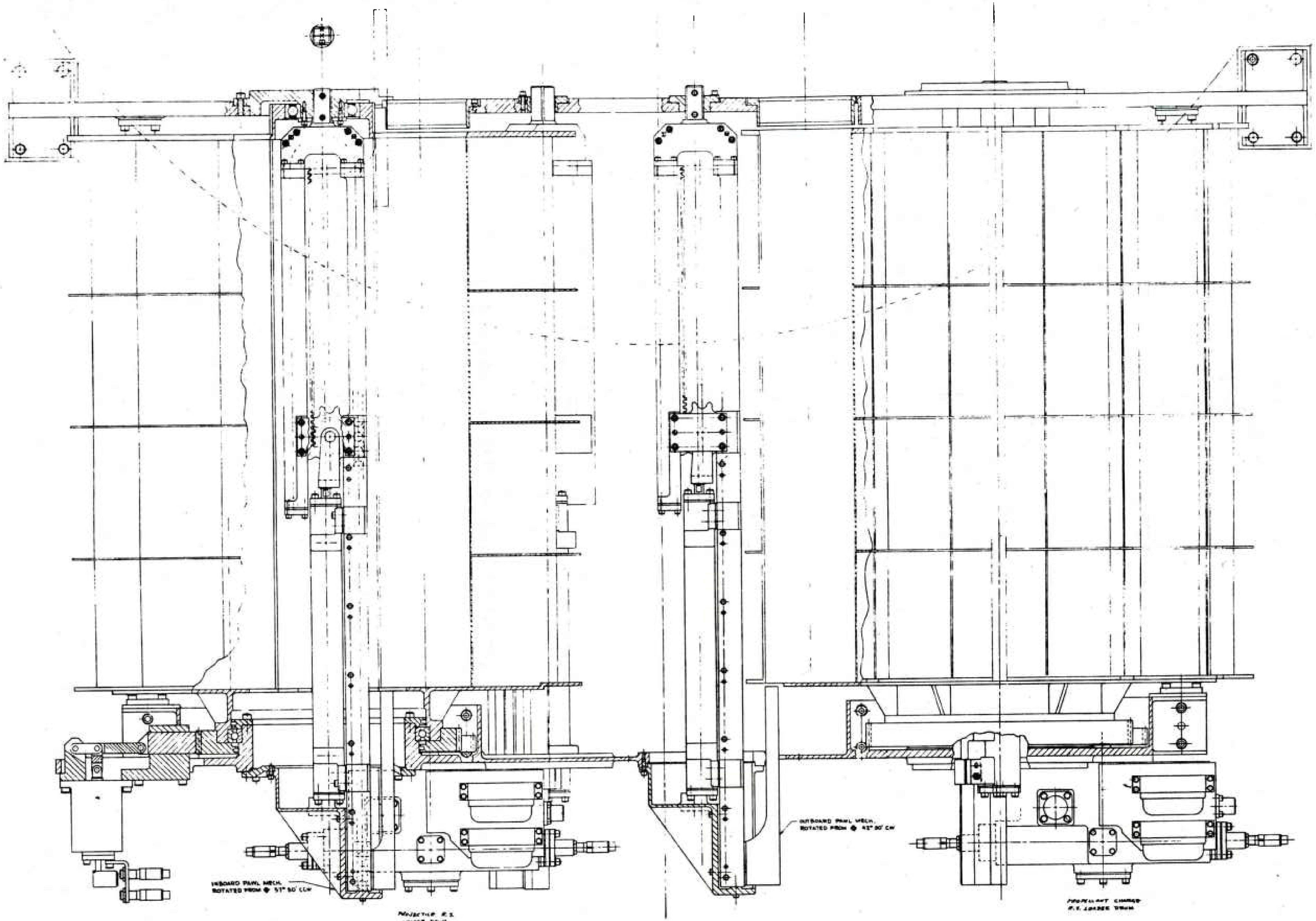

Figure 5. Ready Ammunition Drums/Transfer Drives—Top View

selected from the ready ammunition complement and sequentially transferred and rammed into the breech via two transfer trays and two rammers which are incorporated into a single loading arm which pivots about the cannon elevation axis. The entire basic system rotates in traverse with the turret.

All mechanical functions are hydraulically powered and electrically controlled. Ammunition is under positive control at all times. As previously mentioned, the system is designed around a single fixed length rigid combustable cased propelling charge which is used to achieve positive ram of the projectile.

Ready Service Drums

Two modular ready service drums are employed. Each provides 18 ammunition component storage positions in individual tubular cells. The cells are arranged in a circular pattern with an inner ring of six (6) cells and an outer ring of 12 cells. The cell tubes are welded to five circular support ribs to form a lightweight rigid integrated steel structure. Each tubular cell is slotted its full length to allow passage of the associated loader pawls.

The rear end of each drum is supported by an antifriction bearing large enough to allow passage of the inner loader drive chain and pawl assembly. The bearing at the forward end of each drum is designed to allow longitudinal float at the forward end while also providing an overall diameter small enough to clear the inner cell ammunition components (projectile or propelling charge) during forward transfer.

The drums are indexed in rotation by an index drive which provides a 30 degree incremental rotation per stroke, thus giving 12 stop positions. This drive consists of a double-ended rack piston, a clutch, a latch, and a control selector valve.

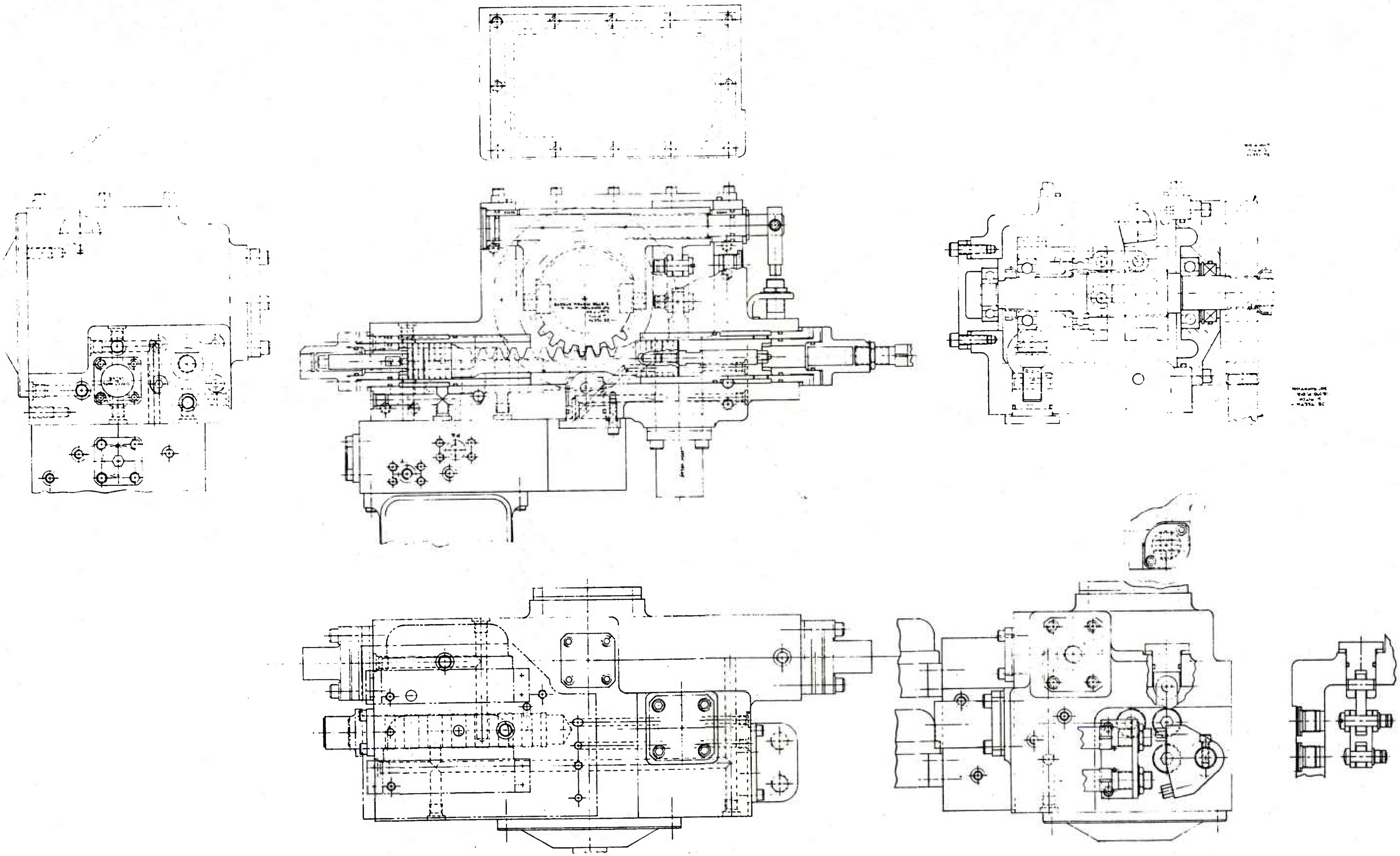

Figure 6. Index Drive

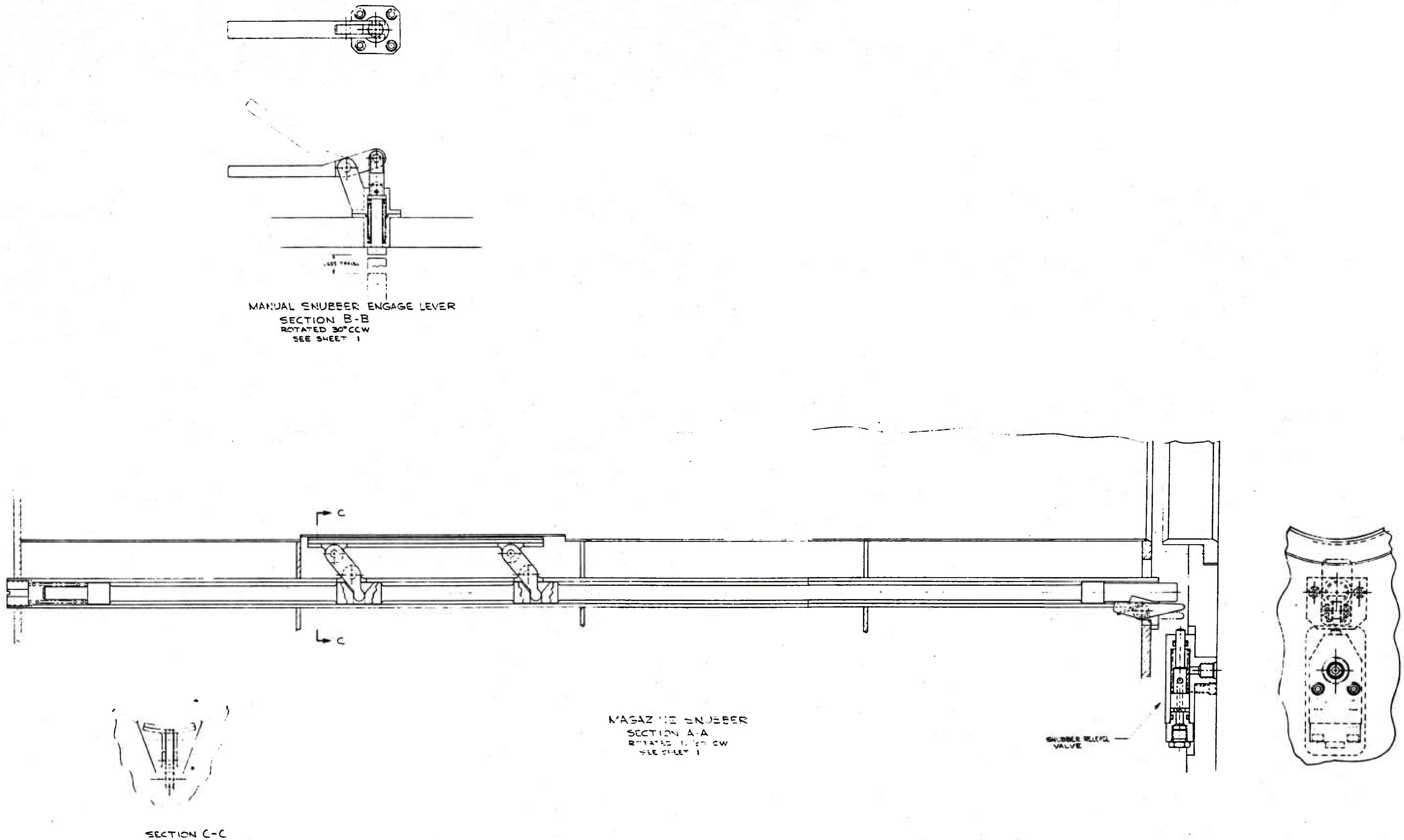

Figure 7. Ammunition Cell Snubbing Mechanism

The incremental index is accomplished by first engaging the clutch to the piston drive pinion, thus connecting the load to the piston. The external latch is then released and the piston stroked to the opposite end of the cylinder. The latch is then re-engaged, the clutch disengaged, and the piston returned to the right end, in position for another stroke. The external latch is employed to relieve the unbalance torque which a partially loaded drum would otherwise place on the clutch, thus allowing the clutch to be engaged/disengaged in an unloaded condition. Position sensor switches are employed to determine the piston end positions, the clutch position, and the latch position.

Round components are snubbed within the individual cells as shown in figure 7. Positive positioning is provided in the rearward direction by seating the projectile or propelling charge against the rear drum stiffener. Both radial and longitudinal restraint are provided by clamping on the cylindrical section of the projectile forward of the rotating band. The propelling charge is restrained in an identical manner. This restraining approach provides the capability to handle a variety of projectile length and ogival shapes and/or propelling charge lengths without the need for adjustment or changeover of the round locking mechanisms.

Transfer Drives

The transfer drive provides the means to transfer ammunition from the ready ammunition drum cells forward into the transfer trays. There are four transfer drives; one each for the projectile drum inner and outer rows of cells and one each for the propelling charge drum inner and outer row of cells. Each transfer drive consists of a linear piston driving a double-ended chain (i.e., not an endless chain) through a sprocket which is driven by a speed increasing rack and pinion. This approach provides the 47.25 inch stroke

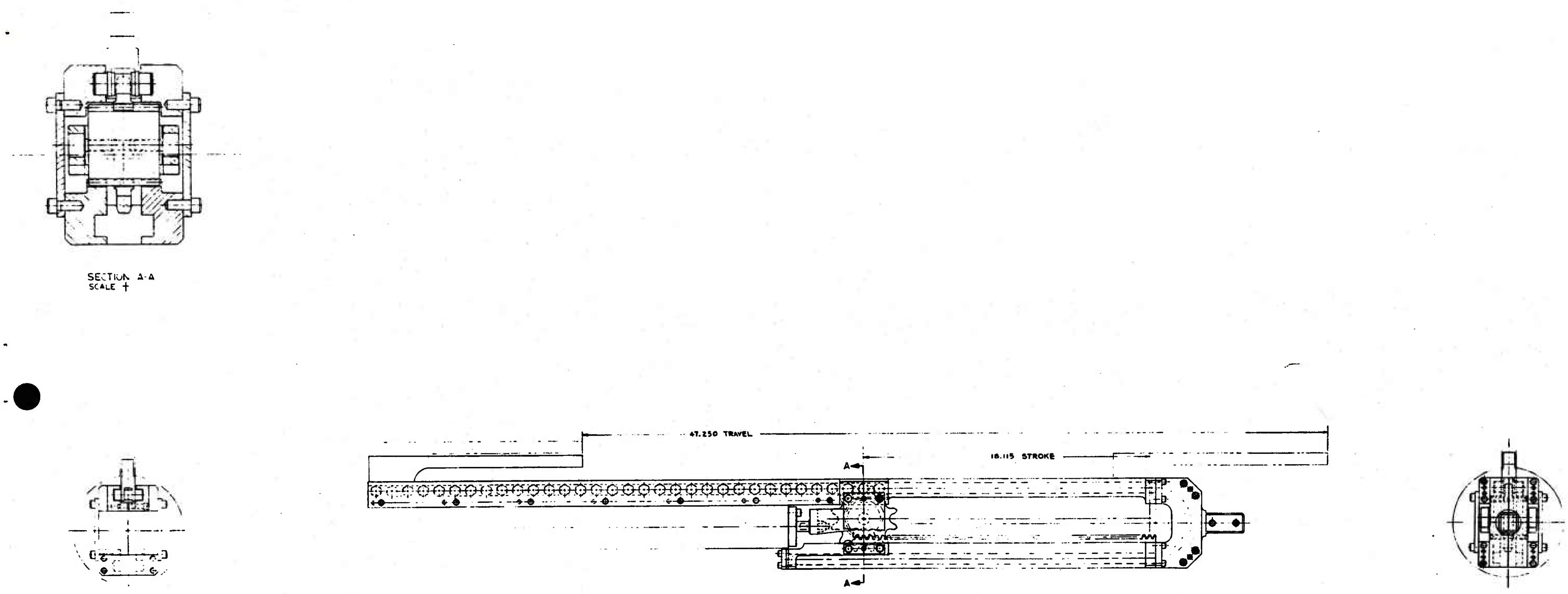

Figure 8. Ammunition Transfer Drive

required at the chain pawl while providing a compact drive mechanism. The four drives are identical except for the ammunition drive pawls which differ slightly between the inner cell drives and the outer cell drives.

Each transfer drive is designed as a module. The aft end support bracket is designed for mounting in a circular opening in the aft ready ammunition drum supporting structure. The opening is large enough to allow rear removal of the entire transfer drive. The forward end of each drive is supported on a square extension closely fitted to a square opening in the front support structure. This provides for longitudinal float at the front end of the drive as well as facilitating easy drive removal for maintenance servicing.

Proximity position sensor switches are employed to indicate the fully retracted position, the fully extended position, and that the pawl is sufficiently retracted so as to permit the loading arm/transfer trays to begin movement toward the elevated cannon tube/cradle assembly.

Subsequent to releasing the ammunition snubbers, the drive pawl is extended by energizing the appropriate solenoid, thus putting pressure to the rear of the piston. Oil is metered through orifices to obtain an initial slow creep movement until the pawl is in contact with the round component. Larger orifices are then uncovered by the moving pistons which then accelerate to top speed. Toward the end of the extend stroke, the piston is decelerated by meter-out orifices on the rod end of the piston. The full extend position is accurately determined by the sensor switch and the solenoid is then neutralized. With the solenoid on neutral, the constant pressure on the rod end of the piston immediately retracts the chain and pawl assembly. Acceleration is controlled by the meter-in orifices at the rod end and deceleration is controlled by the meter-out orifices at the opposite end.

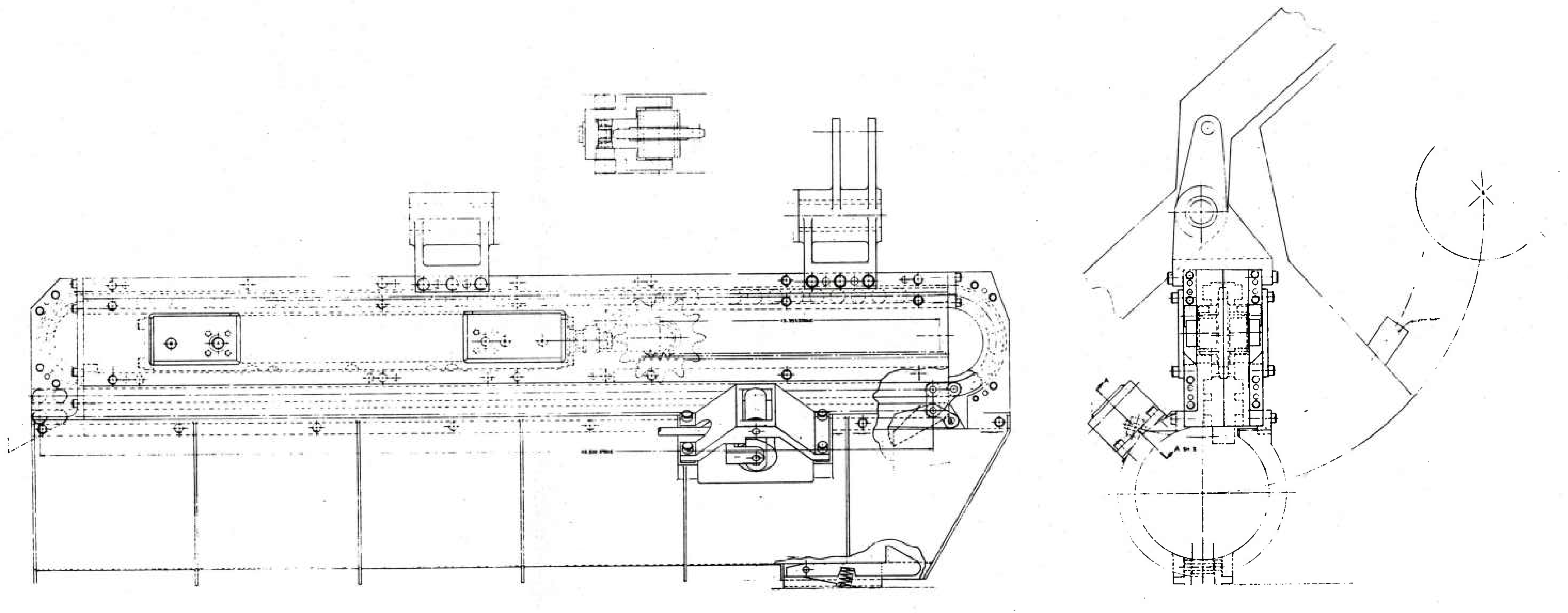

Figure 9. Transfer Tray/Rammer Drive

Transfer Trays

While separate transfer trays are provided for loading projectiles and propelling charges, the mechanisms are almost identical in concept. Each tray assembly consists of a lightweight reinforced steel tube which retains the round component during the loading process, latches for restraining the round component and a hydraulic drive for pivoting the tray about a centerline which is parallel to the centerline of the tray tube. The two trays are rotatable on the single loading arm structure which will be described later. The pivot centerline location and tube centerline to pivot centerline radius have been arranged to allow the transfer tray to be aligned in front of either the inner or outer row of cells in the associated ready ammunition drum for ammunition transfer or directly behind the breech in line with the cannon tube chamber.

Both trays are also provided with a spring biased pressure roller to provide a decelerating force of approximately 3 G's to decelerate the projectile as it enters the tray from the ready ammunition drum. This deceleration force maintains the round component in contact with the transfer drive pawl during the deceleration portion of the transfer cycle. Positive clamping is maintained until the associated transfer tray is positioned behind the breech. The clamping pressure roller is then rotated clear, by the movement of a cam roller at the front of the tray acting through a linkage. As the transfer tray is rotated to the "at breech" position, this cam roller is brought into contact with a cam surface on the rear surface of the breech ring, thus releasing the positive restraint prior to the initiation of ram.

The projectile tray is provided with a spring loaded latch pawl to prevent rearward movement of the projectile once it is pushed into the transfer tray tube by the transfer drive pawl.

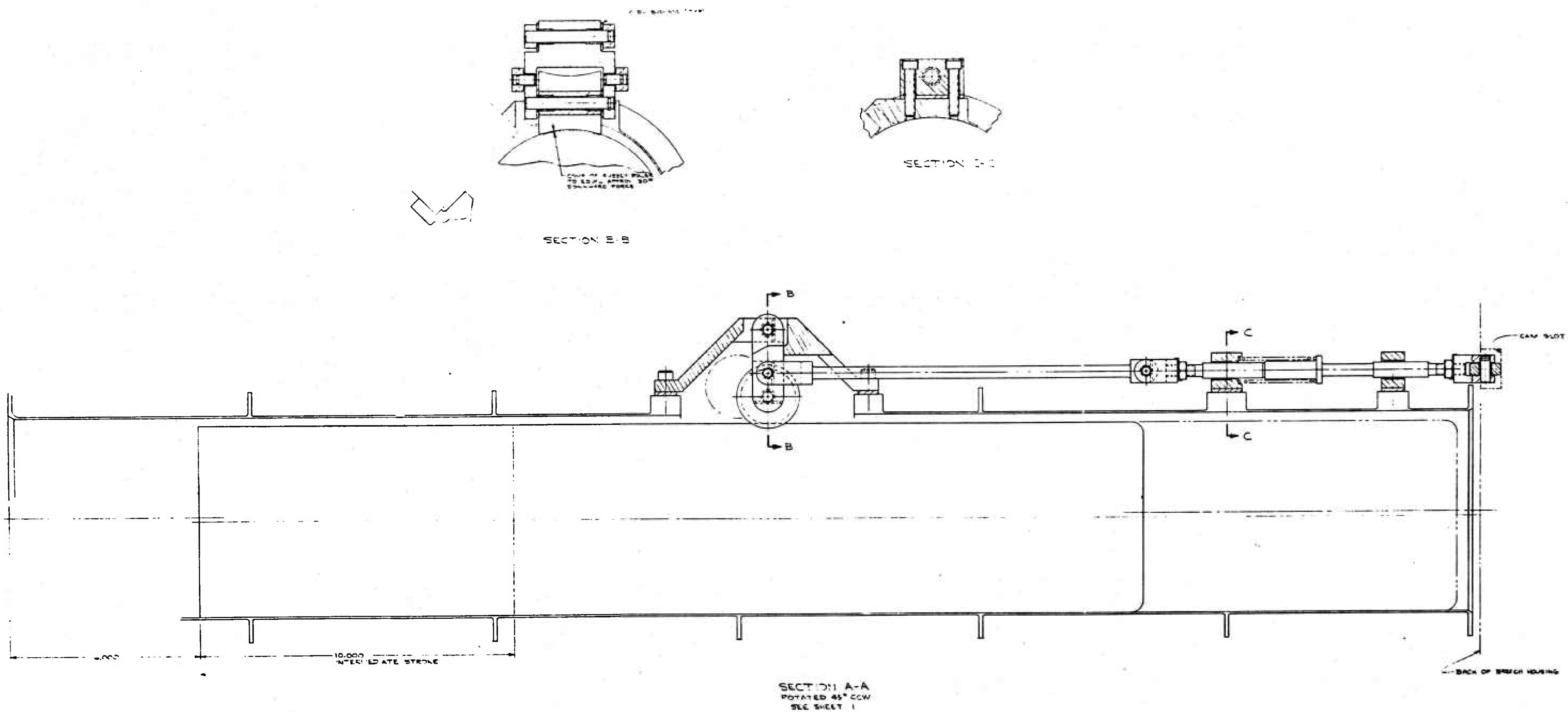

Figure 10. Transfer Tray Deceleration Snubber

The propelling charge tray is provided with a spring loaded latch pawl similar to the projectile tray except that it is affixed to the end of a piston rod/cylinder assembly with a stroke of 10.50 inches. This propelling charge positioner piston, which is provided with simple meter-in/meter-out orifice control, moves the propelling charge 10 inches forward in the tray to position it forward of the long rammer pawl which rams the round into the chamber. Position sensing switches are provided to indicate both the fully retracted and the fully extended positions.

The trays are driven in rotation by independent hydraulic cylinders which are identical. Each modular tray pivot drive cylinder is mounted on the loading arm and drives the associated tray through a bellcrank.

Three stopping positions are provided by employing two pistons in tandem in each cylinder assembly, as shown in figure 10. Piston 1 provides the two stopping positions required at the inner and outer ready ammunition drum transfer positions when piston 2 is bottomed against it. The velocity of piston 1 is controlled by single meter-in/meter-out orifices. Piston 2 which actually drives the tray, provides the third stopping position. When it is fully extended and bottomed on the rod end of the piston, the tray will be aligned behind the breech. Piston 2, because of its longer stroke and the need for a faster cycle, is provided with deceleration orifice slots at both ends of its stroke. Top speed is controlled by fixed size orifices in both directions of movement.

Each tray is equipped with a modular integral rammer assembly which also serves as the structural element between the tray tube structure and the hinge pivots at the loading arm.

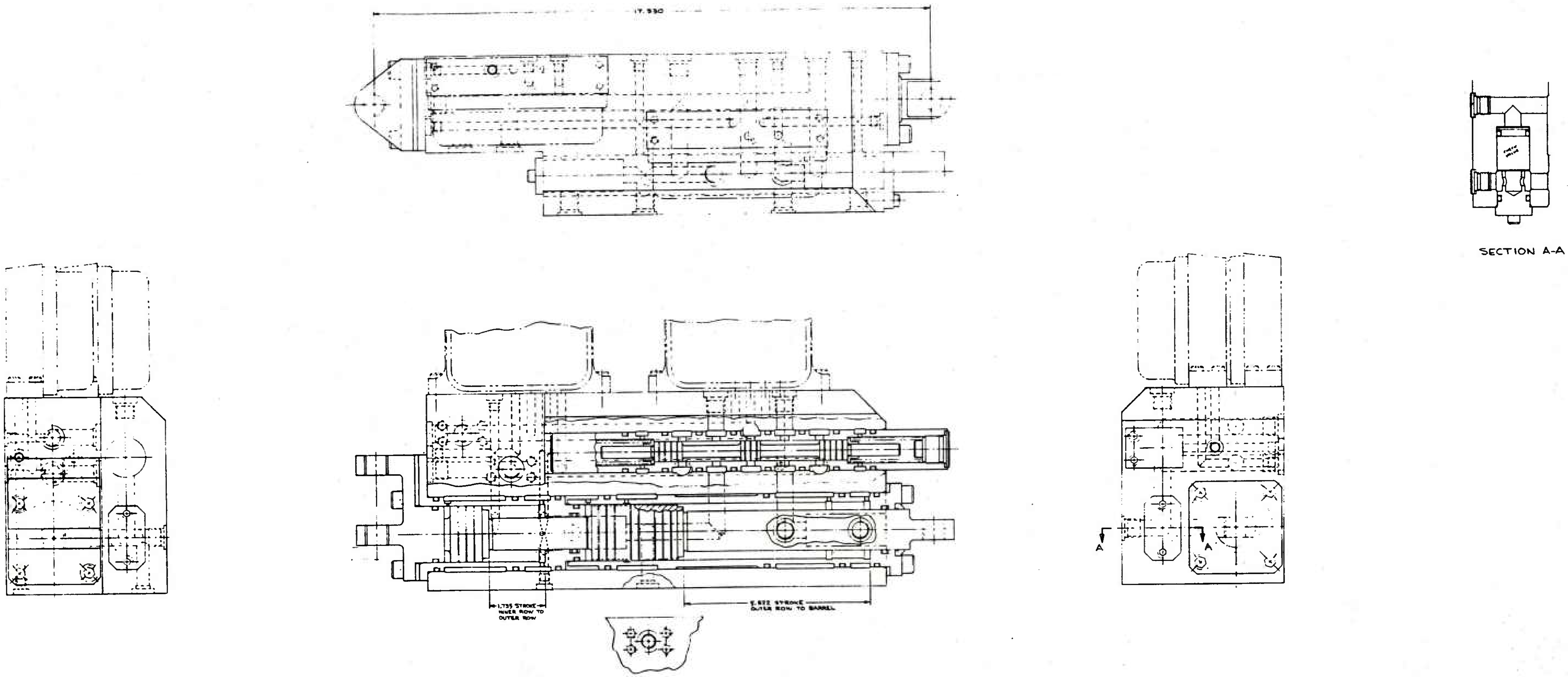

Figure 11. Transfer Tray Drive Actuator

Rammer Drives

Although separate rammers are provided in the projectile and propelling charge trays, they are virtually identical.

Each rammer consists of a linear piston driving a double-ended chain through a sprocket which is driven by a speed increasing rack and pinion. The piston to chain speed ratio is 3.18 to 1. The ammunition component is driven by a retractable pawl which is cammed down behind the projectile or propelling charge during the initial portion of the rammer movement.

This arrangement provides a very compact drive whose overall length is only slightly longer than the length of the longest projectile.

The modular rammer piston is shown in figure 12. The pistons for projectile and propelling charge rammers are identical except for the control orifices in the sleeve and the piston head. These orifices provide a ram stroke which initiates with a slow speed creep for the first 0.875 inches of chain movement while the pawl is being cammed down and is brought into contact with the ammunition component. Continued piston movement opens up a large pressure port and the projectile is accelerated to maximum velocity. Porting in the sleeve and deceleration orifice slots in the piston head decelerate the piston at the end of the stroke. A check valve allows by-pass of these deceleration orifices on the return stroke to minimize the retract cycle time. Deceleration at the end of the retract stroke is provided by the deceleration orifice slots in the piston together with the end fixed orifice.

Position sensing switches are employed to indicate the rammer chain fully retracted position, the fully extended position and that the pawl is sufficiently retracted clear of the breech so as to permit the associated transfer tray to begin movement away from the "at breech" position.

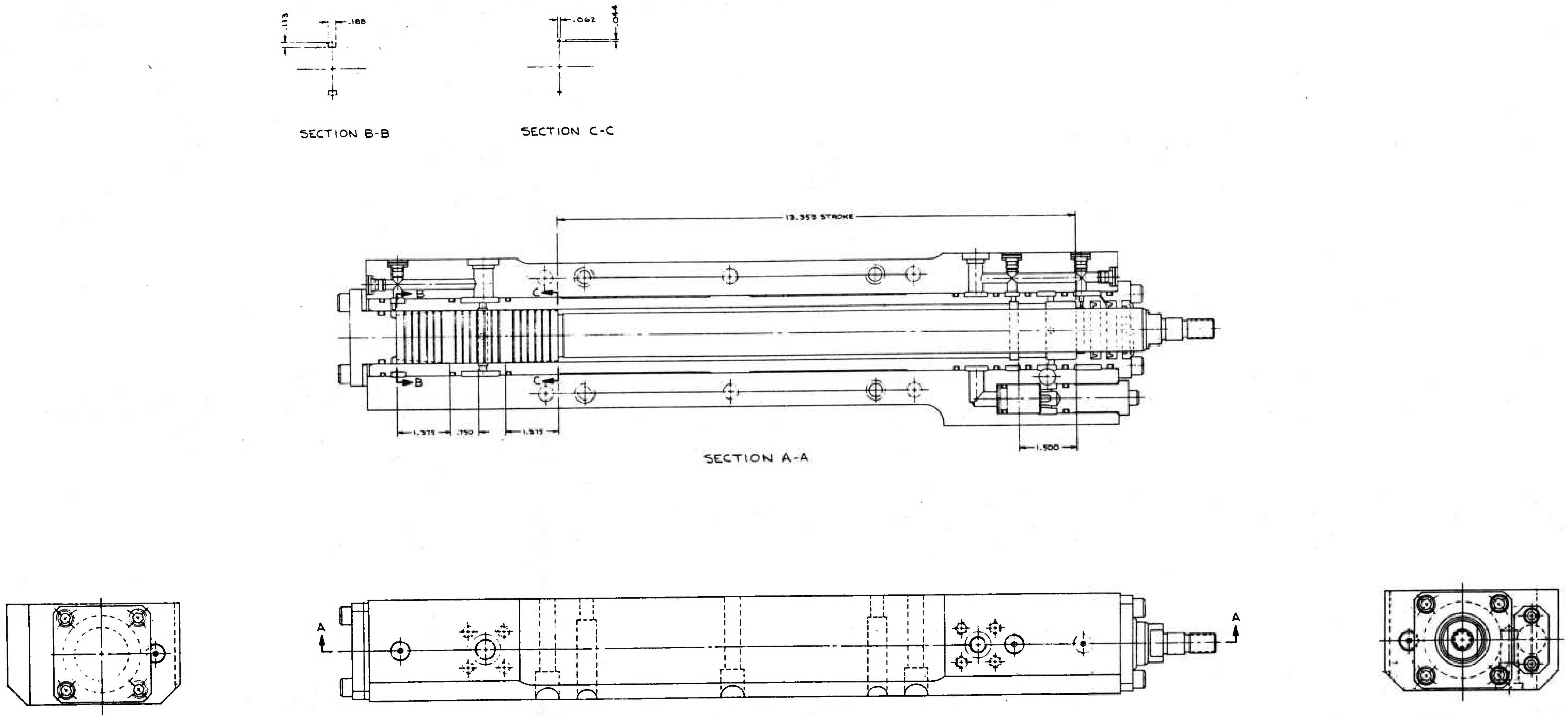

Figure 12. Rammer Drive Cylinder

The major difference in the two rammer assemblies is in the length of the pawl which actually drives the ammunition forward during ram. The projectile pawl is as short as possible to minimize tray length, it provides positive positioning of the projectile one inch inside the rear surface of the breech ring. The projectile is held in position there by a clamping device in the breech which also provides for deceleration of the projectile to maintain contact with the pawl. A much longer pawl is provided on the propelling charge rammer. This pawl provides positive ram of the combined projectile and propelling charge to a position one inch beyond the breech face.

The control valves for both rammers and the propelling charge positioner cylinder are located in one control valve block which is located on the loading arm structure.

Loading Arm

The loading arm together with the two transfer trays provides the means to bring the ammunition from a fixed position in the turret, into alignment behind the breech of the cannon regardless of the elevation angle.

The loader arm drive system incorporates a pair of driving cylinders and a pair of special buffing cylinders. The buffing cylinders are anchored to the cannon cradle trunnion shaft so that the "loading arm lower" cycle deceleration is controlled relative to the cannon tube regardless of elevation angle. The drive cylinders, on the other hand, are anchored to the turret structure. This allows them to be designed with built-in buffing control which decelerates the loader arm to a stop at the horizontal transfer position.

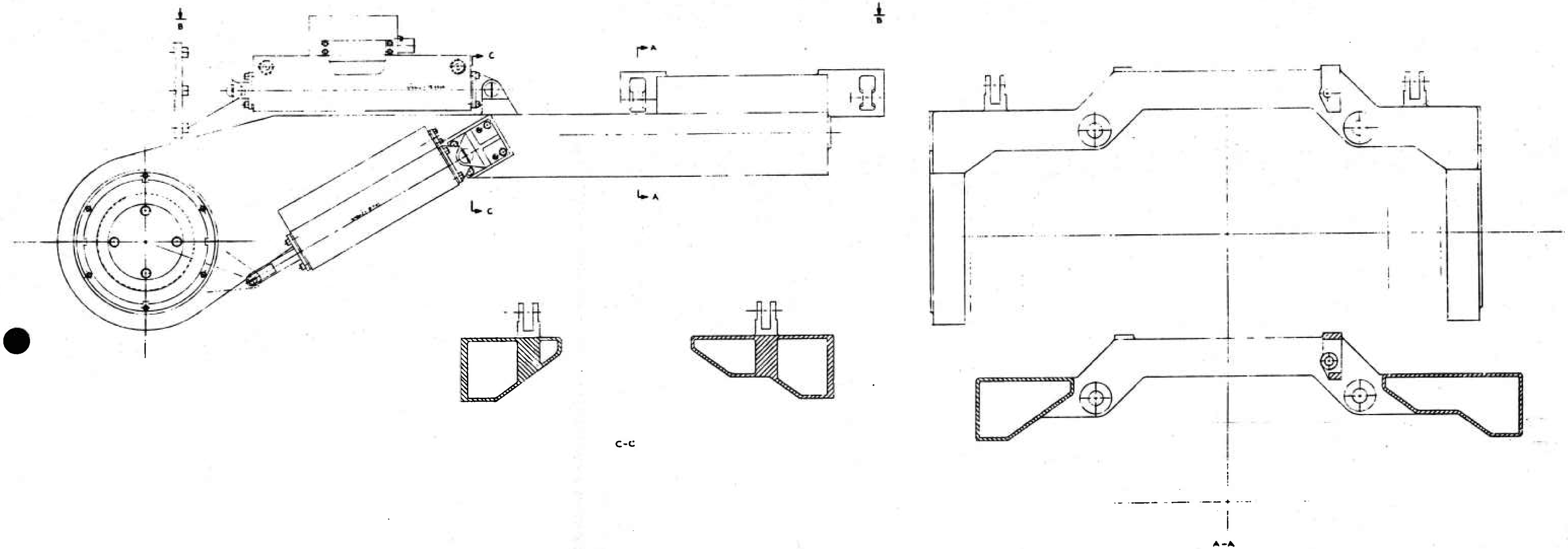

Figure 13. Loading Arm General Arrangement

The loading arm is a yoke shaped steel weldment structure. The yoke configuration which provides for a wide wheelbase over the trunnion supports together with the use of box section construction allows for a lightweight structure with high stiffness. It pivots about the cannon tube elevation axis on sleeve bearings which are located outboard of the elevation trunnion mounts.

The arm is driven by dual hydraulic cylinders located on the upper side of the loading arm structure. The rod end of each piston is anchored to the turret structure directly above the trunnion mounts. Each piston is provided with buffing orifices at the piston head end to control acceleration away from—and deceleration as the arm approaches the fixed angle zero degree ammunition transfer position.

When at the transfer position, the loading arm is latched to the fixed structure which also supports the forward ends of the ready ammunition drums. This guarantees precise alignment during ammunition transfer from the ready ammunition drums into the transfer trays. The latch is cammed back and spring biased into latch position as the loading arm is positioned to the transfer position. A solenoid controlled piston retracts the latch when the loading arm moves away from the transfer position. Position sensor switches indicate the presence of the loading arm at the latch position and whether the latch is retracted or extended.

Reference between the cannon cradle which moves in elevation and the loading arm is provided by two buffing cylinders, one at the left trunnion and one at the right.

The attachment to the cannon cradle is provided by bellcranks which are splined to extensions of the cradle trunnion shafts. The bellcranks thus move in elevation with the gun cradle.

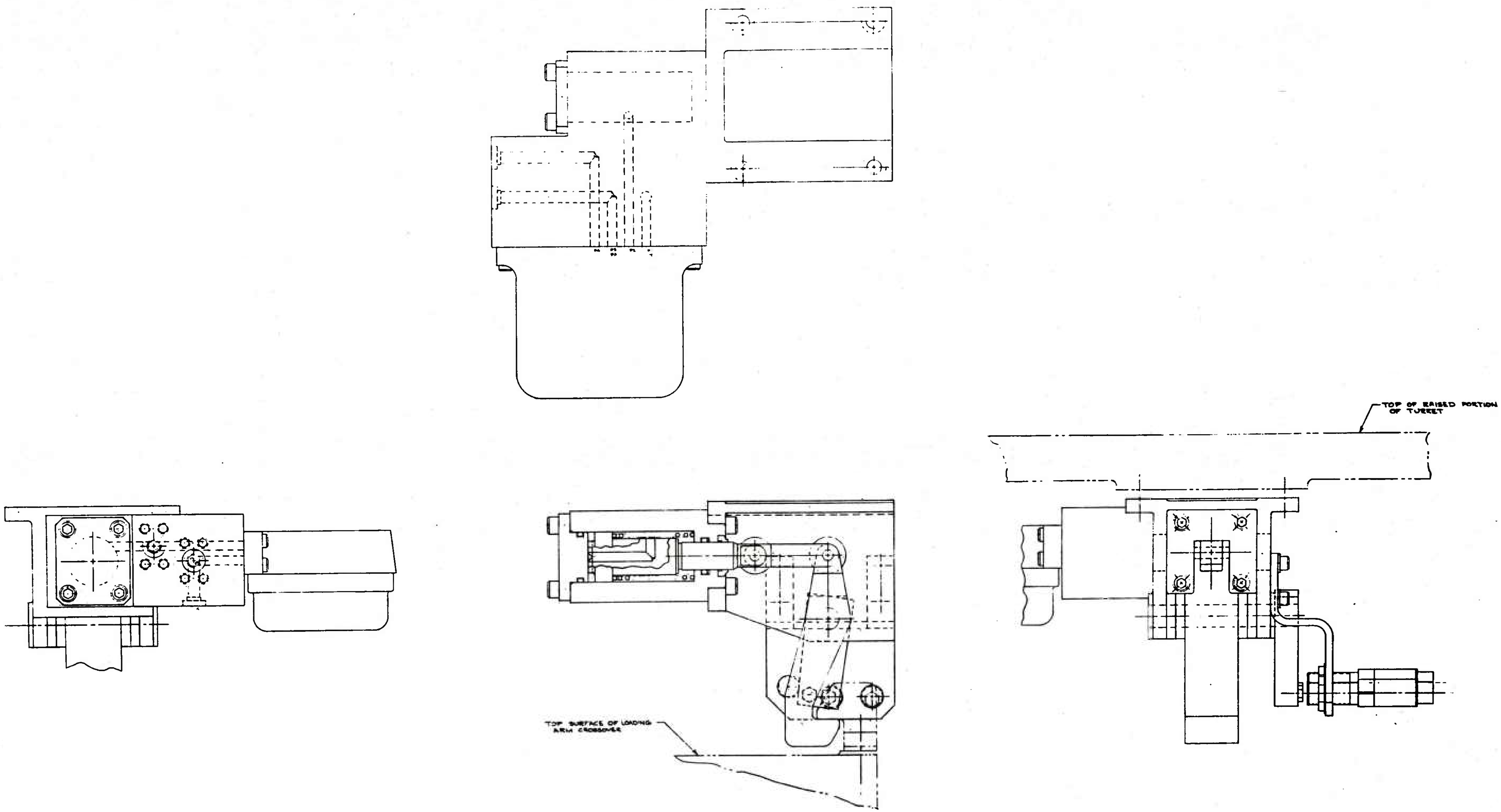

Figure 14. Loading Arm "Raised" Latch

The rod end of each buffing cylinder is secured to one of the bellcranks and the opposite end is attached to the loading arm. The buffing cylinders are designed to be fully retracted (bottomed) when the loading arm is aligned to the breech regardless of the elevation angle. This allows them to provide buffing control to decelerate the loading arm as it approaches the "at breech" position as well as providing positive location when bottomed out. Buffing deceleration control is provided by a series of drilled holes in the piston sleeve. A check valve provides a bypass around the orifices when the arm is moving away from the "at breech" position.

When at the "at breech" position, the loading arm is latched to the cannon cradle extension bellcranks by a latch. This latch consists of a piston operated lever which traps a roller on the bellcrank arm between the latch and a stop on the loading arm. The operating piston is essentially identical to that previously described for the loading arm raised latch. The position sensing switches are also similar, with switches being provided to indicate that the loading arm is in position at the breech and that the latch is either extended or retracted.

Latches as employed here serve several important functions. First, they provide positive control of the loading arm during ammunition transfer. Thus, the loading arm cannot drift out of position even if hydraulic pressure were to be lost at the drive pistons. This is important from a safety viewpoint. Similarly, the loading arm position is maintained when the system is shut down and there is no hydraulic pressure present. Latches also provide for accurate resolution of position indication since the final position indication is read off the latch positions.

As previously discussed, the loading arm provides the hinge pivot axis for the two transfer trays and also acts as the mounting for the tray drive cylinders, their associated controls and the control valve block for the rammers.

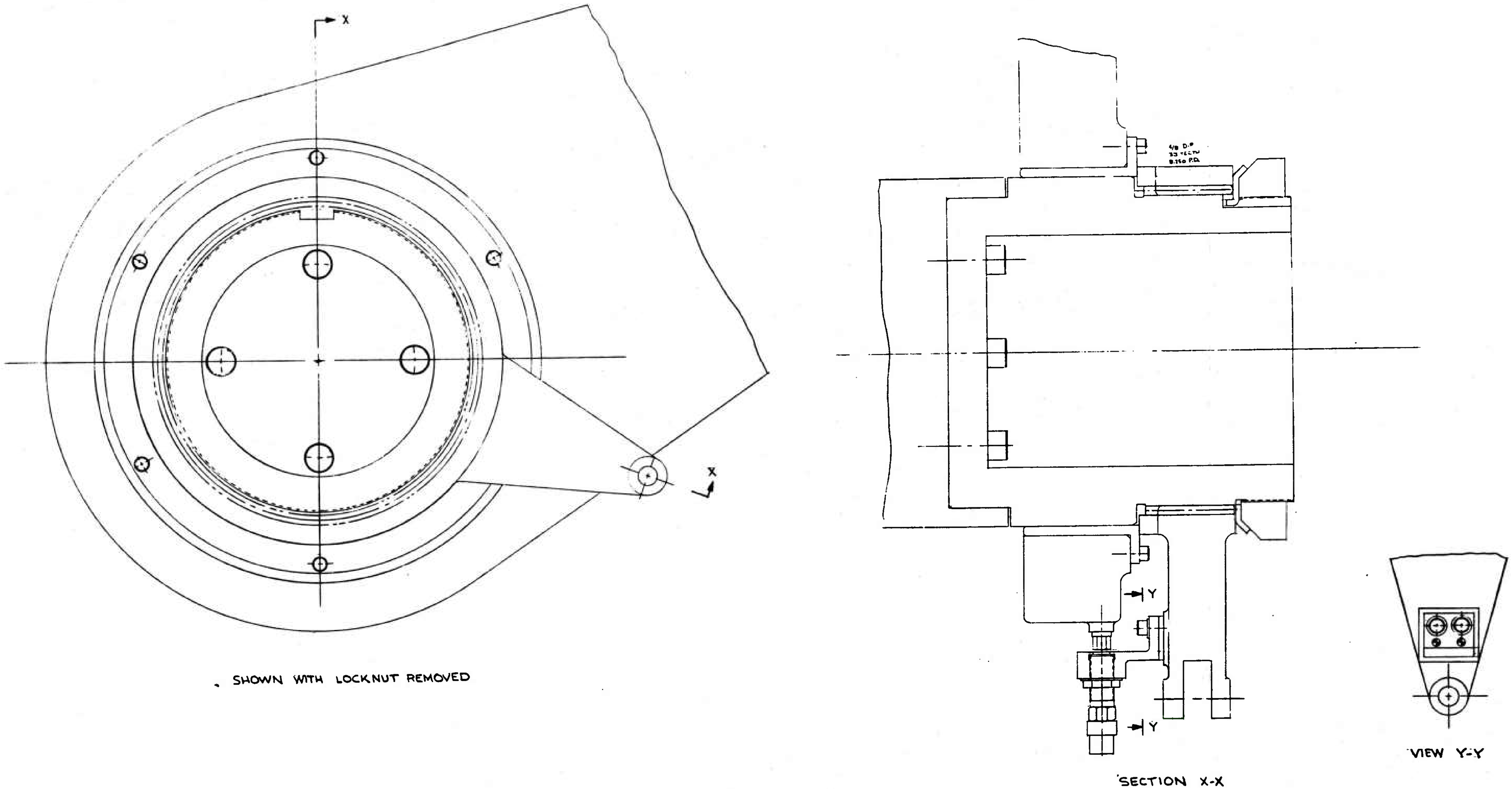

Figure 15. Loading Arm/Elevation Position Bellcrank

IV CONTROL SYSTEM

The control system provides integrated control of the autoloader and the associated elements of the cannon system. It provides safe positive control of all ammunition storage, inventory, handling, loading and firing functions.

As configured for a demonstration prototype autoloading system, all features and functions needed to support the loading system are integrated into this single panel. It is certain that a production configuration system for an automatic cannon system would incorporate some of these input and output functions in other consoles, such as the commander console, the gunners console or an external maintenance control unit. Further, it is likely that some of the functions included in this test bed panel may be eliminated or incorporated with other functional controls.

The control system panel as herein described is designed as a stand alone control panel which could be installed in a howitzer test bed without need of modifications to other equipment or need for the expense of developing several control consoles and electronic modules.

The control system performs the following functions:

- Monitors the motion and position of mechanical components.
- Orders hydraulically powered movements.
- Electronically interlocks hydro-mechanical functions for safe, reliable operation.

- Monitors firing conditions sensors, e.g. autoloading system hydraulic pressure, counterrecoil nitrogen pressure and breech temperature.

- Maintains ammunition inventory status information.

- Directs the firing mechanism.

- May direct the on-board fuze setter when required.

- Tests itself and the mechanical system for proper operation.

- May process the cannon firing system order.

- Interfaces the automatic loading system with the panel operator.

The basic technical approach and the various components such as position sensor switches, solenoid operated pilot valve initiators, buffing and output circuits, control input switches, dedicated display lights and microprocessor controlled logic are all proven state-of-the-art hardware in current use in similar applications in automatic naval guns and other automatic ordnance systems designed and developed by FMC/NOD.

- <u>CONTROL ELECTRONICS</u>

The Autoloader mechanism positions are sensed by Hall Effect Proximity Switches, a fully solid state electronic switch. Switch outputs are received by Inverter-Buffer circuits which level shift and condition the switch signals and provide complementary outputs to the Control Logic. A properly operating switch input channel is determined automatically by comparing these complementary outputs. Improper comparison results in a FAULT condition. The FMC/NOD Proximity Switch and Inverter-Buffer circuit are used extensively in Naval Ordnance Systems and their reliability has been proven to surpass that of mechanical switches.

The Control Logic system is a microprocessor designed to accept system position sensor inputs and command signals. It is programmed to process this information, make logic decisions, and then generate outputs to energize the solenoid/pilot valves of the autoloader mechanism in the proper sequence for automatic loading, handling, and firing of ammunition. The microprocessor makes its logic decisions based on inputs from the manual input switches on the panel and the proximity position sensor switches located in the autoloader mechanism.

Electrically actuated hydraulic pilot valves are used to drive the autoloader hydraulics. For increased reliability, power to these solenoids is wired with redundant isolated circuits. The FMC/NOD developed solenoid operated pilot valve is used extensively in Naval Ordnance Systems.

Safety for the crew, the mechanism and the ammunition is a primary design criteria. Special care is taken in the design to ensure that improper operator action and/or electronic failures will not endanger the safety of personnel or result in secondary equipment casualties. High speed, reliable operation is the result. Multiple modes of operation are made possible by this control system concept, which permits versatility in component usage and graceful degradation of operation in the event of a failure. Built-in-test (BIT) is another capability which is essentially inherent in such a system.

The system control interface with the operator consists of:

- Manually Actuated Control Switches—Are used to select firing and operational modes, select ammunition types, and direct mechanical operations, when desired.

- Dedicated System Status Displays—Provide an indication of system ready status, completed firing interlocks, ready ammunition inventory, and initial fault indications.

- The Online Monitor Display—A dynamic alphanumeric display which indicates online monitor function results and troubleshooting instructions, including misfire and initial fault indications.

All control and displays may be conveniently located on a single control panel or grouped and packaged separately as required for system integration.

- MANUALLY ACTUATED CONTROL SWITCHES

The System Power Switch activates system power supplies. This switch should be locked in the Off position and the key removed by the authorized operator when the system is not to be used.

The Firing Safety Switch is used to enable the Firing Order. This switch has three positions: Safe, Normal Firing, and Emergency Firing.

The Safe position prevents any firing of ammunition. The Firing Safety Switch must be in the Safe position to enable Replenish, Maintenance, and Simulate modes of operation. The handle is removable when in the Safe position.

The Normal Firing position enables the Firing Order and the Firing Safety Switch must be in this position to enable Autoload mode.

The Emergency Firing position enables the emergency firing circuits in the event of a misfire condition.

Closing the Firing Key is the command to fire, or Firing Order, which initiates the Load-And-Fire sequence following the Ready-To-Fire indication. The Autoloader completes the Load Cycle by:

1. Opening the breech[1]

2. Partially ramming the projectile

3. Lowering the projectile tray to the latched position

4. Raising the propelling charge tray to the breech position

5. Ramming the combined propelling charge and projectile

[1] Assumes that the breech will remain closed to maximize NBC protection until the "load & fire" order is given for the first round. Subsequent to firing the breech will open at the initiation of counterrecoil to maximize effectiveness of bore evacuation. The breech will then remain open between rounds in a burst, as long as continuous automatic fire is called for (mode switch at Continuous). When the last round in a burst has been fired, (mode switch returned to Off) the breech will open in counterrecoil for bore evacuation, and then after an appropriate time delay it will again close to maximize NBC protection.

6. Lowering the charge tray to the latched position

7. Closing the breeech

8. Firing the round

9. Returning the loading arm to the ammunition transfer position

The Operating Mode Switch is used to select the mode of system operation. The switch positions directly reflect the type of operation intended. Transitions between selections are interlocked in the logic so that no unsafe or out-of-sequence mechanical action will result from random switching.

The Autoload Mode will automatically sequence the Autoloader through a load cycle. Normal operation is as follows:

1. Firing Safety Switch set to Normal Fire

2. Select an available projectile/fuze combination with the Projectile and Fuze Select switches.

3. Select an available charge with the charge select switch. At this point, the ready ammunition drives will index the selected round components to the transfer stations and the Ready-to-Load indicator will be illuminated.

4. The Load Mode Switch is then set to Single or Continuous load mode. The projectile/fuze combination and charge will be advanced to the "behind-the-breech" position and the Ready-to-Fire indicator will be illuminated.

5. Close the Firing Key. The autoloader will partially ram the projectile, followed by the combined charge and projectile and fire the round. If the Load Mode switch was initially set to Continuous, the mechanism will return for another round and advance it to the Ready-to-Fire position. In Single Load Mode, the mechanism returns to the Ready-to-Load position.

The Replenish Mode position allows step control of the magazines by the cannoneer for reload purposes. The cannoneer has a remote ready ammunition drum index switch for each drum which provides him with a safe means of locating empty stowage cells. All hydraulic functions, exclusive of ready ammunition drum indexing are locked out. The control panel operator will select the type of projectile/fuze and charge to be loaded. As the round is inserted in the magazine cell, the selected projectile/fuze or charge type will be automatically stored in the control system logic. The cell location, together with the ammunition information, is stored by the Control System and used in the Autoload mode to locate and execute the Load-and-Fire sequence in the most expeditious manner.

The Maintenance Mode position allows step control of individual mechanical functions. The control logic allows no ammunition to transfer either from the ready ammunition drums to the transfer trays or from the transfer trays to the breech. Independent out-of-sequence mechanical manipulation is sometimes requested for maintenance. This is accomplished in maintenance mode with the Step Control switches.

The Simulate Mode position is used to exercise the autoloader in an automatic Load-and-Fire sequence without ammunition. This mode acts as a system functional test and effectively provides inbedded training.

Off Mode instructs the control system to disable all mechanisms by cutting off all power to the solenoid operated pilot valves and the position sensor switches.

The Ammunition Selection Switches are used by the control panel operator to select projectile/fuze combinations and charge types to be fired. The available inventory of each projectile/fuze combination and charge type is displayed by the counters. Ammunition selection may be changed at any time. Once a Load-And-Fire sequence has been initiated, however, the autoloader will complete the cycle, including firing, with the ammunition selected when the load order was given.

In Replenish mode, the ammunition selection switches are used to enter ammunition type as loaded by the cannoneer. See Replenish mode description.

The Online Monitor Test switch is used to interact with the online monitor. This is a spring-return-to-off switch which is used to select "GO" after test pass or complete and "NO-GO" after test fail or incomplete.

The Step Control switches are used to initiate individual mechanical functions. They are available for use in maintenance mode only. All actions directed by the Step Control switches are interlocked with the autoloader mechanism to ensure proper sequencing and safe operation.

The Projectile Ready Ammunition Drum Index switch selects clockwise (CW) or counterclockwise (CCW) rotation of the projectile ready ammunition drum. This is a spring-return-to-off switch. Each actuation initiates a single indexing step of the ready ammunition drum.

The Charge Ready Ammunition Drum Index switch is similar to the Projectile Ready Ammunition Drum Index switch.

The Projectile Tray Position switch selects one of three positions to which the projectile tray must move: to the Breech, to the Outer Ring, to the Inner Ring. This switch detents in each of its three positions.

The Charge Tray Position switch is similar to the Projectile Tray Position switch.

The Projectile Transfer Drive Extend switch initiates the load cycle from either the Inner Ring or Outer Ring of the projectile ready ammunition drum to the projectile tray. This is a spring-return-to-off switch. Each actuation initiates the transfer drive extend cycle which automaticaly retracts upon completion of the cycle.

The Charge Transfer Drive Extend switch is similar to the Projectile Transfer Drive Extend switch.

The Loading Arm switch is used to initiate a loader arm Raise or Lower cycle. This is a spring-return-to-off switch.

The Breech switch is used to initiate breech Open and Close cycles. This is a spring-return-to-off switch.

The Rammer Extend switch is used to initiate either ramming of the projectile or the charge/projectile combination. This is a spring-return-to-off switch. The rammers automatically retract upon completion of a rammer extend cycle.

The Remote Projectile Ready Ammunition Drum Index switch initiates a ready ammunition drum indexing in the Replenish mode only. This switch is located in the area forward of the ready ammunition drums adjacent to the reload tray. Each actuation directs the projectile magazine control logic to rotate the projectile ready ammunition drum to the next empty cell.

The Remote Charge Ready Ammunition Drum Index switch is similar to the Remote Projectile Ammunition Drum Index Switch.

As previously discussed, this panel as presently configured, contains functions which may be located elsewhere in a production system. The Step Control switches are a typical example, they could be packaged in a portable plug-in unit to be used only by battery or by DS maintenance personnel. The decision to do so will depend on the level of training planned for the SPH crew.

- DEDICATED SYSTEM STATUS DISPLAYS

Ready Indications

Ready-to-Load illuminates when the magazines have indexed to the cells of the ordered projectile and charge, and the trays are positioned for loading. It remains illuminated as long as the cells at the transfer stations are loaded with an ordered projectile/fuze combination and charge, and the trays remain positioned for loading.

Ready-to-Fire illuminates when the loading arm latches to the gun cradle with the loaded projectile tray positioned at the breech. At this point, a firing order is required to complete the loading cycle. It will remain illuminated until that order is received.

Firing Interlocks

Firing interlocks indicate completed autoloader functions leading to the Ready-to-Fire status. In the event of a system failure in the loading sequence, the Firing Interlocks can point out the problem area.

Loading Arm Latch at Breech illuminates when the loading arm latches to the trunnions, indicating the trays are at the Ready-to-Fire position. It will remain illuminated until the loading arm begins its return to the magazine.

The Projectile in Breech illuminates when the ordered projectile-fuze combination has been rammed into the breech and will remain illuminated until the projectile is cleared either by firing or by prescribed misfire procedures.

Projectile Tray Down and Latched illuminates when, following ramming of the projectile, the tray lowers to the inner ring position on the loading arm; indicating the tray is clear of the area into which the breech will recoil. It remains illuminated until the projectile tray is otherwise located.

Charge in Breech illuminates when the ordered charge has been rammed into the chamber and remains illuminated until cleared either by firing or by misfire procedures.

Charge Tray Down and Latched illuminates when, following ramming of the charge, the tray lowers to the inner ring position on the loading arm, indicating the tray is clear of the breech area. It remains illuminated until the charge tray is otherwise located.

Breech Closed indicates the charge and projectile have been properly and completely rammed and the breech hydraulics have closed the breech. It remains illuminated until the breech is opened.

Ready Ammunition Inventory

The Projectile Count indicator indicates the number of projectile/fuze combinations available in inventory, i.e. actually in the ammunition drum, exclusive of the projectile in the loading tray or breech, as selected by the Projectile and Fuze Select switches. Thus, the number displayed indicates quantity of projectiles in the loaded drums of the type the Projectile Select switch is positioned to. The count increments upon completion of a Replenish cycle and decrements when the projectile tray is loaded.

The Charge Count indicator functions the same as the Projectile Count indicator when selected by the Charge Select switch.

Fault Indicators

Fault Indicators provide an indication of system malfunctions. They are the initial indication of a system problem. The operators attention is then directed to the on-line monitor/display.

The Misfire lamp is illuminated when a primer ignition attempt fails to ignite the charge. This is determined when after applying the firing voltage the cannon fails to recoil as detected by the "in-battery switch". The lamp will remain on until the bore is cleared.

The Fault lamp is illuminated whenever a system fault is detected.

- ONLINE MONITOR AND DISPLAY

Self-test programs constantly monitor electronic and mechanical system operations. The Online Monitor, by continuously evaluating the control system sensors and control switches, compares the actual system state against the pre-determined correct state. A difference between the two is considered a system fault and the operator is alerted via the Fault lamp and the Online Monitor Display. The display will then indicate the operator action to be performed.

Three types of directives will be displayed by the Online Monitor, as configured for this test bed application:

- A single directive to be performed by the operator—If the operator fails to sequence his control switches in the proper order or conditions change requiring a mode change, the proper control switch selection will be displayed. Example: "Select Autoload" would be displayed if a system ready order was given and the Operator Mode switch was set to Off or Simulate.

- A sequential series of step by step instructions to be performed by the operator in order to resolve a system malfunction. Example, assume that the Load-to-Fire sequence has progressed to the point where: the Charge in Breech firing interlock lamp has illuminated; that the system has stopped; and that the Charge Tray Down and Latched interlock lamp has failed to illuminate.

  Before directing the operator to perform an action, the on-line monitor checks the system electrical power supplies, hydraulic pressure, sensor circuits, and whether or not the charge tray rammer has cleared the breech. The on-line monitor would then display: "Manually latch charge tray". After this is accomplished and the "area clear" interlock is once again made, the load-to-fire sequence continues; i.e. the breech closes and the firing circuit is energized.

To further investigate the problem, the operating mode switch may be positioned to "maintenance mode". With the step control switches and sequential step by step instructions provided by the on-line monitor, both electrical and mechanical faults can be quickly isolated.

- If information gained from system sensors through on-line monitor self-test programs are sufficient to pin-point the problem without operator interaction, corrective action will be called out. Example: "Replace circuit board PCB1".

Use of "maintenance mode" and the step control switches will require specialized training which may be beyond the training requirements for the operator. If this is the case, the step control switches should be packaged separately as a part of a plug-in unit and made available only to trained maintenance personnel.

The Online Monitor offers quick accurate responses to system malfunctions. It allows personnel with lower skill levels to successfully operate and maintain the auto-loading system as well as providing valuable imbedded training to maintain and/or improve skills thus improving combat readiness.

V OPERATIONAL DESCRIPTION

Prior to a firing demonstration, the full length propelling charges are prezoned and the projectile/fuze combination is selected and assembled. The ammunition components are then manually loaded into the appropriate ready ammunition drums. As each round component is loaded, its type identification is manually entered into the control system memory. The control system also automatically enters the cell location into memory, thus providing the capability for automatic selection of any projectile or charge zone combination.

At the start of the load cycle, the ready ammunition drums automatically index to bring the requested projectile and propelling charge to the transfer position. With the loading arm latched in the horizontal position and the transfer trays aligned with the selected row of cells in the respective ready ammunition drums, the appropriate projectile and propelling charge transfer drive chains are extended, simultaneously sliding both the selected projectile and propelling charge into their respective transfer trays. The ammunition components are captured in the transfer trays by the latch pawls and the loading arm is released to rotate downward toward the elevated gun tube. The projectile transfer tray also begins its rotation to the "at breech" position. With the loading arm latched in position at the elevated gun tube and the projectile tray in the "at breech" position, the projectile rammer is extended to ram the projectile to a position one inch inside the breech face where it is decelerated and restrained in that position.

As soon as the rammer is retracted clear of the breech, the projectile tray can be lowered to the outboard transfer position. As the projectile tray clears the area, the waiting propelling charge tray begins raising into position.

Both the projectile restrainer and the propelling charge restrainer are cammed clear as the tray arrives at the breech position. With the propelling charge tray at the breech, the associated rammer slowly extends to close the gap between the propelling charge and the projectile, it then accelerates and rams the complete round into the chamber. With the base of the propelling charge in position one inch beyond the breech face the breech block is raised partially to retain the charge and the rammer retracted.

Breech closure and movement of the propelling charge tray toward the outboard transfer position are initiated as soon as the rammer is retracted clear of the breech ring. The cannon is ready to fire as soon as the propelling charge tray is latched in the outboard position.

After firing, the cannon recoils into the space between the two lowered transfer trays. At the initiation of counter-recoil, the breech is automatically opened. Subsequent to the completion of counter-recoil, the loading arm is released to move toward the horizontal transfer position.

Given a continuous load/fire order, the transfer trays will move to the appropriate transfer position during the loading arm raise cycle, if necessary. With the loading arm at the horizontal, the transfer drive chains begin to transfer the next projectile and propelling charge.

As indicated in the time cycle chart of figure 16, this sequence requires 5.8 seconds.

VI QUANTITATIVE SYSTEM CHARACTERISTICS

In this section the operating time cycle, a power requirements analysis and a weight analysis are presented for the demonstration prototype autoloader system.

• OPERATING TIME CYCLE

A time line analysis of the autoloader operation sequence is presented in figure 16. As shown, the sequence is initiated assuming that the first round has been chambered and the second round has been pre-positioned in the transfer trays prior to the firing mission. The sequence starts as round 1 is fired, the 2nd round will be fired 4.19 seconds later followed by round 3, 5.8 seconds later. The total time for the first 3 rounds is thus 9.99 seconds. All subsequent rounds will be fired at 5.8 second intervals, and thus the sustained rate of fire is 10.3 rounds per minute.

The time cycle chart also provides information concerning the maximum time for each event in the loading cycle and the timing of its execution in the sequence. For instance, reference to the chart will show that no ammunition handling equipment is moved or ammunition transfer attempted during the 0.5 second recoil/counterrecoil cycle while the vehicle reaction to the firing impulse is generating the highest accelerations.

• ESTIMATED SYSTEM WEIGHT

It is estimated that the demonstration prototype autoloader would weigh 5,105 pounds without fluids or ammunition. Assuming an average weight of 104 pounds and 30 pounds respectively for projectiles and propelling charges, the total system dry weight including ammunition would be 7,517 pounds.

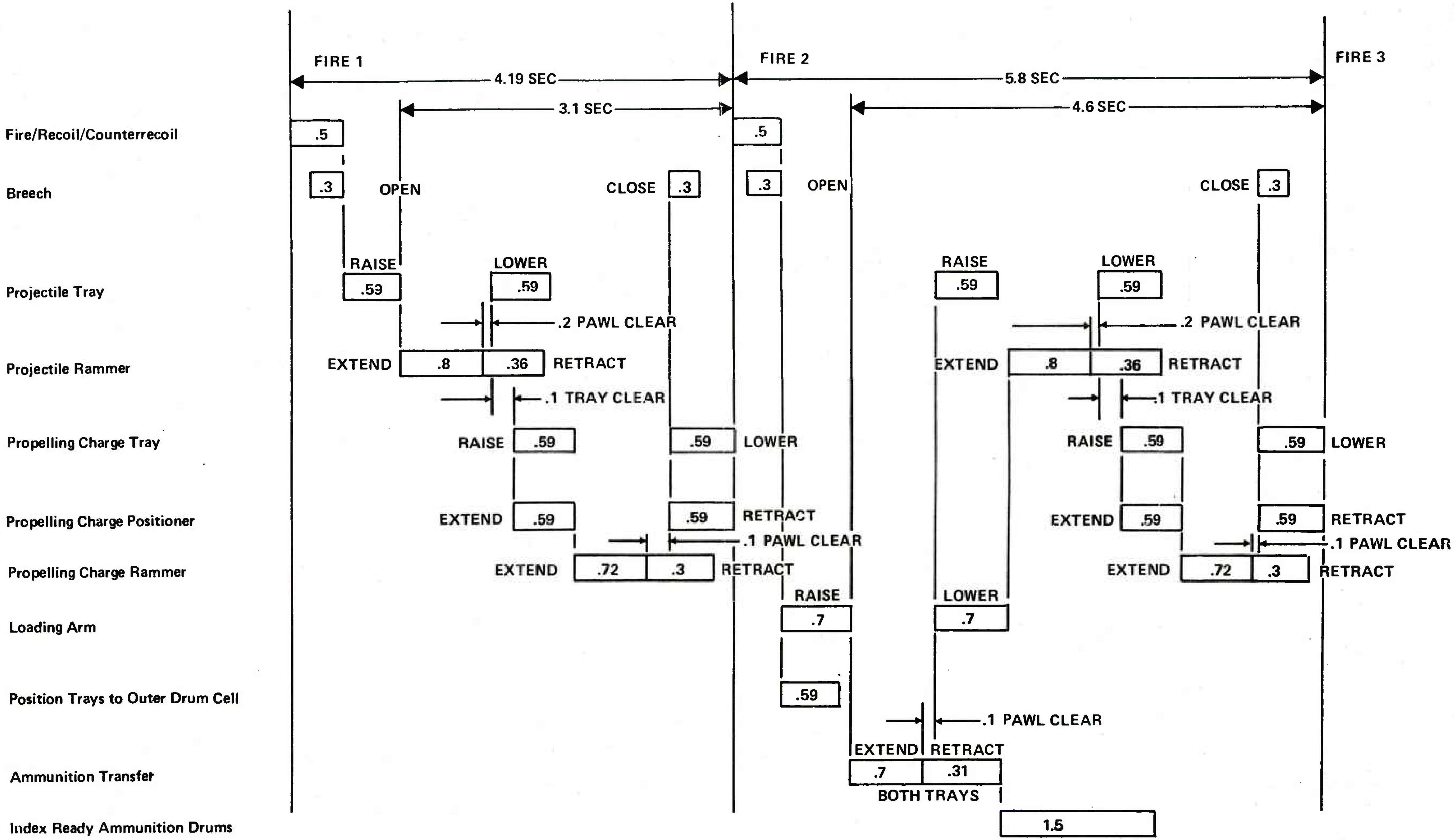

Figure 16. Auto-Loader System Time Cycle

Table 17 shows the distribution of this estimated weight over the various system components. The weight of the external hydraulic power source, the electrical power source and the interconnection lines and/or slipring is not included in this estimate.

Table 17. Automatic Loading System Weight Analysis

	Projectile Side (Pounds)	Propellant Side (Pounds)
Ready Ammunition Drums	840	840
Drum Index Drives	105	105
Transfer Chain Drives (2)	375	375
Transfer Trays (Complete with rammers)	300	330
Loading Arm Drive Cylinders	54	54
Loading Arm Down Buffers	40	40
Transfer Tray Drive Cylinders	50	50
Subtotals	1764	1794
Total		3588
Ammunition Drum Support Structure		265
Loading Arm Structure		360
Rammer Control		35
Loading Arm Latches & Control		124
Proj. & Propellant Reload Trays		40
Elec. Cabling & Hydraulic Piping		435
Misc.		173
Control Panel		85
Subtotal		1517
Total		5105

Figure 17. Automatic Loading System Weig.ıt Analysis

POWER REQUIREMENTS

An analysis of fluid consumption for a firing cycle is presented in Table 18. The total consumption for each full cycle is 311.39 cubic inches. Based on a pump/accumulator hydraulic supply system which would maintain pressure between 1775-2000 psi, the average available pressure would be 1888 psi. Given the stated consumption, pressure and cycle time of 5.8 seconds--the power requirement would be 15.4 horsepower for continuous fire. This will require a minimum pump delivery rate of 14 gallons per minute to maintain the 10.3 round per minute firing rate.

Table 18. Fluid/Energy Consumption During Loading and Firing Cycle

Functional Component	Operation	Fluid Usage (in^3) Each Operation	Fluid Usage (in^3) Functional Component	Component Energy Consumption (%)
Projectile transfer tray	Raise to breech	9.83		
	Lower to inner ring	6.86		
	Position to outer ring	4.17	20.86	6.7%
Projectile rammer	Extend	8.03		
	Retract	5.24	13.27	4.3%
Prop. charge transfer tray	Raise to breech	9.83		
	Lower to inner ring	6.86		
	Position to outer ring	4.17	20.86	6.7%
Prop. charge positioner	Extend	2.82		
	Retract	5.42	8.24	2.7%
Prop. charge rammer	Extend	13.27		
	Retract	6.55	19.82	6.4%
Loading arm	Raise	53.05		
	Lower	87.05	140.1	45.0%
Transfer drives (2)	Extend	29.50		
	Retract	14.60	44.1	14.2%
Index drives (2)	Index	14.14	14.14	4.5%
System Internal Leakage		30.00	30.00	9.5%
	Total per cycle	311.39 in^3		100.0%

Assuming an average pressure of 1,388 psi, the average horsepower required for continuous firing is 15.36 hp.

Figure 18. Automatic Loading System Fluid Consumption

VII OTHER CONSIDERATIONS

This section presents views and commentary on overall system issues which have an impact on autoloader system design but which were not studied in depth under this contract effort. These issues include: resupply concepts, manual backups, requirements for interfacing components, and the design of equipment to withstand shock and vibration.

• RESUPPLY

The subject of replenishment or resupply of ammunition to the ready ammunition drums was not extensively studied during the subject contract. Primarily, because the outside interfaces were not sufficiently well defined. The specific design approach to resupply is driven by the mechanization concepts to be employed by the ARSV or other ammunition resupply vehicle.

The initial design approach taken in this study effort was to provide for replenishment of the ready ammunition drums from the front of the drums, i.e., the replenishing personnel are inside the vehicle.

As shown in figure 19, a hinged tray is provided at the forward drum support structure. The tray may be manually hinged down into a horizontal position for on-load or off-load of ammunition. Its primary function is to provide ease of alignment with the cell in the ready ammunition drum. As discussed in section IV, a local switch is provided to enable the person who is replenishing the drum to initiate a drum index cycle. Note, when the system is in the replenish mode of operation, all other hydraulically powered equipment is inhibited from operating to ensure the safety of the reload personnel.

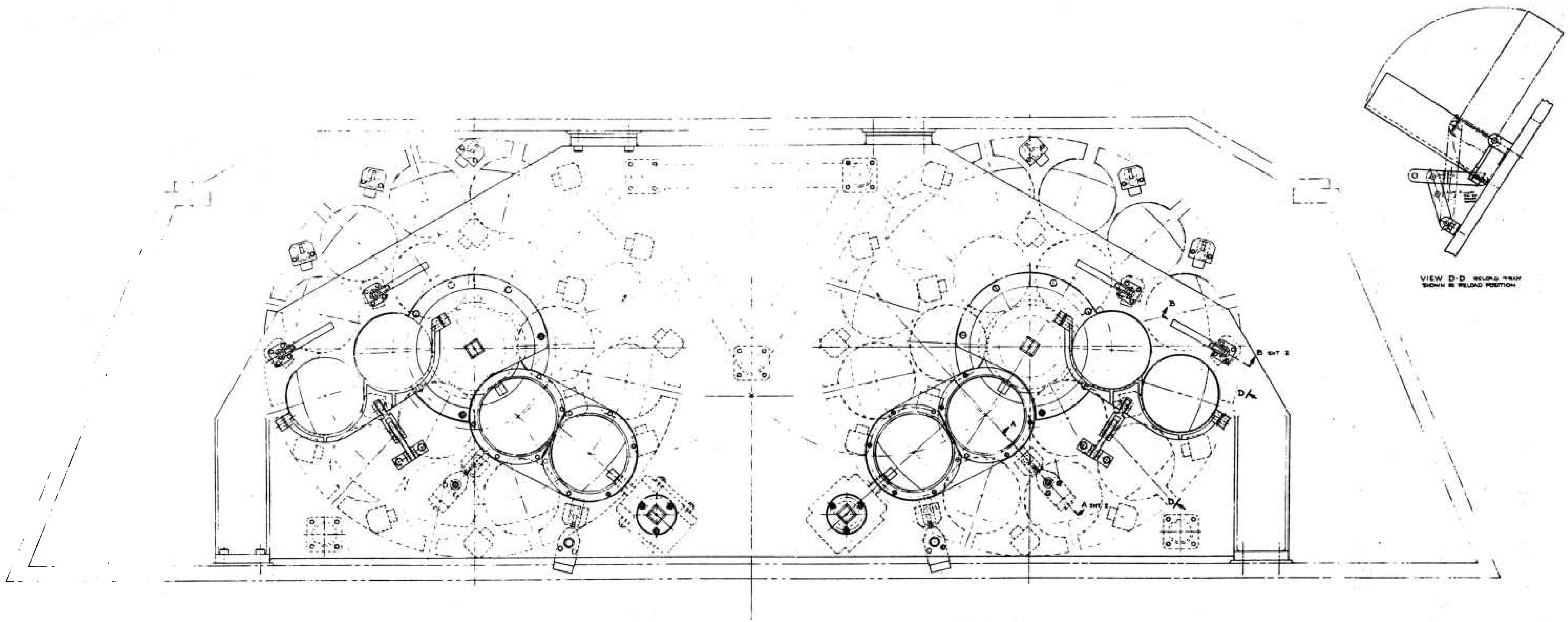

Figure 19. Ready Ammunition Drums/Reload Tray—View Looking Aft

While this approach to replenishment is believed to be the correct one for a demonstration prototype autoloading system, it is almost certainly not the primary resupply approach which would be used for an operational system in a combat vehicle. The most likely access for reload will be from the rear of the vehicle and thus the ammunition drums will have to provide for access to each row of cells from the rear as well as the front. Some minor redesign of the drum support bearings and the supporting structure will be necessary to accomplish this. Again, the specific design will depend upon the specific ARSV/SPH resupply concept.

- MANUAL BACKUPS

The study of manual backup approaches to be employed with such a system remains to be studied. This is a complex subject. It is clear at this point in the autoloader concept study that provisions for various levels of degraded mode operation of the overall weapon system are necessary. Malfunctions of automatic equipment are going to occur, both as a result of equipment failure and combat damage. In some portions of the weapon system the approaches to be used to obtain either degraded semi-automatic operation or manual operation are fairly straight-forward and understood. In other portions of the system however, there are unresolved design problems which need further study.

Those areas which seem well resolved at this point include:

- The firing mechanism, which can be quickly replaced with another assembly.

- The breech, which can have manual backup operation similar to current manually operated breeches.

- The cannon laying drives, which can incorporate manual backup concepts similar to present systems.

- Rearm or replenishment will most likely be a semi-automatic, manually controlled operation and full manual operation does not appear to require any new concepts or additional hardware.

The primary area where unresolved design problems exist is in the autoloading system. The problem of designing a high speed automatic loading system with large, powered handling equipment which could also safely accommodate personnel in direct interface has not been heretofore attempted. Naval automatic gun systems have tended in the other direction—to keep personnel clear of this potentially dangerous machinery when it is in operation.

It is clear, however, that a successful automatic cannon system for field artillery will require semi-automatic operation, possibly partial automatic/partial manual operation and certainly full manual backup operation. The exact approaches and concepts to accomplish this will require further study and FMC/NOD recommends that this be accomplished in the next phase of auto-loader development. What is needed are design concepts which will allow personnel to safely enter the weapon compartment and perform manual backup functions safely with portions of the automatic system disabled and/or with the entire system disabled. The goal here is "graceful degration", with full manual backup as the baseline degraded mode of operation. Such a system can provide a combat capability no poorer than the existing M109 SPH when all automatic systems are down.

• INTERFACING COMPONENTS

A successful cannon automatic loading system for artillery will require careful integration with those weapon elements with which it directly interfaces. Those elements include: breech, firing mechanism, recoil system, gun chamber, and the cannon laying drives. Based on this and previous study work, the following genera characteristics for these components are recommended.

Breech

A fully automatic power operated sliding wedge breech is highly desirable. The use of hydraulically power operated breech with sensors and initiators identical to those employed on the autoloader, enhances the safety and reliability of the combined autoloader breech operational sequence. Breech position is readily assessed and operation directed by the weapon control system.

Another important benefit of power operation is that the breech opening and lcosing sequence can be optimized for operation with the autoloader and independent of the recoil system, thus the breech operating mechanism does not require adjustment to compensate for cold weather operation or different propelling charge zones.

Firing Mechanism

To obtain interface with the autoloader (weapon) control system, an electrically initiated primer is required. The primers could be electrically fired separate primers or the primer could be integral with the charge. In the case of separate primers, an automatic feed mechanism including a magazine would be necessary at the back of the breechblock.

Recoil System

The key issue with the recoil mechanism is the necessity for a short recoil/counterrecoil cycle. The total cycle time should not exceed 0.75 seconds in order to maintain the desired high firing rate. This recoil/counterrecoil cycle time is similar to the cycle time achieved on the automatic naval guns designed at FMC/NOD and that goal is realistic. Further, a fire-at-battery or conventional recoil cycle is recommended. With a conventional recoil cycle, the loading operations may occur with the gun tube at the forward in-battery position. During recoil/counterrecoil, the loading equipment is raised to clear the area directly behind the breech. Thus, both the breech autoloading and the recoil functions utilize the same space at different times, and the resulting integrated approach uses the limited space within a vehicle to good advantage. The fire-out-of-battery recoil cycle does not appear to offer this space economizing advantage.

Tube Chamber

Based on the initial study effort it appears that a gently tapered or conically shaped chamber will be desirable to obtain a clean insertion of the projectile into the forcing cone. The recommended chamber configuration would thus be similar to that found in the M199 cannon tube.

Cannon Laying Drives

Although there is less direct interface between the autoloading system than the other components discussed in the foregoing, it is clear that the high rate of fire must be complemented with tube laying drives which can relay the gun tube between shots to achieve accuracy on target.

The use of an automatic closed loop laying system in both elevation and azimuth (traverse) will permit the achievement of fast accurate cannon lay during initial emplacement, accurate relay between every round during burst firing, and quick re-stow of the tube during disemplacement. The use of closed loop drives also simplifies the implementation of interlocks in the firing circuit to ensure that the gun is correctly pointed prior to enabling firing. The technology for fully automatic closed loop servo systems for laying large high inertial gun tubes for accurate indirect fire is available and is current state-of-the-art as employed on FMC/NOD designed automatic naval gun mounts.

- SHOCK/VIBRATION

The problem of shock and vibration which is transmitted to the autoloader system from the vehicle hull and turret, must be taken into account in the design of such a system. The autoloading equipment must have the ability to withstand shock loads developed by firing, movement of the vehicle, and combat damage without suffering structural damage or loss of function.

Shock and Shock Mounting

Shock is defined as a sudden and violent impact resulting in agitation of the shocked object. Generally speaking, such shocks exhibit the characteristics of imparting to the vehicle hull a high fundamental acceleration which is generally expressed as a rise time (in seconds) to some velocity together with a total displacement. It is readily seen that such an input, insofar as resulting vibratory oscillation of a damped decaying nature is concerned, is similar in its results to a pure step function input. If the shock is high enough, failure of the shocked component will result. A shock mount is normally designed to accept the relatively sudden shock displacement without imparting damaging forces to the mounted equipment. In most instances, the shock mount must be preloaded to a force level which will support the equipment in its proper alignment position under all conditions of vehicle motion and vibration.

Generally speaking, insofar as shock mitigation is concerned, it is desirable to mount a structure so that it is held firmly in place until some predetermined level of acceleration (much higher than normal operating levels) is reached. At that point, the structure can move under this acceleration level, transversing the required distance determined by the shock duration, without bottoming out. Should the device bottom out, impact shocks can exceed the shock experienced with a hard mounting. If the energy is stored in the mount (as with a pretensioned spring), then snubbing must be provided in the form of a damper to dissipate the energy.

Shock on a vehicle hull results in suddenly acquired velocities of principal structural members with resultant displacement. Transient vibrations of the structural member due to the impulse also occur. It is a well understood fact that equipments of small mass mounted to the hull may experience shock loads running into hundreds of equivalent g's, whereas equipments of large mass will experience much less. Therefore, shock mitigation may be applied to smaller masses with remarkable reduction in their loading. With the proper selection of parameters, a lightweight component that might receive 200 g's acceleration when hard-mounted could quite easily have this reduced to under 50 g's with a shock mitigator.

However, when attempting to design a shock-mitigating device for larger masses such as those represented by the major component elements of the subject autoloader system, it must be remembered that, when hard-mounted, such masses may see equivalent g's of approximately 20 to 40 g's and that reduction or mitigation is extremely difficult to achieve. While such a device could be built, its size and weight would become prohibitive. For instance, the largest military qualified mount is the 5M 10000-H mount which has a capacity of 10,000 pounds mounting load. This mount has a natural frequency of approximately 5 cycles per second when loaded with a mass near 10,000 pounds and bottoms out after a very small travel under shock. It is quite large in size (14.6 inches by 20 inches).

Further, any kind of shock mount which can permit motion of sizable degree under normal operation must necessarily result in misalignments to other associated equipments such that functions are impaired.

Thus, to date, the general practice in the design of relatively large ordnance systems mounted in both vehicles and naval ships has been one of "shock hardening." By "shock hardening" it is meant that equipment is hard-mounted but its structural members are so designed as to "take it." Much can be done in the equipment design to alleviate the problems arising from this shock loading through proper analysis methods.

A nominal value of 20 g's acceleration on all three axis was provided by ARRADCOM/LCWSL representatives. This is generally similar to design shock levels used in the design of automatic weapons handling equipment for the naval ship environment and the structures of the preliminary autoloader design are quite similar to those typically used for that environment. One of the recommended efforts to be undertaken as follow on work to this contract is a thorough structural analysis of the system structure employing a dynamic modal analysis, to establish the exact structural behavior of the various system elements and the shock levels to which various subsystem components will be subjected.

Vibration and Vibration Mounts

Vibration is a periodic motion which reverses its direction twice every cycle. Vibration is usually considered to be of a sinusoidal nature, where amplitude and period are repetitive under a fixed forcing function. However, in complex structures, this uniformity is seldom realized. The vibratory motion is generally more complex as engendered by the frequency of the forcing function and the natural frequencies inherent in the various parts of the system.

For a simple single degree of freedom system having a single fundamental or natural frequency, with near zero damping, the amplitude becomes nearly infinite under a forcing function of that same frequency (resonance), but decreases rapidly as the forcing function deviates from the natural frequency. In such a simple system, the amplitude of vibration is equal to approximately twice that of the forcing function when the forcing function frequency is approximately 3/4 of the natural frequency and is equal to approximately 1/3 that of the forcing function when the forcing function frequency is twice the natural frequency.

Velocity damping in a system, is that property which opposes motion by the generation of a force proportional to the velocity of motion. Damping has the effect (depending on its magnitude) of drastically reducing the resonant frequency amplitude as well as providing some amplitude reduction at all frequencies.

In systems of two degrees of freedom, two natural frequencies with corresponding resonances will be exhibited under exploration with a forcing function throughout the frequency spectrum. Inertial damping is achieved when a single degree of freedom system with a particular natural frequency has added to it a mass spring system which has the same natural frequency. Inertial damping can be applied in such manner as to reduce nearly to zero the amplitude of the system at its natural frequency; but this gives rise to two new resonance peaks above and below the natural frequency.

In general, vibration isolation mounts work in the principle of reducing the natural (first mode) frequency of the system below its normal excitation frequency. Suppose, for example, that a system has a natural frequency of 10 Hertz and is subject only to excitations near 10 Hertz. The addition of an isolation mount which tunes the system to approximately 2 Hertz (or 20 percent of the natural frequency) will reduce the vibration amplitude to approximately 5 percent of the driving amplitude.

Vibration isolators, to be effective for vehicle mounted weapon installations must incorporate damping as well as provide for lowering the natural frequency of the mounted system. Such isolators are best used on small components.

It is readily seen that to prevent vibration being imparted to the structure, "soft" mounts are required. Such mounts have a detrimental effect when subjected to shock. Thus, shock mitigation and vibration isolation mountings are not compatible when relatively large mass structures are under consideration.

The general approach in other large caliber ammunition handling systems has been to design structural members such that their natural frequencies are well above the forcing frequencies. Design guideline data obtained from FMC/OED indicate that the frequency range generally encountered in tracked vehicles is in the range of 0 to 100 Hertz. This is somewhat higher than those encountered in naval ordnance design but the generally smaller more compact nature of the equipment contemplated for SPH autoloading appears to be inherently stiffer and the achievement of sufficiently high natural frequencies does not appear to pose a significant design problem. The recommended follow on dynamic system analysis for the design of the system structure to achieve "shock hardening" will also provide the necessary data to relative to validating the design relative to its natural frequency characteristics.

VIII RELIABILITY AND MAINTAINABILITY

Contract DAAK10-79-C-0188 requires the contractor to prepare and deliver reliability and maintainability models which predict the reliability/maintainability which may be expected of the design concept. This addendum to report is prepared to satisfy that requirement.

Reliability and maintainability prediction for a complex system still in the concept design stage can be made by comparing functionally similar systems, subsystems, or subassemblies. A family of automatic naval guns and automatic guided missile launching systems as designed, developed, and manufactured by FMC/Northern Ordnance Division exists. Of these, the 5-Inch/54-Caliber Gun Mount Mark 42 Mod 10 was selected for comparison purposes. This automatic gun system offers functionally similar subassemblies/subsystems and enjoys world-wide deployment. The reliability/maintainability data base is the largest and best available for an automatic gun in the medium/large caliber range.

This data base represents 1970's field experience with medium/large caliber automatic gun technology of the 1960's. The method employed herein was to compare equivalent subsystems/subassemblies of the two systems with respect to functional, mechanical, hydraulic, and electrical complexities and operational requirements. Failures incurred by the subsystems in the reference 5-inch gun mount were evaluated and interpreted in terms of probability of occurance in similar subsystems of the demonstration prototype 155 mm SPH Automatic Loading and Handling System.

In addition to the assumed validity of basing a reliability prediction for a gun loading system on experience data of an ancestral system, it is further assumed that the functional subsystems are series connected, failures rates are constant, and failures of the subsystems are exponentially distributed.

Since the data base provides single value results for a given parameter, the resulting estimates for the subject 155 mm automatic loading and handling system are necessarily also single value estimates. The selection of the subsystem/subassembly level for which estimates are provided is based upon having data available down to that assembly level.

The reliability data is presented in failure events per million rounds ($\lambda.10^{-6}$ rounds) and in mean rounds between mission critical failures ($MRBF_{CR}$). The following assumptions were made to develop the maintainability data.

- The system fires 465 rounds per year

- The system is operated 44,264 hours per year

The maintainability data is presented in terms of total mean downtime of the system for a given mix of mission/maintenance profiles.

- SUMMARIZED DATA

155 mm Demonstration Prototype Automatic Loading and Handling System for a Self-Propelled Howitzer

—	Mean Rounds Between Mission Critical Failures	$MRBF_{CR}$	= 4873
—	Failure Rate (Mission Critical Failures)	$_{CR}$	= 205.192 x 10^{-6} rounds
—	Mean Time Between Failures (Mission Critical Failures)	MTBF	= 464 hours
—	Time/Rounds Proportion	0.0951923	
—	Mean Rounds Between Failures (All Failures)	$MRBF_T$	= 1608
—	Failure Rate (All Failures)	$_T$	= 6.52949 x 10^{-4} rounds
—	Mean Time Between Failures (All Failures)	$MTBF_T$	= 153.151 hours
—	Total Mean Down Time		15.83 hours
—	Mean Time to Repair		0.80 hours
—	Preventive Maintenance Hours/Year		20 hours
—	Man-Hours/Round		0.043
—	Availability		0.736

- RELIABILITY ESTIMATE

Based on the method and assumptions outlived in the foregoing, two reliability models were developed.

The first of these is shown in figure 20, 155 mm Demonstration Prototype Auto Loader Reliability (based on 1960's automatic gun technology). The estimates in this first model are developed soley from the Mk 42 Mod 10 data base and represent the failure rates one would expect using 1960's automatic gun technology as represented by that data base.

The second model as shown in figure 21, 155 mm Demonstration Prototype Auto Loader Reliability (based on 1980's Automatic Gun Technology). The estimates of this model represents failure rates that FMC/Northern Ordnance Division expects to achieve given the automatic gun technology of the 1980's. These are considered to be realistic design goals. These estimates are based on an upgrade of the Mk 42 Mod 10 experience as a result of:

a) Technology—Component:

Advances in component/material technology are expected to yield improvements in RAM-D.

b) Technology—Design:

Systems Analysis techniques, the designs-to-RAM-D approach, as well as major design features such as BITE and modular componentry, are expected to mature RAM-D significantly in the late 1980's.

	$\lambda \cdot 10^{-6}$ RNDS	$MRBF_{CR}$
AUTO LOADER SYSTEM	332.054	3012
GUN CONTROL SYSTEM	0.344	2908087
FEED SYSTEM	265.448	3767
LOADING ARM	22.070	4.5310
PROPELLING CHARGE TRANSFER TRAY	65.278	15319
PROJECTILE TRANSFER TRAY	109.469	9135
PROJECTILE RAMMER	33.902	29497
PROPELLING CHARGE RAMMER	22.615	44219
PROPELLING CHARGE POSITIONER	12.114	82547
READY AMMUNITION MAGAZINE	66.262	15092
PROPELLING CHARGE LOADER DRIVE	2.478	403510
PROPELLING CHARGE LOADER DRIVE	2.478	403510
PROJECTILE LOADER DRIVE	3.706	269858
PROJECTILE LOADER DRIVE	3.706	269858
PROJECTILE DRUM INDEX DRIVE	25.749	38836
PROPELLING CHARGE DRUM INDEX DRIVE	25.749	38836
PROJECTILE AND PROPELLING CHARGE SNUBBERS	2.397	417134

λ = Failure Events per Million Rounds

$MRBF_{CR}$ = Mean Rounds Between Mission Critical Failures

Figure 20. 155 mm Auto Loader Reliability (Based on 1960's Automatic Gun Technology)

	$\lambda \cdot 10^{-6}$ RNDS	$MRBF_{CR}$
AUTO LOADER SYSTEM	205.192	4873
GUN CONTROL SYSTEM	0.294	3399204
FEED SYSTEM	165.334	6048
LOADING ARM	17.286	57850
PROPELLING CHARGE TRANSFER TRAY	38.970	25661
PROJECTILE TRANSFER TRAY	64.952	15396
PROJECTILE RAMMER	20.886	47879
PROPELLING CHARGE RAMMER	13.928	71799
PROPELLING CHARGE POSITIONER	9.309	107420
READY AMMUNITION MAGAZINE	39.567	25274
PROPELLING CHARGE LOADER DRIVE	2.142	466817
PROPELLING CHARGE LOADER DRIVE	2.142	466817
PROJECTILE LOADER DRIVE	2.889	346105
PROJECTILE LOADER AMMUNITION DRIVE	2.889	346105
PROJECTILE DRUM INDEX DRIVE	14.625	68378
PROPELLING CHARGE DRUM INDEX DRIVE	14.625	68378
PROJECTILE AND PROPELLING CHARGE SNUBBERS	0.245	4086747

λ = Failure Events per Million Rounds

$MRBF_{CR}$ = Mean Rounds Between Mission Critical Failure

Figure 21. 155 mm Auto Loader Reliability (Based on 1980's Automatic Gun Technology)

• MAINTAINABILITY ESTIMATE

The maintainability estimates for the 155 mm demonstration prototype automatic loading and handling system for a self-propelled howitzer, are based upon historical experience, subjective evaluation, expert judgement, and selective measurement obtained from the 5-Inch/54-Caliber Gun Mount Mark 42 Mod 10 data base. The estimates have been adjusted to reflect the late 1980's automatic gun technology.

The analytic foundation for the task analysis procedure is presented in the following:

Preventive Maintenance Task Analysis

The task times for preventive maintenance actions P_m are given by:

$$PDT_M = \sum_{i=1}^{M} T_{i_M}$$

Where:

PDT_M = The total preventive maintenance time for action P_m

T_{i_M} = The time to perform the maintenance task on end item I_i as required by action P_m

Corrective Action Task Time Analysis

The system end items I_i which can cause identifiable malfunction during P_m or operational function O_r are given by:

For action P_m:

$$T_{i_M} = \left[\Sigma\, T_{s_{i_m}} \right] + T_{c_{i_M}} + T_{v_{i_M}}$$

Where:

T_{i_M} = The total time required to correct malfunctioning end item I_i during P_m of an operational function

$T_{s_{i_M}}$ = The troubleshooting test times required to isolate end item I_i during action P_m

$T_{c_{i_M}}$ = The time required to remove, replace, adjust, or otherwise repair malfunctioning end item T_i during action P_m

$T_{v_{i_M}}$ = The time required to verify that the system is good, given that I_i is replaced, repaired, adjusted etc., during action P_m

For action O_r:

$$T_{i_R} = \left[\Sigma T_{s_{i_R}} \right] + T_{c_{i_R}} + T_{v_{i_R}}$$

Where:

T_{i_R} = The total time required to correct malfunctioning end item I_i during operation O_r

$T_{s_{i_R}}$ = The fault isolation test times required to isolate end item I_i during function O_r

$T_{c_{i_R}}$ = The time required to remove, replace, adjust, calibrate or otherwise correct the malfunctioning end item I_i during function O_r

$T_{v_{i_R}}$ = The time required to verify that the system is good, given that I_i is replaced, repaired, adjusted, etc., during function O_r

In addition, the time to isolate the non-repairable end item groups is given by:

$$T_{j_M} = \Sigma T_{s_{j_M}}$$

Where:

T_{j_M} = The total time required to isolate the jth group during P_m of an operational function

$T_{s_{j_M}}$ = The trouble shooting time required to isolate the jth group during action P_m

The time required to isolate the non-repairable end item groups during function O_r is given by:

$$T_{j_R} = \Sigma\, T_{s_{i_R}}$$

Where:

T_{j_R} = The total time required to isolate the jth group during the function O_r

$T_{s_{j_R}}$ = The troubleshooting time required to isolate the jth group during function O_r

The mean-corrective-downtime ($MCDT_m$) during action P_m is given by:

$$MCDT_M = \left[\left[\Sigma\lambda i_M \cdot T_{i_M} \right] + \left[\Sigma\lambda i_{j_M} \cdot \Sigma T_{s_{j_M}} \right] \right] / \left[\Sigma\lambda i_M + \Sigma\lambda i_{j_M} \right]$$

Where:

$MCDT_M$ = The mean-corrective-downtime for the system during action P_m of an operational function

λ_{i_M} = The failure rate of detectable malfunctioning end item I_i during action P_m

$\lambda_{i_{j_M}}$ = The failure rate of the ith end item in the jth non-repairable group which can be isolated during action P_m

The mean-corrective-downtime of the system ($MCDT_R$) during operation O_r is given by:

$$MCDT_R = \left[\left[\Sigma\lambda i_R \cdot T_{i_R} \right] + \left[\Sigma\lambda i_{j_R} \cdot \Sigma T_{s_{i_R}} \right] \right] / \left[\Sigma\lambda i_R + \Sigma\lambda i_{j_R} \right]$$

Where:

$MCDT_R$ = The mean-corrective-downtime for the system during function O_r

$\lambda_{i_{j_R}}$ = The failure rate of the ith end item in the jth non-repairable group which can be isolated during function O_r

Total Maintenance Task Analysis

The total time required to perform preventive maintenance, is given by:

$$PDT_T = \Sigma \; A_M \; PDT_M$$

Where:

PDT_T. = Total preventive-downtime during the specified calendar time

M = Frequency of occurrence of the Mth preventive maintenance action during the specified calendar time

The mean corrective downtime for the system is derived from the mission/maintenance profiles.

$$MCDT_S = \left[\Sigma \left[\lambda_{i_R} + \lambda_{i_{g_R}} \right] \cdot MCDT_R + \Sigma \left[\lambda_{i_M} + \lambda_{i_M} \right] \cdot MCDT_M \right] / \left[\Sigma \left[\lambda_{i_R} + \lambda_{i_{G_R}} \right] + \Sigma \left[\lambda_{i_M} + \lambda_{i_{g_M}} \right] \right]$$

The total mean-corrective-downtime of the system for the mission maintenance profile is given by:

$$MCDT_T = F \left[MCDT_S \right]$$

Where:

$MCDT_T$ = The total mean-corrective-downtime of the system for the mission/maintenance-profile

F = The number of detectable failures occurring during the calendar time

The total mean downtime of the system with a specified mission/maintenance profile is given by:

$$T_P = \Sigma A_M \cdot PTT_M + MDCT_T$$

Where:

T_P = Total mean downtime of the system with a specified mission/maintenance profile for the calendar time

A_M = The frequency of the occurrence of the action P_m during the calendar period

The use of a mix of mission/maintenance profiles for the system gives a total mean-downtime of:

$$T_T = \Sigma A_P \cdot T_P / \Sigma A_P$$

Where:

T_T = The total mean-downtime of the system for a given mix of mission/maintenance profiles

A_P = The frequency with which the P^{th} mission maintenance profile will occur during the calendar time.

The availability of the autoloader system is:

$$A = \frac{\text{(Total up time)}}{\text{(Total up time)} + \text{(total down time)}}$$

Figure 22 presents the estimated annual total mean-downtime for the total system and the subsystems, given the technology of the late 1980's.

	T_T (Hours)
AUTO LOADER SYSTEM	15.83
GUN CONTROL SYSTEM	0.02
FEED SYSTEM	12.76
LOADING ARM	1.33
PROPELLING CHARGE TRANSFER TRAY	3.01
PROJECTILE TRANSFER TRAY	5.01
PROJECTILE RAMMER	1.61
PROPELLING CHARGE RAMMER	1.08
PROPELLING CHARGE POSITIONER	0.72
READY AMMUNITION MAGAZINE	3.05
PROPELLING CHARGE LOADER DRIVE	0.17
PROPELLING CHARGE LOADER DRIVE	0.17
PROJECTILE LOADER DRIVE	0.22
PROJECTILE LOADER DRIVE	0.22
PROJECTILE DRUM INDEX DRIVE	1.13
PROPELLING CHARGE DRUM INDEX DRIVE	1.13
PROJECTILE AND PROPELLING CHARGE SNUBBERS	0.02

T_T = Total Mean Downtime

Figure 22. 155 Autoloader Maintainability (Based on 1980's Automatic Gun Technology)

DISTRIBUTION LIST

Assistant Secretary of the Army
Research and Development
ATTN: Department for Science
and Technology
The Pentagon
Washington, DC 20315

Commander
U.S. Army Materiel Development and
Readiness Command
ATTN: DRCDE
5001 Eisenhower Avenue
Alexandria, VA 22333

Commander
U.S. Army Armament Research and
Development Command
ATTN: DRDAR-LC
DRDAR-LCA
DRDAR-LCN
DRDAR-LCU
DRDAR-LCE
DRDAR-LCM
DRDAR-LCS
DRDAR-LCB
DRDAR-TSS (5)
Dover, NJ 07801

Commander
U.S. Army Armament Materiel
Readiness Command
ATTN: DRSAR-LE
DRSAR-LEP-L
Rock Island, IL 61299

Director
Ballistics Research Laboratory
U.S. Army Armament Research and
Development Command
ATTN: DRDAR-TSB-S
Aberdeen Proving Ground, MD 21005

Commander
U.S. Army Electronics Command
ATTN: Technical Library
Ft Monmouth, NJ 07703

Commander
U.S. Army Mobility Equipment Research
and Development Command
ATTN: Technical Library
Ft Belvoir, VA 22060

Commander
U.S. Army Tank-Automotive Research
and Development Command
ATTN: DRDTA-UL
DRDTA-RK
Warren, MI 48090

Commander
U.S. Military Academy
ATTN: CHMN, Mechanical Engineer Dept
West Point, NY 10996

Commander
Redstone Scientific Information Center
U.S. Army Missile Research and
Development Command
ATTN: DRSMI-RB
DRSMI-RRS
DRSMI-RSM
Redstone Arsenal, AL 35809

Commander
Rock Island Arsenal
ATTN: SARRI-ENM (Mat Sci Div)
Rock Island, IL 61202

Commander
HQ, U.S. Army Aviation School
ATTN: Office of the Librarian
Ft Rucker, AL 36362

Commander
U.S. Army Foreign Science and
Technology Center
ATTN: DRXST-SD
220 7th Street, N.E.
Charlottesville, VA 22901

Commander
U.S. Army Materials and Mechanics
Research Center
ATTN: DRXMR-PL (Tech Library) (2)
Watertown, MA 02172

Commander
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709

Commander
Harry Diamond Laboratories
ATTN: Technical Library
2800 Powder Mill Road
Adelphia, MD 20783

Director
U.S. Army Industrial Base
Engineering Activity
ATTN: DRXPE-MT
Rock Island, IL 61201

Chief, Materials Branch
U.S. Army R&S Group, Europe
Box 65, FPO NY 09510

Director
U.S. Naval Research Laboratory
ATTN: Director, Mech Div
Code 26-27 (DOC Library)
Washington, DC 20375

NASA Scientific and Technical
Information Facility
P.O. Box 8757
ATTN: ACQ Branch
Baltimore/Washington Intern'l Airport,
MD 21240

Administrator
Defense Technical Information Center
ATTN: Accessions Division (12)
Cameron Station
Alexandria, VA 22314

Metals and Ceramics Information Center
Battelle Columbus Laboratory
505 King Avenue
Columbus, OH 43201

Mechanical Properties Data Center
Battelle Columbus Laboratory
505 King Avenue
Columbus, OH 43201

Director
U.S. Army Materiel Systems
Analysis Activity
ATTN: DRXSY-MP
Aberdeen Proving Ground, MD 21005

Commander/Director
Chemical Systems Laboratory
U.S. Army Armament Research and
Development Command
ATTN: DRDAR-CLJ-L
DRDAR-CLB-PA
APG, Edgewood Area, MD 21010

Chief
Benet Weapons Laboratory, LCWSL
U.S. Army Armament Research and
Development Command
ATTN: DRDAR-LCB-TL
Watervliet, NY 12189

Director
U.S. Army TRADOC Systems
Analysis Activity
ATTN: ATAA-SL
White Sands Missile Range, NM 88002