ALUMINUM CARTRIDGE CASE CONCEPT

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14. ABSTRACT

The infantryman in the field is expected to carry over 60 lbs of material. In order to reduce the weight carried by the soldier, a lightweight alternative to the brass cartridge case is an aluminum cartridge case. This comprehensive detailed report describes the design of the cartridge case, the finite element analysis, the quality functional deployment analysis, the manufacturing of over 2,500 cases using production methods, and the results of ballistic testing of these 5.56-mm aluminum cartridge cases.

15. SUBJECT TERMS

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INTRODUCTION

An infantryman in the field is expected to carry over 60 lbs of material. In order to reduce the weight being carried by him, a lightweight alternative to the current brass cartridge case (C26000) (PN 11820451) used on 5.56 mm, is being developed. The portion of this weight due to the weapon and ammunition is significant. For instance, using the M249 machine gun as an example, the weapon portion of the load to be carried includes the machine gun (17.45 lbs), a spare barrel (4.05 lbs), and at least three magazines of ammunition each holding 200 rounds [3 at 6.78 lbs each = 20.35 lbs (ref. 1)]. At the cartridge level, one M855 5.56-mm projectile round weighs approximately 188 gr. The cartridge case with no other materials weighs approximately 95 gr and is nearly half of the assembly's weight. By changing from brass to aluminum and maintaining the brass case, geometry would reduce the case weight by a third to about 31.3 gr (0.0045 lbs). For 600 rounds of ammunition, this change corresponds to a 5.46 lb decrease in the weight carried. Figures 1 and 2 show the weight breakdowns for the weapon and ammunition (ref. 1).

Total M249 Weapon Weight - 27.29 lbs.

Feed Tray Assembly (0.17 lbs.) 1%

Operating Rody Assembly (0.32 lbs.) 2%

Gas Cylinder Assembly (0.33 lbs.) 2%

Heat Shield Assembly (0.43 lbs.) 2%

Bolt and Slide Assembly (0.51 lbs.) 3%

Hand Gauard Assembly (0.53 lbs.) 3%

Trigger Assembly (0.77 lbs.) 4%

Piston Group (0.8 lbs.) 5%

Bipod (1.07 lbs.) 5%

Cover & Feed Mechanism Assembly (1.51 lbs.) 9%

Buttstock/Buffer Assembly (1.6 lbs.) 9%

Driving Spring (0.11 lbs.) 1%

Sling & Snap Hook Assembly (0.42 lbs.) 2%

Receiver Assembly (4.84 lbs.) 28%

Barrel Assembly (4.05 lbs.) 23%

Figure 1
M249 weapon weight breakdown

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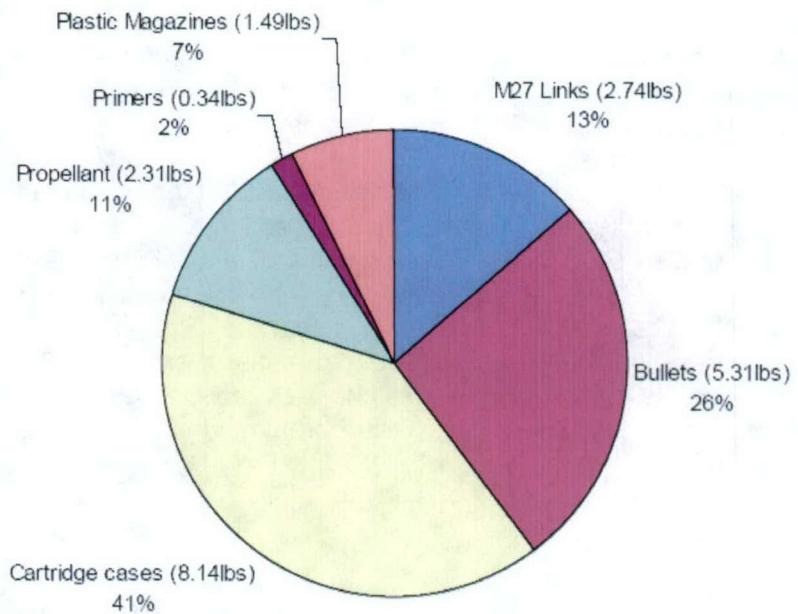
Figure 2
M855 600-round combat load weight breakdown – 20.35 lbs total weight

The Aluminum Cartridge Case Concept (ACCC) development program was a 14-month activity to design an aluminum cartridge case for the M855 5.56-mm round of ammunition. It was divided into two phases with phase 1 consisting of the initial design activity and phase 2 that consisted of fabricating and testing a limited number of aluminum cartridge cases. Phase 2 ended with the delivery of 1,000 aluminum cartridge cases to the government.

This report is submitted as CDRL No. A002, Contractor Summary Report, under contract DAAE30-03-C-1128 for the ACCC development program. The sponsor was the Joint Service Small Arms Program Office (JSSAP). This is the final Contractor Summary Report and covers the period from 01 September 2003 to 15 October 2004.

PROGRAM SUMMARY

The phase 1 activity began with a contract award on 27 August 2003 followed by a formal kickoff meeting on 03 September 2003. The program plan that was presented showed a design activity for the aluminum cartridge case and associated tooling that would be used to manufacture the cases in phase 2. This design activity consumed the bulk of the resources in phase 1, while case fabrication and testing were the focus of phase 2. In addition, an update to the Lightweight Family of Weapons and Ammunition Quality Functional Deployment (LFWA QFD) analysis was completed that was geared specifically towards the aluminum cartridge case. Risk mitigation was a key part of the program plan and an initial risk assessment followed by several risk updates were completed.

The initial cartridge case testing conducted in a Mann barrel identified a propellant that will yield chamber pressures sufficiently high enough too thoroughly evaluate the aluminum cartridge case. Because the case has a smaller interior volume than a brass case, it was known

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that a different propellant than that used in the M855 cartridge would be needed. This testing has identified a suitable propellant and has shown that an aluminum cartridge case for the M855 cartridge is feasible. This conclusion is based upon firings in both the M16A2 and M249 weapons (discussed later). However, based on the results of this testing, there are changes to the design that need to be made to the current configuration. This is because, while the majority of cases tested functioned without incident, there were some instances of case failures. As for the burn-through issue that was experienced on previous aluminum cartridge case programs, this did not always occur when the case failures happened. The main design change that was recommended was to smooth out the transition of the base taper to the wall taper on the inside of the cartridge case because this was the area where the bulk of the case ruptures occurred. Additionally, improvements in the manufacturing process needed to be made to prevent any contamination to the raw material during the forming process from creating small inclusions in the material, which turn into small holes during the firing cycle.

The design of a lightweight cartridge case for small caliber ammunition was broken into structural and coating sections. Structurally, aluminum alloy A97475 is capable of providing the needed mechanical properties and weight reduction. The cartridge case designed, using this alloy, meets the outer configuration of the current case and will, therefore, be compatible with both Legacy and Future Weapon systems. Since the new case requires a thicker base and sidewalls, the interior volume was slightly reduced. Case coatings are an important factor in controlling corrosion and minimizing burn-through. For corrosion control, cases were anodized in accordance with MIL-A-8625 Type II, Class 2. Technical literature has suggested that burn-through, an effect of case failure, can be controlled or minimized by coatings applied to the interior of the cartridge case. Silicone, polysulfide, intumescent, and thermal barrier coatings were all considered, but testing was conducted using silicone and polysulfide coatings only. A polysulfide manufacturer will be contacted in the near future. Besides minimizing burn-through, candidate-coating materials were also required to not significantly reduce propellant volume (maintain projectile performance) and to be explosively compatible with the propellant.

The design of the aluminum cartridge case started with an investigation into what had been done in the past by reviewing historical documents, such as previous program reports, discussions with personnel associated with previous aluminum cartridge case efforts, and by reviewing current aluminum cartridge case manufacturing of commercial ammunition with Alliant TechSystems (ATK) CCI/Speer company. The results of this investigation are detailed later in this report. The key finding of this investigation was that the main issue was burn-through. This is where the cartridge case wall is breached by the hot propellant gas causing the aluminum to burn. Because of the close proximity of the shooter to the chamber of the weapon, this is a severe safety risk. The cartridge case design addresses this in two ways. First, the cartridge case walls were increased in thickness in key areas to provide as much material as possible to prevent any splitting even with some amount of mechanical damage. Second, the interior of the case was coated with a material that will mitigate any burning by acting as a seal and preventing the propellant gas from escaping. Figure 3 shows the final phase 1 cartridge case design and figure 4 shows the cartridge case with the interior coatings that were evaluated in phase 2. Table 1 summarizes the aluminum cartridge case key parameters, both actual and projected, and compares them to the current brass cartridge case. As can be seen, the actual cartridge case parameters came in exactly where the analysis indicated they would be.
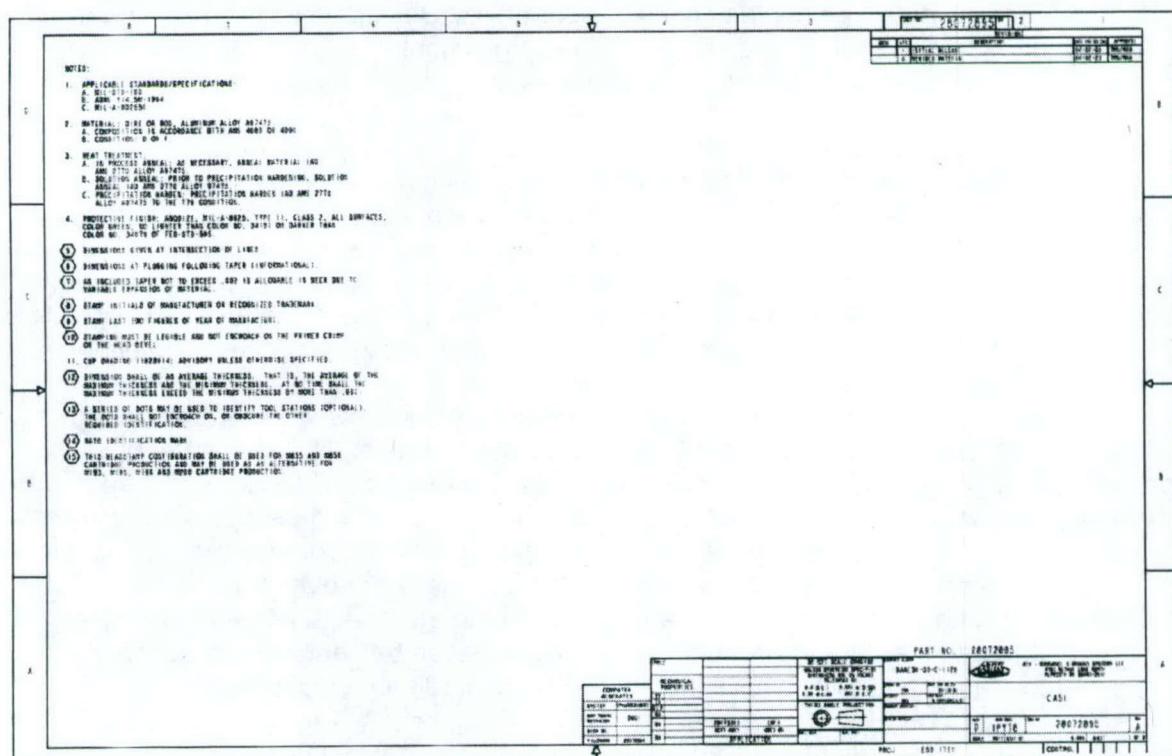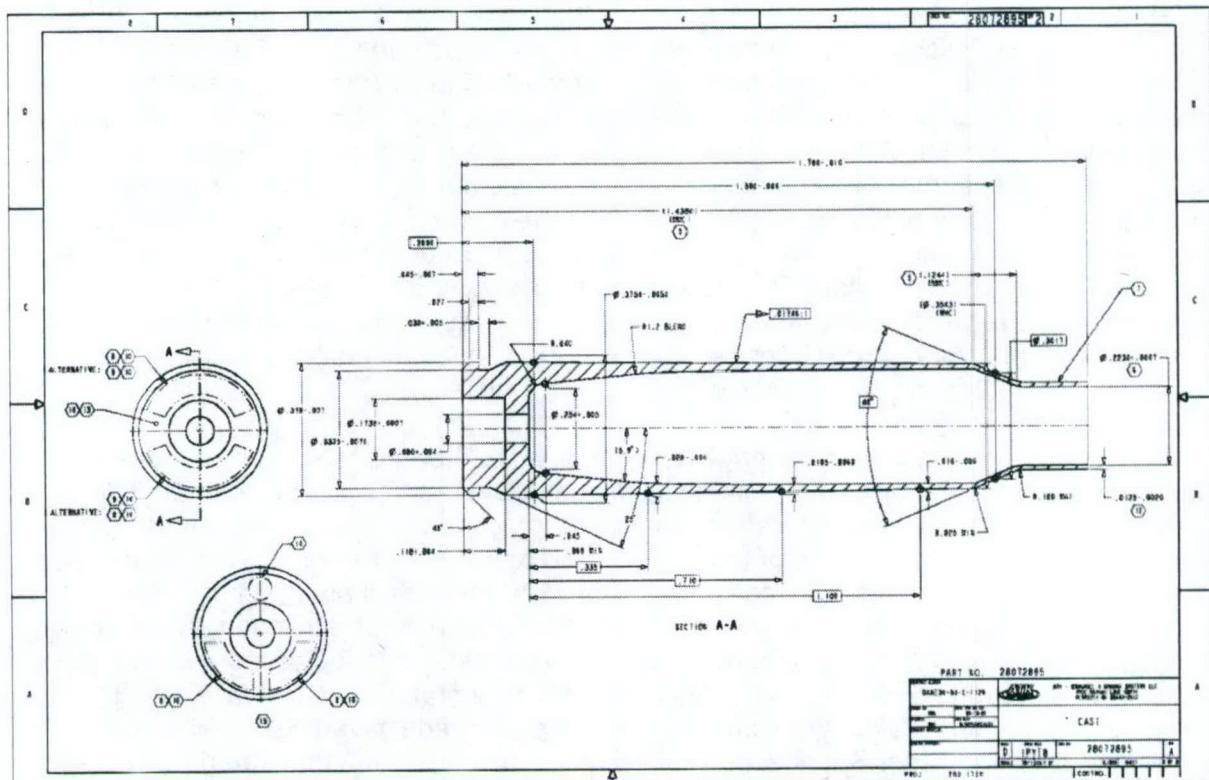
Figure 3
Phase 1 – aluminum cartridge case drawing

Figure 4
Phase 1 – aluminum cartridge case drawing with interior coating
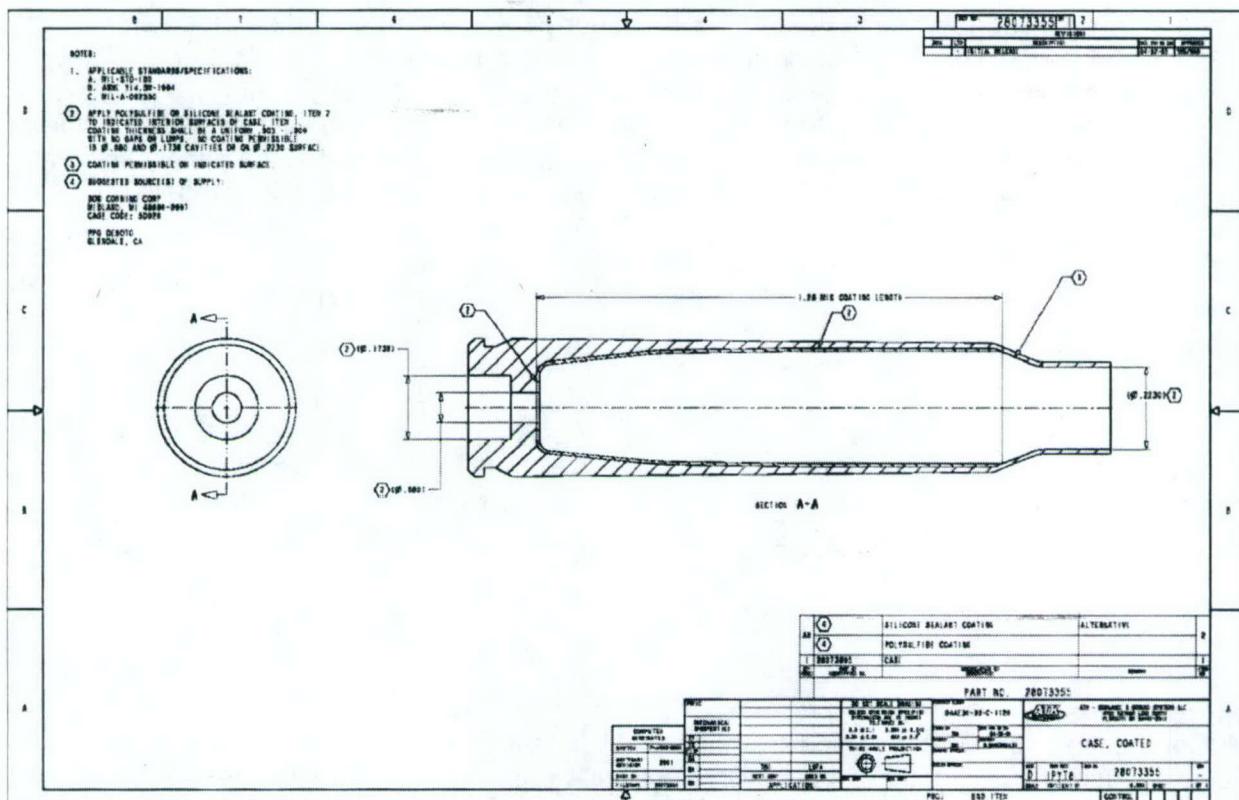
Table 1
Aluminum and brass cartridge case key parameters

Parameter	Aluminum (actual)	Aluminum (projected)	Brass
Metallic material weight (gr)	36.0	38.0	95.0
Interior coating weight (gr)	2.5	~4.0	N/A
Total case weight (gr)	38.5	42.0	95
Interior volume (cm^3)	1.60	1.43	1.75
Percent weight savings over brass	59.5%	55.8%	N/A
Estimated 600 round weight savings (lbs)	4.84	4.54	N/A

Once the case design and tooling design were complete, AMRON of Antigo, Wisconsin began the fabrication at the beginning of phase 2. As the manufacturing operation began, some material tearing was observed and the process had to be adjusted to prevent this from occurring.

The first cases that came off this tooling were very close to the drawing requirements, but did not quite meet all of them. AMRON then spent a significant amount of time refining and modifying the tooling and manufacturing process in order to produce cases that would meet all of the dimensional requirements. This portion of the phase 2 activity required a significant amount of time and caused the program to fall behind schedule to the point that the amount of testing that was conducted was reduced.

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Because the aluminum cartridge case is thicker than the brass case and has an interior coating as well while maintaining the M855 external envelope, it was anticipated the ballistics of the M855 round would not be met with the current production propellant WC844, and this was confirmed with the first Mann barrel firings. However, an alternate propellant that was being developed for a plastic cartridge case, where it too had a reduced interior volume, was identified and initial testing in aluminum cases without an interior coating indicate that the necessary ballistics can be achieved. Table 2 summarizes the Mann barrel firings for both propellants.

Table 2
Aluminum cartridge case initial Mann barrel ballistic summary

Parameter	Requirement	WC844 propellant	WCR 845S lot 73
Chamber pressure (psi)			
Mean	56,700	55,079	55257
Mean + 3SD	62,700	58,320	
Muzzle velocity (fps)			
Mean	3,000 – 3,040	2,936	3051
SD	<25	20	
Port pressure (psi)			
Mean	No requirement	15,277	17396
Mean –3SD	>15,300	14,942	
Charge weight (gr)	N/A	24.5	26.1

All of the firings summarized in table 2 were done at ambient (70°F) conditioning. The cases used for these firings were from some of the initial lots that AMRON had manufactured. Because these cases would not meet all of the gaging requirements, they were hand loaded manually and not on production equipment. These cases were used so that the test portion of the program could begin as soon as possible, and it was felt that the necessary dimensional changes that AMRON needed to make to the cartridge case would not significantly affect the ballistic performance because they were so small in nature.

TECHNICAL RESULTS

Historical Investigation

Aluminum cartridge cases have been considered for many years. A review of technical literature indicates that the earliest investigation of an aluminum case was in 1893. In the 1950's and 1970's, the Ammunition Group at Frankford Arsenal in Philadelphia, Pennsylvania investigated aluminum cartridge cases.

Between 1950 and 1956, Frankford Arsenal intermittently studied aluminum cases for the cal .50, M33 (ref. 2). Ultimately in 1956, materials, forming, and lubricants were analyzed. At this time, an undisclosed aluminum company had developed a high purity version of alloy 7075 (A97075). Other projects at Frankford Arsenal had shown that 7075-T6 could achieve hardness values equivalent to 2024-T4 and have four times the toughness. Based on this information, the modified 7075 alloy was evaluated. At the study's end, Frankford Arsenal concluded that aluminum cases were easily formed, and that occasionally when a round was fired, an effect called burn-through occurred. While they were unable to determine the cause, it was noted that burn-through was occurring approximately ¼ in. forward of the extractor groove. Finally, Frankford Arsenal recommended additional work to determine the causes of the burn-through problem.

In 1972, Frankford Arsenal was again studying aluminum cartridge cases and the burn-through problem. A status report from April 1972 documents the effects of holes and scratches on cartridge case function, completion of a finite element analysis of cartridge case stresses and strains during firing, and on the thermodynamics of the burn-through problem (ref. 3). During the study, it was observed that a thin rubber membrane was effective in preventing erosion of a simulated cartridge case sample (aluminum disc). The thermodynamic section of the report indicated that, when burn-through occurs, the aluminum metal around the hole was eroded by burning propellant gases, also, that aluminum at the hole edges was being melted by the high temperature gases, and that there was an exothermic reaction between any available oxygen and the aluminum. The report concluded by stating that two solutions to the burn-through problem were found. One solution was to prevent a propellant gas flow path through the case. The second solution was to alter the effect of propellant gas flow through such a gas path.

Additionally, during this period, an undated paper discussed both the dynamics of the burning propellant-aluminum case reactions and methods of modifying either the cartridge case or weapon to better seal the chamber (ref. 4). The paper assumed that if the chamber could be sealed, the large flame and gas release associated with burn-through would not occur. The paper considered several alternative case designs and an alternate chamber design. It concluded that a cartridge case with a reduced extractor groove would be best. The paper also recommended that a sealed chamber be used. While this paper was undated, some of its recommendations are documented in a report dated March 1974.

In 1974, Frankford Arsenal reported the results of a project evaluating various methods of sealing aluminum cartridge cases (ref. 5). They considered 11 different case sealing techniques, and sketches of these candidate-sealing methods are shown in figure 5.
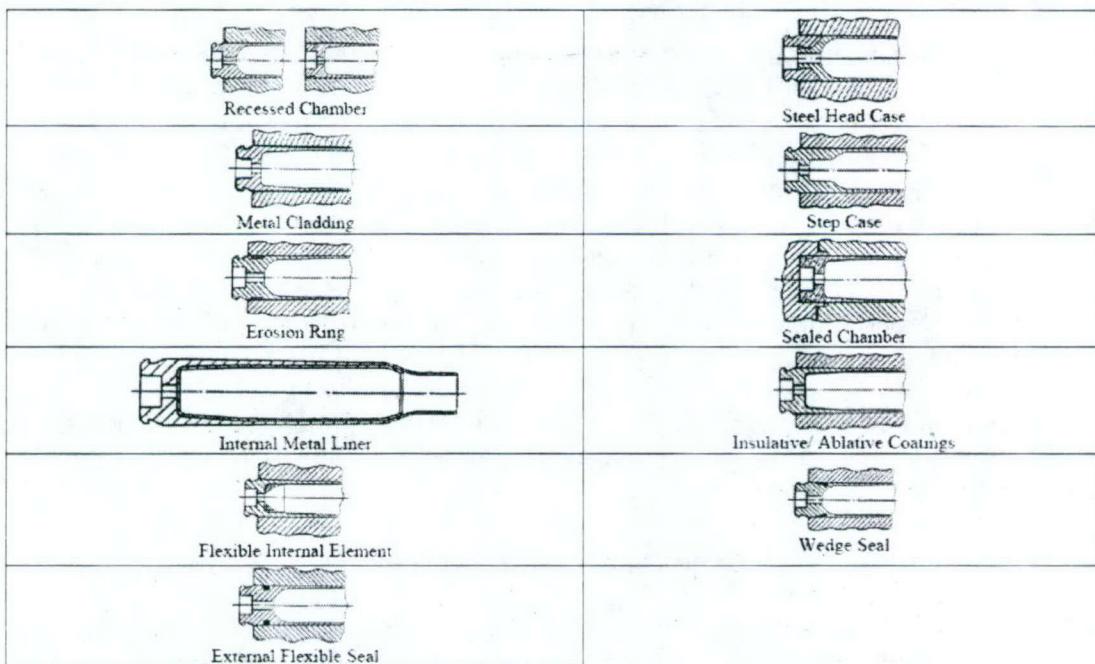

Figure 5
Cartridge case/breech/chamber sealing mechanisms considered by Frankford Arsenal

Many of these concepts were physically tested by building and firing ammunition. Other candidate designs were analyzed and found to have a low probability of success. At the conclusion of the report, concepts, which were observed to have the greatest success or potential for success, were a steel head with an aluminum body, intumescent coatings (20 mil thick), and a flexible internal element. Because the steel head complicated assembly and reduced the overall weight reduction, it was not recommended. The flexible coating on the case inner diameter functioned well, and the report recommended it for further analysis. Intumescent coatings on the case inside diameter were also suggested as being promising and recommended as for additional study.

Several internal sealant materials were investigated in the 1974 study, both as separate elements and as coatings. Of these materials, the most successful were soft rubbery type polymeric materials. The polymers tested include epoxies, urethanes, and silicon rubbers. Silastic 734, a Dow Corning silicone rubber, performed the best.

In 1975, Thiokol Chemical Corporation, Elkton Division completed a series of tests for Frankford Arsenal (ref. 6). Thiokol's project was to study cartridge case coatings designed to prevent the occurrence of burn-through. They determined the effectiveness and feasibility of five materials: red grip core paste, polyimide varnish (Dupont), NASA 45B3 intumescent coating, polysulfide sheeting, and RTV-734 (Dow Corning Silastic 734). In this study, the NASA intumescent coating and polysulfide sheeting both applied internally were most successful at preventing burn-through. While the tests may not have been biased against Silastic 734, the investigators admitted that they did not apply a uniform layer on the case inside diameter (ID). Thiokol's recommendation was that an internally applied case coating could prove most effective in the prevention of burn-through in 5.56-mm ammunition. Their suggestion was to use polysulfide sheeting and to investigate further the NASA 45B3 intumescent coatings.

Frankford Arsenal completed a testing program in 1976 that documented the series of events needed for the burn-through condition to occur (ref. 7). They performed test shots combined with analysis of the physical processes to show that burn-through was the result of a sequence of events beginning with mechanical damage (scratches, nicks, etc.) on the surface of aluminum cartridge cases. When a round is fired, the cartridge case expands and under the correct conditions tears, allowing the propellant gases to vent into the weapon chamber section. These gases, following the path of least resistance, flow to the rear of the cartridge, eventually reaching the extractor groove and release. Burn-through is the melting and chemical reaction of the burning propellant gases with the un-coated aluminum exposed when a case fails. Frankford Arsenal also concluded that an engineering application of a rubber liner could successfully prevent burn-through.

In summary, studies performed by Frankford Arsenal over almost 30 years of research and conversations with a commercial ammunition manufacturer and Quality Engineering personnel indicated the following:

- Cartridge cases can be easily formed from aluminum alloys.

- Once structural and corrosion considerations are answered the primary problem with aluminum cartridge cases is mechanical damage.

- Scratches and other mechanical damage on cartridge case outside diameter surfaces can result in splits through the cartridge case wall.

- Venting of hot propellant gases other than through the mouth of the cartridge case results in a burn-through condition.

- Burn-through is the erosion and chemical reaction of burning propellant gases with the aluminum cartridge case.

- Hot propellant gases passing through a leak or hole in the cartridge case wall will follow a path of least resistance to the extractor groove region of the part.

- The damage to the weapon and injury of the operator due to burn-through can be controlled by either sealing the chamber or by interfering with leak path.

- Since not all weapons have closed chambers, the leak path interference method of either minimizing or preventing burn-through has the greatest potential benefit and cost effectiveness.

- Testing has shown that intumescent and rubber coatings applied to the inside of cartridge cases can either stop or significantly reduce the conditions, which allow burn-through to occur.

Material Selection

When only lighter cartridge case materials are considered, several metals are available. These include aluminum, beryllium, magnesium, and steel alloys. Reducing weight does not totally mean choosing a lighter material. If a candidate alloy were stronger and tougher and possibly even stiffer than the current brass, a thinner walled case might be possible even though the material has a comparable or greater density. Of the lighter alloys, magnesium has about the lowest density of commercial engineering metals, but it also has the lowest mechanical properties and has as great a problem with burning as aluminum and titanium. Beryllium is a very light and strong alloy, but it is extremely expensive and is a hazardous material. Titanium weighs more than aluminum. It can also burn, is difficult to machine, and difficult to form. Of these material groups, aluminum probably has the best combination of strength, low cost, minimal health hazards, and the greatest potential for success. Figure 6 provides a comparison of these materials.

	Cartridge Brass (C26000)	Steel (G10400)	Titanium (R56400)	Aluminum (A97475)	Beryllium (Brush Wellman S200)	Magnesium (M16600)
Density	1.00	0.92	0.52	0.33	0.22	0.21
Elastic Modulus	1.00	1.82	1.04	0.65	2.75	0.41
Tmelt	1.00	1.64	1.75	0.58	2.33	0.55
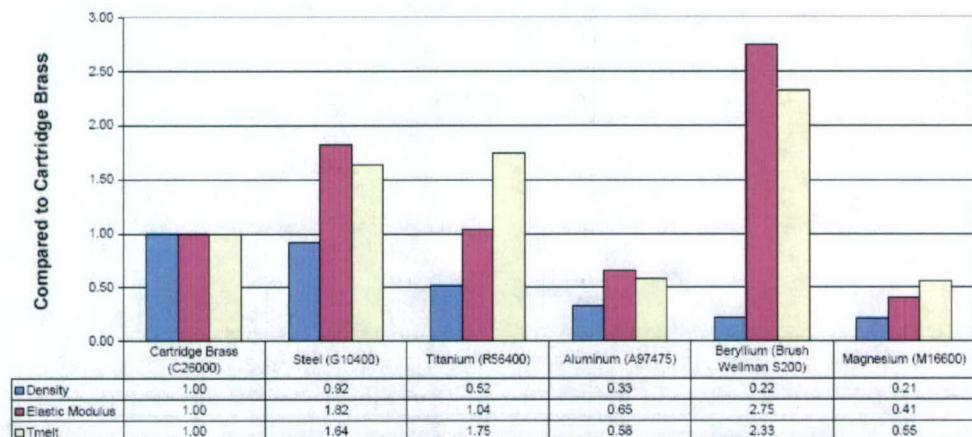
Figure 6
Potential cartridge case materials comparison

The engineering analysis of the 5.56-mm cartridge case was broken into two parts. One part of the study consisted of a structural analysis of both aluminum and brass cartridge cases. For this analysis, the baseline new cartridge case, besides being an aluminum alloy, was also assumed to have an anodic coating. While other aluminum coatings are available, anodizing provides good wear resistance, is corrosion resistant, is commonly available, and is currently being used on medium caliber ammunition rounds. Concurrent with the structural analysis, a coating study was performed to identify methods of protecting cases from corrosion and to identify methods of controlling the burn-through problem. These analyses were done at ATK Ordnance and Ground Systems in Plymouth Minnesota and at Arrowtech in Burlington, Vermont.

Selection of a baseline material for the structural analysis initially considered all aluminum alloys. While this is a broad range of materials, several were quickly eliminated as candidates. Examples of easily unsuitable aluminum alloys include the non-heat treatable grades and the higher strength aluminum-lithium grades. Non-heat treatable alloys, while highly formable, typically have mechanical properties below those capable of being precipitation hardened (fig. 7). If used as cartridge cases, their lower yield strengths would allow a significant amount of plastic deformation to occur, and potential weapon jamming if the case could not be ejected. It was concluded after surveying the commonly available aluminum-lithium alloys, that their mechanical properties were not significantly improved over those of more conventional grades, and that they would probably be more expensive.
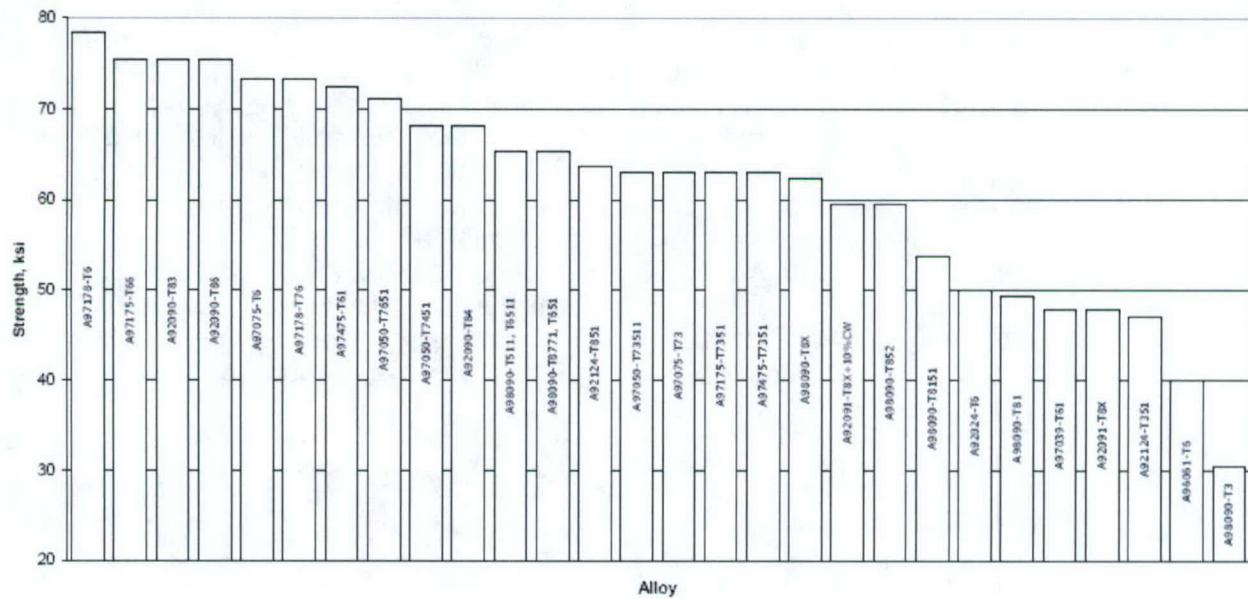
Figure 7
Comparison of candidate cartridge case aluminum alloy yield strengths

Elimination of lower strength and more expensive aluminum grades reduced the candidate cartridge case material list to A96061, A92024, and the A97XXX series. Of these, alloy A96061, while easily worked and protected from corrosion has the same yield strength problem that the non-heat treatable grades have. During firing, when the chamber pressure reaches 61,000 psi, the plastic deformation of an A96061-T6 cartridge case would probably be large.

Alloy A92024, a high strength grade, was rejected as a candidate cartridge case material because it is difficult to anodize. Most A92XXX series aluminum alloys have over 3% copper as a constituent. Experience has shown that while these alloys can be anodized, special precautions need to be taken to insure significant chemical attack does not occur. Since most comercial electroplaters are not capable of this level of control, it was thought that anodizing A92024 would add considerable risk and expense to the round. Of the remaining candidate materials, alloy A97475 was selected because of its high strength and use on other cartridge cases. Commonality with other designs will benefit the program by simplifying the tooling development. Figure 7 compares the tensile yield strength for the candidate aluminum alloys.

Consideration of protective coatings for the cartridge case began prior to the government technical reports becoming available. Initially, it was assumed that the major problem with cartridge case function in both Legacy and Future Weapon systems was mechanical damage and corrosion. Anodizing was among the coating systems considered, but others were also reviewed. These included chromate conversion coatings, paint, aluminum nitride coatings, electroless nickel, electroless nickel-boron coating, and others. Generally, the challenge of these coating systems was how to apply a protective layer both inside and outside the cartridge case, and how to apply the protective layer at a reasonable cost for the potential production rates.

For comparison, a Type II Class 2 MIL-A-8625 anodic coating was used as a baseline. A Type II coating has a thickness ranging form 0.00007 in. to 0.0010 in... The Class 2 requirement allows for both hot water and nickel acetate sealing. This coating is comparable to those currently used on medium caliber ammunition. It has, therefore, been shown capable of providing corrosion protection and resisting stresses due to firing. Structurally, the anodic coating is hard and wear resistant. Since it is essentially aluminum oxide, an anodized coating also provides a small amount of thermal barrier protection to the substrate.

Blending the anodic coating with other materials was among the concepts considered. One common anodized coating additive was polytetrafluoroethylene (PTFE). This type of coating was rejected because burning propellants would most likely decompose the PTFE. When this occurs, carbon and fluorine are released into the cartridge case volume. Aluminum will exothermically react with fluorine to form AlF_3. Since this reaction was exothermic, the addition of PTFE to the anodic coating could potentially make the burn-through problem worse. Electroless nickel and nickel-boron coatings were also considered. Because of the plating bath chemistry, it would be possible to deposit an electroless coating on both the cartridge case ID and outer diameter (OD). Electroless nickel and nickel-boron coatings characteristically are hard ($\geq$ 350 HV or 38 HRC) and corrosion resistant. The high hardness corresponds to a high strength and low ductility. If plated with an electroless nickel type coating, it is possible, that during firing, the coating could possibly crack, which could then extend into and through the basis metal resulting in venting of propellant gases and a burn-through condition. As a result, low ductility electroless nickel coatings were not considered further.

Intermetallic coatings provide a method of creating a high melt temperature, low coefficient of friction layer on metallic surfaces. Intermetallic materials are metallic oxides and nitrides that have properties different from those of the pure metal. The most common example of this type of material is titanium nitride, which is used as a coating on tools because of its low coefficient of friction and hardness. Another useful intermetallic coating is aluminum nitride. As

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with titanium nitride, aluminum nitride is hard, has a low coefficient of friction and a high melt temperature. These are typically thin coatings, having thickness values of less than 50 μin and are normally measured in Angstroms.

For cartridge cases, the nitride coating could be formed by driving nitrogen into the aluminum alloy matrix through an ion deposition or implantation method. The complexity and high cost of this process would be due to processing. This type of coating is applied in a vacuum chamber. Application of the coating to the ID would also require that an electrode be located in each of the cartridge cases. Batch type vacuum processing combined with potentially high racking costs makes this type of coating a costly method of protecting cartridge cases. Considering the potential production costs and the limited protection from a very thin layer of material, it is unlikely that these coatings would provide adequate protection from either mechanical damage or burning propellant.

Other coatings considered included Emralon (PTFE in a phenolic matrix) and E Coat (a proprietary epoxy painting process). Emralon, while providing a reduced friction surface and corrosion resistance, was rejected because of the PTFE component. E Coat was rejected because it uses a combination of bath immersion and an electrical potential difference to apply the paint. In the case of the cartridge case, epoxy is typically a brittle material. If the ability to seal a hole in a cartridge case was dependant on the pliability of the protective layer, an epoxy coating may not be a good choice. The Frankford Arsenal studies showed this result. The coatings considered in this initial review are summarized in table 3.

Based on the information from Frankford Arsenal papers, a review of current cartridge case designs and conversations with industry resources, it was concluded that, at minimum, aluminum cartridge cases should be anodized. Historical experience has shown that a Type II anodize coating in accordance with MIL-A-8625 provides adequate corrosion protection and mechanical damage protection from all but the most severe conditions.

An anodized coating will not be sufficient to protect the cartridge case from mechanical damage that precedes the formation of a hole in the side of a cartridge case. Anodized coatings are hard and wear resistant, but they cannot prevent the scratches and nicks that occur as a result of normal handling and loading systems. The ammunition belts used by the M249 SAW are an example of a component that will leave witness marks on the surface of a cartridge case. The effect of these defects will be an occasional cartridge case split or failure allowing the propellant gases to vent through a hole other than the case mouth. Since leaking propellant gases can result in burn-through and operator injury, either the chamber or case must be sealed. Chamber sealing can be accomplished by designing new weapon operating mechanisms and chambers, which would make Legacy systems unsuitable for aluminum cartridge cases. A second method of minimizing or preventing burn-through is to seal the cartridge case as discussed later in this report.

Table 3

Cartridge case corrosion preventative and wear coating matrix

Coating	Process	Equipment	Benefits	Liabilities	Comment
Anodizing with hot water seal	Electro-chemical	– Plating baths – Part handling system – Chemical waste handling equipment	– Can be added to production line as a continuous process – Hard, wear resistant coating – Although the process may not be, the coating is environmentally friendly – Used on medium cal cartridge cases	– Highly corrosive chemicals are used to produce coating	– Assume baseline – Natural color
Anodizing with nickel acetate seal	Electro-chemical	– Plating baths – Part handling system – Chemical waste handling equipment	– Can be added to production line as a continuous process – Hard, wear resistant coating – Used on medium cal cartridge cases	– Highly corrosive chemicals are used to produce coating – Nickel acetate is not considered an environmentally friendly material – Need contact points on part	– Include dyes for color
Anodizing with PTFE filler	Electro-chemical	– Plating baths – Part handling system – Chemical waste handling equipment	– Can be added to production line as a continuous process – Hard, wear resistant coating – Used on medium cal cartridge cases	– Highly corrosive chemicals are used to produce coating – Nickel acetate is not considered an environmentally friendly material – Need contact points on part	– Natural color
Nickel boron (electroless)	Electro-chemical	– Plating baths – Part handling system – Chemical waste handling equipment	– Hard wear resistant coating – Water based plating solutions – Basically, an electroless nickel type coating	– Not been tried on cartridge cases – Requires a thermal treatment	– Ultrachem and EWA representatives were contacted – Potentially, too brittle
Nickel phosphorus (electroless)	Electro-chemical	– Plating baths – Part handling system – Chemical waste handling equipment	– Hard wear resistant coating – Add PTFE to bath to improve lubricity – Basically, an electroless nickel type coating	– Not been tried on cartridge cases – To achieve maximum properties requires a thermal treatment	– Wear-Cote International and Nickel Development Institute literature reviewed – Potentially, too brittle
Aluminum nitride	Vapor deposition	– Deposition chamber – Racks – Handling equipment	– Aluminum nitride would be a nitride rich layer in the aluminum cartridge case – Hard wear resistant – Physically part of aluminum cartridge case – no flaking	– Batch type process	– If can do in a salt bath, may be able to do as a continuous process – Kolene – sent technical question, no response
Emralon (baked)	Spray coat	– Spray booth – Handling equipment	– Continuous layer on part surface – Emralon – PTFE particles in a phenolic matrix – Emralon is a solid film lubricant – Can be added to production line as a continuous process – Corrosion resistant coating	– Spray process that needs clean parts and associated monitoring. – Potentially have to spray into case ID – Potential primer vent hole contaminant	– Used on many devices, for example Medium Caliber fuzes (M758 & M759) – Acheson Colloids Emralon 305, 330, 333, or 334 – sent technical question, no response
E Coat	Bath type paint	– Coating baths – Ovens for curing – Part handling equipment	– Wear resistant coating – Corrosion resistant coating	– Dip process requiring electrodes and a potential difference. – Potentially have insert an electrode into case ID – Potential primer vent hole contaminant	– PPG proprietary process

Mechanical Design

In order to design the aluminum cartridge case, it was decided to use a unique finite element (FEM) modeling code for the majority of the work and then do an independent check of the results using a high fidelity FEM code (ABAQUS), which ATK has a significant amount of history. Arrow Tech Associates was contracted to conduct the modeling using their case analysis system (CASAS) as the primary modeling code.

CASAS is a specialized FEM code specifically designed to analyze the non-linear behavior of the cartridge case as it interacts with the gun chamber. The case is divided into individual rings along its longitudinal axis (fig. 8). Each ring is capable of being assigned unique linear and non-linear material properties, static and dynamic coefficient of friction. This allows the user to select the ring lengths and locations. Then each ring is modeled with its density, yield strength, elastic and plastic modulus, and static and dynamic coefficients of friction. One of the key flexibilities of the model is that multiple materials and hardness values per case can be evaluated. CASAS is capable of rapidly assessing changes in headspace; case base-bolt face gaps, changes in coefficients of friction, peak pressure, and material properties. Integration of CASAS into the projectile analysis and simulation (PRODAS) analytical environment ensures rapid and seamless hands-off between dependent analytical modules such as interior ballistics and CASAS.
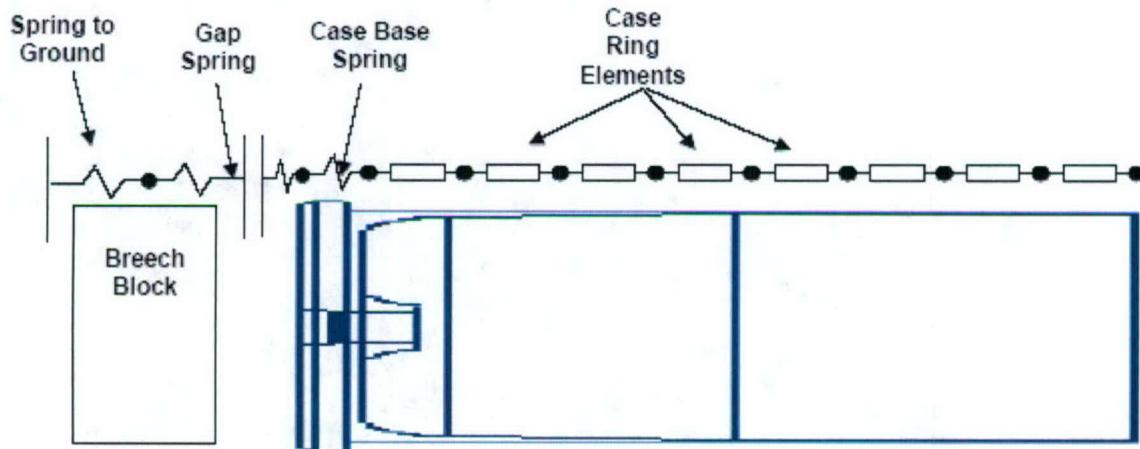
Figure 8
CASAS model approach

The CASAS code has been successfully used in numerous small, medium, and large caliber applications over the past 20 yrs. Initial validation was performed in 1984, and the results of the 5.56-mm aluminum case analysis were shown to be in agreement within approximately 7% of ultimate strain, given similar inputs. CASAS can perform non-linear analyses of the cartridge case and chamber interaction in a fraction of the time of general-purpose finite element codes, so it is a valuable design tool, particularly in the early stages of the design. Table 4 outlines the history of the CASAS model.

Table 4
CASAS model history

Year	Event
• 1984	Validated versus ANSYS (non-linear) in 1984
• 1984	30 x 173 mm light weight steel case and aluminum case
• 1985 – 1986	25 x 137 mm aluminum case
• 1986	20 x 102 mm aluminum case
• 2001	20 x 120 mm aluminum case
• 2001	155 x1069 mm AGS steel case
• 2001	5.56 x 45 mm brass/polymer case
• 2001	40 x 217 mm ALACV steel case

When designing a cartridge case, strain usually becomes the dominant variable that must be controlled within a material's limit. The total strain experienced by the case is the resultant of its hoop strain, longitudinal strain, and radial strain. CASAS sums these strains for each ring analyzed to allow rapid comparison of total strain for each ring as a percent of its ultimate strain. A cartridge case is "optimized" (minimum weight) when the peak total strain achieved in the case during pressurization attains 85 to 90% of ultimate strain under worst-case conditions (e.g., friction, axial and radial gaps, pressure, wall thickness, etc.) The effect and importance of various CASAS inputs on bolt load and peak strain is shown in table 5. These results allow the user to prioritize requirements and focus on attributes most important to the application of interest.

Table 5
CASAS qualitative results

Analysis variable	Bolt load	Peak strain	Relative significance
Material properties Increase Decrease	 - +	 - +	Very important
Friction Increase Decrease	 - +	 - +	Important
Radial gap Increase Decrease	 Same Same	 + -	Minor
Axial gap Increase Decrease	 Slightly lower Slightly higher	 + -	Important
Bullet pull Increase Decrease	 + same	 + same	Minor and only at low pressure

The stress -strain behavior of the 7475 T6511 aluminum alloy is shown. Aluminum has lower yield strength than the hardest brass, but much better elongation.

The geometric and CASAS lumped mass and ring element model are shown side by side for comparison (fig. 9). Below some critical stiffness value, the ultimate strains exhibited by the case are strongly influenced by the stiffness of the bolt with respect to the chamber wall. Thus, it is critical to ensure an appropriate value for lock stiffness is used.
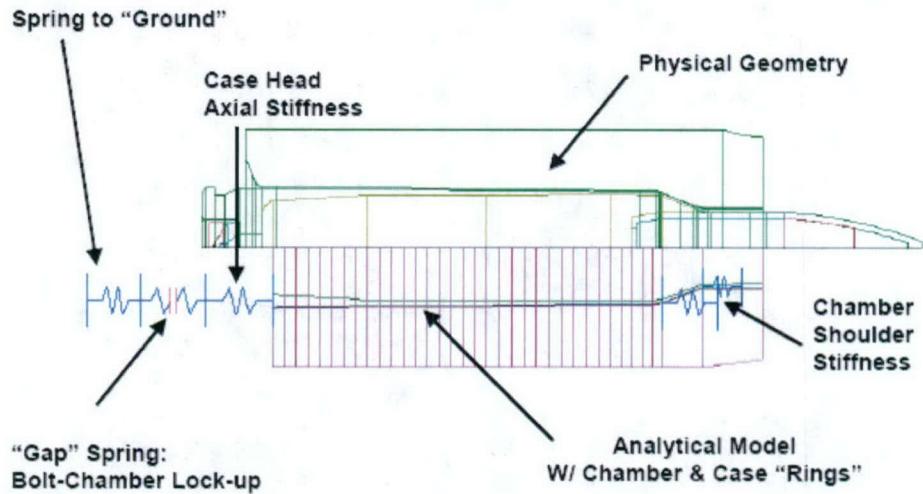
Figure 9
CASAS physical and analytical model comparison

As part of the first step of the CASAS analysis, a decision had to be made as to which weapon to use in the analysis. The approach taken was to evaluate both guns, identify the "worst" one in terms of cartridge case function, and then use those weapon parameters in the model. Because the M16 and the M249 have differing chamber dimensioning and tolerances, this leads to significantly different boundary conditions for each gun (table 6). Because the M16A2 has the larger difference between case minimum and chamber maximum, the maximum headspace of 0.010 in. of the M16A2 was used for worst-case conditions in this analysis.

Table 6
Gun interface analysis

Weapon/parameter	Value
M16A2/M4	
• Headspace	
o Minimum	-0.002 in. (-0.051 mm)
o Average	+0.004 in. (+0.102 mm)
o Maximum	+0.010 in. (+0.254 mm)
• Bolt	
o Stiffness	6.0×10^6 lb/in. ($.237 \times 10^6$ N/mm)
o Bolt mass	0.0995 lb (45.13 gm)
M249	
• Headspace	
o Minimum	-0.006 in. (-0.152 mm)
o Average	-0.001 in. (-0.025 mm)
o Maximum	+0.005 in. (+0.127 mm)
• Bolt	
o Stiffness	33×10^6 lb/in (3.36×10^6 N/mm)
	0.1495 lb (67.81gm)
Bolt Mass	

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Brass Cartridge Case Analysis

Now that the key model parameters with respect to the weapon were established, the cartridge case analysis and subsequent design could begin. However, in order to validate the CASAS code for this particular application, it was first used to evaluate the current brass cartridge case. Additionally, this analysis would allow the complete understanding of how and why the brass cartridge case works.

The stress-strain behavior of 70-30 brass is shown in figure 10. The material properties gradient of the baseline brass case is key to its structural robustness. Brass is harder (and higher yield strength) with lower elongation at failure at the case base, gradually getting less hard with increased elongation moving along its longitudinal axis. The properties gradient is clearly shown in the 9378276 drawing.
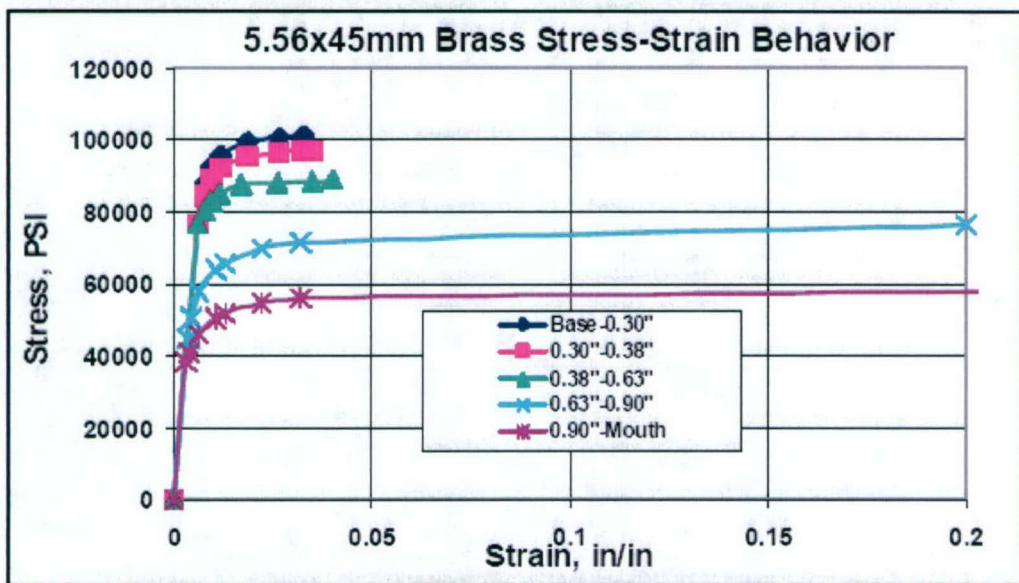
Figure 10
Brass cartridge case stress-strain data and case location

Assessing the ultimate strain performance of brass case as a function of case base-bolt face gap and coefficient of friction is done to ensure accuracy of the analytical and case models. Hot (52°C) peak pressures are used to provide worst-case loads on the case. Strains are lower than 50% of ultimate for all examined gaps up to 0.012 in. and coefficient of friction form factor of 1.5 on the 0.10 static coefficient of friction and 0.080 dynamic coefficient of friction generally used for brass cases. This means the brass case is quite robust, and the gaps and/or friction would have to get quite large to provoke structural failure of the brass case.

The minimum wall brass case is expected to exhibit less than 35% of ultimate strain under all case base-bolt face gap conditions up to 0.010 in., which means that there are no structural integrity issues with the brass case regardless of the value of the coefficient of friction. Since obviously the brass cartridge case works, there is now a model that matches the real world and can then be exercised to design an aluminum cartridge case.

Aluminum Cartridge Case Analysis

The design analysis for the aluminum cartridge case will follow the same order as for the brass case. First, figure 11 is a plot of stress versus strain for 7475 aluminum alloy. This alloy was selected after a basic aluminum materials investigation (discussed previously) identified it as the preferred material. Not surprisingly, this is the same material that LW30 mm and GAU-8/A cases are also made.
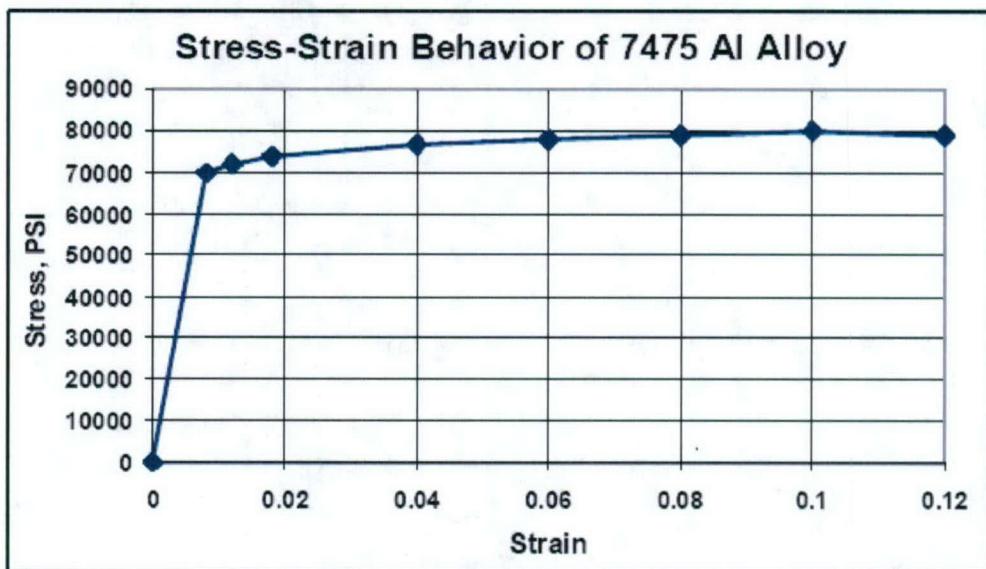
Figure 11
7475 aluminum alloy stress strain curve

The initial 5.56-mm cartridge case configuration borrowed heavily from the brass case (drawing 9378276), but incorporated a thicker base and thicker side walls to improve structural integrity during pressurization due to undefined external scratching that might occur as a result of stripping from the links, feeding, and ramming. There were actually several iterations of the aluminum cartridge case design that was evaluated before the one shown in figure 3 was identified. The primary tradeoff was to balance structural integrity against ballistic performance. Because the QFD analysis made safety the number one priority, it was emphasized. This resulted in a thicker wall case that does not currently have enough volume to maintain the current M855 ballistics. This was a conscious decision made by the government/ contractor program team and was selected as the baseline starting point. The logic used was to begin testing a case with a high degree of confidence in its structural integrity and then, after test data became available, to determine if its interior volume could be increased to regain some or all of the lost ballistics. The result is a case with approximately 18% less internal volume than the baseline brass case. This design was subsequently subjected to various interior ballistic and structural analyses to ensure adequate ballistic performance and adequate structural margin. As an independent check, the FEA code ABAQUS was also run by ATK on the final verification as an independent check to the CASAS model. The results of both models showed a cartridge case that functioned as designed. The next several pages summarize the final cartridge case design results from CASAS. As with the brass case, the worst-case conditions were used in the analysis. For the aluminum case, this meant a minimum material because this will cause the highest section stress along with maximum gap levels, since this will cause the highest strain

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levels before the case contacts the gun chamber. The aluminum cartridge case analysis used peak pressures and looked at all three conditioning temperatures of hot, cold, and ambient. The static and dynamic friction values of 0.12 (static) and 0.09 (dynamic) represent our best friction expectations.

At the completion of this initial baseline case analysis using CASAS, the configuration was then evaluated using ABAQUS. As mentioned previously, although CASAS is a valuable tool for quickly evaluating and configuring cartridge cases due to its flexibility and quickness, a higher fidelity FEA code should also be run on the final design. When the initial baseline design was analyzed using ABQUS, it was noted that there was a relatively high strain area towards the aft end of the case. A second run was made where the wall thickness was increased in the area of concern and the results showed an acceptable strain level. Figure 12 shows the initial and increased wall thickness strain plots from ABAQUS. While these results were being analyzed, AMRON was also working on the preliminary tooling design. During this initial design activity, AMRON requested that the interior of the case be slightly modified at several transition points to improve the producibility of the case. Because these changes were minor, they were incorporated into the design. Now a revised baseline case was defined and both CASAS and ABAQUS were run using this new configuration, which compared to the initial design had an increased wall thickness towards the base and a revised interior contour for manufacturability. The CASAS code showed that while there was a region of relatively high strain at the worst-case conditions, the cartridge case would survive and function as designed. When ABAQUS was used, the results were even better with no high strain areas noted for the worst-case conditions. In evaluating the somewhat difference in model result, it was determined that this was due to the models predicting different contact timing sequences (table 9) with the chamber walls. It was concluded that the revised design would provide the desired safety margin and would function in the worst-case conditions and was, therefore, adopted as the final phase 1 design. This decision was based on two key points. First, the higher fidelity FEA model, ABAQUS, showed the lowest strain in the case walls. Second, the final cartridge case design was somewhat outside of the normal CASAS analytical zone and this coupled with the highly localized strain location put into question the high specific strain value observed in the case wall. Figures 13 through 16 summarize the results of this last portion of the design analysis. The first series of plots show the CASAS analysis for the initial case and final case design. The last figure shows the case strain using ABAQUS under the worst-case conditions.

Table 7
Contact time comparison between models for all case designs

Case configuration	Model used for contact time estimate	Initial wall contact time (ms)	Final wall contact time (ms)	Case base-bolt face contact time (ms)
Brass	CASAS	0.1035	0.2691	0.31
Initial aluminum	CASAS	0.1432	0.2659	0.29
Final aluminum	CASAS	0.1281	0.3204	0.34
Final aluminum	ABAQUS	0.0910	~0.400	0.12
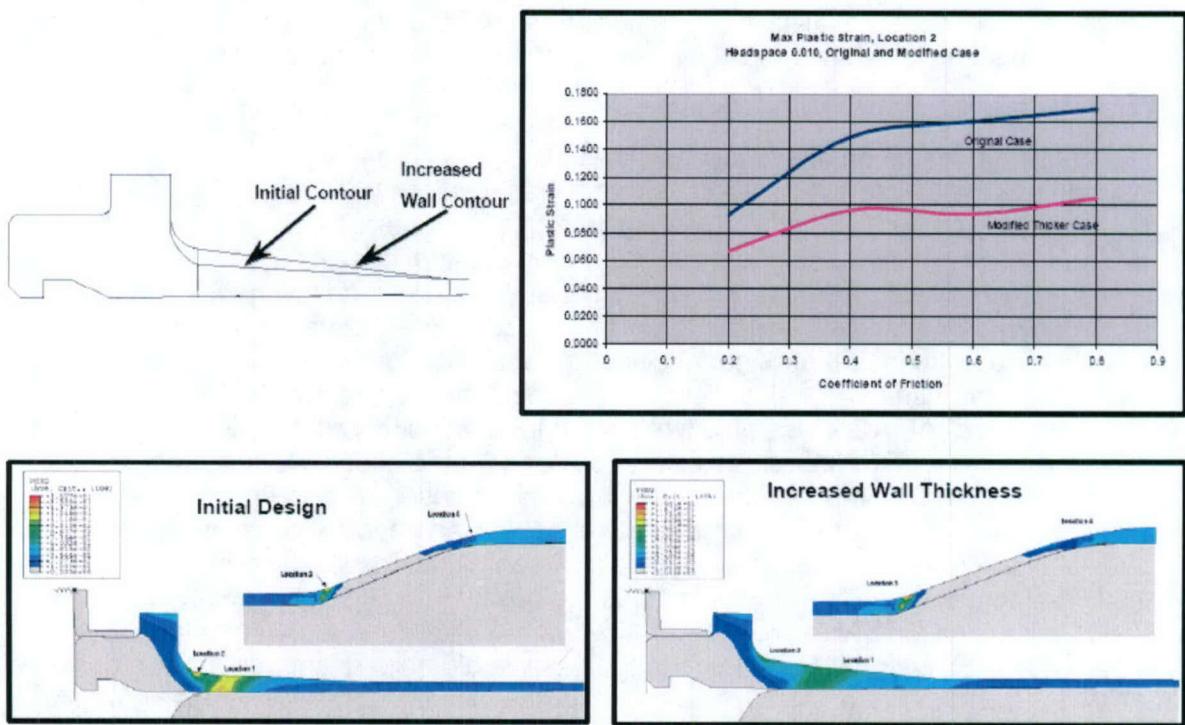
Figure 12
ABAQUS strain plots for initial baseline and increased wall thickness case configurations
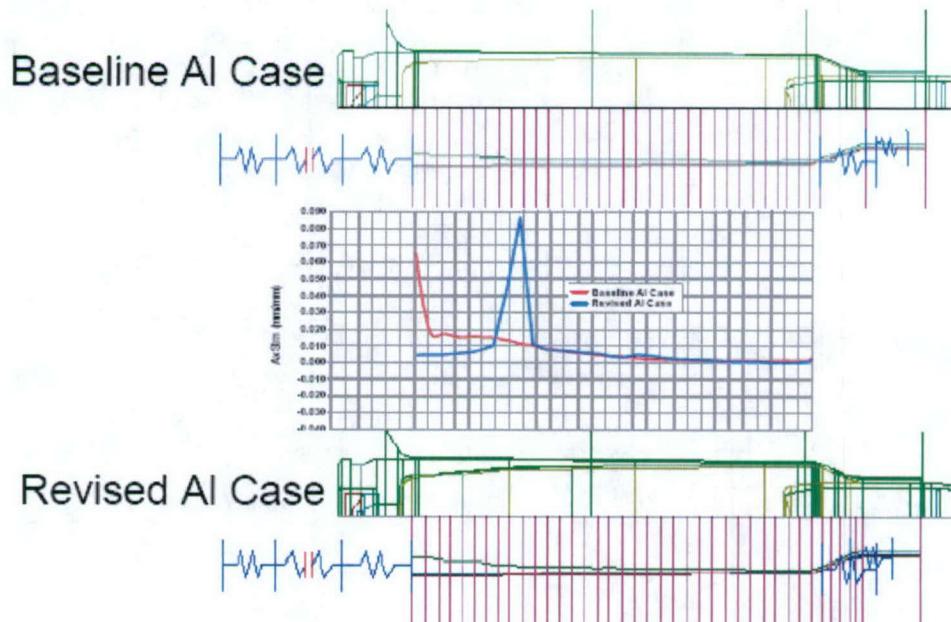
Figure 13
CASAS axial strain versus location initial baseline and revised case geometries

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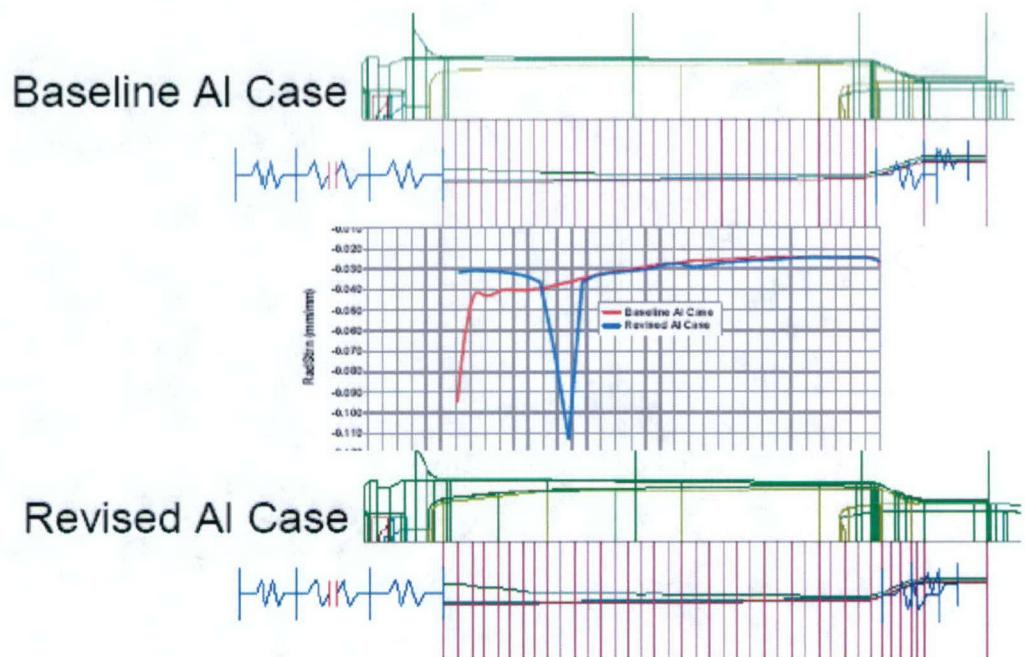
Figure 14
CASAS radial strain versus location initial baseline and revised case geometries
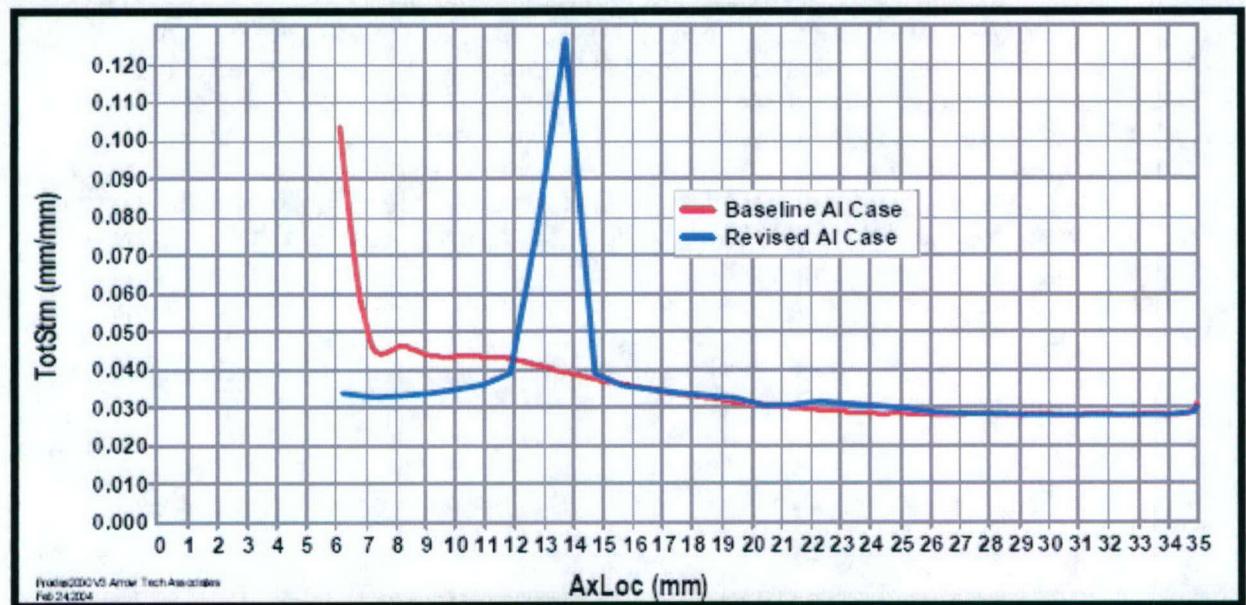
Figure 15
CASAS total strain versus location initial baseline and revised case geometries
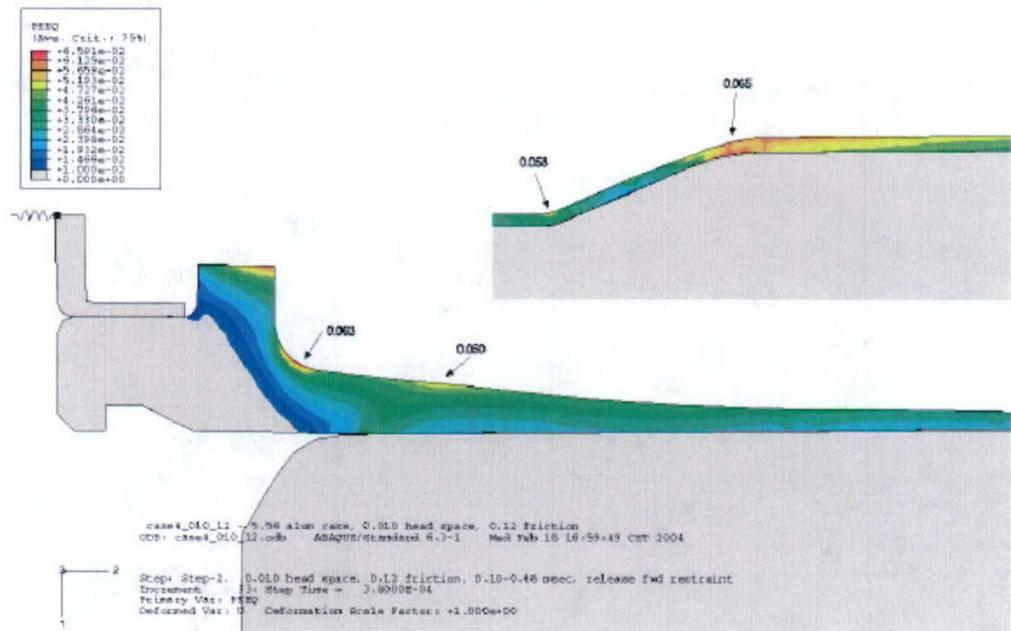
Figure 16
ABAQUS case strain plot for revise case design

Interior Ballistics Analysis

The interior ballistic performance of the M855 projectile using the aluminum cartridge case was assessed at ambient and hot temperatures using the computer code IBHVG2. Because of the interior volume reduction of the aluminum case including its interior coating, the muzzle velocity of the projectile was also expected be reduced if the current production propellant, WC844, was used. The current model estimates a muzzle velocity of 828 m/s using production propellant compared to a muzzle velocity of 935 m/s for the brass cased M855. If a new propellant with a modified web and or formulation were to be used, the velocity was predicted to increase to within about 40 m/s of the production round. However, as is discussed later, a propellant was identified that will meet the ballistic requirements in cases without the interior coatings. It still needs to be verified that the ballistics can be met once the coating is applied. Table 8 compares the brass case, initial aluminum case, and revised case volumes and velocities.

Table 8
Projected brass versus aluminum cartridge case performance comparison

	Cartridge case material/configuration		
	Brass M855	Initial aluminum	Revised aluminum
Charge weight (gm)	1.69	1.64	1.39
P_{max} (MPa at 15°C)	409	409	327
V_{max} (m/s at 15°C)	935	936	828
Maximum case temp (K)	681	791	712
Charge type	Cake (14)	Cake (14)	Cake (14)
P_{max} (MPa at +52°C)	452	450	344
V_{max} (m/s at +52°C)	967	966	851

The interior ballistic performance of systems with varying case capacities was studied to determine the muzzle velocity sensitivity to creating cases with walls thicker than the baseline aluminum case. It is estimated that the interior case volume can reduced to 1.66 cm³ without a reduction in muzzle velocity provided the propellant web is adjusted to keep peak chamber pressure constant. If a propellant web change is allowed, muzzle velocity drop with decreasing case volume is relatively minor, with only a 10 m/s velocity penalty paid at a case volume of 1.60 cm³. The results of this analysis are shown in figure 17.
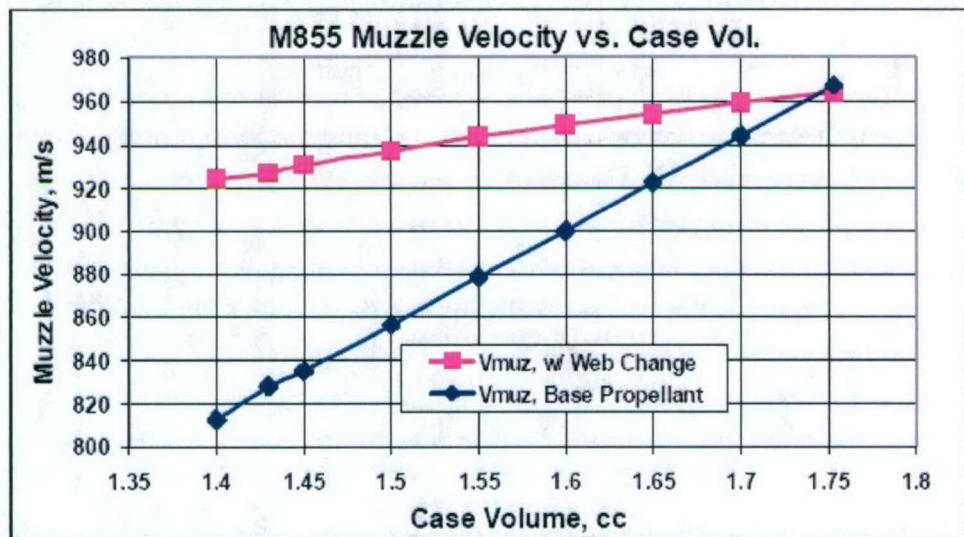
Figure 17
Muzzle velocity versus case volume at 450 MPa chamber pressure

Burn-through Investigation

In addition to reviewing government studies of burn-through, cartridge case manufacturers were contacted to determine the extent of this problem in industry. Among the companies contacted and visited were AMRON in Antigo, Wisconsin; ATK CCI/Speer in Lewiston, Idaho; and ATK Ammunition Company in Arden Hills. Minnesota.

AMRON manufactures medium caliber cartridge cases for the ATK Ammunition Company. They are currently supplying ATK with cases for the GAU-8 and lightweight 30-mm rounds, both of which are made from aluminum alloy A97475. In conversation, AMRON reported that they did not know of any major burn-through problems related to cartridge cases.

After the AMRON meeting, ATK Ammunition Company manufacturing plant in Arden Hills, Minnesota was contacted. A Quality Engineer responsible for testing of completed rounds stated that burn-through is occasionally observed in medium caliber cartridge cases. When it occurs, it is normally related to mechanical damage on the case OD surface.

ATK's CCI/Speer division was also contacted for information on aluminum cartridge cases and burn-through. The Engineering Director and Development Engineer stated that they had observed burn-through problems twice. The first occurrence was related to a specific rifle operating mechanism, suggesting that mechanical damage may have been involved. This problem went away when that weapon fell out of favor and when it became known aluminum cartridge cases were not a good ammunition choice for the weapon.

The second occurrence of burn-through was due to inter-granular corrosion. In their failure analysis, CCI personnel found that the problem began with completed and boxed ammunition getting wet when stored outside in a rainstorm. This product was later shipped to a distributor in Texas who repackaged the damp paper ammunition boxes into plastic bags. CCI/Speer uses a light chromate type coating to protect their cases. This coating was apparently not sufficient to minimize the corrosive combination of moisture, heat, and a material susceptible to inter-granular corrosion.

Manufacturing Investigation

A manufacturing process for the aluminum cartridge was developed by AMRON and is similar to their other cartridge case manufacturing processes. All of the tooling and gaging for the cartridge case manufacture was designed in phase 1 and the tooling and cartridge cases were manufactured in phase 2 of the program.

In terms of manufacturing the cartridge cases for both this effort and in high volume production, both coil and rod stock as the raw material were evaluated and the decision was made to begin with rod stock. This decision was made because it was felt that by starting with rod stock and sawing it into the appropriate slug size would yield a more consistent product by eliminating an annealing operation and retaining a better grain size. One of the lessons learned from the manufacturing of medium caliber ammunition is the need/desire to maintain both strength and hardness of the base and rim. This was found to be greatly affected by the grain size of the incoming material as well as by the manufacturing process in terms of how much work hardening was put into the material. Current calculations show that the impact operation will cause an 84% reduction and the draw operation will yield a 28% reduction through the top die and a 16% reduction through the bottom die. Lubrication will be a key factor in ensuring that the draw operation works as planned. Table 9 summarizes the differences between coil and rod stock as the starting material.

Table 9
Coil versus rod stock raw material comparison

Item	Coil stock	Bar/rod stock
1	Requires one more anneal operation - potential for larger grain - annealing with minimal work hardness	Requires sawing operation - additional product scrap
2	Potential for inconsistent amounts of work hardness while coiling/uncoiling	Potential to develop impact operation without a pre-form - block/cupping
3	Shear operation to form slug - reduces product scrap	More consistency in the process- maintain consistent grain size - work hardness

The cartridge case manufacturing process developed at AMRON is similar to other case forming processes. It begins with a blank, which is then formed into a cup. Next, the cup is drawn and headed to the general length and shape of a case and then tapered. During the forming process, in-process annealing treatments are used to control formability and grain size. After each of these anneals, the cases are cleaned (de-smutted) and lubricated. At the conclusion of all forming and machining operations, cases are precipitation hardened to the T76 condition. Finally, the formed and aged cases are anodized. This process is outlined in table 10 and shown in a flow chart format in figure 18.

```
┌──────────────┐     ┌──────────────┐     ┌──────────────┐     ┌──────────────┐     ┌──────────────┐
( START )       │ 090          │     │ 170          │     │ 230          │     │ 300          │
│              │ ETCH, RINSE & │     │ ACID CLEAN   │     │ DEOXIDIZE    │     │ ANODIZE      │
┌──────────────┐│ DRY          │     │              │     │ AND SOAP     │     │              │
│ 010          │├──────────────┤     │              │     │ COAT         │     │              │
│ RECEIVE AND  ││ 100 ZINC     │     │              │     │              │     │              │
│ CHECK ORDER  ││ STEARATE     │     └──────────────┘     └──────────────┘     └──────────────┘
└──────────────┘│ COST         │     ┌──────────────┐     ┌──────────────┐     ┌──────────────┐
┌──────────────┐└──────────────┘     │ 180          │     │ 240          │     │ 310          │
│ 020          │┌──────────────┐     │ ETCH, RINSE &│     │ TAPER AND    │     │ FINAL        │
│ RECEIVING    ││ 110          │     │ DRY          │     │ MARK BASE    │     │ INSPECT      │
│ INSPECTION   ││ IMPACT       │     │ DRAW TRIM    │     │              │     │              │
└──────────────┘└──────────────┘     └──────────────┘     └──────────────┘     └──────────────┘
┌──────────────┐┌──────────────┐     ┌──────────────┐     ┌──────────────┐     ┌──────────────┐
│ 030          ││ 120          │     │ 190          │     │ 250          │     │ 320          │
│ CUT SLUGS    ││ ACID CLEAN   │     │ ZINC         │     │ HEAD TURN    │     │ PACK AND     │
└──────────────┘└──────────────┘     │ STEARATE     │     │ AND MACHINE  │     │ SHIP         │
┌──────────────┐┌──────────────┐     │ COST         │     │ VENT HOLE    │     │              │
│ 040          ││ 130          │     └──────────────┘     └──────────────┘     └──────────────┘
│ ETCH, RINSE &││ ANNEAL       │     ┌──────────────┐     ┌──────────────┐
│ DRY          ││ CONDITION "0"│     │ 200          │     │ 260          │     ( END )
└──────────────┘└──────────────┘     │ INDENT AND   │     │ CLEAN        │
┌──────────────┐┌──────────────┐     │ HEAD         │     └──────────────┘
│ 050          ││ 140          │     └──────────────┘     ┌──────────────┐
│ ZINC         ││ ETCHH, RINSE │     ┌──────────────┐     │ 270          │
│ STEARATE     ││ & DRY        │     │ 210          │     │ SOLUTION     │
│ COAT         ││              │     │ PRE-TAPER    │     │ HEAT TREAT   │
└──────────────┘└──────────────┘     └──────────────┘     │ T-4          │
┌──────────────┐┌──────────────┐     ┌──────────────┐     └──────────────┘
│ 060          ││ 150          │     │ 215          │     ┌──────────────┐
│ PRE-FORM     ││ ZINC         │     │ TRIM AND     │     │ 280          │
└──────────────┘│ STEARATE     │     │ WASH         │     │ ARTIFICIAL   │
┌──────────────┐│ COST         │     └──────────────┘     │ AGE          │
│ 070          │└──────────────┘     ┌──────────────┐     └──────────────┘
│ ACID CLEAN   │┌──────────────┐     │ 220          │
│              ││ 160          │     │ ANNEAL       │
└──────────────┘│ DRAW         │     │ CONDITION "0"│
┌──────────────┐└──────────────┘     └──────────────┘
│ 080          │
│ ANNEAL       │
│ CONDITION "0"│
└──────────────┘
```

Figure 18
Flow chart of the AMRON aluminum cartridge case manufacturing process

Table 10
Summary of 5.56-mm aluminum cartridge case forming process at AMRON

Operation number	Description	Comments
010	Receive and check order	
020	Receiving inspection	
030	Cut slugs	
040	Etch, rinse, and dry	
050	Zinc Sterate coat	Lubricate
060	Pre-form	Forming cup
070	Acid clean	Remove lubricant
080	Anneal, "O" condition	
090	Etch, rinse, and dry	Clean after annealing
100	Zinc Sterate coat	Lubricate
110	Impact	Second cup forming operation
120	Acid clean	Remove lubricant
130	Anneal, "O" condition	
140	Etch, rinse, and dry	Clean after annealing
150	Zinc Sterate coat	Lubricate
160	Draw	
170	Acid clean	
180	Etch, rinse, and dry	Clean after annealing
190	Zinc Sterate coat	Lubricate
200	Indent and head	
210	Pre-taper	
215	Trim	
220	Anneal, "O" condition	
230	Deoxidize and soap coat	
240	Taper and mark base	
250	Head turn and drill primer vent hole	
260	Clean	
270	Heat treat – T4 condition	
280	Artificial age T76 condition	
290	Mouth over-age (if required)	
300	Anodize	
310	Final inspection	
320	Pack and ship	

Cartridge case raw stock can come in either bar or wire (coiled lengths of bar) form. Since A97475 is more typically a sheet alloy, neither the wire nor the bar forms are commonly available. Additionally, since this project required only a limited number of cases, the amount of stock needed was small. Therefore, to make parts, a larger diameter bar stock than necessary was purchased and was turned down to the correct size and then cut to length.

Following cutting, the blanks were annealed to the "O" condition. For more information, the heat treatment of aluminum alloys is described in AMS 2770, "Heat Treatment of Wrought Aluminum Alloy Parts." The full anneal and in process anneal soak temperature and time was 399 to 427°C (750 to 800°F) for 2 hrs.

After the first annealing and after all subsequent in-process thermal treatments, the parts being worked were de-smutted, and if a forming step was to follow, they were lubricated. De-smutting is the chemical removal of the aluminum oxide formed at elevated temperatures. This involved etching, rinsing, and drying the parts being worked. During most of the forming process, lubrication of working pieces consisted of dipping them into a solution of zinc Sterate

and water and allowing the resulting coating to dry. Additionally, if the lubricant were left on the work piece during an anneal cycle, the coating would burn and become a hard to remove layer, all parts were chemically cleaned before each thermal treatment.

Lubricated slugs were next impact formed into a cup shape in two steps (fig. 19). The first impact hit created a shallow cup on one end of the slug, which was then called a pre-form (operation 060). The pre-form was then cleaned, annealed for a second time and then re-lubricated (operations 070, 080, 090, and 100). The second impact-forming step increased the length of the cup to nearly its final length (operation 110). This was again followed with cleaning (operation 120), annealing (operation 130), de-smutting (operation 140), and lubrication (operation 150).

A single drawing operation followed the impact forming steps (operation 160). The purpose of this step was to extend the length of the formed cup to approximately its final length. After drawing, the working part was cleaned to remove the zinc sterate (operation 170), and then trimmed to length. This piece was then etched, rinsed, and dried prior to being lubricated (operations 180 and 190). Operation 200 headed and formed the primer pocket in the work piece. The primer vent hole was not pierced during this step, but in production opening the primer vent hole would probably occur when the pocket was formed.

Two tapering steps followed heading. Operation 210 pre-tapered the cartridge case mouth by creating a slight reduction in diameter at its mouth. The work piece was then cleaned and trimmed (operation 215). Trimming adjusted the length of the part and washing prepared it for annealing (operation 220).

Following annealing, the pre-tapered case was cleaned and lubricated (operation 230) for the final tapering operation (operation 240). The lubricant for this, unlike other operations, is soap. During the development of the manufacturing process, this step caused the most problems. The observed problems were mostly due to the completed case not fitting into a receiver gage.

Forming the final taper, finished the forward end of the case and all that remained was to turn the head, pierce the vent hole, precipitation harden the aluminum, and then anodize. Head turning and piercing were done at one time as operation 250. Since only a limited number of parts are being made, the vent hole was machined into the head rather than pierced. At the conclusion of this operation, the cartridge case was in its final shape and size. Figures 19 and 20 show the cartridge case form as it progresses through the manufacturing process.

SLUG   PRE-FORM   IMPACT   DRAW   HEAD   PRE-TAPER   TAPER   HEAD TURN   FINAL

5.56MM ALUMINUM CARTRIDGE CASE
MANUFACTURING OPERATIONS
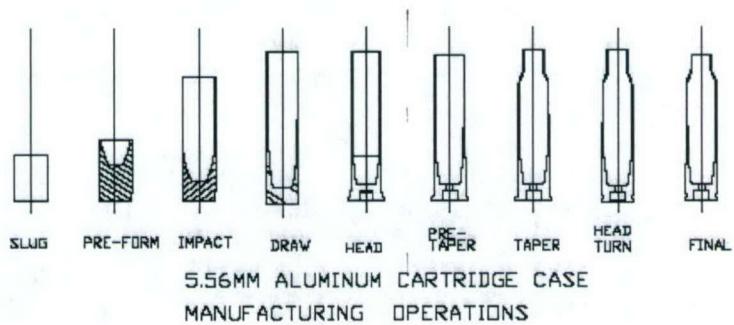
Figure 19
Cross-sectional views of major manufacturing steps

Figure 20
Photograph of cartridge case forms

Mechanical properties were achieved by first solution treating and then precipitation hardening the cartridge cases. Solution treatment of A97475 requires soaks at two different temperatures. Initially, parts were held at 471°C (870°F) for approximately 25 min. Next the temperature was increased to 513°C (917°F) and held for 60 min, which was followed by quenching. Precipitation hardening was also a two-step process. In the first stage of aging, cases were soaked at 121°C (250°F) for 3 to 5 hrs to create a T4 condition. Next, to achieve the final T76 condition, the cases were held at 163°C (325°F) for 12 to 18 hrs. AMRON chose to break this process into two operations. The solution treating and aging to the T4 condition was operation 270, and the precipitation hardening of cases to the T76 condition was operation 280. Following hardening, the cases are anodized in accordance with MIL-A-2550 Type II Class 2.

During the manufacture of the test cases, the most significant problem observed concerned the final taper operation. The current drawing specifies the diameter at the aft edge of the taper as being for reference. Gages at ATK LCSCAC were set for this diameter to be at a minimum.

During manufacture of these cases, the parts were at the maximum diameter, which resulted in them not fitting in the gage.

Although the forming operations for the aluminum cartridge case are similar to the brass case, there is a significantly longer processing time for both the precipitation hardening and anodizing steps. Not counting heat-up and cool-down, solution treatment and precipitation hardening of aluminum cases will take at from 17 to 25 hrs. Since, the precipitation hardening cannot be sped up, if not anticipated by planning, this step will slow the production line down. A similar situation exists with anodizing.

Internal Coating Process

The phase 2 internal cartridge case coating development involved identifying methods of applying either a polysulfide or silicone coating to the interior of a cartridge case. Conceptually, several coating methods could have been used. Those considered included spraying, injecting, and then using gravity to pull the liquid coating material over the case interior and blow molding. Because of time constraints, spraying and the injection methods were used.

Several manufacturers of spray coating equipment were contacted for information and assistance in developing a process for coating the cartridge case interior. Of these companies, Spraymation of Ft. Lauderdale, Florida was the most helpful.

After an initial telephone contact, a meeting was held on 26 May 2004 between Spraymation and ATK OGS personnel. The meeting began with a summary of the project and its goals and a summary of Spraymation's capabilities. Next, the process for applying a coating to the interior of cartridge cases was discussed. Spraymation stated that their company manufactures spray equipment for a similar sized application in the medical industry. He thought that it was possible that the cartridge cases could use comparable equipment. Two alternatives were discussed for the coating process development. In one, Spraymation would sell a small spray system typically used for equipment evaluation and application development. The second alternative discussed was that Spraymation assist ATK in developing coating parameters and then use the small spray system to coat the 1,000 to 2,000 parts being manufactured. Spraymation stated that they could assist in determining if the silicone and polysulfide materials could be sprayed and parameter identification and that this would best be done between 13 and 25 June 2004. ATK would supply the required materials to Spraymation's plant in Ft. Lauderdale.

The following materials were sent to Spraymation in early June 2004.

- PPG Aerospace PRC 1440LS (polysulfide – Parts A and B)

- Dow Silastic 99-007 silicone

- Methyl ethyl ketone (MEK) for thinning the polysulfide (drop shipped from Fisher Scientific)

- 200 brass cartridge cases (aluminum cases were not yet available)

- Clear glass tubes with stoppers of the maximum case ID

- Desoclean (used to clean over-sprayed silicone)

From 13 June and 15 July, Spraymation worked on developing polysulfide and silicone coating parameters. Their initial tests, using tubing and the Dow 99-007 silicone, had positive results. The coating material successfully flowed through the spray head, although the coverage was inconsistent, three applications were required for a uniform coating. In a second attempt at applying the coating, they increased the fluid pressure and lengthened the fluid tip. This resulted in more consistent results inside glass tubes.

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Component	Test 2	Test 3	Comments
Coating	Silicone	Silicone	
Glass tube	1 ½ x 7/16	2 in. length x 7/16 diameter	
Nozzle	Extended internal mix coaxial	Extended internal mix coaxial	
Fluid orifice	0.030 0.082 OD	0.030 0.082 OD	
Air cap	390418-14-1500	390418-14-2250	Longer than earlier
Fluid tip	390417-18-1500	390417-18-2250	-2550 is longer
Tube rotation	600 rpm	600 rpm	
Fluid pressure	10 psi	40 psi	
Atomizing air	12 psi	20 psi	
Fluid time on shot		400 ms (four revolutions)	
Tip angle	15 deg	15 deg	
On time		400 ms	
Indexing per cycle	0.2 in.	0.3 in.	

After completing the silicone spray tests, Spraymation applied PRC-Desoto PR-1440LS (polysulfide) to the interior of glass tubes. Their initial observation about the polysulfide was that it appeared very thick, and Spraymation questioned whether it could be sprayed. Conversations with a PRC engineer indicated that the 1440LS is a material normally used to coat gas tank interior surfaces, which is an application that requires it to be self-leveling. For the 1440LS to be self-leveling, PRC blends it to have approximately 90% solids. For spraying, this specific polysulfide needs to be thinned with MEK.

The coating trial began with preparation of the polysulfide material. First, Spraymation mixed equal parts by volume of MEK and the part A component of the polysulfide. Next, they added the catalyst (part B), 10 % by volume and mixed again.

Initially, Spraymation began with the settings used for the silicone. They observed excellent coverage, although there was some blowback in the tube and overspray slowly accumulating in the tube bottoms. Next, they attempted to reduce the blowback and over spray by decreasing the air pressure to 30 lbs. At this lower pressure, the coating was still good. After making two more spray parameter adjustments, they noted that the polysulfide in the pot had thickened significantly, and they stopped the tests.

Overall, Spraymation's opinion was that both materials could be sprayed inside cartridge cases, and that their equipment was capable of applying the coatings. They did have concerns about the orientation of the cases during spraying and with the MEK.

Due to the length of time it took to complete the Spraymation tests and to obtain cartridge cases, a backup coating system was prepared. Essentially, it consisted of injecting or dropping, the uncured coating material into a cartridge case and then inserting the case into a fixture that allowed both rotation and gravity to spread the coating over the ID. All parts were rotated approximately 1 hr, at which point they were essentially tack free. Next, they were placed in a convection oven, which accelerated the final curing of the polymer. As with the Spraymation process, good coverage was observed.

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Testing

A detailed test plan was developed for this program and has undergone some modifications due to ongoing customer discussions and schedule requirements. Table 11 shows the final version of the test matrix. Each of the tests conducted in this program is discussed individually in the following sections.

Table 11
Aluminum cartridge test matrix

Item	Test	MIL-C-63898 paragraph	Pilot lot quantity	Deliverable lot quantity	Comment
1	Workmanship	3.18	~100	1,000	All works visually inspected for workmanship.
2	Cartridge, component parts, and materials	3.1 - 3.2	~100	1,000	Excluding hardness, non-destructive tests only
3	Bullet extraction	3.3	N/A	50	Will use coated cases that fail gaging for length
4	Waterproofness	3.4	N/A	50	

5	Charge establishment testing
	    Uncoated 1
	    Uncoated 2
	    Coated - silicone
			15
			25
			14
				N/A	WC844 propellant
					WC845S6371, lot 73 and
					SMP745x6367

6	Initial M16 compatibility (F&C)
	    Uncoated
	    Coated – silicone
		----	14
			N/A
				N/A
				N/A
					Ambient only, five single shot and three round bursts

7	Initial M249 compatibility (F&C)
	    Uncoated
	    Coated – silicone
		----	11
			N/A
				N/A
				N/A
					Ambient only rounds linked with brass cases in a 50-round belt

8	Velocity, chamber pressure, port pressure, action time, temperature stability	3.6 – 3.8, 3.10, 3.15	N/A	60	Test (20) each at hot, ambient, and cold conditioning
9	Accuracy	3.11	N/A	90	Test at 600 rds with brass control rounds
10	Case strain evaluation		N/A	5	• Use laser mic to measure diameters at specific lengths • Use acceptable weapons only for this test • Includes weapon strain testing • Ambient conditioning only
11	Function and casualty	3.12	----	90 20 200	• Ambient, M16A3 • Ambient, M249, rounds mixed with brass cases • Ambient, M249, complete belt fired out in burst

12	Coating trials
	    Silicone
	    Polysulfide
		----	20
			20
				N/A
				N/A
					Lab tests to develop coating application method

13	Compatibility
	    Silicone
	    Polysulfice
		----	----
			---- 	
				N/A	Polysulfide found to not be compatible

	Total tests		119	575	

Charge Establishment Test 1

The first testing of the aluminum cartridge case was a charge establishment test that was conducted using the M855 WC844 production propellant. The purpose of this test was to verify the ballistics that the production propellant would yield. It was anticipated that the pressures achieved would be too low for adequately evaluating the aluminum cartridge case.

However, it turned out that suitable chamber pressures could be reached. The velocity did not meet the specification requirement, but it was not expected to and since it does not affect cartridge case performance, this was acceptable. However, the port pressures for this propellant was either too low or at the low limit. This was cause for concern because without adequate port pressure, the M16 and M249 automatic weapons would not operate properly. The ballistic results are summarized in table 12 and the velocity versus charge weight graph is shown in figure 21.
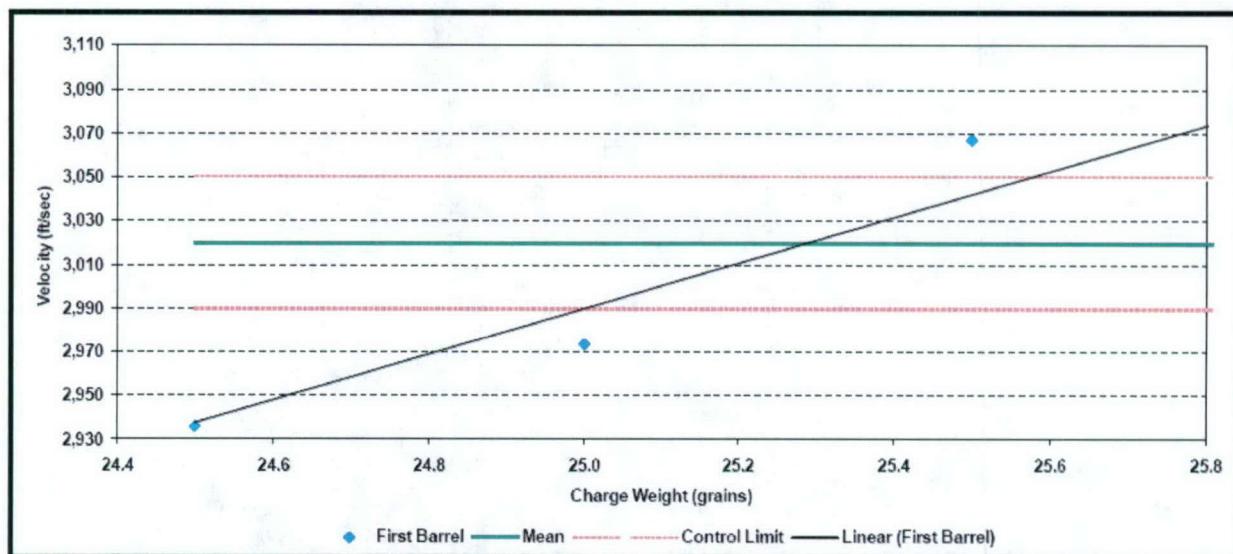

Figure 21
First charge establishment test muzzle velocity versus charge weight

The cases used in this test represented the first samples that came off the AMRON tooling. During the inspection of these cases, it was determined that while they were close too meeting all of the dimensional requirements, they did not conform to the external profile gage although they were close enough that they would fit into a Mann barrel. As a result of this and in order to test fire the cases, they needed to be hand loaded because they could not be run through the production equipment. The major drawback of the hand loading operation was that the case head could not be ring staked around the primer. During the testing of these cases some primer leaks were observed. It was felt that while the staking would help resolve this issue, a primer pocket manufactured to the lower end of the diameter requirement would also be of some benefit and this information was provided to AMRON. Figure 22 shows cases without and with a primer leak along with a view of the bolt face that was eroded due to the propellant gas flow from the primer leak unit .

As a result of this test, the propellant manufacturer was contacted to determine if a more suitable "off-the-shelf" propellant was available. Such a propellant was identified and is discussed in the Charge Establishment Test 2 section.

Table 12

First charge establishment test results

WC 844 Propellant Lot OMF04F-081060
Charge Establishment for 5.56mm M855 Ball Cartridges Tested At Ambient Temperature
SMP ID WC844-208, Vendor's Charge 27.0 Grains, Airspace ± 0.0

| | | | | Barrel | | First Barrel | | | | | | | | | Second Barrel | | | | | | | | | | |
| | | | | | | Velocity | | | Chamber Pressure | | | Port | | | Barrel | | Velocity | | | Chamber Pressure | | | Port | | |
Date	Test	Case	Charge	No.	RFTD	Mean	S.D.	OK	Mean	X + 3SD	OK	Mean	X - 3SD	OK	No.	RFTD	Mean	S.D.	OK	Mean	X + 3SD	OK	Mean	X - 3SD	OK
	Maximum / Minimum Requirements					3020±20	25		55,700	62,700		16,300	16,300				3020±20	25		55,700	62,700		16,300	16,300	
7/20/04	Handload	Aluminum	26.8	124	1685	3,171		No	68,278	74,521	No	16,673	15,856	Yes											
7/20/04	Handload	Aluminum	25.5	124	1715	3,067	36	No	60,773	69,120	No	15,798	15,266	No											
7/20/04	Handload	Aluminum	25.0	123	360	2,974	29	No	56,123	66,327	No	15,703	15,047	No											
7/20/04	Handload	Aluminum	24.5	123	355	2,936	20	No	55,079	58,320	Yes	15,277	14,942	No											
6/30/04	Handload	Brass	26.5	120	1,425	3,006	10	Yes	53,546	55,649	Yes	16,888	16,463	Yes											
6/30/04	Handload	Brass	27.0	120	1,420	3,055	12	No	56,574	57,932	Yes	17,107	16,602	Yes											
6/30/04	Handload	Brass	27.5	120	1,415	3,112	9	No	59,358	62,448	No	17,283	17,058	Yes											
7/8/04	Handload	Brass	26.7	121	1,305	3,024	6	Yes	53,738	56,001	Yes	16,848	16,769	Yes	121	1,315	3,033	11	Yes	54,646	56,813	Yes	16,913	16,770	Yes
7/13/04	Preload	Brass	26.7	124	535	3,002	29	No	52,978	58,786	Yes	16,925	16,325	Yes	123	1,085	2,996	28	No	52,544	56,314	Yes	16,973	16,373	Yes
	125°F	Brass				3,051	49	Yes	57,565	4,587	Yes	17,354	429	Yes											
	-65°F	Brass				2,899	-103	Yes	47,434	-5,544	Yes	16,477	-448	Yes											

Function and Casualty					
Brass	M16A2	6442418	@ 125°F	200 Rounds -	No Defects
Brass	M16A2	6442418	@ -65°F	200 Rounds -	No Defects
Brass	M249	129184	@ 125°F	200 Rounds -	No Defects
Brass	M249	129184	@ -65°F	200 Rounds -	No Defects

| Accuracy (Brass Case)		
Horizontal	Vertical	Acceptable?
3.72	3.50	Yes
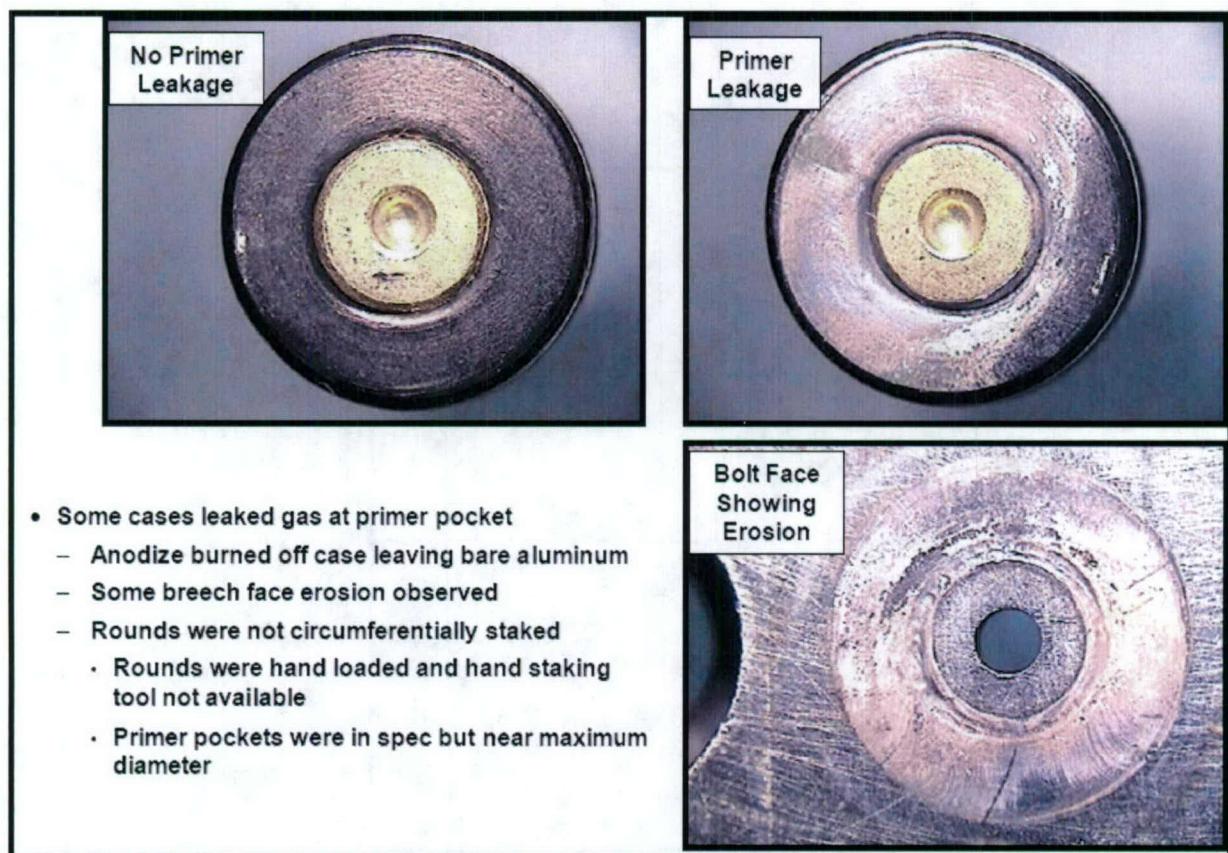
Figure 22
Charge establishment 1, primer leak detail

Charge Establishment Test 2

After the first charge establishment test, the propellant manufacturer was contacted to see if more suitable propellants were available. Three potential propellants were identified and samples received for testing. These propellants were under development for a plastic 5.56-mm cartridge case and since that case would also have a reduced internal volume, it was believed that they would be of benefit to the aluminum cartridge case effort as well.

The testing of these samples showed that they could provide the necessary pressures and still meet the muzzle velocity requirement when tested in cartridge cases without the interior coating. The next step will be to verify the ballistics in coated cases. Table 13 shows the ballistic results for the second charge establishment test. As with the first charge establishment test, these rounds were also hand loaded. The primer pockets on these cases also had a slightly reduced diameter and no primer leakage was observed except for the very high-pressure rounds. What is impressive is that even at the elevated pressures, the cartridge cases did not fail, lending more confidence to the aluminum cartridge case design. Additionally, all three formulations had higher port pressures, which will ensure adequate energy for operating the automatic weapons properly.

Table 13
Second charge establishment initial test results

Parameter	Requirement	WCR 845S x6370	WCR 845S lot 73	SMP 745X6367
Chamber pressure (psi)				
Mean	56,700	51274	55257	60491
Mean + 3SD	62,700			
Muzzle velocity (fps)				
Mean	3,000 – 3,040	3045	3051	3076
SD	<25			
Port pressure (psi)				
Mean	No Requirement	17797	17396	16418
Mean –3SD	>15,300			
Charge weight (gr)	N/A	26.7	26.1	24.8

Based on the results of these propellant formulations, the WCR845S x6370 propellant was selected to conduct the testing with and a second charge confirmation test was conducted using both coated and uncoated cases. This test showed no difference in the ballistics between coated and uncoated cases and set the charge weight at 26.6 gr. Figure 23 is a scan of the shot-by-shot test results.

Figure 23
WCR845S x 6370 charge confirmation test results

During the charge confirmation portion of this test, examination of one of the cases showed that the sidewall had a small circumferential split where the interior taper transitions. Some case wall necking in this area was observed in the initial function and casualty testing on rounds fired in the M16. Although the split did breech the wall, there appears to have been very little gas leakage or flow. This observation is based on the consistent pressure and velocity data as well as no aluminum erosion in the area of the split, although there is some discoloration of the anodize coating. Figures 22 and 25 show the split area in detail.

Figure 24
External view of localized case wall split observed

Figure 25
External view of localized case wall split observed

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Initial Weapon Compatibility Testing

An initial weapon compatibility test was conducted using uncoated cartridge cases from the pilot lot of cases. This test was done as a "quick-look" test to verify that there were no significant compatibility issues with either the M16 of M249 weapons.

The firing sequence started out with five rounds in single-shot mode from the M16 followed by three 3 rounds bursts for a total of 14 rounds fired through the weapon. All of these rounds functioned as expected with no case splits or primer leaks.

The second portion of this test consisted of firing 11 rounds through the M249. These 11 rounds were part of a 50-round belt with the other 39 rounds being standard brass cased M855 cartridges. All of these rounds also performed as expected.

Upon further examination of the spent cartridge cases, it was noticed that there was some necking occurring in the case walls. This necking was happening in the region where the interior case wall taper transitions from a relatively thick to thinner area (fig. 26). Although the cases did not split, this type of localized yielding is not desirable. Fortunately, it should be relatively easy to eliminate or greatly reduce this localized necking by slightly modifying the cartridge case in this transition area by making it more gradual through the use of a large, blended radius.

Figure 26
Sectioned view of localized case wall necking observed

Bullet Extraction Testing

Two bullet pull tests were conducted consisting of 25 rounds in each test. The difference was that one test used cases without the internal coating, while the other test used cases with the silicone coating. Both tests were run because although the excess silicone was removed from the coated cases mouths, there was always some residue left and any effects on the bullet pull values would need to be quantified. The uncoated cases had an average bullet

pull value of 121 lbs with a range of 102 lbs to 150 lbs. The coated cases had an average bullet pull of 41 lbs with a range of 18 lbs to 98 lbs. This lower bullet pull value along with the higher standard deviation indicates that the effects of the residual coating are high enough that a better method of applying the coating and cleaning up any residual material is required. Table 14 shows the bullet pull test results.

Table 14
Bullet pull test results

Sample number	Coated cases Bullet pull (lb)	Uncoated cases Bullet pull (lb)
1	32	130
2	98	118
3	20	122
4	46	116
5	18	112
6	54	150
7	28	130
8	54	118
9	36	114
10	34	114
11	40	116
12	82	120
13	44	128
14	24	116
15	36	110
16	28	120
17	24	108
18	38	132
19	40	142
20	48	126
21	24	102
22	24	112
23	32	112
24	28	126
25	96	112
Average	41	120
Maximum	98	150
Minimum	18	102
Standard deviation	22	11

Waterproofness Testing

As with the bullet pull testing, two 25-round groups of cases were evaluated for waterproofness. The waterproofing was applied using the standard M855 production equipment. The waterproofness test was then run and the results showed that nearly all of the cases leaked. In examining the pulled hardware, it was observed that the waterproofing material was not applied completely around the inside circumference of the case mouth, thus providing a leak path. Upon further investigation, it was learned that because of the small number of rounds, the equipment needed to be started and stopped continuously and this resulted in incomplete coverage of the waterproofing material, so this part of the case evaluation should be considered a no-test. Unfortunately, there was not enough time left in the period of performance on the contract to repeat this test.

Pressure, Velocity and Action Time (PVAT) Testing

The purpose of this test was to validate the ballistics across the temperature range (-65°F, +70°F, and +125°F) for the propulsion system and to show, at least in a low strain Mann barrel environment, that the cartridge case would survive. All of these cases used silicone as an interior coating. Ballistically, all of these firings went well as can be seen in figures 27 through 30. However, there was one case failure from the hot conditioned group. This failure occurred on the last shot of that group. The ballistics of this shot showed a loss of both pressure and velocity as would be expected to occur in a case failure. Examination of the breechblock showed a fair amount of erosion. Since the gun bay did not have a window, there was no data obtained in terms of any flash that may have occurred. Figures 31 through 34 show the failed cartridge case.

Laboratory examination of the failed case seems to indicate that the case was soft, which would occur if it did not see the complete heat treat cycle and therefore did not have adequate mechanical properties. The softness was discovered by the technician who observed that the sectioned failed case was difficult to polish while the sectioned control case polished up easily. Figures 35 and 36 show the sectioned failed and control cases.

M/g Eng. BAA 0410 Aluminum Case

ATK 6096 (10-24-02) ATK	5.56MM SAWS BALL M855		*SW.*
FIRING TESTS	**ROUNDS FIRED**	**RECORD**	**SPEC. LIMITS**
VELOCITY @ 78' (f.s.)			
Corrected Mean @ 70°F	20	2996	3,020 ± 40
Standard Dev. @ 70°F	/////////	18	40 Max.
+125°F Variance from Avg.	20	+ 56	-250 From
-65°F Variance from Avg.	20	- 60	Avg. at 70°F
CHAMBER PRESSURE (psi)			
Corrected Mean @ 70°F	20	48 184	58,700 Max.
Max. @ 70°F	/////////	49 930	64,700 Max.
Mean + 3 Std. Dev. @ 70°F	/////////	51 407	64,700 Max.
+125°F Variance from Avg.	20	+ 4027	± 7,000 from avg. at 70°F
-65°F Variance from Avg.	20	+ 965	or avg. not to exceed 63,700
PORT PRESSURE			
Corrected Mean @ 70°F	20	17266	/////////
Corrected Mean - 3 Std. Dev. @ 70°F	/////////	17 006	15,300 Min.
+125°F Variance from Avg.	20	-204	± 2,000 from avg. at 70°F
-65°F Variance from Avg.	20	- 818	or avg. less than 14,600
ACTION TIME*			
70°F Mean + 5 Std. Dev.	20	.821	
+125°F Mean + 5 Std. Dev.	20	.844	3.0 ms Max.
-65°F Mean + 5 Std. Dev.	20	.830	
*Fired simultaneously with Velocity using EPVAT.			

Figure 27
Summary of PVAT test firings

DEHLER System 82   04/10/07-00:05a SlowFire Mode

00:05a Comment: C:\Data\WED-90.DAT
        Lot Number: BAA 0400   Gunner: WHITEHURST
                Cal: 5.56 M855 BL   C.P. Gauge#: 1064562
               BBL#: VP-SAWS-133   P.P. Gauge#: 1288776
               Rec#: 47247   Time In: 4:30 PM 10-6-
               H.S.: 1.499   Time Fired: 1:35 AM 10-7-
               Bay#: 3   ROB: 2570
ALUMINUM CASE/MFG. ENG. V&P AMB TEST

Round	-564 9808 1-P-Max-	34 100.000 1-Vel/TA	-142 9962 2-P-Max-	2-T-Pt--
1	46894	2988	17105	768
2	49930	3018	17349	746
3	49243	3006	17284	745
4	46090	2964	17374	794
5	48025	2995	17259	763
6	46720	2973	17334	768
7	49266	3022	17404	750
8	47179	2981	17184	768
9	48437	3003	17344	755
10	47863	2992	17304	751
11	47865	2985	17389	752
12	48385	3001	17179	742
13	48456	2999	17272	740
14	47770	2990	17264	748
15	49052	3014	17172	759
16	48476	2995	17219	769
17	48885	3003	17217	758
18	48711	3010	17269	735
19	46603	2960	17294	761
20	49827	3027	17112	7465

20 Valid Rounds

Mean	48184	2996	17266	756
Std Dev	1074	18	87	13
Max	49930	3027	17404	794
Min	46090	2960	17105	735
Range	3840	67	299	58
Mean+3S	51407	3050	17527	796
Mean-3S	44961	2942	17006	716

00:16a Comment: C:\Data\WED-90.DAT

Figure 28
Ambient (+70°F) shot by shot PVAT test firings

40

OEHLER System 82   04/10/07-01:02a SlowFire Mode

01:02a Comment: C:\Data\WED-92.DAT
        Lot Number: BAA 0400   Gunner: WHITEHURST
              Cal: 5.56 Me55 BL   C.P. Gauge#: 1084562
             BBL#: VP-SAW5-133   P.P. Gauge#: 1288776
             Rec#: 47247   Time In: 1:35 AM 10-
             H.S.: 1.499   Time Fired: 2:30 AM 10-
             Bay#: 3   ROB: 2610
-65 TEST

	-564 9808	34 100.000	-142 9962	
Round	1-P-Max-	1-Vel/TA	2-P-Max-	2-T-Pk--
1	49057	2957	16803	746
2	49099	2931	16472	744
3	48984	2923	16330	765
4	49256	2940	16517	739
5	46446	2880	16193	762
6	51399	2963	16255	731
7	48599	2919	16569	746
8	48790	2928	16529	764
9	46914	2887	16363	769
10	50602	2942	16233	730
11	57951	3115	17214	704
12	46924	2896	16457	760
13	49677	2940	16348	733
14	49496	2944	16462	740
15	49337	2946	16480	742
16	49072	2933	16375	743
17	46034	2862	15864	767
18	45936	2883	16432	768
19	50514	2964	16422	719
20	48900	2959	16636	7396
20 Valid Rounds				
Mean	49149	2936	16448	745
Std Dev	2563	52	262	17
Max	57951	3115	17214	769
Min	45936	2862	15864	704
Range	12015	252	1350	65
Mean+3S	56837	3090	17234	798
Mean-3S	41461	2781	15662	693

01:17a Comment: C:\Data\WED-92.DAT

Figure 29
Cold (-65°F) shot by shot PVAT test firings

OEHLER System 82   04/10/07-00:21a SlowFire Mode

00:21a Comment: C:\Data\WED-91.DAT
        Lot Number: BAA 0400   Gunner: WHITEHURST
            Cal: 5.56 M855 BL   C.P. Gauge#: 1084562
           BBL#: VP-SAWS-133   P.P. Gauge#: 1288776
           Rec#: 47247   Time In: 4:30 PM 10
           H.S.: 1.499   Time Fired: 1:35 AM 1(
           Bay#: 3   RDB: 2590
+125 V&P TEST

	-564 9808	34 100,000	-142 9962	
Round	1-P-Max-	1-Vel/TA	2-P-Max-	2-T-Pk--
1	54074	3102	17448	768
2	54741	3084	16940	750
3	54069	3102	17526	745
4	52859	3083	17498	767
5	49342	3053	17438	770
6	49447	3030	17209	778
7	53365	3102	17610	757
8	53620	3090	17226	766
9	52598	3071	17057	768
10	51519	3039	17381	746
11	51754	3074	17364	746
12	53000	3100	17506	757
13	52559	3090	17553	762
14	52801	3083	17277	778
15	50582	3051	17152	746
16	53184	3080	17389	768
17	53365	3091	17436	774
18	51911	3067	17478	753
19	53292	3092	17416	762
20	46333	2554	11230	8159
20 Valid Rounds				
Mean	52211	3052	17062	764
Std Dev	1992	119	1383	16
Max	54741	3102	17610	815
Min	46333	2554	11230	745
Range	8408	548	6381	70
Mean+3S	58186	3409	21211	812
Mean-3S	46235	2695	12912	715

00:41a Comment: C:\Data\WED-91.DAT

Figure 30
Hot (+125°F) shot by shot PVAT test firings

Figure 31

Ruptured case from hot (+125°F) shot 20

Figure 32
Growth in external diameter of case from hot (+125°F) shot 20

Figure 33
Failed case from hot (+125°F) shot 20, primer area

Figure 34
Circumferential failure of case from hot (+125°F) shot 20
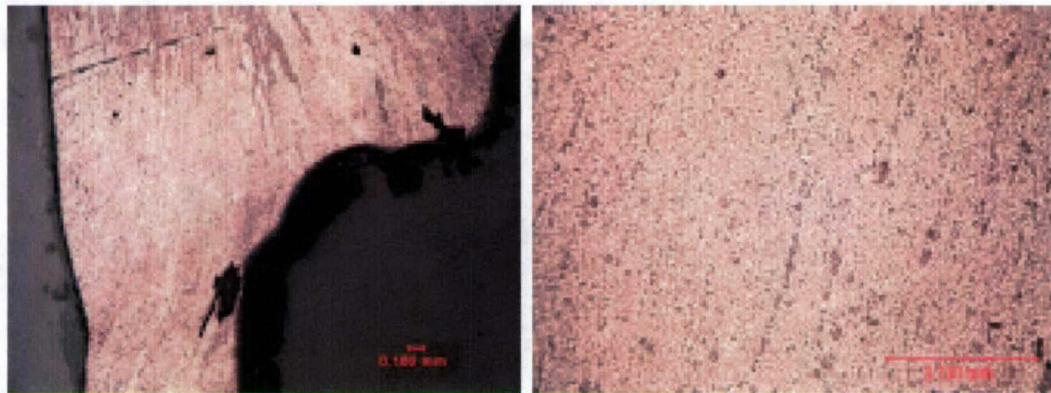
Figure 35
Failed case micro examination
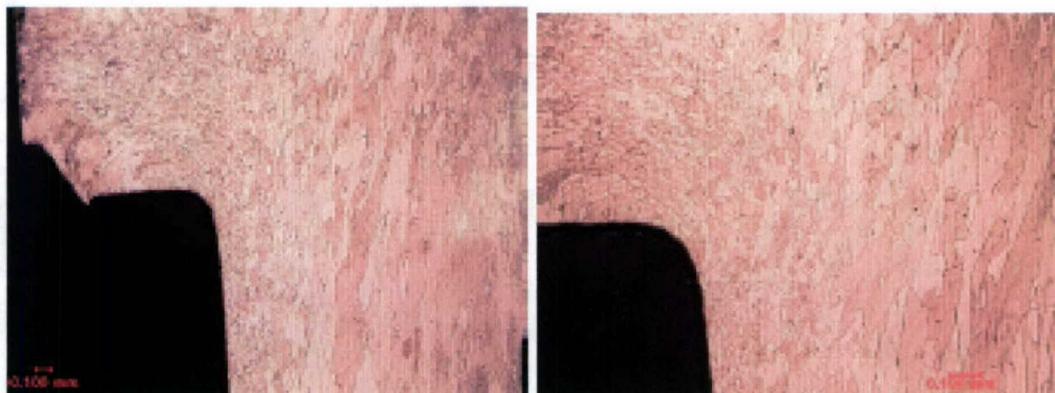
Figure 36
Control (unfired) case micro examination

Accuracy Testing

Accuracy testing of the aluminum cartridge case was conducted per the current M855 specification. Three 30 round groups were fired at a range of 600 yards from an M700 rifle. The results of this test were excellent with all groups meeting the current M855 accuracy requirement. Figure 37 shows the group-by-group results for this test.

```
                          ACCURACY TEST
──────────────────────────────────────────────────────────────────

            Test #: PROCESS                Cartridge Type: M855

            Date Produced: 10/06/04      Shift Produced:

    Primer Lot:                  Gunner: KEY            Plotter: MITCHELL

    Powder Type: WCR845       Powder Lot: X6370      Powder Charge: 26.6

    Range #: 4A   Range Length: 600    Wind Vel: 2-3    Wind Direction: 120

    General Condition: DARK                 Barometric Pressure:

    Remarks:
       H&V=6.3        PROJECT # BAA0400   J02.10401.04

──────────────────────────────────────────────────────────────────

                         No            Horz  Vert
    Unit    Arm          Rds   Mean    Stand Stand  Ext   Ext   Ext
    No      No    RFTD   Fired Radius  Dev   Dev    Vert  Horz  Sprd
──────────────────────────────────────────────────────────────────

            107   2395    30   5.79    5.29  4.07  14.30 20.80 22.15

            736   2575    30   7.48    6.20  6.05  27.95 27.30 28.40

            759   1735    30   5.76    3.88  5.30  21.35 15.80 22.35


    AVERAGE                    6.35    5.12  5.14




    FOREMAN                              Thu  Oct 07 2004  08:06 PM
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Figure 37
Accuracy test results

Case Strain Evaluation

Five aluminum cartridge cases were measured before and after firing to identify the amount of plastic deformation in the cases. This was done by measuring the case diameter at 13 locations from the base of the case before and after firing. The cartridges were fired in a strain gaged AR15 weapon. Of the five cases tested, two experienced a circumferential failure. As expected, the cases showed a growth in the external diameter. The amount of this growth was up to almost 0.007 in. on one of the cases. The results are shown in table 15.

The weapon strain gage results were very consistent for the cases that did not fail. For comparison, three brass cases were also fired in the strain-gaged weapon. These results are shown in figures 38 through 40.

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Table 15
Aluminum case dimensional analysis

Position on Case from Base (in)	Case 24 OD Before (in)	h-s 1.4972 OD After (in)	Difference (in)	Case 49 OD Before (in)	h-s 1.4973 OD After (in)	Difference (in)	Case 57 OD Before (in)	h-s 1.4955 OD After (in)	Difference (in)	Case 32 OD Before (in)	h-s 1.4977 No Data OD After (in)	Complete Rupture Difference (in)	Case 38 OD Before (in)	h-s 1.4979 No Data OD After (in)	Complete Rupture Difference (in)
0.0250	0.3748	0.3748	0.0001	0.3747	0.3747	0.0000	0.3747	0.3750	0.0003	0.3760	N/A	N/A	0.3765	N/A	N/A
0.0500	0.3293	0.3292	-0.0001	0.3295	0.3293	-0.0002	0.3296	0.3295	-0.0001	0.3317	N/A	N/A	0.3311	N/A	N/A
0.1500	0.3768	0.3771	0.0003	0.3765	0.3769	0.0003	0.3767	0.3769	0.0002	0.3770	N/A	N/A	0.3766	N/A	N/A
0.0200	0.3737	0.3744	0.0007	0.3740	0.3748	0.0008	0.3738	0.3747	0.0009	0.3747	N/A	N/A	0.3737	N/A	N/A
0.2500	0.3714	0.3744	0.0030	0.3716	0.3745	0.0029	0.3716	0.3745	0.0029	0.3719	N/A	N/A	0.3716	N/A	N/A
0.3000	0.3703	0.3753	0.0050	0.3707	0.3752	0.0045	0.3707	0.3752	0.0045	0.3709	N/A	N/A	0.3707	N/A	N/A
0.4000	0.3684	0.3745	0.0061	0.3690	0.3745	0.0054	0.3688	0.3744	0.0057	0.3691	N/A	N/A	0.3690	N/A	N/A
0.5000	0.3666	0.3730	0.0063	0.3672	0.3729	0.0057	0.3674	0.3730	0.0056	0.3671	N/A	N/A	0.3671	N/A	N/A
0.6000	0.3644	0.3708	0.0064	0.3652	0.3709	0.0057	0.3658	0.3709	0.0050	0.3654	N/A	N/A	0.3653	N/A	N/A
0.7000	0.3624	0.3685	0.0062	0.3637	0.3687	0.0050	0.3638	0.3686	0.0048	0.3634	N/A	N/A	0.3632	N/A	N/A
0.8000	0.3604	0.3667	0.0063	0.3617	0.3669	0.0051	0.3618	0.3667	0.0049	0.3616	N/A	N/A	0.3611	N/A	N/A
0.9000	0.3585	0.3651	0.0066	0.3599	0.3652	0.0053	0.3597	0.3651	0.0054	0.3598	N/A	N/A	0.3594	N/A	N/A
1.0000	0.3567	0.3630	0.0063	0.3581	0.3635	0.0054	0.3576	0.3632	0.0056	0.3579	N/A	N/A	0.3576	N/A	N/A

Test: Aluminum Case Test   3 | **Gun:** AR-15 HB Match | **Load:** 5.56MM Ball M855

Muzl to Scr1: N/A feet
Scr1 to Scr3: N/A feet
Scr4 to Scr6: N/A feet
Muzl to Trgt: N/A feet
Target Size: N/A inches
Temperature: 70 °F
Humidity: 50 %
Altitude: 498 feet
Baro Press: 29.92 in Hg
Wind Speed: 0.0 MPH
Wind Dir: 12:00 O'clock
Time Scale: 4 Msec.
Date: 10/15/2004   **Time:** 16:03

Mfg/Model: Colt
Caliber: 5.56mm
Serial #: CMH04309
Bullet Dia: 0.224 inches
Barrel Len: 20.00 inches
Gun Weight: 8.0 lb
Sight Height: 0.70 inches
Gage Factor:
Outside Dia: inches
Inside Dia: inches
Max Press: 1000 PSI
Offset Press: 40 PSI
File: Aluminum Case

Bullet Mfg: ATK
Bullet Wgt: 62.0 grains
Bullet Style: FMJBT
B.C.: 0.290 G1
Powder: WC-844
Powder Wgt: 26.0 grains
Lot Number:
Primer:
Brass:
Load OAL: 0.000 inches
Note: Aluminum Case
10/15/04

OEHLER

Aluminum Case all shot hold together

SHOT DATA

Rnd	Peak	Area	Rise
1	31	—	427
2	28	—	309
3	32	—	395
4	28	—	443
5	22	—	377

SUMMARY — Est Pressure

	Peak	Area	Rise
Avg	28	—	390
SD	4	—	52
HI	32	—	443
LO	22	—	309
ES	10	—	134

Figure 38
Aluminum case weapon strain gage data (no case rupture)

Test: Aluminum Case Test   5 | **Gun:** AR-15 HB Match | **Load:** 5.56MM Ball M855

Muzl to Scr1: N/A feet
Scr1 to Scr3: N/A feet
Scr4 to Scr6: N/A feet
Muzl to Trgt: N/A feet
Target Size: N/A inches
Temperature: 70 °F
Humidity: 50 %
Altitude: 498 feet
Baro Press: 29.92 in Hg
Wind Speed: 0.0 MPH
Wind Dir: 12:00 O'clock
Time Scale: 4 Msec.
Date: 10/15/2004   **Time:** 16:03

Mfg/Model: Colt
Caliber: 5.56mm
Serial #: CMH04309
Bullet Dia: 0.224 inches
Barrel Len: 20.00 inches
Gun Weight: 8.0 lb
Sight Height: 0.70 inches
Gage Factor:
Outside Dia: inches
Inside Dia: inches
Max Press: 1000 PSI
Offset Press: 40 PSI
File: Aluminum Case 2

Bullet Mfg: ATK
Bullet Wgt: 62.0 grains
Bullet Style: FMJBT
B.C.: 0.290 G1
Powder: WC-844
Powder Wgt: 26.0 grains
Lot Number:
Primer:
Brass:
Load OAL: 0.000 inches
Note: Aluminum Case
10/15/04

OEHLER

Aluminum Case 1st 2 complete Rupture

SHOT DATA

Rnd	Peak	Area	Rise
1	53	—	69
2	53	—	165
3	25	—	473
4	24	—	499
5	24	—	468

SUMMARY — Est Pressure

	Peak	Area	Rise
Avg	36	—	335
SD	15	—	202
HI	53	—	499
LO	24	—	69
ES	29	—	430

Figure 39
Aluminum case weapon strain gage data (case rupture)

Figure 40
Brass case weapon strain gage data

Function and Casualty Testing

Function and casualty testing was conducted from both the M16A3 and M249 weapons. The testing of the aluminum cartridge case experienced some case splits in both weapons. These case splits took the form of complete circumferential ruptures and partial ruptures. It should be noted that the complete circumferential failures that occurred in the M16A2 weapon did not have any sidewall burns indicating that there was no gas leakage. However, the failures in the M249 did have sidewall burns indicating gas leakage. At this point, it is unclear if it was the interior coating that prevented the gas leakage or if it was related to the cartridge case/ weapon interface. Because the coating was applied manually, it is likely that the consistency in the thickness was not as good as desired, nor was it as good as would be expected from an automated dispensing and coating system. Obviously more testing and analysis needs to be conducted in this area. The fact that there was not gas leakage in all of the failures is encouraging and indicates that the burn through issue can be resolved.

Additionally, there were two cases, one in each weapon, which had a sidewall perforation. It is believed that these perforations are related to contamination being introduced during the manufacturing process and can be prevented in a production environment through improved process control methods and in-process inspections. Figures 41 through 46 show the function and casualty test results.

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ATK-742 (3/01)	ATK	FUNCTION & CASUALTY
		BALLISTIC DEPARTMENT

TEST __MFG. ENG. TEST____ PROJECT # B A A - 0400 ___
CALIBER __5.56 MM__ TYPE __M855 SAWS ALUMINUM CASE__
PRIMER LOT_____ POWDER TYPE ___WCR 846___ POWDER LOT __X 6370__
POWDER CHARGE ___26.6___ L.M. NO. _____ SHIFT __DAYS_____

GUN DATA

			AMB				
TYPE OF WEAPON			M249				
GUN NO			67537				
BBL. NO.			7				
R.F.T.D. BBL.			2850				
R.F.T.D. GUN			62010				
HEADSPACE			1.497				
PIN PROTRUSION			.100MM				
BAY NO.			12				

FUNCTION AND CASUALTY DATA

MISFIRE							
HANGFIRE							
LEAKY PRIMER - LARGE							
LEAKY PRIMER - SMALL			0				
PIERCED PRIMER							
LOOSE PRIMER							
BLOWN PRIMER							
SPLIT CASE *NECK*			1				
RUPTURED CASE complete ○ partial ▢			1 1				
STRETCHED CASE							
DROPPED PRIMER							
FAILURE TO EXTRACT							
SHORT ROUND STOPPAGE							
WEAK REPORT							
CYCLIC RATE							
~~FUNCTION~~ PERFORATED CASE (body)			1				
TOTAL ROUNDS FIRED			50				

REMARKS

20 ALUMINUM 5.56mm CASES loaded As BALL M855
Mixed in 50 rd belt with 30 Regular brass case M855
Rupture is Aluminum Case

GUNNER:_____ RECORDER:_____ FOREMAN:_____

Figure 41
Function and casualty test results (M249 short burst)

ATK-742 (3/01)	ATK	FUNCTION & CASUALTY
		BALLISTIC DEPARTMENT

TEST __MFG. ENG. TEST____ PROJECT # B A A - 0400___
CALIBER __5.56 MM__ TYPE __M855 SAWS ALUMINUM CASE__
PRIMER LOT_____ POWDER TYPE____WCR 846____ POWDER LOT___X 6370__
POWDER CHARGE ___26.6___ L.M. NO. _____ SHIFT __DAYS_____

GUN DATA							
			AMB				
TYPE OF WEAPON			M249				
GUN NO.			67537				
BBL. NO.			7				
R.F.T.D. BBL.			2900				
R.F.T.D. GUN			62060				
HEADSPACE			1.497				
PIN PROTRUSION			100MM				
BAY NO.			12				

FUNCTION AND CASUALTY DATA							
MISFIRE							
HANGFIRE							
LEAKY PRIMER - LARGE							
LEAKY PRIMER - SMALL							
PIERCED PRIMER			①				
LOOSE PRIMER							
BLOWN PRIMER							
SPLIT CASE NECK			②				
RUPTURED CASE Complete ○ PARTIAL ☐			③ [3				
STRETCHED CASE			④				
DROPPED PRIMER			①				
FAILURE TO EXTRACT							
SHORT ROUND STOPPAGE							
WEAK REPORT							
CYCLIC RATE							
FUNCTION							
TOTAL ROUNDS FIRED							

REMARKS

GUNNER:_   RECORDER:_   FOREMAN:_____

Figure 42
Function and casualty test results (M249 long burst)

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ATK-742 (3/01)	**ATK**	FUNCTION & CASUALTY
		BALLISTIC DEPARTMENT

TEST __MFG. ENG. TEST____ PROJECT # B A A - 0400 ___
CALIBER __5.56 MM____ TYPE __M855 SAWS ALUMINUM CASE__
PRIMER LOT_____ POWDER TYPE ____WCR 846____ POWDER LOT___X 6370__
POWDER CHARGE ___26.6____ L.M. NO. _____ SHIFT __DAYS_____

GUN DATA

	AMB						
TYPE OF WEAPON	M16A2						
GUN NO.	6551541						
BBL. NO.	6						
R.F.T.D. BBL.	5640						
R.F.T.D. GUN	58100						
HEADSPACE	1.502						
PIN PROTRUSION	0.032						
BAY NO.	7						

FUNCTION AND CASUALTY DATA

MISFIRE							
HANGFIRE							
LEAKY PRIMER - LARGE							
LEAKY PRIMER - SMALL							
PIERCED PRIMER							
LOOSE PRIMER							
BLOWN PRIMER							
SPLIT CASE *NECK*	①						
RUPTURED CASE *Complete ☐ partial ☐*	⑨ 2						
STRETCHED CASE							
DROPPED PRIMER							
FAILURE TO EXTRACT							
SHORT ROUND STOPPAGE							
WEAK REPORT							
CYCLIC RATE							
~~FUNCTION~~ *PERFORATION*	①						
TOTAL ROUNDS FIRED	90						

REMARKS

GUNNER	RECORDER	FOREMAN:_____

Figure 43
Function and casualty test results (M16A2 short burst)

Figure 44
Function and casualty case perforation in M249
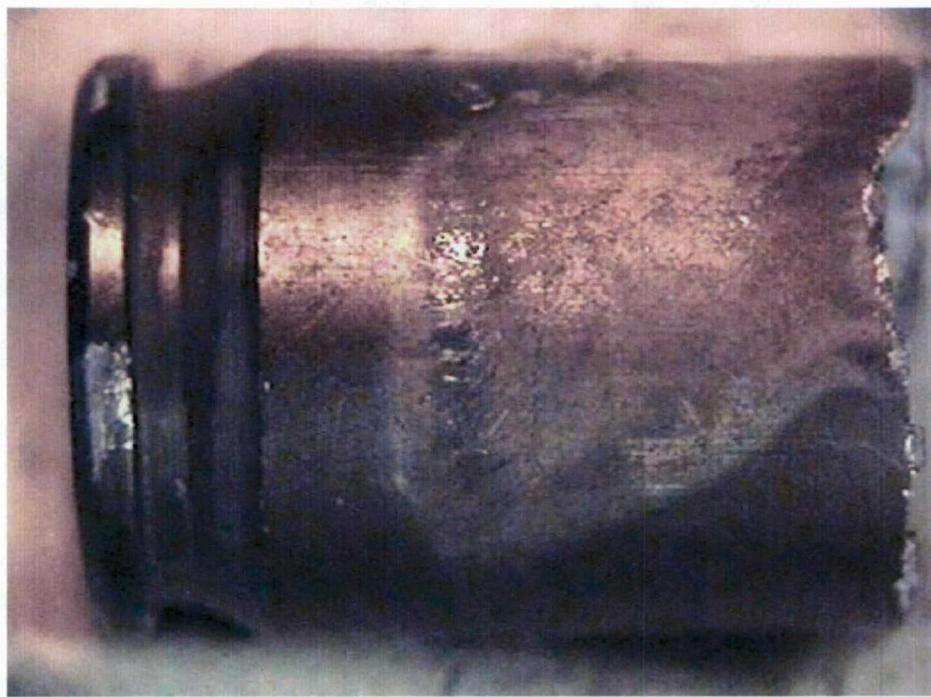
Figure 45
Function and casualty case rupture in M249

Figure 46
Function and casualty case perforation in M16

QFD Analysis

QFD is a structured method for translating customer requirements into appropriate company requirements at each stage of the product development and production cycles. It is being applied to the aluminum cartridge case program by completing the "Design Matrix" or phase I of the QFD analysis. The objective of the phase I QFD is to identify the design criteria that are the most important to meeting the customer requirements. The expected outcome is a prioritized list of design criteria that is used to make design decisions and help allocated design resources and testing. The results of this analysis were used in trading off cartridge case wall thickness, which translates to safety in the QFD analysis, against ballistic performance. Because safety was the highest priority item, the cartridge case wall thickness was increased at the expense of muzzle velocity for the cartridge case design. This analysis was begun in phase 1 of the program and completed in the first part of phase 2.

The design matrix or "House of Quality," as it is sometimes referred to, consists of different sections or rooms. Figure 47 shows the general structure of the design matrix. The results of the QFD analysis are shown in figures 48 and 49 and represent the aluminum cartridge case QFD matrix and Pareto chart of the design criteria.
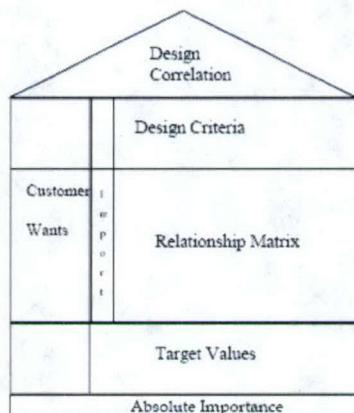
Figure 47
House of quality
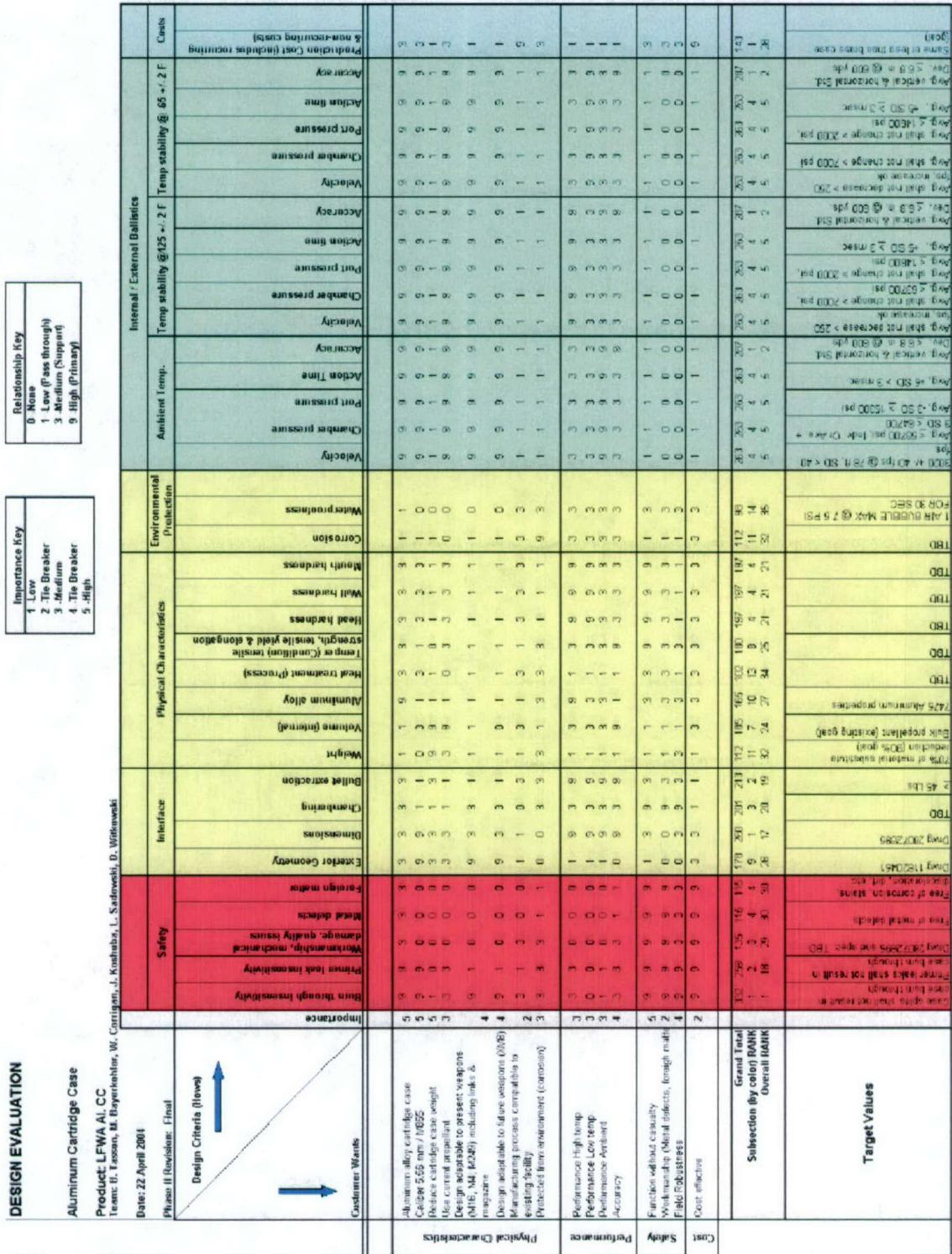
Figure 48
Aluminum cartridge case QFD matrix

55
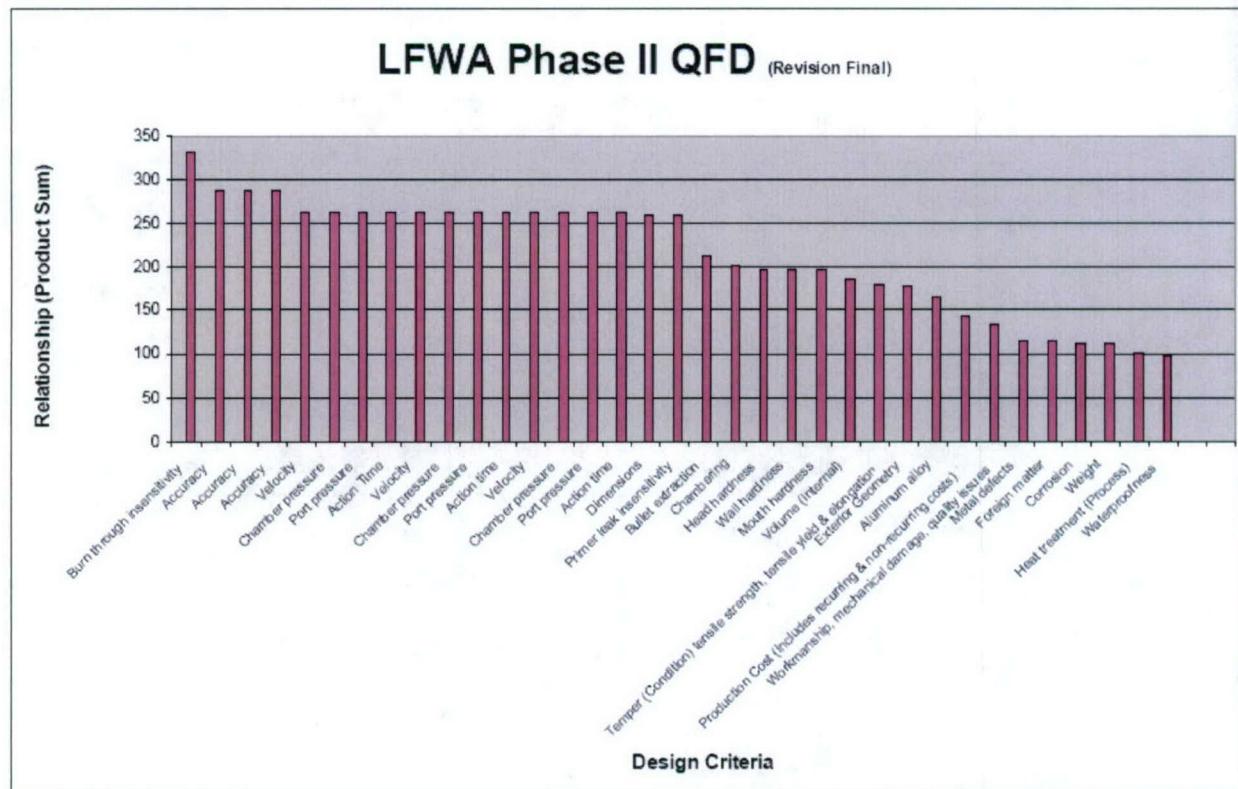
Figure 49
Pareto chart of QFD matrix

The process steps that were followed for developing the QFD matrix were as follows:

1.   A list of "customer wants" or important requirements to the customer was developed.

The customer wants were developed from the SOW and requirements/ compliance matrix, listed down the left side of the matrix and the pro- gram team reviewed the matrix.

2.   The importance for each performance criteria or customer want was established. It is important to remember that all of the customer requirements will be met, but the importance rating helps prioritize the customer require- ments.

•   The importance of each of the customer requirements was determined by using a scale of (1 to 5) with a one being a low priority, three medium priority, and five high priority. Two and four were used only to break ties.

•   In terms of a process flow, ATK initially identified the importance ratings in the matrix and they were then modified based on customer review.

3.   The design criteria are listed across the top of the matrix.

- Secondary and tertiary levels were built to help see the design criteria relationship.

- For the aluminum cartridge case effort, the secondary level of design criteria includes safety, interface, physical characteristics, environmental protection, ambient temperature, temperature stability at 125°F, temperature stability at -65°F, and cost.

- All the levels of the design criteria were reviewed by the customer and modified per consensus of the team.

4. The relationship matrix is completed by

- Determining the relationship between the design criteria (How) and the customer wants. This is done by looking at the intersecttion of each design criteria and customer want. The question the team asked is: "If the design criteria varied how would that affect meeting the customer want? A (9) indicates a strong relationship; a (3) is a moderate relationship; a (1) is a weak relationship; and (0) is no relationship exists.

5.   The absolute importance for each column or design criteria has now been calculated.

- This is a product/sum of the importance rating times the relationship value and summed for each column.

- The larger the absolute importance the more important the design criteria is to meeting the customer wants.

6.   The matrix was then diagnosed and evaluated by the team.

- At this point, all of the important design criteria have been identified and reviewed by the team. Also, all of the importance values seem to be reasonable. That is, they pass a sanity check.

7.   Prioritizing the design criteria was next completed.

- A Pareto chart (fig. 49) of the design criteria by absolute importance values was then created. The larger the absolute importance the more important the design criteria to meeting the customer wants.

- The Pareto chart indicates:

  - The three highest absolute importance values are:

    - Safety: Burn through insensitivity
    - Performance: Accuracy
    - Performance: Velocity

  - The next plateau of the Pareto would include the six design criteria that have absolute importance values between 100 and 150.

8. Establish Target Values.

   The target values or specification for each design criteria was established.

9. Finally, the design correlation matrix (roof) was completed.

   - The correlation matrix evaluates both a positive or negative correlation or interaction between design criteria. It helps the team identify design tradeoffs that must take place and is not yet completed.

   - One tradeoff has already been identified between burn through insensitivity and wall thickness. Because of the high ranking of the burn through insensitivity the wall thickness will be increased to prevent the risk of burn through at the base of the cartridge case.

UPC Analysis

A UPC analysis was conducted to verify that the aluminum cartridge case, if successful, would provide a cost effective solution as well as provide a weight savings. The initial analysis was conducted in phase 1 and was revisited in phase 2 with no changes to it identified in that the additional information obtained only tended to validate the basic assumptions used in phase 1. Because the design has not been confirmed, this analysis should be viewed as preliminary in nature. Additionally, the UPC study only examined the potential recurring costs and did not address the non-recurring cost. The study leaned heavily on comparing the baseline aluminum cartridge case against the current production brass cartridge case. This was done to provide a real world comparison and to provide a meaningful benchmark for which to ultimately determine the cost effectiveness of the design.

The current brass cartridge case is produced in essentially one operation at the Lake City Army Ammunition Plant (LCAAP) on high volume automated tooling. The process starts with a pre-form that is supplied to LCAAP by a subcontractor. This pre-form is then fed into the automated equipment and after a series of forming operations and in-line anneals; a finished cartridge case emerges from the other end of the equipment. Because the cartridge case is brass, no additional metal finishing coatings are required. For the purposes of this preliminary UPC analysis, it will be assumed that the aluminum cartridge case will be manufactured on

similar types of equipment such that the only real difference in cost will be for the material change and for the coatings, which will be both the anodize and interior burn through protection. Rough order of magnitude material costs were developed for these coatings and when all of the recurring costs are projected, it is estimated that the aluminum cartridge case will cost between 20% and 100% more than the brass cases in high volume production. The range in UPC cost is due to the wide range in the cost of the interior coating material. The UPC assumption assume that all of the coatings will be put on with the same amount of effort and this will be about a third the complexity of drawing the case. So the only difference in UPC is due to the cost of the coating material. The real cost driver will be the labor cost and that will be dependent upon the degree of automation employed in the manufacturing process.

PROGRAMMATIC DISCUSSION

Contractor Team Organization

Figure 50 shows the ACC development program contractor team and includes ATK personnel as well as the subcontractor companies. In terms of the roles of these companies, AMRON LLC was responsible for the cartridge case tooling design and manufacture as well as the fabrication of the cartridge cases necessary for testing during the program and the 1000 cartridge cases for delivery to the government at the end of the program. Arrow Tech Associates assisted ATK in the modeling effort through the use of some of their cartridge case/weapon models and was also involved in the test data analysis. Quality in Design's responsibility was to facilitate the update of the LFWA QFD analysis with respect to the aluminum cartridge case.
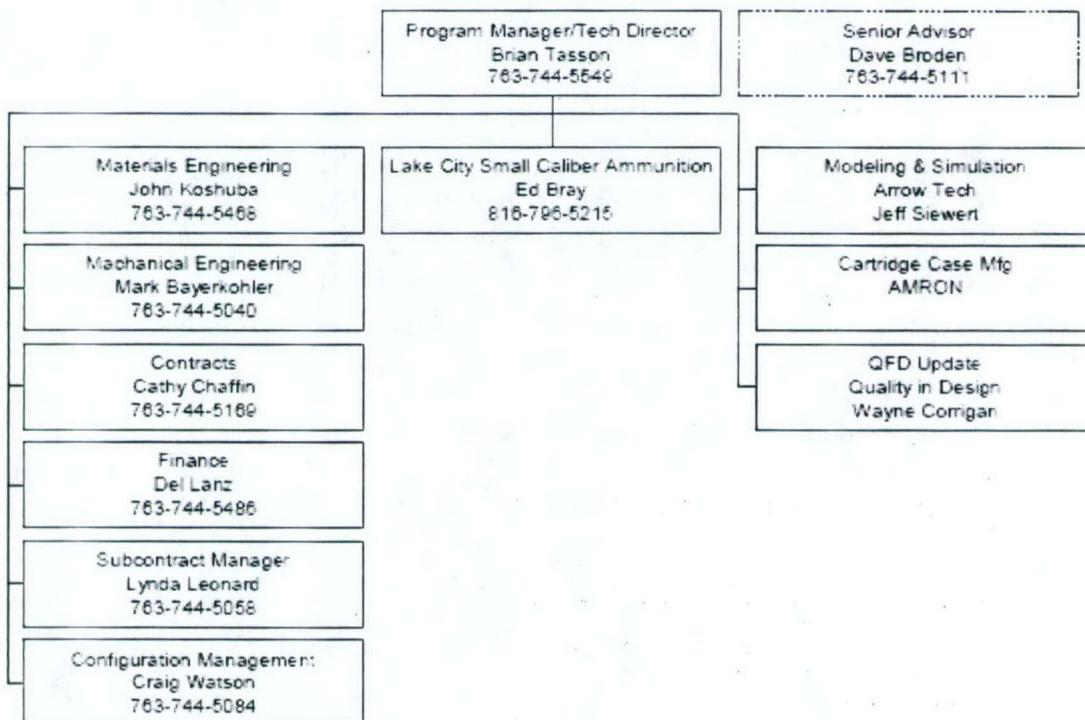
Figure 50
Aluminum cartridge case concept contractor team

CONCLUSIONS

An aluminum cartridge case was designed for the 5.56-mm M855 round for satisfactory performance in both Future and Legacy weapons. The design of the case was driven by the need for safety and as such, additional material was placed into the sidewalls at the expense of ballistic performance. This cartridge case meets the goal of a lighter case.

The testing conducted in this program has shown that the design is feasible, although the testing has also shown that some changes to the design will be necessary to improve its reliability due to the few case failures that occurred during testing.

Successful cartridge case manufacturing and cartridge case coating processes were developed. AMRON has a process for forming aluminum cartridge cases from an aluminum slug. This is a technique similar to that currently being used to manufacture brass cases. Spraymation and ATK have also demonstrated that it is possible to apply either a silicone or polysulfide coating to the inside of an aluminum case.

While a process of producing an aluminum cartridge case has been demonstrated, another alternative to cartridge brass may also be capable of a weight reduction and does not require the added protection of an internal coating. That material is steel. Steel is capable of great ductility and strength. It can be formed nearly as well as cartridge brass and aluminum. It is not limited by the low melting point nor the exothermic chemical reactions that are related to the aluminum burn-through problem. Additionally, when comparing mechanical properties, the elastic modulus of steel is higher than the modulus of either aluminum or cartridge brass. Finally, steel has a density comparable to that of copper. These characteristics can potentially combine to produce a cartridge case that is lighter because of its thinner wall, rather than lower density. The following table is a comparison of some of the properties of these materials.

Comparison of potential cartridge case materials

Characteristic	Alloy steel	Cartridge brass	Aluminum alloy
Grade	G41300	C36000	A97475
Density g/cm^3 (lb/in.^{3})	7.8 g/cm^3 (0.284)	8.53 (0.308)	2.81 (0.102)
Elastic modulus GPa (10^6 psi)	205 GPA (29)	110 (16.0)	70.3 (10.2)
Protective coating	Phosphate	None	Anodize

From a cost standpoint, the UPC analysis shows that the aluminum cartridge case will not be able to compete with its brass counterpart. However, because of its lighter weight, it will be up to the user to determine if this performance advantage is cost effective or not.

REFERENCES

1. Army BAA, DAAE3003BAA0400.

2. Miller, S., "Design, Development and Fabrication of 100,000 Cartridges, Ball, Caliber .50, M33 Type Assembled with Case, Cartridge, Aluminum, Caliber .50, FAT39," Frankford Arsenal Report No. R-1265, 1956.

3. Donnard, R. and Squire, W., "The Aluminum Cartridge Case Exploratory Development Program Status Report, Frankford Arsenal Report No. AD-901510, 1972.

4. Donnard, R.; Grandy, A.; Skochko, L.; and Squire, W., "The Aluminum Cartridge Case "Burn-through" Problem – Characteristics – Isolation and Means of Elimination," Frankford Arsenal Preliminary Technical Note.

5. Skochko, L.; Rosenbaum, M.; and Donnard, R., "Aluminum Cartridge Case Concepts Task – Work Summary, Frankford Arsenal Report R-3001, 1974.

6. Marziano, S. and Vriesen, C., "Prevention of 556mm Aluminum Cartridge Case Burn-through," Thiokol Chemical Corporation for Frankford Arsenal, Report No. FA-TN-75002, 1975.

7. Squire, W. and Donnard, R., "A Critical Assessment of the Aluminum Cartridge Case Failure Mechanism, Frankford Arsenal, Report No. FA-TR-76011, 1976.

BIBLIOGRPAHY

1. Dow Corning Product Literature for Silastic 99-007, Silastic 99-009 and Silastic 34.

2. PPG Aerospace product literature for PR 1440 LS.

3. Matweb, http://matweb.com.

4. Metals Handbook 9th Edition.

5. Aerospace Structural Materials Handbook.

6. MIL-Handbook-5.

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