Cartridge Cases & Case – Chamber Interactions

Jeff Siewert

Systems Engineer

Arrow Tech Associates, Inc.
1233 Shelburne Rd. D7

S. Burlington, VT 05403

802-865-3460 x5

jsiewert@prodas.com

Cartridge Case Analysis

- **Cartridge Cases are:**
  - "Single" use, hi pressure, disposable seal
  - Container for powder & primer
  - Typically stressed above yield for most applications
- Unlike most mechanical structures, stress > yield and "single" use mean that combined stress is not a desirable design criterion, cases would be too heavy
- Percent of ultimate strain is better choice, allows case to be appropriately designed & specified
- What interface parameters concern gun designers?

Typical Brass Case Development "Philosophy"

- **Engineering "experience" drawn from similar applications/pressures, brass is assumed to yield in operation..**
- **Use "other" cases as baseline, mod geometry**
- **Lots of "cold work" done to base to increase hardness (yield strength)**
- **Abrupt slope changes & sharp corners are avoided**
- **Gradual wall thickness taper from base to neck**

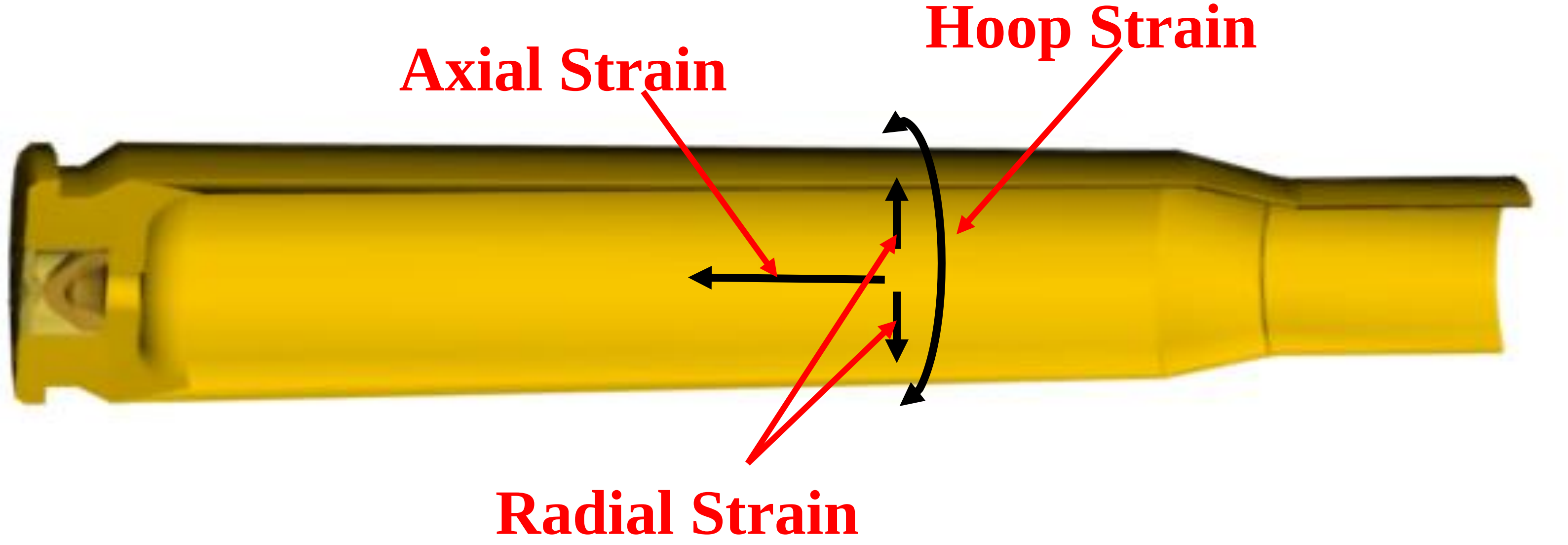
Cartridge Case Design: Problem Description

1. **Can case structurally survive in selected weapon?**
   - Is case % ultimate strain < 100% under all conditions?
     - Peak Pressure
     - Friction
     - Material
     - Gaps
     - Lock Stiffness
     - Thermal Event
2. **Is case compatible with varying weapon mechanisms?**
   - **A. Case base-bolt face load at unlock**
     - Does weapon mechanism have enough energy to unlock? (influences wpn design)
     - How much bolt movement must happen to remove residual load?
   - **B. Residual case-chamber load at start of extract**
     - Does weapon mechanism have enough energy to extract? (influences wpn design)
     - Case body taper influences distance required to remove residual load
3. **Can we minimize case mass?** (max stowed load & mfg profit, min mat'l cost)
4. **Maximize case internal volume** (max powder, MV & MV margin)

Why is Case-Chamber Analysis so Complex?

- **Multiple computational non-linearities**
  - Case material pushed above yield (typically)
  - Gaps between case & chamber/bolt face: no load until contact is made
  - Case temperature changes rapidly
  - Case-chamber friction varies w/ what's on case exterior
  - Structural forcing function varies (statistically)
  - Case can only expand until shot start is reached, then it accelerates to rear
- **Desired Output:**
  - Case survival (is percent Ultimate Strain < 100%?)
  - Peak bolt load
  - Residual load between case base & bolt face resisting unlock
  - Residual load between case & chamber wall resisting extract

Case Strain Components



- **Total strain is Vector Sum of Axial, Hoop & Radial**
- **Is total strain seen during firing < 100% of Ultimate?**
- **Where is total strain a maximum?**
- **Generally: things that are good for case are bad for gun & vice versa..**

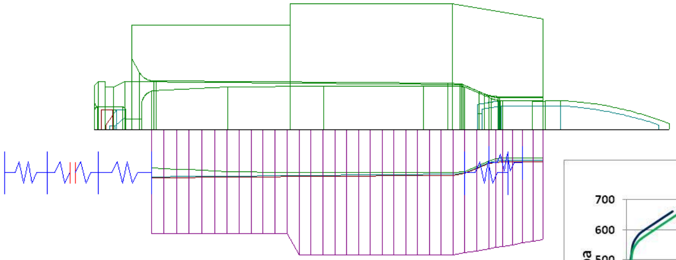
Case-Chamber Analysis History

Year	Caliber	Gun	Case Material
1984	30x173mm	GAU-8/A	Lt. Wt. Steel & Aluminum
1985-86	25x137mm	GAU-12/U	Aluminum
1986	20x102mm	M61A1	Aluminum
2001	20x102mm	M61A1	Aluminum
2001	5.56x45mm	M16/M249	Brass/Polymer
2001	40x217mm	Mk44	Steel
2001	155x1059mm	AGS	Steel
2003	5.56x45mm	M16/M249	Aluminum
2005	105x617mm	M68	Steel
2006	25x59mm	XM302	Aluminum
2007	40x51mm	Mk19	Aluminum
2007	5.56x45mm	M16/M249	Steel/Polymer
2008	12.7x99mm	XM806	Brass
2009	40x180mm	ALACV	Steel
2011	5.56x45mm	M16/M249	Brass
2015	300 Win Mag	M2010	Brass
2015	105x615mm	M68	Brass
2017	8.5x63mm	338 MMG	Brass
2019	5.56x45mm	M16/M249	Steel

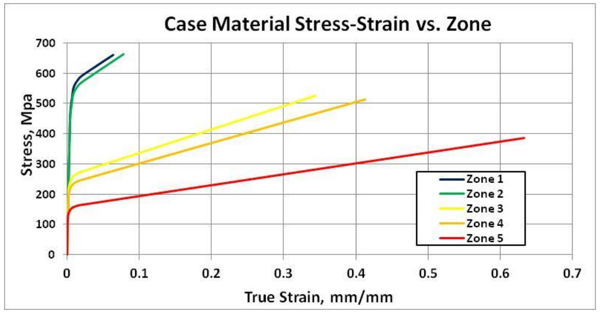
If you can’t get a bigger target...

What Info is Required?

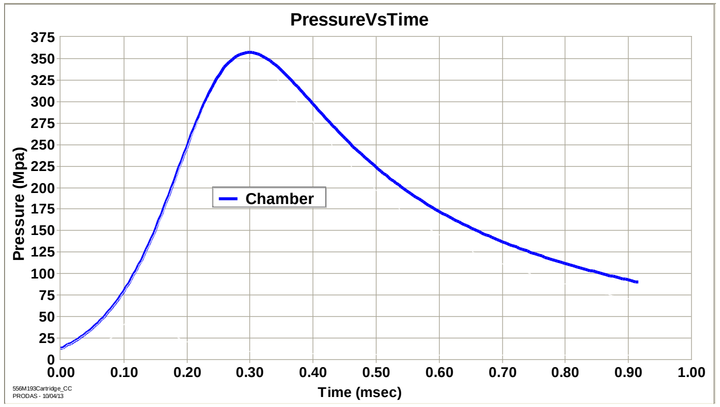
- **Geometry:**
  - Min Case & Max Chamber



- **Material Properties:**
  - Case: Stress-Strain vs Location (& Temp), Density, CTE, Diffusivity, Poisson’s Ratio
  - Chamber: Density, Modulus, Diffusivity



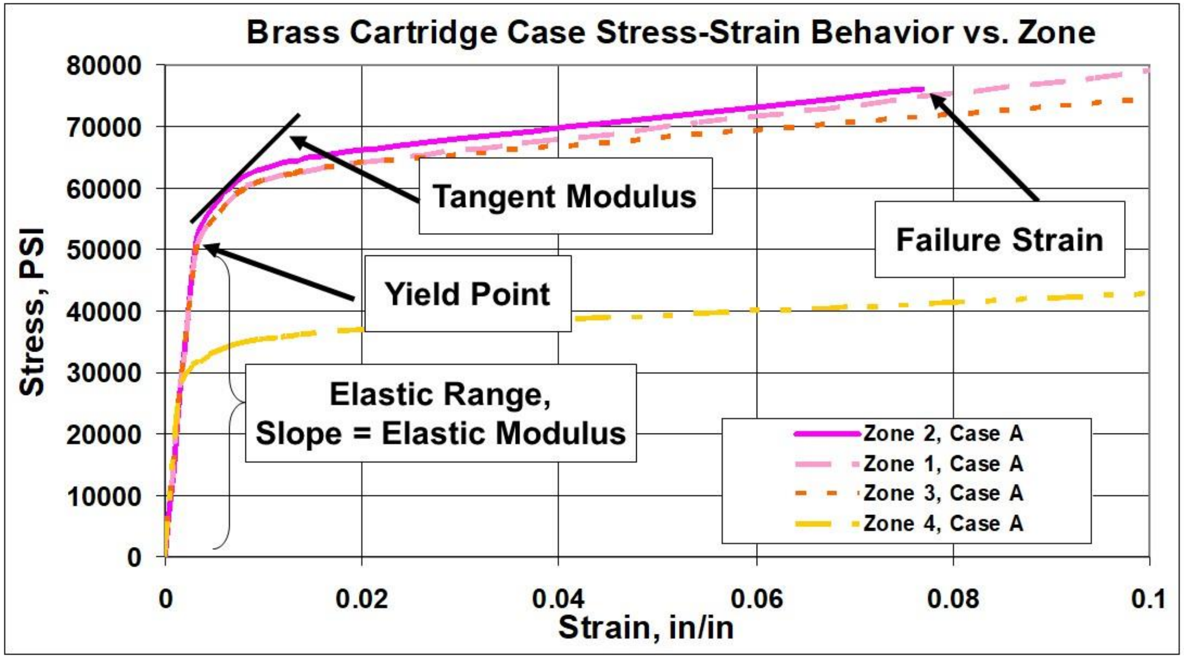
- **Structural Forcing Function:**
  - Pressure vs. Time, Case Temp vs. Time



- **Interface Parameters:**
  - Static & Dynamic Coeff. of Friction, Lock Stiffness, Case Base – Bolt Face Gaps, case base mass, case base stiffness

Info required for any case-chamber interaction analysis

Generalized Material Properties



- **Plot of "True" Stress-Strain**
- **Below yield stress, material is elastic (stress linear w/ strain)**
- **Above yield is "plastic regime"; non-linear material behavior**

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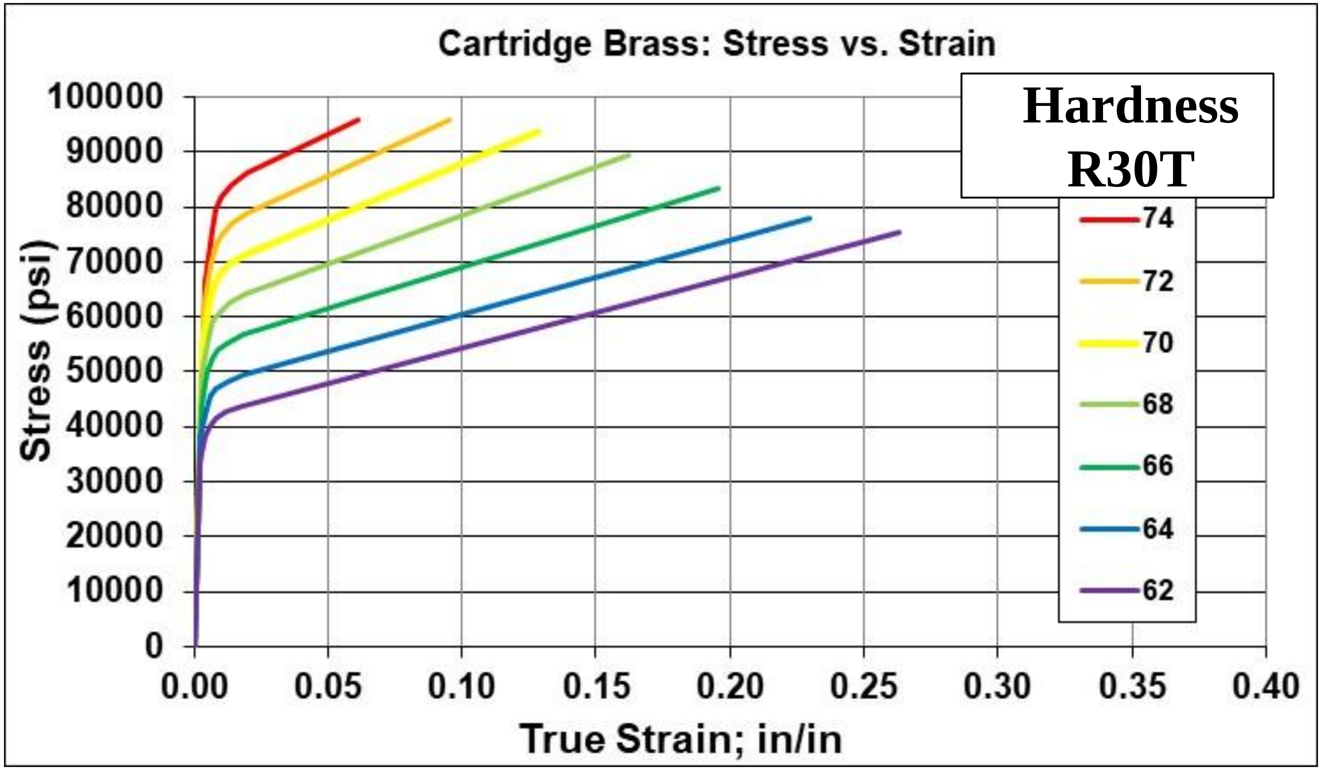
Brass Properties vs. Hardness



- **Hardness (processing) affects yield, failure stress & elongation at failure**
- **Hardness gradient along length of case combined with case wall thickness gradient provides appropriate behavior**

Phases of Case Function Cycle

1. Initial Conditions
2. Propellant Ignition
3. Pressure Load Increase
4. Elastic Recovery
5. Residual Clearance or Interference
6. Weapon Unlock
7. Case Extraction/Eject

Function – Phase I: Initial Conditions

- **Case and Chamber As-manufactured Dimensions**
- **Case and Chamber Initial Temperatures**
- **Case "Head Space" Approach**
  - **Shoulder**
  - **Rim or Belt**
  - **Case Mouth**

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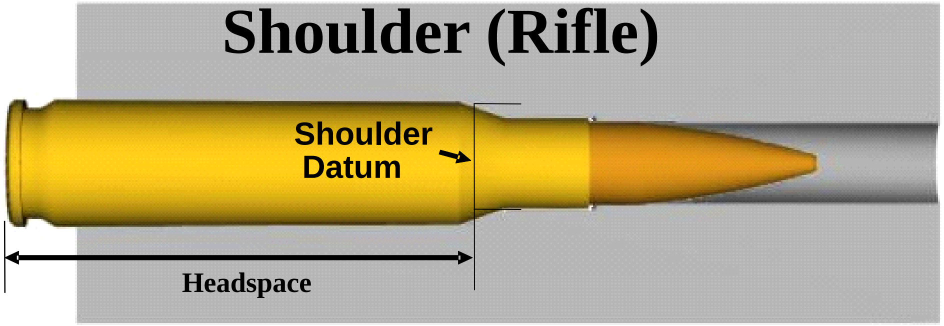
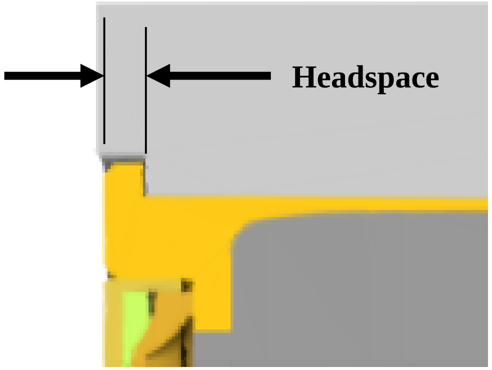
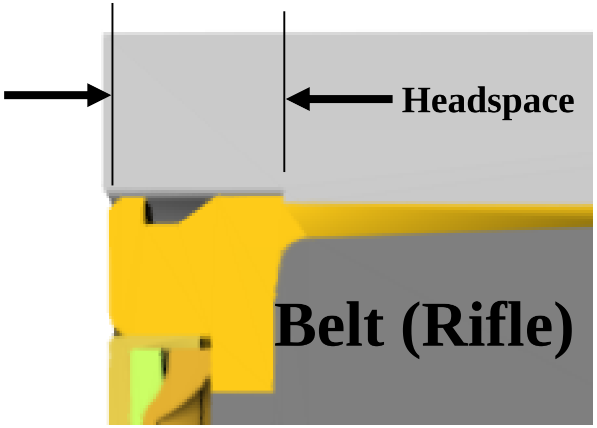
Headspace Details

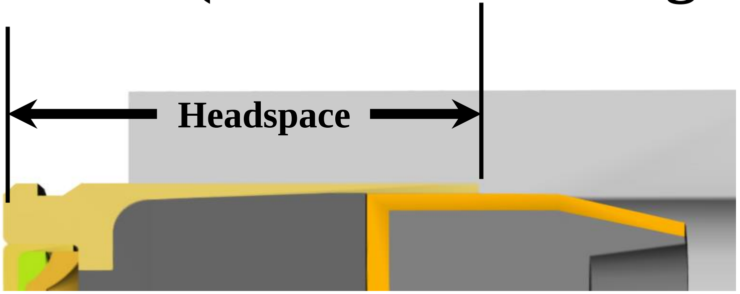

Shoulder (Rifle)



Rim (Revolver & Shotgun)



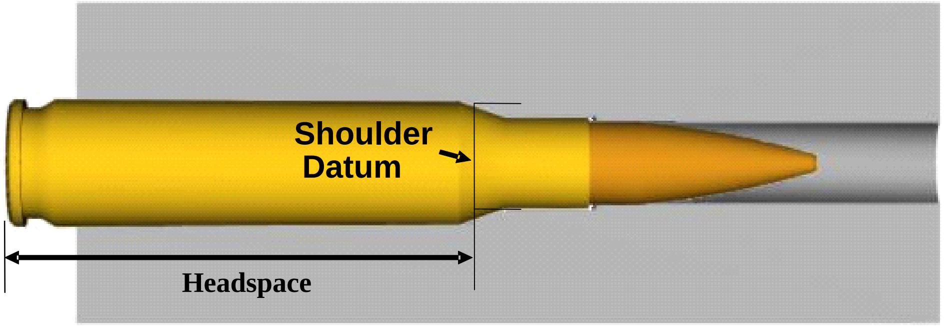
Belt (Rifle)

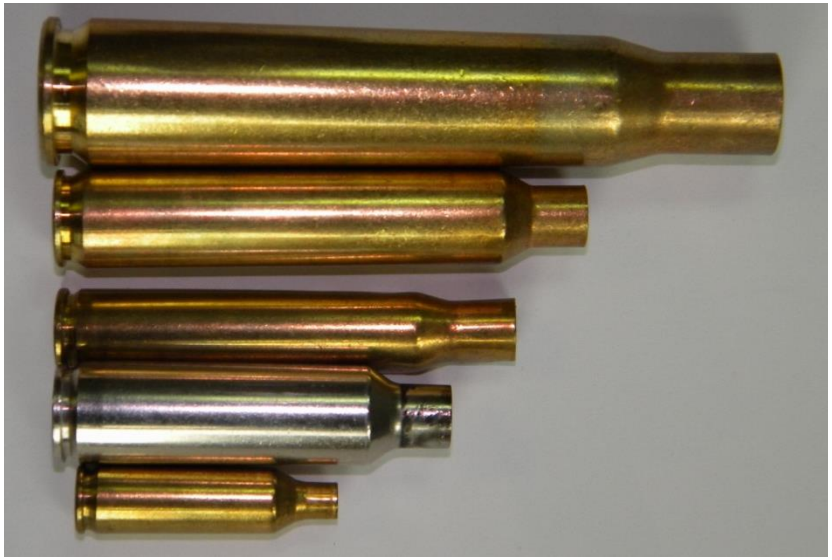


Case Mouth (Pistol)

- **Headspace selection based on gun mechanism**
- **Does spring drive case forward in chamber?**

Shoulder Headspace





50 Cal

300 RUM

30.06

300 WSM

17 Mach IV

Belt Headspace

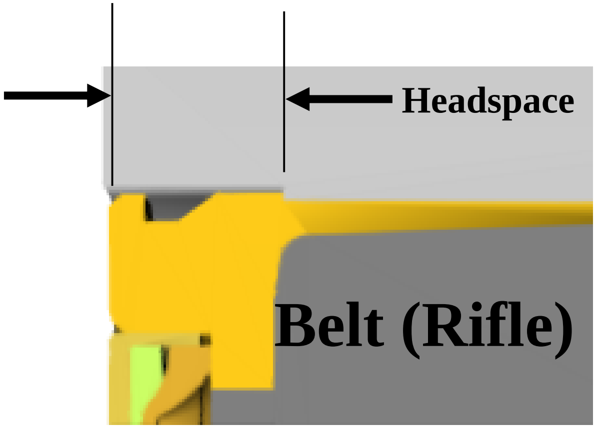
27x145mm

30x113mm

Originally Developed for use in Revolver Cannon

25x59mm

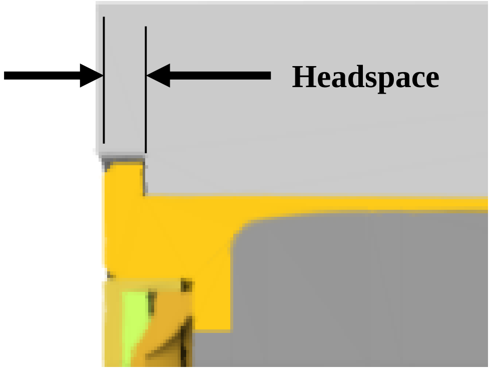
300 Win Mag



Flange or Rim Headspace

357 Magnum

22 Hornet



Rim (Revolver & Shotgun

Case Mouth Headspace

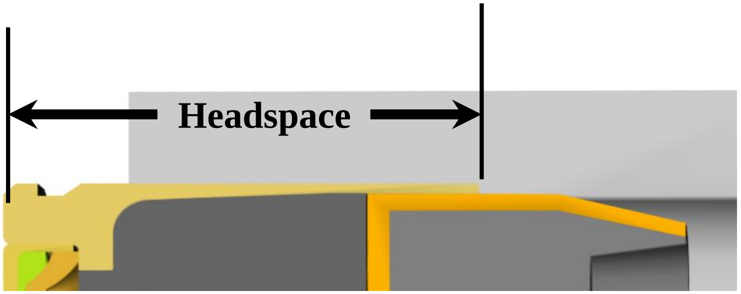
25 ACP

9x19mm

40 S&W

45 ACP

45 ACP



Case Mouth (Pistol)

Function – Phase II: Powder Ignition / Shot Start

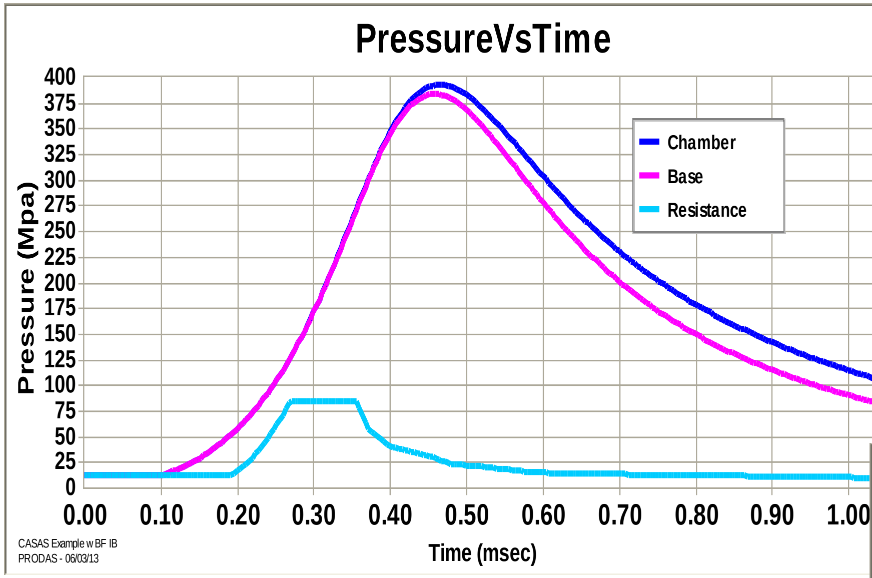
- **Case radial expansion to contact chamber**
  - **Speed of action precludes significant temperature rise in case**
  - **Case expansion continues in all directions until shot start is reached**
- **Once bullet moves from case, case accelerates aft, closes aft gap & contacts bolt face**
- **Elastic and/or plastic deformation of the case**
  - **Depends upon case/chamber radial clearance**

Function – Phase III: Pressure Load Increase

- **After case contact w/ chamber wall, case and chamber deflect radially with stiffness varying due to case plastic behavior**
- **Temperature of the case inside wall surface and internal chamber pressure peak at nearly the same time**
- **The average case temperature is relatively low**
  - **Large thermal gradient through the case wall during this phase**
- **Case avg. temp increase begins to contribute to reducing the load carried by the case**
- **Chamber reaches its maximum radial deflection**

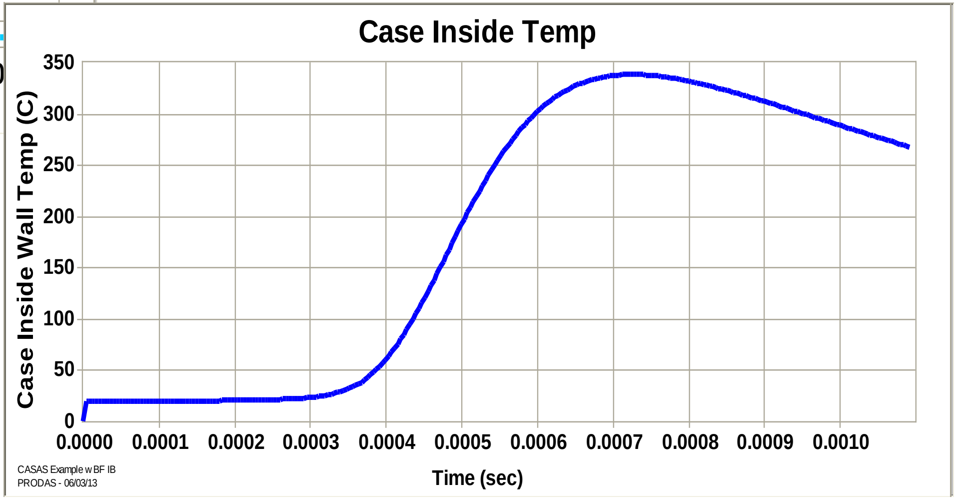
Forcing Functions

Pressure vs. Time



CASAS Example w BF IB
PRODAS - 06/03/13

Inside Case Wall Temp vs. Time



CASAS Example w BF IB
PRODAS - 06/03/13

Function – Phase IV: Elastic Recovery

- **As the case internal pressure decreases, the case and chamber move as a combined unit with each carrying a share of the applied gas pressure (thru case-chamber friction)**
  - **The case-chamber load ratio is determined by the relative loads carried at maximum radial displacement in the previous stage and the thermal expansion of the case**

- **Recovery for both the case and the chamber is elastic**

- **The addition of thermal strain at maximum load produces variable total strain through the case thickness**

- **The case mean temp. continues to increase during the early part of this phase**

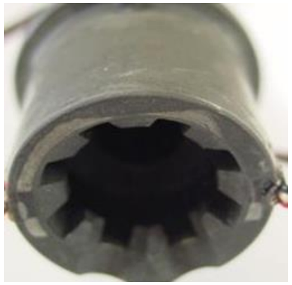
Function – Phase V: Residual Clearance/Interference

- **The gas pressure is removed completely and the breech is ready to be unlocked**
- **If the case leaves contact with the chamber, a residual case-chamber clearance will exist**
- **If the case does not leave contact with the chamber, a residual radial force will be developed between the case and chamber impeding case extraction after the bolt is unlocked**
- **Any residual load between case base & bolt face will impede unlock (gun mechanism dependent)**

Function - Phase VI, Unlock

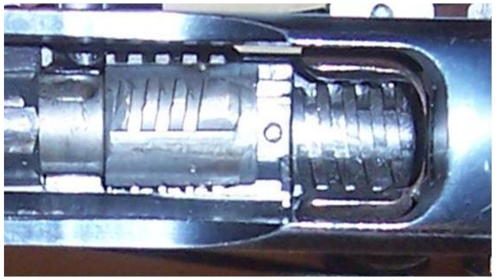
- **Residual load between case base & bolt face may impede unlock of bolt.**
- **Gun mechanism/operator requires sufficient energy to unlock bolt to allow extraction to begin.**
- **Gun mechanism influences bolt motion/energy required to unlock bolt**
- **Bolt lock design influences motion/energy required to unlock**

Bolt



Short Throw Bolt

Drop Block (Tapered?)



Interrupted Helical Lug

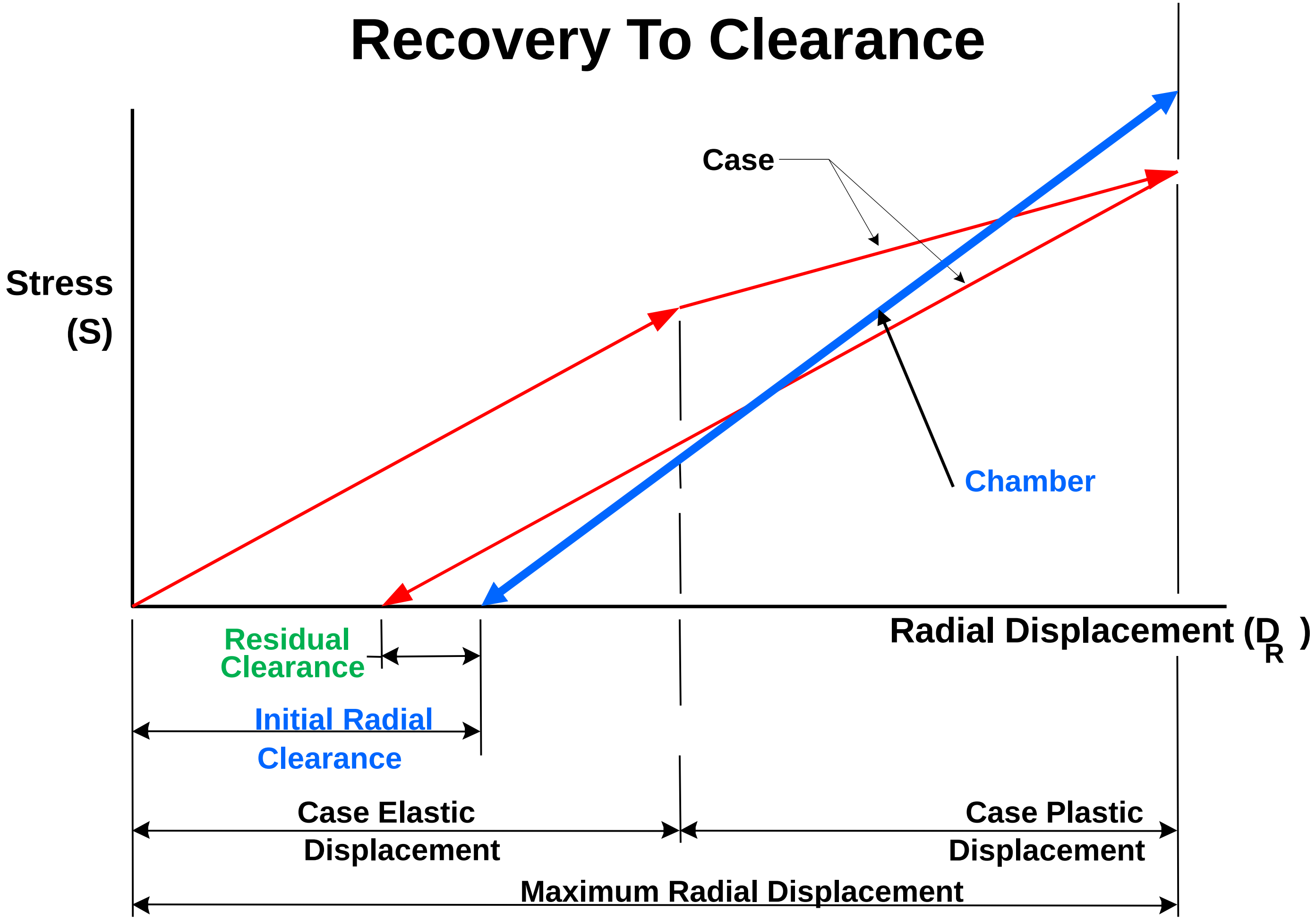
Function – Phase VI: Case Extraction

- **Where the case recovers to an interference condition, the residual load results in a friction load upon extraction**

- **The average case temperature variation with time has a considerable influence on the final residual clearance between the case and chamber**

- **Extensive analyses show that case temp at maximum radial displacement (where maximum plastic strain occurs), as well as the final case temperature at time of extraction, is of primary importance to the residual clearance. The temp versus time profile between these points is of lesser importance.**

Case Recovery to Clearance



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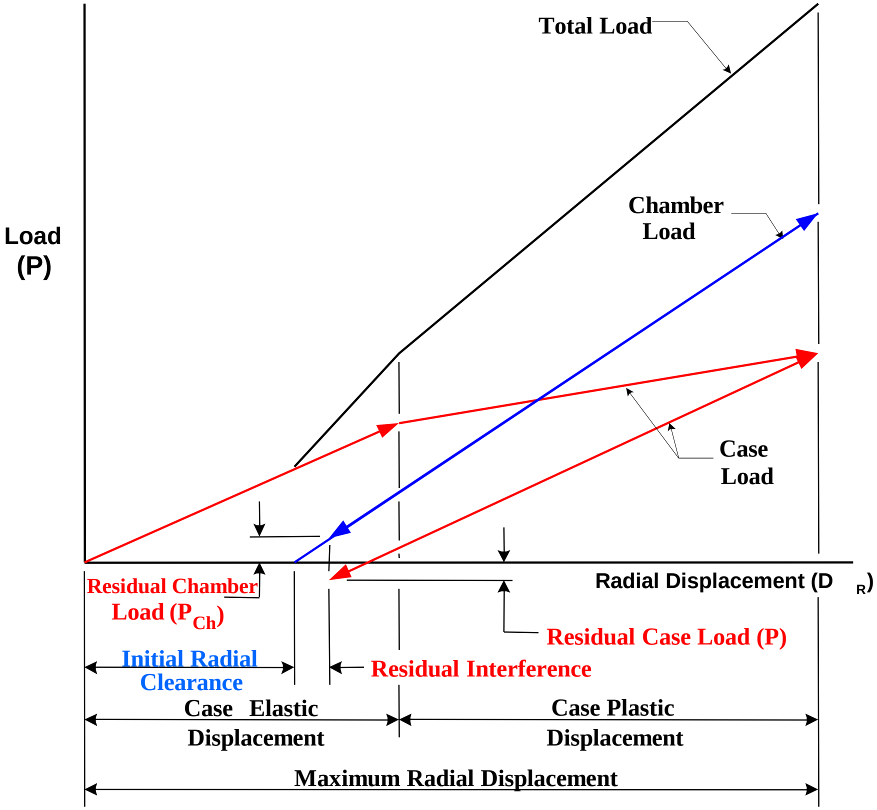
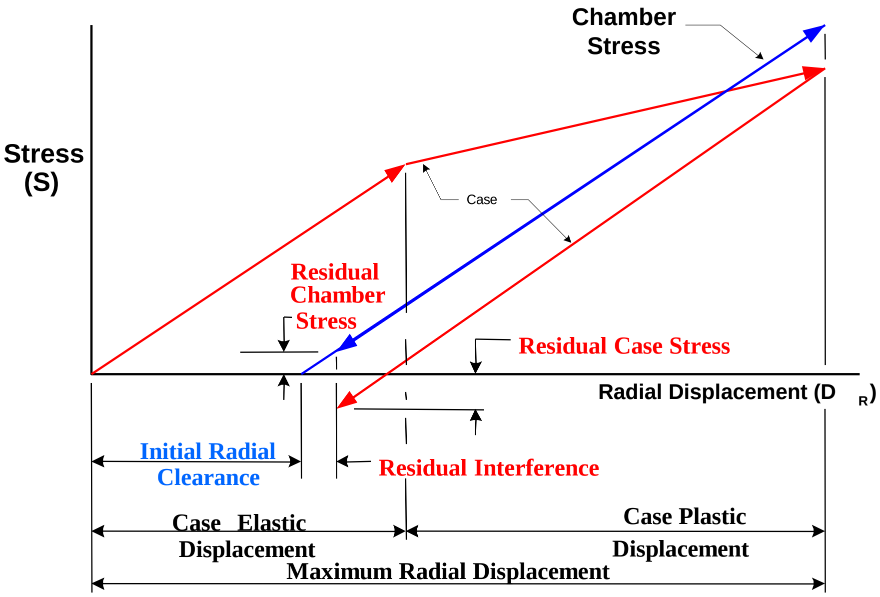
Case Recovery to Interference





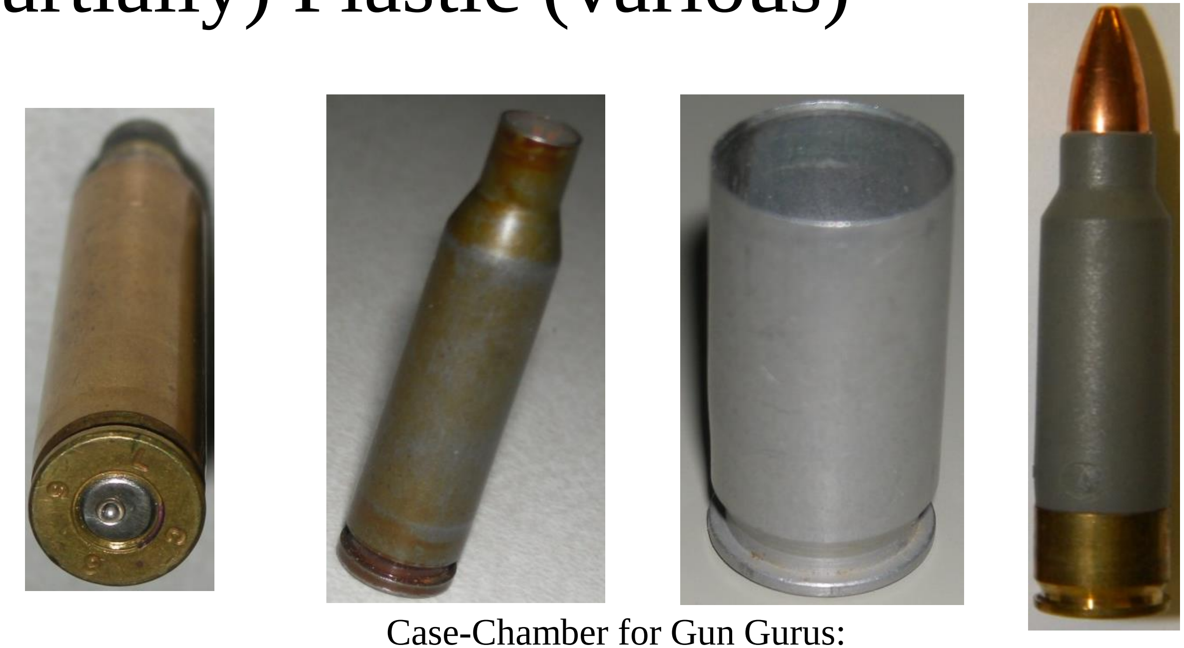
- **Case & Chamber load depends on internal pressure, case-chamber friction**
- **Residual interference dependent on case material properties & initial gaps**

Case-Chamber Interface Factors

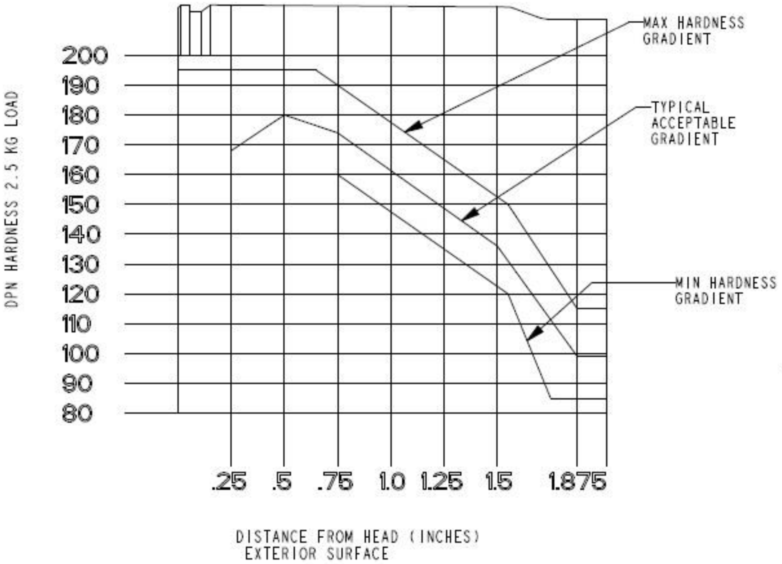
- **Initial case / chamber radial gap (Headspace details)**
- **Case material properties (including variation with temperature and load rate)**
- **Case thermal characteristics (specific heat, density, conductivity, and/or diffusivity)**
- **Case and chamber wall thickness**
- **Chamber design stress level**
- **Chamber thermal / mechanical properties**
- **Ambient temperature of case and chamber**
- **Thermal forcing function (especially, the change in temperature at peak radial strain and at unlock & extraction)**
- **Gun axial response (gaps, breech stiffness, unlock loads, etc.)**
- **"Other" Factors (e.g. fluted chambers)**

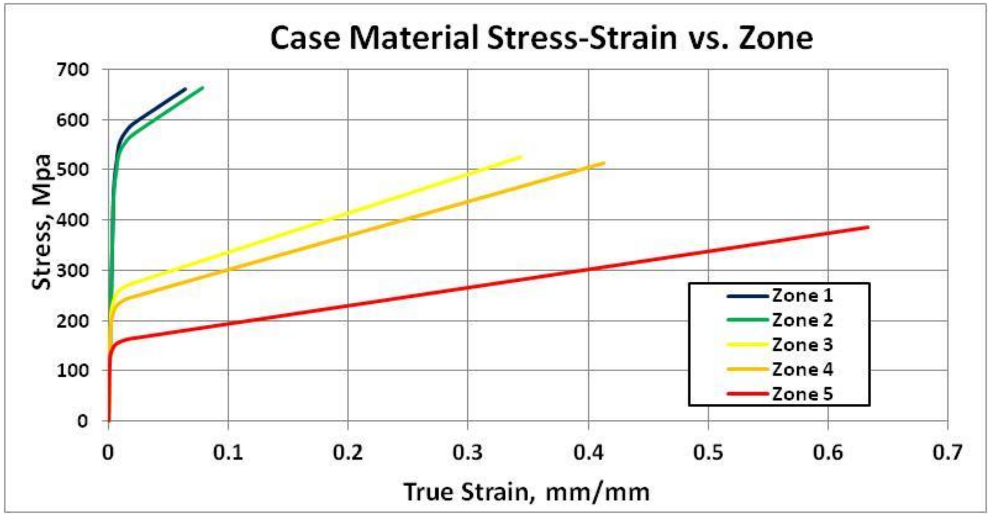
Case Materials

- Brass (70% copper – 30% Zinc)
- Steel (typically low carbon)
- Aluminum (5000 or 7000 series alloy)
- (Partially) Plastic (various)



Case Material Properties





- **Hardness profile changes with distance from case base**
- **Hardness must be "translated" to non-linear material properties**
- **Non-Linear properties are a function of case temperature**

Case Material Samples

"Dog-Bone" Samples from Different Case Zones

Micro Hardness Sample from Case Sidewall

- **"Dog bone" test samples provide stress-strain data**
- **Hardness testing measures hardness along case**
- **Allows correlation between hardness & stress-strain**

ARROW TECH

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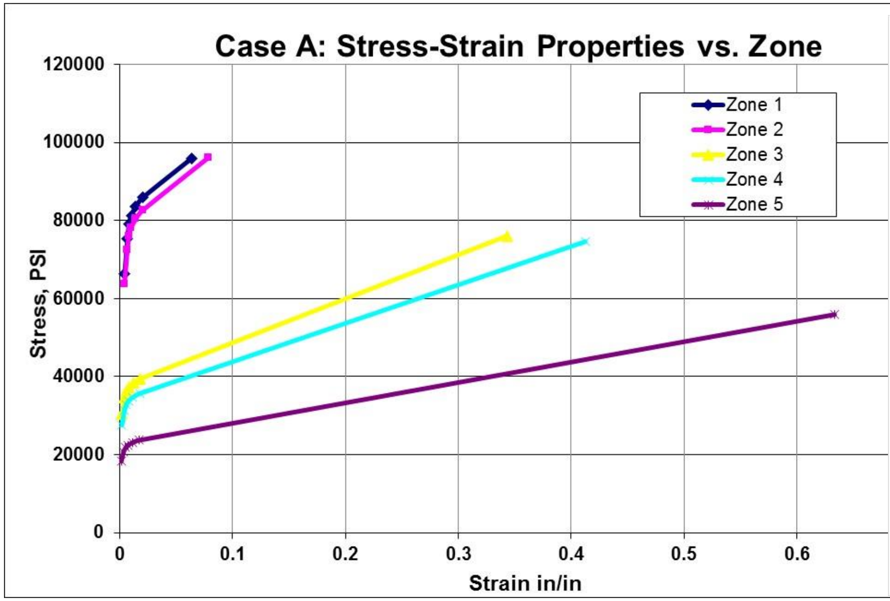
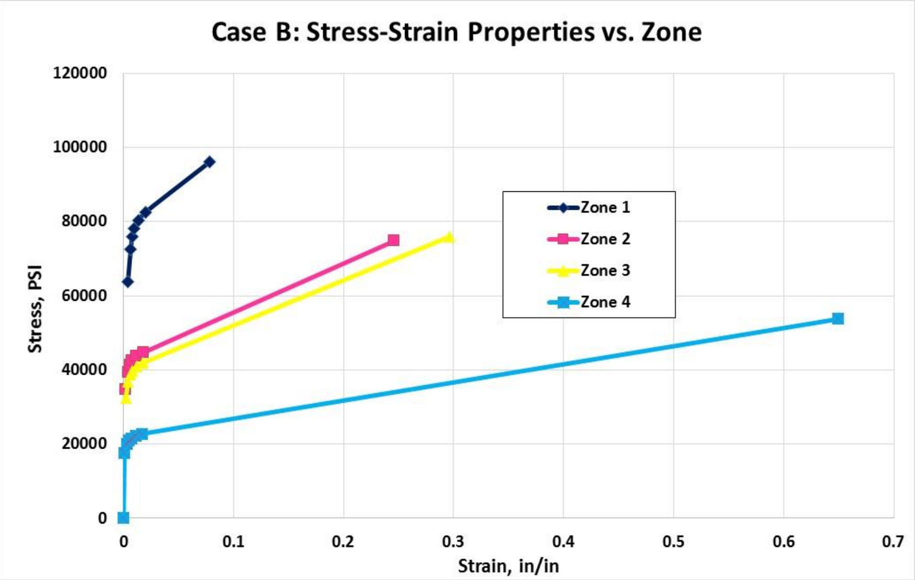
Material Properties Measurement

- Cut "dog-bone" samples from case in various places
- Machine to appropriate geometry
- Tensile Test to Failure measuring stress-strain behavior
- Requires use of "extensometer" for good data

If you can't get a bigger target...

Case Material Stress-Strain Behavior



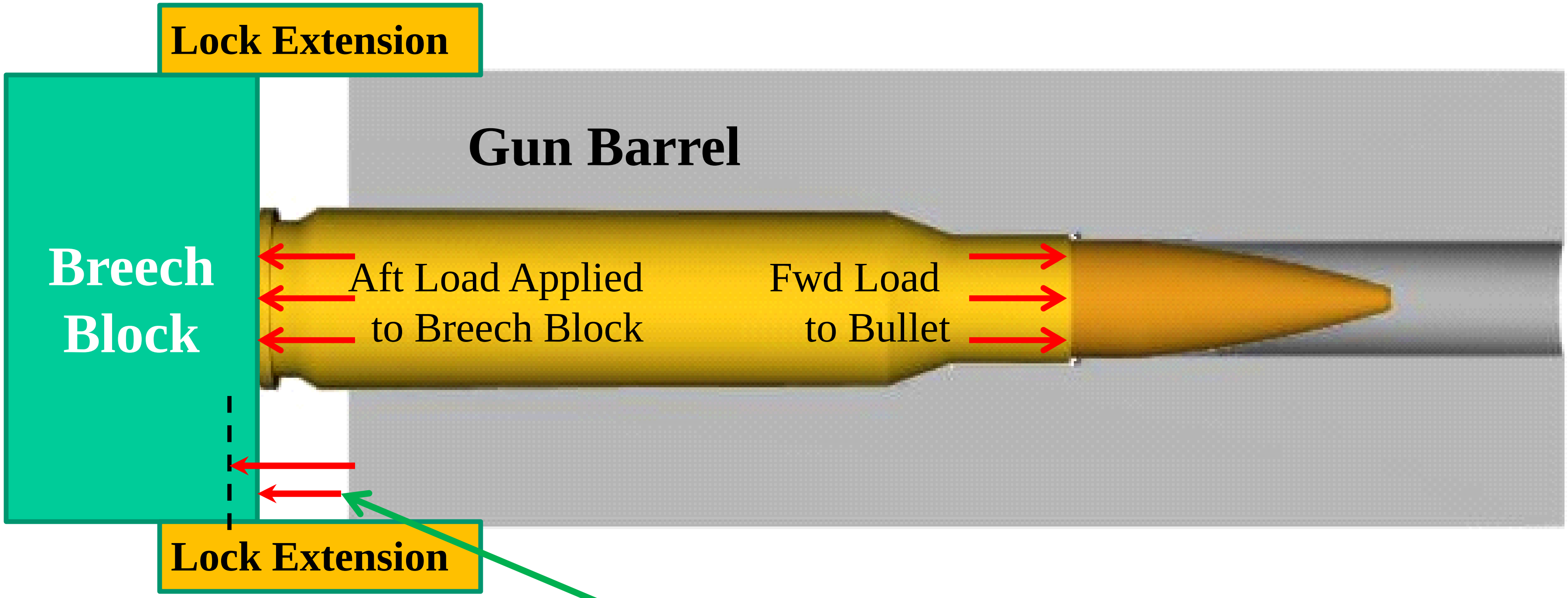


- **Same case, different mfg.**
- **Different unlock/extract performance..**
- **Not a SAAMI / CIP controlled parameter**

Lock Stiffness Definition

Lock Stiffness:

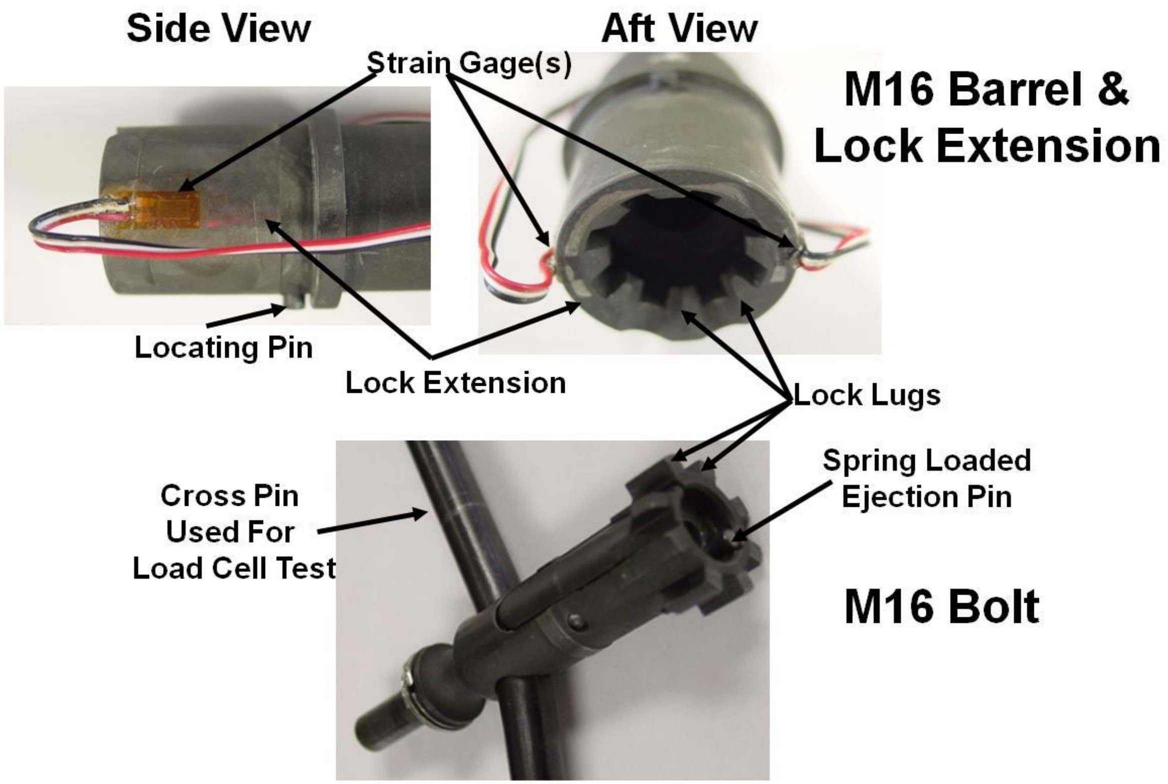
How Far will breech move relative to barrel face in response to load applied to breech face and reacted at base of bullet? Load/deflection = lock stiffness.



What is elastic movement at peak load?

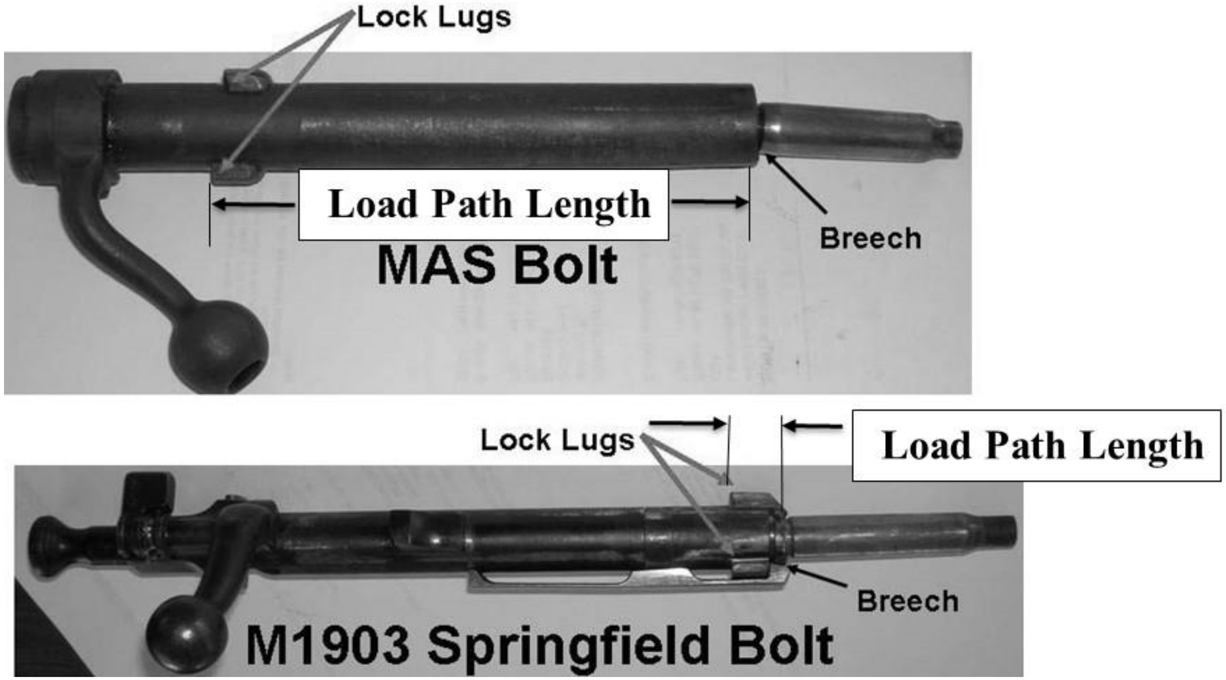
- **Also Not a parameter controlled by SAAMI / CIP**

Lock Stiffness Measurement



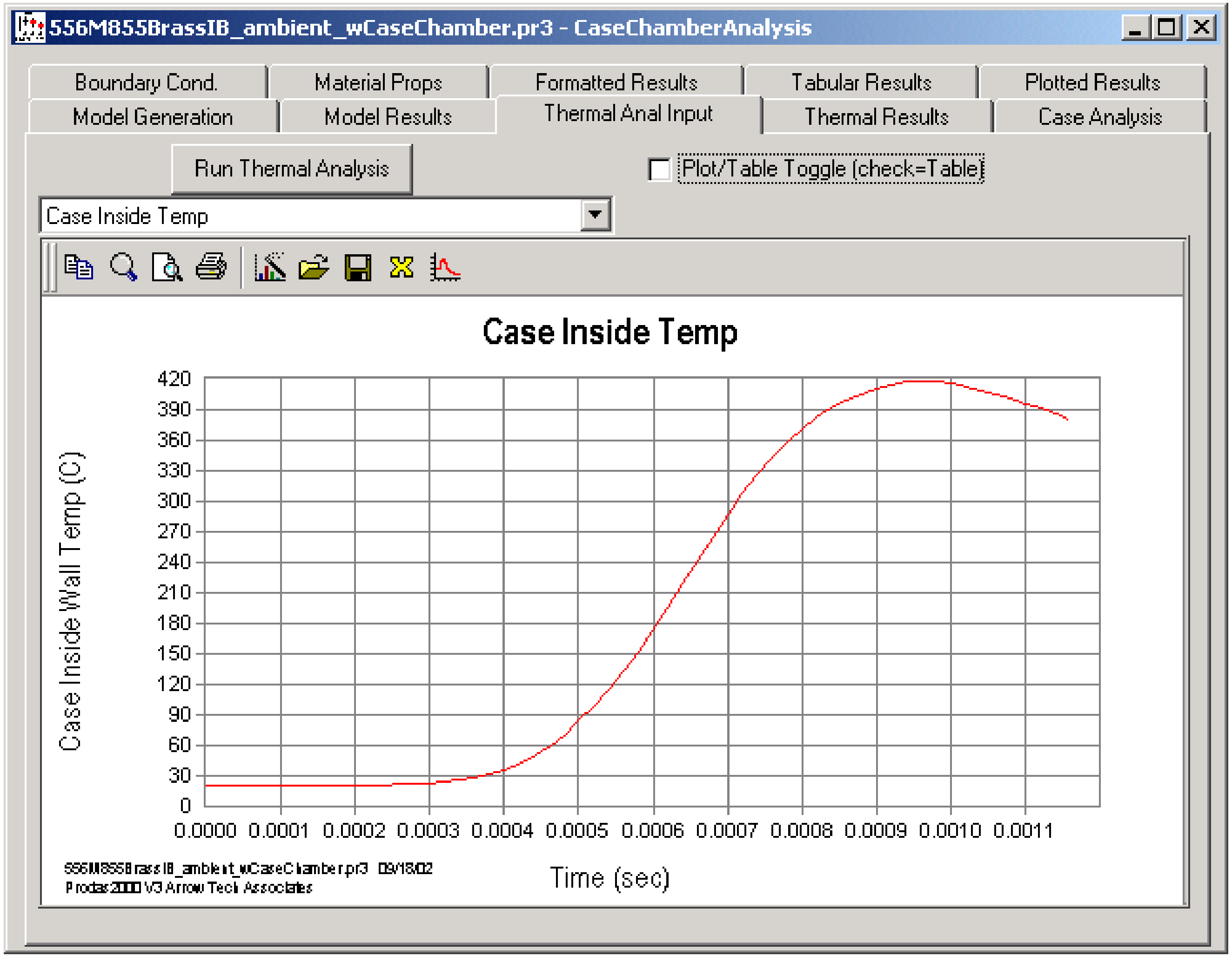
- **Strain gages need to be located in appropriate spot to accurately measure strain**
- **Accurate 3-D linear FEA model is acceptable alternate**

Load Path Length Affects Lock Stiffness



- **MAS has long load path & low lock stiffness (return not shown)**
- **Mauser has short load path & high(er) lock stiffness**

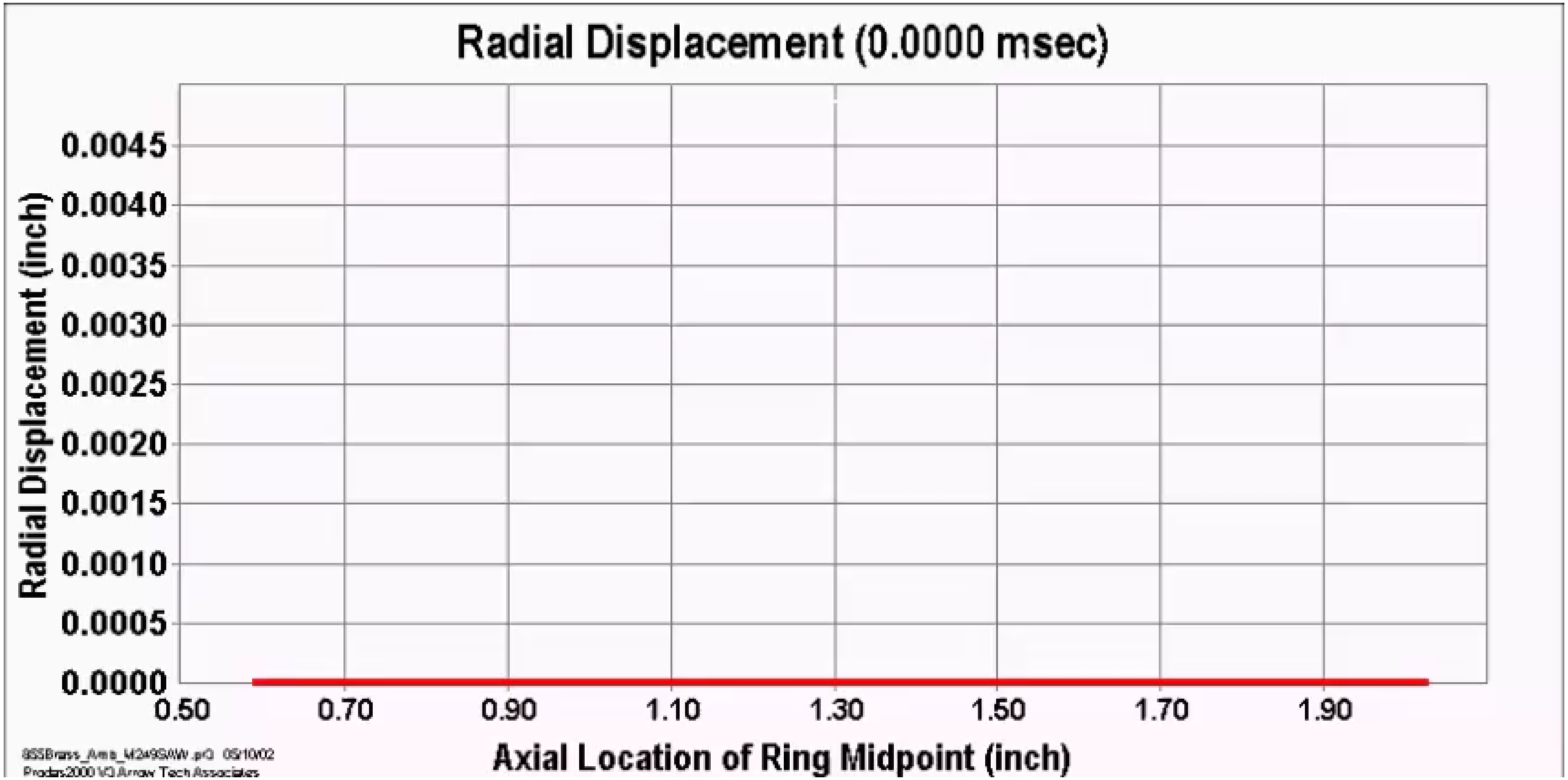
Case Inside Wall Temperature Input



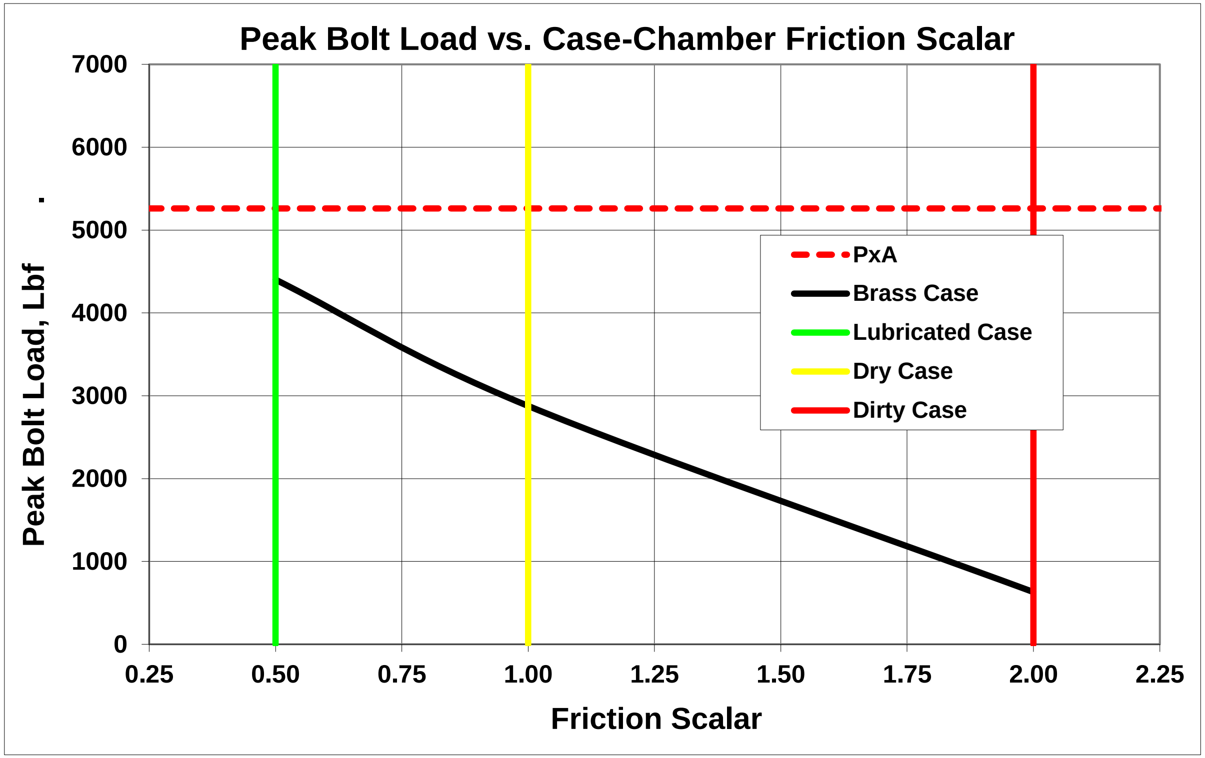
Evaluating Case Designs

- **Look for undesirable conditions**
  - Excessive Axial & Total Strain (<80% "Worst Case" is desirable)
  - Interference at end of cycle indicates potential unlock/extraction problems
  - Long time between fwd and aft case contact with chamber (large strain)
  - Assess case structural robustness WRT deviations in nominal friction, gaps, lock stiffness, etc.
  - Assess residual axial load prior to unlock (hi may impede bolt unlock)
  - Assess peak bolt load & estimated extract load vs. friction/mat'l properties
- **Study the effects of manufacturing tolerances and temperature**
  - "Gap factor" available to quickly evaluate these effects
  - CASAS assumes that dimensions apply at the initial temperatures specified
- **Evaluate bolt loads under various conditions**
  - Peak Bolt Load is Primary Factor in bolt & lock extension fatigue life
  - Large Case Base – Bolt Face Load at unlock may stall gun mechanism
  - Peak Extraction load may stall gun mechanism

Case-Chamber Movement

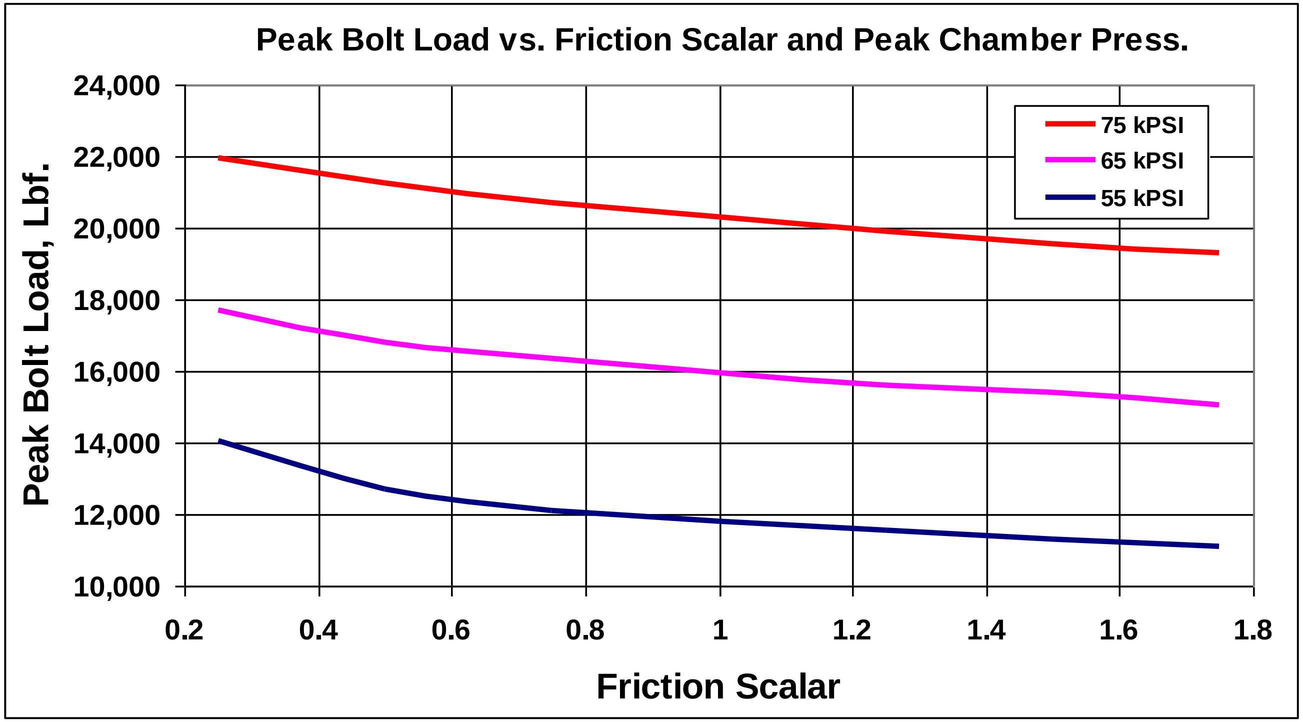


Peak Bolt Load vs. Friction Scalar



- **Simple PxA leaves a lot on the table…**
- **But, it gives you fatigue life margin..**
- **What's good for gun hurts cartridge & vice versa**

Bolt Load vs. Pmax & Friction



- **Highly non-linear result**
- **Peak load is primary gun fatigue life driver**

ARROW TECH

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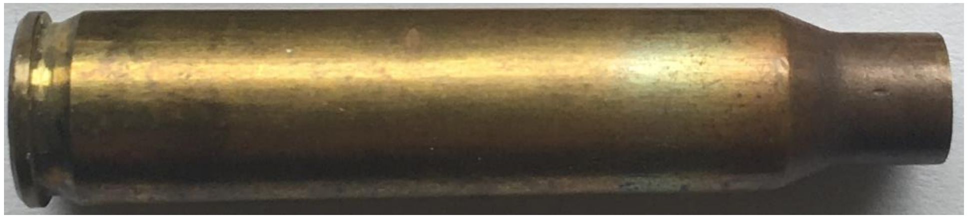
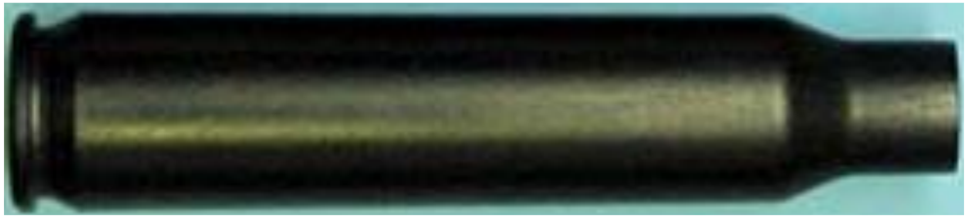
Effect of Case Material on Peak Bolt Load

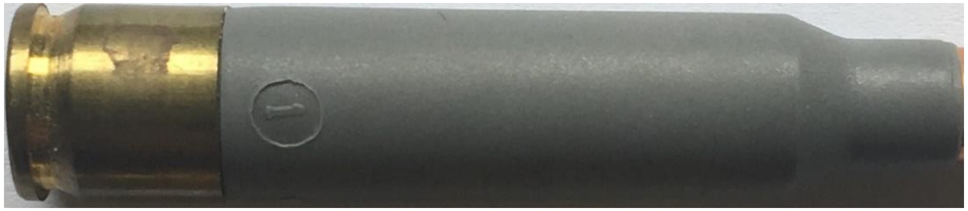


70/30 Brass (Baseline)



Aluminum Alloy

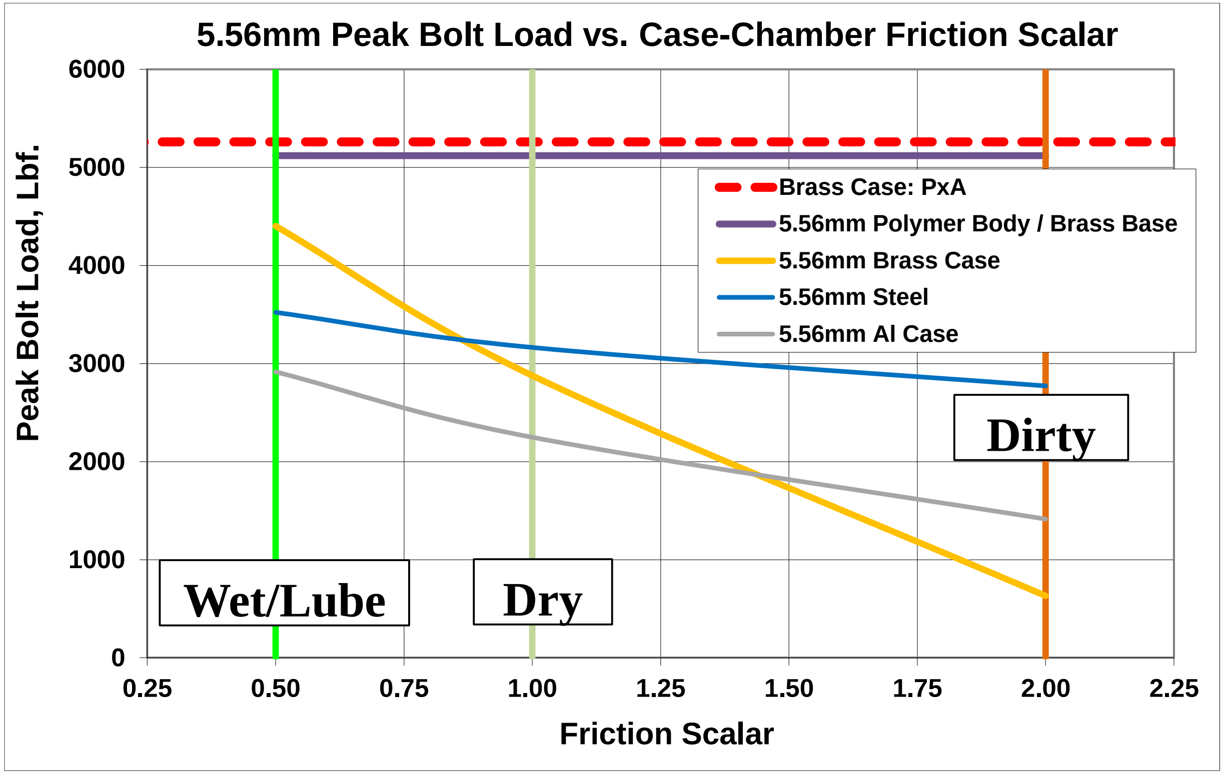
Steel Alloy



Brass / Polymer Composite

- **Various Mat'l solutions for hi pressure seal**

Peak Bolt Load vs. Case Material

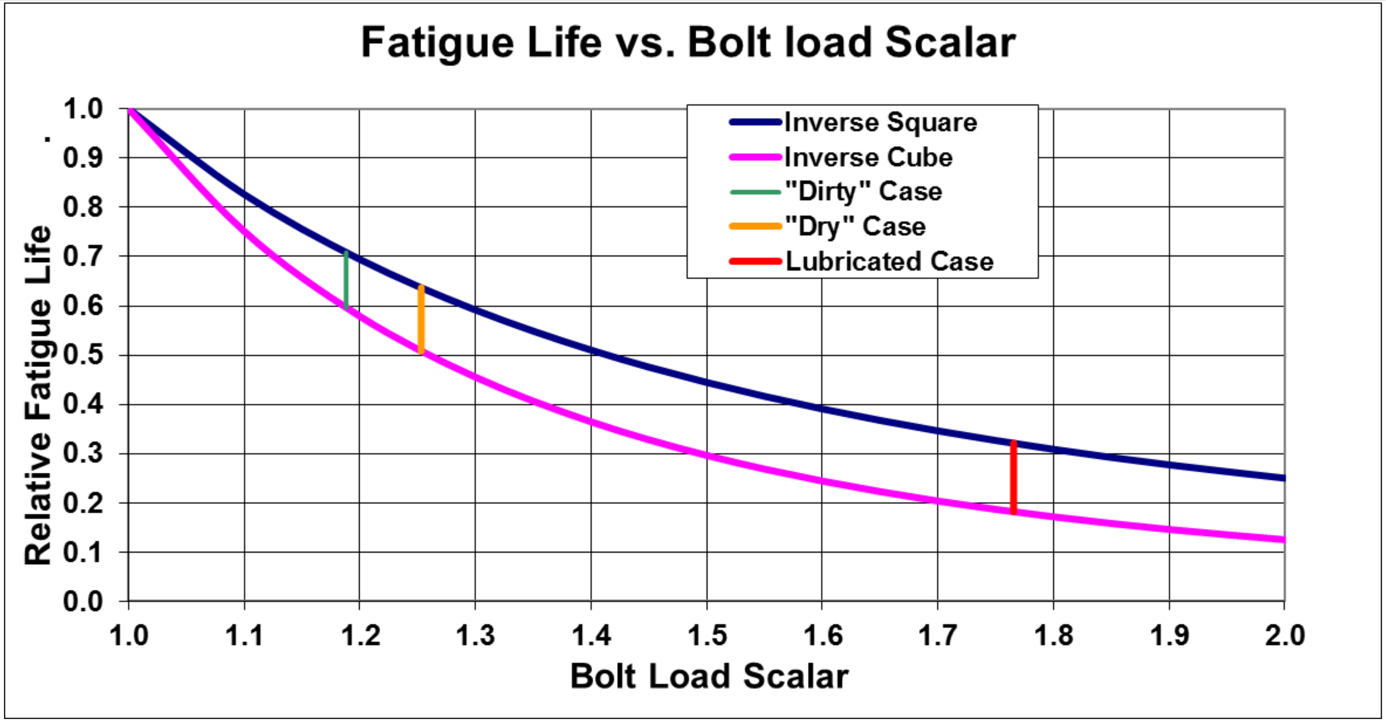


- **P_{max} held constant at 52.5kPSI (362 MPa)**
- **Cases designed to provide % Ultimate Strain < 100%**
- **Peak bolt load is a factor determining fatigue life of gun bolt/lock mechanism**

ARROW TECH

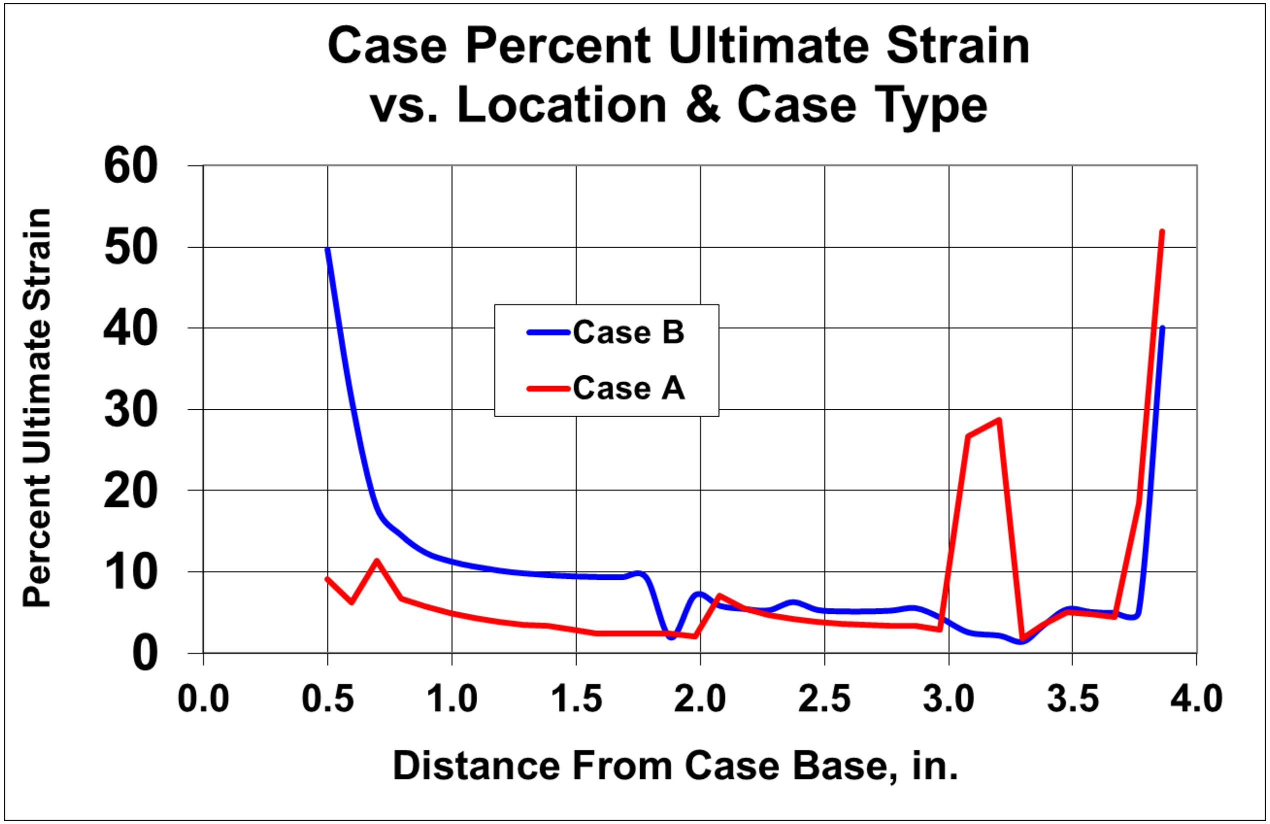
If you can't get a bigger target...

Effect of Bolt Load on Gun Parts Life



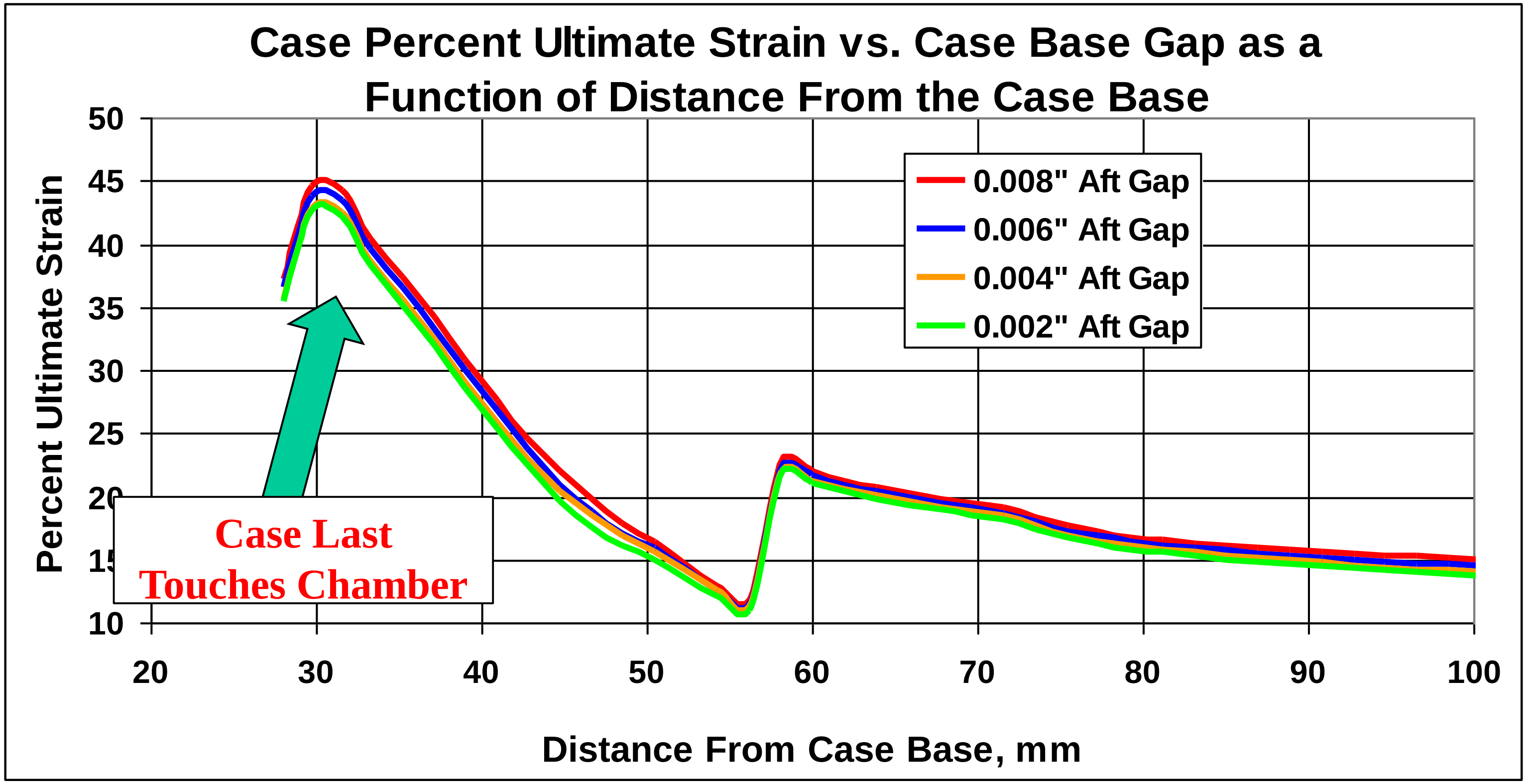
- **Increased peak bolt loads are not your gun's friend…**
- **Wet/lubricated case increases bolt loads**
- **So does steel or partially plastic cases…**

Case % Ult. Strain vs. Location



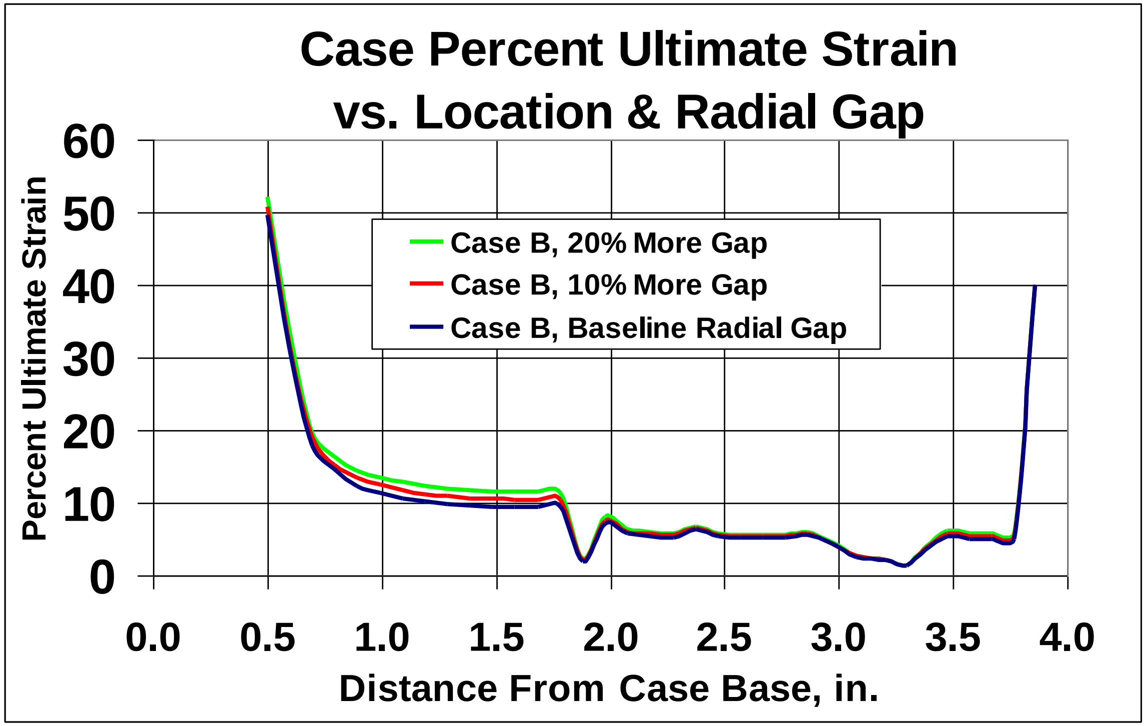
- **Both cases have % Ult. Strain < 100%**
- **Peak % Ult. Strain is in different location (mat’t props)**

CASAS Results
%US vs Base Gap



- **Non-linear behavior along case length**
- **Not very sensitive to gap magnitude**

CASAS Results
%US vs. Radial Gap

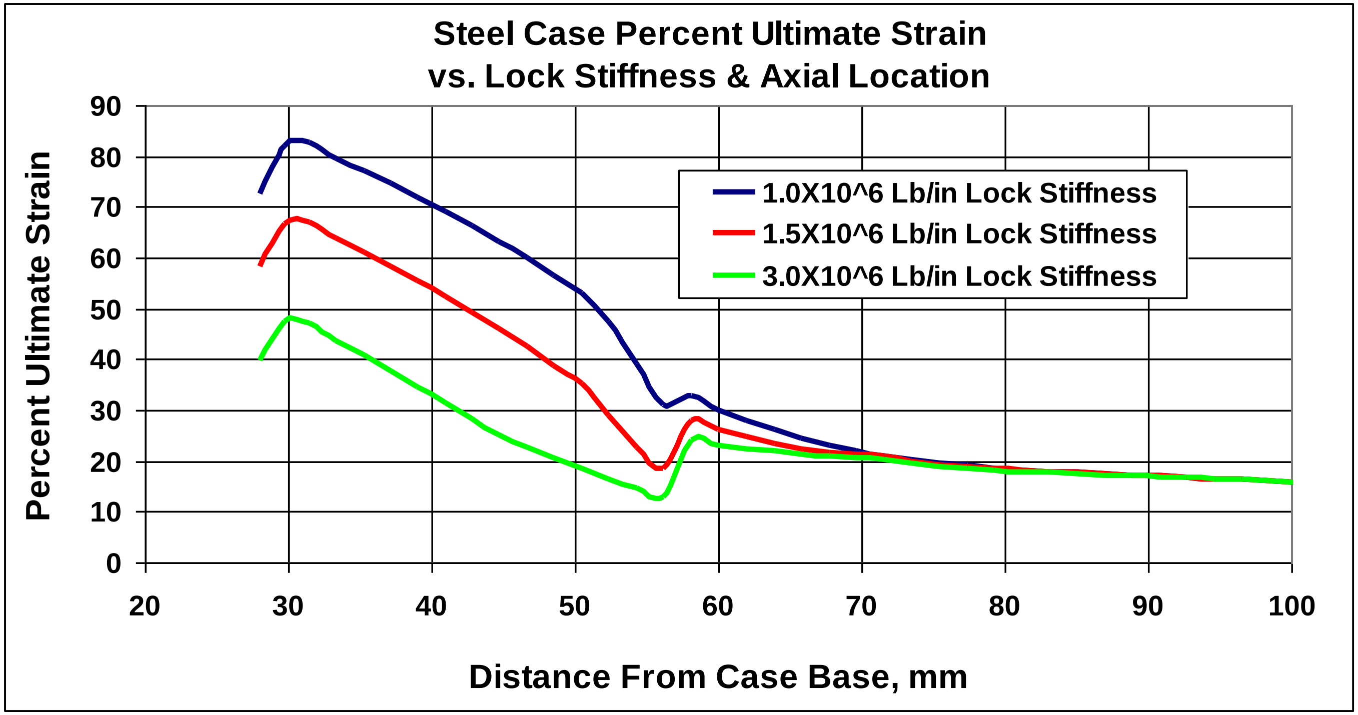


- **Non-linear behavior along case**
- **Not very sensitive to gaps…**

ARROW TECH

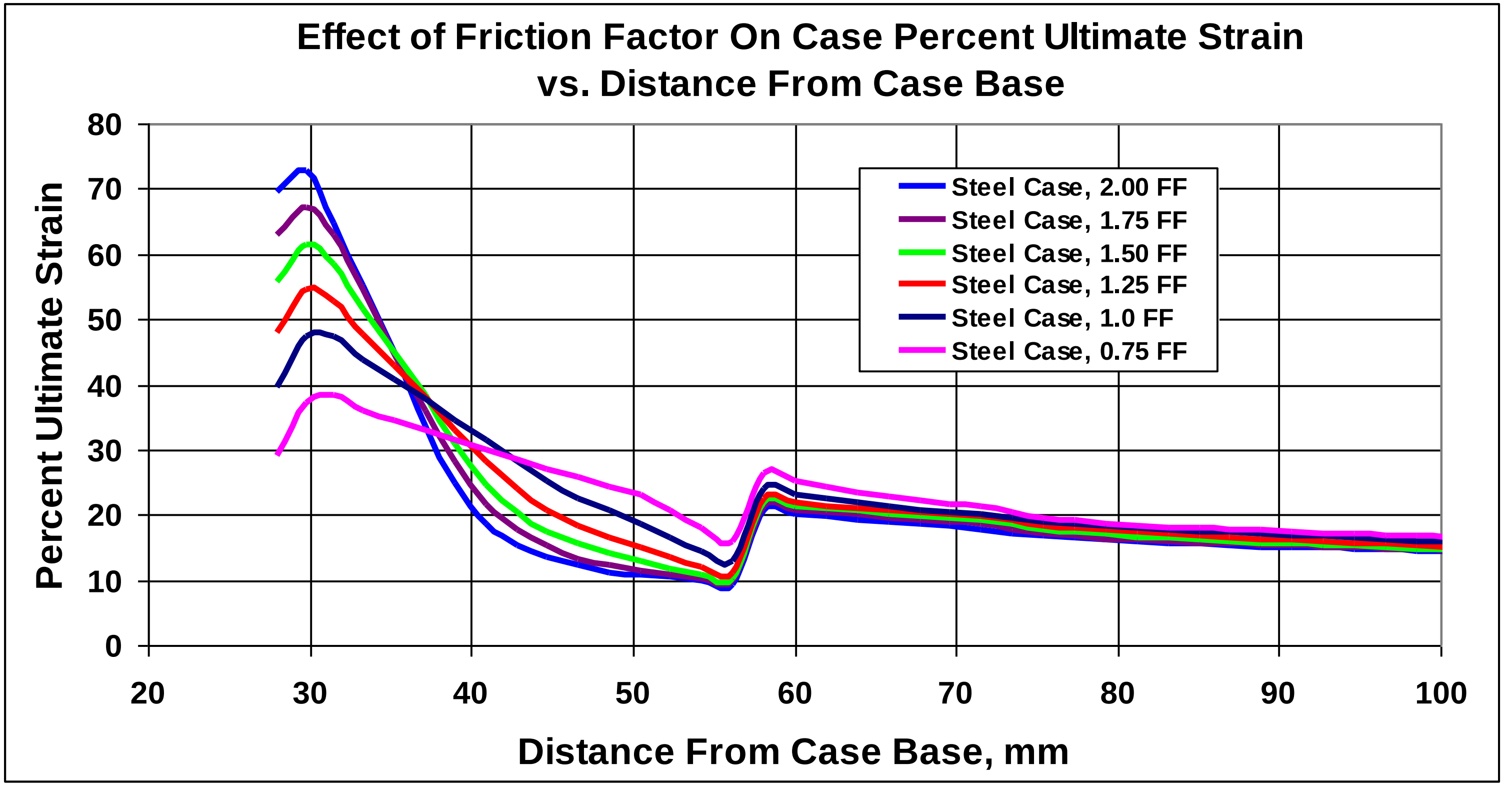
If you can't get a bigger target...

%Ult. Strain vs Lock Stiffness



- **Highly non-linear behavior**
- **Lock stiffness is an "Uncontrolled" SAAMI/CIP firearm interface parameter**

% Ult. Strain vs Friction Factor

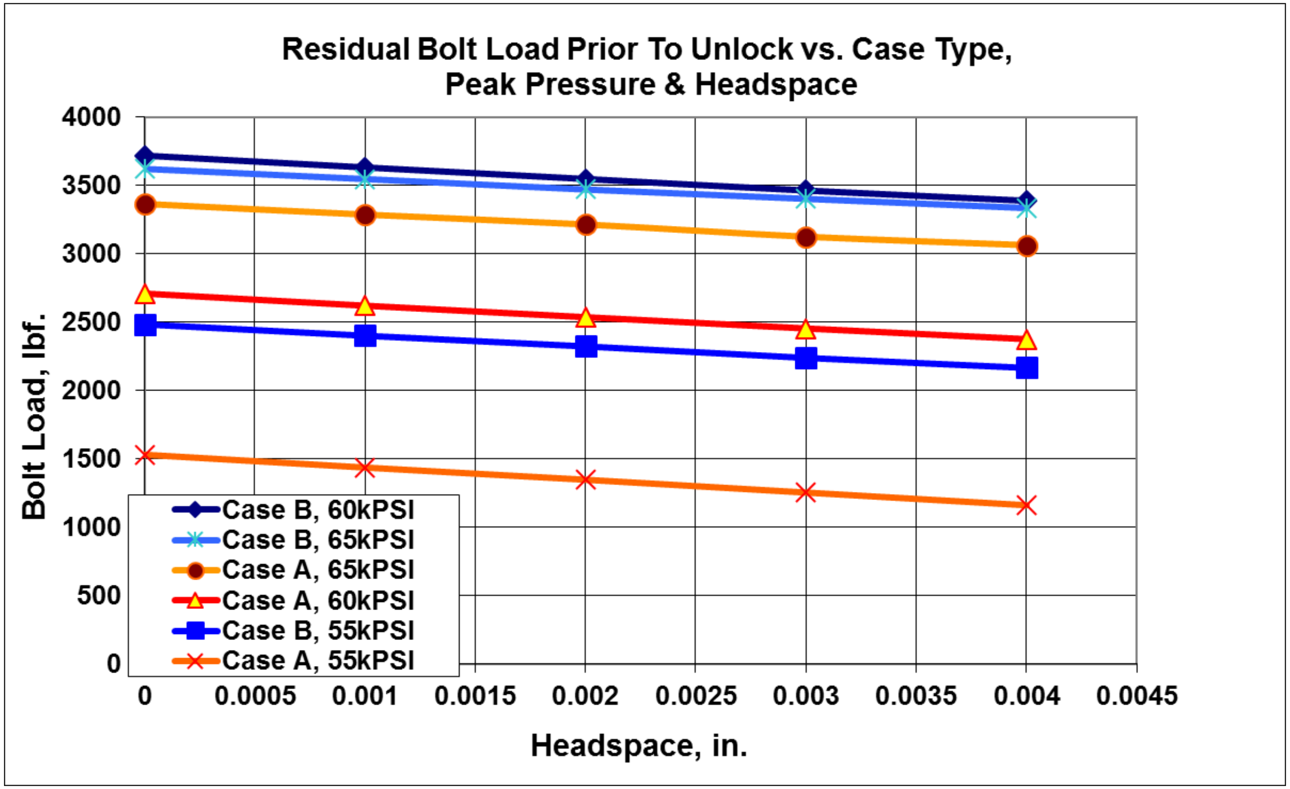


- **Highly non-linear behavior**
- **Friction factor influences % Ult. Strain in aft of case**
- **Evidence suggests friction gradient may exist**

ARROW TECH

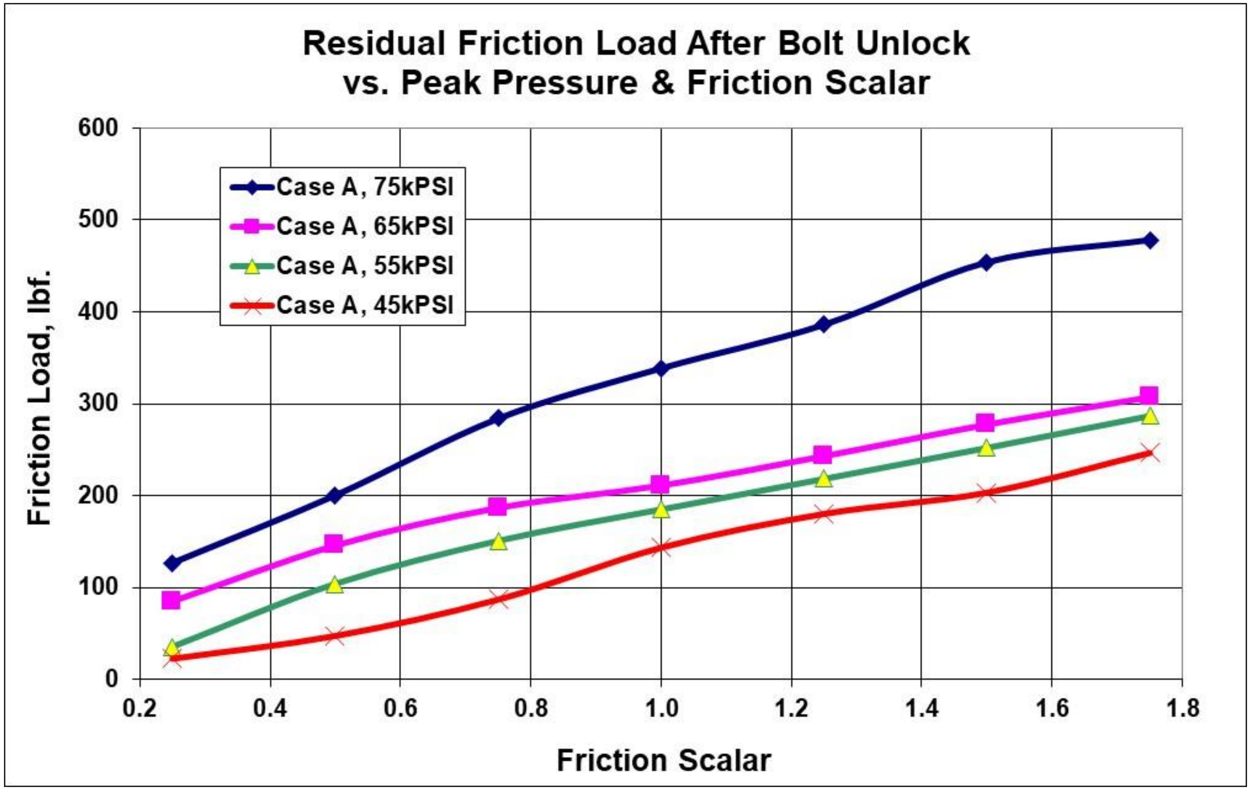
If you can't get a bigger target...

Residual Case Base – Bolt Face Load



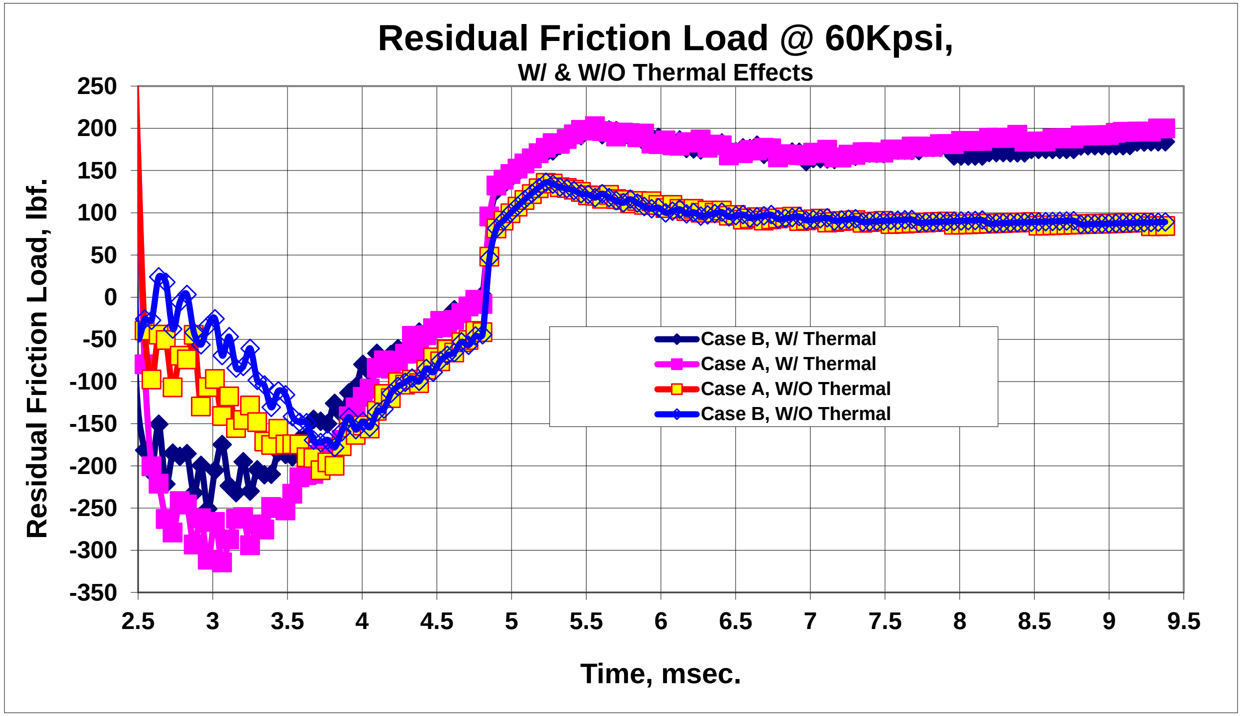
- **Residual Load prior to unlock**
- **Resists unlock…**

Friction Load Resisting Initial Extraction



- **Increased pressure & friction = increased extract load (no surprise)**
- **(Somewhat) linear behavior at lower pressures, slope change at higher peak pressures**

Friction Load Resisting Initial Extraction



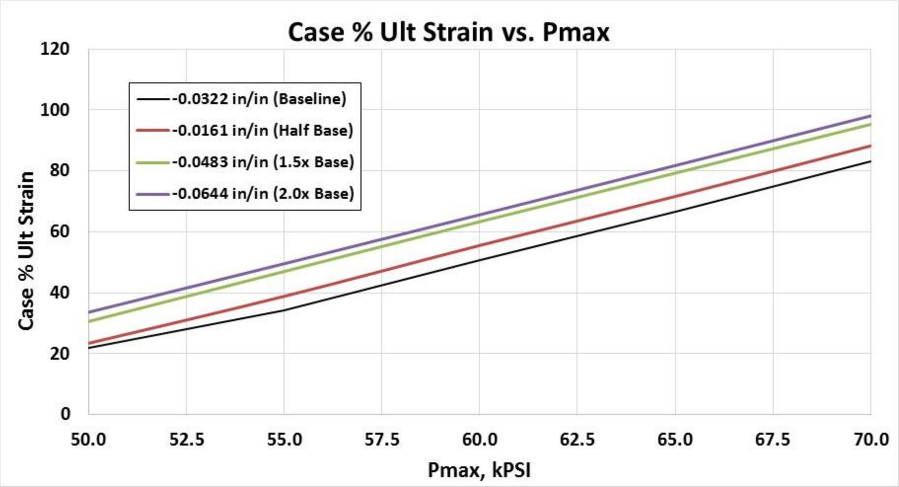
- **Residual Load after unlock**
- **Resists extraction…**
- **Case Taper affects load/distance before clearance develops**

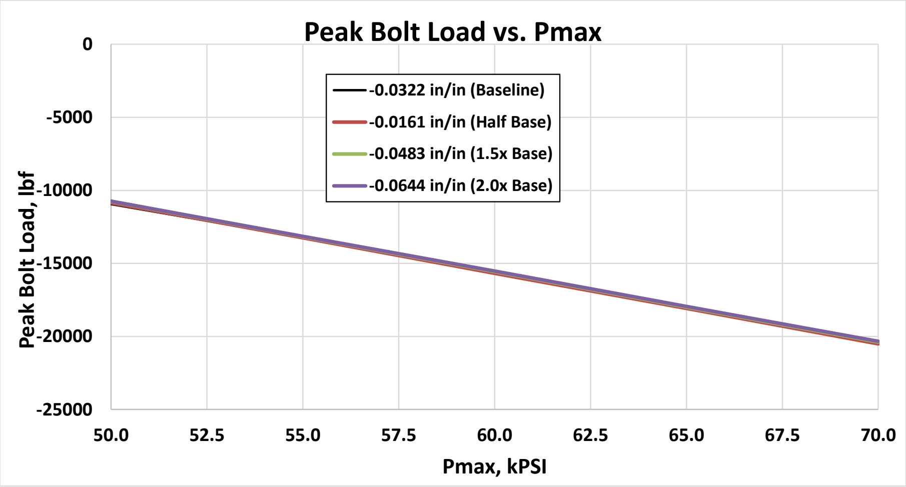
Case Taper Study

- **Compare results to "baseline" case**
- **Tapers of 0.5x, 1.5x & 2.0x baseline**
- **Identical wall thickness & case-chamber gaps**
- **Identical press-time, temp/time & lock stiffness**
- **Identical case material props as f(n) of dist from base**

If you can't get a bigger target...

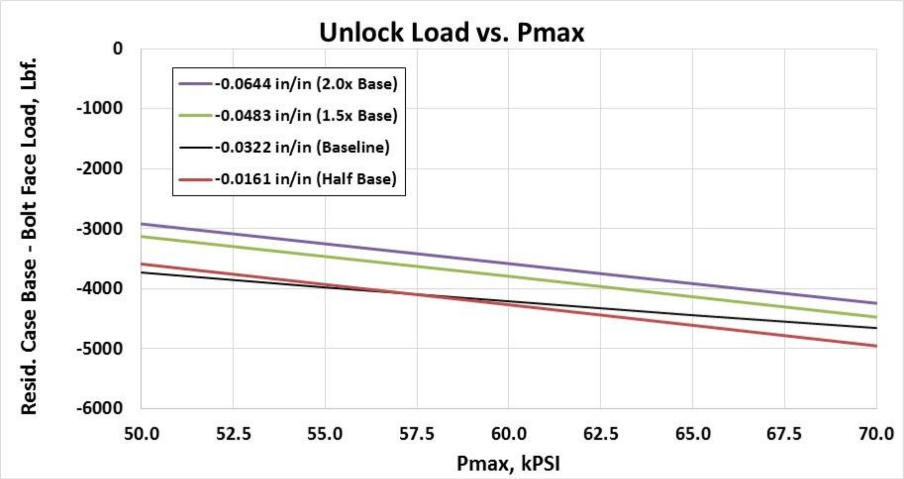
Effect of Case Taper on Case Strain & Bolt Load

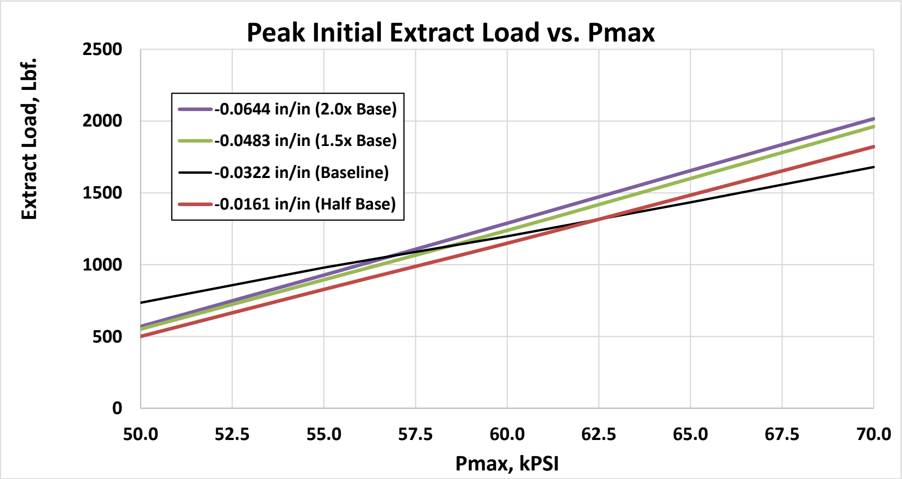




- Case % Ultimate Strain is structural margin of case.., Baseline taper is lowest (most margin)
- Peak Bolt Load is Key factor in gun parts life, Taper has little effect on this parameter

Effect of Case Taper on Unlock & Extract Load



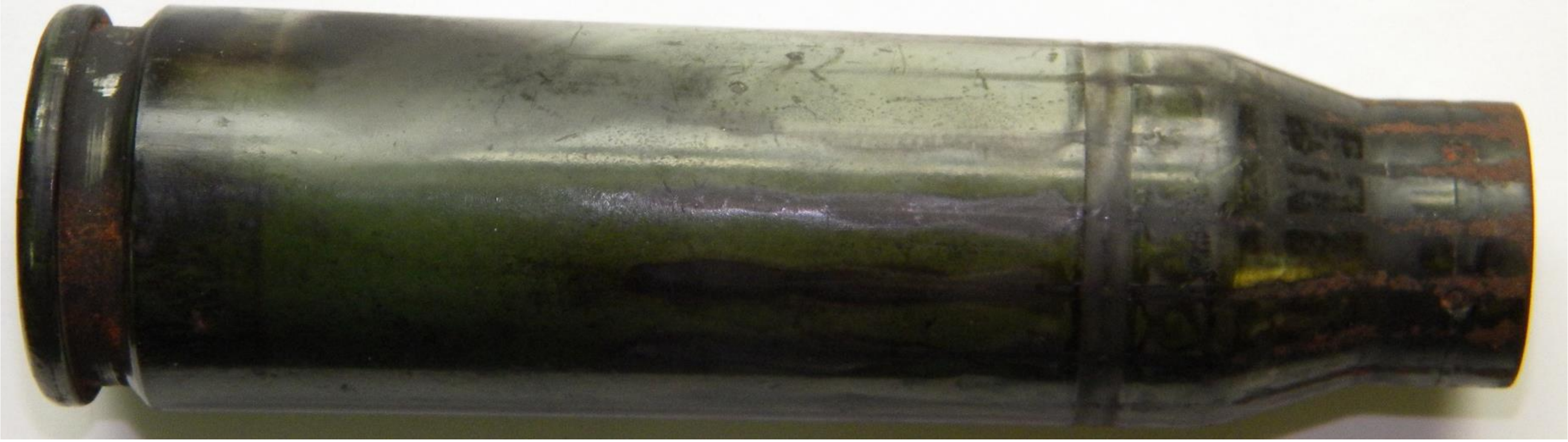


- **Unlock load is residual case base – bolt face load at end of "blow-down", resists unlock**
  - **Baseline has lowest slope….**
- **Peak initial extract load is residual case-chamber friction resisting extraction**
  - **Baseline has lowest slope..**
- **Expect different behavior based on case matl props, dimension & taper**

ARROW TECH

If you can’t get a bigger target...

Fluted Chamber Effects



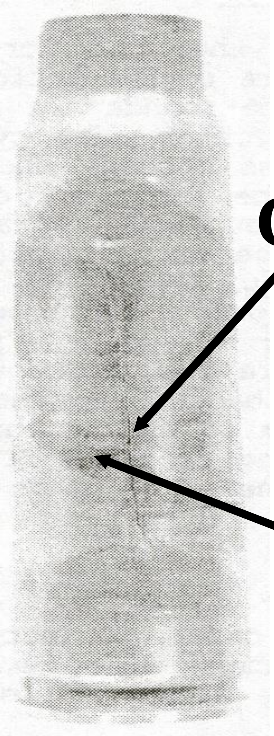
- Chamber flutes balance inside-outside pressure at case shoulder & neck
- Typically used on hi rate of fire guns to assist w/ early unlock
- Reduces case axial stretch & residual case base – bolt face loads
    - Particularly advantageous for this case w/ link groove…
- Allows case to be extracted under higher residual case pressure
- Increases peak bolt load by preventing case-chamber shear transfer at affected zone

Other Issues…

- Original Case Material: 70% Copper, 30% Zinc (260 Alloy)
- Susceptible to Stress Corrosion Cracking (season cracking)
  - Originally Observed by British in India on Brass Cartridge Cases Stored in Stables & Exposed to Horse Urine
  - Caused by combination of material, residual stress & corrosive atmosphere
  - Residual stress caused by forming processes
  - Corrosive atmosphere from nitrogen bearing compounds in propellant
  - Aggravated by "dezincification" of brass during processing
  - Causes internal case wall split that propagates to exterior during firing
  - Gas Wash on Exterior of Case
  - Gas Cutting of Chamber??
  - Case may show no outward signs of problems prior to firing

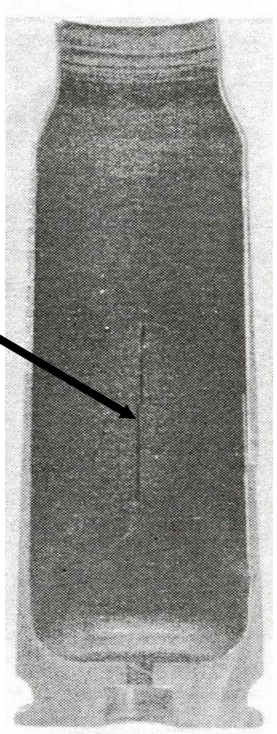
If you can't get a bigger target...

Stress Corrosion Cracking: Symptoms



Exterior

Photo Thru Wall Section W/ Crack



Interior

- **Unless crack allows gas to vent aft, little, if any, damage is done to chamber or barrel**

Stress Corrosion Cracking, Small Caliber

- **17 HMR**
- **No preferred crack orientation WRT firing pin strike (not a gun or chamber issue)**
- **No external signs prior to firing, no damage to gun**
- **Effect on dispersion(?)**

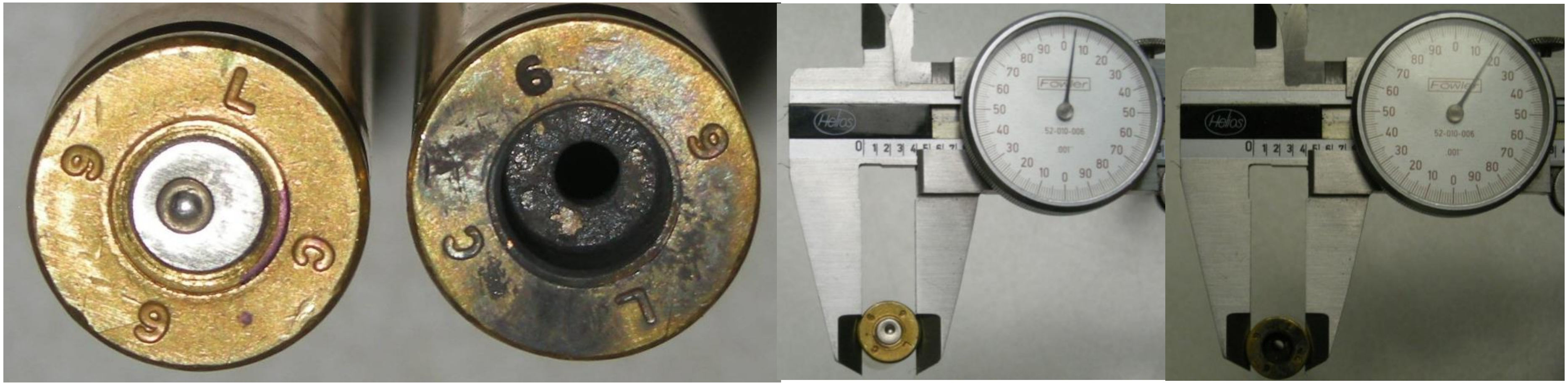
Verdigris

- **Toxic green exterior corrosion caused by contact w/ tanned leather (typically)**
- **Sticky surface can cause gun malfunction, case separation**
- **Reason for "plated" cases**

Aft Venting of Al Cases

- **Case not properly heat treated**
- **Low strength base allowed large deflections, cracking case anodize**
- **Resulting hi pressure, hi velocity flow cause significant erosion**
- **Significant damage to case, bolt face & barrel**

Proof Positive of Over Pressure



- 25.06 case, no primer cup visible upon opening breech
- ~ 0.012" larger extractor groove diameter
- Don't substitute lead core bullet data for solid copper bullets of same caliber & weight.

Take-Aways

- **Brass** is robust material, long history
  - Hardness & stress-strain properties follow defined profile along case length; hard aft, softer at neck
  - Must be properly processed (neck annealed) to function properly.
  - Stress corrosion cracking is a potential downside
  - Reuse is possible with careful attention to wall thickness (esp. rifle ctgs)
- **Steel** has lower strain at failure than brass of same hardness, somewhat thicker walls, less load transfer in shear to chamber walls = higher bolt loads. Gun should be designed for steel cases.. **Reuse not recommended due to low strain at failure ref brass**
- **Aluminum** has lower strain at failure than brass, somewhat thicker walls compared to brass. Peak bolt loads can be lower than brass depending on case-chamber friction. Gun should be designed for Al cases.. **Reuse not recommended, low strain at failure WRT brass**
- **Plastic** can have much higher strain at failure than brass, but must have thicker walls. Near zero shear load transfer means very high bolt loads. Gun must be designed for plastic cases. **Reuse not recommended, heat checking = cracking = more brittle failure than initial design**
- **If your primers fall out, your pressures are too high.**