NDIA – 2010
Numerical Prediction of Large Caliber Cannon Impulse

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

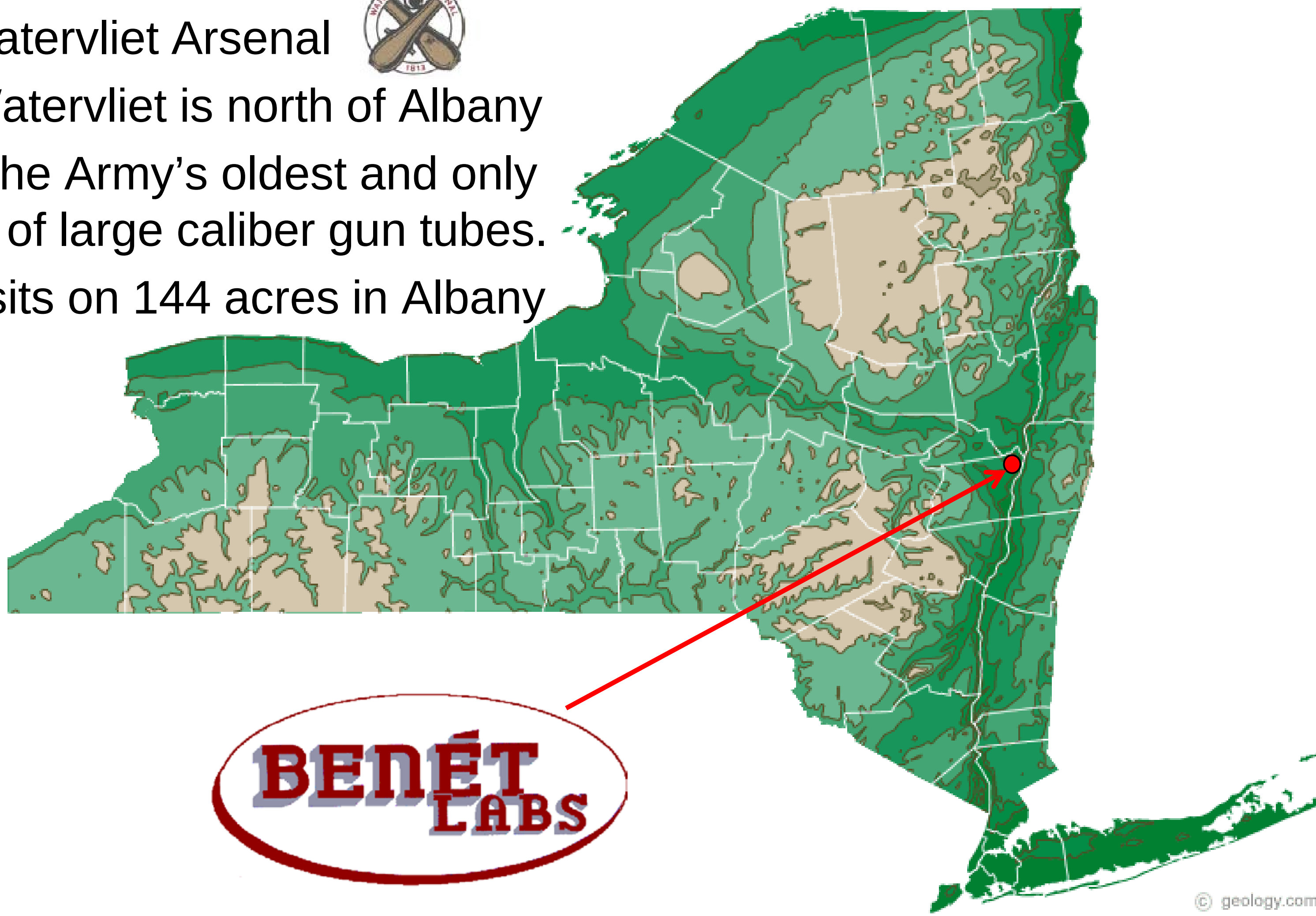
Bob Carson
Mechanical Engineer
Fluid Dynamics Analyst
Date: 19 May 2010

AGENDA

- Where is Benet Laboratories?
- What is a Large Caliber Cannon?
- What is a Cannon Muzzle Brake?
- Why is this Relevant?
- Results of Analysis
- Conclusions and Ongoing Work

OUR LOCATION

- Located at Watervliet Arsenal
- The City of Watervliet is north of Albany
- Watervliet is the Army's oldest and only manufacturer of large caliber gun tubes.
- The Arsenal sits on 144 acres in Albany County.



BENÉT LABS

ORGANIZATIONAL HIEARCHY

DEPARTMENT OF THE ARMY

ARMY MATERIEL COMMAND (AMC)
GEN ANN DUNWOODY
Wash, DC

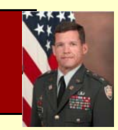
RESEARCH, DEVELOPMENT, & ENG'G COMMAND (RDECOM)
MAJ GEN NICKOLAS JUSTICE
Ft. Belvoir, VA

TACOM LIFE CYCLE MGMT COMMAND (TACOM-LCMC)
MAJ GEN SCOTT G. WEST
Detroit, MI

ARMAMENT RD&E CENTER (ARDEC)
DR. JOSEPH A. LANNON
Picatinny, NJ

Benet Laboratories
developer of
Army and USMC Large Caliber Cannon

Mr. Lee Bennett



Watervliet Arsenal
producer of
Army & USMC Large Caliber Cannon

Col. Scott Fletcher

Joint Manufacturing and Technology Center at Watervliet (JMTC-WV)
Watervliet, NY

- Research & Engineering Division of Watervliet Arsenal renamed Benét Laboratories in 1962
- Became part of the US Army Armaments RD&E Center (ARDEC) in 1977
- Benét Laboratories' cannons have been produced at Watervliet Arsenal since 1887.

Malcolm Baldrige National Quality Award 2007 Award Recipient

ORGANIZATIONAL MISSION

MISSION

Plan, program, budget, manage, and execute the technology base, life cycle engineering, manufacturing technology development & implementation, production support, and field support and sustainment for:

- ***Large Caliber Cannon*** (conventional and electromagnetic)
  - Howitzer Cannon (indirect fire)
  - Guns (direct fire)
  - Mortar Cannon, BiPods & Baseplates
- ***Large Caliber Direct Fire Gun Mounts***
- ***Large Caliber Direct Fire Vehicle Turret Components***

} Mission Items

Large Caliber Cannon   CRADLE-To-GRAVE

Armament Technology - Design & Development – Manufacturing Technology Development @ WVA
Production Support - Field Support & Sustainment – Industrial Base Support

Benet Laboratories -Watervliet Arsenal Cannon Product Line

Technology- Design- Development- ESIP- Field Sustainment

120mm M256 Cannon
M1A2 ABRAMS System

155mm M284 Cannon
M109A6 PALADIN System

81mm M253 Mortar Barrel
M252 Medium Mortar System

120mm M298 Mortar Barrel
M120 Heavy Mortar System

105mm M68A2 Cannon
Stryker System

155mm XM776 Cannon
M777 System

81mm M253 Mortar Barrel / M252 Mortar System on
USMC LAV Carrier-mounted Mortar Vehicles

60mm M225 Mortar Barrel
M224 Mortar System

155mm M199 Cannon
M198 System

120mm M298 Mortar Barrel / M121 Mortar System on
M1064 Carrier-mounted Mortar Vehicles

105mm M20A1 Cannon
M119 System

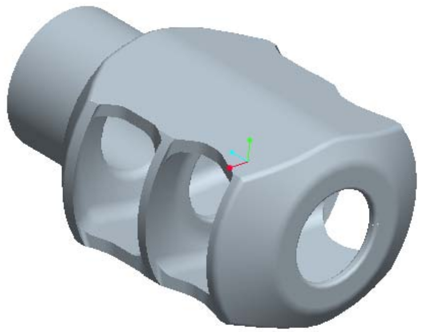
105mm M137 Cannon
M102 System

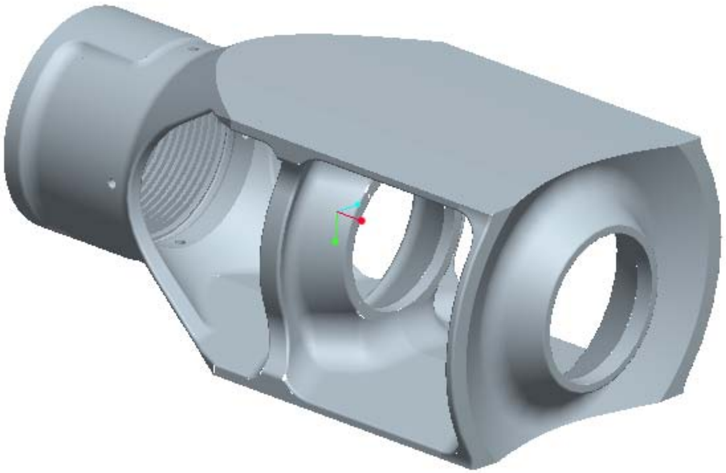
105mm M137 Cannon
AC-130 Gunship

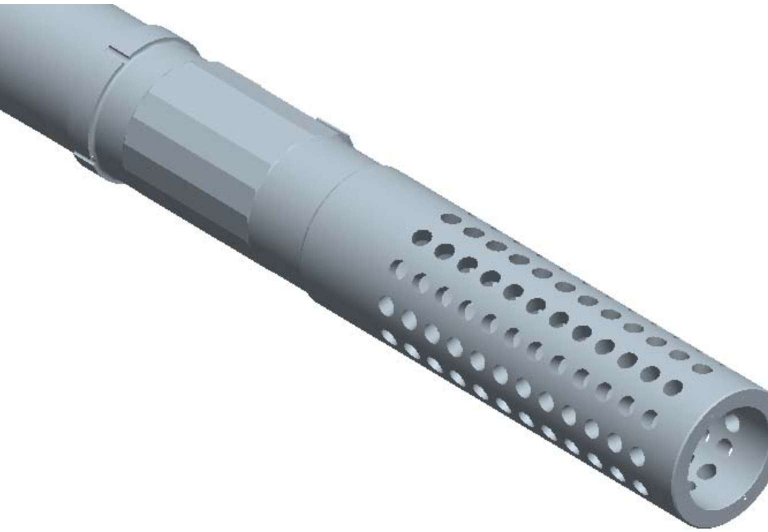
XM360 Cannon System

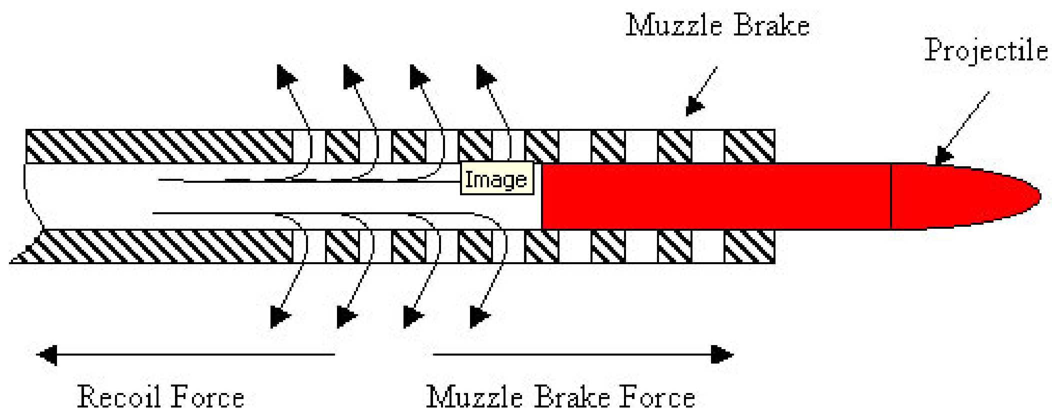
- Future Combat Systems (FCS) 2003 – 2009.
  - Goal - strategically deployable, tactically superior and sustainable force
- Mounted Combat System (MCS)
  - Lighter and more easily transportable
  - Reduced crew requirements
- 120 mm smooth bore cannon
- Fires kinetic energy rounds
  - Anti-tank round

Muzzle Brake Technology









Muzzle Brake Relevance

"Lethality of the 120 with impulse of 105."

- M1A2 Abrams Battle Tank
- 70 ton class
- 120 mm Cannon

- FCS MCS
- 20 ton class
- 120 mm Cannon

Interior Ballistics of the XM360

- Breech pressures consistent with Hot round.
- High velocity at muzzle exit.
- Tube length around 5.5 m.
- Propellant mass was matched.
- Patched pressure vs time, velocity vs time and temperature using custom field functions.

Measuring the Efficiency

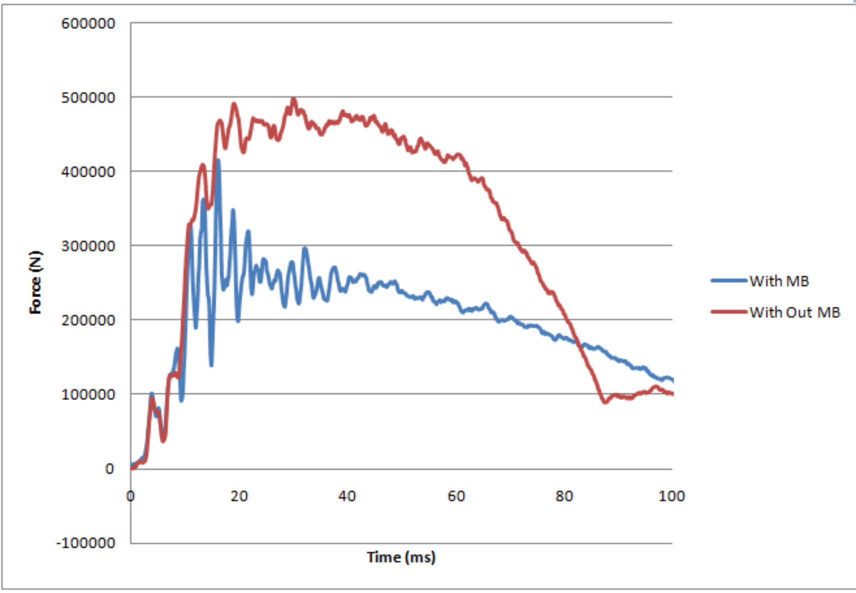
- Overall Efficiency

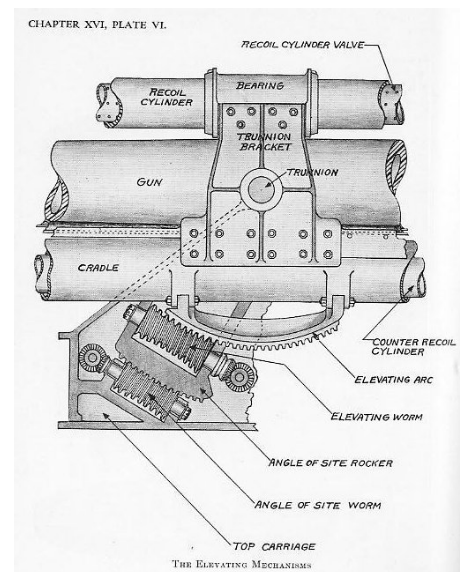
$$\psi = \frac{I_{wo} - I_w}{I_{wo}}$$

- Gas Dynamic Efficiency

$$\beta = \frac{\Delta recoil_a}{\Delta recoil_s} \longrightarrow \beta = \frac{I_{wo} - I_w}{I_{wo} - m_p V_e}$$

Test Results for the Impulse





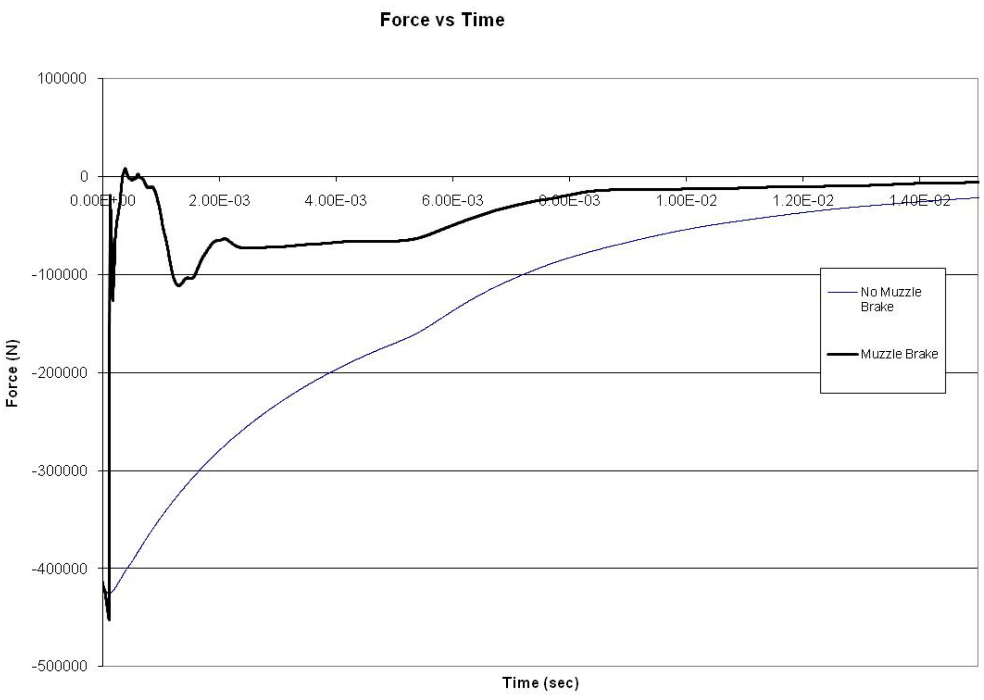
- Overall Efficiency – 24.8%
- Gas Dynamic Efficiency – 49.0%
- Max Force is 355,000 N

$$I = \int F dt$$

$I = \int Fdt$

RDECOM

Modeling the Impulse



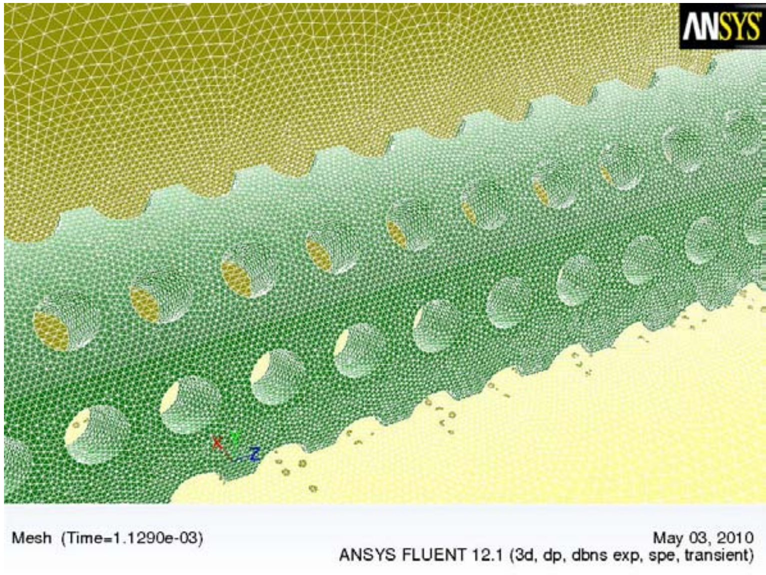
- Impulse

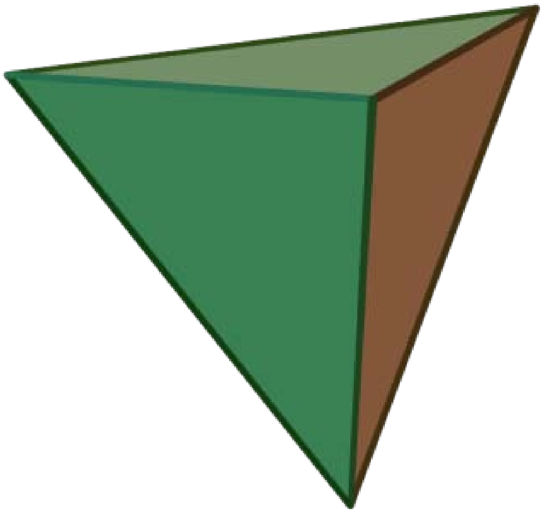
$$I = \int Fdt$$

- ANSYS Fluent models the fluid flow.
- Force in the x Direction
- The Force curve is then integrated wrt time during the blown down of the muzzle brake

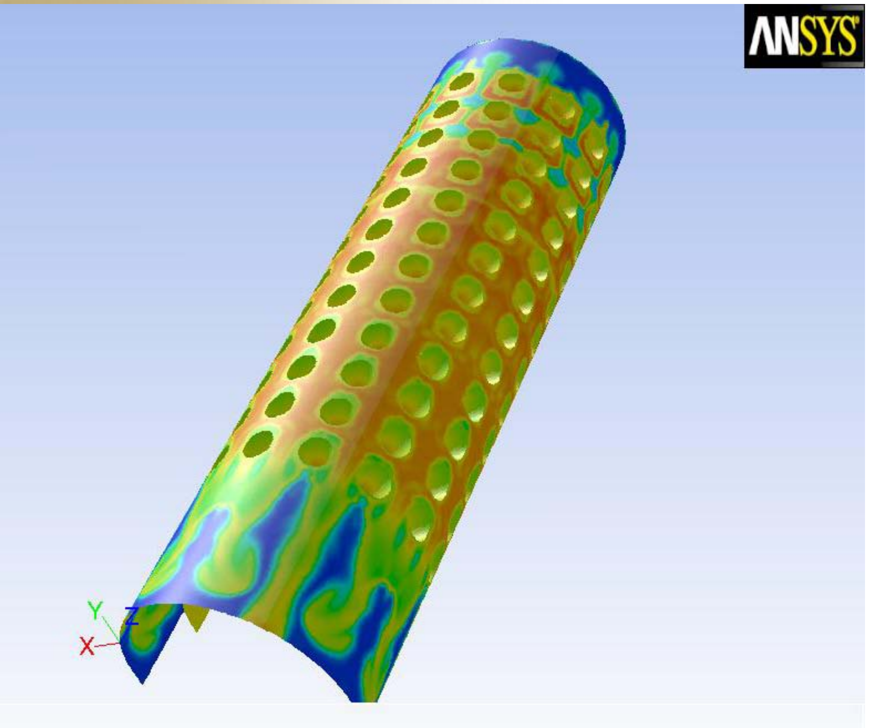
Modeling the Impulse – Sim1

- Simulation 1
- Utilized 3D 1/8 model
- No projectile in simulation
- Fully Tet pave mesh with control around the muzzle brake for size.
- Fine mesh in muzzle brake holes.
- Tube interior and muzzle brake from Pro-E models

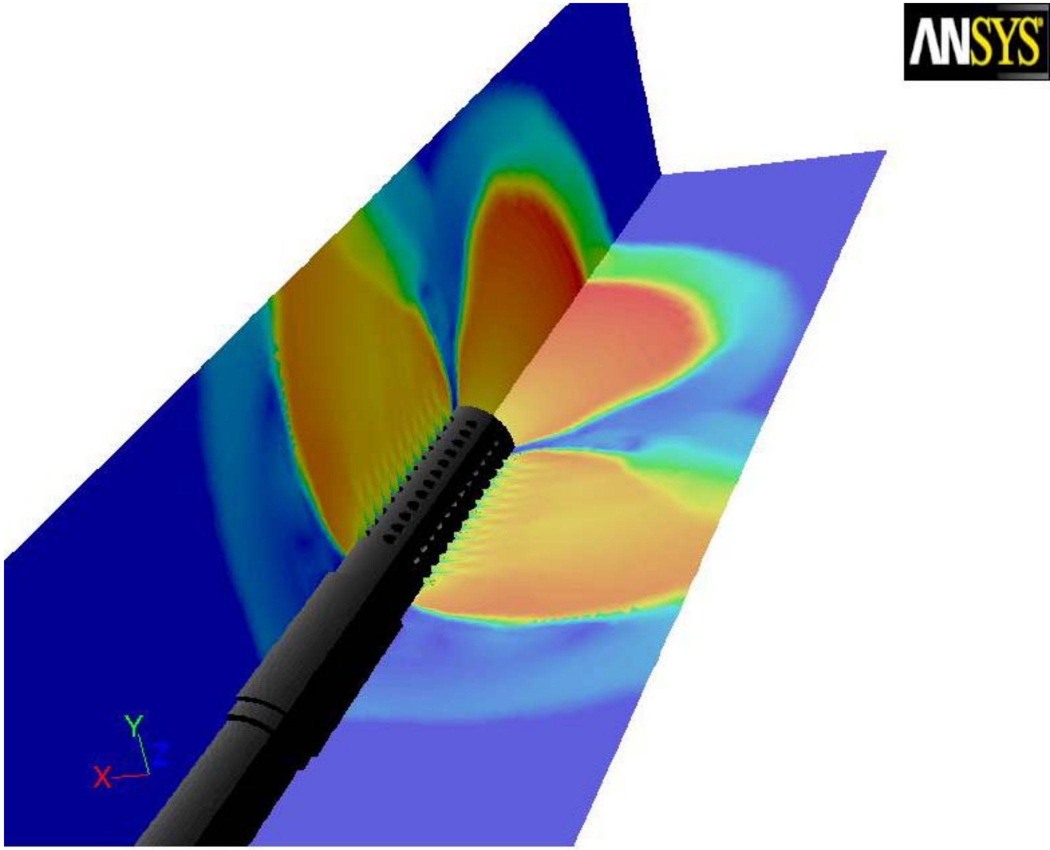




Modeling the Impulse – Sim1

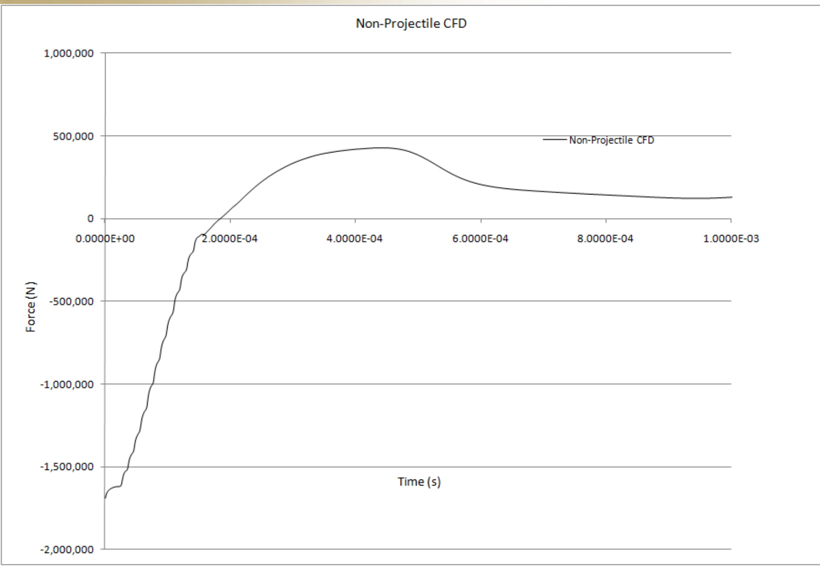


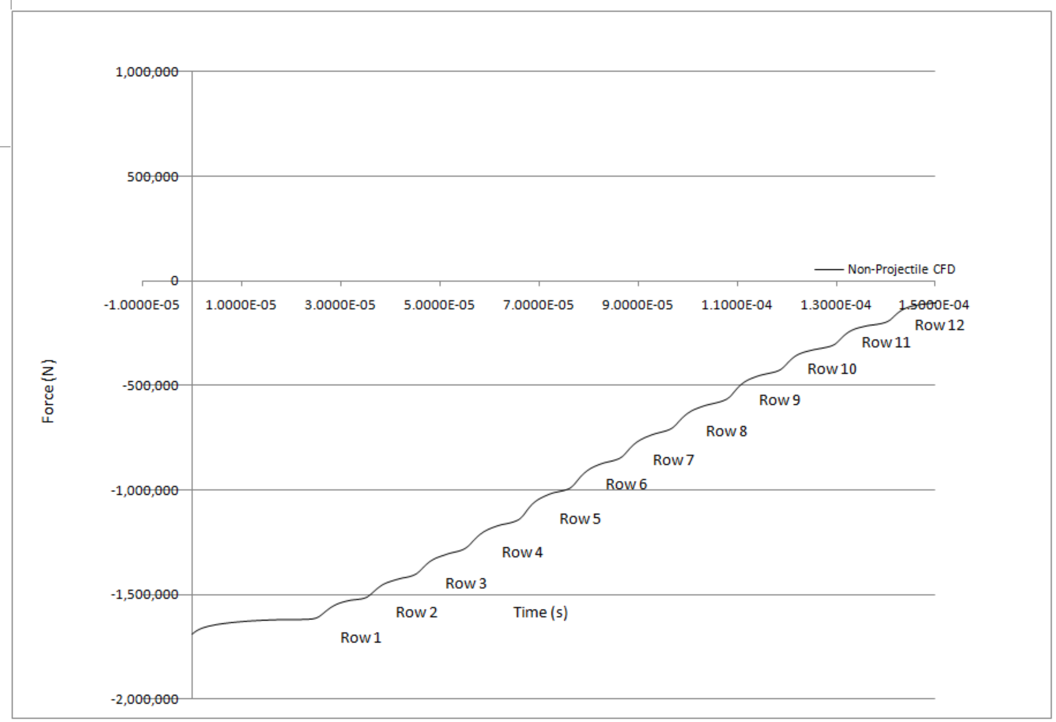
Static Temperature
Time – 0.5 ms



Velocity
Time – 0.5 ms

Modeling the Impulse – Sim1





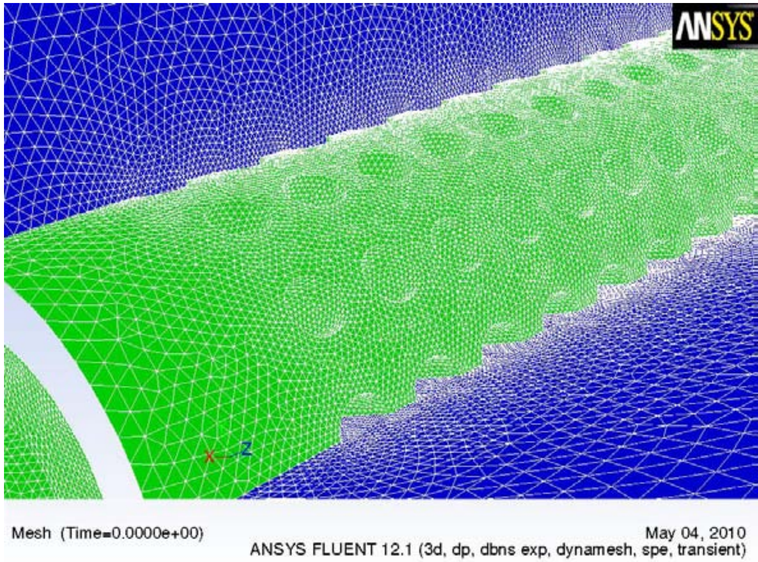
- Force in the rearward direction peaks at around 450,000 N.

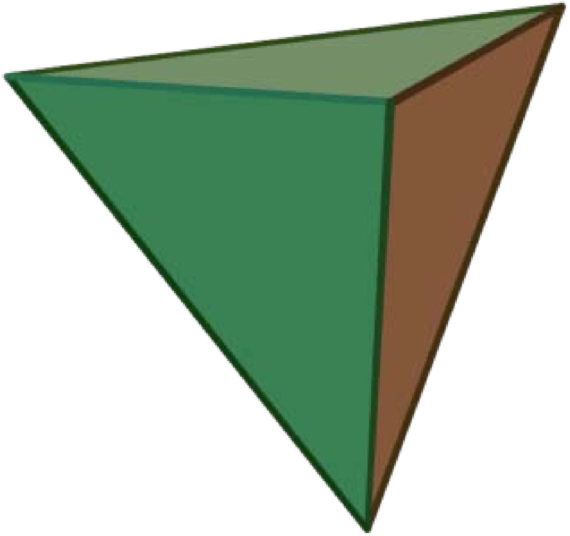
Modeling the Impulse – Sim1 vs Test

- Simulation 1
  - Runtime approximately 2.5 days on 16 processors
  - Overall Efficiency – 26%
  - Gas Dynamic Efficiency – 52%
  - CFD Prediction of Impulse – 1.7% high
- Test
  - Overall Efficiency – 25%
  - Gas Dynamic Efficiency – 49%

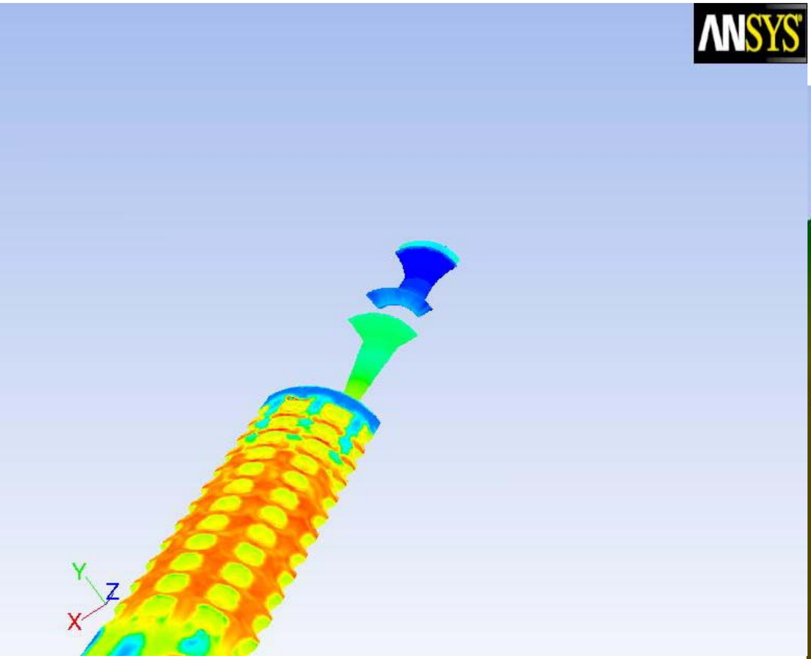
Modeling the Impulse – Sim2

- Simulation 2
- Utilized 3D 1/8 model
- 120mm projectile in simulation
- Tetrahedral (four sided) dominate mesh with control around the muzzle brake for size.
- Fine mesh in muzzle brake holes.
- Tube interior and muzzle brake from Pro-E models

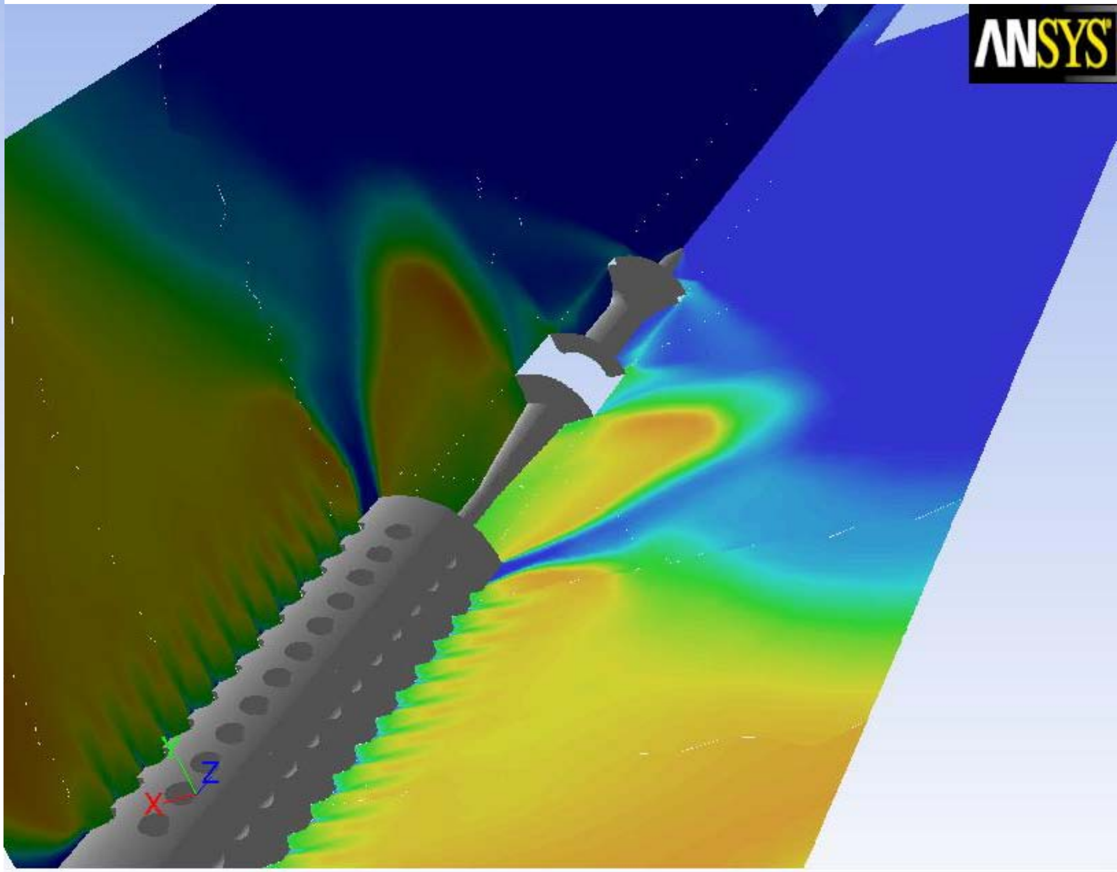




Modeling the Impulse – Sim2

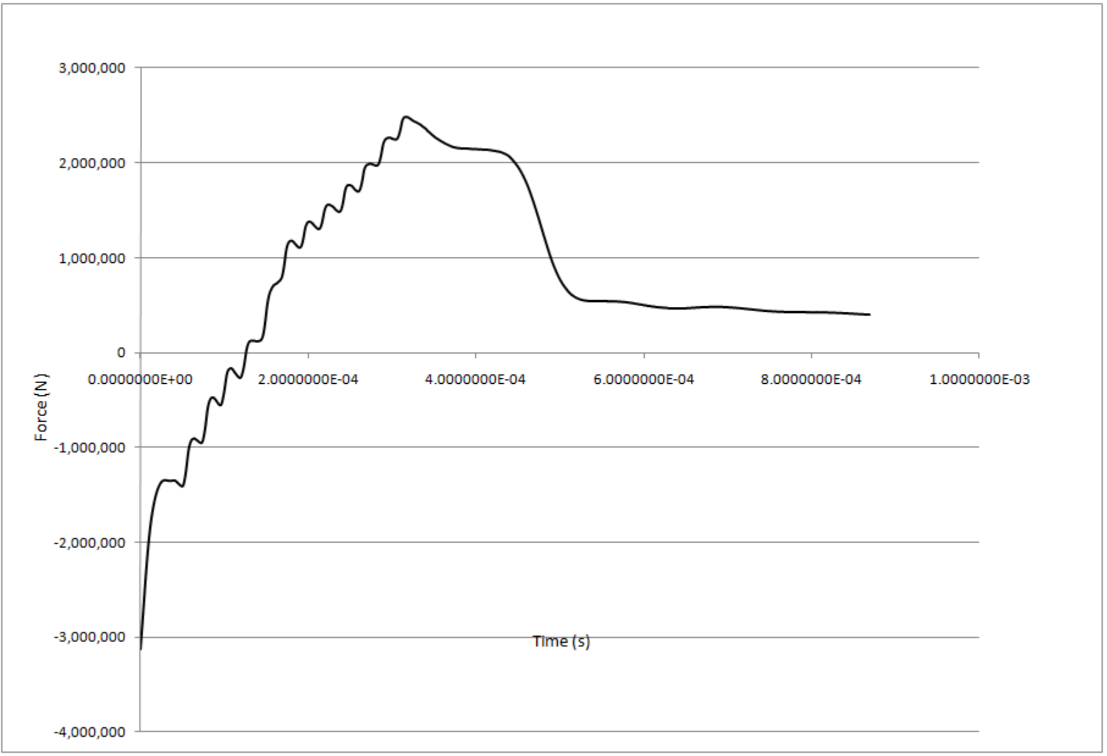


Static Temperature
Time – 0.5 ms



Velocity
Time – 0.5 ms

Modeling the Impulse – Sim2



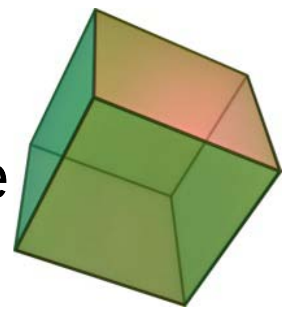
- Force in the rearward direction peaks at around 2,500,000 N.

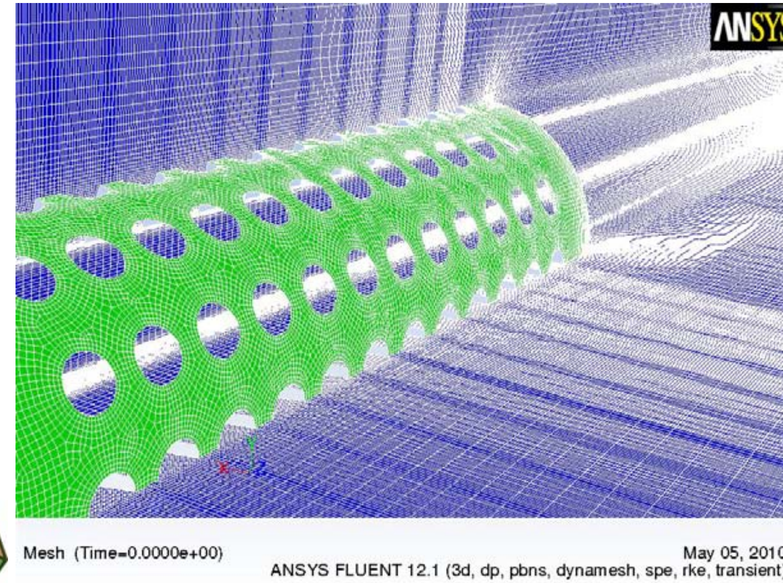
Modeling the Impulse – Sim2 vs Test

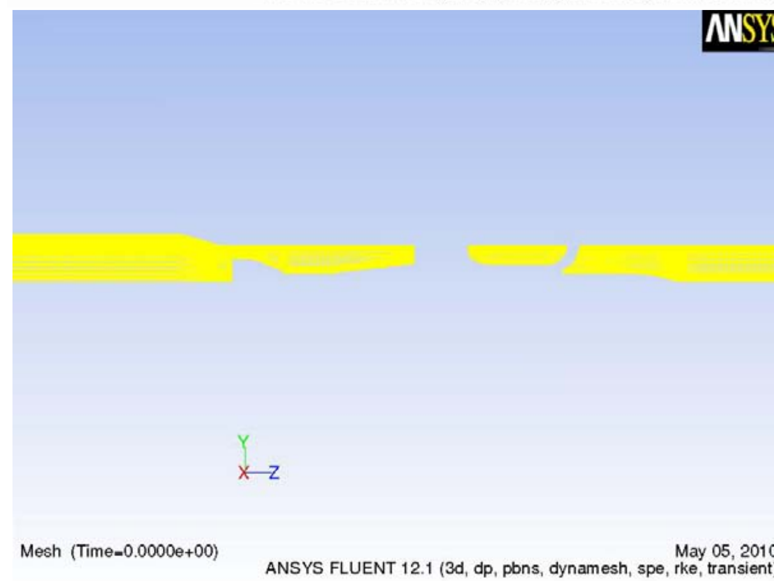
- Simulation 2
  - Runtime approximately 1 month on 32 processors.
  - Overall Efficiency – 28%
  - Gas Dynamic Efficiency – 55%
  - CFD Prediction of Impulse – 4.2% high
- Test
  - Overall Efficiency – 25%
  - Gas Dynamic Efficiency – 49%

Modeling the Impulse – Sim3

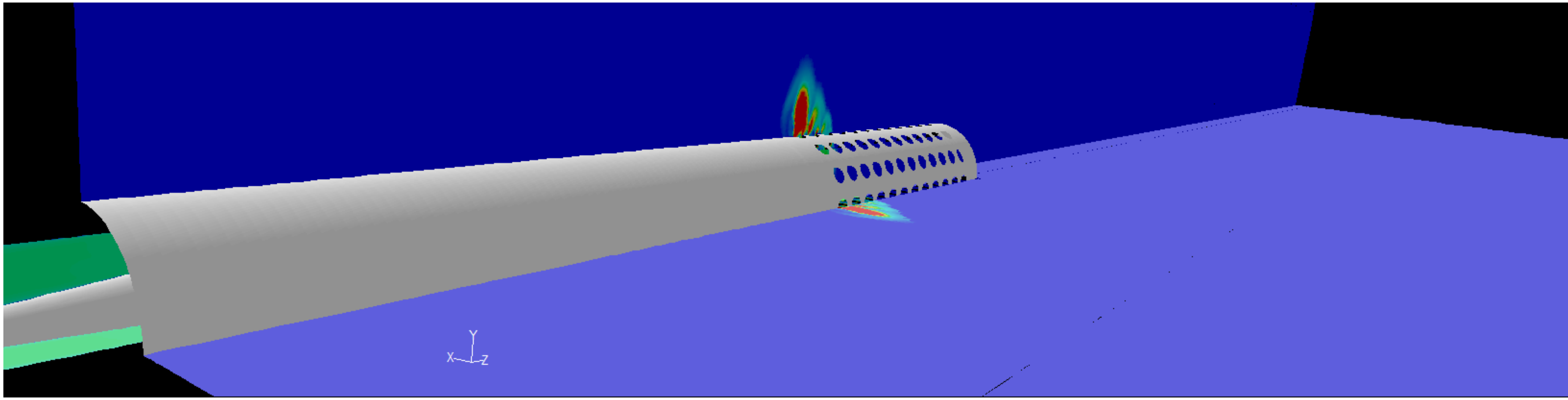
- Simulation 3
- Utilized 3D 1/8 model
- 120mm projectile in simulation
- Hexahedral (six sided) dominate mesh with control around the muzzle brake for size.
- Fine mesh in muzzle brake holes with significant domain deconstruction.
- Tube interior and muzzle brake from Pro-E models







Modeling the Impulse – Sim3



- Precursor shot due to projectile motion more accurately models the realistic effect of firing.
- Simulation running approximately 3 weeks on 48 processors.

Modeling the Impulse – Sim3 vs Test

- Simulation 3
  - Runtime approximately 1 month on 48 processors.
  - Overall Efficiency – UNKNOWN
  - Gas Dynamic Efficiency – UNKNOWN
  - CFD Prediction of Impulse – UNKNOWN
- Test
  - Overall Efficiency – 24.8%
  - Gas Dynamic Efficiency – 49.0%

RDECOM

Summary of Results

- Simulation 1
  - Runtime approximately 2.5 days on 16 processors
  - Overall Efficiency – 26%
  - Gas Dynamic Efficiency – 52%
  - CFD Prediction of Impulse – 1.7% high
- Simulation 2
  - Runtime approximately 1 month on 32 processors.
  - Overall Efficiency – 28%
  - Gas Dynamic Efficiency – 55%
  - CFD Prediction of Impulse – 4.2% high
- Simulation 3
  - Runtime approximately 1 month on 48 processors.
  - Overall Efficiency – UNKNOWN
  - Gas Dynamic Efficiency – UNKNOWN
  - CFD Prediction of Impulse – UNKNOWN
- Test
  - Overall Efficiency – 24.8%
  - Gas Dynamic Efficiency – 49.0%

Concluding Remarks

- Inconclusive on whether the incorporation of a projectile has a significant impact on impulse modeling.
- Grid plays a major role in the refinement of the solution.
- Current results show the non-projectile case produces best results but expectation is that the hexahedral dominate mesh will produce superior results.
- Impulse prediction is adequately close in all simulations and can be used as a tool for design.
- CFD application can be extended beyond large caliber.

Concluding Remarks

- Advantages to M&S reduce the test cost and development timeframe.
- Display of Benet designed FCS equipment currently at NDIA 2010.

Questions?