Firearm and Munitions Development with Ansys Webinar

Alex Austin – DRD's Structures Group Lead

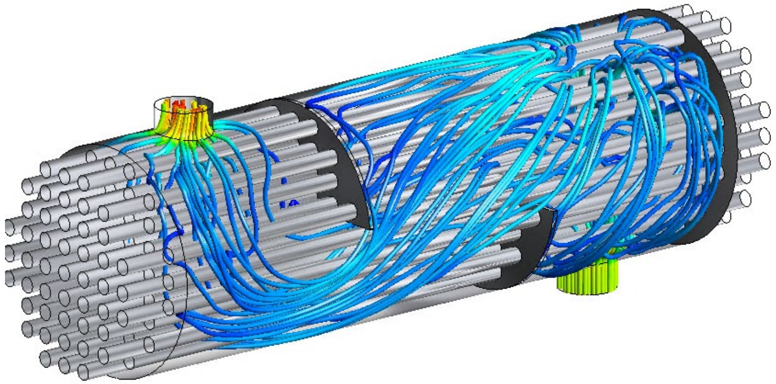
20 February 2025 @9AM CT

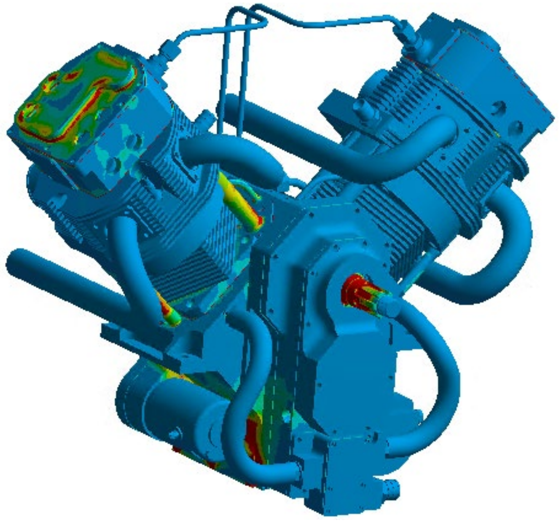
Agenda

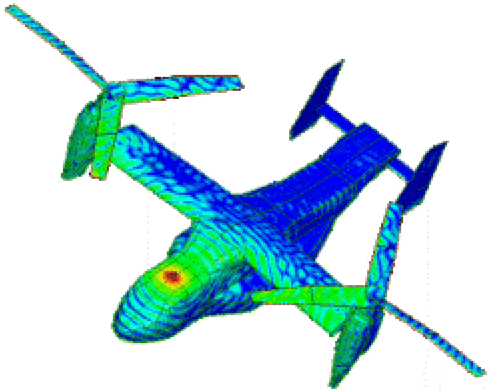
- Short overview of DRD
- Why use simulation for firearm development?
- What is physics-based simulation?
- Application examples (Barrel dynamics, felt recoil, action dynamics, thermal effects, ballistics etc.)
  - New technology development
  - Reliability
- Summary

Mission Statement

DRD Technology helps engineering teams accelerate product development. With in-house expertise spanning the entire range of physics, we ensure customers succeed when using Ansys simulation tools for virtual prototyping and design verification.







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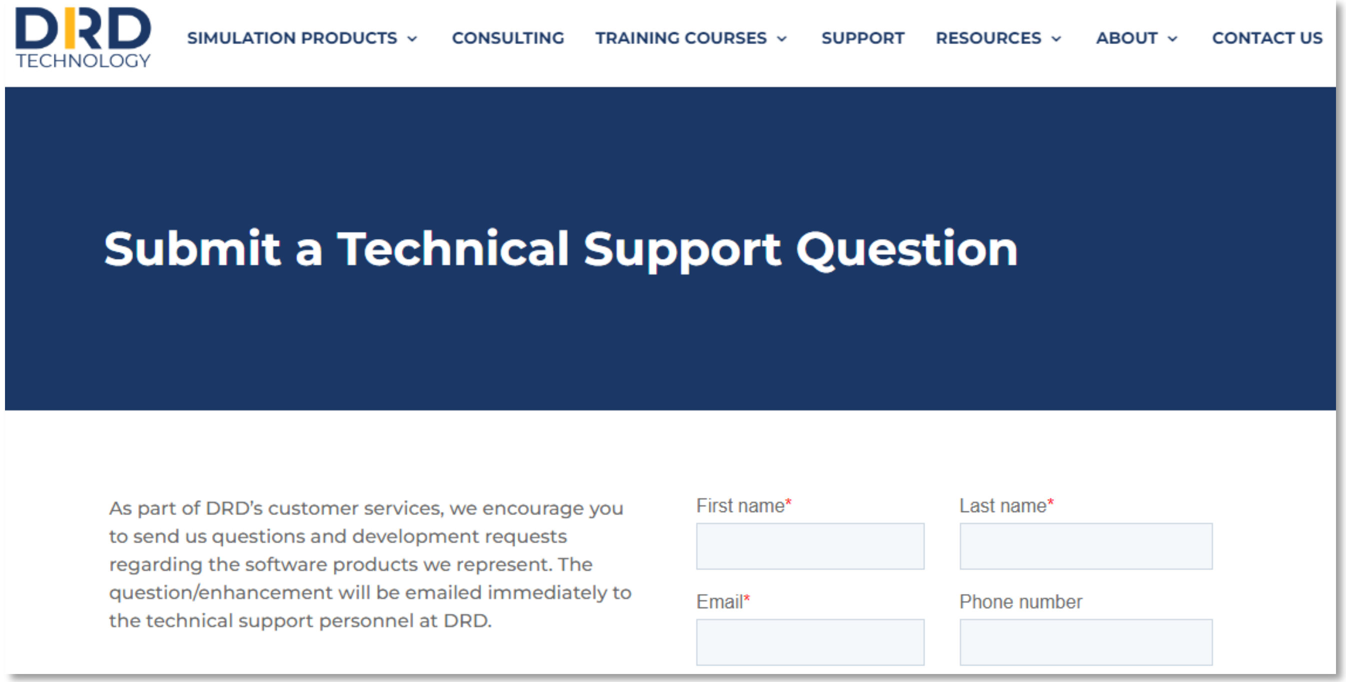


For more than five years, I have worked closely with DRD Technology to execute tactical and strategic initiatives here at EaglePicher due to our unprecedented growth. We've been very happy with DRD and will continue to work with them as our business partner for using Ansys tools effectively and efficiently.

- *Doug Austin*

Director of Research and Development

EaglePicher™ Technologies, LLC

Physics Based Simulation = Significant Competitive Advantage

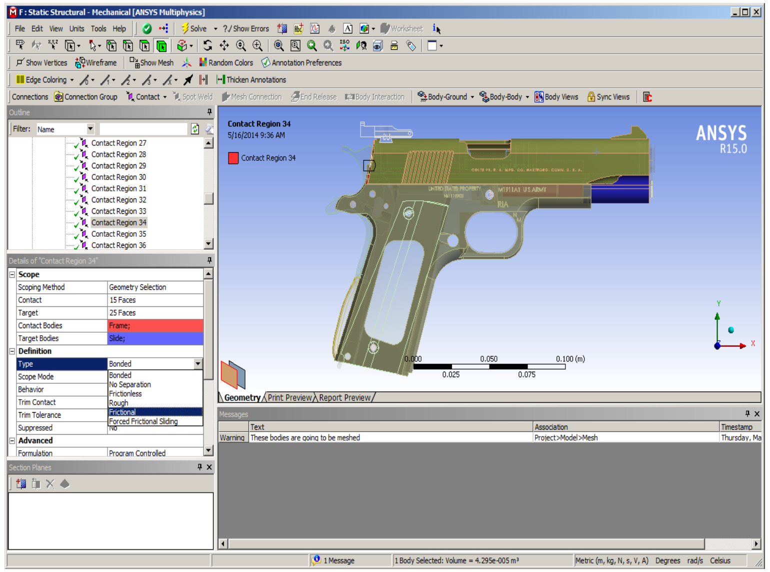
- **Solving fundamental laws of physics**
  - Mass, Momentum, Force balances
- **Predicting**
  - Real life behavior
- **Gain design insight into**
  - High shooting accuracy
    - reduce bullet drag
    - barrel dynamics tuning
    - optimized rifling
  - Where to shave weight, make trigger glide more smoothly
  - Where grime and dirt may build up causing jams
  - Tolerances and conditions that may lead to product recall

What is Physics Based Simulation?

1

2

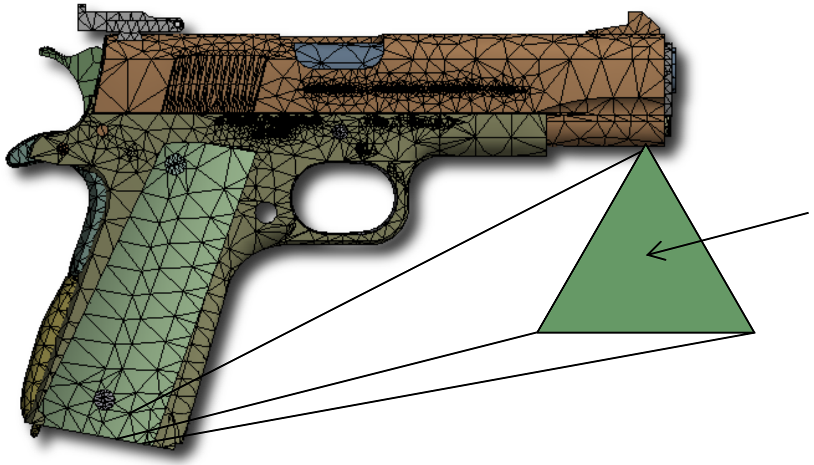
3



4

1. Provide CAD geometry
2. Computational mesh generation
3. Set up physics (Sliding friction, pressure, heat transfer etc.) and solve
4. Post process results

Physics Based Simulation at its Core



- Each type of physics has its own constitutive equations
  - Mechanical
  - Fluids
  - Electromagnetics
- Solutions are known at EVERY mesh cell
  - Velocity, strain, pressure, voltage etc.
- Models are physics based so can be quantitatively predictive

Typical equations solved in each cell depending on physics

Mechanical Stress

$$F = \frac{EA_0 \Delta L}{L_0}$$

$$F = \left(\frac{EA_0}{L_0}\right) \Delta L = kx$$

$$k = \frac{EA_0}{L_0} \text{ and } x = \Delta L.$$

Electromagnetics

$$\nabla \cdot \mathbf{D} = \rho$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J}$$

Fluid Dynamics

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = S_m$$

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla p + \nabla \cdot (\overline{\overline{\tau}}) + \rho \vec{g} + \vec{F}$$

$$\overline{\overline{\tau}} = \mu \left[(\nabla \vec{v} + \nabla \vec{v}^{\,T}) - \frac{2}{3} \nabla \cdot \vec{v} I \right]$$

$$\frac{\partial}{\partial t}(\rho E) + \nabla \cdot (\vec{v}(\rho E + p)) = \nabla \cdot \left(k_{\text{eff}} \nabla T - \sum_j h_j \vec{J}_j + (\overline{\overline{\tau}}_{\text{eff}} \cdot \vec{v}) \right) + S_h$$

Benefits of Simulation

- Insight …
  - Stresses, plastic deformation
  - Velocity, pressure
  - Crack propagation and wear
  - Vibration modes
  - Tolerances and deformation due to thermal load
  - Dynamics / Drop tests
- … leads to improved performance
  - Lighter weight
  - Less felt recoil
  - Better accuracy
  - Better durability (less fouling, resistance to impact damage)
  - Better ergonomics and trigger pull

1942 m1 carbine – build and test

1994 m4 carbine – CAD refined 1960's dsn

2008 Tavor – 3D simulation integrated

Application Examples

- Bullet drag prediction
- Rifling
- Barrel dynamics for accuracy
- Rigid body dynamics for function tests
- Sound and flash suppression
- Gas dynamics
- Bullet impact
- Thermal
- Gas and powder effects

Projectile Drag Prediction

Fig. 1 155mm M2000 (left), and 155mm M107 (right).

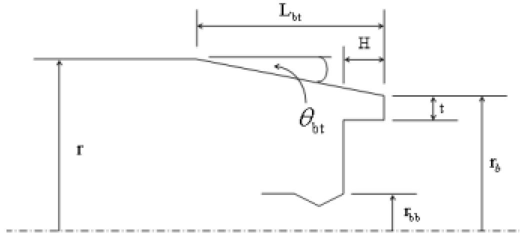


Fig. 2 Geometric parameters of the projectile afterbody with boattail, base bleed, and base cavity.

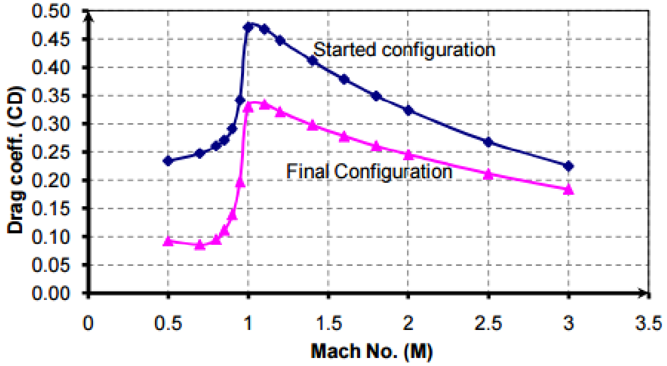


Fig. 16 Reduction in drag coefficient by using a combination of boattail, base cavity and base bleed at different flight regime

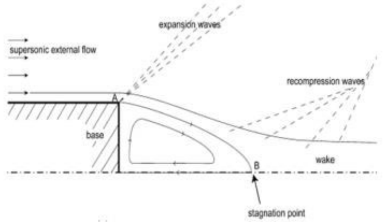


Fig. 4.a Stream lines over circular cylinder afterbody [11]

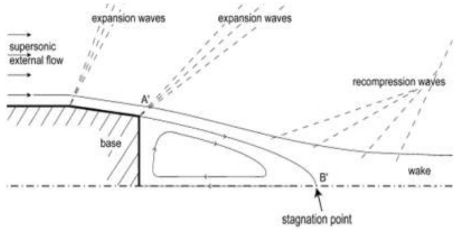


Fig. 5.a Streamlines over a boattailed afterbody [11]

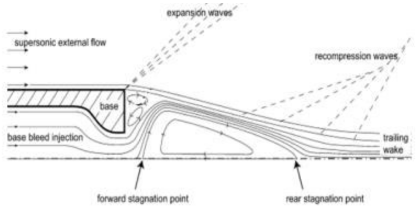


Fig. 8.a Stream lines over afterbody with base bleed [11]

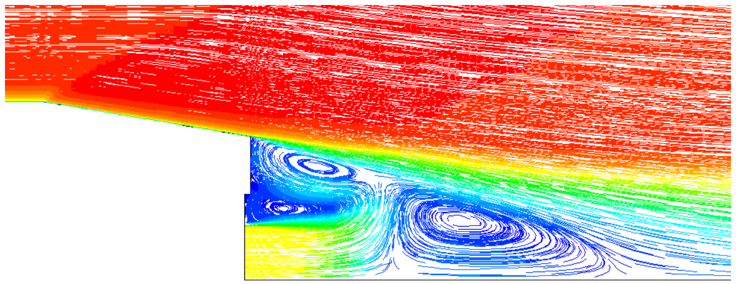


Fig. 15 Stream lines on after body with boattail, base cavity and base bleed

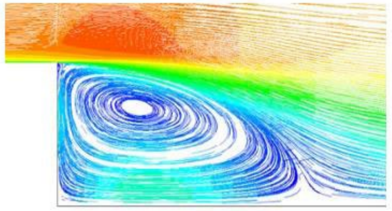


Fig. 4.b Stream lines over circular cylinder afterbody (basic configuration)

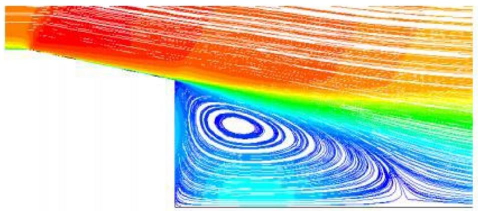


Fig. 5.b Streamlines over a boattailed afterbody

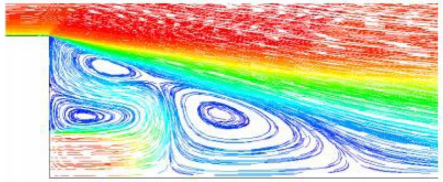
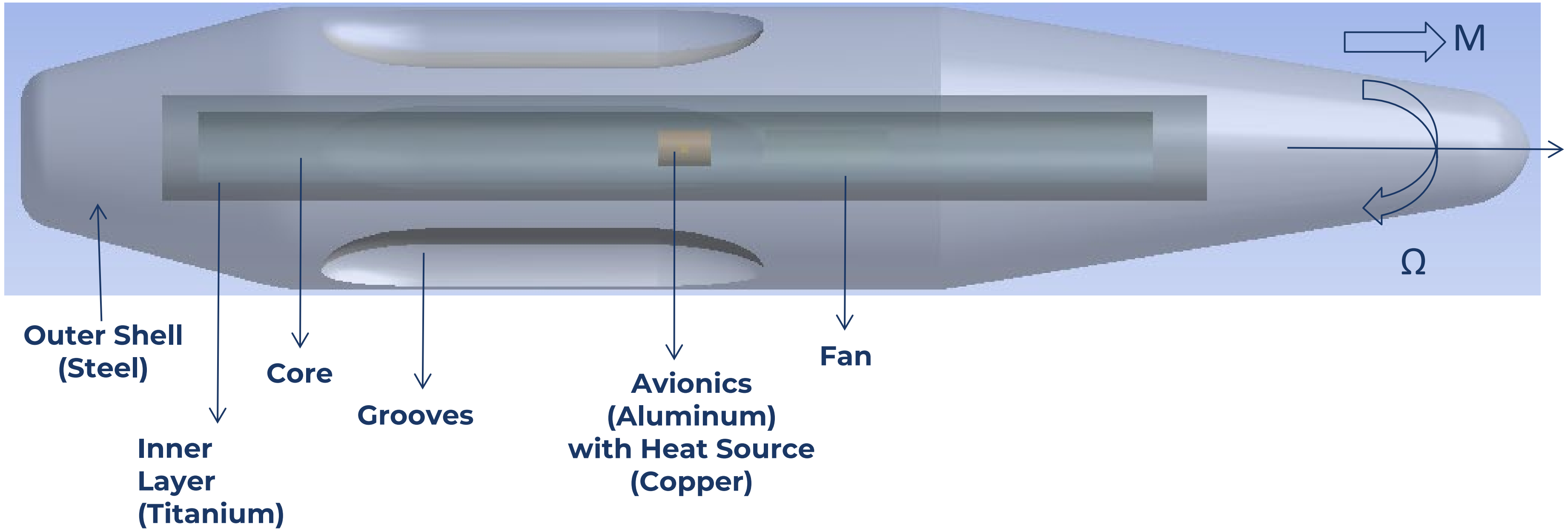


Fig. 8.b Stream lines over afterbody with base bleed

Source : "Computational Investigation of Base Dag Reduction for a Projectile at Different Flight Regimes"

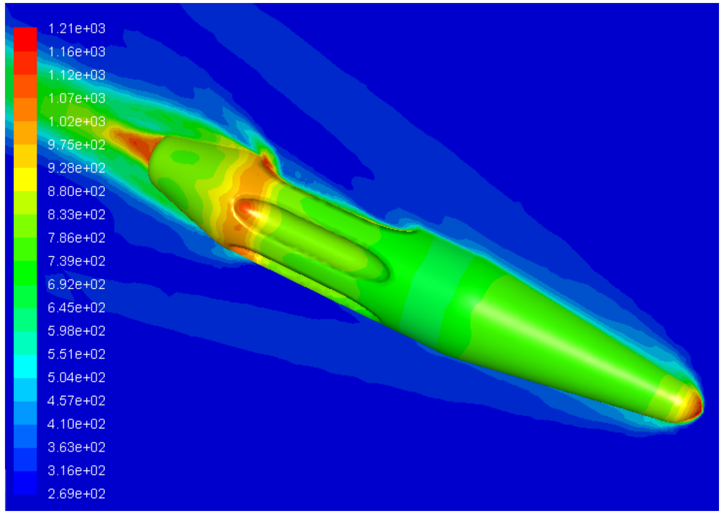
Overview of the Problem

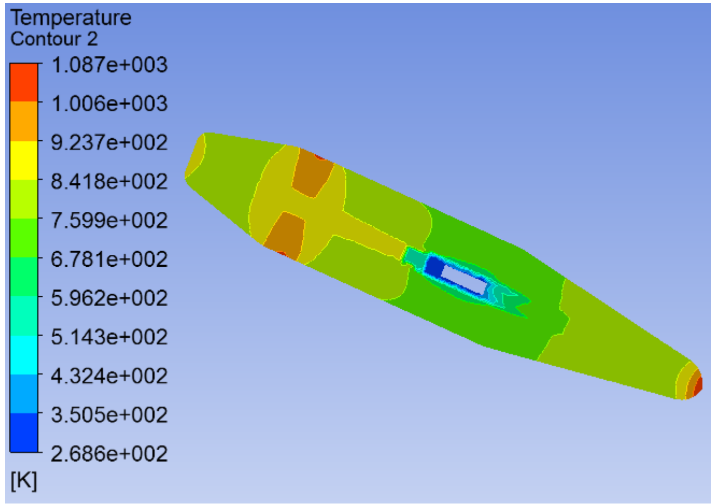
- Supersonic Spinning Projectile with Integrated Avionics
  - Projectile moving at Mach 4
  - Spinning at 30,000 RPM
  - Avionics system containing a heat source of 6.4E6 W/m^3
  - Fan to cool the Avionics system



Flow and Temperature Distribution

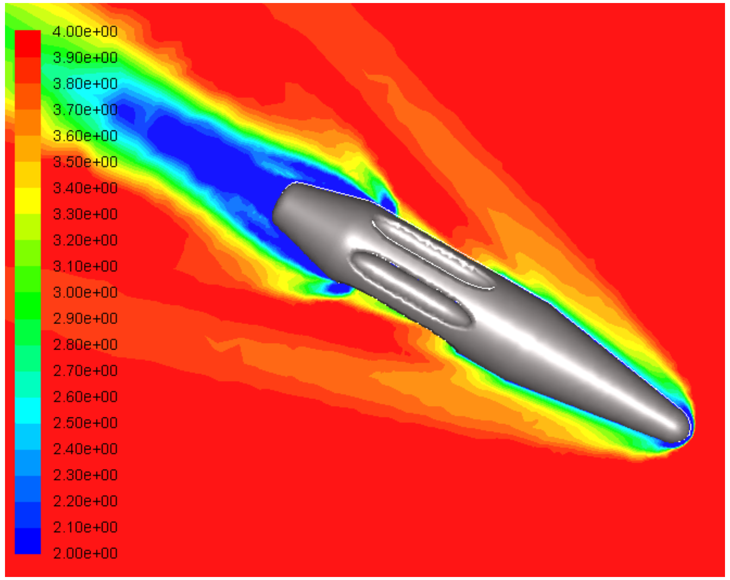
Temperature

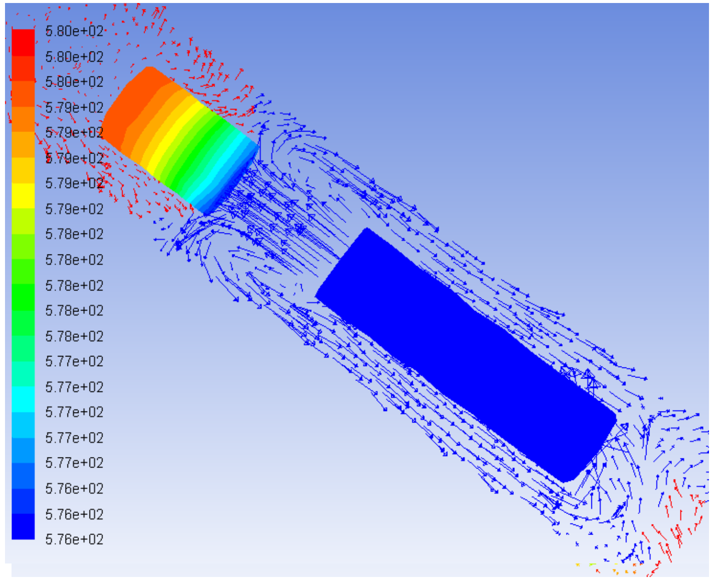




Temperature at a section

Mach Number



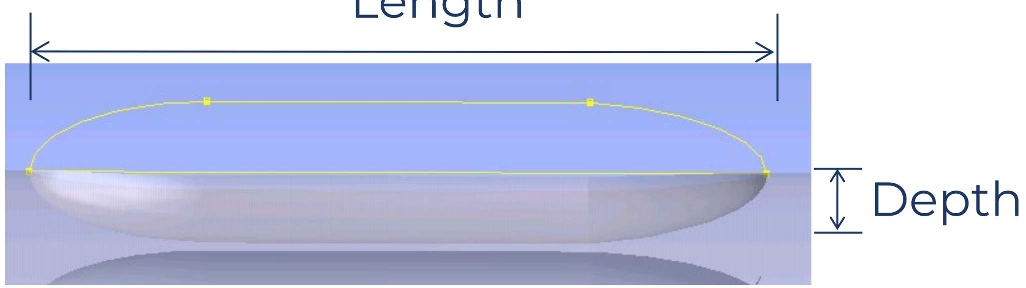


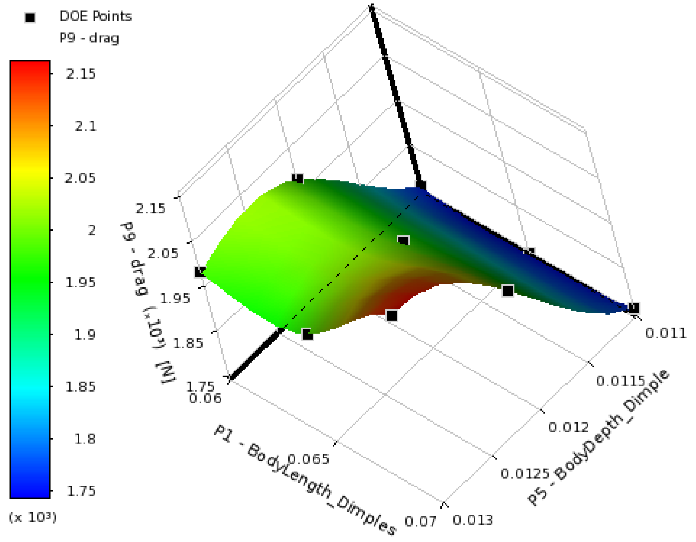
Fan cooling the Avionics system

Optimization of Aerodynamic Loads w.r.t. Groove Length and Depth

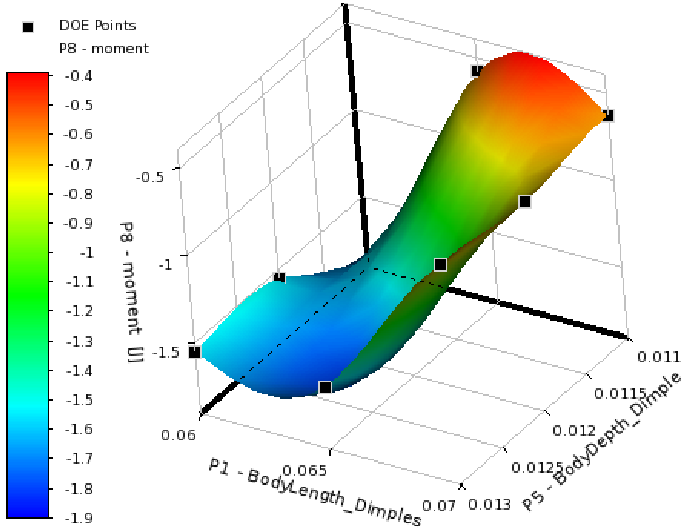
Parameters:

- Length of groove
- Depth of groove





A	B	C	D	E
	P1 - BodyLength_Dimples	P5 - BodyDepth_Dimple	P8 - moment (J)	P9 - drag (N)
Optimization Study				
Objective	No Objective	No Objective	Seek Target	Minimize
Target Value			0	
Importance	Default	Default	Default	Default
Candidate Points				
Candidate A	0.06645	0.011026	★ -0.41761	★★★ 1747.4
Candidate B	0.06805	0.011088	★ -0.45049	★★★ 1759.1
Candidate C	0.06725	0.011151	★ -0.47147	★★★ 1769.4

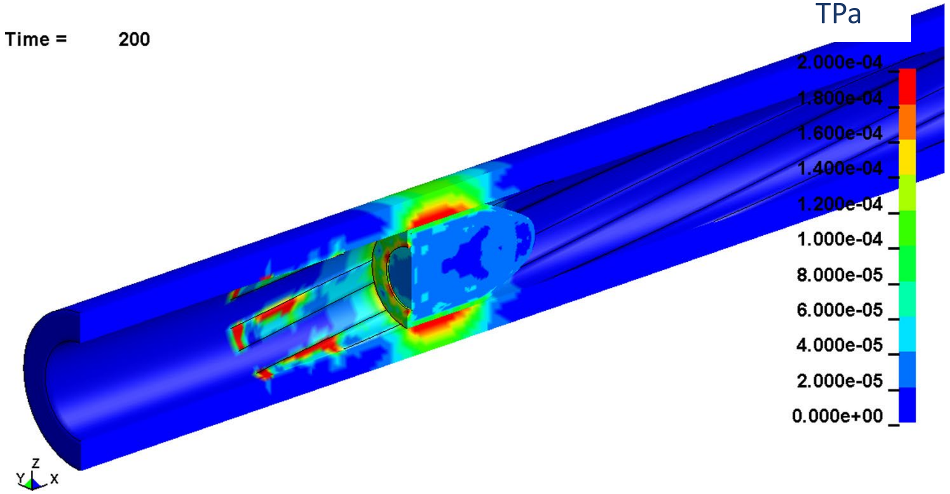


DIRD

In-Bore Ballistic: Rifling

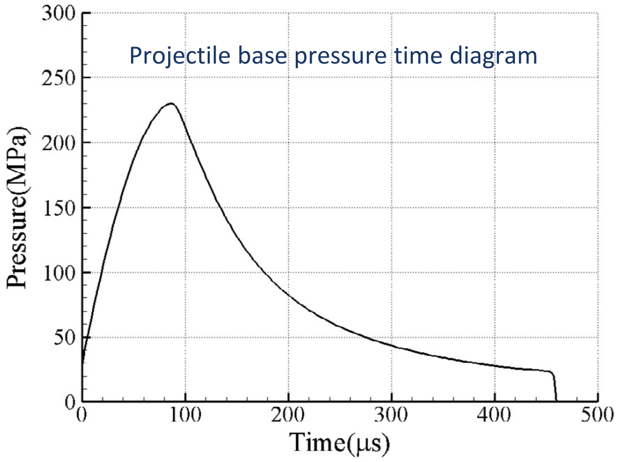
Pistol parameters.

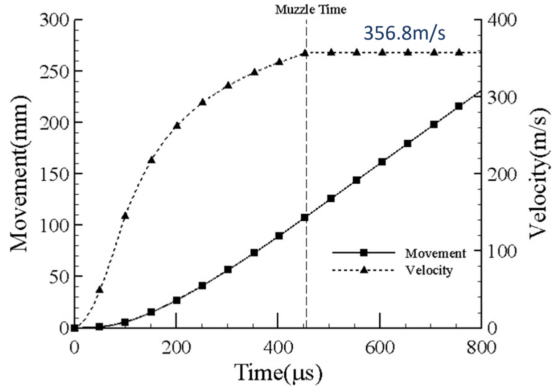
Target	Items	Parameters
9 mm pistol	Caliber (mm)	9
	Length of barrel (mm)	98
	Muzzle velocity (m/s) (measured from experiments)	350
	Quantity of riflings	6
	Mass of propellant (g)	0.325
	Mass of bullets (g)	9.45

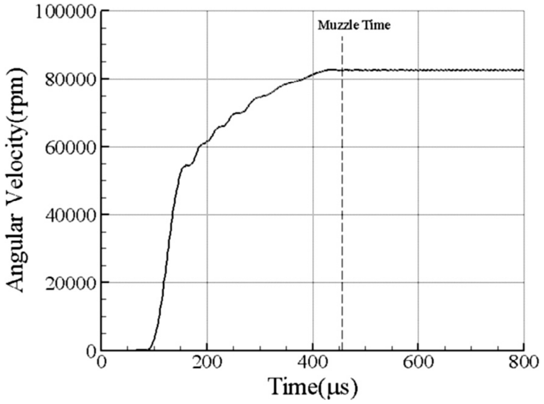


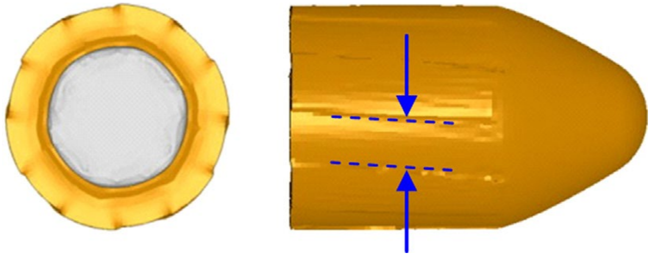
Instantaneous stress and residual stress at t= 200 us

Deformed bullet after shooting by real shot







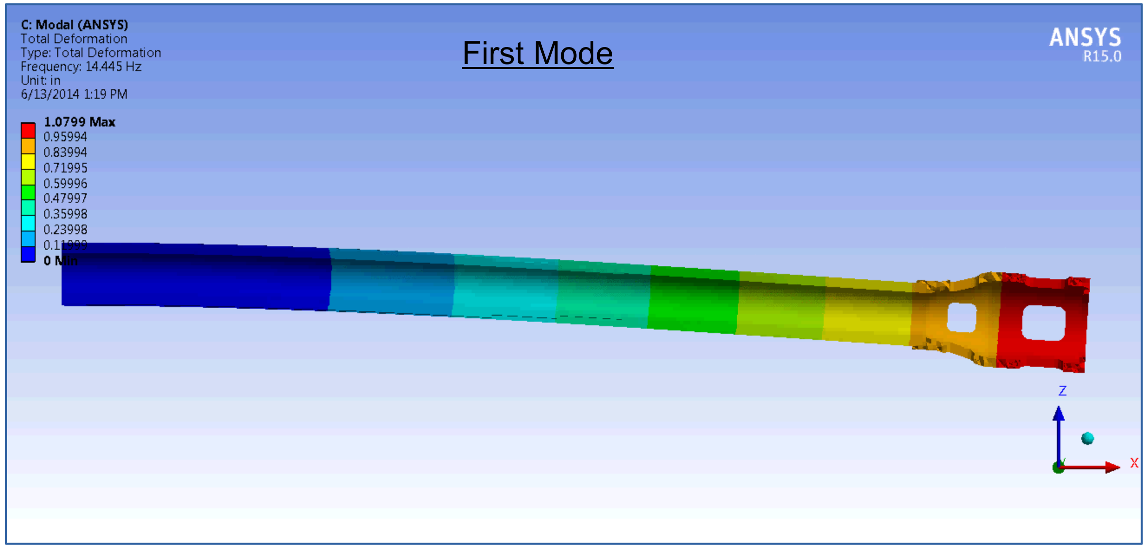


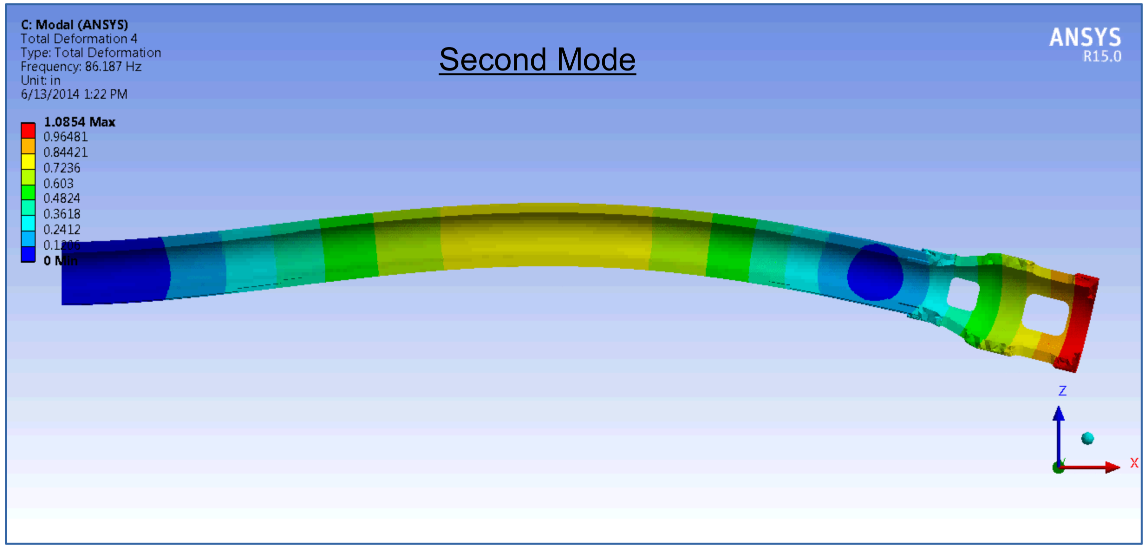
Deformed bullet after shooting by numerical simulation

Source: Transient finite element for in-bore analysis of 9 mm pistols, S. Deng et al., Applied Mathematical Modelling 38 (2014) 2673–2688

Barrel Dynamics
Vibrations & Harmonic Tuning

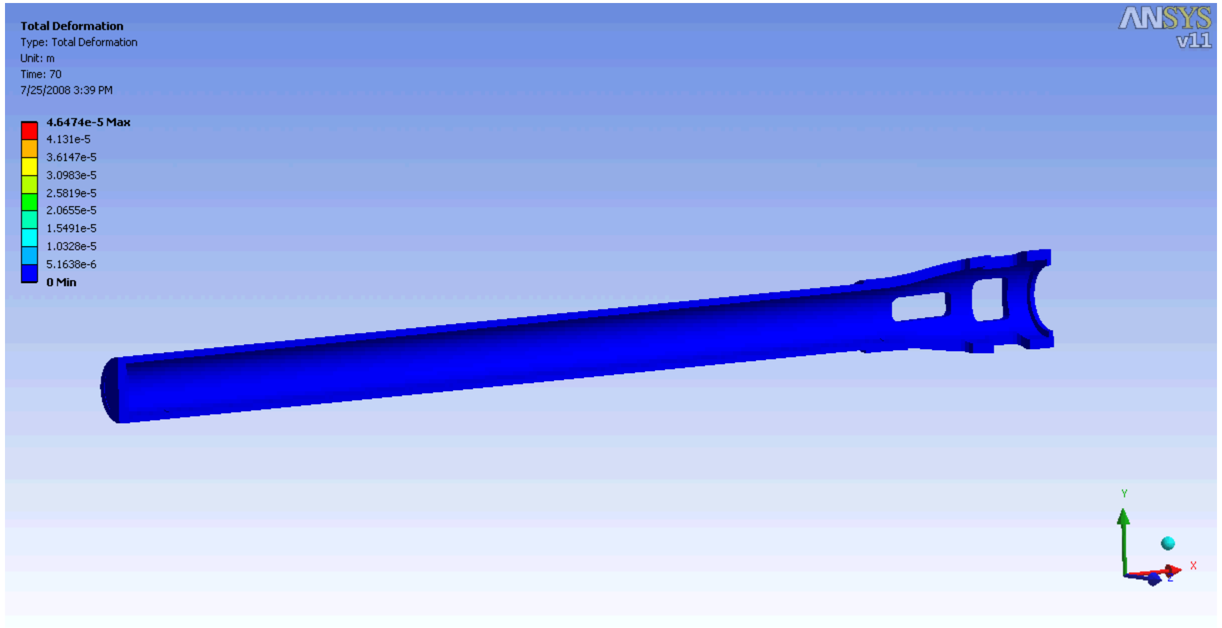
- Important for out-of-the box accuracy
- Depends on barrel shape
- Thermodynamics (non-uniform barrel heating/cooling) can be considered
- Find modes through simulation to minimize muzzle effect



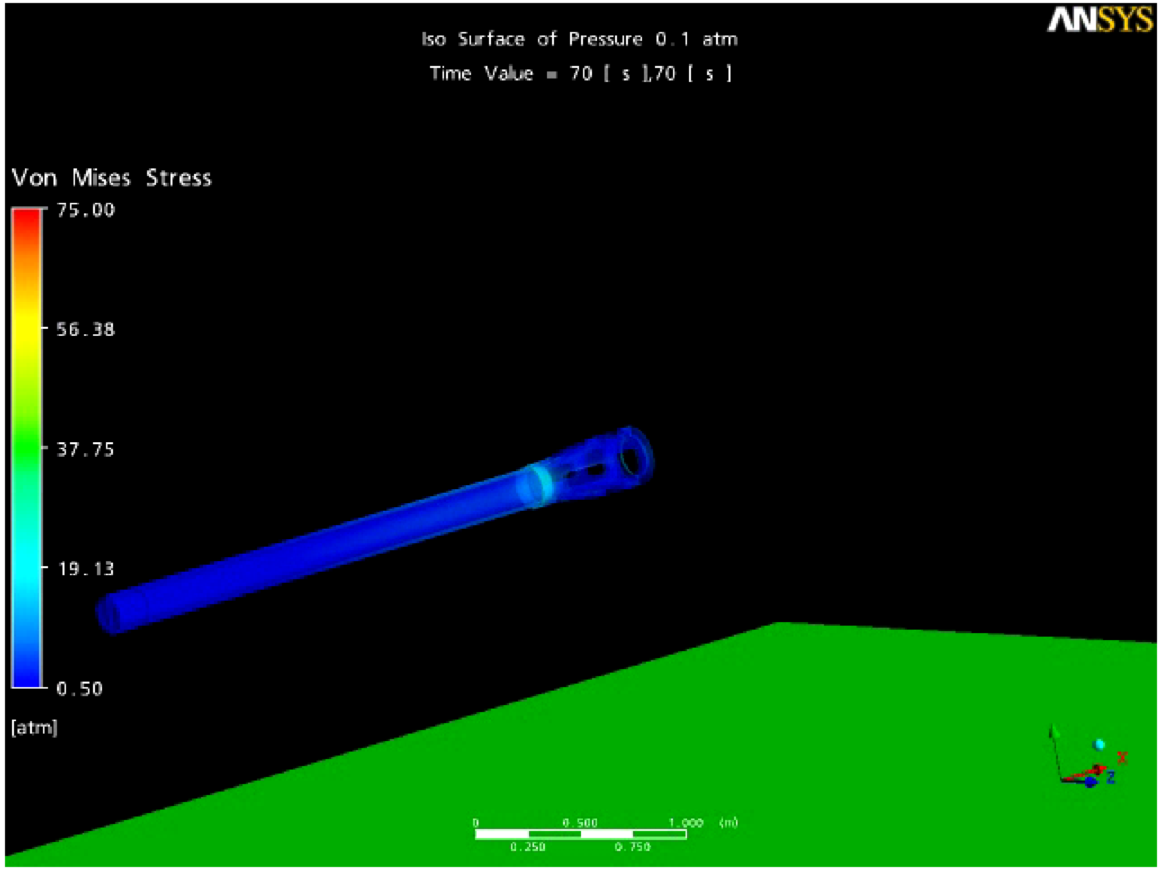


Barrel motion amplified ~ 1000x for ease in visibility

ANSYS FSI : Large Caliber GUN FSI



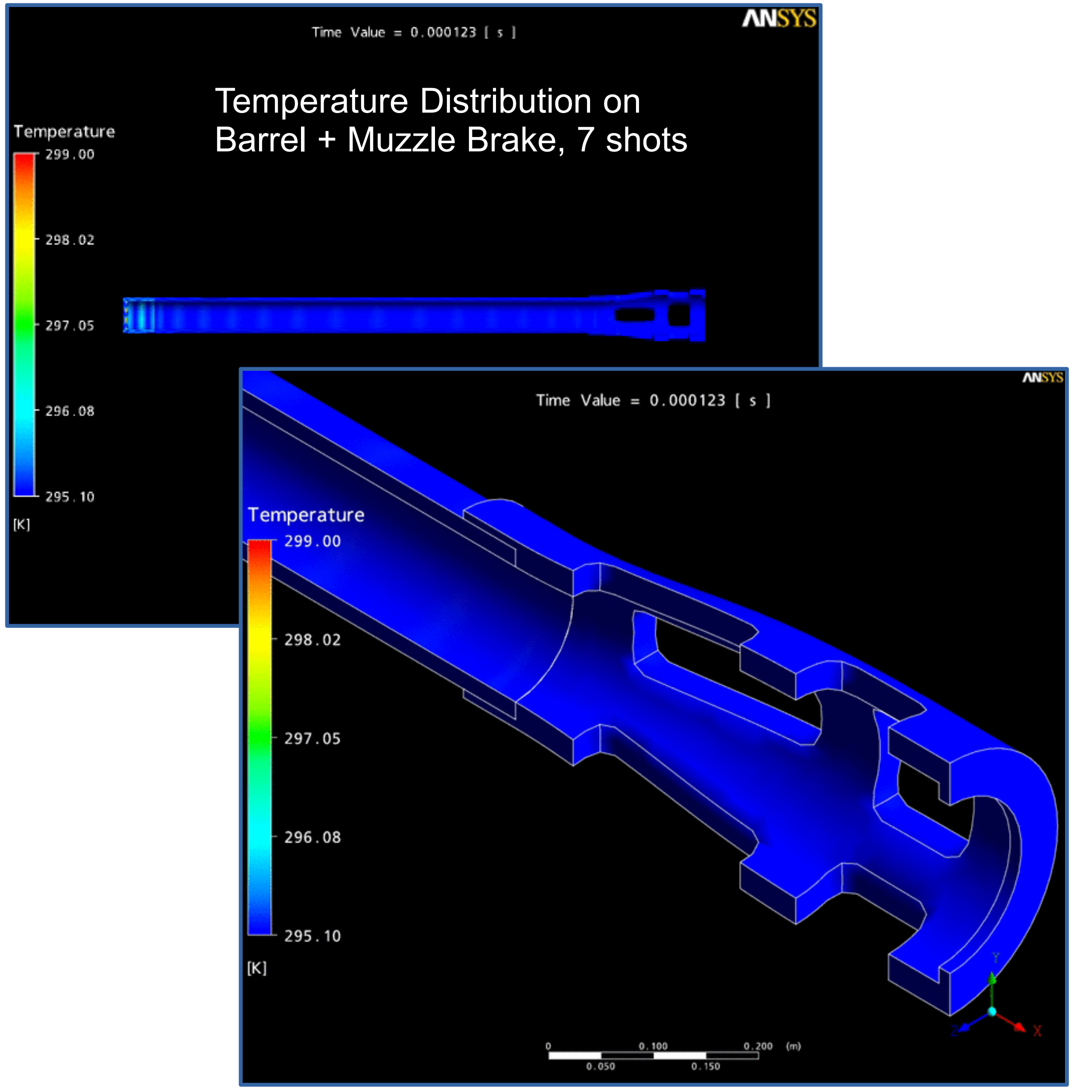
Gun Deformation * 25000 – 7 Shots



Stress Distribution & Iso-surface of Pressure – 7 Shots

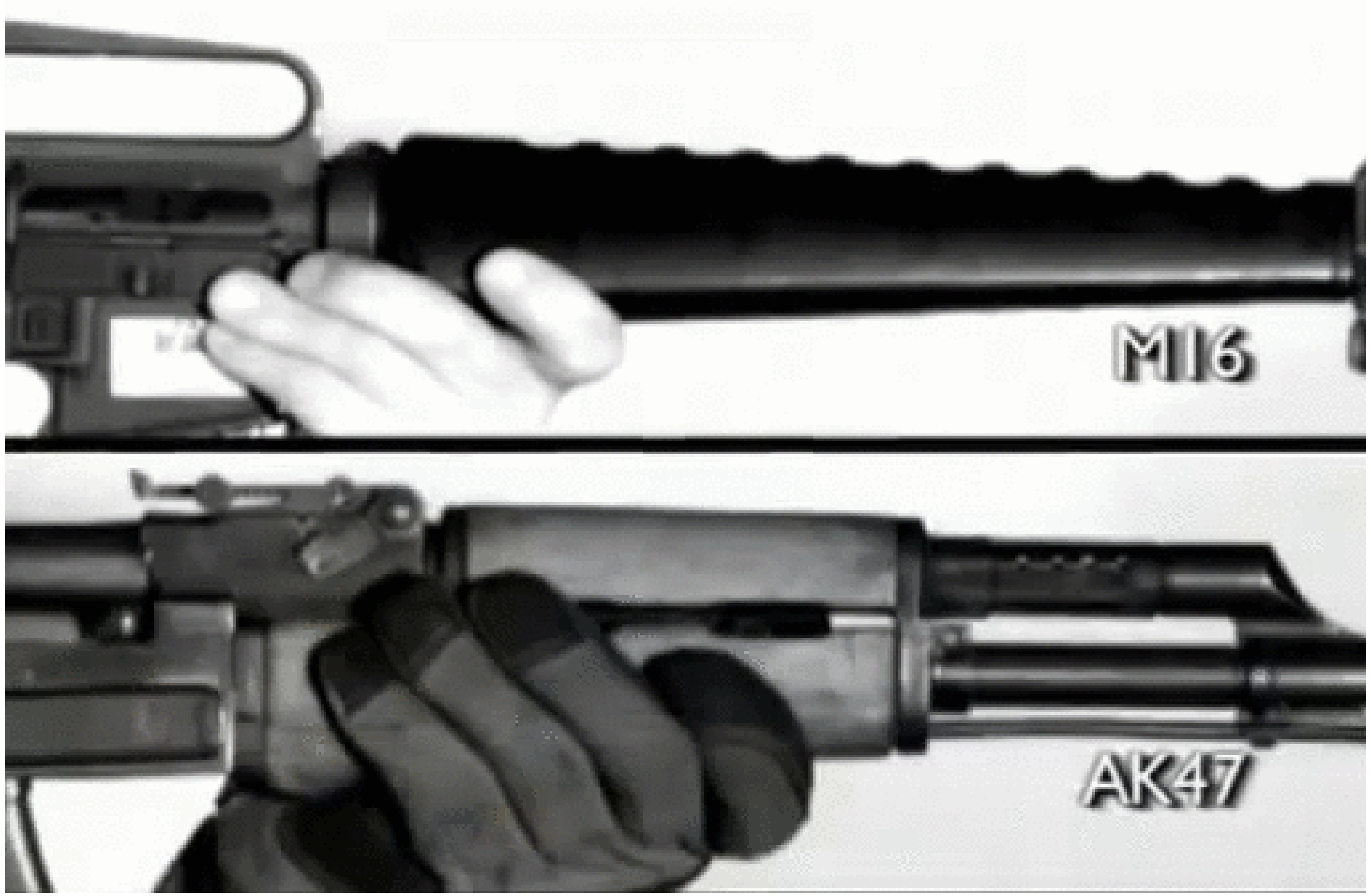
Thermal Management for High Firing Rates

- Determine barrel and muzzle break/suppressor temperature due to rapid fire scenarios
- Determine risk of cook-off due to prolonged firing
- Determine risk of thermal expansion changing aim point or increased blow-by



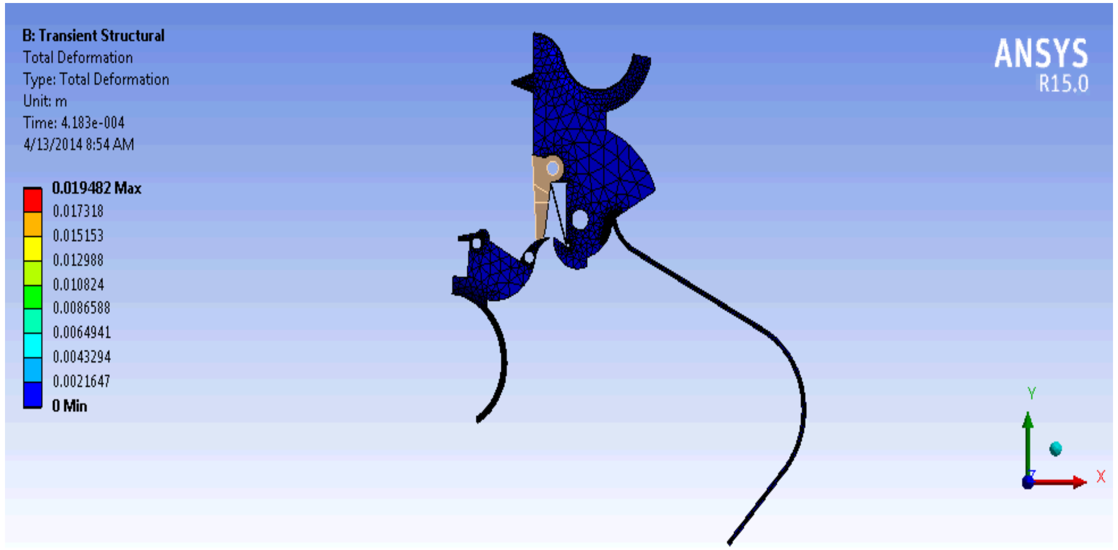
Barrel Dynamics

- ANSYS solves fundamental physics
  - Barrel thickness and profile can be examined
  - Behavior of barrel as part of a weapon system including lights, sights etc.



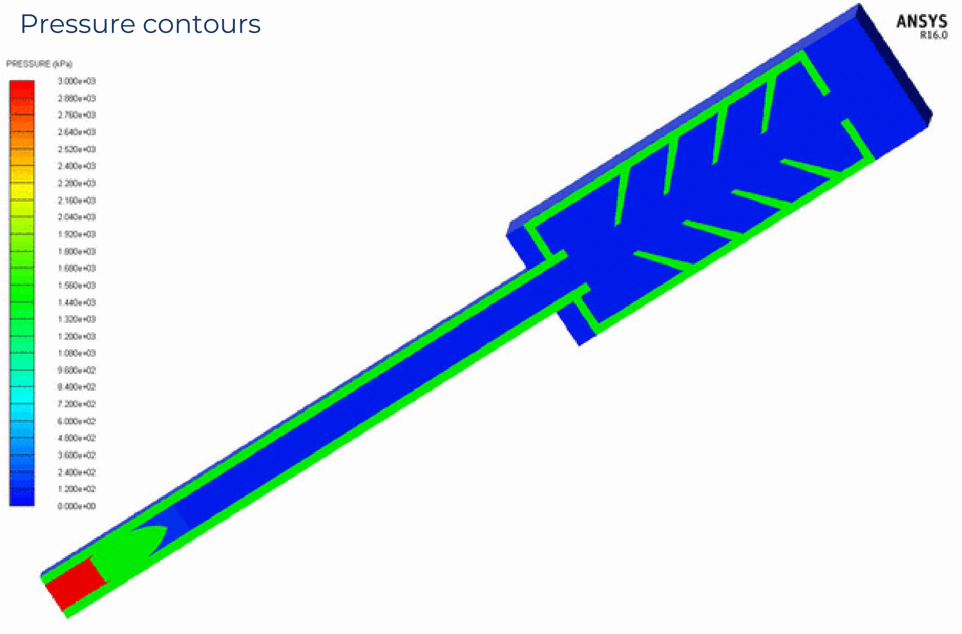
Rigid Body Dynamics for Function

- Optimize trigger pull
- Predict safe, smooth trigger pull
- Optimize materials and design before cutting metal
- Parametrically test before determining final design
- Tolerance stacking for proper operation while accounting for manufacturing inconsistency

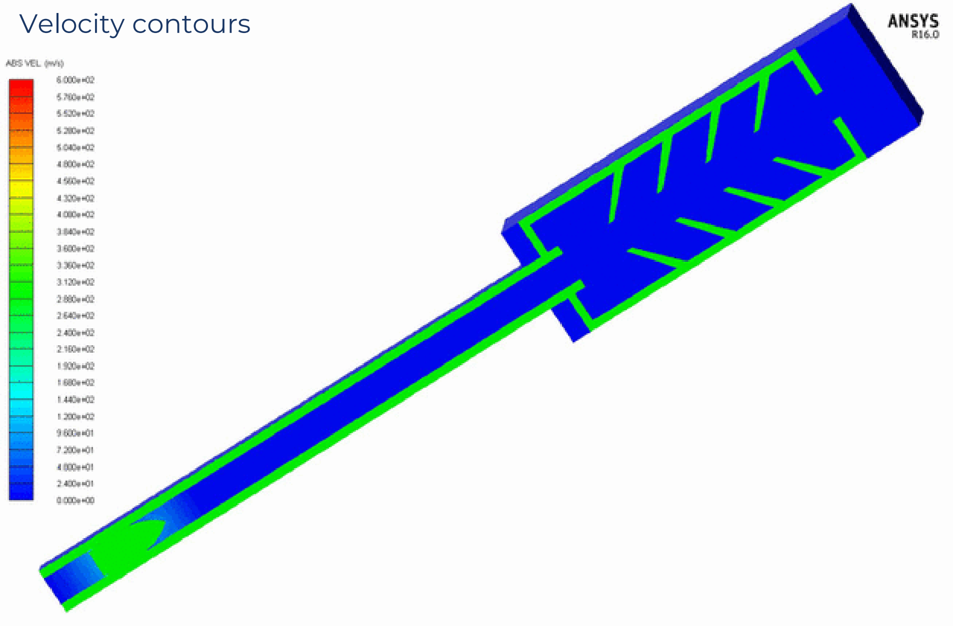


Suppressor/Silencer

- Primary goal of a suppressor is to cancel out pressure waves and expand gasses more slowly
- There can be positive impact on accuracy with a high-quality design
  - Additional weight at end of barrel
  - Lower velocities as bullet exits which reduces effect of muzzle end non-uniformities



Pressure contours

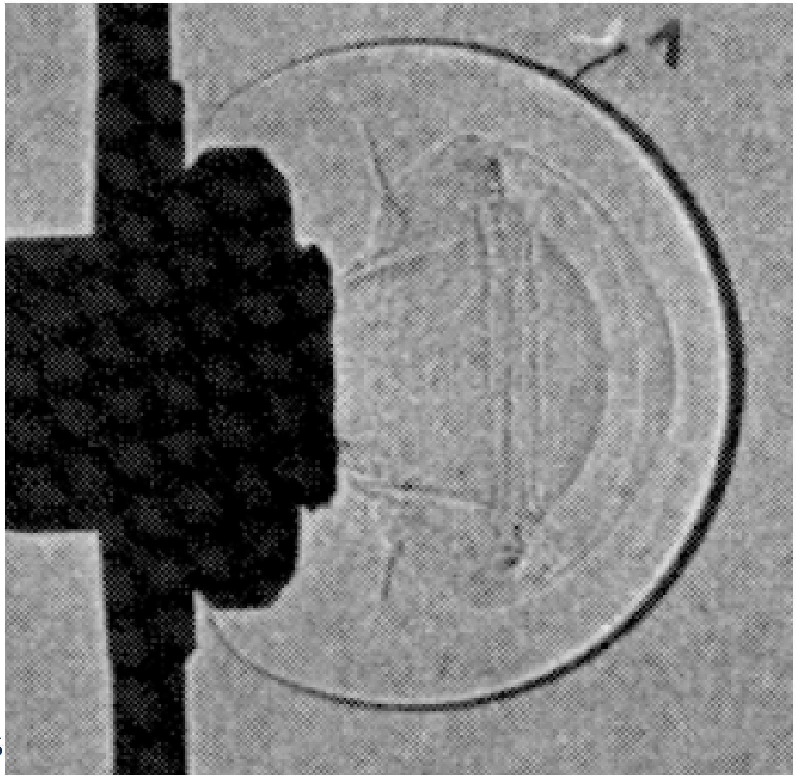


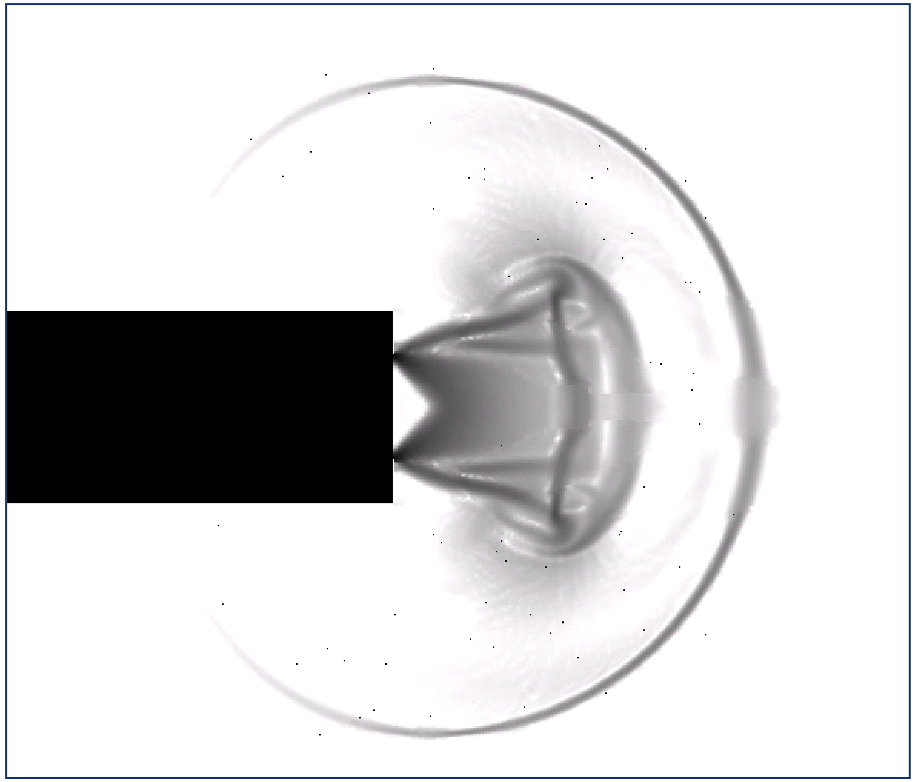
Velocity contours

Muzzle Blast and Gas Dynamics

Gun Muzzle Blast and Flash, Progress in Astronautics and Aeronautics, Vol. 139; Klingenberg, Gunter, Heimerl, Joseph M., Seebass, A. Richard Editor-in-Chief, AIAACFD

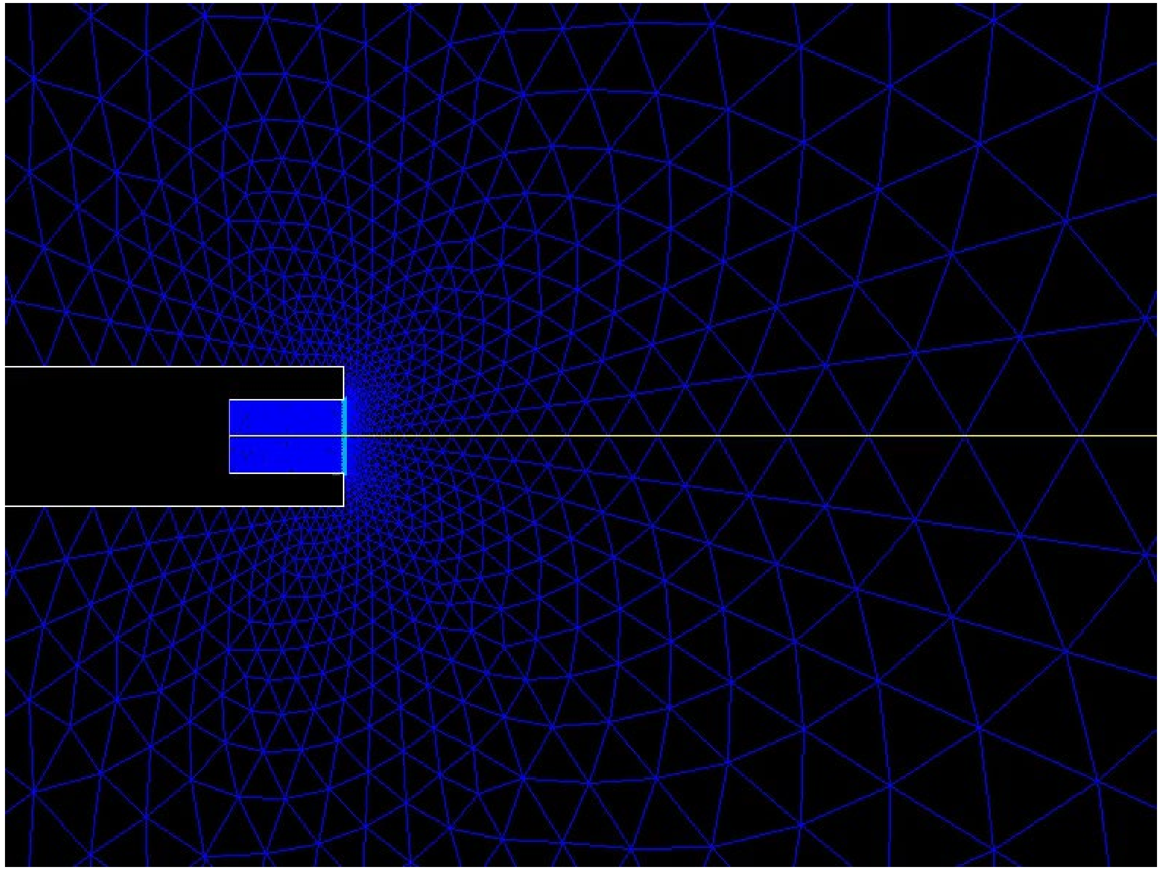
- 350 microseconds after ignition
- Muzzle geometries are slightly different
- Remarkable similarities in shock waves which will impact noise level and bullet flight



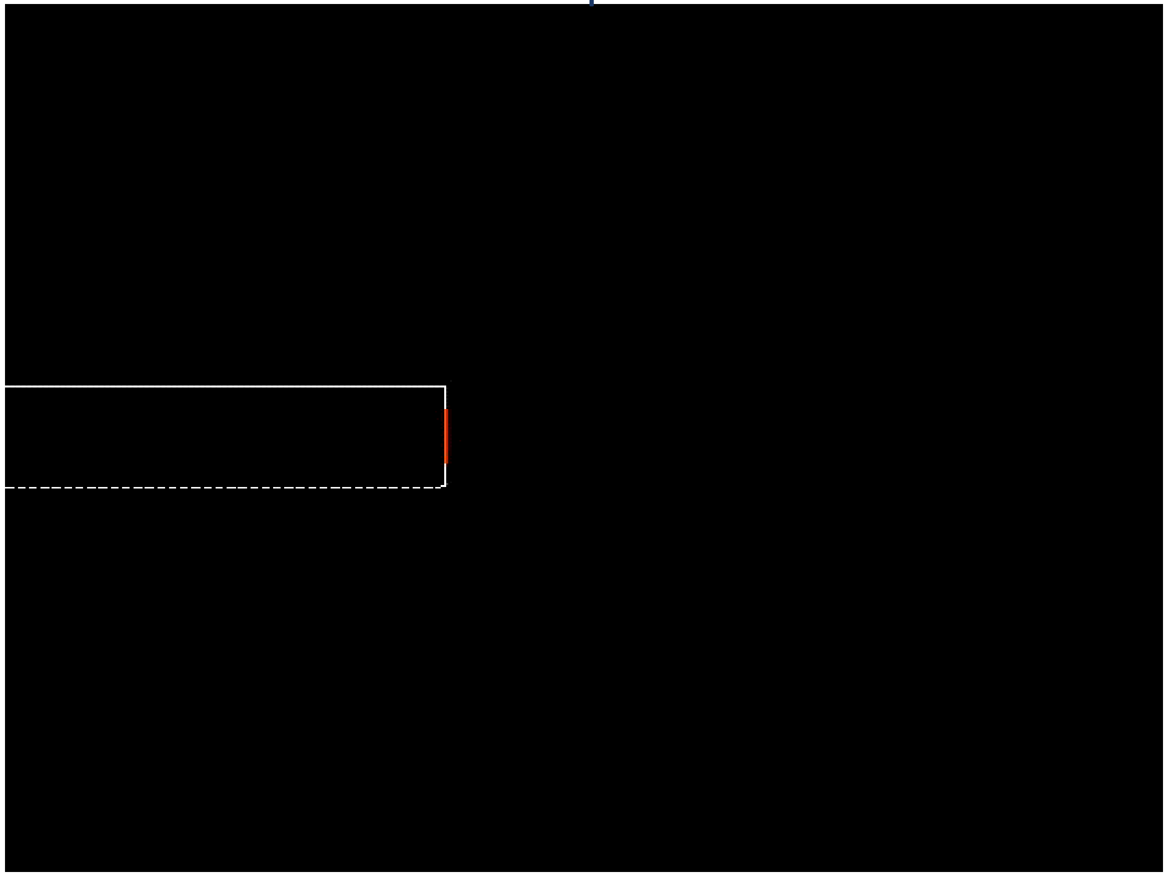


Solution Based Adaptive Mesh

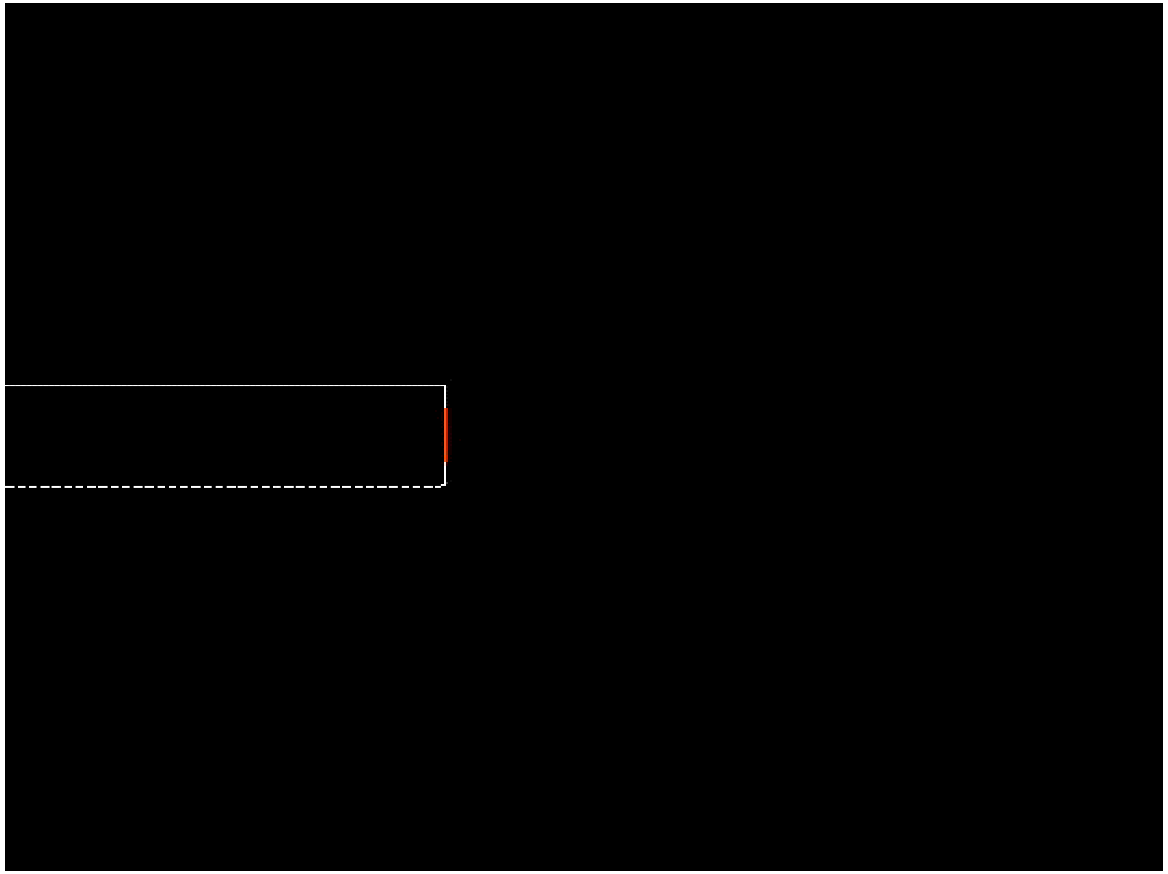
Solution based adaptive mesh refinement

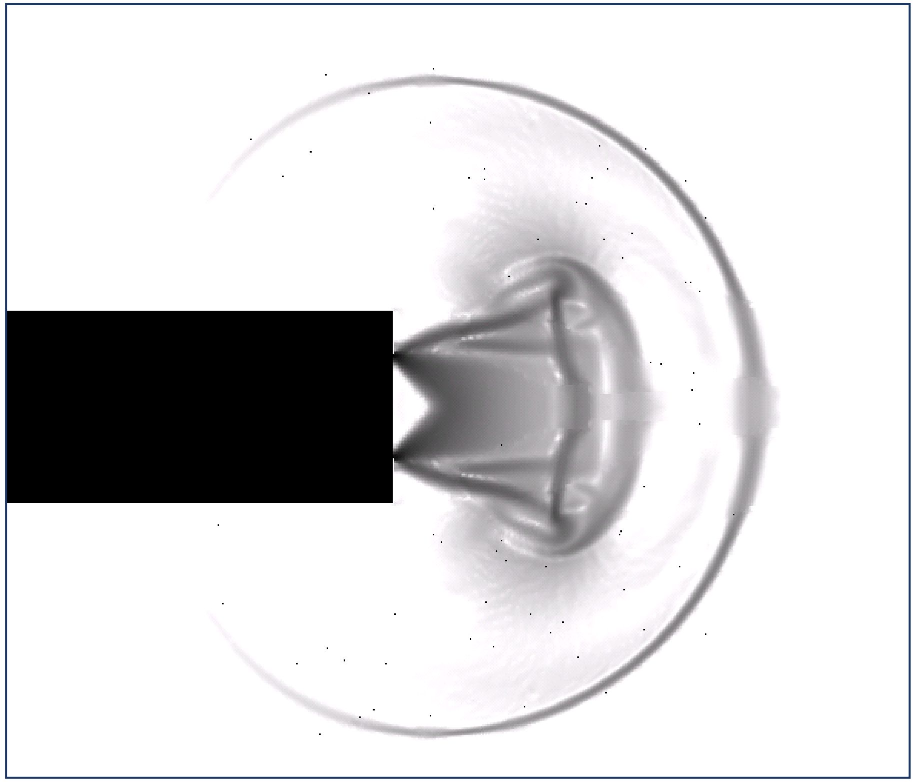


Near field pressure wave



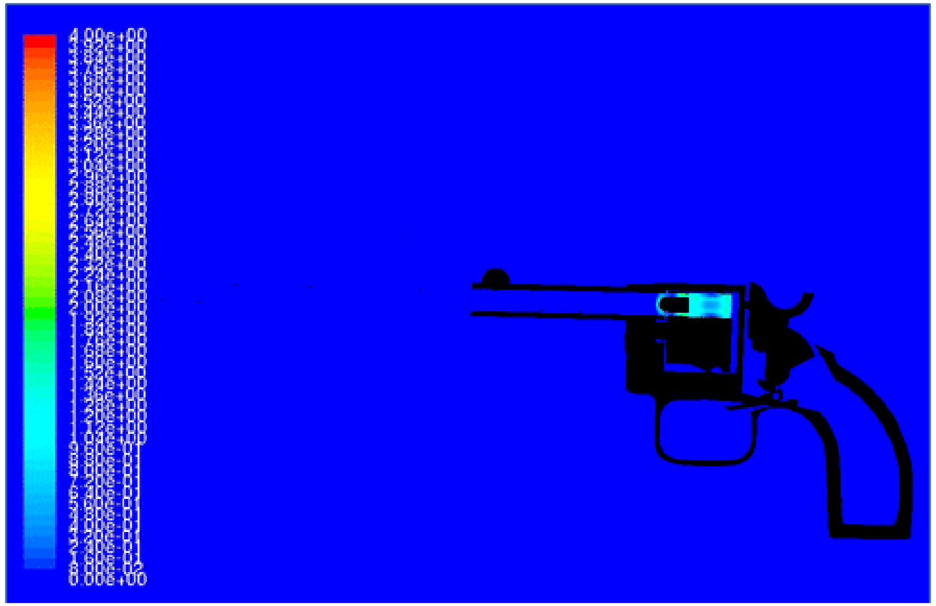
Comparison of Simulation to Test





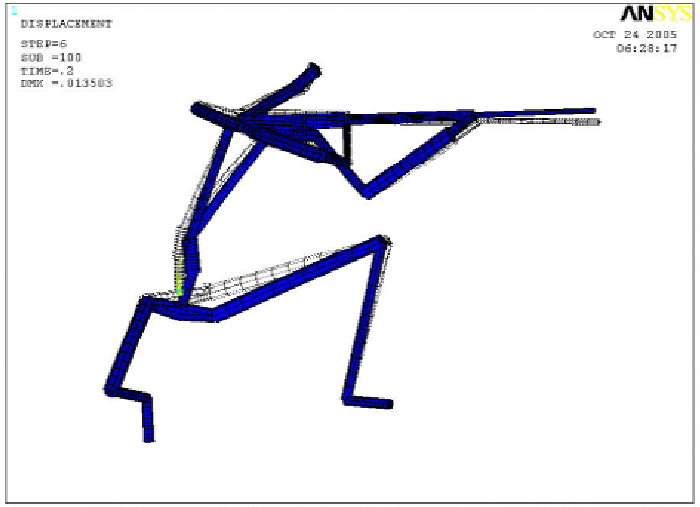
Gas/Powder Effects

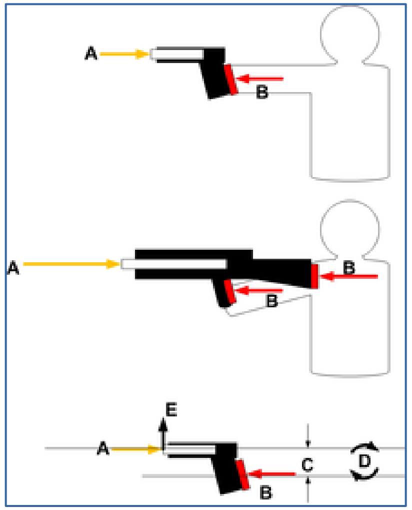
- Powder splash back
- Blow by
- Gas operation
- Fouling



Reducing and Predicting 'Felt Recoil'

- Ergonomics and position of forces
- Prediction of human body interaction
- Effect of action delay and length of travel
- Effect of active devices like barrel porting or muzzle brake

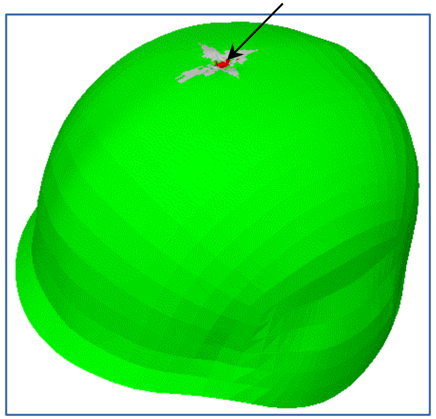




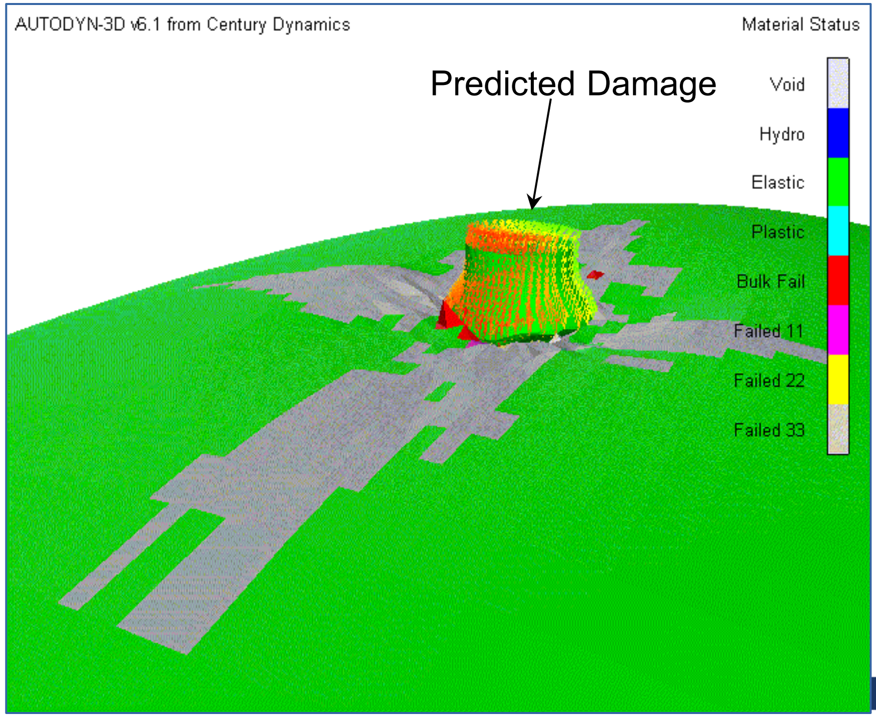
Bullet Penetration into Composite Body Armor or Helmet

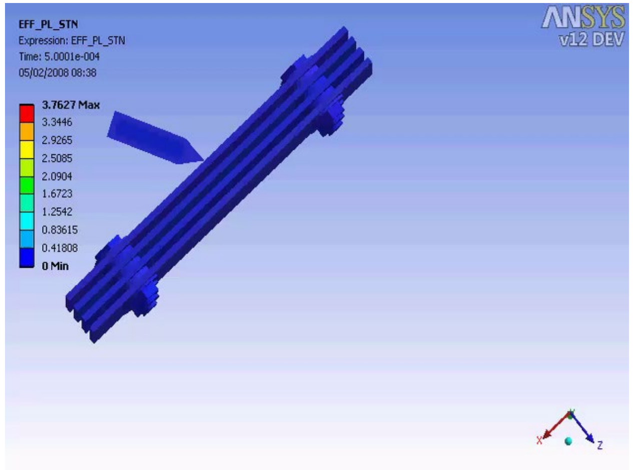
- Confirm penetration power of bullet
- Confirm if impact velocity and hence muzzle velocity is sufficient for penetration of target threat
- Confirm bullet design
- Confirm design of helmet or body armor to resist current threat

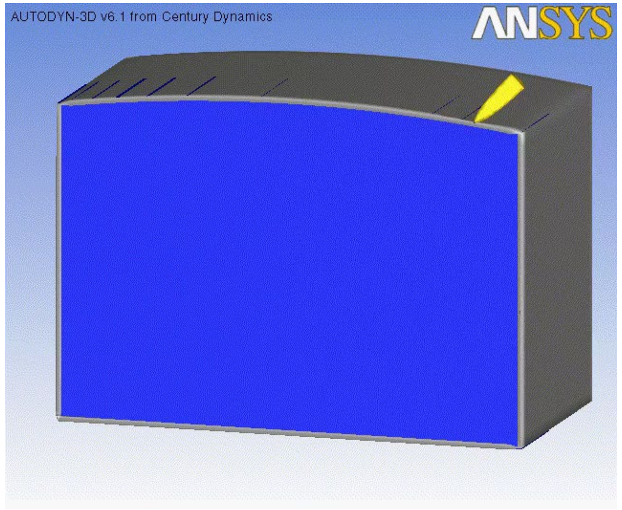
Predicted Damage



Actual Damage







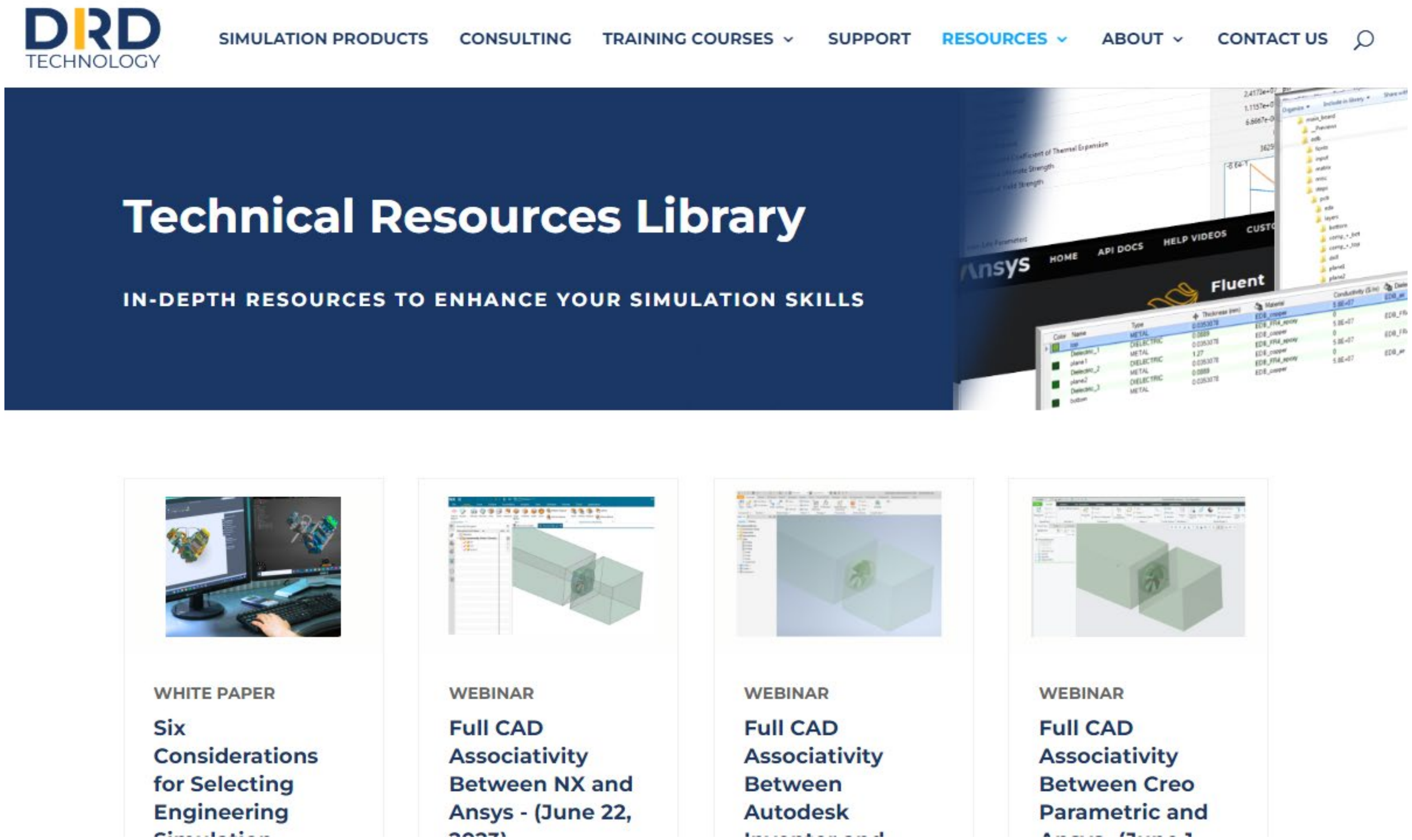
DRD

Summary

- ANSYS provides comprehensive tools for firearm and armament simulations
  - Bullet drag prediction and optimization
  - Gun barrel dynamics
  - Rifling
  - Silencer and muzzle design
  - Bullet penetration and impact
  - And more..
- Top notched technical support to ensure customer success
  - Customer can start simple and grow as expertise accumulates and/or business needs arise

Wrap Up

The recording and slides for this webinar are in our Technical Resources Library.



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Wrap Up

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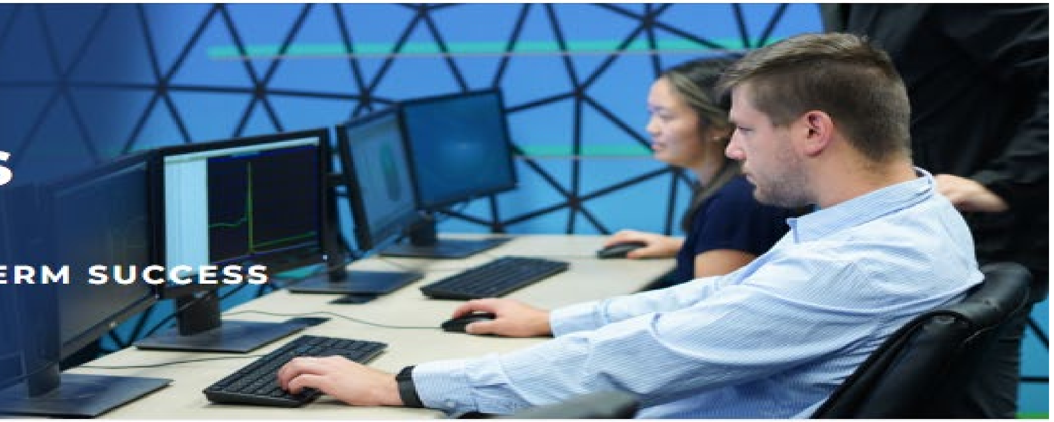
Ansys Training Courses

COMPREHENSIVE TRAINING FOR YOUR LONG-TERM SUCCESS



Whether you're onboarding with the Ansys platform or looking to take your simulation proficiency to the next level, we have a training course carefully designed to fit your needs. With frequent introductory and advanced courses conducted live virtually and in-person or on-demand, we offer many opportunities for you to get the training experience that best suits your needs. Additionally, since our trainings are conducted by our in-house engineering and physics experts, we have the unique opportunity to carefully listen to your requirements and further refine our custom training materials to help you continually meet your goals.

Explore our training center below.

Wrap Up

Thank you for your attention!

May I address any questions?