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'EVELOPMENT OF A LINEAR LINKLESS EED SYSTEM

MERSON ELECTRIC COMPANY
100 WEST FLORISSANT
T. LOUIS, MISSOURI 63136

ANUARY 1975

FINAL REPORT: JUNE 1974 - DECEMBER 1974

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The Linear Linkless Storage and Feed System was required to interface with a multibarrel gun similar in configuration to the GAU-8A and the ammunition and gun bays of the F-15 aircraft. A linked carrier concept was used to transfer ammunition through each of two ammunition compartments operating in parallel. The ammunition is extracted from an endless belt of protective metallic carriers at the exit of each compartment, the pitch spacing between rounds is expanded, and the two separate streams of ammunition are combined for transfer

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20. ABSTRACT (CONCLUDED).

to the weapon. Misfired rounds and empty cases returning from the weapon are separated into two streams, the pitch spacing between rounds is contracted, and they are restowed in the belt of carrier elements. The carrier elements are stored inside the magazine compartments in a folded arrangement so as to best utilize the available storage volume and further reduce the linear velocity of the belt within the magazine.

As the belt translates through the magazine compartment, a series of guide tracks in the compartment walls unfold and refold the belt as it passes over a series of powered sprockets at the ends of each compartment. A separate flexible conveyor operating in flexible chuting between the combining unit and the weapon serves to isolate the fixed elements of the feed system from gun motions due to recoil and counter-recoil or boresighting.

PREFACE

This report was prepared by the Emerson Electric Company, Electronics and Space Division, 8100 West Florissant Avenue, St. Louis, Missouri 63116 under Contract No. F08635-74-C-0162 with the Air Force Armament Laboratory, Armament Development and Test Center, Eglin Air Force Base, Florida. The Program Managers for the Armament Laboratory were Major Robert F. Grasmeder and Mr. Virgil W. Miller (DLDG). This effort was conducted during the period from June 1974 to December 1974.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER:

A. D. Brown Jr.

ALFRED D. BROWN, JR., Colonel, USAF
Chief, Guns, Rockets, and Explosives Division

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION I

INTRODUCTION

This report describes the concept of a 25mm Ammunition Storage and Feed System designed to be compatible with the F-15 aircraft and a high rate of fire rotating barrel gun.

Section II, supplemented by Appendices A, B, and C, gives a functional description of the system and its operation. The manner in which the system design accommodates the interfaces with Airframe, Weapon, Power Distribution, and Control is included in the descriptions.

Section III, supported by Appendices D and E, describes the characteristics of the system as developed by analysis of the design.

The basic characteristics of the Storage and Feed System are given in Table 1.

TABLE 1. 25MM STORAGE/FEED SYSTEM CHARACTERISTICS

Storage Container	● Rectangular Box ● Power Operated ● Dual Bays ● Recirculating Conveyors
Storage Container Size	● 48.5 x 22.5 x 28.6 Inches
Transfer/Feed Mechanism	● Dual Pitch Expanders ● Multiple Conveyor Carriers ● Buckets Cam Positioned ● Flexible Conveyor Chute For Gun Motions
Ammunition Capacity	● 694 Rounds
Ammunition Feed Rate	● Gun Demand Includes Any Rate Up to 6000 Round/Min
Time to 6000 SPM Rate	● Common Drive Accelerates or Stops Weapon and Storage Container at Same Rate in 0.4 Second
Time to First Round	● System Reversible to Align First Cleared Round with First Safe Round Position in Gun
Method of Powering	● External Power Drive on Gun or Aircraft
Operating Power	● 29.6 HP, 6000 SPM Steady Rate 40.9 HP, Peak Acceleration

SECTION II

FUNCTIONAL DESCRIPTION

2.1 SYSTEM DESCRIPTION

The system described in this report is designed to be utilized on an advanced air superiority fighter to feed and store 25mm linkless ammunition. This system was selected for two reasons. First, the system offers the maximum utilization of the available volume for round storage and, secondly, significantly reduces the power required to achieve and hold firing rate. Because of the size of the round and volume limitations within the aircraft envelope, only rectangular configurations were considered. The feed and storage system consists of three primary components (Figure 1):

25mm Linear Linkless Magazine
Pitch Expander/Combining Unit
Weapon Interface Unit

The magazine consists of two storage bays operating in parallel, with each bay functioning at one-half gun rate. The ammunition within each bay is carried within and cradled by conveyor elements. This arrangement provides maximum protection of the round cases and avoids, wherever possible, rubbing of the rounds along guide surfaces. All loads required to handle the rounds within the magazine are imposed first on the conveyor elements and only indirectly upon the rounds themselves. Wherever possible, the conveyor elements are folded accordion style for increased capacity and to further reduce velocity and accelerations imposed upon the rounds.

The Pitch Expander/Combining Unit attaches to the upper right-hand corner of the magazine. The Pitch Expander extracts the rounds from the magazine conveyor elements, expands their pitch, and places the rounds into buckets carried in the combining portion of this unit. The rounds from each of the magazine bays are placed in alternate buckets which are then cammed toward the centerline of the combining unit as it is rotated.

The Weapon Interface Unit consists of a magazine turnaround unit, a weapon interface conveyor housed in flexible chutes, and a weapon turnaround unit. After the rounds are cammed into a common path, they are picked off by the lower transfer sprocket in the magazine turnaround unit and inserted into the weapon interface conveyor elements.

The rounds are cammed out of these conveyor elements as they pass over the drive sprocket in the Weapon Turnaround Unit for hand-off to the lower weapon transfer sprocket for insertion into the barrel group (Figure 2).

Fired cases are removed from the barrel group by the upper weapon transfer sprocket. This sprocket reinserts the cases back into the Weapon Interface Conveyor at the drive sprocket for restowage in the magazine.

The sections which follow describe these components in detail.

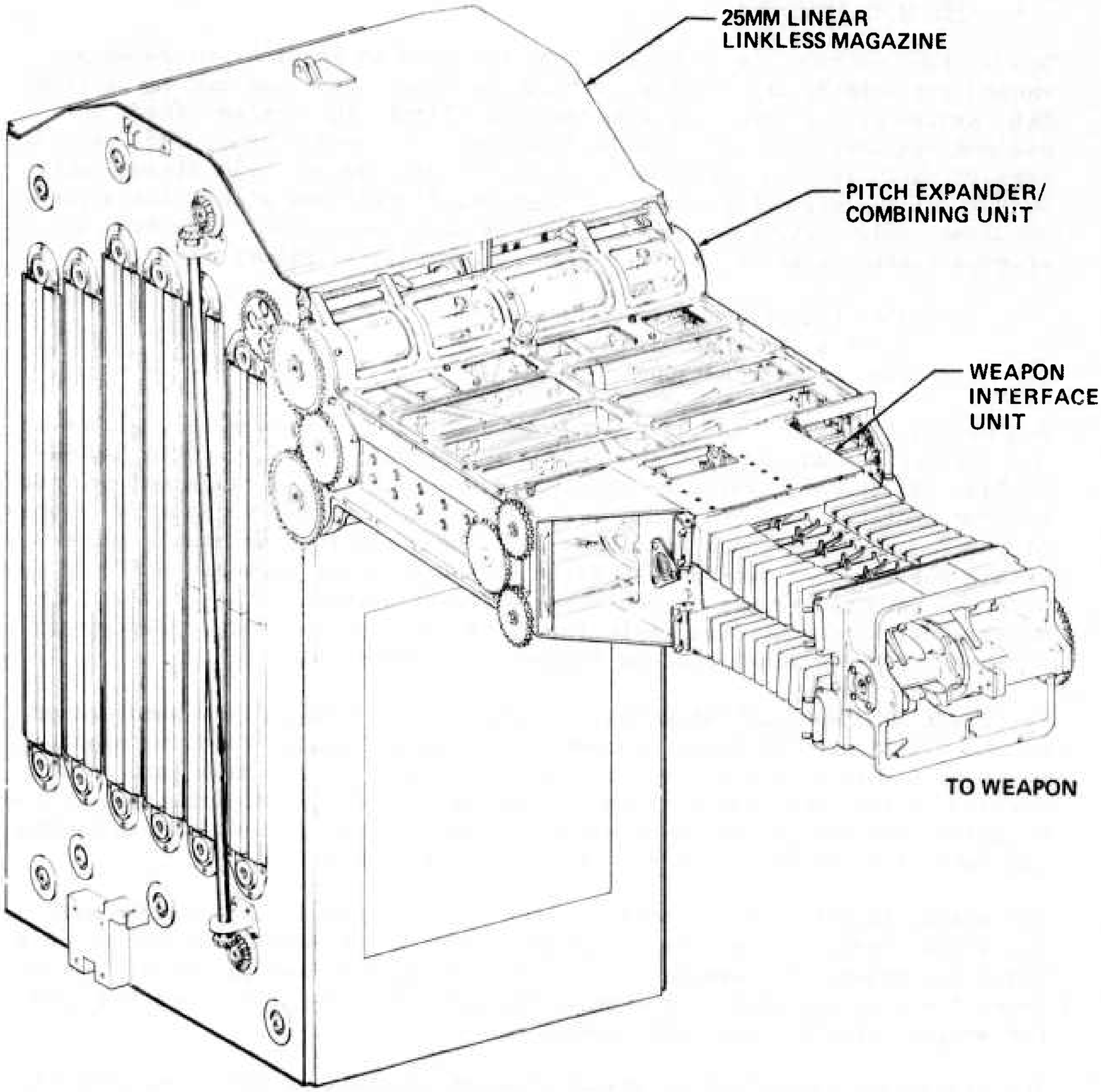


Figure 1. 25mm Linear Linkless Storage and Feed System

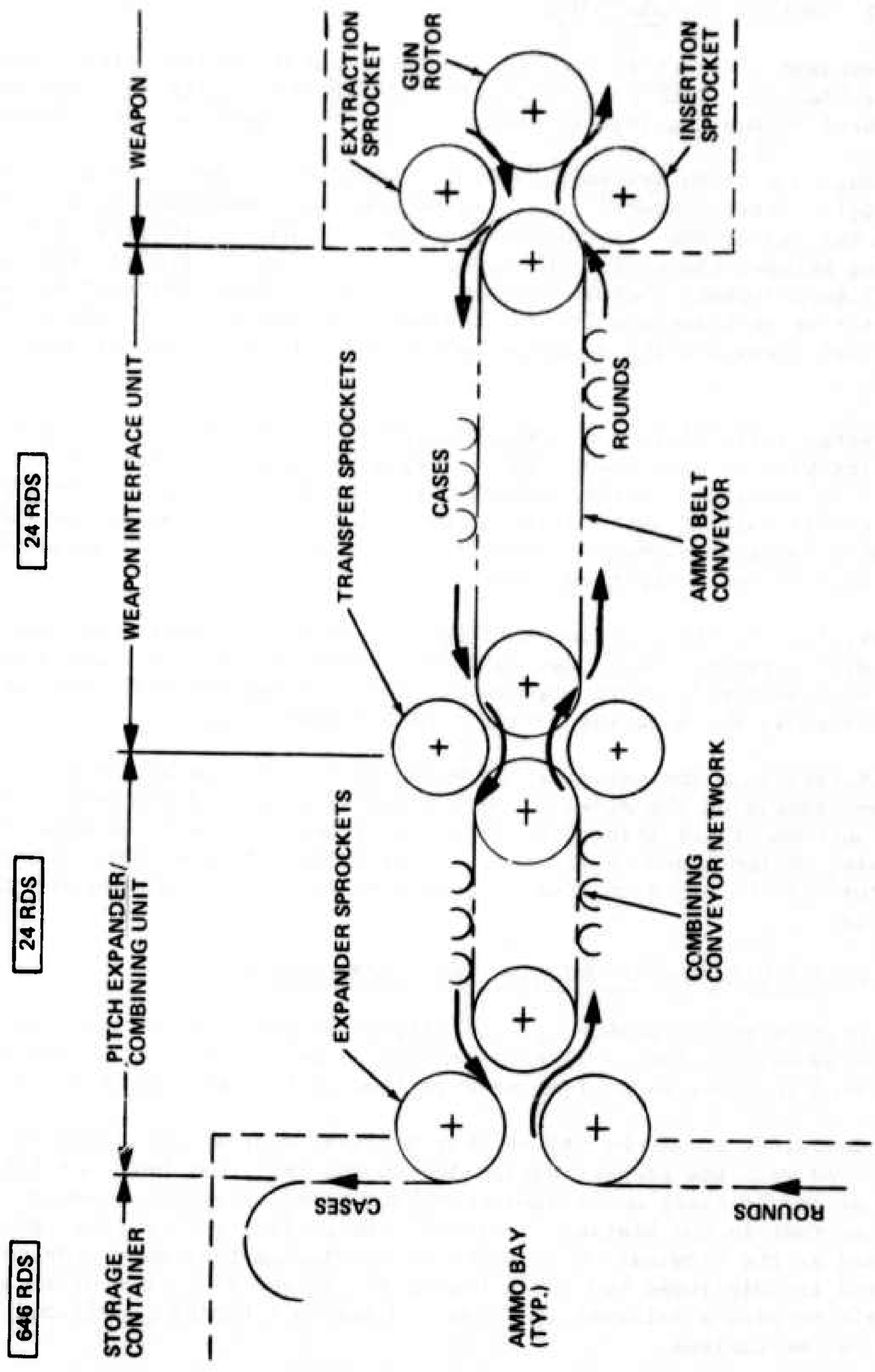


Figure 2. Ammunition Flow

2.2 SYSTEM IMPROVEMENTS

2.2.1 MAGAZINE IMPROVEMENTS

The magazine (Figure 3) has been reconfigured to achieve significant advantages (Table 2) with respect to reliability, visibility, and operation when compared to the magazine described in Emerson Report No. NB-4833-014-1.

The magazine drive system is made up entirely of conventional gearing with all drive shafts powered centrally between the ammunition bays rather than from the end of one bay, minimizing shaft windup and thereby insuring proper timing between the bays. The upper and lower drive sprocket shafts are bevel gear meshed, thereby reducing backlash between conveyor drive sprockets. Minimizing backlash results in smoother flow and better timing at the folding sprocket areas and the magazine handoff area to the pitch expander/combining unit.

Increased reliability has been achieved by alternately extending the connecting pins on each end of the conveyor elements. These extended pins track in continuous guides throughout the magazine bays. These guides form the throat path at each folding sprocket, thereby dictating the folding path of each conveyor element eliminating all dependency on the toggle effect of the conveyor elements themselves.

Protrusions to the magazine outline have also been reduced by centralizing the drive system. This results in increased aircraft envelope clearance and a reduction in protective covers required and minimizes the possibility of damage to the magazine during handling operations.

Visibility into the magazine has been improved by the addition of removable access panels on the sides of both magazine bays. In the event of a jam or malfunction or for inspection purposes, removal of these panels permits viewing of the conveyor elements in the folded state without structurally disturbing the magazine itself, resulting in reduced maintenance time required.

2.2.2 PITCH EXPANDER/COMBINING UNIT IMPROVEMENTS

The Pitch Expander/Combining Unit (Figure 8) has been designed to achieve major advantages (Table 3) with respect to operation and reliability when compared to those mechanisms as described in Emerson Report No. NB-4833-014-1.

Initially, it should be stated that a significant weight reduction has been achieved with the present design due to the fact that both the Pitch Expander and Combiner Mechanisms have been packaged within a common housing rather than in two distinct housings. Primarily, this weight reduction is caused by the elimination of mounting provisions that were previously required to join these two units together. In addition, the utilization of a single housing eliminates the need for external timing provisions between the two mechanisms.

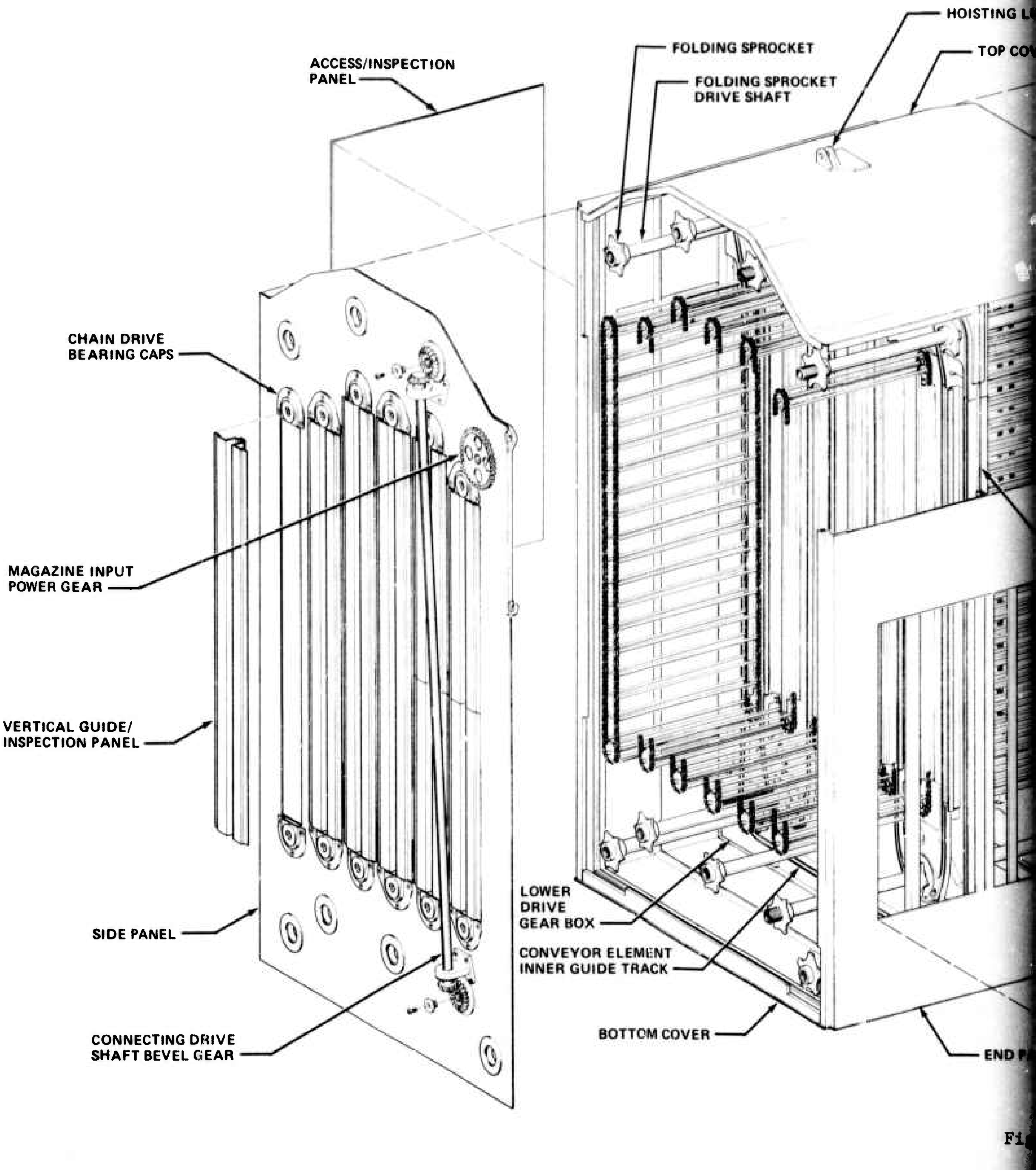
In the present design, each carrier element in the combiner mechanism is supported and guided by a steel dovetailed crossbar whereas previously this function was achieved by means of two relatively small diameter crossrods.

TABLE 2. 25MM MAGAZINE CONFIGURATION IMPROVEMENTS

MAGAZINE PER REPORT NB-4833-014-1	RECONFIGURED MAGAZINE	IMPROVEMENT
Complete Drive System Outboard	Only Input Drive Gear and Bevel Pinion Shaft Outboard	More Compact, Increased Envelope Clearance, Reduced Handling Damage Potential, Reduced Maintenance Requirement
Combined Chain and Gear Drive System	Completely Geared System	Lighter Weight Minimized Timing Problems
Upper and Lower Drive Sprockets Chain Connected	Upper and Lower Drive Sprockets Bevel Meshed	System Backlash Minimized Less Susceptible to Extended Conveyor Element Variances
Drive Sprockets and Push Rods From One End	Drive Sprockets and Push Rods Powered From Center of Bays	Minimized Shaft Windup - Improved Timing Bay to Bay
Conveyor Element Pins Flush	Conveyor Element Pins Alternately Extended Each End	No Reliance on Toggle Effect of Links For Folding, Extended Pins Provide Positive Guidance Control Throughout Bay
Fixed Side Panels	Removable Side Access Panels	Increased Access to Folded Conveyor Elements Without Structurally Disturbing Magazine. Reduced Maintenance Time In Event of Jam or Malfunction

TABLE 3. 25MM PITCH EXPANDER/COMBINING UNIT IMPROVEMENTS

PITCH/EXPANDER/ COMBINING UNIT PER REPORT NB-4833-014-1	RECONFIGURED PITCH EXPANDER/COMBINING UNIT	IMPROVEMENT
Pitch Expander and Combining Unit are Contained in Two Distinct Housings	Pitch Expander and Combining Units are Contained in a Single Housing	Reduced Weight. No Requirement For External Timing Between the Two Units.
Each Carrier Element is Supported by Two Crossrods	Each Carrier Element is Supported by an Individual Dovetailed Crossbar	Increased Stiffness. Improves the Support and Guidance of the Carrier Elements.
Utilization of a Standard 2.00 Inch Pitch Drive Chain	Utilization of a Special Articulated Drive Chain with a 1.00 Inch Pitch and Extended Cam Followers	Provides Improved Guidance of Crossbars and Carriers. Minimizes Chain Hop. Increases Strength of the Drive Chain.
Pitch Line of Drive Chain and Rounds are not on the Same Horizontal Centerline	Pitch Line of Drive Chain and Rounds are on the Same Horizontal Centerline	Rounds Undergo Minimal Accelerations and Deaccelerations as They Undergo a Transition From a Straight to a Curvilinear Path at the Sprocket.



ACCESS/INSPECTION PANEL
CHAIN DRIVE BEARING CAPS
MAGAZINE INPUT POWER GEAR
VERTICAL GUIDE/ INSPECTION PANEL
SIDE PANEL
CONNECTING DRIVE SHAFT BEVEL GEAR
FOLDING SPROCKET
FOLDING SPROCKET DRIVE SHAFT
HOISTING L
TOP CO
LOWER DRIVE GEAR BOX
CONVEYOR ELEMENT INNER GUIDE TRACK
BOTTOM COVER
END P

Fi

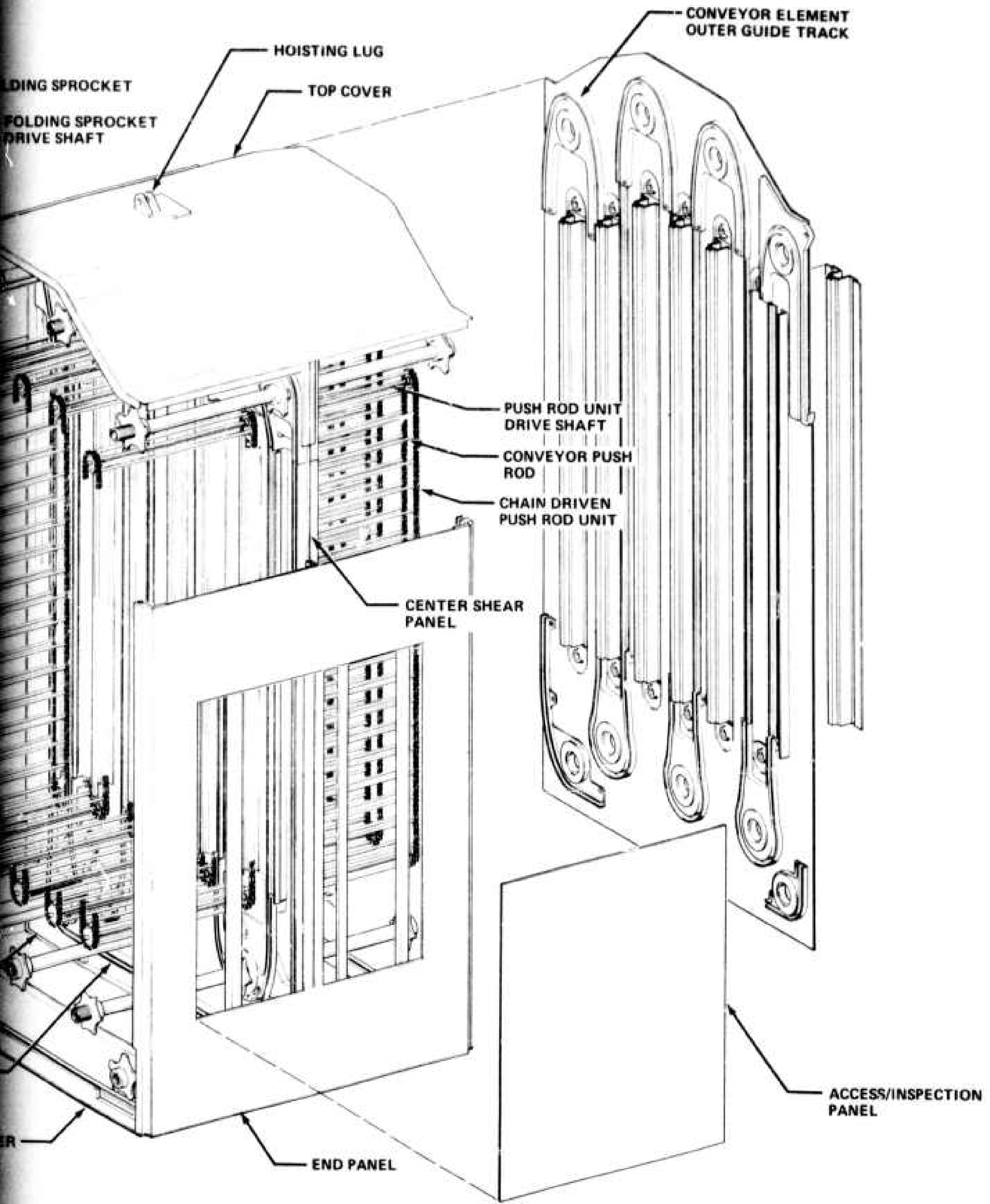


Figure 3. 25mm Linear Linkless Magazine

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This change was facilitated by the replacement of the previously specified standard roller drive chain with that of a special articulated one, thus permitting a greater design latitude in the attachment and sizing of these items. This greater design flexibility has permitted each crossbar to achieve a significant increase in stiffness as compared to that of the previous concept by the maximization of its sectional properties (EI). In addition, each crossbar has incorporated positive control features which effectively improve the guidance and support of each of the carrier elements.

As was previously mentioned, the present design utilizes a special articulated drive chain. This chain design which is comprised of a series of support and connecting links has a 1.00-inch pitch rather than the 2.00-inch pitch associated with the standard roller chain. The utilization of this reduced spacing tends to minimize "chain hop" and thus provides for a smoother transition of the chain and round carriers as they travel from a straight to a curvilinear path at the sprockets. In addition, this reduced pitch contributes to a significant reduction in shock loads and its associated power consumption at the sprockets. Besides the reduced spacing, the present drive chain concept has incorporated extended cam followers which are positioned and contained in a continuous cam track on the outboard side of these chains. These cam followers together with its cam track not only form an effective horizontal support for each of the associated crossbars, but also aids in the establishment of the previously mentioned transitional drive chain path.

In the present design configuration, the pitch line of the drive chain and the rounds have been positioned on the same horizontal centerline. This change was initiated so that the rounds would undergo only minimal accelerations and decelerations as they are led on and off of sprockets. In other words, the present design insures that the linear velocity of the round in the straight is equivalent to the tangential velocity of round in a curvilinear path at the sprocket. The end result of this change is that power consumption is minimized.

2.3 SYSTEM DESIGN

2.3.1 MAGAZINE

The magazine (Figure 3) is a dual bay magazine, utilizing maximum aircraft bay volume, with a storage capacity of 646 rounds of 25mm ammunition, 323 rounds per bay, and provides for ammunition feed at a selectable weapon demand rate.

The magazine permits restowage of all fired cases and unfired rounds returned by the pitch expander/combining unit from the weapon, and is completely reversible for round repositioning at burst termination and during the reloading cycle. The magazine is capable of being operated completely filled, partially filled or in an empty state. A closed loop linked conveyor system is contained in each magazine bay (Figure 4). The conveyor elements position and carry the rounds minimizing actual round contact with guide surfaces or folding sprockets. The conveyor routing, throughout each bay, consists primarily of a series of vertical loops, folded accordion style, terminated at each end by a six-cavity sprocket which unfolds the conveyor elements, reverses the direction of motion and refolds the belt. The conveyor belt path at the forward feed end and bottom of the magazine bay is straight line with the conveyor elements extended at their normal pitch of 1.875 inches. At the forward feed end of the magazine bay, five cavity sprockets terminate the straight line conveyor path.

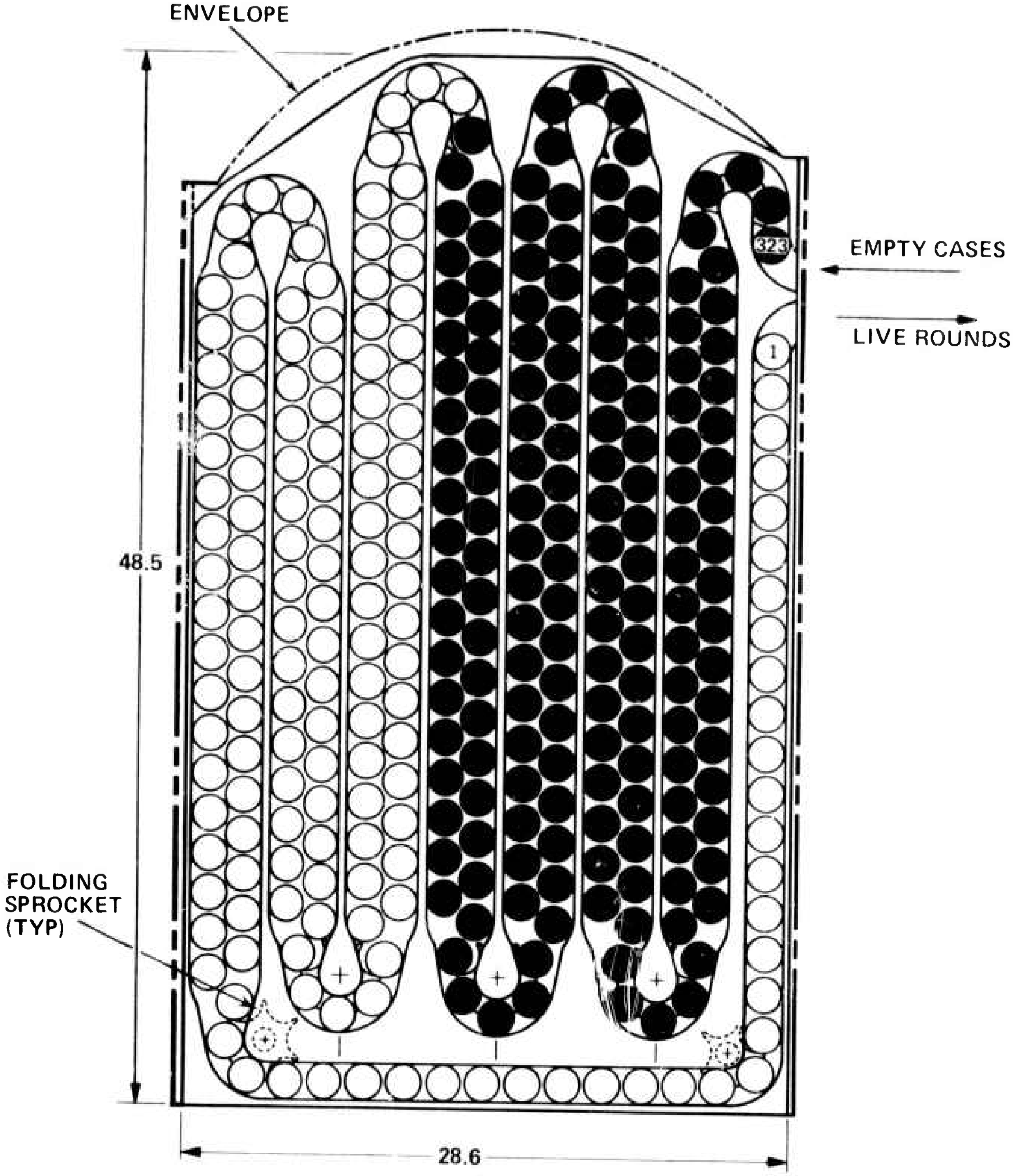


Figure 4. Storage Design

Utilization of the accordion folding technique increases the number of rounds per unit volume by 40 percent insuring high storage density and reduces the conveyor belt velocity by 50 percent of that for an extended belt (Figure 5).

With a weapon demand rate of 6000 SPM, using the dual bay magazine, each bay is required to supply 3000 SPM to the weapon.

The extended conveyor belt velocity is 93.75 inches/second

p = 1.875 inch Conveyor Pitch, SPM = 3000

$$V = \frac{SPM(P)}{60\ Sec/Min} = \frac{3000(1.875)}{60} = 93.75\ \text{inches/second}$$

The accordion folded belt velocity is 46.88 inches/second

p = 0.9375 inch Equivalent Conveyor Pitch; SPM = 3000

$$V = \frac{SPM(P)}{60\ Sec/Min} = \frac{3000(.9375)}{60} = 46.88\ \text{inches/second}$$

The conveyor elements are pinned together, with one pin on each element being an extended guide pin. The extended guide pins alternate on each end of every other conveyor element. These guide pins follow two separate closed loop guide tracks (see Figure 3) in each magazine bay, one track mounted to the center bay divider and one track mounted to the outer bay cover. These two guide tracks together form a complete and positive conveyor guide path throughout each magazine bay.

The throat geometry of the guide tracks at each folding sprocket (Figure 6) has been established by a computer program (see Appendix A) to assure smooth folding and unfolding of the conveyor elements and to minimize chain hop effects of the conveyor elements while on the sprockets.

The use of the guide pin and track design greatly increases the magazine reliability by completely eliminating dependency on the toggle effect of the conveyor elements themselves to maintain their respective folded and unfolded positions during magazine operation.

To aid in the folding and unfolding process, push rods (see Figure 3) are strategically located laterally between each conveyor element in the folded state. These push rods are fixed at their ends to closed loop chains located between each vertical folded loop in the magazine bays. The chain and push rod units are powered by gear takeoffs in the upper and lower gearboxes. The push rod drive shafts are common to both bays and extend the full width of the magazine. The rods effectively push the folded conveyor belt through each vertical loop to the folding sprockets achieving a constant conveyor velocity in the vertical loops. This reduces friction between the guide surfaces and the conveyor elements and lowers the forces exerted on the folding sprockets which reduces wear and power requirements.

The pitch spacing of the conveyor element, 1.875 inches, dictated the chain pitch which could be used. Number 35 chain was selected based upon its pitch of 0.375 inch, and a push rod is positioned at every fifth pin joint.

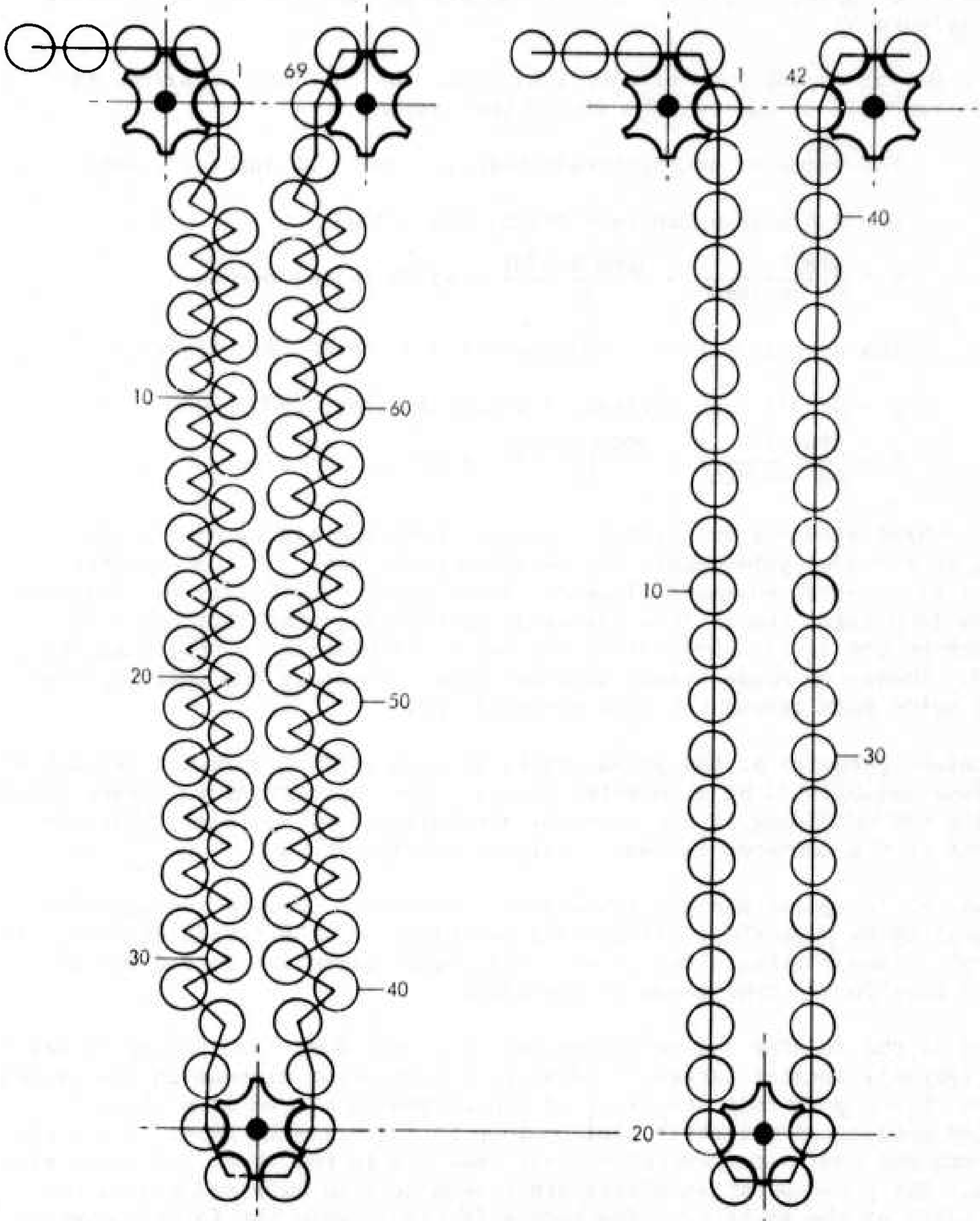


Figure 5. Folded Belt Geometry

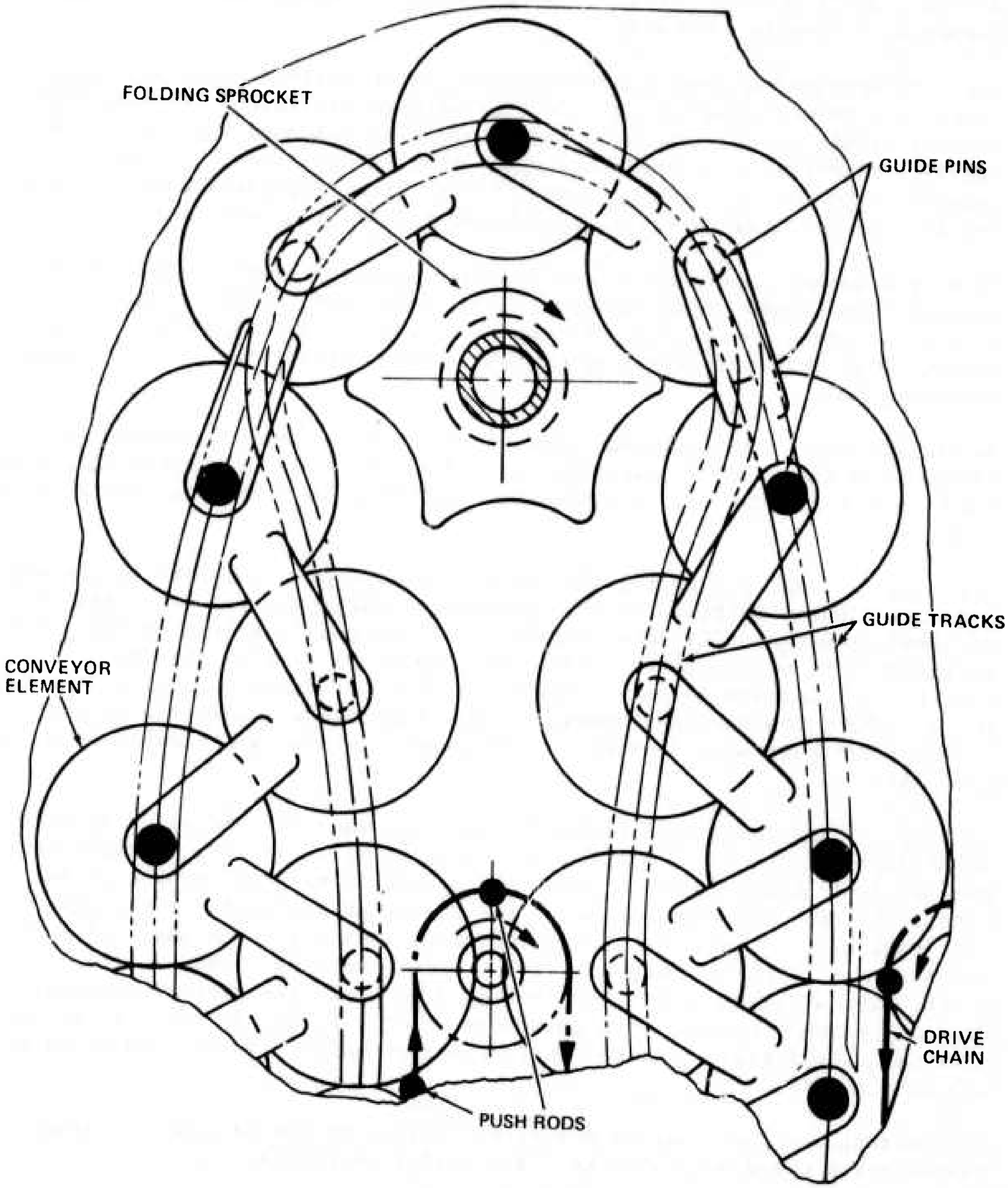


Figure 6. Folding Throat/Chain Drive

This chain has an ultimate tensile strength of 2100 pounds but is loaded to only 90 pounds at 7.5 g's inertial load. This represents an effective derating of 95 percent. Operating the chains at these low load levels will assure long trouble-free life.

Vertical extruded guides, mounted on the center divider panel and outer cover of each magazine bay, are located between the folded loops to provide support tracks for the push rod chains and side guidance for the folded conveyor elements. Openings have been provided near the top of both magazine bays for the exit of rounds to the pitch expander/combining unit and for the re-entry of cases and unfired rounds from this unit.

On weapon demand, movement of the magazine conveyor belts is initiated causing live rounds to be simultaneously cammed out of their respective conveyor elements by exit guide fingers located in the magazine opening areas, where they are picked up by the expander sprockets in pitch expander/ combining unit.

As the empty conveyor elements proceed slightly further, re-entry guide fingers cam either empty cases or unfired rounds from the expander sprockets into these empty conveyor elements for restowage in their respective magazine bays.

Locating fittings for mating the pitch expander/combining unit to the magazine are mounted outboard on the magazine at the upper and lower extremes of these openings. The lower fittings are slotted to accept external close tolerance pins on the pitch expander/combining unit while the upper fittings have close tolerance holes to accept pip pins for quick removal of the two units. The pitch expander/combining unit fittings when mated with the magazine fittings also provide for the proper lateral positioning of these two units.

In order to provide compatibility between the magazine and pitch expander/ combining unit network conveyor, the conveyor belts in each magazine bay are precisely one-half round pitch out of alignment with respect to each other. Loading and downloading of the system is accomplished through utilization of AGE equipment, mounted to an access port in the bottom of the magazine, with the complete feed system remaining intact in the aircraft. The AGE essentially consists of a multiple sprocket arrangement driven from the magazine spur gear located at W.L. 98.152 and B.L. 11.699, causing a simultaneous exit of empty cases or unfired rounds and entry of new live rounds.

This arrangement requires no additional access to insure that the lead rounds enter the system sprockets and guides correctly.

2.3.2 MAGAZINE DRIVE SYSTEM

The magazine drive system (Figure 7) is made up of the following components:

- Drive gear
- Upper gear box
- Lower gear box
- Bevel gear set connecting upper and lower gear boxes.

The magazine is driven from the pitch expander/combining unit by means of a spur gear drive.

The drive gear is located outboard on the magazine at B.L. 11.699 and W.L. 137.62 and is splined to the feed end drive shaft of the upper gear box.

This gear box powers the four upper conveyor folding sprockets and has three takeoffs for powering the push rod drive shafts located at B.L. 4.50, B.L. 3.00, and B.L. 10.50.

The lower gear box is powered from the upper gear box by a connecting double bevel pinion shaft, one pinion meshing with a bevel gear on the upper conveyor sprocket drive shaft and the other pinion meshing with the lower conveyor sprocket drive shaft. Utilizing gearing to power all conveyor drive sprockets rather than chains minimizes the backlash between the sprockets. Backlash is of particular concern between sprockets where the conveyor is running in the extended rather than the folded configuration. This occurs across the bottom of the magazine (reload area) and along the right side (pitch expander interface). Excessive backlash between sprockets in these areas would allow the conveyor to act as a redundant load path. The transmission of power through the conveyor elements would result in excessive loads and wear on the connecting pins and should be avoided. The lower gear box powers five conveyor folding sprockets and has three takeoffs for powering the push rod drive shafts located at B.L. 8.25, B.L. 0.75, and B.L. 6.75.

Conventional spur gearing is used entirely in both gear boxes with proper gear reductions (Table 4) utilized to insure simultaneous acceleration and deceleration of all conveyor elements in the magazine. Proper rotation of all conveyor and push rod drive shafts is achieved through the use of idler gears.

The gear boxes are internally mounted to the center divider panel in the magazine, with the conveyor and push rod drive shafts extending the entire width of both magazine bays. Using this approach, all drive shafts are powered from their centers, minimizing shaft windup, and maintaining proper timing of the conveyor elements between the two bays.

This drive system design incorporating all lightweight drive gears in place of comparably heavy chain and drive sprockets reduces weight and minimizes timing problems associated with chain-driven components. The problems of chain stretch and tension adjustment are eliminated by using the

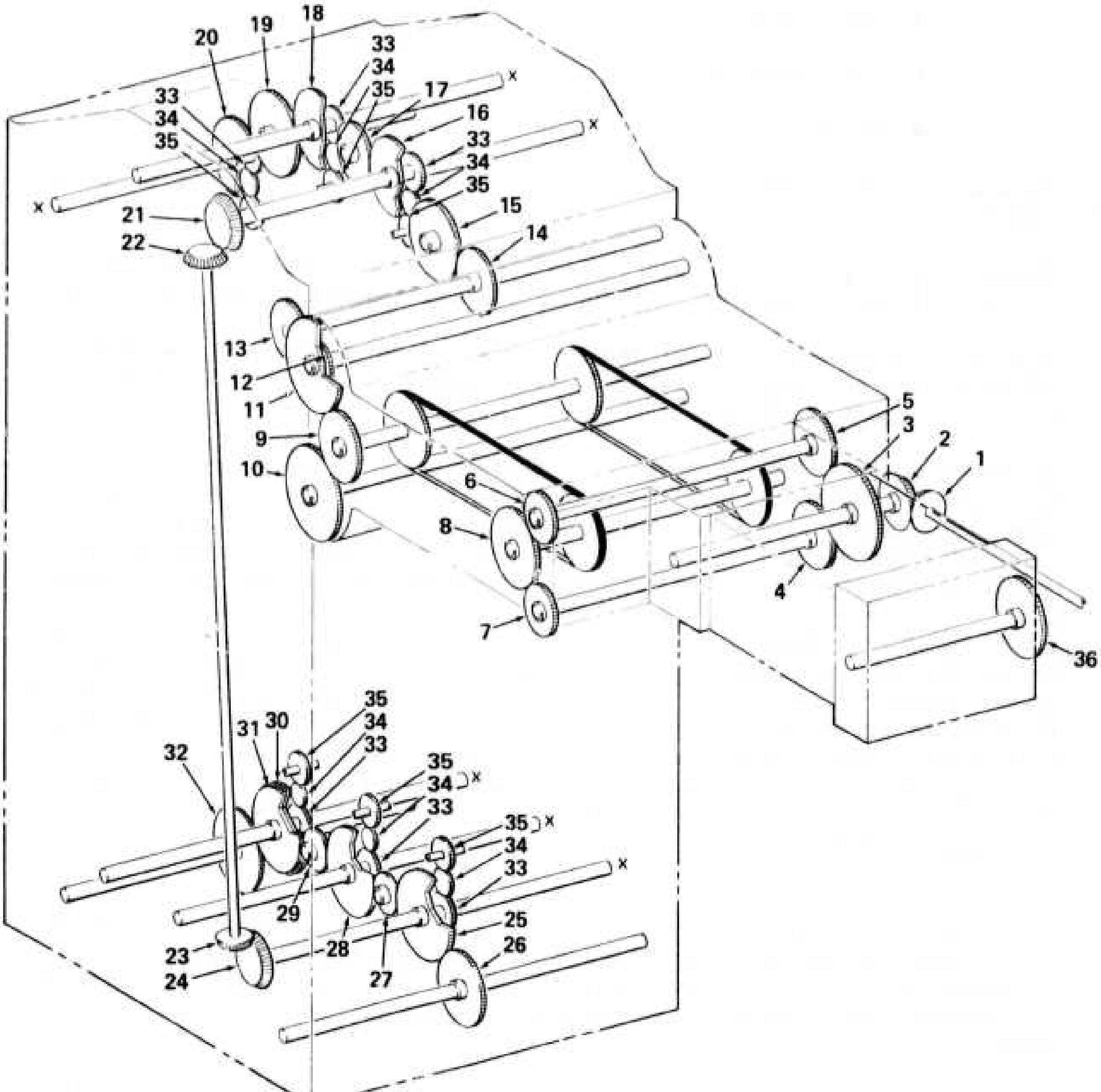


Figure 7. 25mm Magazine Drive System Schematic

TABLE 4. MAGAZINE GEAR SYSTEM

GEAR NO.	GEAR D.P.	GEAR P.D.	NO. TEETH	P.A.	RATIO WITH MATE	
13	14	3.5714	50	20°	.8 : 1	
14	10	3.500	35	20°		
15	10	4.200	42	20°	Idler	.833:1
16	10	4.200	42	20°		
17	10	3.300	33	20°	Idler	1:1
18	10	4.200	42	20°		
19	10	4.500	45	20°	Idler	1:1
20	10	4.200	42	20°		
21	16	2.000	32	20°		2:1
22	16	1.000	16	20°		
23	16	1.000	16	20°		
24	16	2.000	32	20°		1:2
25	10	4.800	48	20°		
26	10	4.000	40	20°		1:2:1
25	10	4.800	48	20°		
27	10	2.700	27	20°	Idler	
28	10	4.800	48	20°		1:1
29	10	2.700	27	20°	Idler	
30	10	4.800	48	20°		1:1
31	10	4.500	45	20°		1:1
32	10	4.500	45	20°		
33	16	3.9375	63	20°		
34	16	1.4375	23	20°	Idler	1:5:1
35	16	2.625	42	20°		

gear-driven sprockets. The only chains utilized in the current design are those powering the push rods and these are operated at loads less than 5 percent of their ultimate capability.

External timing, between the magazine and pitch expander/combining unit at assembly or disassembly in the field, is reduced to one point which occurs at the power drive gear mesh. Timing provisions are incorporated at this point such that the units cannot be mated without proper timing having been achieved.

2.3.3 MAGAZINE CONSTRUCTION

The basic magazine construction consists primarily of aluminum sheets reinforced with right-angle extrusions. The magazine utilizes a hard back center as the primary structure. The hard back consists of the center shear web, also serving as the ammunition bay divider, to which the upper and lower power drive gear boxes are attached.

The gear boxes run the full width of the center shear web, providing lateral rigidity and pickup aluminum right angle extrusions, riveted back-to-back at the sides and bottom of the center shear web. The upper magazine contour is formed by the power drive gear box which also mounts the magazine hoist fitting.

The magazine top cover consists of a formed aluminum sheet, with right-angle extrusions riveted to the outer edges providing stiffness, and is attached by fasteners to the upper gear box.

Vertical extruded guide sections are mounted to the center shear web providing continuity between the gear boxes. These guides control the conveyor in its folded configuration and provide running spaces for the push rod drive chains. The guides are secured with screws and plate nuts providing for easy removal in the event of guide damage.

Individual steel folding sprocket throat guides are piloted to their corresponding gear box bearing bores and are attached to the gear boxes and center shear web by means of fasteners. The use of individual guides reduces weight, provides for easier assembly, and minimizes maintenance time required in the event of guide damage. The repetitive use of individual guides permits economy of fabrication due to both size and quantity. The magazine bottom cover consists of a flat aluminum sheet with riveted right-angle extrusions along the sides and ends of the sheet. Reload access ports are provided in this cover. The cover attaches to the center shear web by means of fasteners and matching plate nuts mounted on the center web right-angle extrusions.

The extrusions, attached to the bottom cover and running the width of the magazine bay, also incorporate the horizontal portion of the conveyor element guide track.

The magazine end panels are constructed of aluminum sheets with right-angle extrusions riveted to their vertical edges. These extrusions incorporate the vertical portions of the conveyor element guide track. The magazine side panels consist of flat aluminum sheets, attached entirely around their periphery by fasteners to the aforementioned panels and providing continuity to the magazine.

Steel folding sprocket throat guides, housing the drive shaft bearings, are piloted to the side panels. Vertical slots are machined into the side panels in the area of the chain-driven push rod units. The chain-driven shafts are held by bearing caps, spanning the slots.

Extruded vertical guides extend into the slots between the bearing caps. These guides control the conveyor in its folded configuration and provide running space for the push rod drive chains. The guides are mounted outboard on the side panels by means of fasteners that match side panel plate nuts. Removal of these guides provides visibility to the folded conveyor elements for inspection purposes or in the event of a jam or malfunction. All gearing and drive shafts are supported by ball-type bearings containing double shields for protection from contaminants.

All drive shafts span both magazine bays with only the push rod chain and conveyor sprockets reoriented to insure that one magazine conveyor is precisely one-half round pitch-off with respect to the other conveyor to maintain proper hand-off timing to the pitch expander/combining unit.

All drive shafts, excluding the push rod chain drive shafts, are hollow-centered utilizing maximum material effectiveness. The drive sprockets and shafts are splined, with blind spline timing provisions incorporated, for ease of field service and repair. Except where noted, all fabricated magazine components are made of aluminum alloys.

2.3.4 MAGAZINE MOUNTING

Magazine mounting in the aircraft ammunition bay is accomplished by three sets of fittings which prohibit aircraft deflections from transferring loads into the magazine. These fittings are:

Ammunition magazine support - Forward bulkhead
Ammunition magazine support - Aft bulkhead
Upper and lower sideload fittings

The ammunition magazine support-forward bulkhead consists of an adjustable pivoted turnbuckle connection to the fuselage station 481.50 forward bulkhead.

The ammunition magazine support-aft bulkhead consists of a pin and seat-type fitting which locates the magazine to the lower section of the fuselage station 509.5 aft bulkhead. The fitting positions the magazine in its waterline and station positions.

The upper and lower sideload fittings locate the magazine in its buttline position. This is accomplished through closely defined fittings which locate on the aircraft vertical "tee" fittings of the forward and aft bulkheads.

In addition, these fittings serve to guide the magazine as it is hoisted into or removed from the aircraft ammunition bay.

2.3.5 PITCH EXPANDER/COMBINING UNIT

This unit consists of two distinct mechanisms, the pitch expander and the combiner, both of which are enclosed within a common housing (Figure 8). The primary function of this unit is to transport rounds from a dual bay magazine system and to combine them into a single flow of ammunition suitable for transfer to the weapon.

2.3.5.1 PITCH EXPANDER MECHANISM

The pitch expander mechanism has been designed to transfer rounds sequentially from each of the magazine bays to the combining mechanism at an expanded pitch. In order to avoid overboard discharging of spent cases and unfired rounds, provisions have been incorporated into the mechanism so as to permit the return of these items from the weapon to the magazine for stowage. The expander operates at firing rates of up to 6000 shots per minute while synchronized with the weapon. In addition, due to the necessity of weapon clearing at burst termination, the mechanism is capable of operating in the reverse direction. Finally, all of these capabilities can be performed regardless of whether the mechanism is empty, partially filled, or totally filled with complete rounds or empty cases in any combination.

The pitch expander mechanism consists of a total of four expanding sprockets that are so situated that one pair is aligned with each of the individual magazine bay openings. Each pair of sprockets has the capability of transferring rounds and cases and also of effecting a round pitch expansion or contraction prior to handoff.

In the operation of the mechanism, upon weapon demand, the two lower expander sprockets assisted by hardened steel round guides extract live rounds from each of the two magazine bays. Prior to extraction, each round must be partially cammed out of its respective carrier element by a set of magazine guide fingers so that the round guides can effectively move the extracted round into a vacant cavity of the expander sprocket. To insure a smooth extraction of rounds, each expander sprocket is designed to provide a precise velocity match of its pitch line with that of the magazine conveyor at the point of transfer. The equations used to formulate this velocity match are given below:

V_c = Linear velocity of magazine conveyor in inches/second

R = Firing rate in shots/second

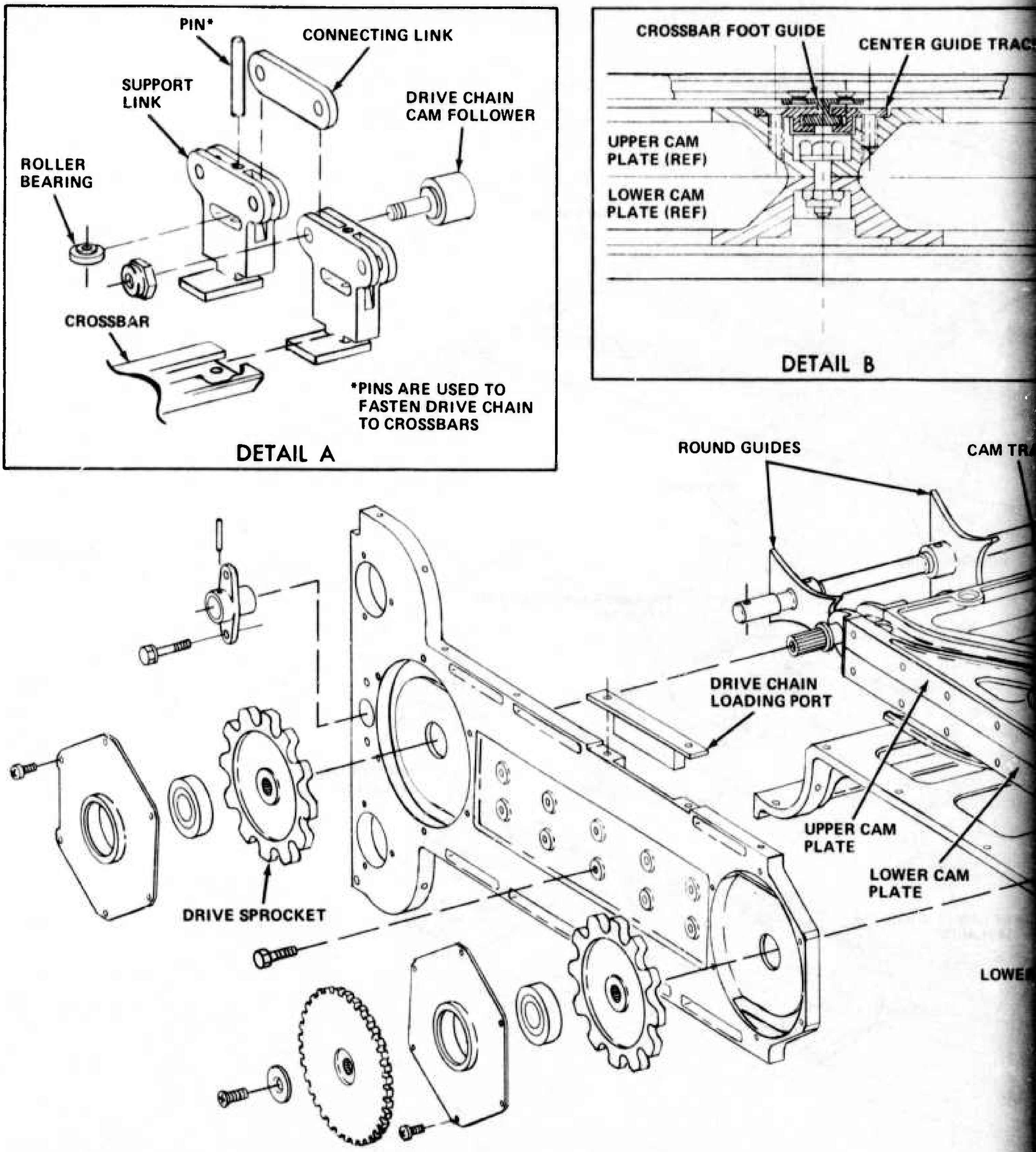
P = Pitch distance between rounds in inches

W_s = Angular velocity of expander in radians/second

N = Number of cavities in expander sprocket

V_s = Tangential velocity of expander sprocket in inches/second

Y_s = Radial distance between sprocket pitch line and the center of rotation of the expander sprocket in inches.


PIN*
CONNECTING LINK
SUPPORT LINK
DRIVE CHAIN CAM FOLLOWER
ROLLER BEARING
CROSSBAR
*PINS ARE USED TO FASTEN DRIVE CHAIN TO CROSSBARS
DETAIL A
CROSSBAR FOOT GUIDE
UPPER CAM PLATE (REF)
LOWER CAM PLATE (REF)
DETAIL B
ROUND GUIDES
DRIVE CHAIN LOADING PORT
UPPER CAM PLATE
LOWER CAM PLATE
DRIVE SPROCKET

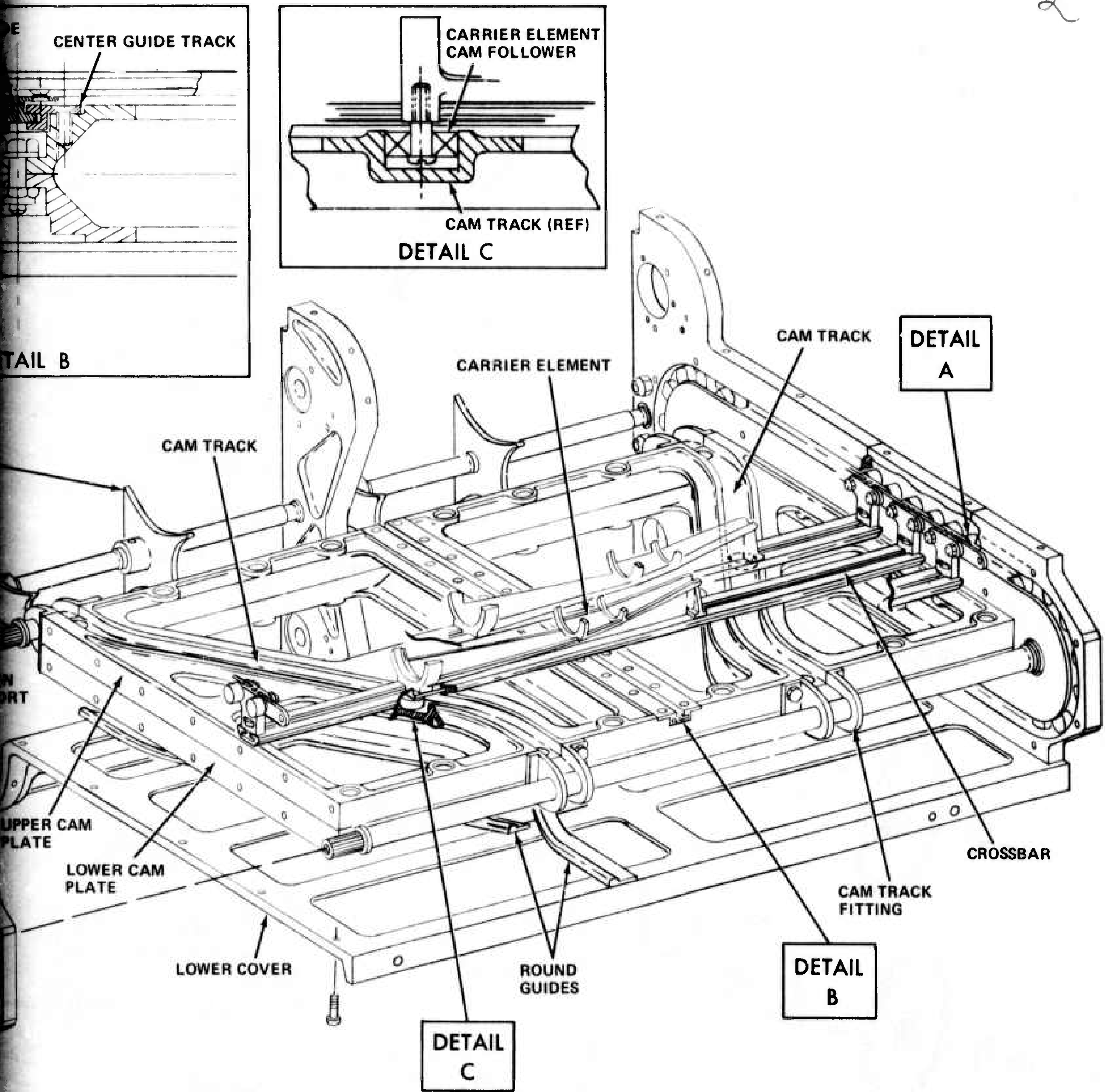


Figure 8. Pitch Expander/Combiner

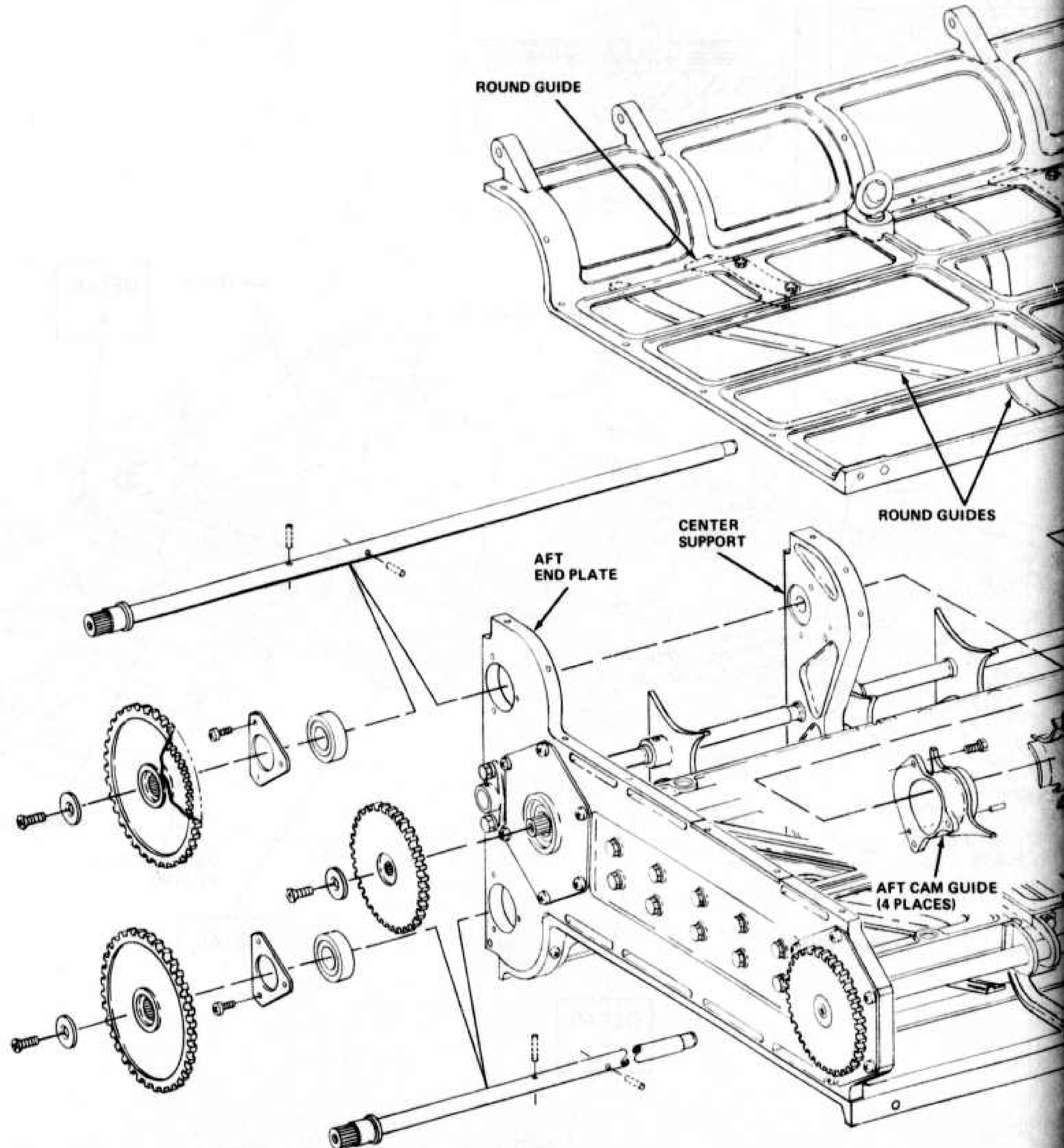
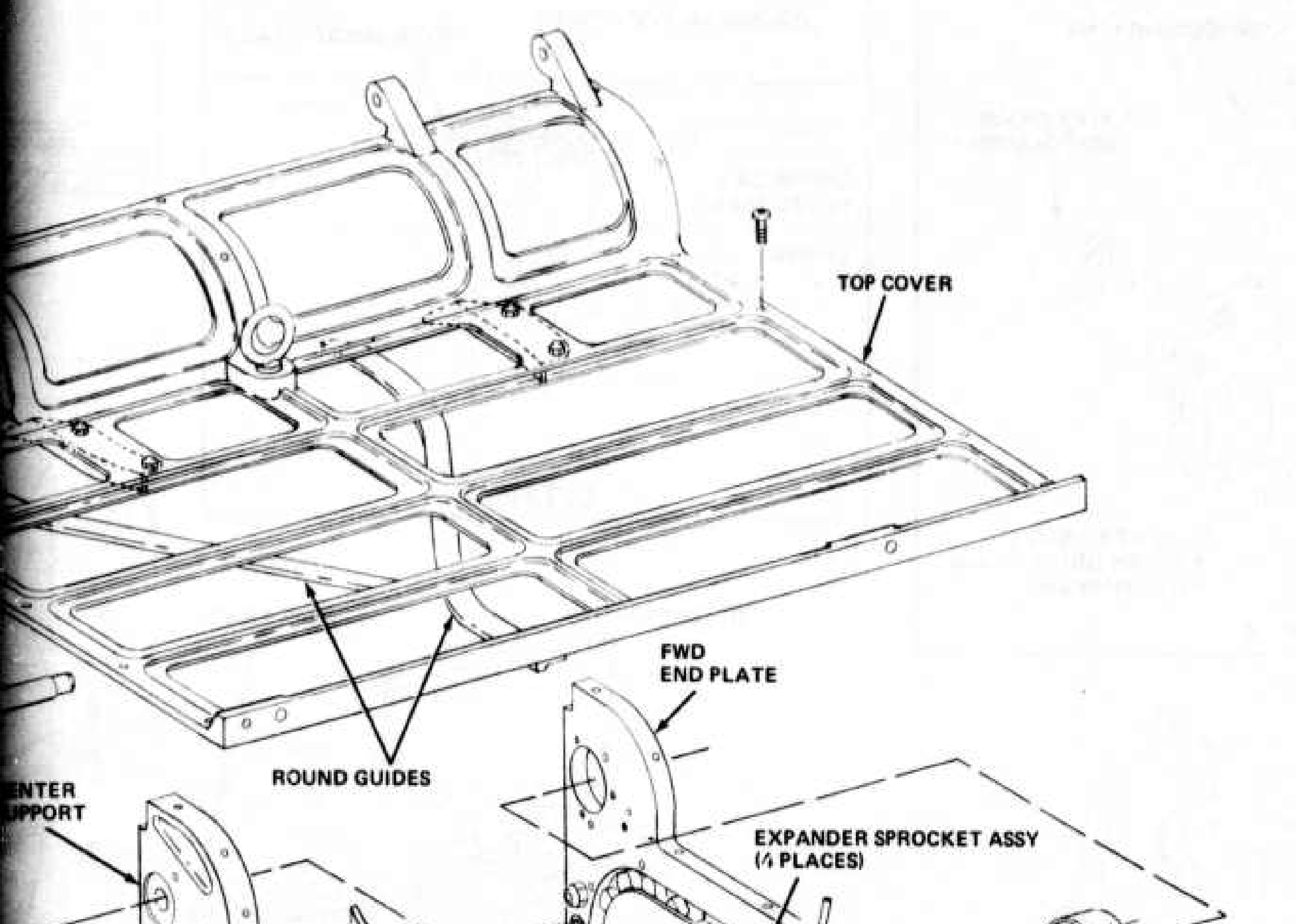


Figure 8. Pitch Expander/Combiner (Concluded)


TOP COVER
ROUND GUIDES
FWD
END PLATE
ENTER
UPPORT
EXPANDER SPROCKET ASSY
(4 PLACES)
FWD CAM GUIDE
(4 PLACES)
AFT CAM GUIDE
(4 PLACES)

ncluded)

At a maximum firing rate of 6000 shots/minute or 3000 shots/minute for each magazine bay, the following can be computed:

$$R = 3000 \text{ shots/minute} \div 60 \frac{\text{sec}}{\text{min}} = 50 \text{ SPS}$$

$$V_c = RP = (50 \text{ SPS})\ (1.875) = 93.75 \text{ inches/second}$$

For velocity matching V_c must be equal to V_s

$$V_s = 93.75 \text{ inches/second}$$

$$W_s = R2\pi/N = (50 \text{ sps})\ (2\pi)/4$$

$$W_s = 78.539 \text{ radians/second}$$

$$V_s = W_s\ r_s = 93.75 \text{ inches/second} = (78.539 \text{ radians/second})\ r_s$$

$$r_s = 1.194 \text{ inches}$$

Therefore, r_s must be 1.194 inches at the point of transfer to assure a precise velocity match. The rounds are transported within the magazine at a minimum pitch; for this reason, the pitch lines of the expander sprocket and magazine conveyor had to be separated by .210 inch to avoid, upon system reversal, the interference of the sprocket cavity sidewalls with the conveyed rounds as they retreated from the handoff point.

Subsequent to extraction, each of the lower expander sprockets must effect a pitch expansion from 1.875 inches to 4.000 inches where it is compatible with that of the combiner mechanism. The angular interval over which this expansion can occur is dictated by the timing relationship that exists between the expander sprockets and its two physical interfaces. The equations used to formulate this timing relationship and thereby establish the sprocket centers are presented in Appendix B. A computer program was developed using these equations to determine a solution which satisfied the above stipulated design parameters. The results of the program showed that three possible solutions existed, only one of which was compatible with the aircraft envelope and round geometry. This solution stipulated that the angular interval over which the pitch expansion could occur would be contained within 125°.

The expander sprockets have utilized a design philosophy similar to that which was used on the GAU-8/A feed system. This design entails the use of four expanding carriers which, when driven by a drive sprocket and controlled by a set of cam guides at each end, induces a reciprocating motion which effectively expands the pitch of the rounds contained within each of the carriers (Figure 9). Based upon extensive testing during the GAU-8/A program, it was proven that this type of mechanism was extremely reliable and durable at speeds approaching 4500 shots/minute. Design of the expansion cams was based upon cam/follower contact angle in order to minimize sensitivity of the device to friction variations. It was evident that a reduction in wear and power consumption was achieved due to the smaller frictional level. The only disadvantage encountered with this approach was that the round accelerations were somewhat higher. However, an analysis of the

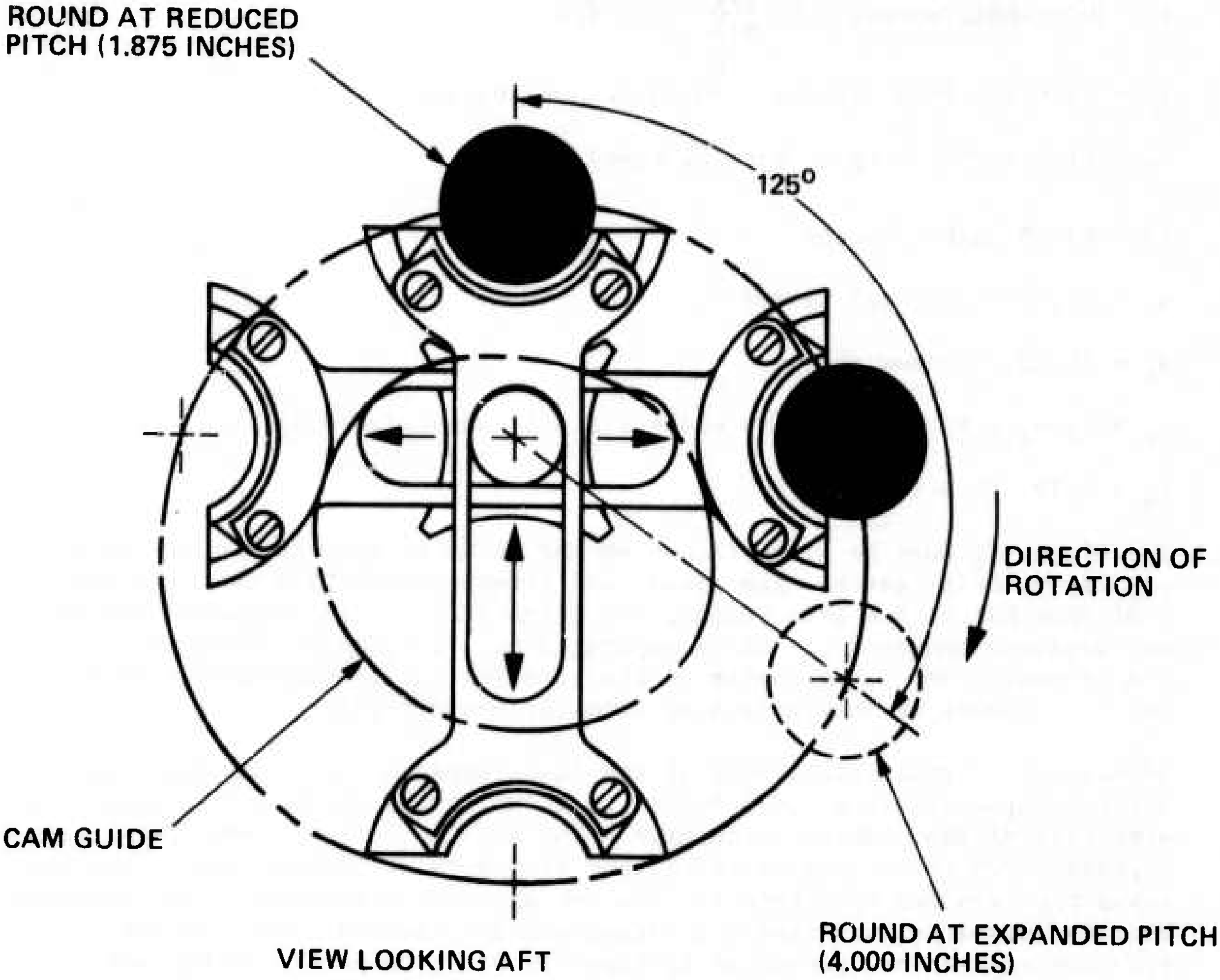


Figure 9. Pitch Expander Mechanism

final configuration showed that, at the maximum weapon demand rate, the peak tangential acceleration was 21 g's while the peak normal acceleration was 41 g's. These values demonstrate that the acceleration levels exerted on the round are well within the acceptable limits of 200 g's.

Throughout the expansion process, positive axial and longitudinal control of rounds is maintained. The former is achieved by means of a set of hardened steel guides while the latter is accomplished by means of a guide surface designed to engage the extractor groove of each round.

Subsequent to expansion, the rounds are transferred simultaneously from the two lower expanding sprockets to a succession of carrier elements on the combiner mechanism. In order that this simultaneous transfer of rounds take place, it was necessitated that one expander sprocket be rotated one-half round pitch with respect to the other. Once again, as was the case at the magazine interface, each expander was designed to insure a precise velocity match with the combining conveyor. The equations used are identical to those stated previously except that, in this instance, the transfer is occurring between two rotating sprockets rather than between a rotating sprocket and translating belt. For this reason, it is only necessary to utilize that equation which related to a rotating sprocket, that of $V_s = W_s r_s$. Results of these computations revealed that r_s must have a value of 2.488 inches at the point of transfer to effect a smooth handoff. Once again, hardened steel guides are utilized to extract the rounds from the expander, insert them into the combining conveyor, and provide positive axial and longitudinal control.

As was stated at the beginning of this section, one of the requirements of the pitch expander mechanism is to restow empty cases and unfired rounds. In operation, both expanding sprockets simultaneously extract empty cases from the combining conveyor, effect a necessary pitch contraction from 4.000 inches to 1.875 inches and sequentially insert them into empty magazine carrier elements. This is achieved by using expanding sprockets and cam guides which are identical to their lower counterparts except that they are opposite hand parts. Cam angles, accelerations, and velocity matches are identical to those which were discussed previously in this section.

2.3.5.2 COMBINER MECHANISM

The combiner mechanism takes rounds from the two pitch expander sprockets and translates them over a given distance into a single stream of ammunition at a maximum combined rate of 6000 shots per minute.

In the operation of this mechanism, rounds are sequentially transferred into a conveyor network in which each of the alternate carrier elements are aligned with one of the two lower expander sprockets. In order that proper round transfer can be achieved, it is required that the round pitch of both the expander sprocket and of the carrier elements be identical at the point of transfer. The conveyor network has been designed to provide a round pitch of 2.00 inches between successive carrier elements and consequently a 4.00-inch pitch between alternate ones matching the output pitch of the expanders.

Subsequent to handoff, each of the carrier elements containing a round is translated over a distance of 16 inches. This motion is achieved by a series of crossbars which are spaced at 2.00-inch intervals and which are laterally restrained by roller bearings positioned near each end of the crossbar. Each crossbar has been designed to support a single carrier element. Support is accomplished by means of two integrally cast carrier foot guides which engage a continuous machined way in the crossbar. Short support links at each end are used to combine the crossbars into a continuous chain.

Motion is imparted to these drive chains by means of cam followers positioned and contained in a continuous cam track on the outboard side of these chains. These cam followers essentially perform four functions. First, they engage pairs of sprockets which provide the power transmission necessary to drive the conveyor network. Second, because of cam track constraint, they serve as a horizontal support for each of the associated crossbars and consequently their carrier elements. Third, the cam followers together with the cam track form a lead-on and lead-off path for the sprockets in such a manner as to minimize chain impact and associated power losses. Finally, because rolling rather than sliding friction exists as the cam followers are translated along the cam path, power consumption is minimized.

It should be noted that while the carrier elements are maintained at a 2.00-inch pitch, the cam followers are positioned on 1.00-inch centers. This reduced spacing is to minimize chordal action and thus diminish dynamic loads and premature chain wear. This reduction in pitch is achieved by the addition of intermediate articulating points (connecting links).

During the process of longitudinal motion, a transverse movement is superimposed upon each of the carrier elements. This movement causes them to converge towards the centerline of the combiner mechanism so that at the end of 16 inches, the two streams of carrier elements have been converted into a single flow at a reduced pitch of 2.00 inches.

This transverse movement is achieved by the utilization of two independent cam tracks. Each alternate carrier element is controlled by one of the tracks. The control is effected by means of a ball-bearing cam follower secured to the bottom of each carrier. This cam follower, when inserted into either of the cam tracks, causes the carrier to move transversely along its crossbar as it is translated longitudinally along the cam track. The crossbar has been configured to insure a smooth sliding action between it and the carrier element. The crossbar has been designed to provide maximum stiffness and preclude magnification of the cam loads. In addition, the utilization of cam followers running in a cam track permits a lower level of power consumption due to the lower coefficient of rolling friction associated with it.

The design of the cam track profile provides a lateral movement of 5.73 inches in a distance of 13.40 inches. In order to minimize the loads associated with this lateral movement, it was established that the cam profile be so shaped as to permit camming action to occur over as long an interval as possible. Final definition of the cam track profile was accomplished through the use of a computer program which was developed using the above design criteria (Appendix C). Results of this program demonstrated that the most desirable solution was that shape which simulated a modified sinusoidal curve. Subsequent calculations based on this curve revealed maximum cam angles of 30 degrees and round accelerations of approximately 37 g's, which are well within the acceptable round design limit of 200 g's.

After the rounds are cammed into a common path at the far end of the combiner mechanism, they are sequentially extracted from their respective carrier elements where, in turn, they are inserted into a transfer sprocket in the weapon interface assembly. In effecting this handoff, the rounds undergo an incremental pitch expansion from 2.00 inches to 2.22 inches. This increase is one segment of a multiple step pitch expansion process that occurs as the round is conveyed through the weapon interface assembly with the final desired result of achieving a pitch that precisely matches that of the weapon.

In that the combiner mechanism must handle empty cases and unfired rounds that are returned by weapon for restowage, a design philosophy identical to that discussed above is incorporated into this mechanism. However, the utilization of a closed loop drive chain in conjunction with an identical carrier cam track in this instance causes the empty cases to be diverted from a single common path to that of two streams of flow which are then suitable for transfer to the pitch expander mechanism. Since the same design philosophy has been used, it necessarily follows that all previously stated comments with regard to functions, accelerations, and loads are applicable.

2.3.6 PITCH EXPANDER/COMBINING UNIT CONSTRUCTION

The pitch expander and combiner mechanisms are enclosed in a common housing. This housing essentially consists of a total of seven structural members: (a) an upper and lower cam plate, (b) a forward and aft end plate, (c) a top and bottom cover, and (d) a center support. Each of these structural members has been fabricated of aluminum for reasons of cost and weight reduction. In addition, each of these items has been so designed as to preclude numerous machining operations.

The upper and lower cam plates, which are bolted to one another, are positioned on the horizontal centerline of the combiner mechanism. These plates serve to provide a structural shape in which two pairs of sinusoidal cam tracks are machined. The design criteria that was utilized to develop these plates was based upon stiffness rather than stress levels so as to preclude deformation of the cam tracks.

At each end of the cam plates, aluminum fittings have been mounted in such a manner as to align with each of the cam tracks. These fittings, which possess an identical shape to that of the cam tracks, provide a smooth continuous path for the cam followers as they travel from the lower to the upper set of cam tracks.

In addition to the cam tracks, a continuous rectangular slot has been machined into each of the plates. Steel fittings are, in turn, installed into each of these slots. These fittings provide a center guide track for a series of crossbar foot guides whose purpose is to furnish additional stiffness for each of the crossbars.

Positioned and bolted to either side of the cam plate assembly are the forward and aft end plates. As one of its functions, these end plates furnish the means of supporting the four gear-driven shafts that comprise a portion of the pitch expander and combiner mechanisms. Two of these shafts are utilized to support the upper and lower expander sprocket assemblies. The position and retention of these assemblies are achieved by a cross-pinning of the drive sprockets. Each of the elements that comprise the expander sprocket assemblies is of steel construction because of high loads and wear to which they are subjected during the expansion and contraction processes. In particular, the carrier element has utilized a steel investment casting which has been so configured as to effectively cradle the round by providing support at both the neck and the base of the round. A casting configuration was utilized for reasons of weight and cost. The other two shafts provide support for the pairs of aluminum chain sprocket that drive the combining conveyor network.

All of the four shafts are supported in the end plates by sealed radial bearings and have incorporated a spline at the gear interface end. These splines have a blind tooth so as to achieve repeatable timing upon reassembly in the field. Both the shafts and associated gears are fabricated from heat-treated steel alloys.

Another function of the forward and aft end plates is that they provide a mounting surface upon which a series of steel cam guides are bolted. To insure proper positioning, these guides have been piloted into the adjoining bearing bores.

Extended close toleranced locating pins have been installed in the lower portion of each of the end plates. These pins engage slotted magazine fittings while close toleranced pip pins located in the upper cover mate close toleranced holes provided in a set of upper magazine fittings. The combination of these extended pin and pip pins vertically position as well as support the pitch expander/combining unit on the magazine. Lateral positioning is achieved by closely defining those machined surfaces on both units which physically interface with one another upon attachment.

A different technique was utilized to attach the magazine turnaround unit. In this instance, a pair of close tolerance pins are mounted on the turnaround unit in such a manner that when the two units are joined, the pins engage a set of close tolerance holes in each end plate of the pitch expander/combining unit. Upon engagement, both units are effectively aligned and positioned to one another so as to insure smooth round transfers. High strength, quick-release fasteners have been installed in the top and bottom covers of both units to effectively connect the units. Due to the restricted aircraft envelope, each of the fasteners has incorporated the added feature of a retaining ring so as to capture the fastener on the turnaround unit in the disassembled state.

External timing at both of the above-mentioned interfaces is reduced to a single gear mesh at either end. Timing provisions have been incorporated at both of these points in such a manner that assembly is prohibited without proper timing being effected.

Bolted to the upper and lower surfaces of the end plates are the top and bottom covers to which steel round guides are riveted and bolted. These guides, eight in number, provide effective radial control of the rounds throughout the combiner mechanism while longitudinal control is achieved by the individual carrier elements. These carriers of aluminum bronze cast construction achieved this round control by the incorporation of a protrusion which engaged the extractor groove of each round. In addition, two other protrusions were utilized to cradle the cartridge case and projectile nose. All driving loads are imparted to the carrier element rather than the round, thus minimizing the possibility of the round being damaged mechanically.

The round guides mounted on each cover also fulfill the capability of extracting and inserting rounds to and from the upper and lower expander sprocket assemblies. In order to minimize weight and still provide sufficient structural capabilities, lightening holes have been incorporated into each of the cast covers.

The funtion of the center support is to provide an additional mounting surface for the remaining set of expander sprocket cam guides, utilizing the same technique of mounting. In addition, the expander sprocket drive shafts when inserted into machined bronze bushings installed in this casting provide a center span support for each of the rotating shafts.

2.3.7 WEAPON INTERFACE ASSEMBLY

The Weapon Interface Assembly is configured to accommodate the weapon throughout its range of boresight adjustments, which include horizontal, vertical, pitch, and yaw directions, and the recoil excursions as cited of .75-inch recoil and .40-inch counter-recoil. A further objective is to isolate, to the greatest extent possible, the weapon recoil loads from the ammunition feed system.

The Weapon Interface Assembly is made up of three units:

- Magazine turnaround unit
- Flexible chutes
- Weapon turnaround unit

In the following paragraphs, a brief description of each of these units is presented.

2.3.7.1 MAGAZINE TURNAROUND UNIT

The magazine turnaround unit consists of an aluminum cast housing that contains two round handling transfer sprockets and a single conveyor drive sprocket, all of which are attached to gear-driven rotating shafts (Figure 10). One portion of this unit sequentially extracts rounds from the pitch expander/combining unit, effects a two-step pitch expansion and, subsequentially, transfers the rounds to the weapon interface conveyor while the other portion simultaneously reverses the above process so as to permit the return of spent cases and duds.

Due to the fact that in the wrapped configuration, the combining network conveyor has an equivalent round pitch of 1.93 inches, and the weapon interface conveyor has an equivalent pitch of 2.44 inches, it becomes necessary to perform a pitch expansion so as to effect a round transfer from one conveyor to the other. An intermediate transfer sprocket has been incorporated to provide a means by which the above-mentioned pitch expansion can be achieved. This expansion is accomplished in two stages. The first stage occurs when the rounds are cammed out of their respective combining conveyor elements and are inserted into the transfer sprocket by hardened steel round guides. Subsequent to this hand-off, the transfer sprocket undergoes a small angular rotation at which time the second stage occurs. Round guides again cam the rounds out of the transfer sprocket where they are, in turn, inserted into the weapon interface conveyor. Throughout both pitch expansion stages, positive longitudinal and axial control of the live round have been provided. Longitudinal control is achieved by an aft round guide which engages the round extractor groove while continuous upper and lower guides control the axial motion of the round. In addition, each transfer sprocket utilizes a high side-wall design whose function is to provide control of each round along its pitch line once it has been partially cammed out of its respective cavity.

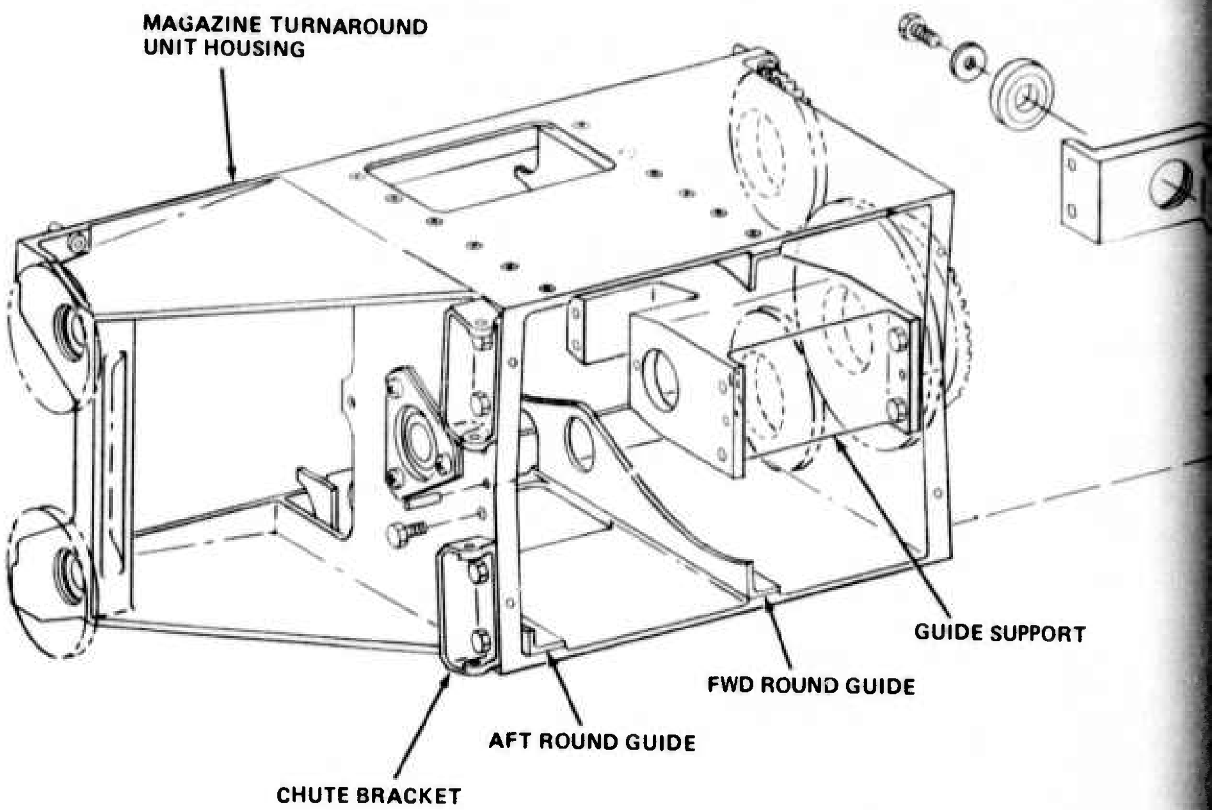
While the weapon interface conveyor is powered by the conveyor drive sprocket, its motion is controlled by a set of guides mounted in the magazine turnaround unit. These guides, which are of steel construction, consist of two link guides and a finger guide which have all been configured in such a manner as to establish a conveyor pitch line which makes a smooth transition from a straight to a curvilinear path. The significant advantage gained from the transitional path is that the chain hop and its associated shock loads are minimized. In order to assure proper positioning of each of the conveyor guide elements, locating pins and piloting techniques have been employed so as to locate all of these items relative to the centerline of the conveyor drive sprocket.

Bolted to the forward end of the magazine turnaround unit housing is a gearbox assembly whose primary function is to provide an interface for the input power that is required to operate the entire feed and storage system. The gearbox assembly essentially consists of a bearing-supported input drive shaft to which is mounted an input bevel pinion which forms one-half of a bevel gear set. Power is transmitted to the input drive shaft by means of an aircraft-supplied, hydraulically-operated line shaft. So as to provide proper alignment and coupling of this line shaft and the input drive shaft, universal couplings have been utilized.

Since both the feed and return chutes are physically interfaced with the turnaround unit, provisions have been incorporated into this design to allow for their attachment. These mounting provisions consist of a series of chute brackets and mounting lugs which effectively engage the standard quick-disconnect type latches that are mounted on each end of the individual chutes. In addition, to insure proper positioning of each of the chutes, close tolerance holes have been provided in the turnaround unit which accept extended guide pins located in each of the chute end fittings.

All of the three sprockets and their associated drive shafts have been fabricated from hardened steel. In particular, each drive shaft has utilized a hollow center design for reasons of weight reduction and utilization of maximum material effectiveness.

All three drive shafts are supported in the turnaround unit by a combination of sealed roller and angular contact bearings. In addition, a spline has been incorporated at each of their gear interface ends. Each of these splines utilizes a blind tooth technique so as to achieve repeatable timing upon reassembly in the field. All spur and bevel gears are fabricated from heat-treated steel alloys. All other components that comprise the turnaround unit are of aluminum construction for reasons of weight reduction.


MAGAZINE TURNAROUND
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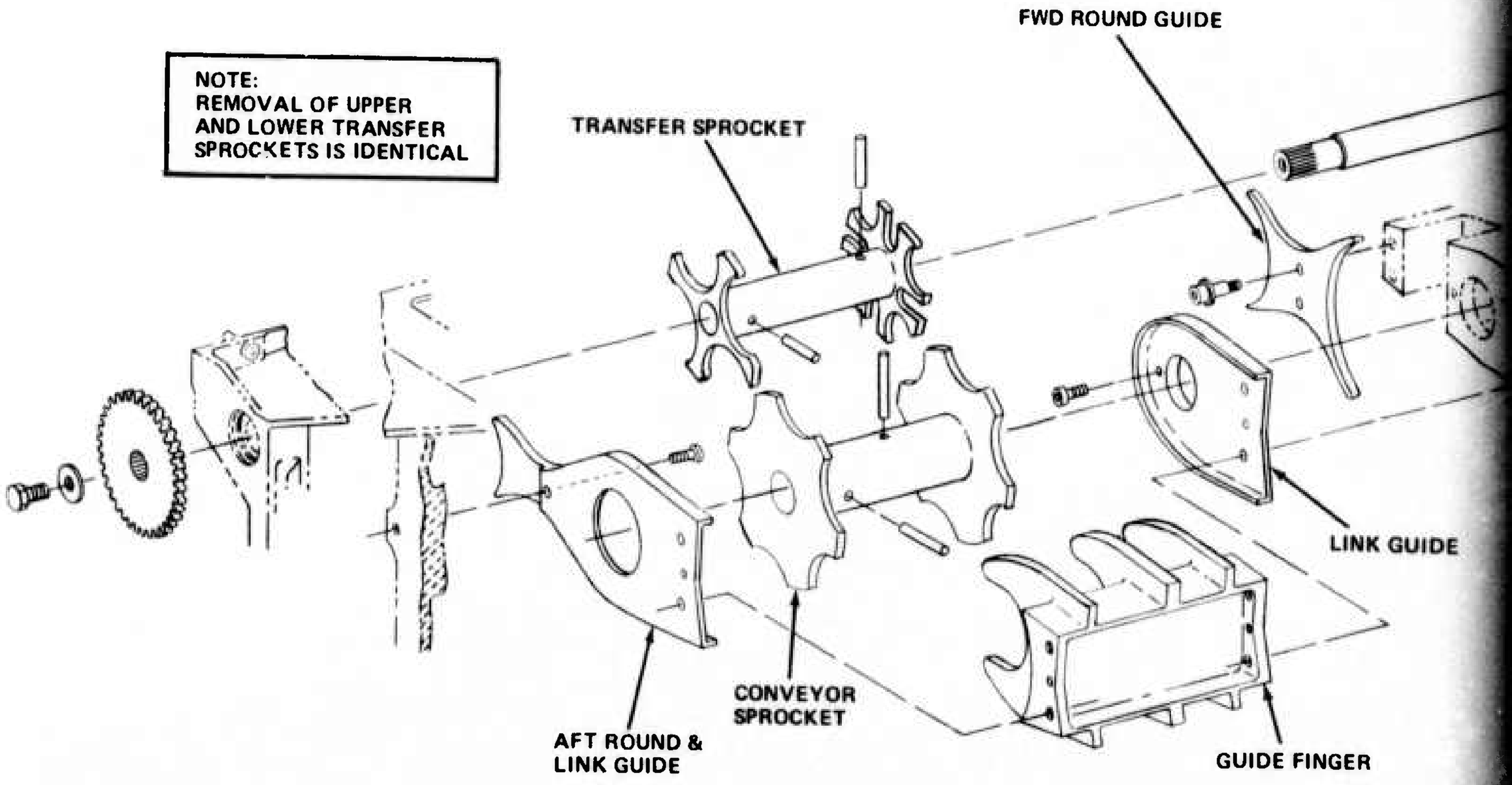
GUIDE SUPPORT
FWD ROUND GUIDE
AFT ROUND GUIDE
CHUTE BRACKET


FWD ROUND GUIDE
NOTE:
REMOVAL OF UPPER
AND LOWER TRANSFER
SPROCKETS IS IDENTICAL
TRANSFER SPROCKET
LINK GUIDE
CONVEYOR
SPROCKET
AFT ROUND &
LINK GUIDE
GUIDE FINGER

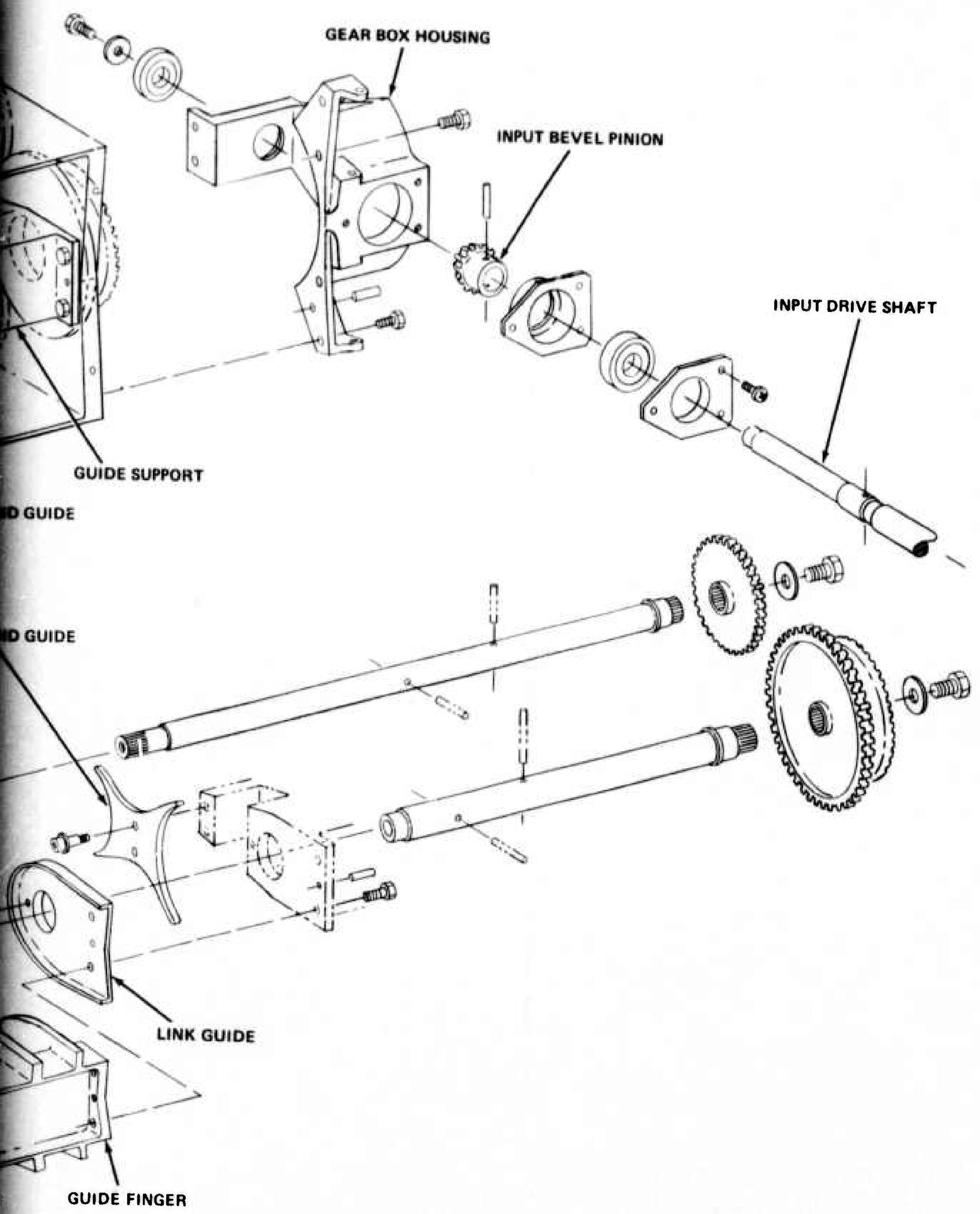


Figure 10. Magazine Turnaround Unit

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2.3.7.2 FLEXIBLE CHUTES

Two custom-designed flexible chutes have been integrated into the feed system to transfer the linked conveyor elements. One chute guides the conveyor elements full of rounds from the magazine turnaround unit to the weapon turnaround unit. The other chute guides the return of the conveyor elements full of spent cases and unfired rounds from the weapon turnaround unit to the magazine turnaround unit.

Both flexible chutes are predominantly of aluminum construction with stainless steel guide surfaces to afford the best combination of weight reduction and wear resistance. The chutes have been sized to accommodate the conveyor elements at rates up to 6000 rounds per minute while avoiding large energy drains and preventing conveyor element damage. The chute has also been designed to minimize the contact between live rounds and chute guides. Since the 25mm LLFS must operate in the reverse direction for round repositioning at burst termination and for reloading purposes, the chute design must accommodate conveyor element travel in either direction while maintaining its required flexibility. In order to allow complete reversibility, individual leaves, required for flexibility, are interlocked in opposite directions to present a smooth, continuous guide surface for conveyor or rounds.

The chute design permits quick disconnects at both the magazine turnaround unit and the weapon turnaround unit by means of standard chute latches and close tolerance guide pins. The guide pins ensure that the chute opening is accurately positioned for reliable insertion and extraction of the conveyor element at both turnaround units. Sufficient flexibility has been provided in the chutes to allow for normal gun excursions during recoil and counter-recoil as well as accommodating required movement during boresighting operations.

2.3.7.3 WEAPON TURNAROUND UNIT

The weapon turnaround unit interfaces with the weapon transfer unit This interface is preliminary only based on the final configuration of the weapon transfer unit.

The weapon turnaround unit (Figure 11) is designed to convey live rounds to the weapon transfer unit and to accept empty cases and unfired rounds from this unit for restowage in the magazine. This unit consists primarily of an aluminum cast housing containing the weapon interface conveyor drive sprocket.

The flexible chutes are attached to this unit by means of steel fittings mounted to the housing sidewalls. Proper chute positioning is maintained by steel bushings in the housing which accept extended locating pins in the chute end fittings. These pins also isolate recoil and counter-recoil loads from the chute fittings themselves.

The weapon turnaround unit attaches to the weapon transfer unit by means of tension fasteners. Locating pins are utilized to achieve proper positioning between the two units and to isolate all weapon recoil and counter-recoil loads from the fasteners.

The turnaround unit design assumes inclusion of two transfer sprockets, positioned vertically, incorporated into the transfer unit. The expansion design philosophy for the weapon turnaround unit is identical to that previously utilized in the magazine turnaround unit, in that the rounds undergo a double pitch expansion. The total round pitch expansion ratio is approximately 12.2 percent.

Utilization of this expansion philosophy at all conveyor terminating points in the system, coupled with the use of articulated conveyors, provides maximum storage capacity throughout the feed system by maintaining minimum round spacing in the conveyors while still achieving the required round pitch expansion for weapon acceptance.

Rounds enter the turnaround unit from the lower portion of the conveyor feed loop while cases and unfired rounds exit from the upper portion of the conveyor loop.

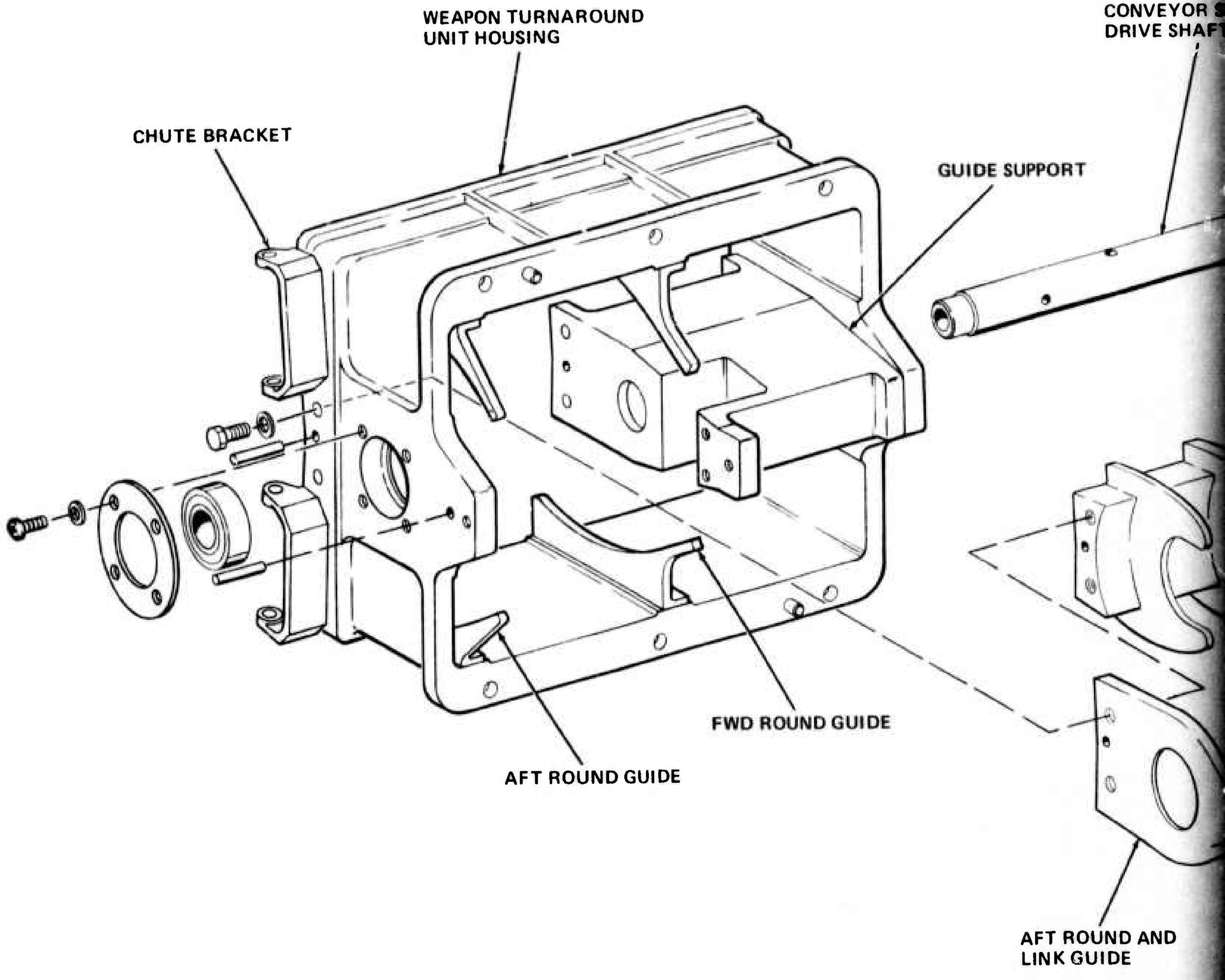
Upon weapon demand, rounds at the drive sprocket are lifted from their respective conveyor elements by hardened steel cams mounted to the sides and bottom of the turnaround housing for hand-off to the lower transfer sprocket where they undergo their first pitch expansion. The second expansion, matching the required weapon pitch, occurs at the hand-off from the transfer sprocket to the weapon barrel group. The expansions between the respective sprockets are achieved by offsetting the sprocket centers coupled with the use of guides to maintain round control.

An identical pitch reduction, from the barrel group to the upper transfer sprocket, to the conveyor drive sprocket, reverts the pitch of the returned cases and unfired rounds for acceptance in the upper portion of the feed system loop for restowage in the magazine. The side cams controlling the conveyor elements in the loop configuration around the drive sprocket, have been tailored to minimize chain hop and acceleration-deceleration effects. These effects are particularly significant in large pitch conveyors running on sprockets with small numbers of teeth. Tailoring of these cams to the conveyor configuration provides for a smooth transition, of conveyor and rounds, from a straight line to circular pitch and reduces the shock loads on the conveyor as it comes on the sprocket.

Timing between the turnaround unit and transfer unit is achieved by the use of conventional spur gearing. A spur gear fixed outboard on the conveyor drive sprocket shaft will mesh with two identical spur gears fixed to the upper and lower transfer unit sprocket drive shafts. The drive sprocket, containing six cavities, and all guides and cams are made of hardened steel.

The steel drive sprocket shaft is hollow centered for weight reduction and utilization of maximum material effectiveness.

The drive shaft is supported by ball bearings equipped with double seals for protection from contaminants. All other components in this unit are made of aluminum for weight reduction. Commonality of parts, wherever possible, between the magazine turnaround unit and weapon turnaround unit will be utilized to reduce system costs.



WEAPON TURNAROUND
UNIT HOUSING
CONVEYOR S
DRIVE SHAFT
CHUTE BRACKET
GUIDE SUPPORT
FWD ROUND GUIDE
AFT ROUND GUIDE
AFT ROUND AND
LINK GUIDE

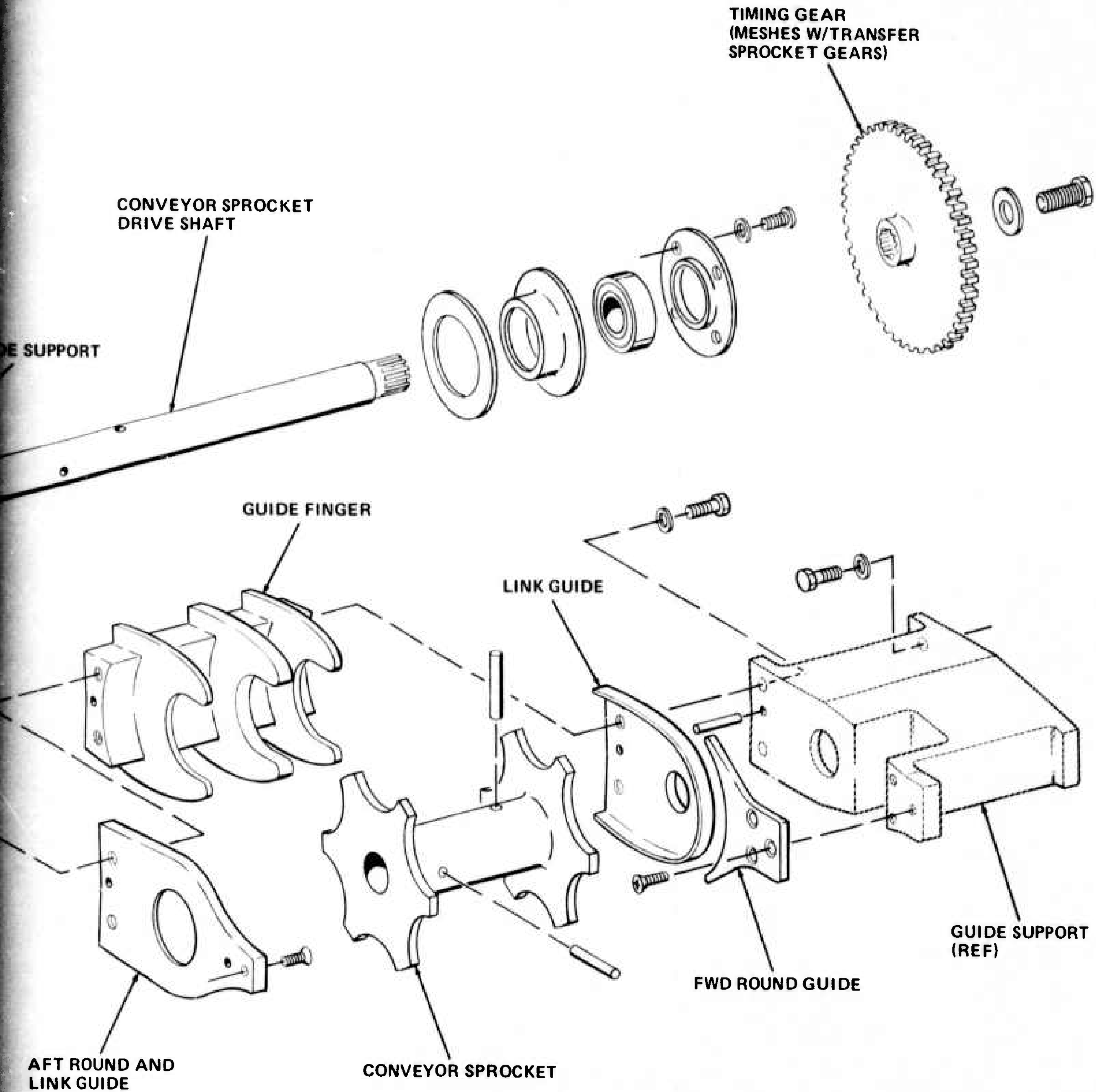


Figure 11. Weapon Turnaround Unit

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2.3.8 SYSTEM CONVEYORS

2.3.8.1 STORAGE CONVEYOR

The magazine storage conveyor system consists of 326 conveyor elements (Figure 12) joined together to form a continuous loop in each magazine bay. Each conveyor element is designed to insure that direct handling of the bare round by sprockets or guides is avoided wherever possible. It is only in the areas where the conveyor element is extended that the rounds will come in direct contact with guide surfaces.

The conveyor belt pitch has been maintained at a minimal pitch of 1.875 inches to achieve maximum magazine capacity and low belt speeds. This technique results in lower power levels and minimal wear. The conveyor elements are constructed from A357-T61 aluminum investment castings.

The conveyor elements have cylindrical ends, 1.870 inches in diameter with cast-in-place links. A rigid spine laterally connects the ends of the elements. Fingers cast from this spine retain the rounds and empty cases throughout the system except in the aforementioned guide areas.

Lateral positioning of the rounds and cases in the conveyor elements is accomplished by a cast radial protrusion, connected to the butt cylindrical end and spine, matching the case extractor groove.

Round contact points, with the conveyor elements, are at the case extractor groove, in the shoulder area of the case, and at the projectile. Full rounds are supported by the extraction groove and the projectile. The empty cases are supported by the extraction groove and the case body at the shoulder. The case shoulder support point is slightly oversize to accommodate case swell at firing. The spine is contoured to allow for lifting of the round from the conveyor elements by guide fingers, located in the magazine exit area, for transfer to the pitch expander sprockets, and for return of empty cases from the pitch expander sprockets to the conveyor elements.

Machining of the conveyor elements is limited to the pitch centers, links, and round control features. The conveyor elements are coated with Emralon 333 to reduce wear and friction with the magazine guide tracks.

Headed bronze bushings pressed in the cast links provide bearing surfaces with the cylindrical ends, during folding and unfolding in the magazine, when the conveyor elements are connected. The alternately extended pins track in the closed loop guide system attached to the center divider and side panel of each magazine bay. This feature completely controls the conveyor loop throughout the magazine bays assuring stabilization and providing positive folding and unfolding of the conveyor elements, eliminating all dependency upon link toggle effects.

L-shaped connecting pins of aluminum bronze are used for joining successive conveyor elements. The pins are hollow with an internal diameter of 0.189 inch. The connecting pins are alternately extended at each end of the conveyor element throughout the entire loop. This necessitates that an even number of conveyor elements be contained in each loop. Removal of the conveyor loop from the magazine is facilitated by the 0.189-inch inside diameters of the connecting pins.

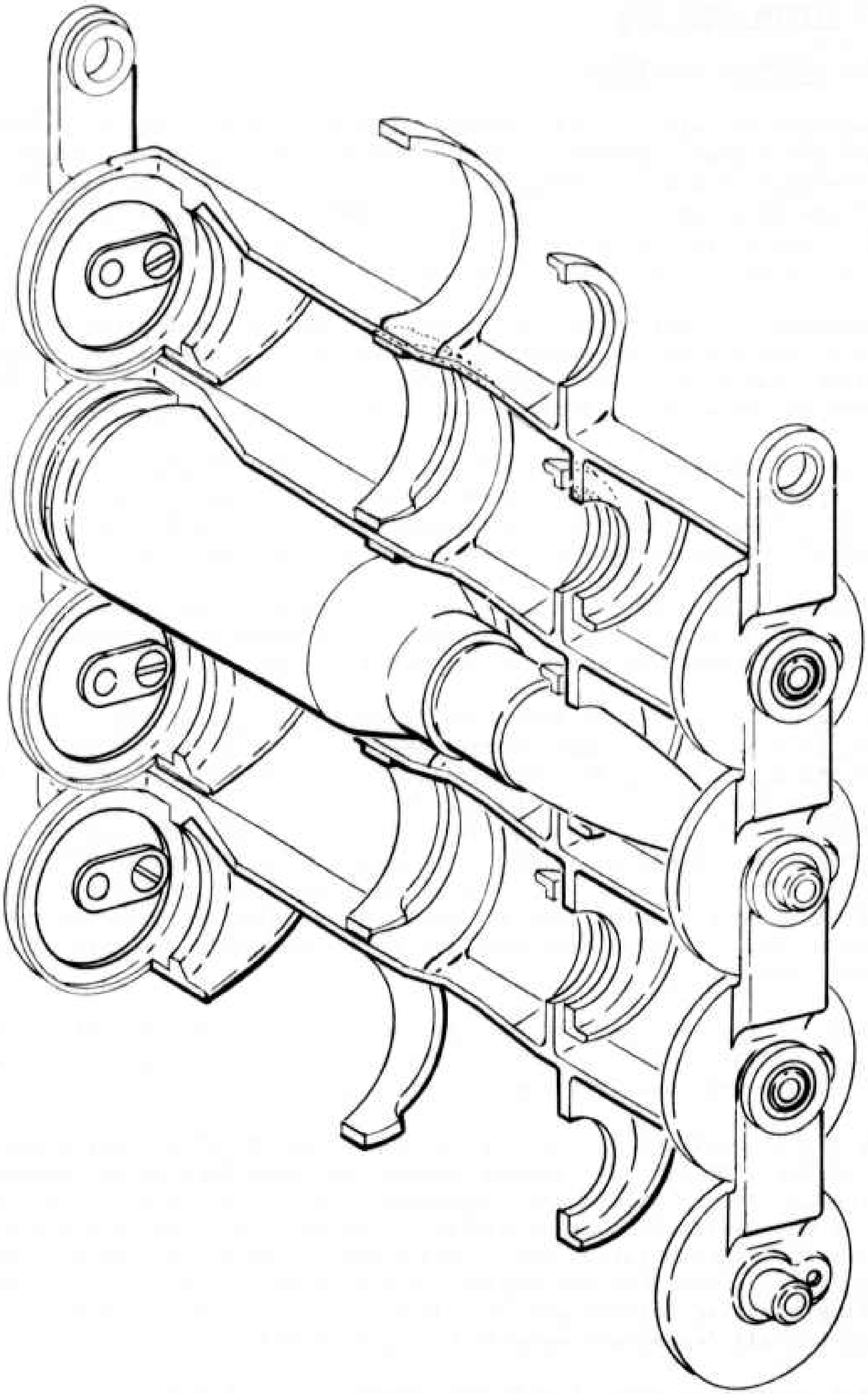

Figure 12. Magazine Carrier Element

This is accomplished by opening of the magazine reloading access panel and moving the telescopic guides aft with respect to the magazine. This removes all conveyor guide features in the reloading access area.

A standard 0.188-inch-diameter quick release pin inserted through the centers of the connecting pins of one conveyor element acts as a pin puller breaking the conveyor loop at that point.

The entire conveyor loop can now be removed from the system intact by manual operation of the magazine.

2.3.8.2 WEAPON INTERFACE CONVEYOR

The primary function of the weapon interface conveyor is to transport rounds, upon weapon demand, from the magazine turnaround unit to the weapon turnaround unit. In addition, the conveyor provides for the return of spent cases and unfired rounds to the magazine for restowage. In each of these instances, the conveyor is capable of performing these functions at a maximum 6000 shots/minute rate.

The conveyor consists of a continuous series of articulated links, each of which has been so designed as to cradle the round rather than grip it. The individual links are connected by a series of local protrusions positioned on the external side walls of each link. These protrusions, when joined, form an effective clevis-type arrangement through which a threaded stud is inserted. This configuration permits the studs to act in double shear, thus reducing the bending loads to an insignificant level. In addition, a spherical bearing has been incorporated into each of these clevis arrangements to permit sufficient flexibility as the conveyor undergoes fan, rolls, and twists during its operational cycle.

Each link has been designed to insure control of the conveyor as it is translated through the flexible chutes and turnaround units. This control is accomplished by the addition of guide feet located at either end of the link. These guide feet, when inserted into a mating set of guide tracks and supported by guide fingers in each of the three units, guarantee both vertical and lateral control of the conveyor.

The conveyor links are constructed from a high strength steel investment casting. This casting design not only incorporates the previously mentioned protrusions and guide feet but also provides three guides which effectively support and control the rounds and cases. One guide engages the round extractor groove while the other two cradle the cartridge neck and projectile nose. The guide at the cartridge neck is oversize so that a complete round is cradled at the extractor groove and at the projectile. The empty cases are supported at the neck with the case swell due to firing partially compensating for the clearance machined into the link.

In order that the rounds and cases may be smoothly transferred in the two turnaround units, two rectangular slots have been integrally cast in each of the conveyor links. These slots permit the insertion of guide fingers which insure a smooth insertion or extraction between the round and the conveyor element.

SECTION III

SYSTEM CHARACTERISTICS

3.1 POWER REQUIREMENTS

The estimated power required to drive the 25mm LLFS at 6000 SPM is 29.6 HP. The predicted peak power necessary to accelerate to 6000 SPM in 0.4 second is 40.9 HP. The peak power figure is the sum of the steady state power at 6000 SPM and power based on the product of the average torque associated with system acceleration and rotational velocities at 6000 SPM. This method of deriving power is judged to yield a reasonable peak value. However, the actual peak power would be expected to occur at a firing rate less than steady state.

The power estimates are based on a friction coefficient of 0.3 for the ammunition aluminum cases in contact with the feed and storage system guides and cams. A friction coefficient of 0.2 has been used for all other surface contact points. These friction coefficients are slightly higher than expected actual values. The larger values were used to compensate for some of the losses due to dynamic loadings which were impractical to calculate directly.

The majority of the steady state losses are due to friction generated by centrifugal loads in sprocket areas and drag associated with the steady state inertial loading. The power estimate in this report is based on an 1-g loading. Other steady state losses are due to round pitch expansion and translation of rounds in the combining unit. The major loss in the magazine is friction generated by centrifugal force at the guides around the sprockets. Losses due to drag on round guides in the pitch expander are about twice the power required to expand the round pitch. The power necessary to handoff the rounds from the combining unit to the Weapon Interface Unit is slightly more than the power necessary to combine the rounds. Friction losses on the round guides consume the majority of the power in the Weapon Interface Unit. A breakdown of the estimated power requirements for each subsystem is given in Table 5 of this report.

The primary drive gear requirements and the gear capabilities are tabulated in Table 6.

The maximum horsepower requirements for the system are based on the maximum accelerating torques at rated system speeds. The steady state horsepower requirements are based on constant rate operation of a fully loaded system.

The gear capabilities of the primary drive gears are predicated on the beam bending strength with respect to maximum horsepower capacity and tooth wear capacity with respect to steady state requirements. A minimum life equivalent to a million rounds is maintained in the system. The remaining gears in the system are sized to maintain compatible capabilities with the primary drive components.

TABLE 5. SYSTEM POWER REQUIREMENTS

SUBSYSTEM	STEADY STATE HP	PEAK HP
Magazine	7.8	12.8
Combining Unit/Pitch Expander	4.6	6.1
Weapon Interface Unit	10.0	11.6
Drive Train Losses		
● Magazine at 65 percent efficiency	4.2	6.9
● Combining Unit/Pitch Expander at 80 percent	1.2	1.5
● Weapon Interface Unit at 85 percent	1.8	2.0
Total System Power	29.6	40.9

TABLE 6. DRIVE TRAIN POWER CAPABILITY

	GEAR CAPACITY	PEAK HP	STEADY STATE HP	GEAR-MESH LIFE-ROUNDS
Weapon Interface Drive	36 HP	13.65	11.8	$> 10^6$
Primary Drive	43 HP	40.9	29.6	$> 10^6$
Combining Unit/Interface Unit Drive	36 HP	16.63/Mesh	11.9/Mesh	$> 10^6$
Combining Unit Drive	39 HP	13.63/Mesh	8.9/Mesh	$> 10^6$
Combining Unit/Magazine Drive	30 HP	19.64	12.05	$> 10^6$

All primary drive shafts are capable of delivering in excess of 50 HP.

3.2 RELOADING/UNLOADING

Reloading and unloading of the system is accomplished through utilization of a reloading unit (AGE equipment). The reloading unit has a multiple sprocket arrangement driven from the magazine spur gear located at W.L. 98.152 and B.L. 11.669 and spans the width of both magazine bays allowing loading or unloading of both bays simultaneously. Utilization of this method attains minimum turnaround time.

The reloader unit contains the cams and guides required to remove and insert rounds into the unfolded conveyor as it crosses the bottom of the magazine. The lower round guides in the area of the reloading access port cover are telescopic. This design allows for the individual removal of four rounds in each magazine bay required for installation of the reloading unit to the magazine.

Two separate ammunition belts are fed into the lower reloader feed throats; the rounds are stripped from the links by the reloader sprocket arrangement and are guided into the magazine conveyor elements. The links are ejected at the lower portion of the reloader along with cases and dud rounds removed from the magazine.

To initially load the system:

1. Lock weapon bolt in rear position.
2. Open magazine reloading access port cover.
3. Move telescopic round guides in the access port cover area aft with respect to the magazine.
4. Attach reloader to magazine using quick release pins.
5. Insert two separate ammunition belts into the reloader feed throats.
6. Operate system in reverse feed direction at approximately 150 to 200 SPM rate until a live round exits from each reloader debris throat. All conveyor elements in the system will now contain live rounds. (Operating the system in reverse feed direction minimizes the number of live rounds passing through the weapon.)
7. Detach reloader from magazine.
8. Insert four rounds individually into the empty conveyor elements in the reloading access area of each bay, moving the telescopic guides forward as the rounds are inserted.
9. Close magazine reloading access port cover.

To reload the system:

1. Lock weapon bolt in rear position.
2. Open magazine reloading access port cover.
3. Operate system at approximately 50 to 100 SPM rate in reverse feed direction until the last live rounds in the system are positioned at the aft end of the telescopic guides in the reloading access port area.
4. Move telescopic round guides aft, with respect to the magazine, individually removing four empty cases or dud rounds from each magazine bay.

5. Attach reloader to magazine using quick release pins.
6. Insert two separate ammunition belts into the reloader feed throats.
7. Operate system in reverse feed direction at approximately 150 to 200 SPM rate until a live round exits from each reloader debris throat. All conveyor elements in the system will now contain live rounds. (Operating the system in reverse feed direction minimizes the number of live rounds passing through the weapon.)
8. Detach reloader from magazine.
9. Insert four rounds individually into the empty conveyor elements in the reloading access area of each bay, moving the telescopic guides forward as the rounds are inserted.
10. Close magazine reloading access port cover.

To unload the system:

1. Lock weapon bolt in rear position.
2. Open magazine reloading access port cover.
3. Move telescopic round guides aft, with respect to the magazine, individually removing four empty cases, dud rounds, or live rounds from each magazine bay.
4. Attach reloader to magazine using quick release pins.
5. Operate system in forward feed direction at approximately 150 to 200 SPM rate until all empty cases, dud rounds, and live rounds have exited from the reloader. The system is completely unloaded at this point. (Operating the system in forward feed direction minimizes the number of live rounds passing through the weapon.)
6. Detach reloader from magazine.
7. Close magazine reloading port cover.

3.3 WEIGHT

System component weight estimates listed in Table 7 are based on the detail and layout drawings developed during the program. The predicted system weight of 486 pounds (less ammunition) exceeds the 373 pounds value stated in the Emerson proposal, Report No. NB-4833-014-1.

3.4 RELIABILITY

3.4.1 MAGAZINE

The inherent reliability that existed in the originally proposed 25mm magazine design was further enhanced by the following significant design revisions:

a. Relocation of both upper and lower main magazine drive gear boxes to the center web location, thereby eliminating unnecessary part redundancy and minimizing shaft wind-up.

b. Replacement of all power transmission chains with minimum backlash gears of greater capacity and utilizing a single rigid drive shaft to transfer power from the upper magazine gear box to the lower magazine gear box. Design of this shaft assures maximum torsional stiffness at a minimum practical weight.

TABLE 7. 25MM LLFS WEIGHT SUMMARY

TOTAL SYSTEM (Less Ammunition)	WEIGHT (LB) (486)
MAGAZINE ASSEMBLY	(333.5)
● Structure	110.0
● Gears	12.8
● Sprocket Assemblies	14.2
● Shafts	22.7
● Bearings	7.1
● Roller Chain	29.3
● Push Rods	7.0
● Conveyor	130.4
COMBINING UNIT/PITCH EXPANDER	(77.1)
● Structure	28.4
● Drive Components	15.7
● Conveyor	18.6
● Pitch Expander	5.0
● Cams and Round Guides	5.4
● Miscellaneous	4.0
WEAPON INTERFACE UNIT	(75.7)
● Weapon Turn-around	16.5
● Magazine Turn-around	35.0
● Conveyor	9.0
● Flex Chute Assembly	15.2

c. Incorporation of internal gear/external shaft splines such that exact, repeatable intra-bay and bay-to-bay conveyor timing is possible.

d. Introduction of special guide extrusions for carriers and carrier drive chain which greatly influences magazine integrity and stiffness with minimum weight penalty.

e. Addition of large, non-structural access openings on the forward and aft faces of the magazine to aid in inspection and, if need be, minor jam clearance.

f. With respect to overall magazine weight, the design and selection of components within the upper and lower main magazine gear boxes and all major sprocket drive shafts are conservatively designed since these parts are generally the least accessible when the magazine is fully assembled.

g. Elimination of periodic lubrication requirements within the magazine and the main magazine drive train and gear box assemblies by the use of sealed and permanently lubricated bearings, permanently lubricated chain, and extreme pressure lubricants within the upper and lower magazine drive gear boxes.

h. Incorporation of reloading provisions concurrent with development of the basic magazine design philosophy to preclude potential problems and reduction of inherent reliability if this feature were added on at a later date in the design cycle.

i. Continued use of hardened steel guides, originally developed during the GAU-8/A program design phase and proven during subsequent testing, which resist adverse wear for extended periods and are readily replaceable when required.

j. Optimization of carrier elements with respect to minimum weight commensurate with required stiffness such that the round is completely controlled and protected from damage during storage and movement to the hand-off position. Equal control and protection is afforded unfired rounds and spent cases returned from the gun.

k. Incorporation of aluminum bronze carrier belt connecting links which allow the required belt flexibility and also serve as guide pins for the carrier belt as it progresses through the magazine, thereby eliminating the requirement for lubrication in this area. The compatibility of aluminum bronze with other materials and ambient in-service environments assure reliable performance of carrier belt assembly.

l. Completion of an exact throat geometry analysis assuring minimum practical carrier (round) accelerations and loads during each unfolding/refolding process. The basic design philosophy employed for the 25mm magazine has been demonstrated during GAU-7/A testing to be adequate at the 3000 spm rate. The addition of carrier guidance particularly around the folding sprockets assures the reliable unfolding-folding at each end of each vertical ammunition column and significantly reduces the likelihood of jams and/or high power consumption when compared to the GAU-7/A magazine.

3.4.2 PITCH EXPANDER/COMBINING UNIT

The pitch expander portion of the pitch expander/combining unit builds upon the proven reliability of the GAU-8/A pitch expanders. Improvements which increase the reliability of the established design include:

a. Automatic timing of the pitch expander/combining unit to the magazine at installation.

b. Precise round pitch and velocity match with the magazine as to minimize round acceleration/deceleration and adverse loading at the magazine-pitch expander interface.

c. Precise round pitch and velocity match with the combining unit conveyor assembly to assure a smooth flow throughout the combination sequence.

d. Full use of hardened steel guides to reliably maintain round control at all times in all attitudes.

e. Conservative gear, cam, sprocket, and conveyor component design within reasonable weight constraints to assure long reliable unit life.

f. Application of lubricated-for-life and self-lubricating components to reduce or eliminate required routine maintenance tasks.

g. Increase of critical cross-sections principally in the area of the expanding sprockets and sprocket guides such that stiffness, strength, and consequently reliability are greatly enhanced at minimal weight penalty.

h. Employment of precision minimum backlash gearing to assure smooth, reliable operation in either direction with an absolute minimum of lost motion within the pitch expander and at the point of power transfer to the magazine.

The combiner portion of the pitch expander/combining unit mechanically translates the outputs of two separate and distinct magazine bays and two sets of expander sprockets into a single stream of ammunition moving in time with the weapon at weapon firing rate and capable of operation at this rate in either direction. As such, this portion draws upon design experience and test results gained from design, fabrication, and functional test during an in-house research and development project. The reliability inherently available in this design is achievable due to:

a. Round control in which the round or spent case is completely cradled and touched only locally by cover mounted rub strips.

b. Conservative derating of drive components within weight constraints such that driving belt stretch is not sufficient to cause loss of system timing.

c. Smooth translating cam paths which limit acceleration loads imposed on the rounds to less than 15 percent of maximum.

d. Design compatibility with the next interfacing unit (magazine turnaround unit) such that round pitch and velocity between the two units exactly match.

e. Use of lubricated-for-life or self-lubricating components to reduce or eliminate required lubrication-type maintenance.

3.4.3 WEAPON INTERFACE UNIT

The magazine turnaround and weapon turnaround portions of the Weapon Interface Unit like several other major assemblies in the 25mm Storage and Feed System build upon design and operational experience gained from the GAU-8/A Feed and Storage Subsystem program. Several additional features have been incorporated in the design of these 25mm turnaround units which assure high reliability throughout their useful life are enumerated below:

a. Precise round pitch and velocity match at the combiner interface (weapon interface) round (spent case) transfer is smooth and without excessive acceleration/deceleration.

b. Automatic timing of the magazine turnaround at installation with the combiner.

c. Conservatism in the design of all gears, cams, sprockets, and conveyor components within reasonable weight constraints.

d. Use of self-lubricating or lubricated-for-life components to reduce or eliminate required routine maintenance.

e. Full use of hardened steel guides to reliably maintain round control during transfer, pitch expansion, and insertion into the conveyor assembly.

f. Use of precision minimum backlash gearing to assure smooth reliable operation in either direction with an absolute minimum of lost motion.

g. Incorporation of internal gear/external shaft splines such that exact sprocket-to-sprocket and sprocket-to-conveyor timing is possible.

The remaining portions of the Weapon Interface Unit, namely the flexible chutes and conveyor elements, are essentially identical to components used successfully on the GAU-8/A Feed and Storage Subsystem design. As such, the reliability of these items can be estimated with a fair degree of confidence. Application differences which mitigate established reliability numbers are enumerated with the items.

Flexible Feed and Return Chutes:

a. Round control in conjunction with the conveyor element is such that the round is subject to minimal rubbing contact within the chute. In this manner the chutes are in identical applications with the GAU-8/A.

b. Reliability is enhanced by the fact that in the 25mm application the chutes are essentially straight and subject to little flexing. Previous applications in this area demonstrate adequacy in the area of weapon interface as regards shock loading and acoustic vibration. Failure rate of less than ten stoppages per million rounds passed is expected.

c. Useful chute life is expected to be 50,000 rounds passed minimum.

Conveyor Elements:

a. Round control in conjunction with the flexible feed chutes is adequate for the application.

b. Reliability of the conveyor element is increased above that demonstrated during GAU-8/A testing due to straight direct runs of the flexible chuting and the incorporation of articulation capability within the link itself eliminating the requirement for additional pieces. Failure rates of less than three stoppages per million rounds transported is expected.

c. Useful conveyor element life is expected to be 100,000 - 150,000 rounds minimum.

3.5 MAINTAINABILITY

In view of the increased emphasis on minimal life-cycle costs and the impact of both preventive and corrective maintenance of any item on the total system cost to maintain, certain items and design features have been incorporated to make the 25mm Linear Linkless Feed System (LLFS) more reliable and thus greatly reduce its required scheduled maintenance. An added benefit is increased subsystem availability with consequently greater mission dispatch potential. Examples of reduced maintenance requirements as a result of good, design practice are enumerated below:

a. Extensive use of permanently lubricated bearings, chain, and other components eliminates the requirement for periodic scheduled flight line or organizational maintenance for subsystem lubrication.

b. Conservative components selection/design eliminates many preventative maintenance part removal/replacement procedures. For example, where-ever possible, bearings were selected so that nominal expected life is 200 hours or approximately 7.5 million rounds.

c. Extensive use of internal gear and sprocket external shaft splines to allow establishment of exact system timing at initial assembly also provides for relatively simple and straightforward reassembly in the timed state after field maintenance.

d. Time required for subsystem installation is greatly reduced due to the incorporation of Go/No-Go features at each interface. In short, if the interface is accomplished, no time is spent in performing timing verification procedures. This feature achieves great importance when viewed in the area of normal airframe clearances, system orientation, and placement which could very well preclude visual as well as manual access in order to assure a timed condition at assembly.

Considering the above major features of the 25mm LLFS, the following preliminary maintenance concept is:

1. No daily preventive maintenance other than that directly associated with load/download procedures. Normal accomplishment of loading or downloading procedure would assure operational availability of the subsystem.

2. Scheduled preventive maintenance tasks to be performed by organizational level personnel and frequency of performance are as follows:

   a. Magazine -

      Every 15,000 rounds - Thorough inspection utilizing minimal tooling to verify operational availability.

      Every 30,000 rounds - Normal 15,000-round inspection plus replacement of carrier belt connecting links.

   b. Pitch Expander/Combining Unit - Every 25,000 rounds - thorough inspection utilizing minimal tooling to verify operational availability.

      Every 50,000 rounds - Normal 25,000-round inspection plus partial disassembly to inspect all cam and guide surfaces, round carriers, and conveyor chain elements.

   c. Weapon Interface Unit - Every 25,000 rounds - thorough inspection utilizing minimal tooling to verify operational availability. Some disassembly is required to allow complete inspection of flexible feed chute frames and conveyor elements.

      Every 50,000 rounds - Normal 25,000-round inspection plus normal chute frame and/or conveyor element replacement as required.

3. Scheduled preventive maintenance tasks to be performed at the intermediate level and their frequencies are:

   a. Magazine - Every 60,000 rounds - partial teardown and thorough interior inspection excluding center web gear boxes. At this level the carrier connecting links are replaced and carrier lifting tubes and chain are repaired or replaced as required. Guide surfaces are replaced as required.

   b. Pitch Expander/Combining Unit - Every 100,000 rounds - complete teardown and thorough inspection replace conveyor parts, guide surfaces.

   c. Weapon Interface Unit - Every 100,000 rounds - replace all flexible feed chutes and all conveyor elements. Guide and cam surfaces are replaced as required.

4. Scheduled preventive maintenance tasks to be performed at the depot level are undefined at this time subject to the results of a cost-effect study which is beyond the scope of the present 25mm LLFS contract.

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APPENDIX A

MAGAZINE THROAT GEOMETRY

The program was developed to determine individual round position, velocity, and acceleration, thereby providing an evaluation of the design geometry. The inputs to the program are the following:

L1 - Round center-to-center distance, equivalent to folding sprocket pitch radius.

L2 - Folding sprocket center to chain drive center distance (Y - direction).

H1 - Distance from folding sprocket center to round center when on the vertical inboard track (x - direction).

H2 - Distance from folding sprocket center to round center when on the vertical outboard track (x - direction).

R1 - Radius of major inner track transition element of folding throat (i.e., folding sprocket to inner vertical).

R2 - Radius of outer track transition element of folding throat.

TA - Timing angle difference between folding sprocket and drive chain sprocket (i.e., position of drive chain pin for next round engagement when round on folding sprocket is at 180°).

R3 - Used in alternate inner throat geometry, transition from folding sprocket to straight line element.

R4 - Used in alternate inner throat geometry, transition from straight line element to inner vertical track.

M - Used in alternate inner throat geometry, slope of straight line element.

B - Used in alternate inner throat geometry, projected intercept of straight line element in y-axis.

Start Ang. - Round 1 position on folding sprocket at start of calculation, typically 180°.

Stop Ang. - Round 1 position where calculations are to cease.

Calc Interval - Increment in degrees of the folding sprocket where position data are to be calculated, typically 1°.

RPM - Revolutions per minute of the folding sprocket.

Print Interval - Interval for printing results, typically 5°.

The initial part of the program generates all relevant geometry data such as radii centers, intersection, and tangency points.

Position of each round is then calculated and utilized in the solution of velocity and acceleration equations. The three-point central difference formula is used for the differentiation.

Except for one round in the folding guide area, either round 5 or round 6, all rounds are assumed to follow the defined geometry. The position of the free round (i.e., round 5 or 6) is calculated based on the position on its adjacent rounds. This position can then be compared to the throat geometry to evaluate the adequacy of the design.

```
EDM
FREEIN
C
 REAL L1,L2,M
 INTEGER PR
 DØUBLE PRECISIØN PØSX,PØSY,DT
 DIMENSIØN VELX(8),VELY(8),ACCX(8),ACCY(8)
 CØMMØN PØSX(8,-1/1),PØSY(8,-1/1),L1,L2,PT(5,6),H1,H2,R1,R2,PI,R1X,R1Y
,
& R2X,R2Y,AØR,T
&,W,R4X,R4Y,R4,R3X,R3Y,R3,M,B
 TYPE 1000
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 TYPE 4000
 4000 FØRMAT(' ENTER: R3,R4,M,B',/)
 ACCEPT,R3,R4,M,B
 TYPE 1020
 1020 FØRMAT(' ENTER: START ANG,STØP ANG,CALC INTERVAL(DEG),
&RPM,PRINT INTERVAL'/)
 ACCEPT ,A0,AF,DEL,RPM,PR
 TYPE 1090
 1040 FØRMAT(///)
 1050 FØRMAT(2X,'RND',6X,'X-PØS',5X,'Y-PØS',5X,'X-VEL',5X,'Y-VEL',
& 5X,'X-ACC',5X,'Y-ACC')
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 RPD=0.0174533
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C******      SET LIMITS & DELTAS
C
 W=2.*PI*RPM/60.
 N=(A0-AF)/DEL
 AØR=(A0+DEL*2.)*RPD
 DT=DEL/(6.*RPM)
 T=DT*(-2.)
C
C*******          GEØMETRY DEFINITIØN - R1 &R2 CENTERS
C
 R1X=R1+H1
 R1Y=-SQRT((L1+R1)**2-R1X**2)
 R2X=H2-R2
 R2Y=-SQRT((R2-L1)**2-R2X**2)
 TYPE,R1X,R1Y,R2X,R2Y
C
C*******          R1 & R2 TANGENCY PØINTS
C
 TH1X=H1
 TH1Y=R1Y
 TPY1=R1Y-(R1Y*R1)/(R1+L1)
 TPX1=R1X-(R1*R1X)/(R1+L1)
 X=ABS(TPY1/TPX1)
 ATPY1=ATAN(X)
 TH2X=H2
 TH2Y=R2Y
 TPX2=ABS(R2X*(R2+L1)/R2)-ABS(R2X)
 TPY2=ABS(R2Y*(R2+L1)/R2)-ABS(R2Y)
 ATPY2=ATAN(TPY2/TPX2)
```

```
570 PT(1,1)=TPX1
580 PT(1,2)=TPY1
590C************          R3 TANGENCY PØINTS
600 R3H1X=H1
620 R3X=H1+R3
630 R3H3X=R3X-R3*CØS(PI/2.-ATAN(M))
640 R3H3Y=M*R3H3X+B
650 R3Y=-R3*SQRT(M**2+1)+M*R3X+B
655 R3H1Y=R3Y
660 PT(5,1)=R3H1X
670 PT(5,2)=R3H1Y
680 PT(4,1)=R3H3X
690 PT(4,2)=R3H3Y
695 TYPE,R3X,R3Y
700C************           H3' - // TØ H3 PERPD. DIST.
710 ANG=PI/2.-ATAN(M)
720 E=R4/SIN(ANG)
730C********        INTERSECTIØN ØF CIR(R1-R4) WITH H3'
740C                 GIVES CENTER FØR R4
750 AA=R1X-(R1Y-B)/M
760 ALPHA=ASIN((AA/R1)*SIN(ATAN(M)))
770 BETA=PI-(ALPHA+ATAN(M))
780 R4X=R1X-(R1-R4)*CØS(BETA)
790 R4Y=R1Y+(R1-R4)*SIN(BETA)
795 TYPE,R4X,R4Y
800C********          R4 TANGENT TØ H3
810 B4=R4X/M+R4Y
820 R4H3X=(B4-B)/(M+1./M)
830 R4H3Y=M*R4H3X+B
840 PT(3,1)=R4H3X
850 PT(3,2)=R4H3Y
860C********          R4 TANGENT TØ R1
870 ALPHA=ATAN(ABS(R4Y-R1Y)/ABS(R4X-R1X))
890 R4R1X=R4X-R4*CØS(ALPHA)
900 R4R1Y=R4Y+R4*SIN(ALPHA)
910 PT(2,1)=R4R1X
920 PT(2,2)=R4R1Y
921 DØ 5 I=1,5
922 TYPE,I,PT(I,1),PT(I,2)
924 5 CØNTINUE
930C
940C******        PØSITIØN LIMITS ØN R2 CØRRESPØNDING TØ
950C                PØSITIØNS ØN SPKT,R1,R4,H3,R3,& H1
960 DØ 800 I=1,5
970 D=SQRT((PT(I,1)-R2X)**2+(PT(I,2)-R2Y)**2)
980 S=0.5*(L1+D+R2)
990 R=SQRT(((S-L1)*(S-D)*(S-R2))/S)
1000 ALPHA=2.*ATAN(R/(S-L1))
1002 BETA=ATAN(ABS(PT(I,2)-R2Y)/ABS(PT(I,1)-R2X))
1004 GAMMA=ALPHA+BETA
1006 PT(I,6)=R2Y+R2*SIN(GAMMA)
1008 PT(I,5)=R2X+R2*CØS(GAMMA)
1010 GAMMA=BETA-ALPHA
1012 PT(I,4)=R2Y+R2*SIN(GAMMA)
1014 PT(I,3)=R2X+R2*CØS(GAMMA)
1016 IF (PT(I,4).GT.R2Y) GØTØ 790
```

```
1018 PØSX(I-1,1)=PT(I,1)
1020 PØSY(I-1,1)=PT(I,2)
1022 CALL FLAT(2,I-1,I)
1024 PT(I,3)=PØSX(I,1)
1026 PT(I,4)=PØSY(I,1)
1030 790 TYPE,I,PT(I,3),PT(I,4),PT(I,5),PT(I,6)
1070 800 CØNTINUE
1090C*********          PØSITIØN CALCULATIØNS
1100C
1110 DØ 10 I=-1,1
1120 DØ 10 J=1,8
1130 PØSX(J,I)=1
1140 PØSY(J,I)=1
1150 10 CØNTINUE
1160 DØ 500 I=II,N+2
1170 T=T+DT
1180 AØR=AØR-DEL*RPD
1190C*********          DATA SHIFT LEFT
1200 DØ 20 J=1,8
1210 PØSX(J,-1)=PØSX(J,0)
1220 PØSY(J,-1)=PØSY(J,0)
1230 PØSX(J,0)=PØSX(J,1)
1240 PØSY(J,0)=PØSY(J,1)
1250 20 CØNTINUE
1260C*********             RØUND 1
1270 CALL ØNSPKT(1)
1280C**********              RØUND 7
1290 PØSX(7,1)=H1
1300 PØSY(7,1)=L2-0.5*L1-(3.*L1*(TA/180.*PI-AØR)*0.5)/PI
1310C******           RØUND 2
1320 IF(AØR-PI/3.-ATPY2) 40,30,30
1330 30 CALL ØNSPKT(2)
1340 GØ TØ 50
1350 40 CALL ØUTER(1,2)
1360C*******          RØUND 3
1370 50 IF(AØR-2.*PI/3.+ATPY1) 70,60,60
1380 60 CALL ØNSPKT(3)-
                               1390 GØ TØ 80
1400 70 CALL INNER(2,3)
1410C************              RØUND 8
1420 80 PØSX(8,1)=H2
1425 PØSY(8,1)=PØSY(7,1)-0.5*L1
1430C***********             RØUND 4
1440 CALL ØUTER(3,4)
1450C*********           RØUND 5
1460 CALL INNER(4,5)
1470C************              RØUND 6
1480 CALL FRØTR(6)
1490 1090 FØRMAT(/)
1500C
1510C***************                 VEL,ACCEL,& PRINT LØGIC
1520C
1530 IF(I-2) 400,300,250
1540 250 IF(I.EQ.N+2) GØ TØ 300
1550 IF(MM.NE.PR) GØ TØ 400
1560C
```

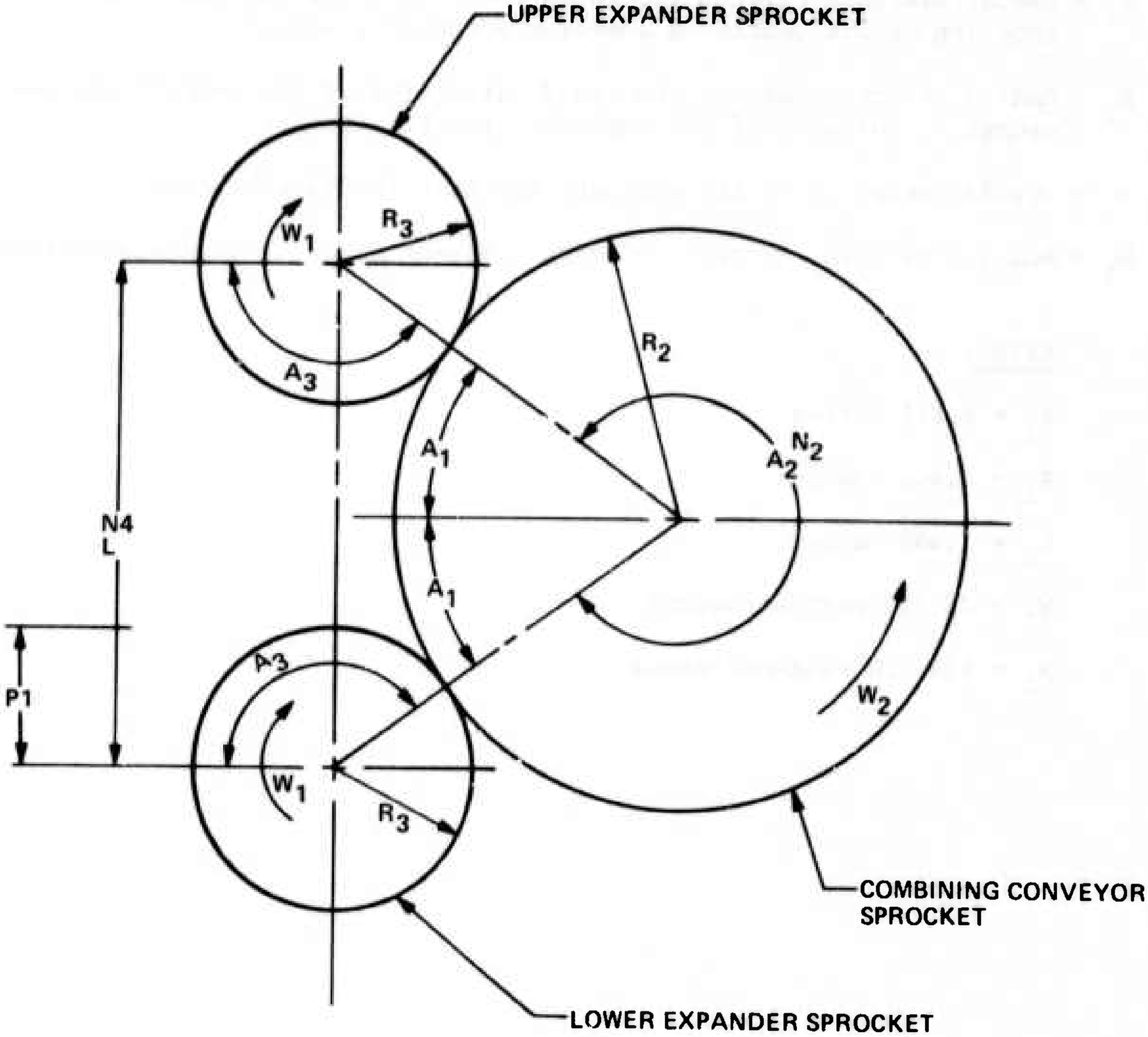
```
C*************                 RØUNDS 1 THRU 8 NUMERICAL SØLUTIØN
C                         3 PØINT CENTRAL DIFFERENCE FØRMULA & PRINT
300 TDT=T-DT
MM=0
AS=AØR/RPD+DEL
TYPE 1070,AS,TDT
1070 FØRMAT(/' SPRØCKET REFERENCE ANGLE(DEG), = ',F9.4,
&'   SECØNDS = ',F9.6)
TYPE 1050
DØ 350 J=1,8
VELX(J)=(PØSX(J,1)-PØSX(J,-1))/(2*DT)
VELY(J)=(PØSY(J,1)-PØSY(J,-1))/(2*DT)
ACCX(J)=(PØSX(J,1)-2*PØSX(J,0)+PØSX(J,-1))/(DT**2)
ACCY(J)=(PØSY(J,1)-2*PØSY(J,0)+PØSY(J,-1))/(DT**2)
TYPE 1080,J,PØSX(J,0),PØSY(J,0),VELX(J),VELY(J),ACCX(J),ACCY(J)
1080 FØRMAT(3X,I1,2X,6F10.3)
350 CØNTINUE
400 MM=MM+1
500 CØNTINUE
TYPE 1040
END
SUBRØUTINE ØNSPKT(N)
DØUBLE PRECISIØN PØSX,PØSY,DT
REAL L1,L2,M
CØMMØN PØSX(8,-1/1),PØSY(8,-1/1),L1,L2,PT(5,6),
& H1,H2,R1,R2,PI,R1X,R1Y,R2X,R2Y,AØR,T
&,W,R4X,R4Y,R4,R3X,R3Y,R3,M,B
GØ TØ(10,20,30),N
10 A=AØR
GØ TØ 40
20 A=AØR-PI/3
GØ TØ 40
30 A=AØR-2*PI/3
40 PØSX(N,1)=L1*CØS(A)
PØSY(N,1)=L1*SIN(A)
RETURN
END
SUBRØUTINE INNER(I,J)
DØUBLE PRECISIØN PØSX,PØSY,DT
REAL L1,L2,M
CØMMØN PØSX(8,-1/1),PØSY(8,-1/1),L1,L2,PT(5,6),
& H1,H2,R1,R2,PI,R1X,R1Y,R2X,R2Y,AØR,T,W,R4X,R4Y,R4,R3X,R3Y,R3,M,B
IF(I.LT.J) GØTØ 100
IF(PØSY(I,1).GE.PT(2,4)) GØTØ 110
IF(PØSY(I,1).GT.PT(3,4)) GØTØ 140
IF(PØSY(I,1).GE.PT(4,4)) GØTØ 130
IF(PØSY(I,1).GT.PT(5,4)) GØTØ 120
CALL FLAT(1,I,J)
RETURN
100 IF(PØSY(I,1).GE.PT(2,6)) GØTØ 110
IF(PØSY(I,1).GT.PT(3,6)) GØTØ 140
IF(PØSY(I,1).GE.PT(4,6)) GØTØ 130
IF(PØSY(I,1).GT.PT(5,6)) GØTØ 120
CALL FLAT(1,I,J)
RETURN
110 RX=R1X
```

```
RY=R1Y
RR=R1
GØTØ 200
140 RY=R4Y
RX=R4X
RR=R4
GØTØ 200
120 RY=R3Y
RX=R3X
RR=R3
GØTØ 200
130 YA=1/(M**2)+1
YB=-2*(B/(M**2)+PØSX(I,1)/M+PØSY(I,1))
YC=(B**2)/(M**2)+2*B*PØSX(I,1)/M+PØSX(I,1)**2+PØSY(I,1)**2
& -L1**2
Y1=(-YB+SQRT(YB**2-4*YA*YC))/(2*YA)
Y2=(-YB-SQRT(YB**2-4*YA*YC))/(2*YA)
IF(I.GT.J)GØTØ 170
IF(Y1.GT.Y2) GØTØ 160
PØSY(J,1)=Y1
GØTØ 190
160 PØSY(J,1)=Y2
GØTØ 190
170 IF(Y1.LT.Y2) GØTØ 180
PØSY(J,1)=Y2
GØTØ 190
180 PØSY(J,1)=Y1
190 PØSX(J,1)=(PØSY(J,1)-B)/M
RETURN
200 CØNTINUE
D=SQRT((PØSX(I,1)-RX)**2+(PØSY(I,1)-RY)**2)
S=0.5*(L1+RR+D)
R=SQRT(((S-L1)*(S-RR)*(S-D))/S)
ALPHA=2.*ATAN(R/(S-L1))
IF(I.GT.J) GØ TØ 10
BETA=ATAN(ABS((RX-PØSX(I,1))/(PØSY(I,1)-RY)))
IF(PØSY(I,1).LT.PT(4,6)) BETA=ATAN(ABS(PØSY(I,1)-RY)/
& ABS(PØSX(I,1)-RX))
GAMMA=PI/2.-ALPHA-BETA
IF(PØSY(I,1).LT.PT(4,6)) GAMMA=PI-ALPHA-BETA
GØ TØ 50
10 IF(PØSY(I,1).LE.RY) GØ  TØ 20
BETA=ATAN(ABS((PØSY(I,1)-RY)/(RX-PØSX(I,1))))
GAMMA=ALPHA+BETA
GØ TØ 50
20 BETA=ATAN(ABS((RY-PØSY(I,1))/(RX-PØSX(I,1))))
GAMMA=ALPHA-BETA
GØ TØ 50
50 PØSX(J,1)=RX-RR*CØS(GAMMA)
PØSY(J,1)=RY+RR*SIN(GAMMA)
RETURN
END
SUBRØUTINE ØUTER(I,J)
DØUBLE PRECISIØN PØSX,PØSY,DT
REAL L1,L2,M
CØMMØN PØSX(8,-1/1),PØSY(8,-1/1),L1,L2,PT(5,6),
```

```
& H1,H2,R1,R2,PI,R1X,R1Y,R2X,R2Y,AØR,T,W,R4X,R4Y,R4,R3X,R3Y,R3,M,B
D=SQRT((PØSX(I,1)-R2X)**2+(PØSY(I,1)-R2Y)**2)
S=0.5*(L1+D+R2)
R=SQRT(((S-L1)*(S-D)*(S-R2))/S)
ALPHA=2.*ATAN(R/(S-L1))
IF(I.GT.J) GØ TØ 10
BETA=ATAN((R2Y-PØSY(I,1))/(R2X-PØSX(I,1)))
GAMMA=BETA-ALPHA
GØ TØ 50
10 IF(PØSY(I,1).LE.R2Y) GØ TØ20
BETA= ATAN((R2Y-PØSY(I,1))/(R2X-PØSX(I,1)))
GAMMA=BETA+ALPHA
GØ TØ 50
20 BETA=ATAN(ABS((PØSY(I,1)-R2Y)/(R2X-PØSX(I,1))))
GAMMA=ALPHA-BETA
50 PØSX(J,1)=R2X+R2*CØS(GAMMA)
PØSY(J,1)=R2Y+R2*SIN(GAMMA)
IF(PØSY(J,1).LT.R2Y) CALL FLAT(2,I,J)
RETURN
END
SUBRØUTINE FRØTR(N)
DØUBLE PRECISIØN PØSX,PØSY,DT
REAL L1,L2,M
CØMMØN PØSX(8,-1/1),PØSY(8,-1/1),L1,L2,PT(5,6),
& H1,H2,R1,R2,PI,R1X,R1Y,R2X,R2Y,AØR,T,W,R4X,R4Y,R4,R3X,R3Y,R3,M,B
D=SQRT((PØSX(N+1,1)-PØSX(N-1,1))**2+(PØSY(N+1,1)-PØSY(N-1,1)
& )**2)
IF(ABS(PØSX(N+1,1)-PØSX(N-1,1)).GT.0.0001) GØ TØ 10
ALPHA=PI/2
GØ TØ 20
10 ALPHA=ATAN((PØSY(N+1,1)-PØSY(N-1,1))/
& (PØSX(N+1,1)-PØSX(N-1,1)))
20 BETA=ACØS((0.5*D)/L1)
GAMMA=ABS(ALPHA)-ABS(BETA)
PØSX(N,1)=PØSX(N+1,1)+L1*CØS(GAMMA)
PØSY(N,1)=PØSY(N+1,1)+L1*SIN(GAMMA)
RETURN
END
SUBRØUTINE FLAT(K,I,J)
DØUBLE PRECISIØN PØSX,PØSY,DT
REAL L1,L2,M
CØMMØN PØSX(8,-1/1),PØSY(8,-1/1),L1,L2,PT(5,6),
& H1,H2,R1,R2,PI,R1X,R1Y,R2X,R2Y,AØR,T,W,R4X,R4Y,R4,R3X,R3Y,R3,M,B
PØSX(J,1)=H1
IF(K.EQ.2) PØSX(J,1)=H2
GAMMA=ACØS((PØSX(I,1)-PØSX(J,1))/L1)
PØSY(J,1)=PØSY(I,1)+L1*SIN(GAMMA)
IF(I.GT.J) RETURN
PØSY(J,1)=PØSY(I,1)-L1*SIN(GAMMA)
RETURN
END
```

APPENDIX B

PITCH EXPANDER TIMING RELATIONSHIP



A1 = Angular interval between horizontal centerline of combining conveyor sprocket and point of round transfer (degrees)

A3 = Angular interval between the two round transfer points (degrees)

L = Distance between the centerlines of the upper and lower expander sprockets (inches)

N_2 = Number of equivalent carriers existent over the A_2 angular interval

N_3 = Number of carriers existent over the A_3 angular interval

N_4 = Number of magazine carrier elements that exist between the upper and lower expander sprockets

P_1 = Magazine conveyor round pitch (inches)

R_2 = Radial distance between the round pitch line and the center of rotation of the combining conveyor sprocket (inches)

R_3 = Radial distance between the round pitch line at the handoff and the center of rotation of the expander sprocket (inches)

W_1 = Angular velocity of the expander sprocket (radians/second)

W_2 = Angular velocity of the combining conveyor sprocket (radians/second)

GIVEN:

P_1 = 1.875 inches

R_2 = 1.866 inches

R_3 = 2.488 inches

W_1 = 78.539 radians/second

W_2 = 104.720 radians/second

```
2      PRINT
5      PRINT"PITCH1"
6      PRINT
10     READ R2, R3, F, X1, X2
199    PRINT"N4", "N5", "D1", "L"
200    LET X3=(X2-X1)/20
300    FOR L=X1 TO X2 STEP X3
310   LET B1=L/(2*(R2+R3+.024))
320    LET B2= SQR(1-B1*B1)
330    LET A1=ATN(B1/B2)
340    LET A2= 6.28318-2*A1
350    LET A3= 3.14159-A1
360    LET N2=A2*3/6.28318
370    LET N3= A3*4/6.28318
380    LET N4=L/F
390    LET N5=N2+2*N3
500   LET E1=N5-N4
525   LET D1=E1-INT(E1)
550    IF ABS(D1)<= .0001 THEN 700
590    PRINT N4, N5, D1, L
600    NEXT L
699    GO TO 800
700    PRINT"L=", L
800   DATA 1.866, 2.488, 1.875, 7.200, 7.275
900    END
```

PITCH1

N4	N5	D1	L
3.84	4.84886	8.85832 E-3	7.2
3.842	4.84718	5.18057 E-3	7.20375
3.844	4.8455	1.50084 E-3	7.2075
3.846	4.84382	0.997819	7.21125
3.848	4.84214	0.994136	7.215
3.85	4.84045	0.990451	7.21875
3.852	4.83876	0.986764	7.2225
3.854	4.83707	0.983075	7.22625
3.856	4.83538	0.979384	7.23
3.858	4.83369	0.975691	7.23375
3.86	4.832	0.971997	7.2375
3.862	4.8303	0.9683	7.24125
3.864	4.8286	0.964602	7.245
3.866	4.8269	0.960901	7.24875
3.868	4.8252	0.957199	7.2525
3.87	4.8235	0.953495	7.25625
3.872	4.82179	0.949789	7.26
3.874	4.82008	0.946081	7.26375
3.876	4.81837	0.942371	7.2675
3.878	4.81666	0.938659	7.27125

APPENDIX C

COMBINER MECHANISM CAM TRACK PROFILE

This program was formulated to determine a cam track profile that would be suitable for use in the combiner mechanism. Definition of this profile was based upon the following design requirements:

(a) Each round carrier shall undergo a transverse movement of 5.734 inches in 13.40 inches of conveyor belt travel.

(b) Cam angles between the carrier cam followers and its track shall be limited to a maximum of 30°.

(c) The profile shall be configured so as to minimize round carrier accelerations.

Based upon previous calculations, it was established that an optimum solution was achieved when the program utilized the following design parameters.

(a) From 0.00 to 3.237 inches the shape of the cam path is derived from an acceleration function which is equivalent to $K_1(1-COS(2K_2L))$

(b) From 3.237 to 10.163 inches the cam path is a linear function with a slope of 30°.

(c) From 10.163 to 13.400 inches, once again the path is derived from the acceleration function $K_1(1-COS(2K_2L))$

Since the derived profile is symmetrical about the midway point of its longitudinal travel, the program has only computed the first half of the curve and its associated velocities and accelerations. The inputs to the computer program are the following:

K1 = A derived constant which influences the magnitude of acceleration.

K2 = A derived constant which influences the interval in which acceleration occurs.

N1 = Carrier transport rate (shots/minute)

P1 = Round carrier pitch (inches)

```
2     PRINT
5    PRINT"CAMC2"
6     PRINT
10    READ P1, N1, L1, K1, K2
100   LET V0=0
110   LET V1=P1*N1/60
120   LET T1= L1/V1
130   LET L=0
133   LET S=0
135   LET A1=0
137   LET T=0
140   LET N=1
142   LET K5=1
145   PRINT"TIME", "DIST L", "ACCEL S", "VEL S", "DIST S"
146   PRINT"SEC", "IN", "IN/SEC2", "IN/SEC", "IN"
148   PRINT"PEAK ACCEL"
149   PRINT"IN/SEC2-S"
150   IF L>=3.2372 THEN 180
160   LET A3= K1*(1-CØS(2*K2*L))
170   GØ TØ 250
180   LET A3=0
182   LET K5=2
250   LET A2=(A3+A1)/2
255   LET A8=A2
260   LET V2= V0+A2*T1
270   LET S1= S+((V0+V2)*T1)/2
272   LET S5= (V0+V2)*T1/2
273   IF K5=1 THEN 275
274   IF A1=0 THEN 287
275   LET X1=(A3-A1)/ABS(A3-A1)
277   IF X1>=0 THEN 285
279   LET A7=A1
280   GØ TØ 300
285   LET A7=A3
286   GØ TØ 300
287   LET A7=0
300 LET V0=V2
310   LET A1=A3
320   LET S= S1
330   LET T= T+T1
340   LET N= N+1
350   LET L= L+L1
375   IF L>=6.7 THEN 430
400   IF N>= 5 THEN 430
420   GØ TØ 150
430   GØ SUB 500
435   IF L>=6.7 THEN 900
440   GØ TØ 150
500   PRINT T, L, A8, V0, S
502   PRINT A7
505   LET N=1
510   RETURN
800   DATA 2.0, 6000, .05, 7040.5995, .9704
900   END
```

CAMC2

FLØATING DIVIDE CHECK FROM LINE 275

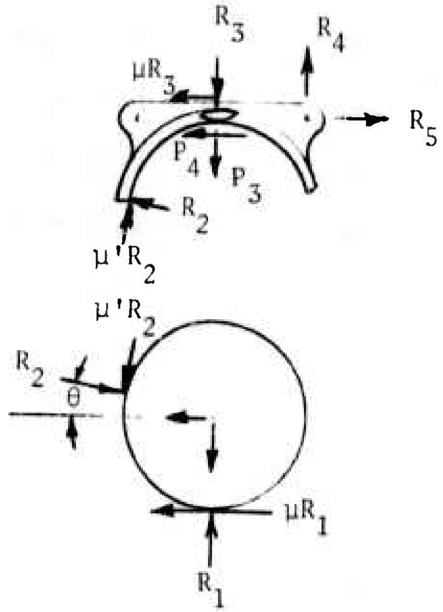
TIME SEC	DIST L IN	ACCEL S IN/SEC2	VEL S IN/SEC	DIST S IN	PEAK ACCEL IN/SEC2-S
0.001	0.2	214.215	7.83578 E-2	1.70308 E-5	296.247
0.002	0.4	1361.45	0.934854	4.24497 E-4	1562.84
0.003	0.6	3353.66	3.48546	2.47172 E-3	3644.44
0.004	0.8	5894.43	8.39821	8.21107 E-3	6231.34
0.005	1	8605.74	15.9897	2.01931 E-2	8938.65
0.006	1.2	11084.2	26.178	4.10872 E-2	11363.6
0.007	1.4	12961	38.4947	7.32841 E-2	13145.3
0.008	1.6	13956.9	52.1549	0.118541	14018.7
0.009	1.8	13923.8	66.1736	0.177718	13993.8
0.01	2	12866.6	79.5126	0.250653	13057.8
0.011	2.2	10942.5	91.2348	0.336185	11226.6
0.012	2.4	8437.9	100.644	0.432324	8772.57
0.013	2.6	5725.39	107.387	0.536551	6060.84
0.014	2.8	3208.57	111.508	0.646192	3494.89
0.015	3	1261.89	113.443	0.758813	1456.49
0.016	3.2	175.008	113.95	0.872584	248.924
0.017	3.4	0	113.967	0.986549	0
0.018	3.6	0	113.967	1.10052	0
0.019	3.8	0	113.967	1.21448	0
0.02	4	0	113.967	1.32845	0
0.021	4.2	0	113.967	1.44242	0
0.022	4.4	0	113.967	1.55638	0
0.023	4.6	0	113.967	1.67035	0
0.024	4.8	0	113.967	1.78432	0

0.025	5	0	113.967	1.89828
0				
0.026	5.2	0	113.967	2.01225
0				
0.027	5.4	0	113.967	2.12622
0				
0.028	5.6	0	113.967	2.24019
0				
0.029	5.8	0	113.967	2.35415
0				
0.03	6	0	113.967	2.46812
0				
0.031	6.2	0	113.967	2.58209
0				
0.032	6.4	0	113.967	2.69605
0				
0.033	6.6	0	113.967	2.81002
0				
0.0335	6.7	0	113.967	2.867
0				

APPENDIX D

POWER ANALYSIS

1. TYPICAL HORSEPOWER CALCULATION FOR STRAIGHT CONVEYOR SECTION (AMMUNITION ON BOTTOM SIDE OF CONVEYOR)



Round Balance

$\Sigma F_H = 0$

$$P_2 + \mu R_1 = R_2 \cos \Theta + \mu' R_2 \sin \Theta = 0$$

$\Sigma F_V = 0$

$$P_1 - R_1 + R_2 \sin \Theta + \mu' R_2 \cos \Theta = 0$$

$\Sigma M = 0$

$$\mu R_1 = \mu' R_2$$

$P_1 = .992$ $P_2 = 1.290$ $\mu = .3$ $\Theta = 5^o$

$\mu' = .269$ $R_1 = 1.642$ $R_2 = 1.831$

LINK BALANCE

$\Sigma F_h = 0$

$$R_2 \cos 5^o + P_4 + \mu R_3 - \mu' R_2 \sin 5^o - R_5 = 0$$

$\Sigma F_v = 0$

$$P_3 - R_2 \sin 5^o - \mu' R_2 = \mu' \cos 5^o R_2 - R_3 - R_4 = 0$$

$\Sigma M = 0$

$$R_4 - .9R_2 - .821\ \mu' R_2 = 0$$

$$P_3 = .527 \quad P_4 = .685$$

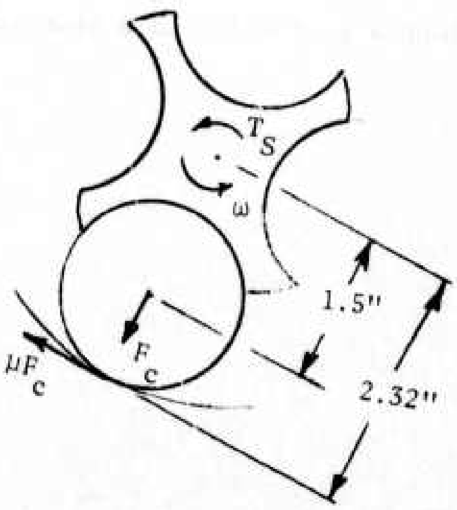
$$R_4 = 2.05 \quad R_3 = 2.17 \quad R_5 = 3.12$$

$$HP = \frac{R_5\ V_B}{6600}$$

Where V_B is belt velocity in inches/second

$$HP/Link = \frac{3.12 \times 200}{6600} = 0.095\ HP$$

2. TYPICAL SPROCKET HANDOFF POWER CALCULATION



$$F_c = \frac{W^2 R_{cg} W_r}{g}$$

Where: W is the sprocket rotational speed in radians/second

R_{cg} is the radius to the round center of gravity in inches

W_r is the weight of a round in lb and g = 386 inches/second^2

$$W = \frac{1500 \times 2\pi}{60} = 157.08 \text{ radians/second}$$

R_{cg} = 1.5 inches

W_r = 0.992 lb.

$$F_c = \frac{(157.08)^2 \times 1.5 \times .992}{386} = 95 \text{ lb.}$$

Drive Torque/Round = T_s

$T_s = \mu R_g F_c$

Where: R_g is the radius of the guide

μ is the coefficient of friction between the round and guide $R_g = 2.32$ $\mu = .3$

T_s = .3 x 2.32 x 95 = 66.12 in-lb/round

HP/RD = T_s x RPM/63000

HP/RD = 66.12 x 1500./63000 = 1.57 HP/RD in a four-cavity sprocket

3. MAGAZINE POWER REQUIREMENTS

	STEADY STATE HP	HP TO ACCELERATION	PEAK HP
AMMUNITION AND CONVEYOR			
● FOLDED ROUNDS (243)	0.63	0.65	1.28
● UNFOLDED ROUNDS (30)	0.97	1.27	2.24
● ROUNDS ON SPROCKETS (36)	4.96	0.93	5.89
● ROUNDS IN SPROCKET TRANSITION AREA (14)	1.17	2.09	3.26
CHAIN AND PUSH RODS	0.04	0.08	0.12
TOTAL MAGAZINE POWER	7.77	5.02	12.79

4. PITCH EXPANDER/COMBINING UNIT POWER REQUIREMENTS

	STEADY STATE HP	HP TO ACCELERATION	PEAK HP
PITCH EXPANDER			
● START UP	-	0.14	0.14
● FRICTION ON CAMS AND GUIDES	1.98	-	1.98
● ROUND PITCH EXPANSION	0.86	-	0.86
TOTAL - PITCH EXPANDER	2.84	0.14	2.98
COMBINING UNIT			
● START-UP	-	1.38	1.38
● ROUND COMBINING AND CASE SPLITTING	0.70	-	0.70
● FRICTION ON GUIDES	0.10	-	0.10
● HANDOFF TO (FROM) WEAPON INTERFACE UNIT	0.94	-	0.94
TOTAL COMBINING UNIT	1.74	1.38	3.12
TOTAL PITCH EXPANDER/ COMBINING UNIT	4.58	1.52	6.10

5. WEAPON INTERFACE UNIT POWER REQUIREMENTS

ITEM	STEADY STATE HP	HP TO ACCELERATION	PEAK HP
STRAIGHT CONVEYOR SECTION DRAG AND START-UP	0.20	1.10	1.30
SPROCKET AND ROUND START-UP	-	0.45	0.45
ROUND AND CASE HANDOFFS	9.80	-	9.80
TOTAL WEAPON INTERFACE UNIT	10.00	1.55	11.55

APPENDIX E

DETAILED WEIGHT BREAKDOWN

ITEM	UNIT WEIGHT (LB)	NO. REQUIRED	TOTAL WEIGHT (LB)
MAGAZINE ASSY.		1	(333.5)
STRUCTURE			(110.00)
Center Shear Web	4.69	1	4.69
Support Angle	-	-	1.33
Center Guide	-	-	4.70
Center Channel Guide	-	-	0.60
Front Panel	3.61	1	3.61
Rear Panel	4.69	1	4.69
Bottom Panel	3.17	1	3.17
Top Panel	3.25	1	3.25
Upper Gear Box Guide	1.57	6	9.42
Upper Gear Box Guide	1.33	2	2.66
Lower Gear Box Guide	1.40	6	8.40
Lower Gear Box Guide	1.09	2	2.18
Lower Gear Box Guide	1.24	2	2.48
Lower Gear Box Housing	4.84	1	4.84
Upper Gear Box Housing	5.64	1	5.64
Outer Side Plate	8.11	1	8.11
Lower Outside Guide	1.09	2	2.18
Lower Outside Guide	1.24	2	2.48
Lower Guide	1.57	6	9.42
Upper Guide	1.50	6	9.00
Upper Guide	1.33	2	2.66
Access Cover	3.42	2	6.84
Outer Corner Support	0.86	2	1.72
Outer Corner Support	0.68	2	1.36
Lower Corner Support	0.58	2	1.16
Outer Guide Angle	0.78	2	1.56
End Caps	-	-	1.85

ITEM	UNIT WEIGHT (LB)	NO. REQUIRED	TOTAL WEIGHT (LB)
MAGAZINE ASSY. (Cont'd.)			
GEARS			(12.78)
Power Takeoff Gear (3.571 P.D.)	0.73	1	0.73
Bevel Gear (2.000 P.D.)	0.2	2	0.4
Bevel Gear (1.000 P.D.)	0.1	2	0.2
Spur Gear (4.800 P.D.)	0.44	1	0.44
Spur Gear (4.75 P.D.)	0.72	3	2.16
Spur Gear (2.700)	0.19	2	0.38
Spur Gear (4.500 P.D.)	0.59	3	1.77
Spur Gear (3.937 P.D.)	0.42	6	2.52
Spur Gear (2.625 P.D.)	0.18	6	1.08
Spur Gear (1.437 P.D.)	0.08	6	0.48
Spur Gear (4.200 P.D.)	0.51	4	2.04
Spur Gear (3.500 P.D.)	0.32	1	0.32
Spur Gear (3.300 P.D.)	0.26	1	0.26
SPROCKET ASSY.			(14.16)
Chain Sprockets	0.10	48	4.80
Sprockets	0.22	36	7.92
Sprocket Set Collar	0.04	36	1.44
SHAFTS			(22.74)
Chain Drive Shaft	0.32	12	3.84
Sprocket Shaft	1.84	9	16.56
Bevel Gear Shaft	2.34	1	2.34
BEARINGS			(7.14)
Chain Idler Brg.	0.013	24	0.31
Chain Drive Brg.	0.013	24	0.31
Sprocket Shaft Brg.	0.14	18	2.52

ITEM	UNIT WEIGHT (LB)	NO. REQUIRED	TOTAL WEIGHT (LB)
MAGAZINE ASSY. (Cont'd)			
BEARINGS (Cont'd)			
Lower Gear Box Brg.	0.14	14	1.96
Lower Gear Box Brg.	0.007	6	0.04
Upper Gear Box Brg.	0.14	14	1.96
Upper Gear Box Brg.	0.007	6	0.04
ROLLER CHAIN	-	-	(29.28)
CHAIN PUSH RODS	0.0175	402	(7.04)
CONVEYOR			(130.4)
Carrier Element	0.161	652	105.0
Pin	0.0195	1304	25.4
COMBINING UNIT/PITCH EXPANDER			(77.06)
STRUCTURE			(28.4)
Side Plates	3.25	2	6.50
Center Shaft Support	1.90	1	1.90
Cover	4.7	2	9.4
Cam Track Structure	4.65	2	9.30
Cam Track Center Guide	0.65	2	1.30
DRIVE COMPONENTS			(15.68)
Gear (#8)	0.59	1	0.59
Gear (#9)	0.55	1	0.55
Gear (#10)	0.85	1	0.85
Gear (#11/12)	1.14	1	1.14
Sprocket	0.40	4	1.60
Shaft (#8 Gear)	2.05	1	2.05
Shaft (#9 Gear)	2.05	1	2.05

ITEM	UNIT WEIGHT (LB)	NO. REQUIRED	TOTAL WEIGHT (LB)
COMBINING UNIT/PITCH EXPANDER (Cont'd)			
DRIVE COMPONENTS (Cont'd)			
Shaft (#10 Gear)	1.33	1	1.33
Shaft (#11/12 Gear)	1.33	1	1.33
Stationary Shaft	2.05	1	2.05
Bearing	0.15	2	0.30
Bearing	0.09	2	0.18
Bearing	0.15	2	0.30
Bushing	0.10	2	0.20
Brg. Retainer	0.26	4	1.04
Brg. Retainer	0.03	4	0.12
CONVEYOR			(18.64)
Track	0.26	22	5.72
Stabilizing Cam Follower	0.022	88	1.94
Stabilizing Brg	0.002	44	0.09
Cam Brg	0.025	22	0.55
End Plate	0.075	22	1.65
Bucket	0.372	22	8.18
Center Guide	0.023	22	0.51
PITCH EXPANDER			(4.96)
Bucket	0.43	8	3.44
Sprocket	0.16	4	0.64
Aft Slide	0.04	8	0.32
Fwd Slide	0.07	8	0.56
CAMS AND ROUND GUIDES			(5.38)
Round Butt Scoop Cam	0.30	4	1.20
Round Nose Pitch Exp. Cam	0.30	4	1.20

ITEM	UNIT WEIGHT (LB)	NO. REQUIRED	TOTAL WEIGHT (LB)
COMBINING UNIT/PITCH EXPANDER (Cont'd)			
CAMS AND ROUND GUIDES (Cont'd)			
Round Butt Cam (Fixed Shaft)	0.15	4	0.60
Fwd Case Cam (Fixed Shaft)	0.22	4	0.88
Cover Round Guides	0.25	6	1.50
RNBM			(4.0)
WEAPON INTERFACE UNIT			(75.6)
WEAPON TURNAROUND			(16.46)
Gear	1.15	1	1.15
Shaft	1.41	1	1.41
Bearing	0.15	2	0.30
Brg. Retainer	-	2	0.09
Sprocket	2.16	1	2.16
Round Butt and Conveyor Guide	0.33	1	0.33
Fwd. Case and Conveyor Guide	0.32	1	0.32
Fwd. Case Guide (Outer)	0.15	2	0.30
Butt Guide (Outer)	0.13	2	0.26
Center Case Guide		1	1.84
Housing	-	-	7.5
RNBN			0.8
MAGAZINE TURNAROUND			(35.00)
Gear #1	0.14	1	0.14
Gear #2/3	2.03	1	2.03
Gear #4	0.42	1	0.42
Gear #5	0.42	1	0.42

ITEM	UNIT WEIGHT (LB)	NO. REQUIRED	TOTAL WEIGHT (LB)
WEAPON INTERFACE UNIT (Cont'd)			
MAGAZINE TURNAROUND (Cont'd)			
Gear #6	0.31	1	0.31
Gear #7	0.31	1	0.31
Shaft #1	0.74	1	0.74
Shaft #2/3	1.52	1	1.52
Shaft #5/6	1.47	1	1.47
Shaft #4/7	1.47	1	1.47
Brg. #1 Shaft	0.15	1	0.15
Brg. #1 Shaft	0.11	1	0.11
Brg. #2/3 Shaft	0.16	2	0.32
Brg. #5/6	0.16	1	0.16
Brg. #5/6	0.13	1	0.13
Brg. #4/7 Shaft	0.16	1	0.16
Brg. #4/7 Shaft	0.13	1	0.13
Brg. Retainer	0.14	1	0.14
Brg. Retainer	0.09	2	0.18
Brg. Retainer	0.05	1	0.05
Brg. Retainer	0.05	1	0.05
Center Sprocket	1.82	1	1.82
Outer Sprocket	0.89	2	1.78
Center Butt and Conveyor Guide	0.49	1	0.49
Fwd. Case & Conveyor Guide (Center)	0.39	1	0.39
Outer Butt Guide	0.42	2	0.84
Outer Fwd. Case Guide	0.39	2	0.78
Center Case Guide	3.44	1	3.44
Chute Attach. Brkts.	0.10	2	0.20
Input Drive Housing	1.25	1	1.25
Housing	11.6	1	11.6
RNBM	-	-	2.0

ITEM	UNIT WEIGHT (LB)	NO. REQUIRED	TOTAL WEIGHT (LB)
WEAPON INTERFACE UNIT (Cont'd)			
CONVEYOR	0.527	17	(8.96)
FLEX CHUTE ASSY.			(15.2)
Chute	-	-	8.8
End Ftg.	1.6	4	6.4

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