2

AFATL-TR-77-53

30MM GAU-8 THIN-WALL STEEL CARTRIDGE CASE

AMRON CORPORATION
525 PROGRESS AVENUE
WAUKESHA, WI 53186

APRIL 1977

FINAL REPORT FOR PERIOD
FEBRUARY 1976-MARCH 1977

Approved for public release; distribution unlimited.

AIR FORCE ARMAMENT LABORATORY

AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE

EGLIN AIR FORCE BASE, FLORIDA

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19 REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

14 1. REPORT NUMBER: AFATL-TR-77-53

2. GOVT ACCESSION NO.:

3. RECIPIENT'S CATALOG NUMBER:

6 4. TITLE (and Subtitle): 30mm GAU-8 THIN-WALL STEEL CARTRIDGE CASE.

9 5. TYPE OF REPORT & PERIOD COVERED: Final Rep[redacted]t, Feb[redacted]76 - Mar[redacted]77

6. PERFORMING ORG. REPORT NUMBER:

10 7. AUTHOR(s): Roy/Rayle, Robert/Brey

8. CONTRACT OR GRANT NUMBER(s): 15 F08635-76-C-0176 new

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Amron Corporation ✓
525 Progress Avenue
Waukesha, Wisconsin 53186

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
Project 670F-01-34
Program Element 63601F

11. CONTROLLING OFFICE NAME AND ADDRESS:
Air Force Armament Laboratory ✓
Armament Development and Test Center
Eglin Air Force Base, Florida 32542

11 12. REPORT DATE: Apr[redacted]77 12 68p.

13. NUMBER OF PAGES: 67

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

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

18. SUPPLEMENTARY NOTES

Available in DDC

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

GAU-8 30mm Ammunition	Hardness Profiles
Rod, Extrude, Draw	Interior Case Volume
Ballistics Measurements	Thin-Wall STeel Cartridge Case
Taper Operations	Stress-Strain Case Clearance Curves
Bullet Pull	Protective Coatings

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Development of the 30mm Thin-Wall Steel Cartridge Case was conducted using an extrusion process with 10B22 steel. Development testing was conducted to refine the design and to modify tooling as required. Preliminary qualification and environmental tests were conducted by the contractor with satisfactory results. A total of 850 cases was delivered to Eglin Air Force Base for further test and evaluation.

Item 20 (concluded):

Former case integrity problems in 1975 involving transverse ruptures or stretches were eliminated in Mann barrel tests. In automatic gun tests, rework of cases with a different finish was required to alleviate cracks and stretches. A former deficiency in bullet pull force was overcome with double groove projectiles. Bullet pull was marginal with single groove projectiles.

Producibility analysis indicates an appreciable cost savings over the present aluminum case due to lower raw material cost.

Steel case weight is 0.05 pound more than the aluminum case weight and the added 18 percent interior volume provides 150-200 feet per second higher muzzle velocity.

PREFACE

This report provides a synopsis of the development of a thin-wall steel cartridge case in support of the GAU-8 program. The program was conducted by Amron Corporation, 525 Progress Avenue, Waukesha, Wisconsin 53186, under Contract F08635-76-C-0176 with the Air Force Armament Laboratory, Armament Development and Test Center, Eglin Air Force Base, Florida, during the period 2 February 1976 to 31 March 1977. The program was managed by Mr. Alvin T. Cox (DLDG).

This report has been reviewed by the Information Officer (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This report has been reviewed and is approved for publication.

FOR THE COMMANDER

Gerald P. D'Arcy

GERALD P. D'ARCY, Colonel, USAF
Chief, Guns, Rockets and Explosives Division

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION I

INTRODUCTION

This report presents the results of the development of the thin-wall steel cartridge case for GAU-8 ammunition. The objective is to develop a case weighing approximately the same as the aluminum case, achieving about 18 percent more interior case volume and having the potential for a lower cost cartridge case in volume production. Shown in Figure 1 are the cartridge case sections comparing the thin-wall steel case with the aluminum case.

General feasibility was previously demonstrated but refinement of design and method of fabrication was indicated. Design changes were to select the internally grooved case to increase interior volume and to refine those areas affecting case stretch and bullet pull. Method of fabrication was changed from the previous blank, cup and draw process using plate material, to the rod, extrude, draw process, using rod material, for better control of dimensions during fabrication, and to reduce waste of raw material.

The contractor developed new tooling to implement these changes and fabricated sufficient cases to conduct Mann barrel firing tests and static bullet pull tests. On achieving a satisfactory design, preliminary qualification tests were conducted. The results were satisfactory.

Deliveries to the Air Force included empty cases and steel-cased cartridges for pull tests and Mann barrel and automatic gun firing tests.

The circumferential stretch or rupture problem identified in the previous program was alleviated by tool changes and design iterative testing. Changes included refinement of the blend radius area between head and sidewalls, increasing head-to-datum length, thus reducing head space and changing coating to a glossy Swiss lacquer. Changes made to increase bullet pull to desired levels included increase in mouth wall thickness and increase in strength and hardness of the mouth. With the new rod material, a potential side split problem was resolved by improved hardening techniques and by non-destructive testing of cases in process.

A producibility analysis was conducted. This indicated that increased direct labor costs in processing the steel case as compared to the aluminum case are more than offset by decreased material cost to achieve a substantial production cost saving. An evaluation was made of the benefits under full production of going from the present process of sawing cold rolled rod for blanks to processing hot rolled coils or rod through shear, block and preform to obtain a lower cost blank.

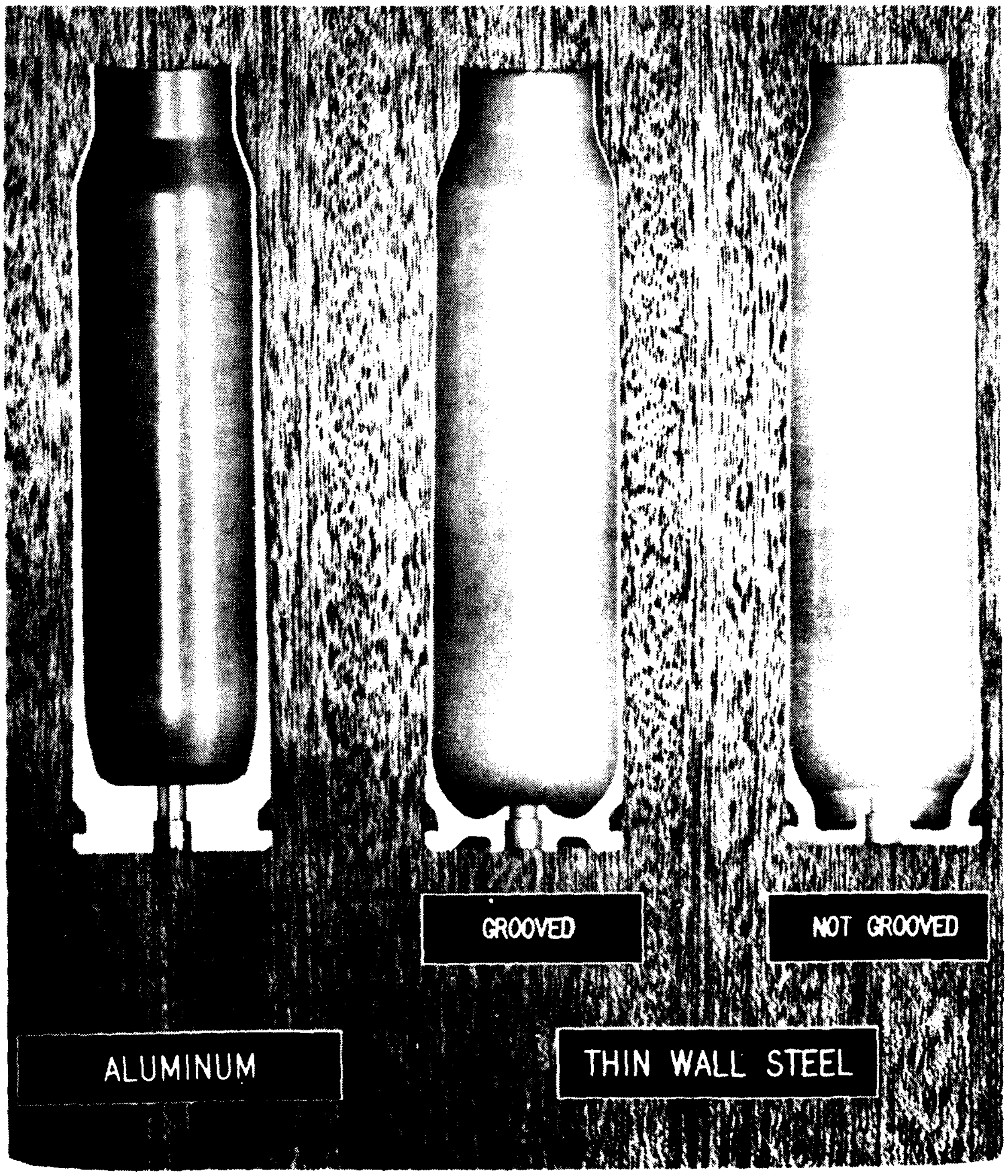


Figure 1. 30mm GAU-8 Cartridge Cases

Environmental testing was conducted at Indiana Ordnance, and transient heat flow tests were conducted by the contractor with satisfactory results.

Functional characteristics are discussed as a basis for a future specification to be prepared covering the GAU-8 30mm thin-wall steel cartridge case.

SECTION II

MATERIAL CONSIDERATIONS

INTRODUCTION

In the previous program, 10B30 plate material was used in a blank, cup and draw process to expedite delivery of first cases. The preferred process is to extrude from rod, and all thin-wall 30mm steel cartridge cases manufactured by the contractor under the present program were manufactured from AISI 10B22 steel. The steel was provided by Jones and Laughlin Steel Corporation as cold drawn 10B22 steel, cold extrusion Quality B, 0.10 maximum Si. The ladle analysis of the steel provided is as follows:

Heat No.	C	Mn	P	S	Si	B
237870	0.18	0.87	0.010	0.018	0.028	0.0005 minimum

This chemistry proved to have adequate hardenability and formability to manufacture the cartridge case and is considered to have been a proper selection for the product.

STEEL GRADE SELECTION

The contractor has also recently employed two similar grades of steel on another 30mm case program. Experience has shown that these grades would also be satisfactory for the manufacture of the thin-wall cartridge case. These grades are modifications of the AISI 10B22 chemistry and offer the advantage of being readily available as standard carbon-manganese-boron steel.

These grades are sold by United States Steel as part of their Q-Temp® series of steels and by Republic Steel as part of their RS B series. Chemistries for these grades and the standard AISI grade are given below:

	C	Mn	B
AISI 10B22	0.18/0.23	0.70/1.00	0.0005 minimum
U.S.S. Q-Temp®10B21 Q or Republic RS B21	0.18/0.23	0.80/1.10	0.0005 minimum
U.S.S. Q-Temp®10B22 Q or Republic RS B22	0.17/0.23	1.00/1.30	0.0005 minimum

All three of the above grades are considered suitable selections for the thin-wall 30mm case. The contractor's experience over the last year has demonstrated that all three grades have adequate formability and hardenability. The latter has the disadvantage in that the higher Mn range adds slightly to the steel cost. This limits the selection to the first two grades. These grades are almost identical, the only difference being the Mn ranges. However, these ranges overlap over the majority of the range. The selection between the two is almost academic, with perhaps the 0.80/1.10 Mn range being preferred.

The silicon range also needs to be specified. The thin-wall cartridge cases were manufactured from a 0.10 percent maximum silicon steel. Other 30mm cases have been manufactured from a steel with a standard silicon range of 0.20 to 0.35 percent. Both ranges were successful. However, the lower silicon range is still preferred for better formability. The standard silicon steel was used only because of availability considerations.

To assure steel availability while the case is still in developmental stages and steel purchases are relatively small, either the AISI 10B22 grade, the U.S.S. 10B21 Q grade, or the Republic RS B21 grade should be allowed. As discussed, these grades are virtually identical. Also, either the low silicon or the standard silicon range should be allowed to assure availability.

For future procurement when quantities increase and availability becomes less of a concern, the following chemistry is preferred and should be specified:

Element	Ladle Analysis (%)
C	0.18-0.23
Mn	0.80-1.10
P	0.030 Maximum
S	0.040 Maximum
Si	0.10 Maximum
B	0.0005 Minimum

The chemistry of the steel used to manufacture the thin-wall cases falls within the above specified range.

Steel quality should also be specified. The quality description applicable is cold extrusion Quality B.

Minor problems were encountered during case manufacture because of seams on the rod. This will probably be a continuing concern and would best be handled by discussions with the steel supplier so that they can produce the steel with a mill practice that is most compatible with the end item. Even with good mill control, the contractor will probably have to accept a small percentage of scrap because of seams and will need to establish an in-process inspection procedure to sort out defective parts.

Steel will be purchased either as hot rolled rod or as cold drawn rod, depending upon the requirements of the contractor's manufacturing process. The steel will be purchased in accordance with one of the following specifications:

ASTM A-576	Special Quality Hot Rolled Carbon Steel Bars
ASTM A-108	Steel Bars, Carbon, Cold Finished, Standard Quality

It may prove economical to scarf or peel the rod to minimize surface defects.

SECTION III

DESIGN ANALYSIS

INTRODUCTION

The material selected for the current thin-wall steel case, as discussed in Section II, is AISI 10B22, which is now used in a rod, extrude, draw fabrication process. This steel is heat treated to a nominal 175,000 psi ultimate strength corresponding to a hardness of Rockwell 30N 58. The design of the case using this material is discussed in this section, as well as design analyses resulting from testing.

Figure 2 reflects the basic design of the 700 cases delivered in October 1976. Changes made during this program are included in this drawing. Principal changes include increase in blend radius of rear wall, increase in head-to-datum length, increase of mouth hardness and wall thickness, decrease in mouth diameter, and modification of primer boss to facilitate manufacture. Surface treatment was changed from zinc plate to phosphate to meet a 600-degree F., ten-minute exposure time in the GAU-8 chamber. The cases initially used a 30 percent TFE DeBeers lacquer coating. This was subsequently changed to Mader lacquer to reduce case stretching after the start of Eglin automatic gun tests. A total of 432 cartridges were returned for this change of coating, and 300 of these cartridges were subsequently shipped to Eglin Air Force Base in February 1977.

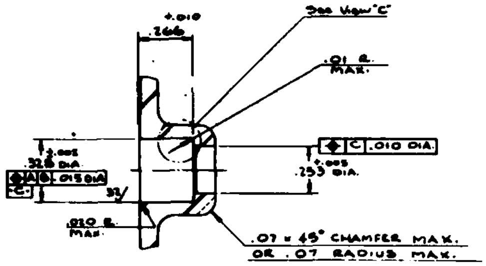
In the course of making slight increases in wall thickness at the mouth and near the base, the weight of the case has increased from 0.337 pound to 0.371 pound. This compares to 0.32 pound for the aluminum case. The interior volume has changed very little and is now measured at 12.27 cubic inches, or 18 percent more interior volume than in the aluminum case, rated at 10.4 cubic inches.

The general design is identified as "not grooved" in Figure 1. This figure permits comparison with the design, used in the preceding program, identified as "grooved." Either design uses much thinner walls than the aluminum case. The transfer of the external groove of the earlier design to the interior of the case at the primer pocket serves to increase the internal volume.

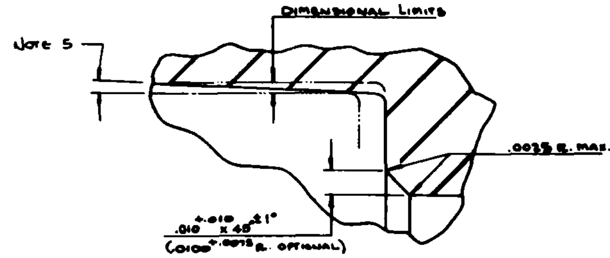
The hardness pattern shown in Figure 2 indicates a range of hardness over the rear half of the case from Rockwell 30N 54 to 62. Based on test results, this range should be narrowed to 30N 57 to 62. This eliminates excess head distortion of softer cases when fired at excess pressure levels. Mouth hardness is to be increased to 30N 47 to 52.

Circumferential cracks and stretches were encountered in automatic gun test firings but not in Mann barrel tests. This was partially corrected for normal pressure levels by changing the coating to Swiss Mader lacquer.

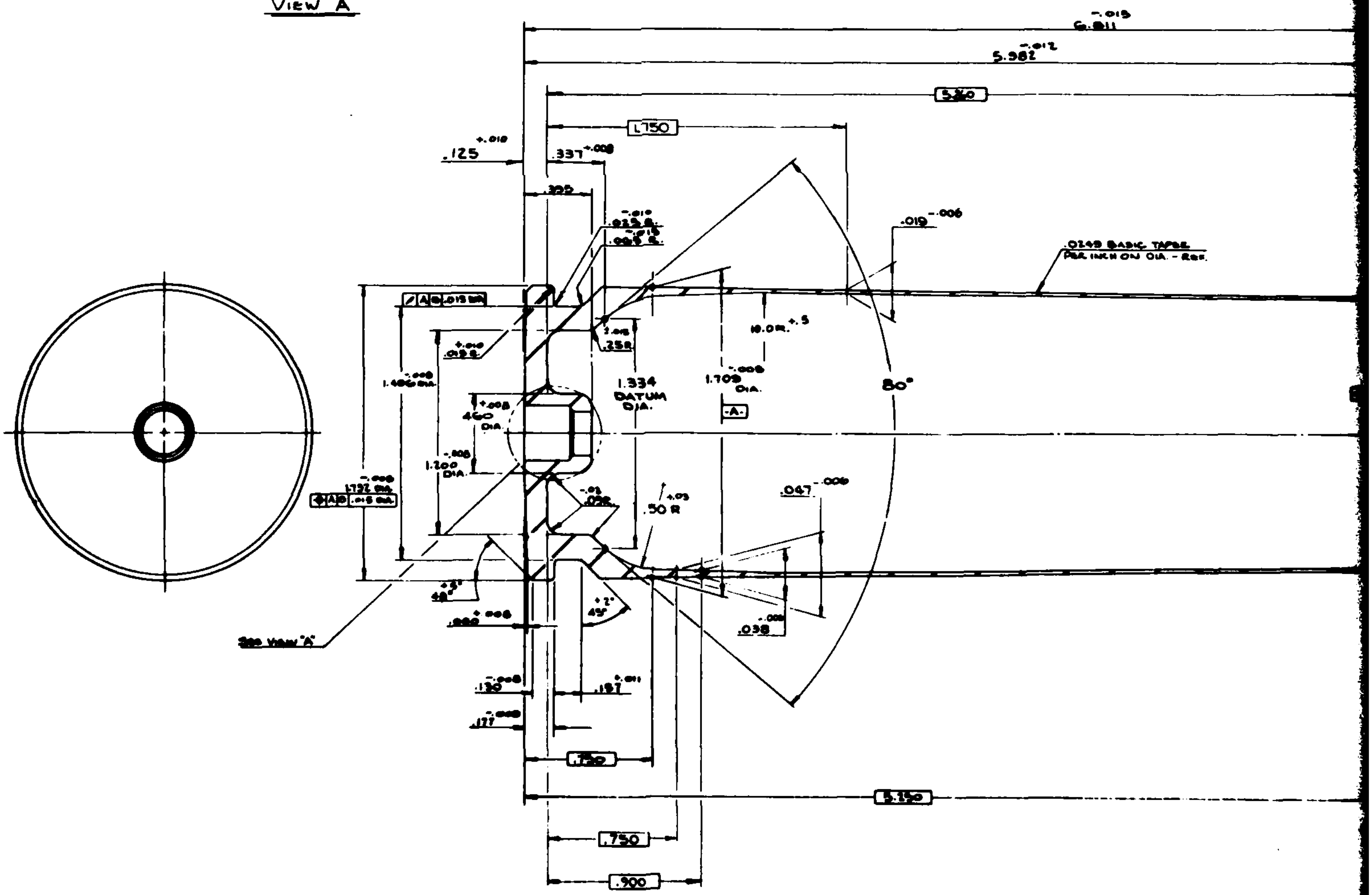
(The reverse of this page is blank)



VIEW "A"



VIEW "C"
SCALE: NONE



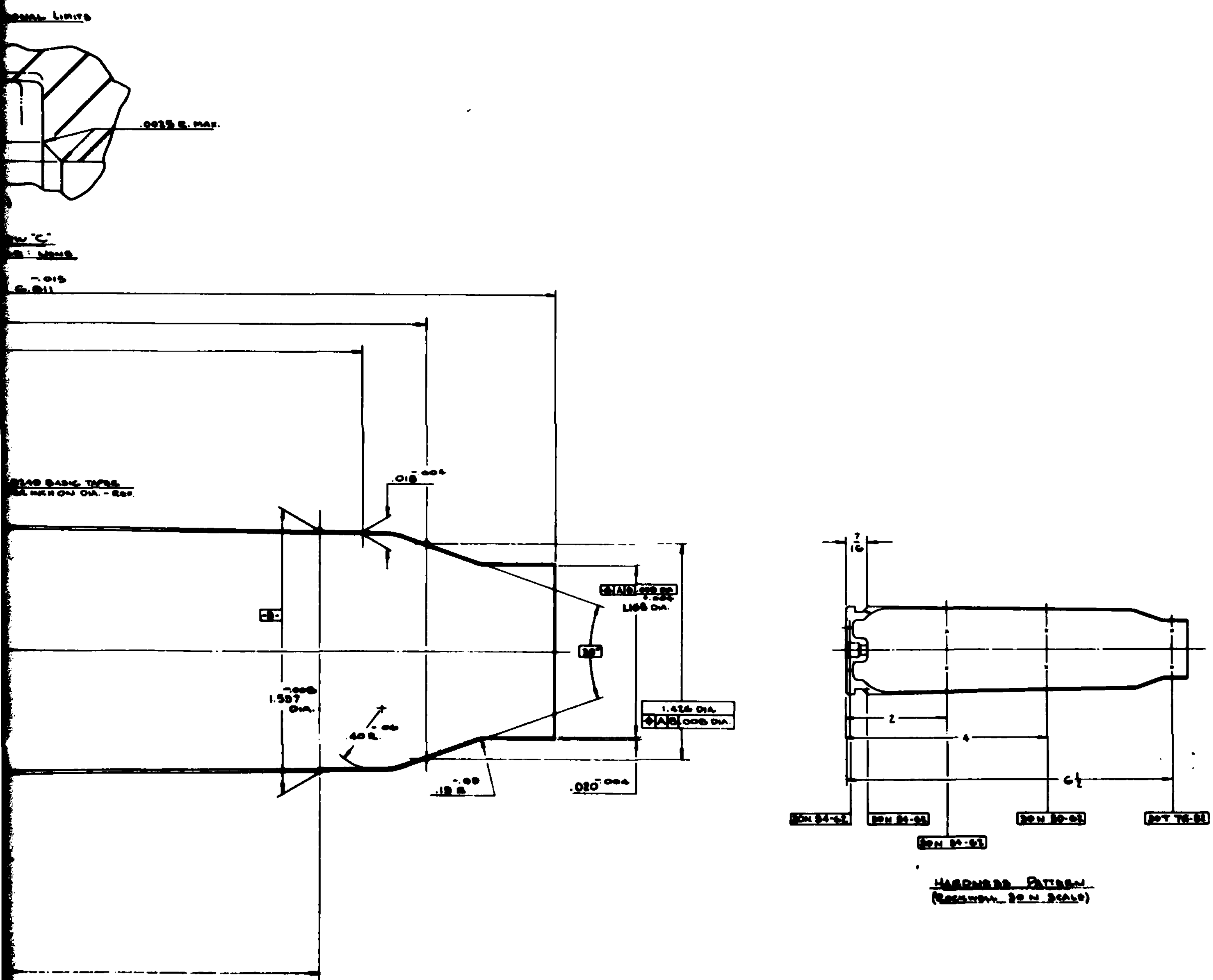


Figure 2. Basic Case Design

(The reverse of this page is blank)

For the next phase, a further grinding and polishing of the punch in the vicinity of the 10-inch blend radius is aimed at elimination of cracks and stretches at excess pressure, as well as designs with slightly thicker rear walls.

The balance of this section will cover design analyses resulting from testing in the areas of case mouth interference fit effect on bullet pull; residual clearance after firing comparing case materials of steel, aluminum, and brass; historic analysis of case rupture examples; case wall and tooling contour analyses; head space studies; plans for dynamic stress-strain analyses; coatings studies; and the effect of case temperature on extraction forces.

EFFECT OF INTERFERENCE FIT AT CASE MOUTH ON BULLET PULL

Due to relatively low bullet pull obtained with thin wall cases, it is desired to ensure that the maximum benefit of an interference fit between the projectile and the case mouth be obtained to increase bullet pull over that already obtained with the crimp grooves. An analysis is made to ascertain the theoretical magnitude of pull forces involved, interference fit ranges required, and total strain at the mouth after firing.

Basic physical dimensions are as follows:

Painted projectile Base:	1.175 inches to 1.182 inches
Case Mouth per Original Design:	1.172 inches to 1.176 inches
Case Mouth per Proposed Design:	1.168 inches to 1.172 inches

With these dimensions, interference will range from 0.003 inch (minimum) to 0.014 inch (maximum) for the new proposed design. The original design has such a large mouth that the fit can range from 0.001 inch clearance to 0.010 inch interference. A maximum interference of 0.014 inch should cause no assembly difficulty, as bullet pull tests for cases with no mouth sizing operation averaged 0.014 inch interference with no assembly difficulty.

For mouth yield strength, σ, of 110,000 psi:

$$\text{Unit strain}, \varepsilon = \frac{\sigma}{E} = \frac{110{,}000}{30{,}000{,}000} = 0.0037 \text{ inches per inch}$$

$$\text{Strain}, \lambda = \varepsilon D = 0.0037 \times 1.18 = 0.0044 \text{ inch}$$

Normal pressure, P, between case mouth and projectile due to interference.

$$P = \frac{2\sigma t}{D} \qquad \begin{aligned} D &= 1.118 \text{ inches diameter} \\ t &= 0.016 \text{ inch mouth wall thickness} \end{aligned}$$

$$P = \frac{2\,(110{,}000)\,(0.016)}{1.18} = 2{,}983 \text{ psi}$$

Bullet pull, due to interference = PAf Where A = Area for intereference fit, exclusive of grooves
f = Coefficient of friction, 0.164

$F = 2{,}983\ (1.18\ \pi\ 0.3)\ (0.164)$

$F = 544$ lb, added bullet pull, besides that due to crimp grooves.

This added bullet pull will be reduced somewhat under minimum interference conditions of 0.003. However, for the range of interference from 0.004 to 0.014, added bullet pull of over 500 pounds should be expected.

Mouth strain at firing:

Chamber diameter at mouth = 1.255 to 1.256
Mouth wall thickness = 0.014 to 0.018

Therefore, allowing for projectile base diameter, minimum diametral chamber clearance is 0.037, maximum is 0.052.

Corresponding maximum unit strain is $\frac{0.052}{1.18} = 0.044$ or 4.4 percent. Existing yield strain, by coupon test of case mouth material = 8 percent.

Therefore, an adequate margin of safety exists in spite of the added chamber clearance with the thin wall case.

CASE CLEARANCE IN CHAMBER AFTER FIRING

Figure 3 shows a set of stress-strain curves for the GAU-8 chamber comparing residual clearance after firing for cases made of hardened steel, aluminum, or brass. The sloped line, designated "chamber," represents enlargement of chamber on firing for a maximum pressure level of 66,000 psi. The abscissa is in unit strain dimensions; so for a chamber strain of 0.0052 inch per inch, as shown, the total strain for the chamber diameter of 1.75 inches is 0.0091. The cartridge case will enlarge in both elastic and plastic flow on pressure rise, but will decrease only along the linear elastic flow slope on pressure decay. Residual clearance after firing is a function of the ultimate strength (hardness) of the material, and the modulus of electricity (slope of the stress-strain diagram) of the material involved. For the three materials, 10B22 steel heat treated to provide 190,000 psi ultimate strength, 7475-T73 at 70,000 psi ultimate strength, and 70/30 brass at 90,000 psi ultimate strength, the residual clearances obtained after converting from unit strain to total strain are: 0.0023 for steel, 0.0032 for aluminum, and 0.0004 for brass. With the effects of temperature added, these clearances may become interferences, and the brass case would be the most difficult to extract. In tests of the thin-wall steel case at excess pressure levels and full hardness, slight extraction forces have been

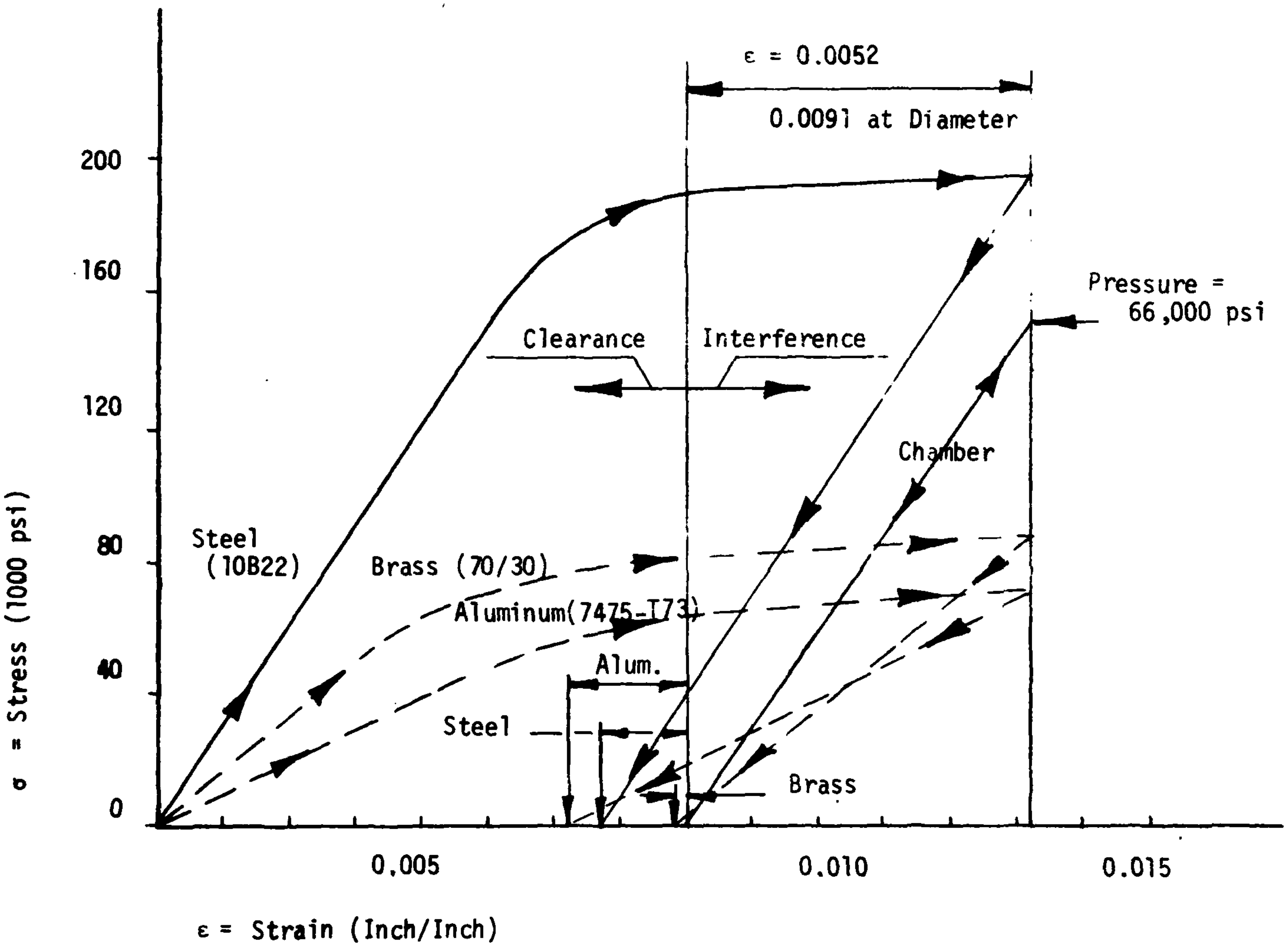


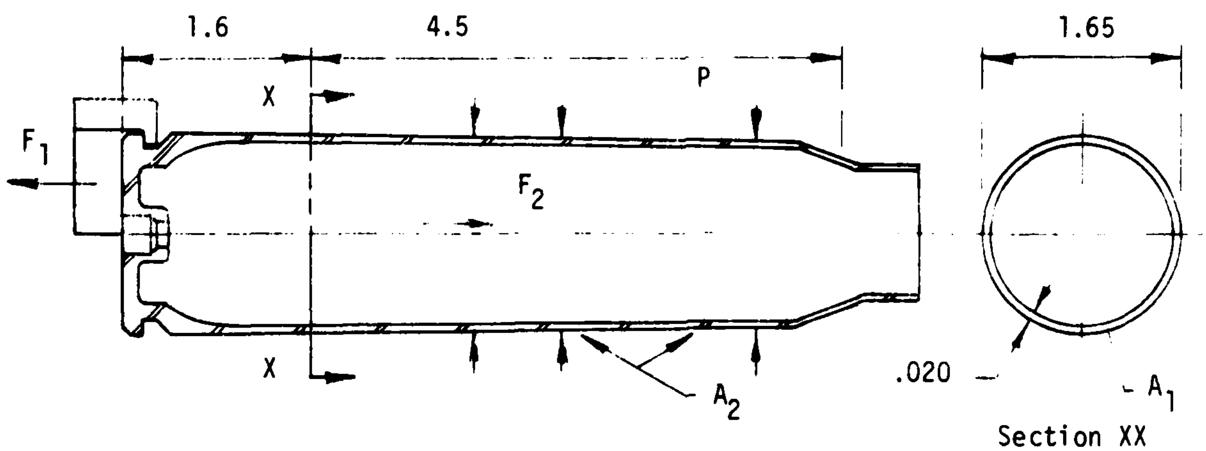
Figure 3. Case - Chamber Clearance at 1.75-Inch Diameter

measured. With cases deliberately softened, for ultimate strengths in the region of 148,000 psi, appreciable extraction forces are measured.

CASE TEMPERATURE EFFECT ON EXTRACTION FORCES

The effect of temperature build-up in the case on firing is analyzed to determine the potential of such effects to result in high enough forces to cause transverse cracks upon extraction. This analysis predicts rupture would not occur for case temperatures at extraction of 208 degrees F. for the steel case compared to 125 degrees F. for aluminum cases. It was subsequently determined by firing the automatic gun in a single barrel mode that cracks occurred without extraction forces, absolving the transient case temperature rise as a cause, and backing up this analysis. Incidence of cracks was later improved by a change of lacquer. However, the analysis of temperature effects is included in this report as a matter of record in identifying the degree to which the heating of thin wall steel cases can result in interferences with the chamber and consequent positive extraction forces.

Extraction Force Analysis:



$A_1 = \pi D t = \pi (1.65)(.020) = 0.104 \; in^2$ Section area at rupture

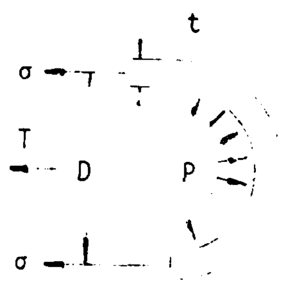
$A_2 = \pi D L = \pi (1.65)(4.5) = 23.3 \; in^2$ Surface area head of rupture

$F_1 = \sigma A_1 = 175{,}000$ lb./sq.in. (0.104 sq. in.) $= 18{,}140 \; lb_f$

This value of F_1 is valid only if the force is distributed uniformly over A_1. Considering shape of extractor, assume extraction force distributed over 25% of A_1 initially:

$F_1 = 25\% \; (18{,}000) = 4{,}500 \; lb_f$, needed to start rupture.

Internal or external pressure, P, needed for σ to reach 175,000 ultimate:



$T = 2t\sigma = PD \quad P = 2T\sigma/D = 2(0.02)(175{,}000)/1.65$

$P = 4{,}240$ psi

First assume external P = 4,240 psi due to thermal transients

$F_2 = fPA_2 = (0.1)(4{,}240)(23.3) = 9{,}840$ lb

f = 0.1 friction coefficient

$F_2 > F_1$

Therefore, forward friction holding forces due to transient heat effects could cause rupture if those forces are large enough. Next, examine those thermal effects.

THERMAL EFFECTS ANALYSIS

Assumptions: Expansion coefficient of steel is 6.5 per degree F. x 10^{-6}, per Marks' Handbook 6-68.

Initial case in chamber clearance after firing without thermal effects is 0.001 inch (see Figure 3, adjusted for average tensile strength of 170,000 psi).

Mean temperature of case at steel case extraction is 208 degrees F., per measurements at Eglin in December 1976. Assume case is at 70 degrees F. mean temperature until after plastic flow on firing is completed. Change in temperature is 208-70= 138 degrees F.

Expansion of hot case = 1.6" (6.5×10^{-6}) (135 degrees F.)

= 0.0014

Interference = 0.0014 - 0.0010 initial clearance = 0.0004 inch

Unit strain = 0.0004/1.6 = 0.00025 inch/inch $= \varepsilon$

$\sigma = E\varepsilon = 30 \times 10^6 = 0.00025 = 7{,}500$ psi

Ratio of actual stress to stress needed for rupture = 7,500/175,000 = 4.3%

Therefore, $F_2 = (0.043)\ (9840) = 423\ lb_f$

Since 423 lb is considerably less than the 4,500 lb_f needed to rupture the case, transient thermal effects do not generate sufficient friction force to rupture the case.

RUPTURE ANALYSIS

Background

In the thin-wall cases tested at Eglin Air Force Base in 1975 (see ADTC-TR-76-11), one complete separation occurred in automatic gun tests and one complete separation occurred in Mann barrel tests. Ruptures (cracks) occurred in about 20 percent of the cases fired, all about one inch from the base. Finish at that time was Dupont 100 percent Teflon® over zinc plate. It was concluded that rupture performance in a Mann barrel could be correlated with automatic gun test firings for initial screening tests. A change of finish to 30 percent TFE over phosphate finish was forced by failure of the original finish to meet the 600-degree F. test without peeling. In addition to the new DeBeers finish, changes were made to the new 1976 case in blend radius and head-to-datum length, apparently clearing up the rupture problem, based on Mann barrel tests. However, when firings were started in the Fall of 1976 in the Eglin automatic gun, initial tests showed 100 percent cracks about 1.6 inches from the base. A change of finish to a Swiss Mader lacquer decreased cracks or stretches at normal pressure but not at excess pressure. Further blend radius improvements by modifying tooling are planned for the 1977 lot of cases. These events resulted in a historical review of case ruptures in other weapon systems and raised the question of the use of analysis, augmented by computer techniques, in analyzing, predicting, and eliminating such failures.

Historical Data

A review was made of new cases in the 20mm to 30mm size range developed since World War II. Eight examples were found in which rupture problem occurred in cases of normal wall thickness, whether the material was steel, brass, or aluminum. Corrections were made by empirical methods for quick solutions, by changing either head-to-datum length, case surface finish, or case hardness.

Two recent examples of transverse rupture incidents are compared with the thin-wall GAU-8 case as to pertinent data and corrections applied, as follows:

Case	Wall Thickness (in)	Maximum Pressure (psi)	Strength	Correction Applied
30mm Steel for 831 Gun	0.056	60,000	156,000 (hard) 100,000 (re-duced hardness)	Reduce the hardness
30mm Aluminum GAU-9	0.080	67,000	72,000	Increase lubricity
30mm Steel Thin-Wall GAU-8	0.018	67,000	180,000 (hard) 150,000 (re-duced hardness)	Three variables: reduce hardness, change surface finish, smooth out profile

Reduction of hardness increases ductility and therefore reduces tendency towards transverse rupture but is limited by increase in case extraction forces and case head growth.

Transient Stress-Strain Computer Analysis

Theory of behavior of metals under impulsive loading, as applied to the GAU-8 steel case, implies that a sudden stretching of the case wall on pressure rise between the case head resting against the bolt face, and the main body of the case locked by friction to the chamber can cause a transient tensile wave to move toward the mouth of the case. In moving from a thick wall region to a thin wall region, a reflected compression wave can result in local high stresses and possible rupture, once local strains exceed the 8 percent limit of the hardened 10B22 steel. Analysis by computer, modifying programs already set up for finite element static stress analysis is theoretically possible and should shed light on the effect of such variables as case wall contour, coefficient of friction, material hardness, and head-to-datum length. Shown in Figure 4 is a schematic of the GAU-8 automatic gun illustrating the portion of the case being stretched, and the test set-up for obtaining the stiffness or spring constant of the bolt face movement under load in relation to the chamber.

A meeting was held at Frankford Arsenal on 10 February 1977 to review the desirability of computer-type analysis of dynamic stress-strain conditions to more fully understand the underlying cause of case cracks or ruptures. Data reviewed included the following:

1. Contractor historical examples of case rupture dated 7 February 1977, covering eight examples in the 20mm through 30mm size of brass, steel, or aluminum cases which have experienced rupture problems.

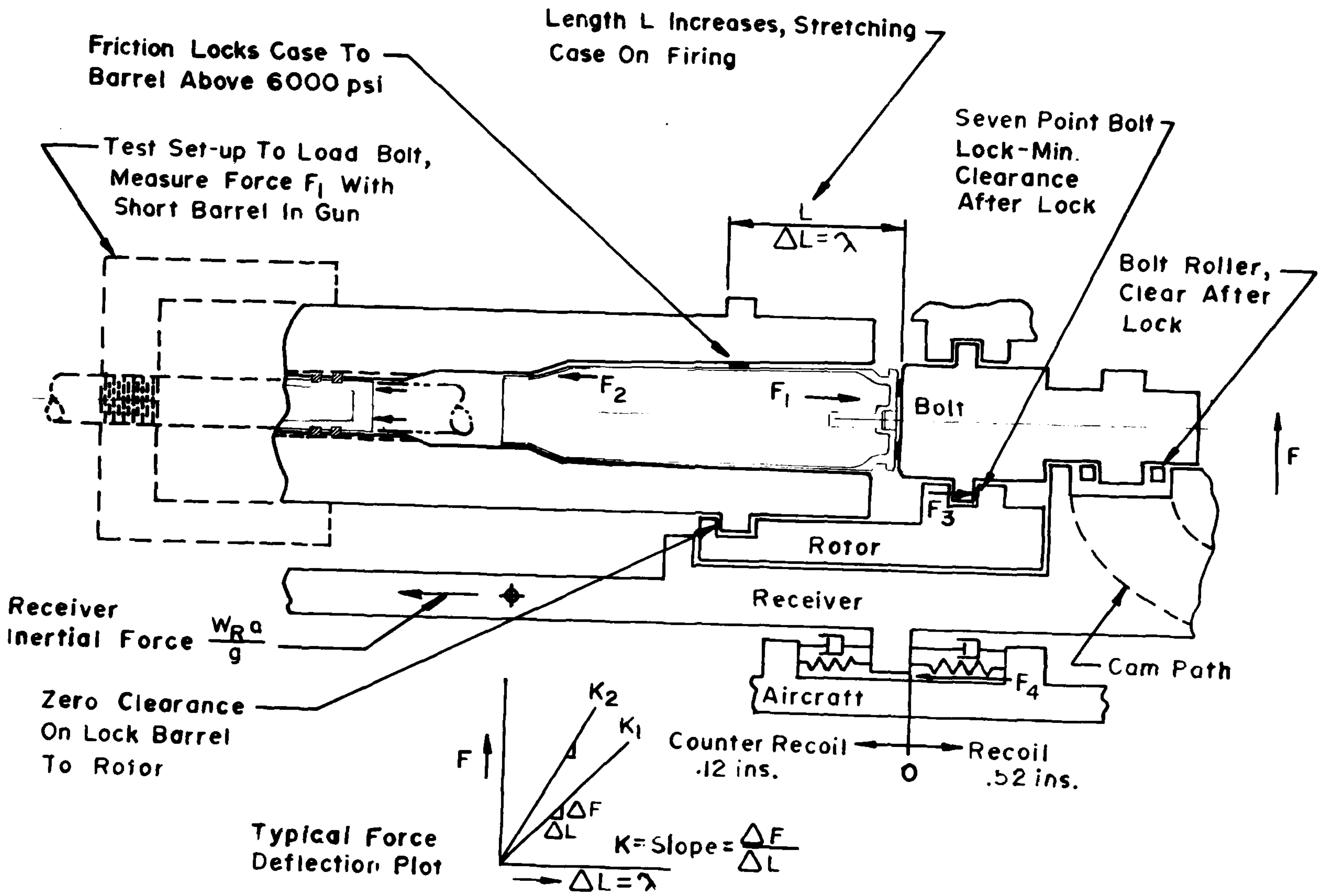


Figure 4. Schematic of GAU-8 Automatic Gun/Case Forces

2. Recent thin wall steel 30mm GAU-8 case progress reports of automatic gun test results.

3. Surge wave references, including Rhinehart, Scabbing of Metals, Journal of Applied Physics, May 1950, and Maier, April, 1963, Product Engineering, Impact between Masses, and Surge Waves.

4. Midwest Research Report on Friction Test of Case Coatings, dated 28 January 1977 by Vern Hopkins.

5. Materials Laboratory, Wright-Patterson Air Force Base, report on Corrosion Test of Coatings, Report No. AFML/MX 76069 dated 6 June 1976 by Gary Stevenson.

6. Hardness pattern per Progress Report No. 11 and contractor's stress-strain curves dated 29 October 1973.

7. Case wall and tooling profile data, vicinity of rupture, see Progress Report No. 11.

8. Head space data obtained from General Electric Company.

9. Contractor's Force Extraction Analysis by R. Rayle dated 14 November 1976.

A discussion of test results indicated significant variables include coating type and hardness level; insignificant variables include temperature levels. It was felt that the slight discontinuity in the punch, resulting in an abrupt change from thick to thin, was significant, and grinding the punch in this zone, removing about 0.003 maximum from the punch diameter, should offer significant improvement.

Results of the meeting indicated the Frankford computer finite stress analysis model could be modified to reflect dynamic load conditions involving surge waves. Further data was needed from General Electric Company as to spring constant value for movement of bolt with respect to chamber under load conditions, as measured in an experimental test set-up with a cut-off barrel. Also needed was the high strain rate data for the case material used. The contractor supplied ten samples of the 10B22 material to the Material Laboratory, Wright Patterson Air Force Base, for test in the Hopkinson bar set-up to permit comparison of normal strain-rate curves with high strain-rate curves, reflecting increased yield strength. The Air Force plans to ask Frankford to proceed with this computer analysis as soon as the necessary input data are obtained.

Case Wall Contour

Qualitative analysis of the effects of transient stress waves in relation to case wall contour in the crack zone about 1.6 inches from the base emphasizes the need for gradual, smooth changes in wall contour to avoid stress concentrations due to reflected shock waves. As a result, a study was made of the final case wall contour and the punch contour which formed the case. Based on this study, the punch has been modified for a more gradual transition zone, and the blend radius has been changed from 10 inches to 15 inches.

Shown in Figure 5 is a plot of the punch contour, showing old and new contours, with metal removed shown in the hatched area. Metal was removed by grinding and polishing. A maximum of 0.0015 inch material was removed, representing a decrease of punch diameter of 0.003 inch at that point. From the tangent points established by trial and error and the slope at the lower tangent point, the blend radius contour was plotted for each tenth of an inch to find the best fit after solution of the equation of the circle and the equation for the slope of the tangents at any point from the equations:

$$(x - h)^2 + (y - k)^2 = R^2$$

$$\text{and } \frac{dy}{dx} = -\frac{x - h}{y - k}$$

With the two points and a slope given, three equations and three unknowns permitted solution to find the radius and the location of radius center. The 15-inch value of the radius was found to be a best fit to the actual contour, matching within about 0.0003.

The expected change in case wall contour is shown in Figure 6. With the present contour, determined from a sectioned case and accurate wall thickness measurements at each tenth of an inch, the present contour was plotted as the lower curve. As the wall thickness approaches the end value of about 0.018, the slope of the interior contour should constantly decrease. Instead, it changes from a value of 2.2 degrees to a sharper 3-degree slope, back to a slope of 1.4 degrees, then in the crack zone the slope changes abruptly from 1.4 degrees to 0.3 degree. Transferring data from the change in the punch contour to a predicted case contour, new cases made with the modified punch should show a gradually decreasing slope from 2.2 degrees to 0.3 degree, with no abrupt changes in slope. This should improve the resistance of the case wall to the effects of transient stress waves.

Shown in Figure 7 are two photographs of the punch before and after modification. In the upper view, the relatively sharp change in contour is clearly visible, as well as minor scratch marks. In the lower view, the sharp change in contour has been eliminated, and the punch surface has a higher degree of polish. Testing at excess pressure in the automatic GAU-8 gun with cases made from the modified punch will be required to determine the benefits of modifying the punch to change the case wall contour.

Head Space

Head space is generally the axial movement permitted by a cartridge in a gun chamber with the bolt locked and is limited to the rear by the bolt and to the front by contact between case shoulder and the forward tapered end of the chamber. The controlled dimension in the cartridge is identified as head-to-datum length, measured from the base or head of the case to a reference datum diameter on the case shoulder. This distance was lengthened last year by 0.012 inch to decrease head space and to decrease the possibility of a ruptured case. Mann barrel firings indicated a slight improvement due to this change and dry cycling tests at Eglin Air Force Base in the Summer of 1976 indicated the slight crush-up at maximum head-to-datum due

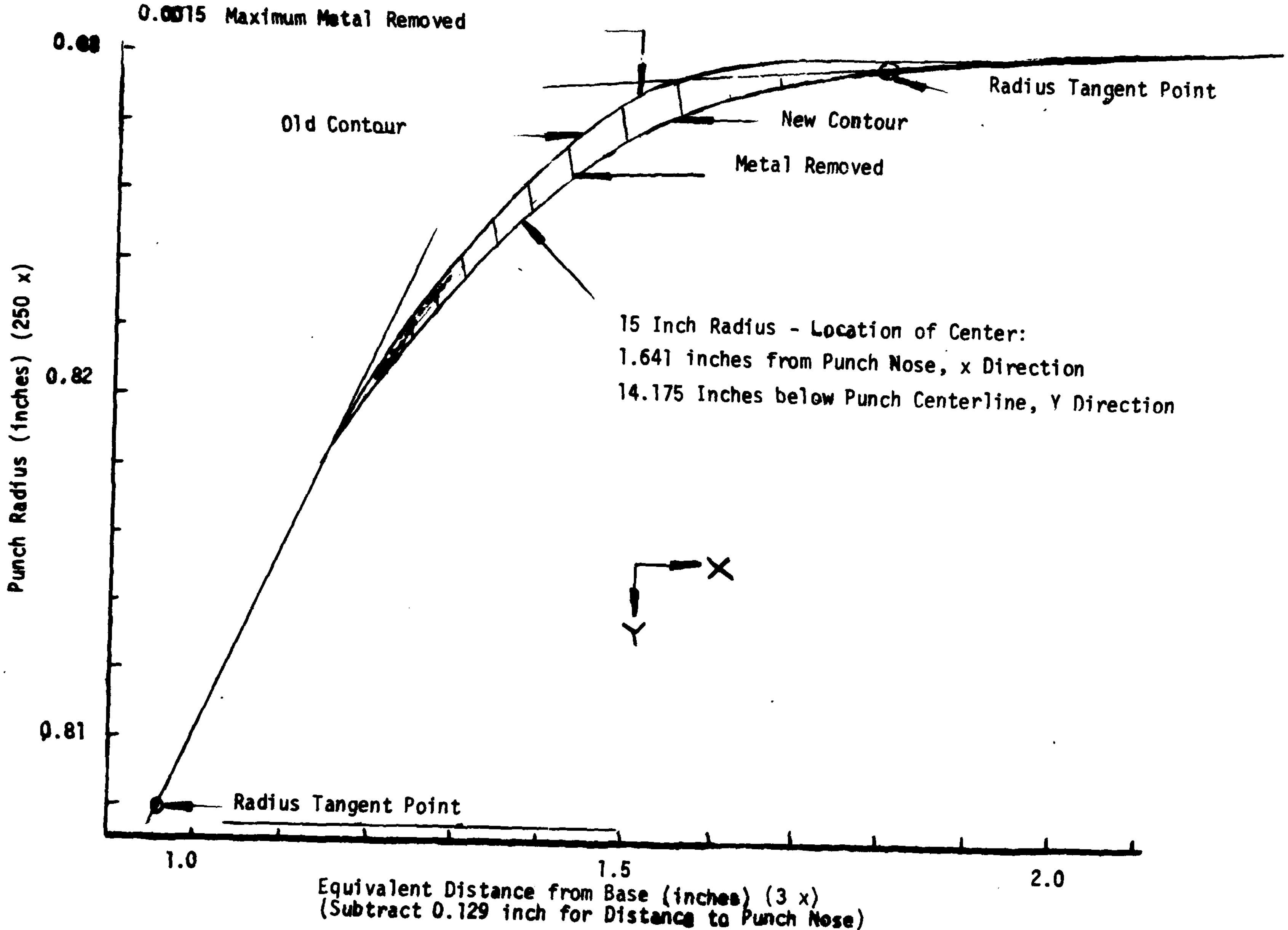


Figure 5. Punch Contour

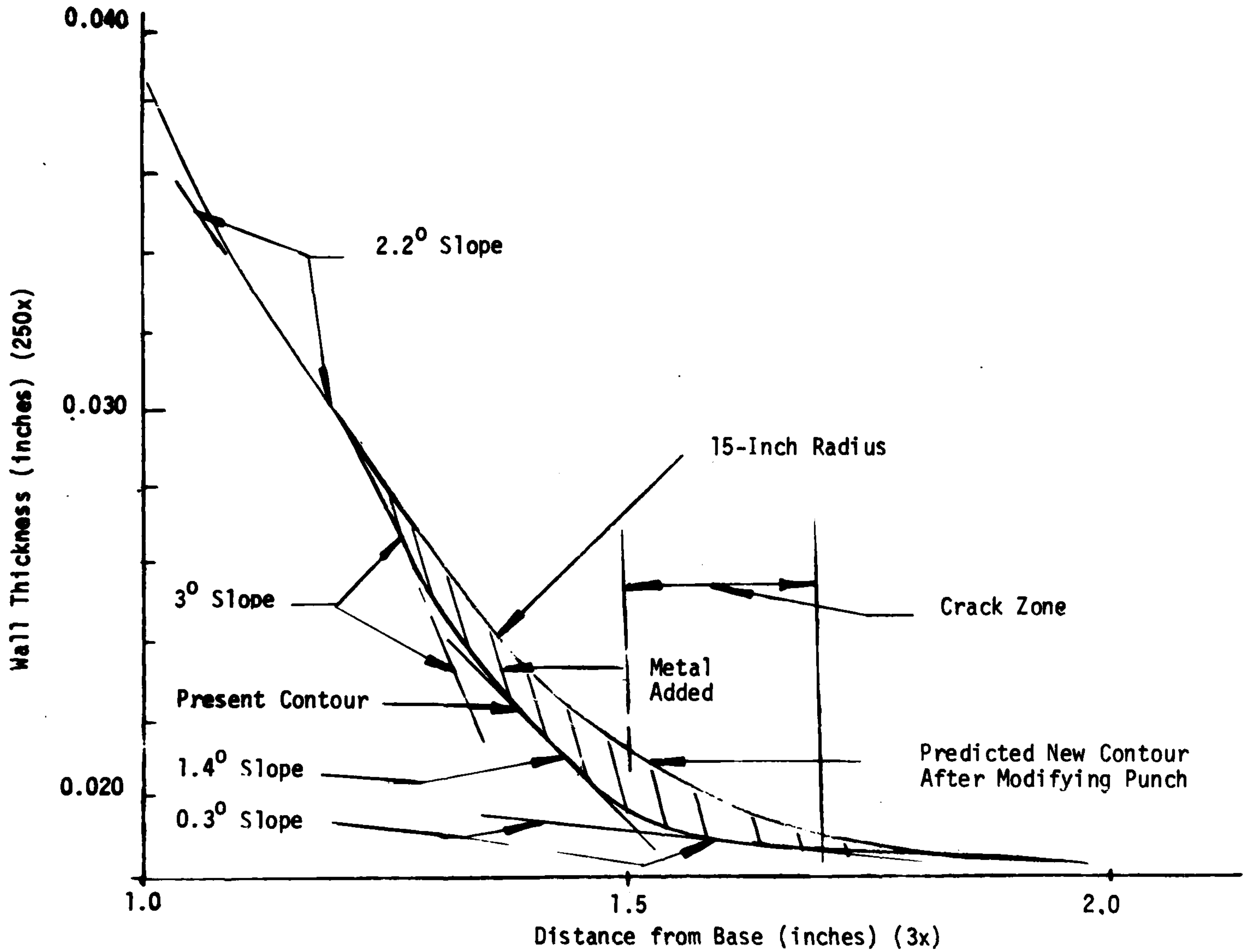
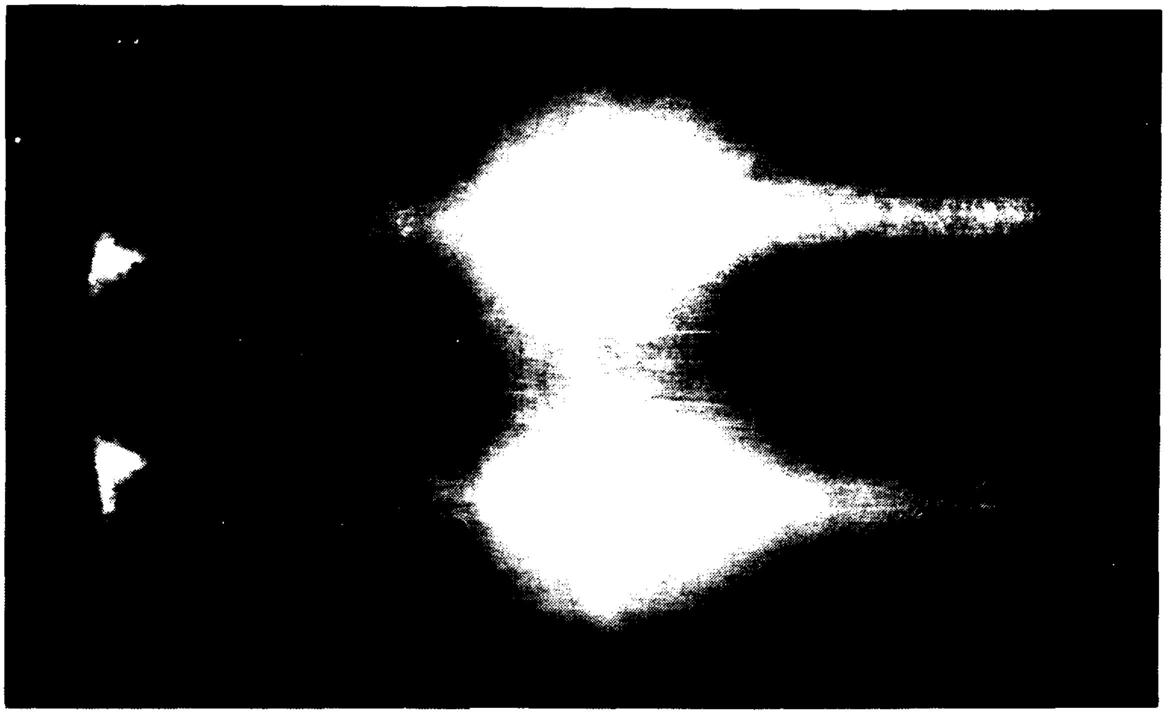


Figure 6. Interior Case Wall Contour



Before Grinding

After Grinding

Figure 7. Punch Contours

to negative head space, had no effect on gun rate. In the Fall of 1976, after cracks were encountered in the automatic gun, a control group of cases with head-to-datum decreased to give positive head space were tested, with no change in the incidence of cracks, which were later found to respond to a change in surface coating. Therefore, it was concluded that present head space is satisfactory, and further change in head-to-datum is not indicated. The purpose of this section is to record the head space data as determined from drawings and from fired cases, in both automatic guns and Mann barrels, as a matter of record of the study made.

Data obtained from General Electric Company indicated a head-to-datum chamber dimension of 5.9915 inches ± 0.0055 inch, for a maximum variation of 0.011 inch. From various case drawings, the range of head space possible was determined to be as follows:

	Maximum Head Space	Minimum Head Space
Aluminum, Honeywell	0.031	0.002
Aluminum, Amron/Aerojet	0.031	0.003
Steel, Thin-Wall, Amron	0.014	-0.009 (crush-up)

The Mann barrel head space is adjustable by selecting shim thicknesses specified on the drawing, including specific shims for maximum or minimum head space. These values were compared with the automatic gun, with the following results:

Head-to-Datum	Change from Auto Gun to Mann Barrel
Maximum	Increased 0.0095
Minimum	Increased 0.0155

From this, the Mann barrel provides a test condition, when equipped with shims for maximum head space, which is more severe than the automatic gun by a factor of 0.0095 inch.

Tests at Eglin Air Force Base were run in November 1976 in the automatic Phase I gun, modified to Phase II chamber contour, and fired cases were measured as a crude method of determining head space. Aluminum fired cases measured 5.997 inches head to 1.417 inches datum, corresponding to maximum head-to-datum of 5.997 inches, with the gun expected to be near minimum wear condition, or 5.986 inches, for an apparent lengthening of the case by about 0.012 due to thermal or dynamic conditions. Similar measurements of fired steel cases showed apparent lengthening of cases by zero to 0.008 inch due to thermal or dynamic conditions.

Excess head space over maximum allowed which would be required to cause case stretch or separation, as determined in Mann barrel firings, but translated to corresponding excess head space in an automatic gun, showed thin wall steel case cracks could be expected at excess head space in the range of 0.020 to 0.028 inch above maximum allowed. With the aluminum case, the point of distress is above 0.028 inch; an exact number was not determined due to misfires at excess head-to-datum conditions.

Coatings

The effect of case coating on incidence of rupture is pronounced, and this has been identified as a very significant variable involved in elimination of case ruptures. However, a correlation has not yet been established to pinpoint specific coating properties which can prevent ruptures. For example, when automatic gun tests at Eglin during the Fall of 1976 showed 100 percent cracks with the 30 percent TFE DeBeers coating, 100 percent elimination of cracks was demonstrated by application of a very thin film of oil, applied by hand to cases. This implies that reduction of coefficient of friction would be a desirable property of a replacement coating. However, of several coatings tested, the most successful in elimination of cracks has been a Swiss Mader lacquer with an unusually high coefficient of friction. This resulted in an examination of various coating properties in order to aid in preliminary selection of candidate coatings made in the United States.

Shown in Table 1 is a tabulation of various properties of four different case coatings, as well as relative firing test results.

TABLE 1. COATING PROPERTIES

Type Coating	Film Thickness (mil)	Sward Rocker Hardness	Pencil Hardness	Coefficient of Friction Static	Coefficient of Friction Kinetic	Comparative Firing Test Results No. 1 Being Best
Mader Glossy Lacquer	0.65	66	4H	0.087	0.20	1
Mader Plus Additive	0.55	46	5H	0.14	0.27	2
DeBeers 30 Percent TFE	0.65	16	9H+	0.043	0.067	4
Wulfing Lubricating Varnish	1.0	36	2B	0.047	0.031	3

Several conclusions have been drawn, assumptions made, working backward from a successful firing test in order to stipulate conditions for a U. S. formulated material. These conclusions are:

1. A TFE type, low friction material may not be advisable, possibly due to the lower hardness and/or lower surface finish.

2. The harder coatings, as measured by Sward Rocker Hardness tests, appear to be the best.

3. Standard coefficient of friction measurements, while indicative, may not be reliable in predicting a satisfactory coating.

4. A thin hard (thoroughly cured) coating may be desirable in preference to thicker coating. This may minimize the plowing effect of a thicker coating which affects the kinetic coefficient of friction.

5. A glossy high surface finish coating is desirable.

Summarizing, it is desirable to look for a material that has a high cure temperature to provide a hard, glossy coating. Also, one that will develop its properties in a thin film on the order of 0.4 to 0.5 mil coating must withstand temperatures on the order of 600^{o} F. for 10 minutes without softening or flaking. Coefficient of friction may be incidental to these requirements.

SECTION IV

PRODUCIBILITY ANALYSIS

INTRODUCTION

This section covers both development and production fabrication processes and techniques applicable to the 30mm GAU-8 thin-wall steel cartridge case. Approximately 1,100 cases were produced during this contract period without automation, following conventional steel case fabrication methods, specifically the rod, extrude, draw process. The case mouth had been increased in thickness to meet bullet pull requirements, and this permitted abandonment of the earlier process requiring a cast lead alloy for satisfactory tapering of the thin walls. The number of draw operations required is only four, in spite of the thin wall, compared to three used in the conventional 20mm M103A1 steel case manufacture. Use of double draw rings in each draw operation aids in reduction of required draw operations.

The previous estimate of production cost was made by calculating the material cost per case for both steel and aluminum and estimating steel labor costs from 20mm steel case data and from estimates based on the added steel operations over aluminum. However, a more detailed analysis is completed in which each production step is considered, and the various types of labor at the appropriate rate for each is calculated. This has resulted in a final value of 3 percent additional labor cost for the thin-wall steel case over the aluminum case. Degree of automation is comparable for each type case at the assumed level of 250,000 per month production rate and is consistent with automation levels for the first year of full production. A net savings of $0.375 overall is estimated for the thin-wall steel case as compared to the aluminum case for the same production rate and the same number of cases produced.

CURRENT PROCESS DESCRIPTION

Given in Table 2 is the Operational Summary Sheet, Rod, Extrude, Draw (RED), used to fabricate approximately 1,100 thin-wall steel cases during calendar year 1976. Figure 8 shows the sections of cases in process, illustrating the mechanical operations in fabrication of the case. The complete sequence is shown in Table 2, including thermal and chemical operations as well. The individual press tooling used is essentially the same as would be employed in full production, but the parts are fed to the press and are moved to subsequent operations manually instead of automatically. The chemical and thermal operations are nearly all carried out on production equipment, in which the flow of other production parts is held up long enough to process the small order of thin wall steel case parts.

The bars of 1-11/16-inch 10B22 steel are cut to the desired slug length on a Wagner saw. After annealing in the conventional wash, anneal,

TABLE 2. OPERATIONAL SUMMARY SHEET, ROD, EXTRUDE, DRAW (RED)

Operation No.		Machine Description
10	Receive and Check Order	
20	Receiving Inspection	
30	Saw Slug	Wagner Saw Model KMLN 2
40	Deburr (If Required)	Tumbler
50	Pre-Anneal Wash	Metalwash (4) Stage/Dry
60	Anneal Slugs	Surface Combustion Anneal Furnace
70	Phosphate Lubricate and Dry	Ransohoff (7) Stage/Dry
80	Block	400-Ton Danly
90	Pre-Anneal Wash	Ransohoff (7) Stage/Dry
100	Anneal	Surface Combustion Anneal Furnace
110	Phosphate Lubricate and Dry	Ransohoff (7) Stage/Dry
120	Extrude	400-Ton Danly
130	Pre-Anneal Wash	Ransohoff (4) Stage/Dry
140	Anneal	Surface Combustion Anneal Furnace
150	Phosphate Lubricate and Dry	Ransohoff (7) Stage/Dry
160	Expand	400-Ton Danly
170	Pre-Anneal Wash	Same as Before
180	Anneal	Same as Before
190	Phosphate Lubricate and Dry	Same as Before
200	Restrike	400-Ton Danly
210	Pre-Anneal Wash	Same as Before
220	Anneal	Same as Before
230	Phosphate Lubricate and Dry	Same as Before
240	First Draw	135-Ton Bliss No. 86
250	Pre-Anneal Wash	Same as Before
260	Anneal	Same as Before
270	Phosphate Lubricate and Dry	Same as Before
280	Second Draw	135-Ton Bliss No. 86
290	Pre-Anneal Wash	Same as Before
300	Anneal	Same as Before
310	Phosphate Lubricate and Dry	Same as Before
320	Third Draw	100-Ton Danly

TABLE 2. OPERATIONAL SUMMARY SHEET, ROD, EXTRUDE, DRAW (RED) (Concluded)

Operation No.	Operation Description	Machine Description
330	Third Draw Trim	V & O Trimmer
340	Pre-Anneal Wash	Same as Before
350	Anneal	Same as Before
360	Phosphate Lubricate and Dry	Same as Before
370	Fourth Draw	100-Ton Danly
380	Fourth Draw Trim	V & O Trimmer
390	Indent and Head	400-Ton Danly
400	Head Turn and Ream Flash Hole	Turret Lathe
410	Wash	Ransohoff
420	Pre-Taper Trim (Optional)	V & O Trimmer
430	Body Anneal	Line of Gas Burners
440	Pickle and Soap Coat	Same as Before
450	Body Taper	100-Ton Bliss
460	Wash	Same as Before
470	Harden (Brine Quench from 1625° F.)	Surface Combusion Tube Furnace
480	Temper (750° F.)	Laboratory Furnace
490	Body Anneal	Same as Before
500	Pickle and Soap Coat	Ransohoff
510	Mouth Taper (7 Operations)	Hydraulic Press
520	Final Trim	Lathe
530	Mouth Size	Hydraulic Press
540	Clean	Ransohoff
550	Final Inspection	
560	Phosphate	
570	Lacquer	
580	Pack and Ship	

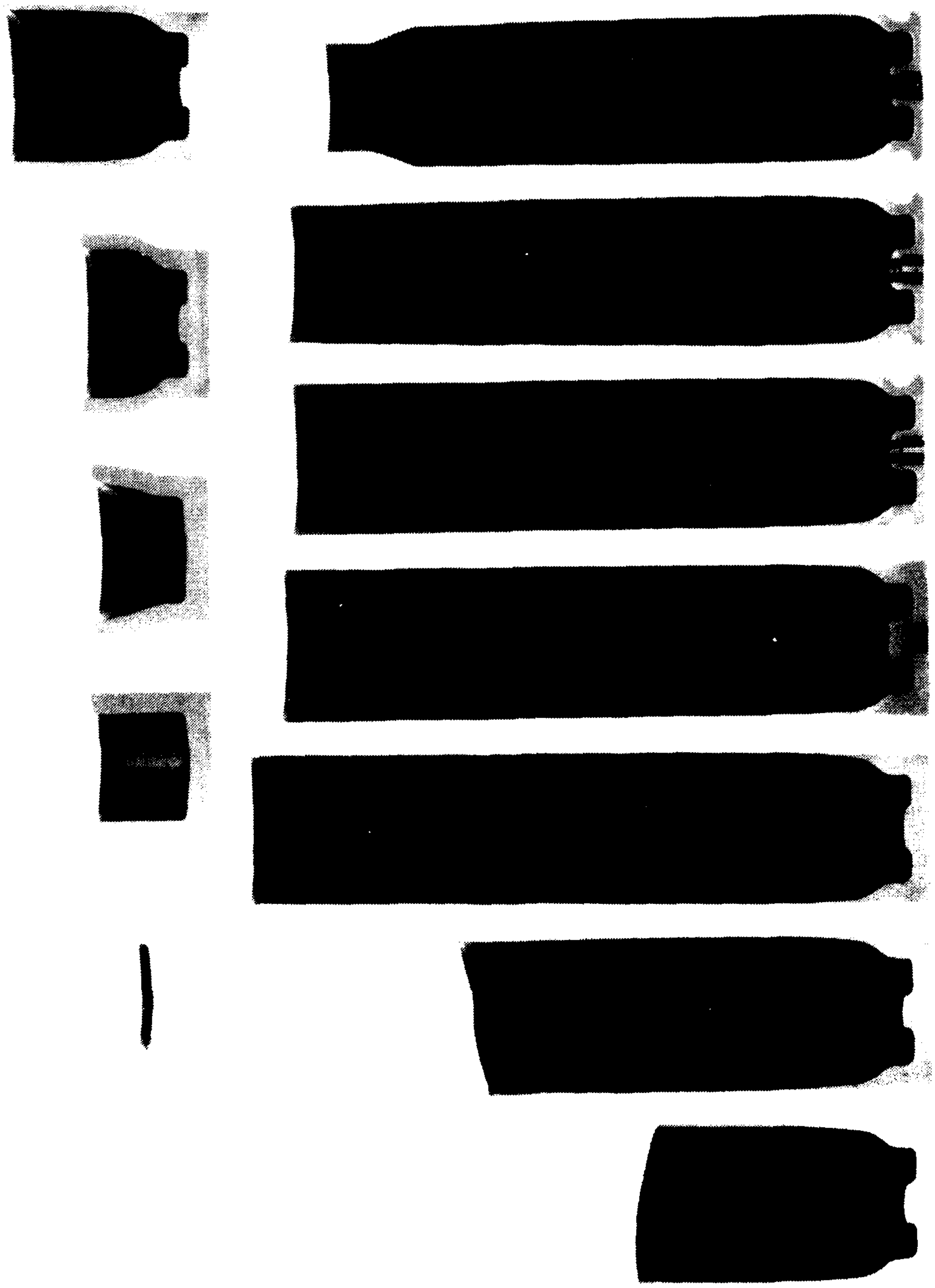


Figure 8. Operational Sequence of Case Fabrication

phosphate and coat process, the slug is blocked in a press to a precise diameter and a pocket to guide the extrusion punch is formed. After another anneal cycle, the extrusion operation is carried out in a 400-ton Danly press. To reach the desired shape needed for drawing, two more operations are needed, each preceded by an anneal cycle. These are designated expand and restrike. Two operations are necessary to avoid splits entailed if a single operation were used. The four draw operations are carried out in 100- to 135-ton presses where the main consideration is adequate stroke rather than tonnage. Each draw operation involves a punch carrying the piece through two draw rings successively. An anneal cycle is required between each draw operation. The last two draw operations are each followed by trim operations. Indent and head forms the interior primer boss and the exterior primer pocket, as well as moving metal to fill out the case rim.

In the head turning operation, the extractor groove, the primer pocket, and the flash hole are machined in a turret lathe due to the smaller quantities involved. Next, the case body is tapered, after anneal, pickle, and coat operations. Hardening and tempering is performed next rather than after mouth tapering to avoid excess ovality in the finished product. After annealing the front half of the case body followed by pickle and soap coat operations, the mouth is tapered in seven separate operations on a small hydraulic press. After final trim in a lathe, the case is mouth-sized in a manually operated hydraulic press. After cleaning and final inspection, the case is phosphate-coated and sprayed with lacquer, which is baked to drive off volatiles while still on the paint line. At this point, the cases are packed and shipped to the loading facility.

PRODUCTION PROCESS CONSIDERATIONS

The case goes through essentially the same operations in production as previously described, but more efficient automated processes are employed. Instead of sawing the steel bars, they are sheared. Automatic shuttles are fitted to the presses, and parts are fed to the shuttles by hoppers and feeder bowls. Parts are automatically moved between operations by conveyor belts. The seven individual mouth taper operations are replaced by a transfer mechanism, located on the bed of a large press and designed in such a way that for each stroke of the press, seven stations operate at once, and while the taper tooling is in a raised position, all cases are advanced one step by the transfer mechanism. A completely tapered case drops off the end for each stroke of the press. A system of patrol sample inspection is used to determine when tools need changing. For head turning, the turret lathe is replaced by a suitable automatic machine such as a multi-spindle chucker for reduced labor content.

At the final coating line, automated equipment is used to cut down on excess manual handling of the cartridge cases.

PRODUCTION COST COMPARISONS

Estimates of production costs have been made to permit comparison of costs between the aluminum case and the thin-wall steel case.

Table 3 covers material calculations to permit direct material cost comparison between the aluminum and steel cases. The aluminum scrap return value includes complete cases scrapped at a rate of 4 percent as well as rings and turnings. The cost of the basic 7475 T6 aluminum bar of $116.50 per hundred pounds includes the cost of the raw ingot. For present contracts, the ingot is Government furnished to the aluminum supplier, but quotes on material are available either way, and for this study the complete cost is used. After the addition of $0.006 per case for anodizing chemicals, the net cost of material per the aluminum case is $0.496.

The steel scrap rate is assumed to be the same as that of the aluminum case, namely 4 percent, but this is considered valid only if the hot rolled steel bars are peeled, or scarfed, to a depth of 0.032 inch below the surface to remove defects. The loss of material in scarfing, as well as the cost of $0.03 per pound for the scarfing operation, are reflected in the cost of $25 per hundred pounds. Basic hot rolled 10B22 bars cost $20 per hundred pounds before the scarfing operation. The estimates of scrap return value are also computed for the steel case. Paint and chemicals required are $0.025 per case, due primarily to the cost of the lacquer required. Net cost per steel case is $0.154. In the unit cost summary, where general administrative and profit are added, the savings per case for steel over aluminum cases comes to $0.401. This compares with a savings of $0.50 estimated a year ago. The difference is due primarily to the lower cost of aluminum this year, and the added cost of scarfing the steel bars.

Shown in Table 4 is the production cost comparison of aluminum and thin-wall steel GAU-8 cartridge cases. Assumptions include a production rate of 250,000 cases per month, use of fiscal year 1977 dollars, a burden of 300 percent, and general-administration-profit at 20 percent. The detailed process analysis for the two case types in terms of direct labor man-hours per thousand cases showed that 3 percent additional labor is required for steel cases over aluminum cases. The net savings, including material costs, turns out to be $0.375 for the steel case as compared to the aluminum case, since the raw material savings in steel material outweight the increase in labor.

As to the processes assumed, about one-half of the operations on each line are automated, which is generally characteristic of the current aluminum case line operating at 135,000 cases per month. Labor is assumed to follow a 90 percent learning curve in translating to a rate of 250,000 aluminum cases per month. The steel case line is assumed to have about one-half of those operations automated. The steel rod is sheared instead of being sawed, a 7-stage transfer die is used for the mouth taper operations, and a more efficient coating line is assumed than the one now used to coat 30mm 831L conventional steel cartridge cases.

TABLE 3. MATERIAL CALCULATIONS

PRESENT ALUMINUM CASE (EXTRUDED FROM BAR)

RAW MATERIAL: Weight/Blank = 0.4109
(12-Foot Bars)

SCRAP RATE = 4 Percent 1.00 - 0.04 = 0.96

$\frac{1}{0.96}$ = 1.042; 1.042 x 0.4109 = 0.428 lb/bar required

SCRAP RETURN VALUE (PER FINISHED CASE)	0.318 solids x $0.145 x 0.04 scrap	= 0.0018
	0.093 rings, etc. x $0.08	= 0.0074
	Total Scrap Return	= 0.0092 (0.0009)
COST: 7475 T6 BAR $116.5/100 lb (Including Cost of Raw Ingot)	0.428 lb x $1.165 (new material)	= 0.499
	Less Scrap Return	= 0.009
	NET ALUMINUM COST/CASE	= 0.490
	Chemicals	= 0.006
	NET COST/CASE	= 0.496

THIN-WALL STEEL CASE (EXTRUDED FROM BAR)

RAW MATERIAL: Weight/Blank = 0.521 lb
(12-Foot Bars)

SCRAP RATE = 4 Percent 1.00 = 0.04 = 0.96
(4% Only If Hot Rolled Bar is Scarfed to 0.032 Depth to Remove Surface Defects)

$\frac{1}{0.96}$ = 1.042; 1.042 x 0.521 = 0.543 lb
Finished Case, Wt = 0.371 lb (solid scrap)
Rings, Turnings, Wt = 0.151 lb

SCRAP RETURN VALUE (PER FINISHED CASE)	0.371 solids x $0.035 x 0.04 scrap	= 0.00052
	0.151 Rings, etc. x $0.04	= 0.00604
	Total Scrap Return	= 0.00656

COST: 10B22 Bar (Hot Rolled Scarfed)
$25.00/100 lb.

0.543 lb x $0.2500 = 0.136 New Material
Less Scrap Return = 0.007
NET STEEL COST/CASE=0.129

Paint (Mader Lacquer),
Chemicals =0.025
NET COST/CASE =0.154

UNIT COST SUMMARY

	Basic	W/G & A, Profit
Aluminum Case	0.496	$0.568
Steel Case	0.154	0.177
SAVINGS	0.342	$0.401

TABLE 4. PRODUCTION COST COMPARISONS FOR GAU-8 CASES

Rate of Production: 250,000 cases per month

Year of Cost Dollars: Fiscal Year 1977

Assumptions on Cost Factors: Burden - 300 percent

General and Administrative, Profit - 20 percent

Cost of Material for Aluminum Case:	$0.578
Cost of Material for Steel Case:	$0.177
Savings of Material Cost with Steel Case:	$0.401

Additional Labor Man-Hours required for Steel Cases: 3 percent

Net Savings, Steel Case over Aluminum: $0.375

Debree of Automation: Approximately 50 percent, each line

Aluminum Case Basis of Cost: Current actual line at 135,000 per month projected to 400,000 per month by 90 percent learning curve.

Steel Case Basis of Cost: Current process with about over half of operations automated, steel rod sheared, transfer die for 7-stage mouth taper operation, more efficient coating line.

SECTION V

TEST RESULTS

INTRODUCTION

The purpose of this section is to summarize the test results obtained throughout this development period. Test and design iteration early in the period involve Mann barrel firings and bullet pull tests. With minor design changes, successful results are obtained. Preliminary qualification tests are completed with successful results. After delivery of 700 cartridges to Eglin Air Force Base last Fall, initial tests in the automatic gun revealed a return of circumferential ruptures. The conclusion is made that the automatic gun and the Mann barrel can give entirely different results, requiring the early use of each in a design test iteration series. Eglin automatic gun test firings are briefly summarized, sufficiently to identify reasons for making further changes. For a brief period, it appeared that by changing the case coating to a hard, glossy type, the cracks would be eliminated. Only after return to the contractor of about 400 cartridges, with rework and return of 300 of these to Eglin with the new coating, was it apparent that coating changes alone are not dependable. Further design iterations are required during the next development phase of the program, including both case geometry and case coatings.

MANN BARREL FIRING TESTS AND DESIGN ITERATION

Tests in CPIC Mann Barrel on 3 June 1976

The internally grooved design was selected over the externally grooved design after preliminary tests in 1975, and test results indicated need for additional strength at the mouth for bullet pull and in the case walls near the base. Blend radii were replaced by a short, tapered section, tapering about 3.4 degrees, with a one-half inch blend radius between this tapered section, about one-half inch long, and the main interior case wall. The purposes of these early tests at high pressure were to determine general case integrity and to redesign as required. A charge of 2550 grains of Hercules 2 percent deterred coating, for use with 6620 grain projectiles, gave peak pressures in the range of 68,000 to 70,000 psi and muzzle velocities from 3335 to 3351 feet per second. Initial firings were in the CPIC Mann barrel for correlation with test results the previous year. Unlike the later GAU-8 Mann barrel, used in all subsequent tests, the high pressure tap required drilling a hole in the case about an inch below the case shoulder.

Shown in Figure 9 are four of these fired cases. The heavy dimpling in the forward portion of the cases on the left are associated with the presence of the drilled pressure holes; such dimpling disappeared in subsequent tests when the pressure tap is located just beyond the mouth of the case.

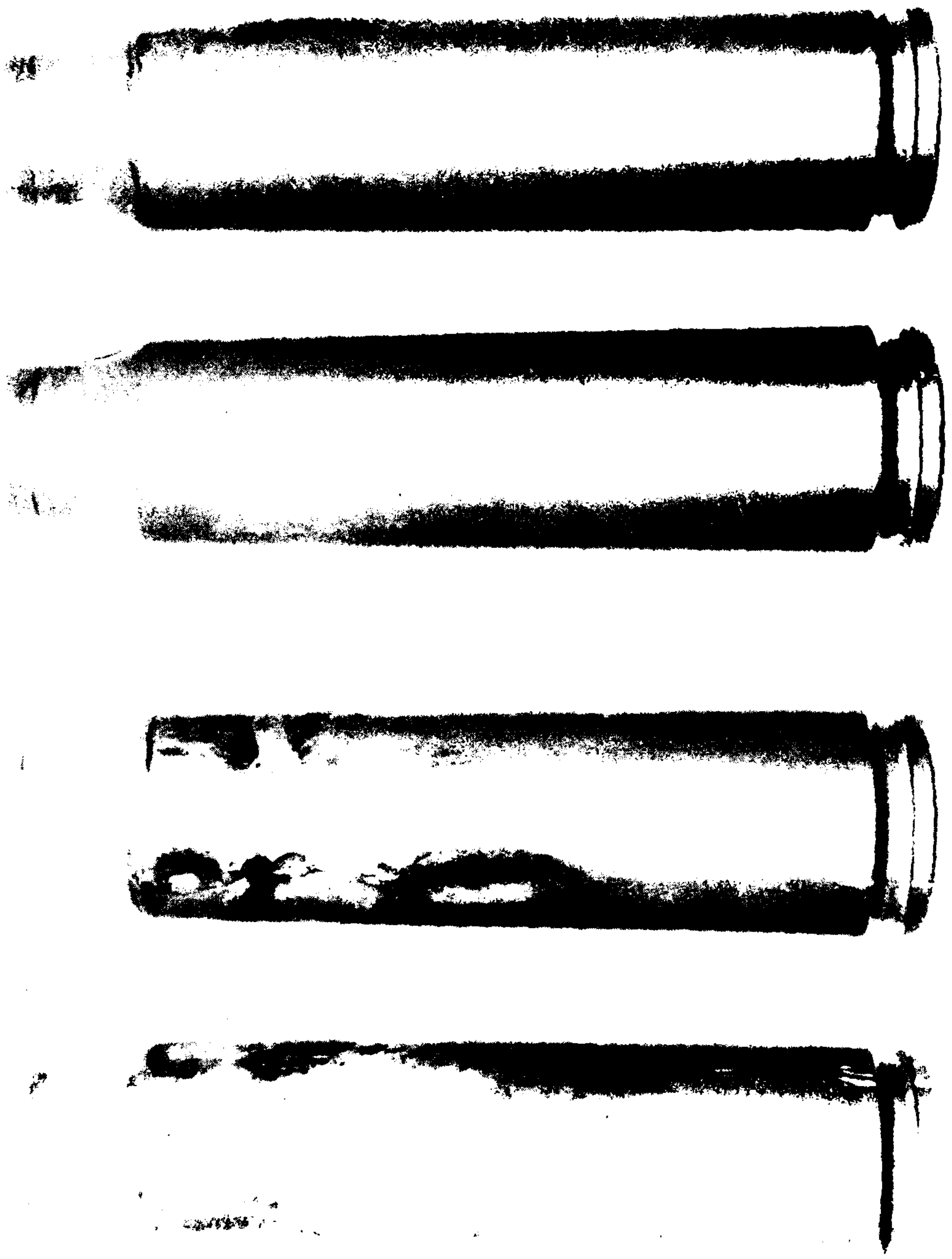


Figure 9. Fired Cases

A more serious clue to case damage under excess pressure is evident in the two cases on the right in the form of faint circumferential lines about 1.4 inches from the base, indicating stretching in this area. On sectioning, an inner groove at this point was measured and found to be about 0.001 to 0.004 inch deep and 0.040 inch wide. As a result of this test, the transition inner radius was changed from 0.5 inch to 10 inches, and this change was accomplished by grinding metal from the fourth draw punch to accomplish a more graudal transition zone. Subsequent Mann barrel tests indicated this step eliminated the stretching. Only toward the end of this program, after occurrence of stretches and cracks 1.6 inches from the base in automatic gun firings, did re-examination of the punch contour and case wall indicate too sharp a change in slope for the blend contour, near the junction of the main inner wall and the blend zone.

Tests in GAU-8 Mann Barrel

After grinding the fourth draw punch to achieve a better blend, excess pressure tests were conducted in the newly received Phase II GAU-8 Mann barrel, on a mount built by the contractor to the design of the Eglin Air Force Base mount. For those cases within tolerance for maximum head space, no stretching occurred. For cases over maximum head space by up to 0.008 inch, slight stretching occurred at a zone 1.6 inches from the base. In one instance, the head space was grossly oversize, by the order of 0.040 inch due to the case being undersize in head-to-datum length. In this instance, the case ruptured along a line 1.6 inches from the base. By increasing head-to-datum length of cartridge cases, head space is reduced. As a result of these tests, head-to-datum length was increased by 0.012 inch, and no further stretching or cracking was observed in Mann barrel tests.

A subsequent dry firing test by Eglin Air Force Base was made in the automatic gun with cases deliberately made to the longer head-to-datum length, which may require a slight crush-up of the case to be chambered. No loss of gun firing rate or other harmful effects were observed. Therefore, the changes to a larger blend radius and a longer head-to-datum length were adopted, and for 80 rounds fired to this design in August and September for qualification tests in Mann barrels at excess pressure and high temperature, no stretches or cracks were observed. Later, when live automatic gun tests were initiated, it was appreciated that the automatic gun represents a more severe test in this area as the deficiency again appeared.

Excess Head Space Tests

In connection with a study of the effects of head space on case rupture, tests were conducted on 18 November 1976 to compare aluminum cases and thin wall steel cases as head space is gradually increased over the maximum allowed.

Using spacers to increase head space in the Amron Mann barrel, a series of thin wall steel and aluminum cases were fired at successively larger head space. Results were as follows:

Head Space Above Maximum (inch)	Type Case	Case Integrity	Comment
0.002	Steel	OK	
0.002	Aluminum	OK	
0.011	Steel	OK	
0.011	Aluminum	OK	
0.019	Steel	Stretch	
0.019	Aluminum	OK	
0.019	Steel	Separation at 1.6 inches	
0.019	Aluminum	OK	
0.019	Steel	Separation at 1.6 inches	
0.019	Steel	OK	Case Oiled
0.019	Steel	OK	Case Oiled

Aluminum case checked at 0.037 inch head space above maximum did not fire due to firing pin not reaching primer.

Measurements before and after firing and chamber measurements indicated all cases increased in head-to-datum due to firing and that after firing steel cases were 0.001 to 0.002 inch clear; aluminum cases had 0.003 to 0.005 inch interference (measured with respect to head-to-datum length).

These results can be converted to excess head space in the automatic gun by adding 0.009 inch to the measured head space in the Phase II barrel, with the following results:

Excess Head Space in Automatic Gun (inch)	Results
0.011	Steel OK
0.011	Aluminum OK
0.020	Steel OK
0.020	Aluminum OK
0.020	Steel: Stretch or Separate
0.028	Aluminum OK

Thin-wall steel cases can be expected to fail at excess head space somewhere in the 0.020- and 0.028-inch range, while the aluminum case failure is at some value above 0.028 inch. Automatic guns fired to date have not worn sufficiently to go outside the present tolerance range of 0.011 inch. In service, barrels will normally go out for tube wear rather than excess head space; however, periodic checks should permit measure of head space and replacement of barrel or bolt assemblies as required to restore specification head space. The margin of safety to the thin wall steel case appears adequate, without needing to equate its margin with that of the aluminum case.

Case Extraction Forces

In connection with reduced hardness cases fired at excess pressure, tests were conducted in January 1977 to correlate case extraction force with hardness. An extraction tool was designed, built, and calibrated to relate torque values read from the tool in terms of foot-pounds to extraction force in terms of pounds. Results were as follows:

Case Hardness	Maximum Pressure (psi)	Head Growth Beyond Maximum (inch)	Case Extraction Force (lb)
Original (RN59)	60,200	None	96
Original (RN59)	68,100	None	208
Reduced (RN53)	67,700	0.006	820

The high extraction force does not affect case integrity and would not be expected to reduce gun firing rate, based on additional power required of approximately 0.5 HP at 4,000 rpm. The case head growth at over normal pressure is undesirable for storage of empty cases after firing, and this level of reduced hardness should be treated as a lower limit, considering actual maximum pressures to be encountered in the automatic gun.

It was subsequently determined that the present specified hardness levels of RN30 54 to 62 can be held to RN30 57 to 62 without adversely affecting producibility.

ESTABLISHMENT OF PROPELLANT CHARGES

Hercules propellants of various types were received including straight 2 percent deterrent-coated, straight 5 percent deterrent-coated, and Hercules blends HC 26 and HC 25. The latter two are Hercules designations identifying the following blends:

	Blend Ratio	
HC Designation	2 Percent Deterrent Coated	5 Percent Deterrent Coated
26	60 Percent	40 Percent
25	50 Percent	50 Percent

Charge establishment tests were run for two weights of projectiles: 5775 grains for the TP and 6620 grains for the API simulator.

Shown in Table 5 is a general propellant summary, identifying propellant properties, the effect of varying deterrent coating, and the equivalent deterrent coating indicated for various applications. For example, HC 25 (50/50 blend) is near optimum for thin wall case application and TP weight projectiles, while for the heavier API-type projectile, a more nearly optimum blend used 40 percent of 2 percent deterrent coated propellent and 60 percent of 5 percent deterrent coated propellant. For new lots of propellant, testing is required to fine-tune and blend for optimum results.

Shown in Table 6 is a summary tabulation of charge assessment tests conducted during 1976. From this table, for example, if an excess pressure charge is desired for a thin-wall case with a TP projectile, either straight 2 percent of 2500 grains can be selected or 2640 grains of HC 26 (40 percent of 5 percent; 60 percent of 2 percent). If either is available, the HC 26 blend is preferred since the higher weight of charge will provide more uniform pressure levels.

The table illustrates that, within HC 25 (50 percent of 5 percent; 50 percent of 2 percent), the two available lots (No. 17 and No. 20), Lot No. 17 is more energetic, with less propellant indicated for the same pressure levels.

The last two lines shown for October 1976 cover lot acceptance tests applicable to the 700 cartridges shipped to Eglin AFB at that time. Pressures and velocities were normal and there were no case casualties.

COOK-OFF TESTS

Laboratory tests were conducted with simulated propellant in aluminum and thin-wall steel cases to evaluate the effect of a malfunction leaving a live cartridge in a hot gun after a burst, where barrel temperatures up to 600 degrees F. are expected. The transient heat flow through the case walls could be expected to result in a cook-off of the propellant. The purpose of the test was to evaluate the difference in case wall material on the rate of heat flow into the cartridge case.

Two cartridge cases, one a thin wall steel case and the other a standard GAU-8 aluminum case, were instrumented with thermocouples, cemented to both inside and outside walls just below the shoulders of the cases. The cases were filled with ground corn cobs as an inert propellant simulant. The cases were then placed in a furnace set for 500 degrees F. The rate of temperature rise resulting from transient heat flow into the two cartridge cases is shown in Figure 10. The temperature rise was from 70 degrees F. to 500 degrees F. over a period of about one-half hour. As an index, the intermediate temperature of 342 degrees F. is highlighted, represented the temperature reaching a value which is 63 percent of the total temperature

TABLE 5. GENERAL PROPELLANT SUMMARY
APPLIED TO THIN-WALL STEEL CARTRIDGE CASE

Source: Hercules, Inc., Kenvil, NJ

Main Characteristics:
Flame Temperature: 2800 Degrees Kelvin Maximum
Composition: 8.5 percent Nitroglycerine
Balance: Nitro Cotton
Burning Rate Control by Deterrent Coating in 2 to 5 percent Range
Coating: A Hercules Proprietary Polyester
Grain Form: Single Perforated

Types Available at Amron: (In terms of percent deterrent coating)

Straight 2 percent	- Very Fast, Hot
Straight 5 percent	- Very Slow, Cool
HC 25, Lot 17	- Nominally 50 percent of 2 percent deterrent coating; 50 percent of 5 percent deterrent coating
HC 25, Lot 20	- Nominally 50 percent of 2 percent deterrent coating; 50 percent of 5 percent deterrent coating, but different from Lot 17
HC 26	- 60 percent of 2 percent deterrent coating; 40 percent of 5 percent deterrent coating; Too Fast
HC 27	- 30 percent of 2 percent deterrent coating; 70 percent of 5 percent deterrent coating; Too Slow

GENERAL APPLICATIONS - 30mm THIN WALL

Approximate Deterrent Coating Equivalent (percentage)	Projectile Type	Application
3.5	TP	HC 25 Near Optimum (50/50)
3.8	API	40 percent of 2 percent deterrent coating; 60 percent of 5 percent deterrent coating; Near Optimum*
3.2	TP or API	HC 26: Special Tests Only, to Assure 66,000 psi with less than full case

Conclusion: No blends used were fully optimized; more tests are needed to refine blend.

Objective: 56,000 psi, nearly full case, 2700 grains propellant, minimum.

*Later tests show optimum needs over 70 percent of 5 percent deterrent coating.

TABLE 6. CHARGE ASSESSMENT PROPELLANT SUMMARY

Charge Coating	Temperature (Degrees F.)	Weight Projectile (Grains)	Weight Propellant (Grains)	Maximum Pressure (psi)	Muzzle Velocity (fps)	Test Date (1976)	Application
50 percent of 8 percent, 50 percent of 2 percent deterrent coating	80	5773	2625	56,000	3500	June	General - TP
60 percent of 5 percent, 40 percent of 2 percent deterrent coating	80	6630	2675	56,000	3340	June	General - API
40 percent of 5 percent, 60 percent of 2 percent deterrent coating	80	6630	2475	66,000	3350	June	HP-API
40 percent of 5 percent, 60 percent of 2 percent deterrent coating	80	6630	2400	62,400	3287	June	HP-API
40 percent of 5 percent, 60 percent of 2 percent deterrent coating	160	6630	2400	66,500	3334	June	HP-API Hi.T.
2 percent	80	5773	2500	65,000	3547	June	HP-TP
2 percent	80	5773	2500	66,000	3580	August	HP-TP
60 percent of 5 percent, 40 percent of 2 percent deterrent coating	165	6630	2690	56,400	3348	August	General - API
60 percent of 5 percent, 40 percent of 2 percent deterrent coating	80	6630	2690	53,672	3332	August	General - API
(Qualification Tests - 10 rounds, σ_p = 1,130 psi, σ_v = 11 fps)							
HC 25, Lot 17	80	5773	2625	55,933	3518	August	General - API
HC 26	80	5773	2640	26,726	3642	August	HP-TP
(Qualification Tests - 10 rounds, σ_p = 1,117 psi, σ_v = 17 fps)							

TABLE 6. CHARGE ASSESSMENT PROPELLANT SUMMARY (concluded)

Charge Coating	Temperature (Degrees F.)	Weight Projectile (Grains)	Weight Propellant (Grains)	Maximum Pressure (psi)	Muzzle Velocity (fps)	Test Date (1977)	Application
HC 26	80	6630	2475	66,414	3369	August	HP-API
(Qualification Tests - 10 rounds, σ_p = 513 psi, σ_p = 7 fps							
60 percent of 5 percent, 40 percent of 2 percent deterrent coating	65	6630	2690	61,544	3379	August	HP-API, Lo.T.
(Qualification Tests - 10 rounds, σ_p = 1,138 psi, σ_p = 8 fps)							
60 percent of 5 percent, 40 percent of 2 percent deterrent coating	165	6630	2690	63,370	3414	September	General-API,
(Qualification Tests - 10 rounds, σ_p = 529 psi, σ_p = 10 fps)							
HC 25 Lot 17	165	5773	2625	58,353	3562	September	General TP Hi. T.
(Qualification Tests - 10 rounds, σ_p = 611 psi, σ_p = 12 fps)							
HC 25 Lot 17	-65	5773	2625	55,420	3510	September	General-TP, Lo. T.
(Qualification Tests - 10 rounds, σ_p = 1,125 psi, σ_p= 19 fps)							
HC 25 Lot 20	80	5773	2700	54,130	3516	October	General-TP
HC 25 Lot 20	80	5773	2700	52,690	3519	October	General-TP

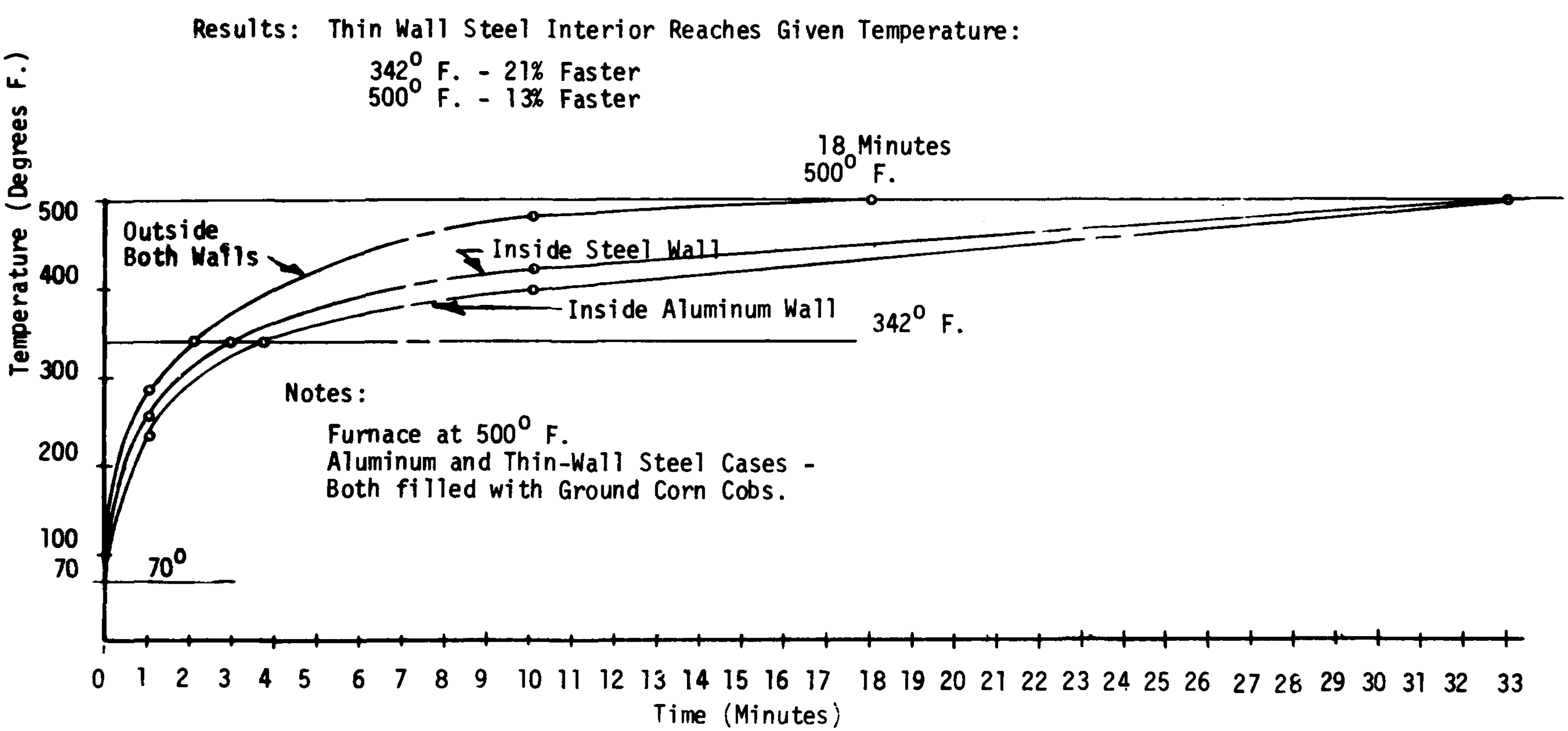


Figure 10. Temperature versus Time GAU-8 Cases

change (500 degrees - 70 degrees - 430 degrees). Taking 63 percent of 430 degrees F. = 272 degrees, and adding 70 degrees, the value of 342 degrees is obtained. Both outside wall temperatures rose at essentially the same rate, reaching 500 degrees F. in 18 minutes.

The time to reach 342 degrees F. and 500 degrees F. was as follows for the two cases:

Case Type	Location	Time in Minutes 342 Degrees F.	Time in Minutes 500 Degrees F.
Steel and Aluminum	Outside Wall	2.2	18
Thin Wall Steel	Inside Wall	3.0	33
Aluminum	Inside Wall	3.8	38

The percent decrease in time for the thin-wall steel case to reach the two temperature levels was as follows:

To reach 342 degrees F.: 21 percent faster

To reach 500 degrees F.: 13 percent faster

Assuming cook-off temperature of propellant to be in the general region of 400 to 500 degrees F. and a malfunction leaving a live round in a hot gun, either cartridge will cook-off in about 5 minutes, with the steel cased cartridge cooking-off first. Considering vulnerability of the aircraft system, and assuming an aircraft ammunition storage system to receive a transient flow of heat to the remaining cartridges, the question of vulnerability to all of the cartridges being set off in rapid succession or the fire dying out is crudely compared in this test. It appears that the thin-wall steel cartridge case would be likely to cook-off about 10 to 20 percent faster than an aluminum cartridge case. No attempt is made here to assess the subsequent contribution of the aluminum or steel wall material to further heat propagation. It is left to the judgment of the Air Force as to whether the somewhat faster transient heat flow into the steel case is possibly compensated by the more inert nature of the wall material, and whether an expensive static test or series of tests judging relative vulnerability, such as was conducted for the caseless 25mm GAU-7 cartridge, is appropriate for the thin-wall steel cartridge case.

BULLET PULL TESTS

Engineering tests established the levels of bullet pulls to be expected as a function of various parameters. The case mouth wall thickness was increased at the beginning of the program by 0.002 inch to a range of 0.016

to 0.020 inch. Instead of designating a maximum mouth hardness, the mouth wall hardness was increased by specifying a range of Rockwell 30N 47 to 52.

The mouth inside dimensions are established in the mouth sizing operation, and the tooling was decreased in diameter by 0.004 inch to aid in significant interference fit on assembly of case to projectile. These design variables were modified to increase bullet pull to insure meeting minimum pull requirements. The sealant used is standard Loctite®601, which is primarily a sealant, not designed for high shear strength, although proper use of the sealant adds slightly to bullet pull. Either too much or too little reduces bullet pull. Shown in Table 7 is a bullet pull summary covering the essential bullet pull results. The correlation of results with the number of crimp grooves in the projectile shows the minimum of 1900 pounds pull is met in all two-groove designs but is below the minimum by about 100 pounds for the single-groove design.

As there is some evidence to indicate that bullet pull levels can be reduced somewhat without adverse effect on gun functioning, it appears that if all projectiles went to the single-groove design, the thin-wall steel would still perform adequately without further redesign to increase mouth wall thickness.

Also shown in Table 7 is the effect of various parameters on bullet pull. Loss of bullet pull is indicated for excess sealant, no sealant, minimum surface protection, lower hardness or strength of mouth material, less than normal interference at assembly, and the use of too shallow a crimp groove.

Figure 11 is a plot of projectile groove profiles for bullet pull extremes. Shallow grooves with maximum radii at rear groove edge give the lowest bullet pull.

PRELIMINARY QUALIFICATION TESTS

Shown in Table 8 is a tabulation of preliminary qualification test results, including both bullet pull and Mann barrel firings, for a total of 118 cases tested, ten of which were for bullet pull tests. Ballistic data is summarized below. With the 18 percent added propellant volume, muzzle velocity is increased at least 150 fps; the increase may be over 200 feet per second with optimized propellant.

Shown in Table 9 is quality assurance data applicable generally to the qualification test cases and the 700 cartridges shipped in October 1976 but specifically applicable to the 75 cartridge cases shipped to Eglin Air Force Base in late August 1976. Results of this inspection indicate that critical dimensions are to tolerances specified and deviations are minor.

TABLE 7. BULLET PULL SUMMARY

Summary of Engineering Tests of Thin-Wall Steel Cases

Projectile Type	Mean Pull (lb)	Standard Deviation
2 grooves, centered	2,302	74
2 grooves, forward	2,251	81
1 groove, centered	1,699	119
2 grooves, centered (later cases, qualification tests)	2,589	188

Effect of Bullet Pull Parameters

Parameter	Change in Pull (lb)	Comment
Excess Sealant (601)	Minus 400	Visible droplets
Minimum Mouth Surface Protection	Minus 400	Light iron oxide
No Sealant	Minus 300	Range of Results: 100-600
Mouth Yield 14,000 psi Low	Minus 100	
Below Normal Mouth Interference (on Assembly to Projectile)	Minus 200	Range of Results: 100-600
Shallow Crimp Groove	Minus 400	
Knurl Radius Projectile Crimp Surface	Plus 400	

Parameters for Higher Bullet Pulls in Thin-Wall Steel Cases

Minimum sealant - Apply thin film to projectile grooves

Interference fit - Maintain 0.005 inch or more interference

Good mouth surface protection - No blush of iron oxide present, adequate time in phosphate tank

Case mouth yield strength - Above 120,000 psi

Projectile groove configuration - Adequate depth, minimum radii

NOTE: 1. Use of chamber ring has no effect on thin-wall bullet pull due to excess clearance in present chamber.

2. Increase of mouth wall thickness to 0.018 inch over 0.014 inch used last year has been the main change to meet minimum bullet pull.

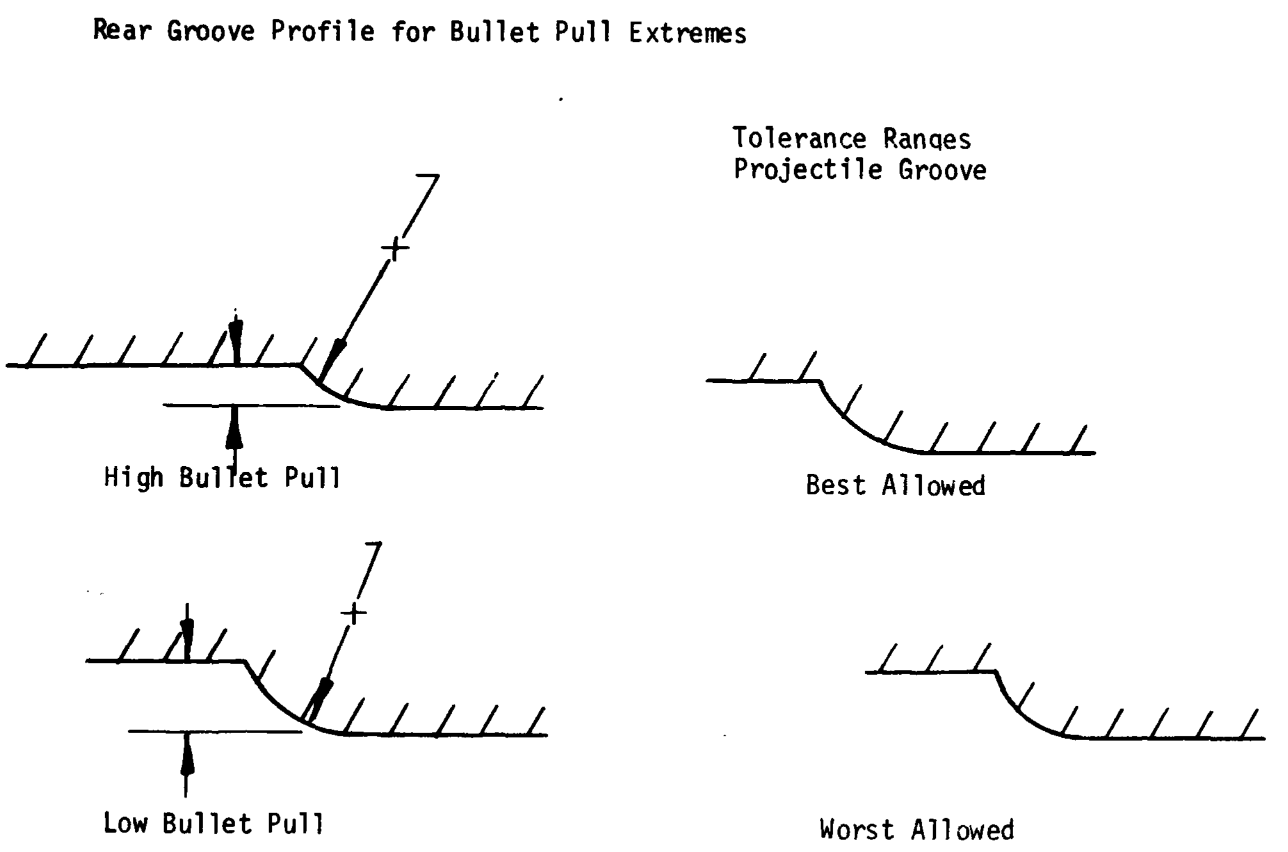


Figure 11. Projectile Groove Profiles, Rear

TABLE 8. SUMMARY OF CONTRACTOR

PRELIMINARY QUALIFICATION TESTS - THIN-WALL STEEL CASE

(Bullet Pull and Mann Barrel Firings)

No.	Type Test	Results
10	Bullet Pull (2 groove projectile)	2,589 lb Mean; 188 lb Standard Deviation, 2,295 lb Minimum; Mean - 3SD:2025 lb
30	Ambient, Normal Pressure Loading	1 - Mouth Split (recrimped) 1 - Slight Stretch (breech not fully locked) TP Maximum Pressure: 55,900; API Maximum Pressure: 53,700 psi
29	Ambient, Maximum Pressure	No Case Casualties - Maximum Pressure: 66,600 psi Pressure:- TP: 66,726 psi API: 66,414 psi
30	High Temperature, Normal Load	No Case Casualties TP Maximum Pressure: 48,000; API Maximum Pressure: 63,000 psi Increase above ambient (new charges); TP: 2,400 psi; API: 3,500 psi
19	Low Temperature, Normal Load	No Case Casualties Decrease below ambient: 600 psi
118 Total		

Summary of Ambient Ballistic Results

Projectile Weight (Grains)	Propellant Weight (Grains)	Maximum Pressure (psi)	Muzzle Velocity (fps)
5773 (TP)	2625	55,933	3,518
6630 (API)	2690	53,672	3,332

Increase in muzzle velocity due to 18 percent added propellant volume: 150 fps Minimum

TABLE 9. QUALITY ASSURANCE DATA

30MM LIGHTWEIGHT CARTRIDGE CASE SHIPMENT - AUGUST 25, 1976 (75 PIECES)

Flange Diameter 1.732 to 1.724 inches	Accepted one part 0.001 inch oversize
Groove Diameter 1.496 to 1.488 inches	Accepted one part 0.001 inch oversize
Flange Thickness 0.168 to 0.177 inch	Accepted four parts up to 0.002 inch oversize
Overall Length 6.796 to 6.811 inch	All parts in tolerance
Datum Length 5.970 to 5.982 inches	All parts in tolerance
Primer Diameter 0.326 to 0.330 inch	All parts undersize - Accepted parts that a 0.3255 inch pin would enter 1/2 the depth - surface finish of wall poor - tool marks.
Primer Depth 0.266 to 0.276 inch	Accepted all parts up to 0.002 inch undersize
Mouth I.D. 1.172 to 1.176 inches	All parts in tolerance
Chamber Gage	All parts enter chamber gage with force binding at area approximately 5/8 inch from base.
Wall Thickness at 1.090 - 0.027 to 0.006 inch	Parts oversize in one area to 0.0295 inch.
Diameter Flash Hole 0.253 + 0.005 inch	All parts in tolerance
Visual	All parts with folds removed

ENVIRONMENTAL TESTS

Environmental tests of jumble, 40-foot drop, and 5-foot drop were conducted by Indiana Ordnance during the week of 23 to 28 August 1976. Table 10 is a summary of those tests, in which inert cartridges of both thin-wall and aluminum cases were tested. All cartridges, steel and aluminum, passed the test. The aluminum cases proved to be more rugged than the thin-wall steel cases.

AUTOMATIC GUN TEST RESULTS

Automatic gun tests applicable to the 700 thin-wall steel cartridges shipped to Eglin Air Force Base in October 1976 were begun in November 1976. Firing single rounds per cycle, at either high or low rate, the first 14 rounds fired showed severe cracks in all cases, extending circumferentially around most of the case, at a distance of 1.6 inches from the base.

Use of lubrication eliminated the cracks. In a program investigating special parameters one at a time, including lower friction coatings, reduced hardness and reduced head-to-datum, the use of Swiss Mader lacquer gave best results (no cracks, one stretch) and reduced hardness lessened the severity of the cracks.

Table 11 is a summary of all tests conducted in the automatic gun for thin-wall cases in November and December 1976 at Eglin Air Force Base. The primary case variables are shown versus firing conditions, which included case lubricant (none, oil or Fluoro-glide Teflon spray), gun rate (low-low, low, high for 1,000 spm, 2000 spm and 4,000 spm), hot or cold gun.

In a special test with no extraction, achieved by cutting hydraulics to the gun at the instant of firing, it was shown that the case is cracked in the barrel during the time of firing and not during rapid extraction of a hot case.

These test results are summarized as follows:

a. Case failures are not associated with high extraction forces due to heat into spent case.

b. Use of oil eliminates case failures.

c. Case failure is less frequent in hot gun than cold gun.

d. Mader lacquer Type 350.8.7.001 eliminates case failures, but 1 of 5 showed stretch marks.

e. Reduced hardness considerably reduced the severity of the cracks.

TABLE 10. ENVIRONMENTAL TEST SUMMARY

Type Test	No. of Cartridges Steel Case	No. of Cartridges Aluminum Case	MIL Standard 331 Test No.	Comments
Jumble	2	2	102.1	Two hours in jumble box; safe to handle
40-Foot Drop	5	5	103	Controlled attitude; safe to handle
5-Foot Drop	10	10	111.1	Two each in five positions; can be fired

The steel cased cartridges were hydraulically crimped with 6,630-grain API simulated projectiles, while the aluminum cased cartridges were assembled with 5,773-grain TP projectiles. Loctite® 601 was used as sealant. Live M36 primers were used. Insert flash tubes and sand to simulate the propellant were used.

All cartridges tested passed the test requirements.

In evaluations of relative ruggedness, it was noted that the steel case showed slight deformation at the shoulder area about one inch from the mouth in the jumble tests, while no such deformation was noted on the aluminum cartridges.

No primers were fired; no projectiles were loosened by the testing.

In the 5-foot drop test, no measurable damage was noted in either steel or aluminum cased cartridges.

TABLE 11. AUTOMATIC GUN TESTS OF STEEL CASES

EGLIN AIR FORCE BASE 11 NOVEMBER 76 AND 16 DECEMBER 76

Variable	Case Lubed	Gun Rate*	Gun Hot** or Cold	No. Cases	Results
1. Basic	No	12L, 2H	Cold	14	All Severe Cracks
	Oil	2L, 3H	Cold	5	OK
	No	H	Hot	9	8 Severe Cracks, 1 Stretch
	Fluoro	H	Hot	5	4 OK, 1 Slight Stretch
	Fluoro	1-LL, 3L, 1H	Cold	5	All Severe Cracks
	Oil	H	Hot	3	OK
2. Basic at High Pressure	Oil	H	Cold	3	2 OK, 1 Minor Stretch
	Oil/Fluoro	H	Cold	3	OK
3. Mader Lacquer	No	LL,L,H	Cold	3	LL, L-OK, H Stretched
	No	H	Hot	2	OK
4. Reduced Hardness	No	LL,L,H	Cold	3	LL Stretch; L, H Less Severe Cracks
	No	H	Hot	1	Less Severe Crack
	Fluoro	H	Hot	1	Slight
5. Reduced Head-to-Datum	No	LL,L, H	Cold	3	All Severe Cracks
	Oil	H	Cold,Hot	2	OK
6. Zinc Plate	No	LL,L,H	Cold	3	All Severe Cracks
	Fluoro	H	Hot	2	OK
7. 100 percent Teflon®	No	LL,L,H	Cold	3	All Severe Cracks
	Fluoro	LL,L,H	Cold	3	LL Stretched; L,H Severe Cracks
	No	H	Hot	1	OK
	Oil a/o Fluoro	H	Hot	3	OK
8. No Extraction	No	None	Cold	1	Severe Crack

Note: Spent case temperatures: Steel - 209° F., 208° F.; Aluminum - 115° F., 134° F.

* LL - Low Low Rate (≈1,000 rpm); L - Low Rate (2,000 rpm); H - High Rate (4,000 rpm)
** Hot Gun: 49 Warming rounds followed by seven test rounds in a single burst.

f. Fluoro-glide sprayed cases showed improvement.

g. Variables not offering improvement:

1. Reduced head-to-datum
2. Zinc plate
3. 100 percent Teflon

h. For future tests:

1. Mader lacquer with thickness increased from 0.3 mil to 0.5 mil.
2. Fluoro-carbon dip added to Mader lacquer.
3. Hardness dropped 10 points instead of 7.
4. Mader-type lacquer with lower coefficient of friction to be sought.

During January 1977, 36 cases were tested in the automatic gun at Eglin Air Force Base in which variables included reduced hardness with original DeBeers lacquer, opaque Mader lacquer over cases of two hardness levels, and Wulfing varnish over cases of reduced hardness. It was concluded that the thicker, opaque Mader lacquer is inferior to the original thickness clear Mader lacquer and should be dropped as well as the Wulfing lacquer.

During February 1977, a total of 84 cases was tested at Eglin Air Force Base in the automatic gun, as shown in Table 12. These results indicated that normal thickness clear Mader lacquer gives good results at ambient pressure but that cracks and stretches appear at excess pressure levels unless the case has its hardness reduced. On the strength of these results, 300 cartridges were reworked from the original 700 to change the finish from DeBeers 30 percent TFE to the clear Mader lacquer. With the original propellant replaced, maximum pressure expected at ambient is 53,000 psi.

Analysis of case lot differences at the bottom of Table 12 showed no significant difference in the two groups. However, later friction tests, reported under coatings (Table 13), showed much lower kinetic friction for the lot of 56.

During March 1977, approximately 100 of these cartridges were tested at Eglin Air Force Base in the automatic gun.

At low temperature and at ambient with a hot gun, no cracks and only minor stretching were noted. However, with a cold gun, severe cracks and stretches were encountered.

From these results, it is concluded that some change in case geometry is required for satisfactory results in the automatic gun.

TABLE 12. AUTOMATIC GUN TESTS OF STEEL CASES

EGLIN AIR FORCE BASE 7 FEBRUARY 1977 and 22 FEBRUARY 1977

All Cases with Clear Mader Lacquer, 0.42 to 0.54 Mil
Arranged in Order of Increasing Severity

No. Tested	Hardness (R30N)	Maximum Pressure (psi)	Cracks	Stretches	Comment
20	53	53,000	0	0	
20	59 (original)	53,000	0	0	
16	53	67,000	0	0	One Stoppage
14	57	67,000	5	9	
14	59 (original)	67,000	11	3	
84 Total					

NOTES:
1. Case casualties somewhat more frequent in cold gun.
2. Case swelled excessively just forward of extraction groove with highest pressure, minimum hardness. One gun stoppage resulted.

ANALYSIS OF CASE LOT DIFFERENCES

I. Data

Quantity	56	28
Date Cases Fired	7 Feb 77	22 Feb 77
Firing Results	No stretch or crack	All stretch or crack (more severe tests)
Days between Coating and Finishing	12	8
Fabrication Period	July-Aug 76	July-Aug 76
Source	Amron	400 cartridges returned from Eglin in Jan 77 and dis-assembled
Propellant Used for Maximum Pressure	2%	14-2%; 14-HC26
Intended Maximum Pressure	67,000 psi	67,000 psi
Case Coating	Clear Mader	Clear Mader
Coating Test Results:		
Hardness	7-8H	7-8H
Thickness	0.42 to 0.48	0.46 to 0.54
Acetone Solvency Cure Test	Cured	Cured
Visual Examination	Glossy, Smooth	Glossy, Smooth

METALLURGICAL TEST RESULTS

Shown in Figure 12 is a hardness profile applicable to cases produced in September 1976. Note that except at the mouth the hardness ranges from 58.5 to 59.5 on the Rockwell 30N scale. The range specified was 54 to 62; this is being narrowed to the range of 57 to 62.

Metallurgical Investigation No. 353, dated 15 October 1976, examined three fired cases with side wall splits returned from Eglin Air Force Base from cases sent to Eglin Air Force Base in August 1976. Microexamination showed normal microstructures. It was concluded that these cases were from an early lot heat treated by laboratory equipment prior to modifications to permit the use of one of the tubes in the production hardening furnace for this purpose. Greater ovality and related taper difficulties had been observed in this early lot, which could have contributed to their side splits. No subsequent side splits were encountered.

COATINGS

Background

In the previous contract, the cases were zinc-plated with a yellow Dupont 100 percent Teflon® paint. This coating did not meet the 600-degree F. 10-minute test in that flaking of the coating occurred, which was also evident around the neck area in normal firing. For the present contract, the zinc plating was replaced by phosphate coating for better lacquer adherence and for lower cost. The lacquer selected was DeBeers 30 percent TFE polyimide-amide, on the basis of lower coefficient of friction per Air Force Materials Laboratory tests at Wright-Patterson Air Force Base. The Air Force Materials Laboratory also conducted evaluation of coatings for corrosion resistance. As automatic gun tests were started at Eglin Air Force Base in November 1976, circumferential ruptures were encountered, and subsequent tests indicated favorable response to a change in lacquer, to clear Swiss Mader lacquer, Type 350.817.0001. In order to identify a suitable U. S. lacquer, various coating properties have been identified, and attempts were made to correlate such properties with case integrity on firing. These properties have included hardness (Sward rocker test or pencil hardness scratch tests), depth of coating, coating cure test, and coefficient of friction (both static and kinetic).

With this background, coatings are discussed under two general headings: corrosion resistance tests and coating tests related to case integrity.

Corrosion Resistance Tests by Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

Report No. AFML/MX76-69, dated 6 December 1976, evaluated protection from corrosion, adhesion, and 600-degree F. stability for DeBeers 945-202

HARDNESS CHECKED WITH TUKON MICROHARDNESS TESTER
500-GRAM LOAD KNOOP INDENTER - CONVERTED TO R30N

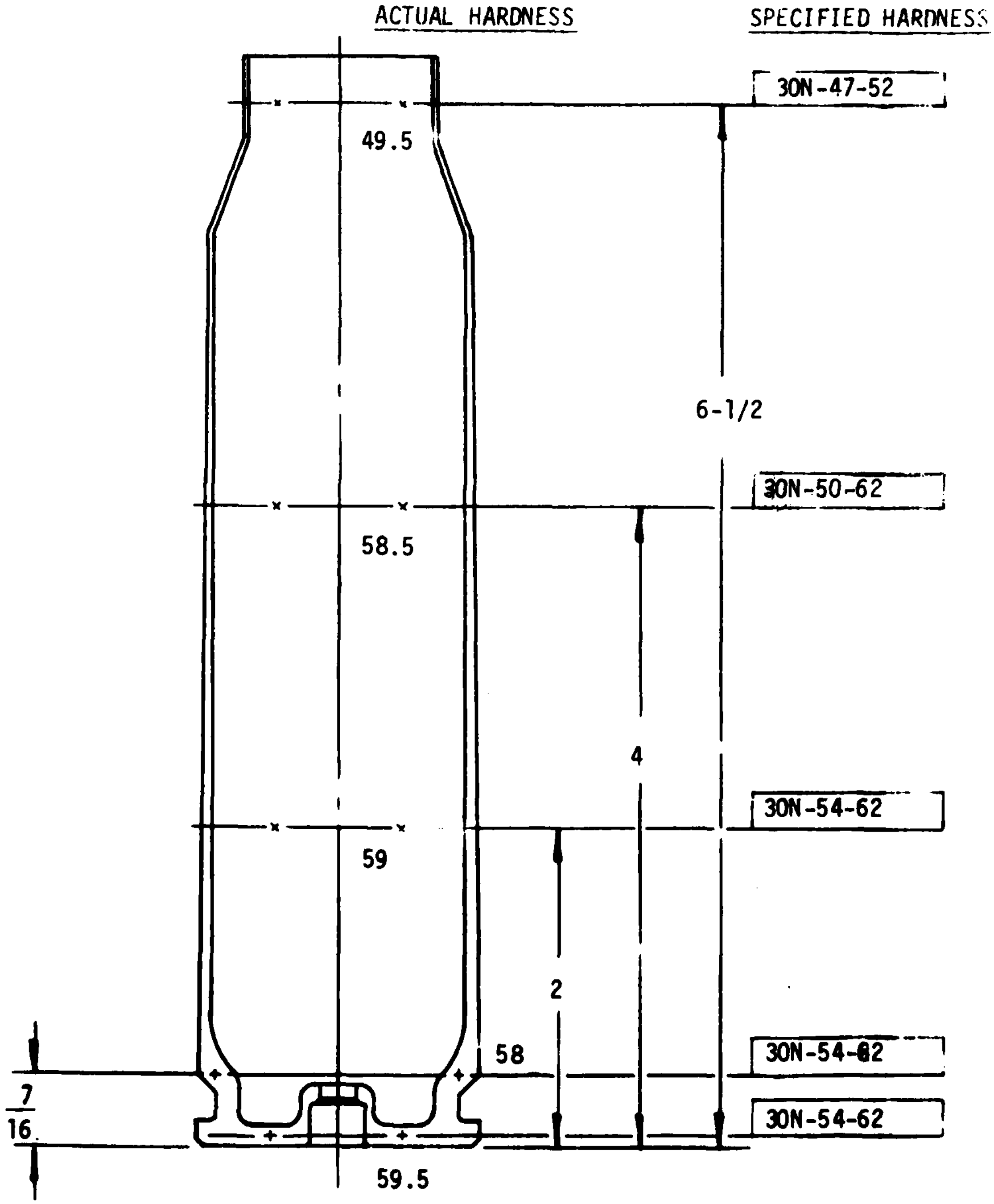


Figure 12. Hardness Pattern

polyimide-amide with 30 percent TFE over phosphate coating per TT-C-00490. An experimental coating, Diamond-Shamrock's Dacromet 320 zinc dip coating, was also evaluated with both DeBeers and Dupont coatings, as well as zinc-plated 20mm M103A1 cases without lacquer.

Satisfactory adhesion and flexibility were noted for both type DeBeers and Dacromet® coatings at ambient and after brief exposure to 600 degrees F.

The DeBeers coating was found to be more continuous and pin-hole free.

The Dacromet® zinc dip panels showed excellent corrosion resistance, but lower flexibility. (The Dacromet® process has been found to require considerably more study as to processes involved before being ready for cartridge case applications.)

Corrosion resistance of standard zinc-plated 20mm steel cases were found to be superior to the phosphated DeBeers finish.

The Air Force Materials Laboratory is currently evaluating the corrosion resistance of Mader lacquer over phosphate-coated cartridge cases.

General 30mm Coating Plans for Thin Wall Steel Cases

A suitable phosphate coating overall is planned, to be followed by an outside surface lacquer providing good case integrity on firing and adequate corrosion protection. The interior of the case might also be sprayed with a corrosion-resistant lacquer over the phosphate if found necessary to prevent corrosion during storage and shipping to a loading facility prior to sealing on projectile insertion. With design to cost an important consideration, it has not been considered necessary to further protect the phosphated case wall interior.

Coating Tests Related to Case Integrity

Report No. AFML/MX76-38, dated 10 June 1976, evaluated the 100 percent TFE Dupont 959-503 coating and the 30T TFE 945-202 DeBeers coating, both over zinc-plated panels. The report indicated severe loss of adhesion of the Dupont coating when exposed to 600 degrees F., while greater adhesion was observed for the DeBeers coating. The DeBeers coating consistently showed lower dynamic coefficient of friction than the Dupont (0.10 versus 0.136).

Table 1 of Section III compares coating properties for four different lacquers, related to case integrity firing results. These tests tended to eliminate the German Wulfing varnish as used on M204 steel cartridge cases, the DeBeers 30 percent TFE lacquer and the Mader lacquer with additives, with the clear Mader lacquer showing up best.

Table 12 of Section V provides further coating properties in two lots of cases, each with clear Mader lacquer.

Table 13 identified coefficient of friction data recently received from Midwest Research Institute based on test results of samples cut from fired cases of these two lots of Mader lacquer-coated cases. For future investigation of Mader lacquer-coated thin wall steel cases, control of final friction properties by control of application techniques should be studied in a program of friction evaluation of panels as a function of the following process variables:

Depth of lacquer coating (0.4, 0.5, 0.6 mil);
Coarse or fine phosphate coating;
Whether to apply a dry abrasive blast to the surface.

TABLE 13. FRICTION COEFFICIENTS FROM MIDWEST RESEARCH INSTITUTE DATA

Quantity in Original Lot	56	28
Date Cases Fired	7 Feb 77	22 Feb 77
Friction Test Results by Samples Cut from Fired Cases		
Static Coefficient	0.18	0.025
Kinetic Coefficient:		
1/4 Travel	0.007	0.047
1/2 Travel	00.007	0.053
3/4 Travel	0.007	0.058
Full Travel	0.007	0.067

Note: Samples cut from case had been flattened but were not perfectly flat. Samples bonding to backing with Eastman 510. Time for full stroke was 20 seconds.

SECTION VI

FUNCTIONAL CHARACTERISTICS

INTRODUCTION

The functional characteristics of the 30mm GAU-8 thin-wall steel cartridge case have been reviewed in relation to existing GAU-8 specifications for the TP cartridge and the aluminum case and the existing 20mm M103A1 steel cartridge case specification. In general, essential functional characteristics are interpreted as those normally found in the case specification, such as excess pressure and temperature extreme tests, while interface characteristics are interpreted as those normally found in the cartridge specification, such as debulleting and action time tests. The tests required to demonstrate achievement of those characteristics are identified and described in detail in those specifications. For the purpose of this report, references are listed and the discussion covers possible modifications to the elements of those references as applied to the thin-wall steel case. This approach avoids the extraction of lengthy data verbatim from these existing documents and avoids any attempt to prepare a comparable specification exclusively for the thin-wall steel cartridge case.

DISCUSSION

Excess Pressure

Excess pressure (Paragraph 3.2.1.1 of Reference 1) identifies the test over-pressure condition to range from 71,000 to 76,000 psi, while Paragraph 3.2.1.3 of Reference 2 identifies the mean peak pressure plus three standard deviations over the temperature range so as not to exceed 66,600 psi. Since the 66,600 psi appears to be the highest pressure expected, this will be used for the thin wall steel case in order to avoid over-design and the addition of unnecessary weight to the cartridge case.

Muzzle Velocity

Muzzle velocity levels identified in Paragraph 3.2.1.3 of Reference 1 will need to be increased by the order of 150 fps to 250 fps to recognize the increased volume available in the thin-wall steel case.

Debulleting

Paragraph 3.2.1.1 of Reference 2 indicates bullet pull shall be greater than 1800 pounds. Tests with two-groove projectiles have met these requirements. However, with single-groove projectiles, the mean pull was 1921 pounds, with six out of ten below 1900 pounds. If projectiles go to the single-groove design, the bullet specifications will need to be revised or the case redesigned with thicker mouth walls.

Case Material

Paragraph 3.7.1 of Reference 1 requires that the case be fabricated from 7000 series aluminum alloy. For the thin-wall steel case, this material would change to 10B22 boron steel.

Protective Coatings

The present 30mm thin-wall steel case employs an exterior sprayed lacquer over a case which is phosphated inside and out. The phosphating is in accordance with Specification TT-C-00490. The thin-wall steel case specification should include data identifying the lacquer selected and tests required to ensure that case structural integrity is satisfactory, and that the exposure to 600 degrees F. for 10 minutes does not adversely affect the coating. Tests may be prescribed for the coated case including lacquer hardness, cure condition, and coefficient of friction.

Coupon Tests

With aluminum cases, it is common practice to prepare metal coupons cut from the aluminum case for tensile tests and notch tests. Such coupon tests are not required in steel cases covered by specifications such as MIL-C-50797. The coupon tests are desirable for aluminum cases considering the additional hazards if defects occur in aluminum cases. Although the steel walls are thinner, the potential hazard, based on observation of tests to date, do not appear to justify the expense of performing the coupon tests.

Hardness

The hardness test methods and procedures should be the same as identified in Paragraph 4.4.1 of MIL-C-50777, except for the substitution of the 30mm thin-wall case drawing reference in place of the 20mm steel case drawing. The thin-wall steel case uses slightly higher hardness levels and changes from Rockwell C to Rockwell 30M scales to permit lower test loads needed for valid readings with the thinner walls. Even better would be to specify Knoop instead of Rockwell since Knoop permits further reduction in test loads and more accurate readings.

Classification of Defects

The classification of defects should be essentially the same as listed in MIL-C-50797.

Additional Developmental Tests

Qualification tests should be planned to evaluate performance of the thin-wall steel GAU-8 case when made a part of complete cartridges of both the TP and API types. Besides functional and interface tests in the automatic gun, environmental tests in connection with service life tests should be conducted. Accuracy tests in Mann barrel and debulleting tests should also be specified.

REFERENCES

1. Honeywell Specification No. DS 8558 Part II, 20 May 1976, Case, Cartridge, 30mm Aluminum for the GAU-8/A Gun System.

2. Aerojet Specification No. A10146 Part II, 6 August 1976, Cartridge, 30mm, PGU-15/B (TP).

3. General Electric Interface Drawings 201F400, 10 October 1974.

4. Military Specification, "Case, Cartridge, 20mm, M103A1"; MIL-C-50797 dated 25 May 1973, with Amendment No. 1 dated 20 May 1975.

(The reverse of this page is blank)

INITIAL DISTRIBUTION

Hq USAF/RDQRM	1
Hq USAF/SAMI	1
Hq USAF/XOXFCM	1
AFSC/IGFG	1
AFSC/SDWM	1
Hq AFSC/DLCAW	1
AFML/DO/AMIC	1
AFIT/DL	1
ASD/ENFEA	1
ASD/ENAZ	1
AFFLD/FES	1
TAC/DRA	1
SAC/LGWC	1
Hq SAC/NRI/STINFO Lab	1
WRAMA/MMEBL	1
AFWL/LR	1
AUL/AUL/LSE-70-239	1
USA Wpns Comd/SAPTR-LW-A	1
USA Material Sys Analy Agcy AMXSY-DD	1
USA Material Sys Analy Agcy AMXSY-A	1
US Army Ballistic Rsch Lab DRXBR-TE	1
SARPA-TS/Picatinny Ars	1
USN Wpns Lab	1
Nav Ord Stn/Tech Lib	1
Nav Wpns Stn/20323	1
USN Wpns Ctr/Code 233	2
NWC/Code 31	1
AF Wpns Lab/Tech Lib	1
Nav Air Sys Comd/Code AIR-5323	1
Office Naval Rsch/Code 473	1
Los Alamos Science Lab/Rpt Lib	1
DDC	2
USAFTFWC/TA	1
Naval Wpns Lab	1
Watervliet Ars/SARWV-RDT-L	1
Naval Wpns Ctr/Code 3123	1
Ogden ALC/MMWM	2
Hq Dept of the Army/DAMA-WSA	2
SARPA-FR-S-A/Picatinny Ars	1
USA Materials Sys Analy Agcy AMXSY-DS	1
US Army Material Comd/AMCR-YN	1
Nav Wpns Eval Fac/Code WT	1
Office of the Chief of Nav Opns Air Warfare Branch/OP-982E	1
USAFTAWC/TX	1
TAWC/TRADOCLO	1
AFATL/DL	1
AFATL/DLY	1
AFATL/DLOU	1
AFATL/DLOLD	2
AFATL/DLYV	1
AFATL/DLDL	1
AFATL/DLDA	1
AFATL/DLDG	20
AFIS/INTA	1
Nav Wpns Ctr/Code 32602	1
Nav Wpns Ctr/Code 3263	1
Ogden ALC/MMWRA	2
AFLC/MMWMC	1
ASD/ENESS	1
AFATL/DLA	1
ADTC/SDC	1
Hq USAFE/DOQ	1
Hq PACAF/DOO	1
AFML/MXA	1
AFML/MXE	1
AFML/LTM	1
AFML/LTN	1
AFML/NA	1
AFML/MB	1
TAC/INA	1
US Army TRADOC Sys Analysis Activity/ATAA-SS/Tech Lib	1
ASD/XRP	1
COMIPAC/I-232	1
AFATL/DLODR	1

(The reverse of this page is blank)