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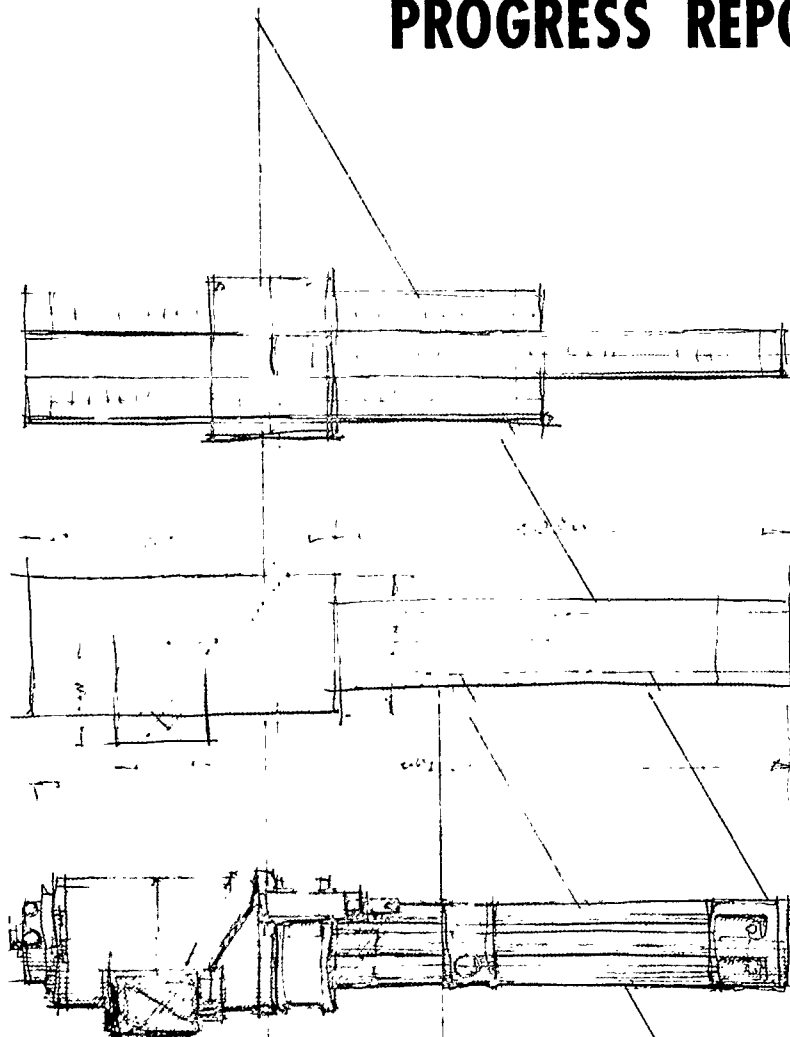
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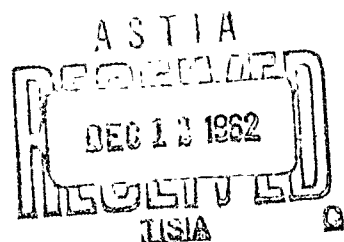


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Project Vulcan.. **RESEARCH and DEVELOPMENT**

GENERAL  ELECTRIC

MISSILE AND SPACE VEHICLE DEPARTMENT, MISSILE PRODUCTION SECTION, BURLINGTON, VERMONT



62APB38

1 NOVEMBER 1962

PROJECT VULCAN RESEARCH and DEVELOPMENT

PROGRESS REPORT NUMBER 36

**CONTRACT DA - 19 - 020 - ORD - 5455
1 AUGUST 1962 TO 31 SEPTEMBER 1962**

**BOSTON ORDNANCE DISTRICT
DEPARTMENT OF THE ARMY**

MISSILE AND ARMAMENT DEPARTMENT

**GENERAL  ELECTRIC
BURLINGTON, VERMONT**

AD _____ Accession No. _____ G. E. Report 62APB38 November 1962 pp - incl. tables, curves Unclassified Report This report describes activities from 1 August 1962 to 31 September 1962 on the following projects and studies: (1) Improved Parts Life: Bolt Roller Shaft Material Studies, Cycloidal Main Cam. (2) Bore-sighting and Target Study: Production Gun Data, Dispersion. (3) Gun - Aircraft Systems Compatibility: F104-G Clearing Problem. (4) Gun Components: Redesigning Unlocking Cam, Hook and Hook Roller Shaft Design, Lubricator, Clearing Cam Solenoid Modification. (5) <u>Range Firing Records.</u>	UNCLASSIFIED 1. Automatic Gun, 20mm, M61 2. Automatic Gun, 20mm, T171E3 I. Title: Vulcan II. Contract DA-19-020-ORD-5455 III. DA Project No. SA-7663
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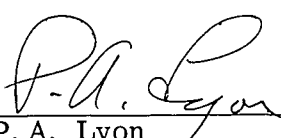
Approved by 
P. A. Lyon
Project Engineer

TABLE OF CONTENTS

<u>Section</u>	<u>Title</u>	<u>Page</u>
I	General	1-1
II	Improved Parts Life	2-1
	Bolt Roller Shafts	2-1
	Cycloidal Cam	2-2
III	Boresighting and Target Study	3-1
	Production Guns	3-1
	Controlled Dispersion	3-1
IV	Gun-Aircraft Systems Compatability	4-1
	F104-G Clearing Problem	4-1
V	Gun Components	5-1
	Universal Guide Bar	5-1
	Redesigned Unlocking Cam	5-1
	Hook and Hook Roller Shaft	5-3
	Lubricator for B-58	5-5
	Clearing Cam Solenoid Modification	5-7
VI	Gun Firing Records	6-1
	Distribution	

LIST OF FIGURES

<u>Figure</u>	<u>Title</u>	<u>Page</u>
3-1	Chamfered Barrel	3-3
3-2	High Azimuth to Elevation Ratio - Target A	3-6
3-3	High Azimuth to Elevation Ratio - Target B	3-6
3-4	Muzzle Deflector Assembly	3-7
3-5	Variable Grip Muzzle Clamp	3-9
3-6	Barrel Shims and Locking	3-11
3-7	Target from Shimmed and Locked Barrel	3-11
5-1	Redesigned Unlocking Cam	5-2
5-2	Hook and Hook Roller Shaft Design	5-4
5-3	Possible Location of Lubricator	5-6
5-4	Clearing Cam Solenoid Modification	5-8

SECTION I

GENERAL

Contract DA-19-020-ORD-5455, awarded to the General Electric Company by the Department of the Army, Boston Ordnance District, provides for the continuation of research and development on the M61 Vulcan gun.

This report describes the work performed through the period 1 August 1962 to 31 September 1962. The following projects and studies are discussed:

Improved Parts Life: bolt roller shaft material studies, cycloidal
main cam

Boresighting and Target Study: production gun data, dispersion

Gun-Aircraft Systems Compatibility: F-104G clearing problem

Gun Components: redesigned unlocking cam, hook and hook roller
shaft design, lubricator, clearing cam solenoid
modification

Range Firing Records

SECTION II

IMPROVED PARTS LIFE

BOLT ROLLER SHAFTS

During this reporting period, Phase II of the program to increase the life of bolt roller shafts was continued.

The two solar tool steel (water tough) roller shafts were fired a total of 12,542 rounds when the trailing fork on shaft #X-87 broke. The other shaft, X-86, was inspected and no cracks were found. Shaft X-86 now has been fired 16,441 rounds and is still in good shape.

A close inspection of the shaft that failed at 12,542 rounds showed deep machine marks done during the milling operation that forms the slot and radius. The drawing calls for a 125 finish, but this is not desired in a highly stressed, critical area such as the shaft forks. The machined finish of the failed shaft was approximately 100 to 120.

A better finish would be very costly due to the close slot tolerance that would have to be ground to size, therefore other methods to improve this surface finish and eliminate machine stress concentrations such as shot-peening blasting the fork area after machining are being investigated. Shot-peening would be less expensive than a grinding operation.

Two NiMark 20% nickel steel alloy shafts are now being tested with very good results indicated. A total of 9,041 rounds has been fired without any cracks.

Continued effort will be centered on solar tool steel and the 20% nickel steel alloys to increase shaft life beyond 15,000 gun rounds.

CYCLOIDAL CAM

During this reporting period firing tests on the cycloidal cam housing were continued. At the end of this period there were 40,800 rounds on this housing. Firing was maintained as close to 6000 spm as possible to minimize any correction error since there is, at this time, no established torque curve. A second attempt to establish a torque curve will be made when there is an indication of a torque rise. The torque is remaining at 420 to 450 inch-pounds at 6000 spm. It appears that this low torque range will continue to approximately 60,000 rounds. Fire testing is continuing on the housing.

SECTION III
BORESIGHTING AND TARGET STUDY

DATA ON PRODUCTION GUNS

Data has been collected on targeting of production guns. A comparison of the new data and that of the past 12 months appears below. All firing was accomplished at "D" rate (6000 spm).

	12 Month Avg.	August	September
No. of guns tested	--	56	52
Distance from avg. boresight to avg. center of impact area (mils)	0.28 left 0.15 up	0.10 right 0.61 up	0.36 right 0.57 down
Avg. Dispersion (mils)			
80% circle	4.97	4.38	4.53
100% circle	9.39	no data	no data

CONTROLLED DISPERSION

Interest has been shown recently in the ability to control target shape and dimensions to obtain patterns other than the characteristic Vulcan pattern. Specifically, different types of targets would influence the pattern of fire desired. A study of three distinct patterns has been made.

These are:

1. High azimuth to elevation ratio
2. Circular diameter of 14 to 18 mils
3. Circular diameter of 4 to 6 mils

The ability to fire targets of these types necessitates certain modifications to the basic weapon since the standard Vulcan pattern is not any of the above. Achievement of this goal is to be made with certain defined restrictions.

- . No external power supply
- . Minimum modification to present gun assembly
- . Slight increase in gun weight and/or silhouette
- . Independent of mounting structure
- . No modification of mounting platform
- . Rapid change from one target type to another.

There are added restrictions outside the gun itself. First, that the rounds be stable in flight, and second, that there be a uniform distribution of rounds on the target with the center of impact unchanged.

Phase I

Attainment of the high azimuth to elevation ratio was the first objective. Four distinct methods were tried. These included bending the barrel cluster; altering the trajectory by reborring the barrels eccentrically; weighting the barrels to produce dynamic imbalance; and, a device to capture muzzle gases and thus direct the barrels. Of these methods, only the last showed promise of producing the desired dispersion. This technique of capturing high pressure muzzle gasses

and using them to direct the motion of the cluster is similar in principle to a Pelton turbine operation.

The first attempt involved chamfering the barrels to produce the force imbalance (see Figure 3-1).

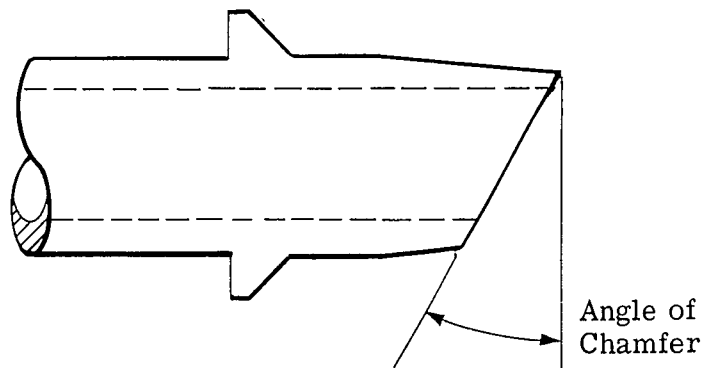
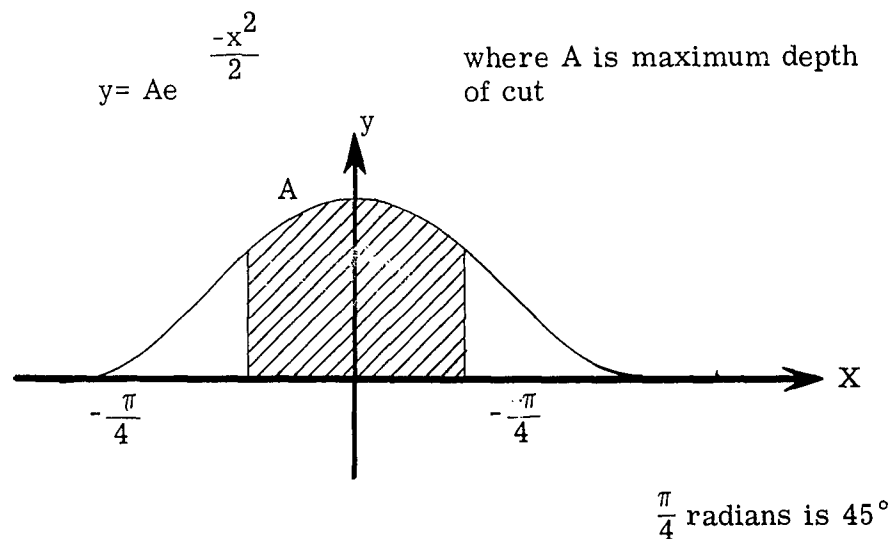


Figure 3-1. Chamfered Barrel

These truncated barrels act as turbine blades to the high pressure gasses as they leave the barrels. The entire cluster is then moved in the direction of the imbalanced force. Using six of these barrels a complete cycle of muzzle whip can be generated, dependent in shape on the orientation of the cut barrels. The magnitude of this

force is related to the barrel pressure and the imbalanced area (angle of chamfer). Before mounting these barrels, a simple calculation allowed a barrel deflection (in the dynamic case this is akin to muzzle whip). Gas pressure at the muzzle is approximately 4000 lbs/in.². Calculation of the effective area can be made as follows. Analytically, a chamfered barrel is the intersection of a cylinder and a skew plane. While no simple expression exists for such a curve, close approximation can be made by noting that the development of the resulting curve of intersection is similar to the curve.



A = .472 inches for a cut of 30°

$$\text{Area} = .472 \int_{-\frac{\pi}{4}}^{+\frac{\pi}{4}} e^{-\frac{x^2}{2}} dx$$

Using 90 degrees of the developed curve is an arbitrary decision

based heavily on the physical appearance of the cut barrel. The area resulting is 0.568 inch². Knowledge of the cluster stiffness will allow determination of the amount of muzzle whip, hence dispersion. The driving force in this case is (4000 lb/in.²) (0.568 in.²) = 2270 pounds. Using a hydraulic drive in the 30mm stand (see Progress Report #35, pg. 10 and following). (K = 900 lb/in.), total deflection should be:

$$\frac{2270 \text{ lb}}{900 \text{ lb/in.}} = 2.5 \text{ inches}$$

In practice this was the magnitude of the muzzle whip recorded for insertion of one cut barrel. In firing at high rate the situation becomes more complex. Each of these gas impulses is rapidly attenuated, and the cluster has its own characteristic motion that must be considered. Synthesis of all the acting forces enabled the barrels to be cut in such a way as to yield a high azimuth to elevation ratio. Actual firing (Figure 3-2) showed the pattern to be tri-modal. Further refinement of the force-displacement system resulted in a more uniform distribution (Figure 3-3).

In order not to damage any barrels, these eccentric areas were built into a muzzle deflector assembly (Figure 3-4). The length of the deflector blades depend heavily on the structural rigidity of the mount being used. Incorporation of this device on any Vulcan gun can be made by simple modification of the muzzle clamp.

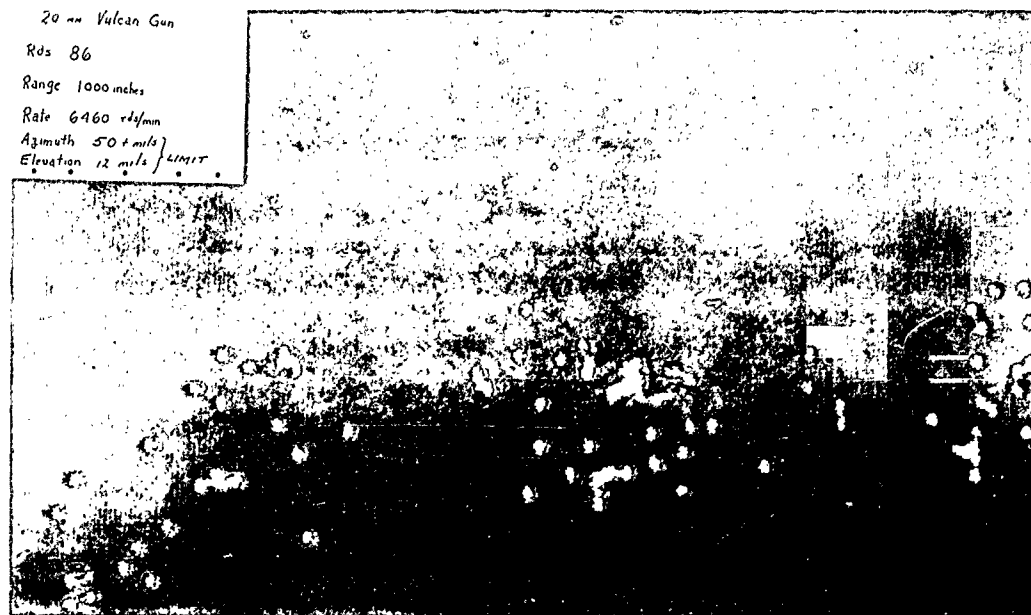


Figure 3-2. High Azimuth to Elevation Ratio - Target A



Figure 3-3. High Azimuth to Elevation Ratio - Target B

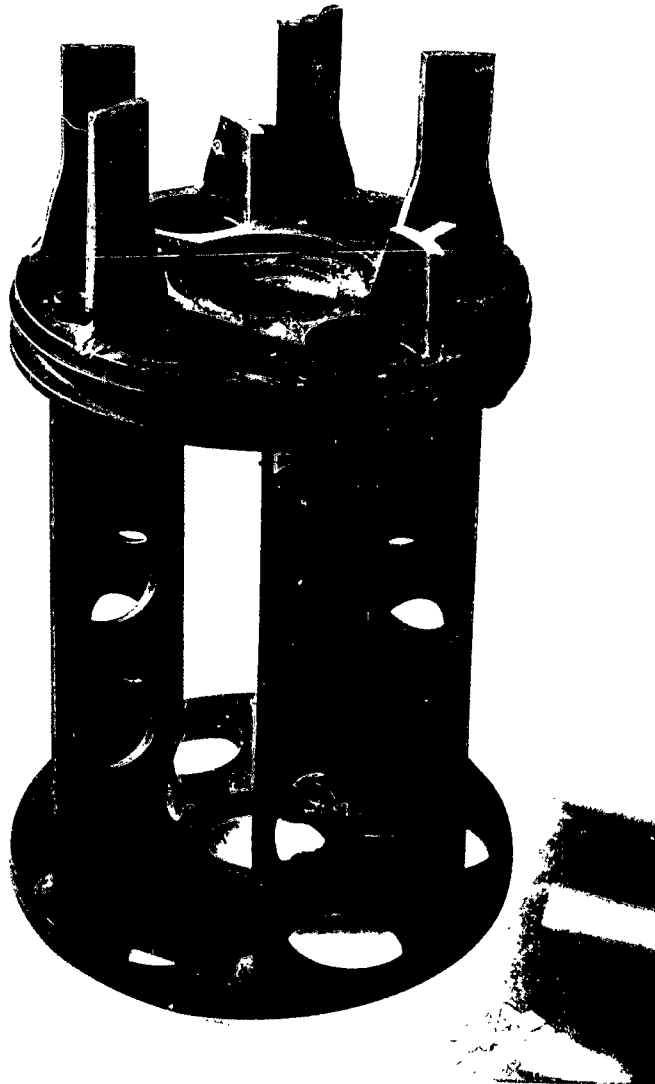


Figure 3-4. Muzzle Ejector Assembly

Addition of this device to a basic weapon will not add materially to the gun weight or silhouette. However, the induced muzzle whip can be as high as 4.5 inches total. Muzzle whip, again, is directly related to target dispersion, Figure 3-2, with maximum azimuthal sweep of 38.0 mils, had whip of 4.5 inches. During the test conducted no projectile instability was found, nor were there any deleterious effects noted on the barrels. Gun torque, however, did increase an average of 50 inch-pounds when these tests were run. High speed films of the targets indicated that after the firing rate is reached (approximately 14 rounds) the rounds were spread in their maximum separation. Those rounds fired prior to full rate fell within a 12 mil spread. The center of impact of these targets does not shift appreciably from the C.I. of a standard burst.

Phase II

It was anticipated that the firing of a large (14 to 18 mil) circular target could be accomplished in a manner similar to that used in the high azimuth-to-elevation ratio case discussed above. Extensive testing, however, indicated that uniform circular distribution could not be achieved with this technique.

The two other methods tried yielded better results. These were a variable force muzzle clamp (Figure 3-5), and excessive shimming of selected barrels.

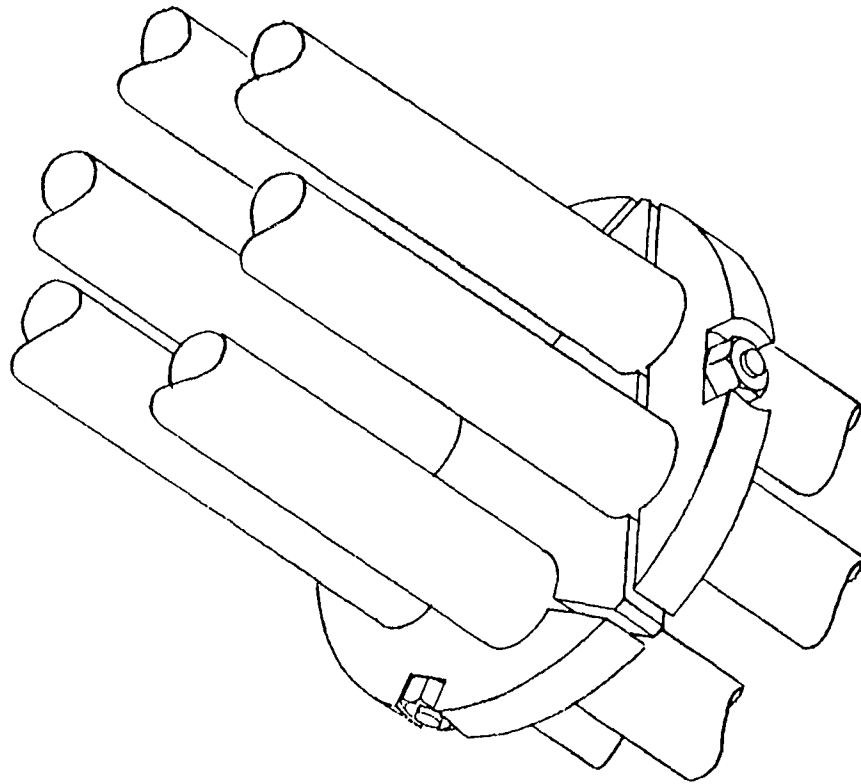


Figure 3-5. Variable Grip Muzzle Clamp.

To date, the second method has been more successful. This technique artificially accentuates the differences in effective barrel length by addition of shims to three barrels (Figure 3-6) and 'locking' on the alternate barrels. An eccentricity of 0.060, 0.040, and 0.020 inch in alternating barrels is successful in producing large circular dispersion. As of this date, however, complete uniformity of round density has not been achieved, (see Figure 3-7). This type of eccentricity could be built into a muzzle clamp if required.

Phase III

The last problem, that of achieving small circular dispersion (4 to 6 mil) is presently under study. A barrel stabilizer has been built and is currently awaiting test. Further evaluation of muzzle locks will be carried out in the near future.

It has been found that the addition of equal shims to three alternate barrels and 'locking' on those same barrels (push-pull technique) can decrease dispersion but further study must be made to fully evaluate this method.

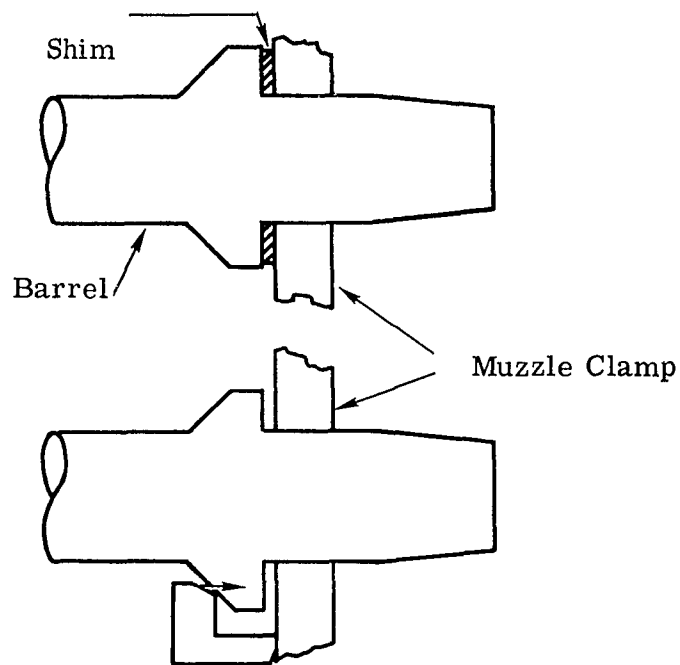


Figure 3-6. Barrel Shims and Locking

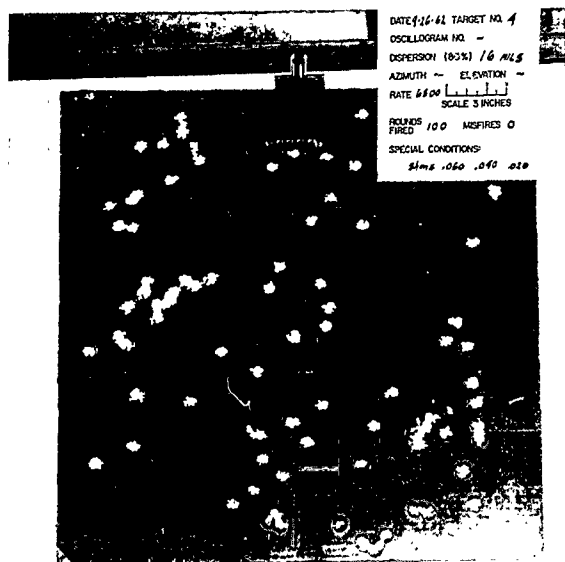


Figure 3-7. Target from Shimmed and Locked Barrel

SECTION IV

GUN-AIRCRAFT SYSTEMS COMPATIBILITY

F-104G CLEARING PROBLEM

During this past reporting period considerable contact has been made with Lockheed Aircraft concerning a problem on the F-104G aircraft. In this aircraft system the gun is cleared upon trigger release by the declutching feeder after each burst fired. Examination of the system after ground firing a burst with a declutching feeder attached to the gun showed that the weapon was not completely cleared. It was also noted that in some cases there were unfired rounds ahead of the firing cam.

It was suspected by Lockheed that the drive stop time was too short and therefore did not give the feeder time to completely clear the gun. It was also brought out that the gun could be fired at as low as 80 percent power which reduces the firing rate to 3420 spm. Since the drive brake is sensitive to rate this definitely could have an effect on the drive stop time.

During initial investigation a look at the various schematics revealed that the brake was applied before initiating the signal to the feeder. This condition is very undesirable.

Before progressing any further the amount of rotor travel required to clear the gun should be explained. This includes feeder actuation and

actual gun clearing. There are five actuating slots in the feeder to initiate clearing action. Therefore it is possible to have a maximum of 72° of feeder motion before clutch action starts or a minimum of 0° . The traveling lock ring takes 35° to actuate. Therefore the maximum feeder rotation to stop is 107° ($72^\circ + 35^\circ$). The minimum feeder rotation to stop is 35° ($0^\circ + 35^\circ$).

107° Feeder rotation = $5/6 \times 107^\circ = 89^\circ$ rotor rotation.

Feeder to gun gear ratio: 5 to 6.

35° feeder rotation = $5/6 \times 35^\circ = 27.5^\circ$ rotor rotation.

Needed to clear the gun alone: 330° .

Therefore, the maximum rotor rotation needed to clear the gun is 419° (330° plus 89°).

The minimum rotation of the rotor needed to clear the gun is, therefore, 357.5° ($330^\circ + 27.5^\circ$).

An aircraft was instrumented and ground firing showed very severe relay chattering and relay arcing. Consequently the feeder was not receiving a true signal when the trigger was released. The firing control box was shock mounted and a diode was added to the circuit to reduce relay arcing. Firing after installation of these items indicated that the gun would satisfactorily clear after each burst.

Continued testing during which the rate was changed indicated, as

was expected, that the stop time would become too short to completely clear the gun if fired at 80 percent power. Currently, all drives are being checked at approximately 474 cycles (100 percent power) which gives a rate of approximately 4200 spm. All drives must stop within 0.20 to 0.40 second from this rate at certain specified loads. It was found that a minimum drive that stopped in 0.20 second at 4200 spm would stop the system in approximately 0.17 second at 80 percent power and this was not long enough to clear the gun. In fact, with this stop time the belt would have to be declutched 0.029 second before applying the brake if the weapon is to be completely cleared. This would produce a maximum stop time of 0.429 second (0.40 maximum drive stop time plus 0.029). To tie this timing to trigger release the Lockheed reports indicate the 0.10 second is the maximum required to actuate the feeder from trigger release. Therefore, 0.129 second ($0.10 + 0.029$) is the minimum time required from trigger release to the time that the brake should be applied. Also, from the Lockheed report, the minimum brake action time is approximately 0.040 second which indicates that the brake signal should be delayed 0.089 second ($0.129 - 0.040$) ... or 0.090 second after the feeder has been given its signal. Since the maximum brake action time is 0.05 second, the maximum stop time expected from trigger release will be 0.539 second or 0.54 second ($0.089 + 0.050 + 0.400$).

Therefore, it is our recommendation that an 0.090 - .1 second delay relay be incorporated to insure that the declutching feeder is actuated before the brake is applied. This should insure that complete clearing is accomplished after every burst. Since this produces a stop time of 0.54 or 0.55 second, the present 0.5 second delay drop-out relay will have to be changed to 0.6 second.

SECTION V
GUN COMPONENTS

UNIVERSAL GUIDE BAR

During this period the testing of a universal guide bar to handle both the linkless feed and standard gun installation was continued.

Universal guide bar #B-14 was damaged in a gun stoppage at the Springfield Armory. Another universal guide bar, #B-23, has been sent to replace the damaged one. No test results have been received for this period from the Springfield Armory.

Universal guide bar #B-22, now has 21,999 gun rounds and is still serviceable.

Another universal guide bar was sent to Aberdeen Proving Grounds for evaluation.

Conclusions from testing at the General Electric Company in Burlington show that the universal guide bar functions equally as well as the standard gun guide bar.

REDESIGNED UNLOCKING CAM

The design of a gradual slope unlocking cam has been completed (see Figure 5-1). The unlocking action has been extended over the greatest distance that will assure safe unlocking. It will maintain the

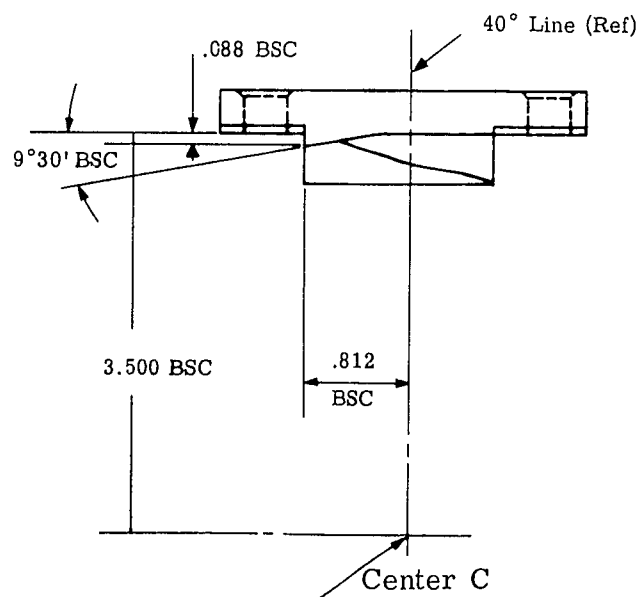
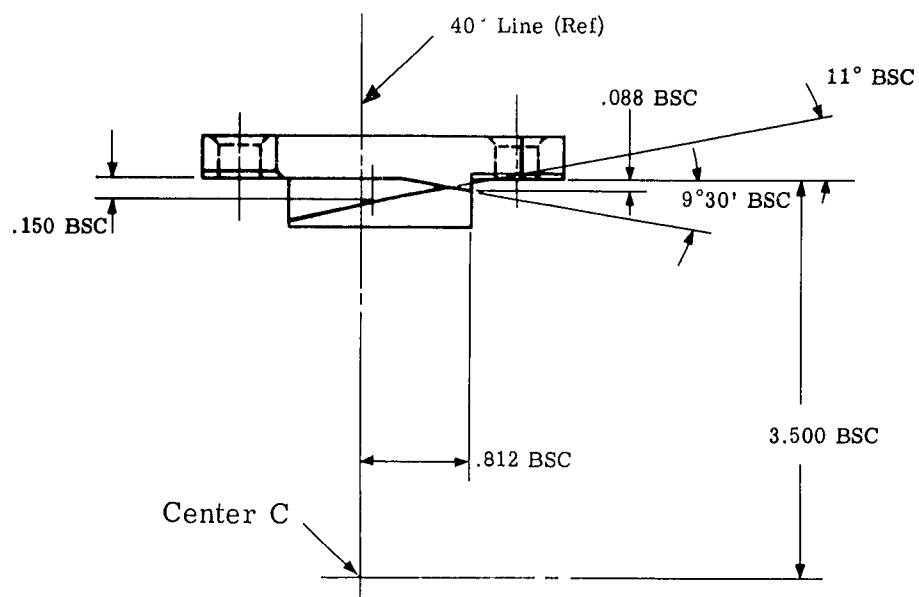


Figure 5-1. Redesigned Unlocking Cam

unlocking action so the roller shaft and lock block cannot bounce back into partial lock after unlocking. This design will be compatible with both the circular arc and cycloidal cam paths. It is expected that the useful life of the roller shafts will be extended as a result of the less severe unlocking action. Some sample unlocking cams are now being machined.

HOOK AND HOOK ROLLER SHAFT DESIGN

The three roller shafts (Figure 5-2A) fired for 8,348 rounds (reported in Progress Report #35) were subjected to closer inspection. This inspection indicated that all three shafts had cracks in the hook area.

Adding a roll pin (Figure 5-2B) failed to keep the shaft from twisting and finally cracking. First the roll pin sheared allowing the two hooks to wedge together in a cycling manner. The shaft hook cracked after 3,654 rounds.

Another attempt was made to keep the shaft hooks from wedging by adding a roll pin to the lock block hook (Figure 5-2C) engaging a slot machined in the bottom rear side of the roller shaft. This kept the shaft from turning in the unlock or bolt driving position. But when the shaft was in the lock position the pin engaged the slot at an angle causing the slot to flare at the bottom to the point where the shaft and lock block hooks were allowed to wedge and consequently crack.



A - Original Design



B - Roll Pin Added



C - Roll Pin in Lock Block

Figure 5-2. Hook and Hook Roller Shaft Design

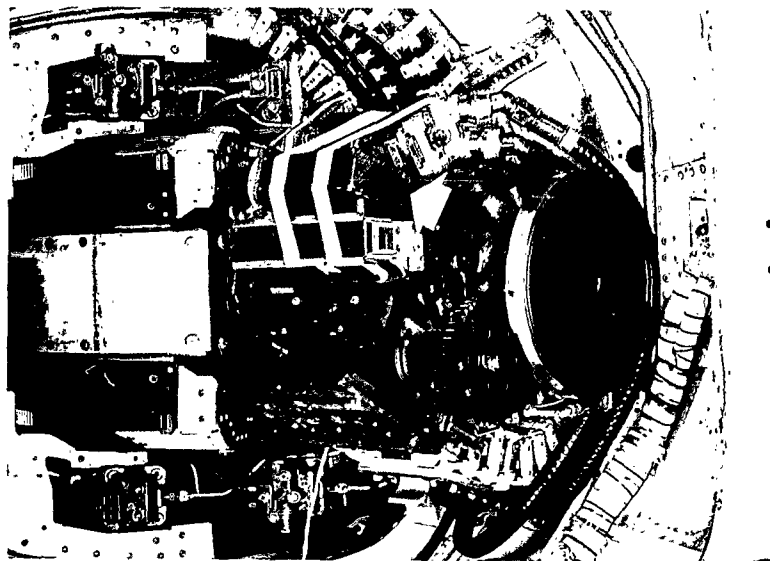
Other methods of holding the shaft hook from wedging with the lock block hook will be investigated to improve the hook and hook design.

LUBRICATOR INSTALLATION FOR THE B-58

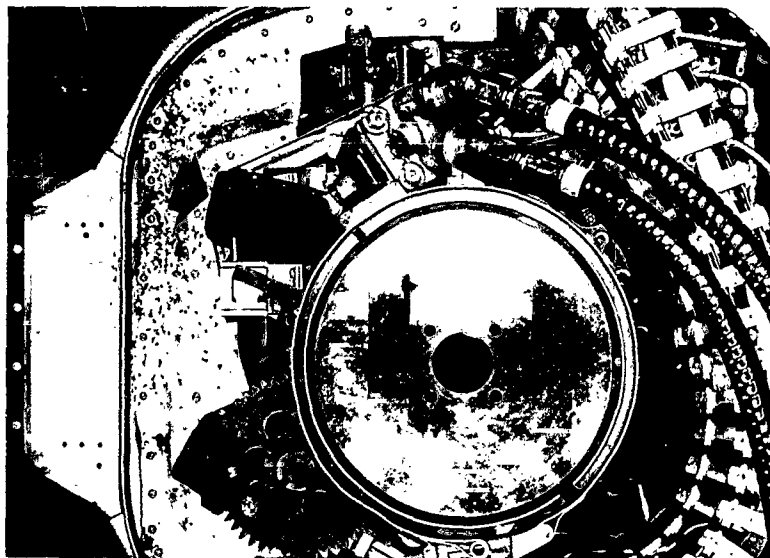
The Vulcan forced lubricator installation (GE dwg No. 716D594) has been built, tested and is known to be compatible with the F-105 fighter aircraft. Recent work has been aimed at installing the lubricator in the B-58 turret. It is anticipated that the configuration of both lubricator installations will be similar, allowing one model to serve both aircraft.

At first it was hoped that the M-7 Electric Drive pad could be used for a mounting surface. However, it was found that there would be interference with the B-58 turret when the gun was in the full right-azimuth position. New information from the Emerson Electric Manufacturing Company, turret manufacturers, indicates that it may be possible to place the installation between the gun case chute and the side-mounted hydraulic drive. This information has been ascertained by placing a mockup lubricator in the position mentioned above (see Figure 5-3).

Further effort will be expended to determine the most suitable method of mounting the lubricator and the associated additions to the actuating rod and the outlet tube. Further reports will be made on the progress of this effort.



Gun Aimed Forward



Gun in - 30° Azimuth Position

Figure 5-3. Possible Location of Lubricator

CLEARING CAM SOLENOID MODIFICATION

As reported in Progress Report #35 interference was experienced when the linkless feed transfer unit was installed or removed from the F-105D aircraft. It was also reported at that time, that one corner of solenoid mounting plate and coil assembly had been cut off to provide the necessary clearance. In addition to the cut off a roll pin has been added (see Figure 5-4) to keep the coil assembly from moving on its base mounting plate. A sample of this addition was presented at the September 1962 engineering meeting and accepted as a suitable device to keep the two parts from moving.

To date 3,560 rounds have been fired with this latest modification and good results have been received.

Another modified solenoid has been installed on the endurance gun scheduled to be fire tested in October 1962 in Endurance Test #1 on contract 5560.

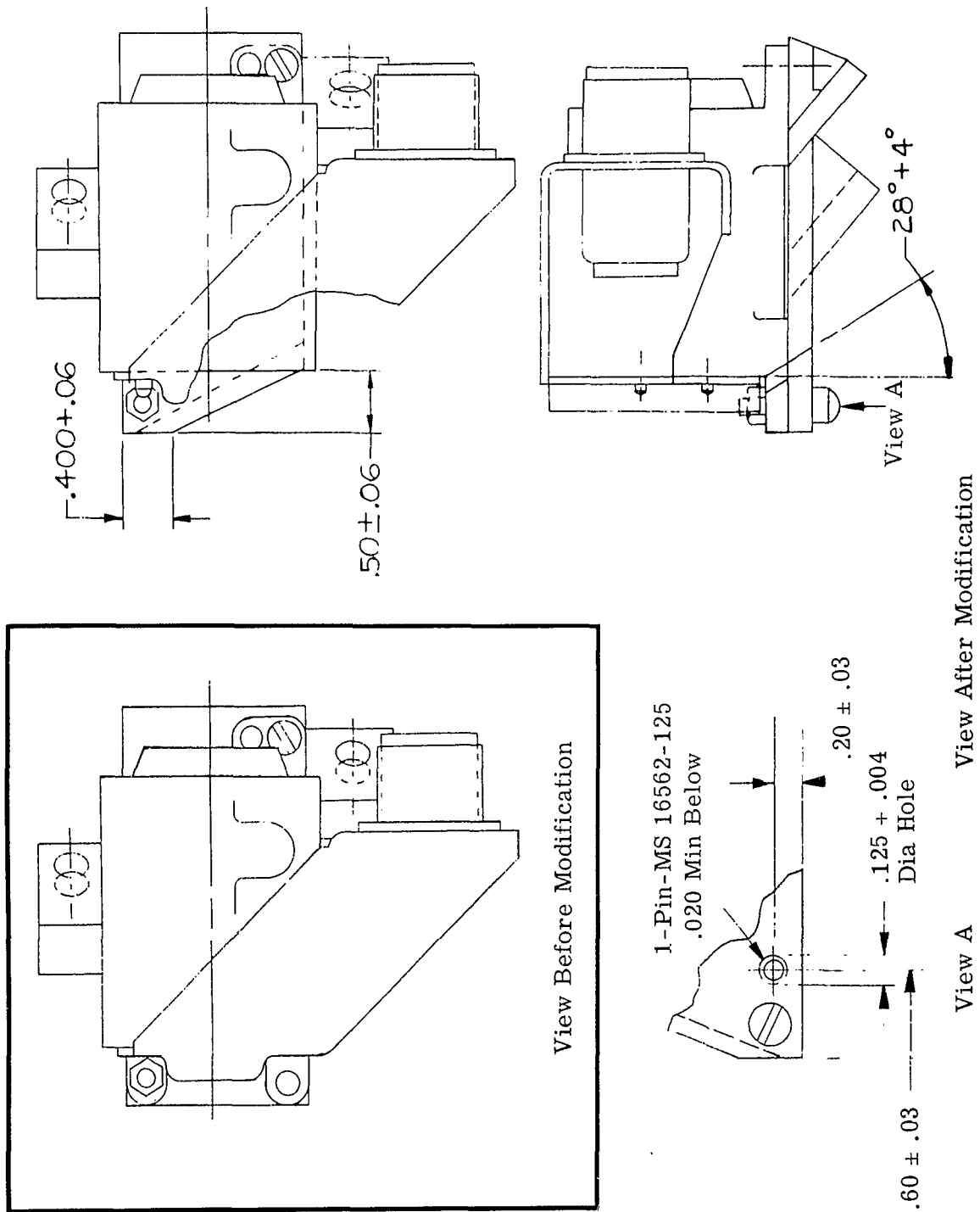


Figure 5-4. Clearing Cam Solenoid Modification

SECTION VI
GUN FIRING RECORDS

GUN FIRING REPORT
Engineering Testing
R&D - Product Improvement

GUN TYPE M61 FACILITY GE Burlington
SER. NO. GE 16 PERIOD FROM 8-1-62 TO 8-31-62
DATE 10-29-62 FIRING RECORD

FIRING RECORD

NO.	TEST DESCRIPTION			ROUNDS FIRED			STOPPAGES	
	2 PURPOSE OF TEST	3 TEST CONDITIONS	4 TYPE 4 AMMO LOT & NO.	5 TYPE 5 LINKS LOT & NO.	6 TYPE DRIVE	7 CUM. GUN ROUNDS	8 RDS. PER TEST CONDITION	9 MIS- FIRES TYPE STOPPAGE
1	Roller Shafts Solar SPS Squeeze lock muzzle clamp Universal guide bar Case chute Dispersion Targeting One end linkless feed		7-10	T-76	T48 D-Rate	49468	4100 3400 3900 2800 1900 500 1985	0
						53568	4100	0
					TOTAL			

STOPPAGE SCHEDULE

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STOPPAGE CODING

A.	H.
B.	I.
C.	J.
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FIRING RECORD

6-4

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STOPPAGE										
THIS PERIOD	0	0	0	0	0	0	0	0	0	0
TOTAL TO DATE	0	0	0	1	0	0	0	0	0	1

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GUN TYPE M61 GUN FIRING REPORT FACILITY GE Burlington
 SER. NO. 0438 R&R Engineering Testing PERIOD FROM 8-1-62 TO 8-31-62
 DATE 10-29-62 R&D - Product Improvement FIRMING RECORD
 10-29-62

TEST DESCRIPTION			ROUNDS FIRED				STOPPAGES	
1	2	3	4	5	6	7	8	9
NO.	PURPOSE OF TEST	TEST CONDITIONS	TYPE 4 AMMO LOT & NO.	TYPE 5 LINKS LOT & NO.	TYPE DRIVE	CUM. GUN ROUNDS	RDS. PER TEST CONDITION	VIS- FIRING TYPE STOPPAGE
	Bolt insert insulation Universal guide bar Sector cam spring Solar steel roller shaft Modified rear track ways on bolt bodies	M55A1 7-10	T76 6-3		T48 D-Rate	63164	3200 3200 3200 3200 3200	0 0 0 0 0
						TOTAL 66364	3200	0

6-5

STOPPAGE SCHEDULE

STOPPAGE	12	13	14	15	16	17	18	19	20	21
	GUN	AMMO	LINK	PERSONNEL	INSTAL.	SPECIAL	UNKNOWN			TOTAL
THIS PERIOD	0	0	0	0	0	0	0	0	0	0
TOTAL TO DATE										

STOPPAGE CODING

A.	H.
B.	I.
C.	J.
D.	K.
E.	L.
F.	M.
G.	N.

024-247(10-60)

GUN TYPE M61 GUN FIRING REPORT FACILITY GE Burlington
 SER. NO. 0444 R&R Engineering Testing PERIOD FROM 9-1-62 TO 9-30-62
 DATE 10-30-62 R&D - Product Improvement FIRMING RECORD

TEST DESCRIPTION			ROUNDS FIRED				STOPPAGES	
1	2	3	4	5	6	7	8	9
NO.	PURPOSE OF TEST	TEST CONDITIONS	TYPE 4 AMMO LOT & NO.	TYPE 5 LINKS LOT & NO.	TYPE DRIVE	CUM GUN ROUNDS	RDS PER TEST CONDITION	VIS FIRES TYPE STOPPAGE
	Dispersion One end linkless feed	136-15	T76 Conveyor Elements		T46E1	46640	500 1530	0 0
TOTAL						48,670	2030	0

STOPPAGE SCHEDULE

STOPPAGE	1	2	3	4	5	6	7	8	9	10
THIS PERIOD	0	0	0	0	0	0	0	0	0	0
TOTAL TO DATE	0	0	0	1	0	0	0	0	0	1

STOPPAGE CODING

A.	H.
B.	I.
C.	J.
D.	K.
E.	L.
F.	M.
G.	N.

GUN TYPE M61 GUN FIRING REPORT FACILITY GE Burlington

SER. NO. 0438 R&R Engineering Testing PERIOD FROM 9-1-62 TO 9-30-62

DATE 10-29-62 R&D - Product Improvement FIRING RECORD

1	TEST DESCRIPTION					ROUNDS FIRED			STOPPAGES	
	2	3	4	5	6	7	8	9	10	11
NO.	PERPOSE OF TEST	TEST CONDITIONS	TYPE 4 AMMO LOT & NO.	TYPE 5 LINKS LOT & NO.	TYPE DRIVE	CUM. GUN ROUNDS	RDS. PER TEST CONDITION	MIS. FIRES	TYPE STOPPAGE	
	Bolt insert insulation Universal guide bar Sector cam spring Solar steel roller shaft Modified rear track ways on bolt body		M55A1 7-10	T76	T48 D-Rate	66364	2800 2800 2800 2800	23	A	
										TOTAL 69164 2800 23 A

STOPPAGE SCHEDULE

STOPPAGE	12	13	14	15	16	17	18	19	20	21
THIS PERIOD	1	0	0	0	0	0	0	0	0	1
TOTAL TO DATE	0	0	0	0	0	0	0	0	0	1

STOPPAGE CODING

- A. Solar steel roller shaft failed, this caused failure to unlock H.
- B. I.
- C. J.
- D. K.
- E. L.
- F. M.
- G. N.

024-247(10-60)

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