Virtual Wind Tunnel Experiments for Small Caliber Ammunition Aerodynamic Characterization

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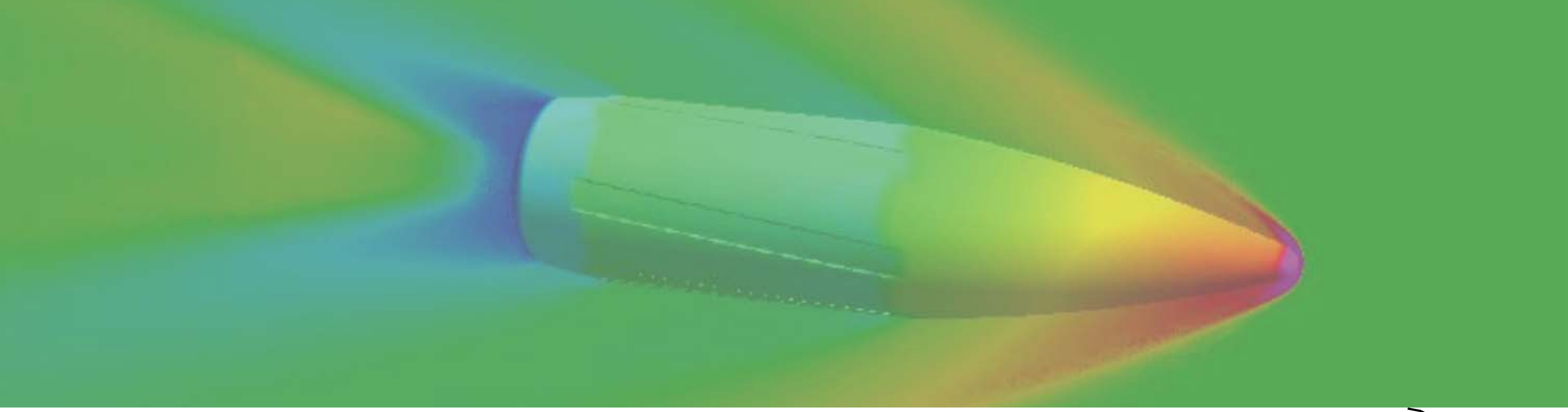


Introduction

- Aerodynamic prediction methodologies and requirements
- The virtual wind tunnel technique
- Recent applications
  - M855 Aero
  - Effect of rifling grooves
  - Effect of base geometry
- Conclusions
- Acknowledgement

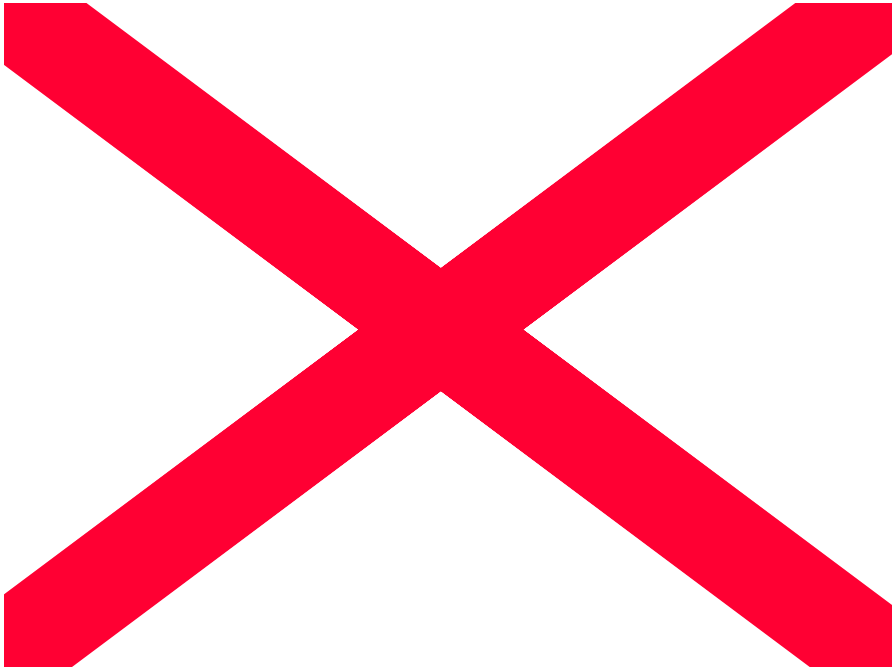
Aerodynamic Prediction Methods

- Fast-design codes
  - Prodas, AP02 (Navy), Missile DATCOM (Air Force)
  - Semi-empirical techniques
  - Good predictions if design is within the database
  - Static aerodynamics (drag, pitching moment) better than dynamic aerodynamics
  - Some geometric aspects not considered

- Computational fluid dynamics
  - High-fidelity physics
  - More capability for assessing geometric details
  - Complete static/dynamic aerodynamic capability now available

Requirements for Small Caliber Aerodynamics Analyses

Desired Analysis	Required Aerodynamics	Predictive Capability
Point-mass Trajectory (Gravity drop, velocity decay, wind drift)	Drag vs. Mach number	Steady Aerodynamics (Two-dimensional)
Gyroscopic Stability (Rifle twist rate)	Pitching moment vs. Mach number	Steady Aerodynamics (Three-dimensional)
Dynamic Stability, Trim Angles, 6DoF Trajectory	Full static and dynamic aero; Magnus and pitch-damping moments	Unsteady Aerodynamics



Observations on Free Flight Motion

- Free flight angular motion is complicated
  - Damped epicycle
  - Time-dependent motion
  - Characteristic frequencies/times
    - Spin rate
    - Fast mode frequency
    - Slow mode frequency
  - First two frequencies driven by rigid body dynamics, not aerodynamics!

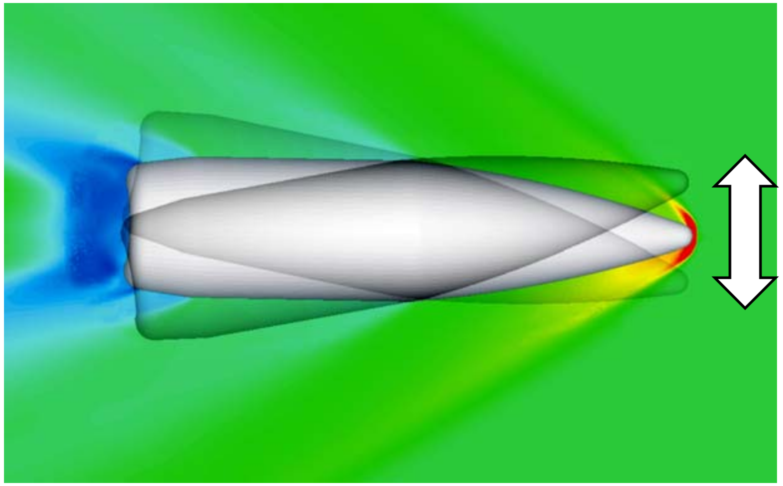
- Is it necessary to duplicate this motion to get the aerodynamics?

Approaches for Determining Aerodynamics

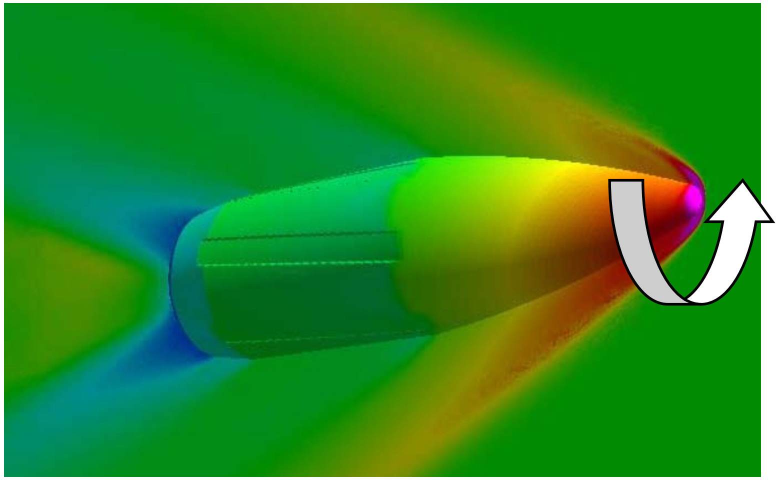
Virtual Fly-Out Technique	Virtual Wind Tunnel Technique
Mimics aeroballistic range tests	Computational analog of wind tunnel
Aerodynamics coupled to rigid body dynamics (RBD) •Time-scales driven by RBD •Single time-scale for all aero •Unsteady/time-dependent flow	Aerodynamics independent of rigid body dynamics (RBD) •Time-scales driven by aerodynamics •Multiple time-scales possible •Steady-flow possible
Full nonlinear coupled aero (CFD) for virtual fly-out, BUT if aerodynamics are extracted from trajectory, aero model required. •Assumed form for nonlinear effects •Potential coupling between nonlinear Magnus/pitch-damping	Aerodynamics modeled as sum of independent effects; pitch/yaw, pitch/yaw rate, spin, spin/yaw coupling •No assumed/pre-determined form for nonlinear effects •Independence of Magnus and pitch-damping

Virtual Wind Tunnel technique should be more efficient and provide better aerodynamics!

The Two Virtual Wind Tunnel Experiments



The Pitch-Damping Experiment



The Magnus Experiment

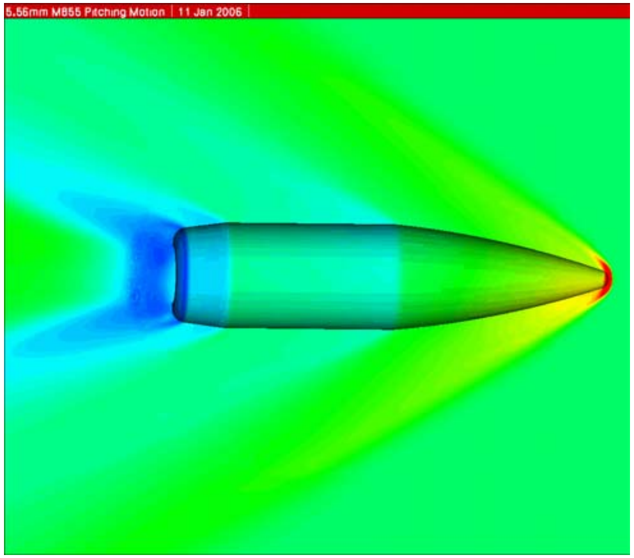
- All required aerodynamics needed to predict stability, performance and free-flight motion can be obtained from these two experiments.
- Key feature: Independent determination of pitch-damping and Magnus – eliminates coupling found in aeroballistics range experiments.

Pitch-Damping Experiment

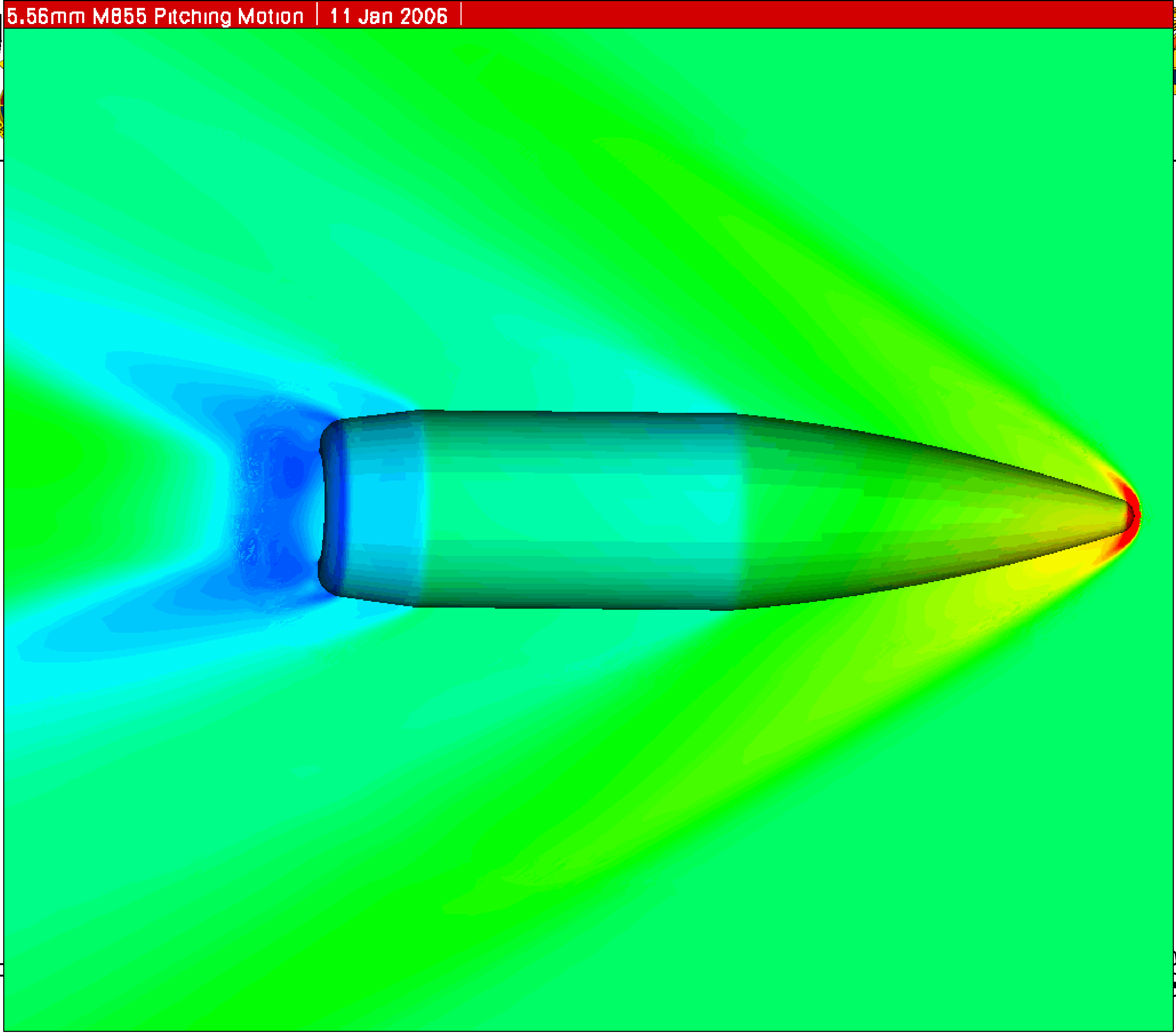
- Two approaches possible
- Planar constant amplitude pitching motion (unsteady flow – non-axisymmetric geometries)

OR

- Coning motion (steady flow – rotationally symmetric geometries)

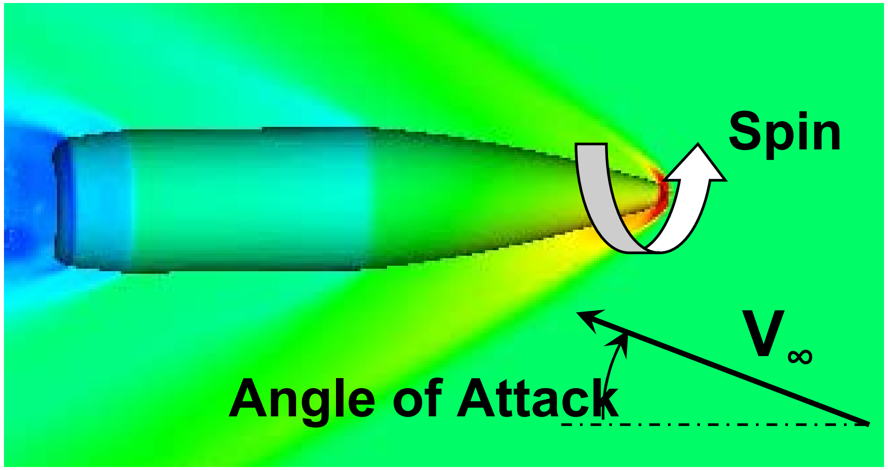


- Predicted Aerodynamics
  - Pitch-damping force and moment
  - Static Aerodynamics (lift, drag, pitching moment)

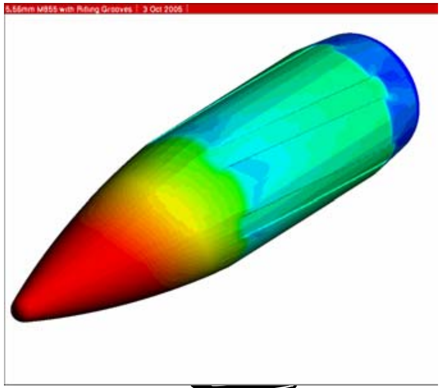

5.56mm M855 Pitching Motion
11 Jan 2006

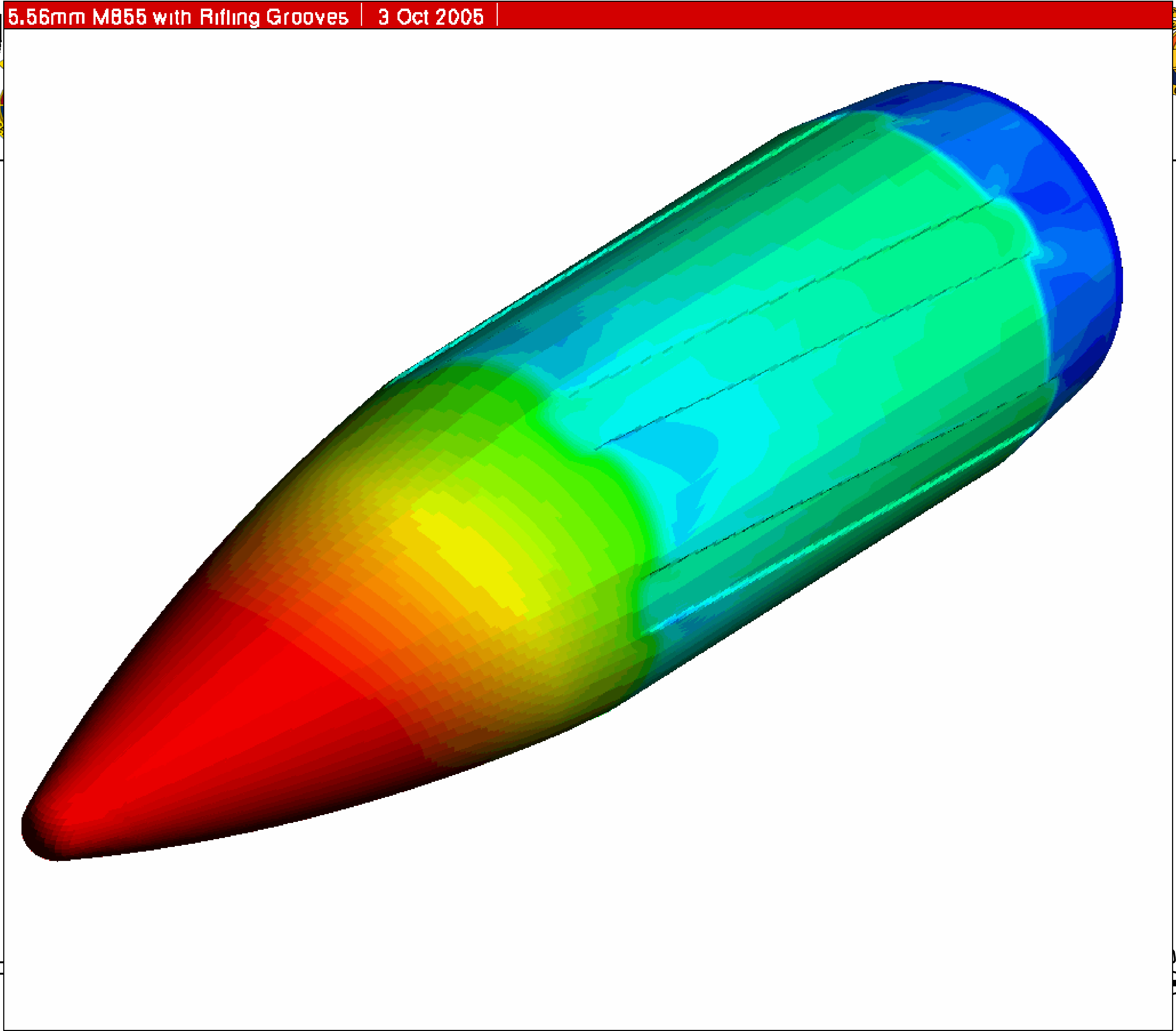
Magnus Experiment

- Constant angle of attack, constant spin rate
- Steady flow for axisymmetric bodies, unsteady flow otherwise



- Predicted Aerodynamics
  - Magnus force and moment (Cross-coupling between angle of attack and spin)
  - Roll damping
  - Static Aerodynamics (lift, drag, pitching moment)

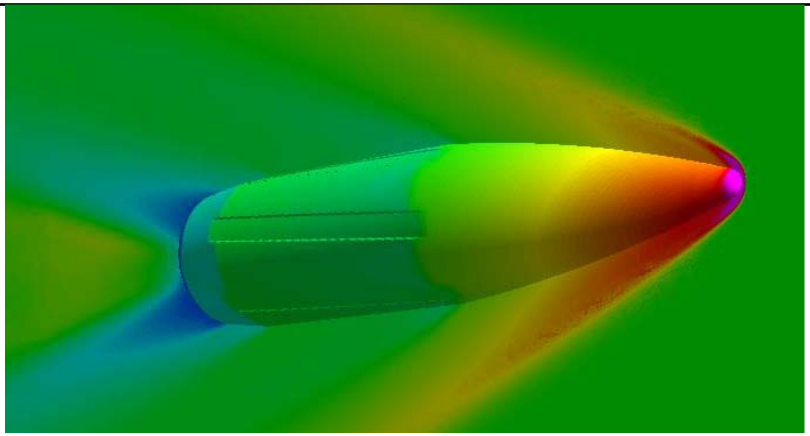



5.56mm M855 with Rifling Grooves
3 Oct 2005

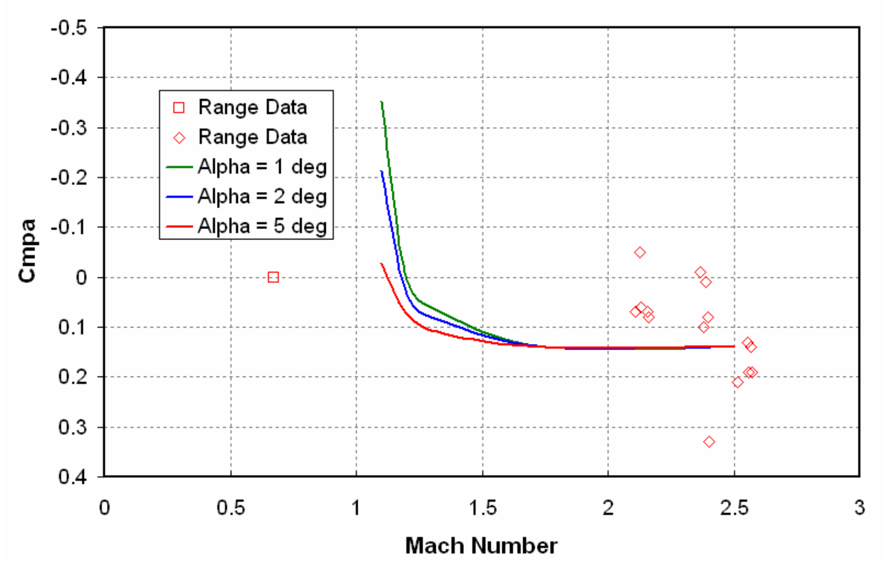
Aerodynamic Predictions for 5.56mm M855

Significance/Purpose:

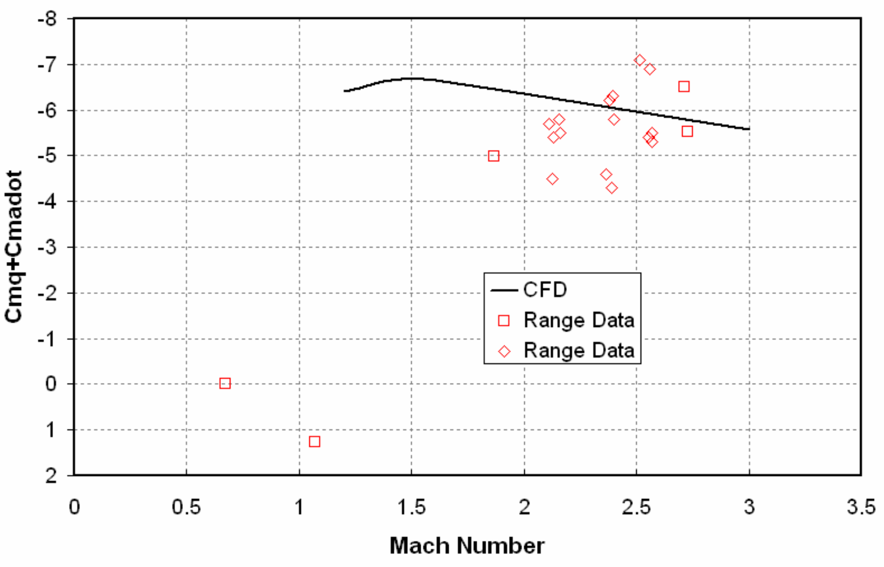
- Virtual wind tunnel approach applied to M855.
- Currently supporting Army Green Ammo development efforts using this methodology.



Nonlinear Magnus Moment

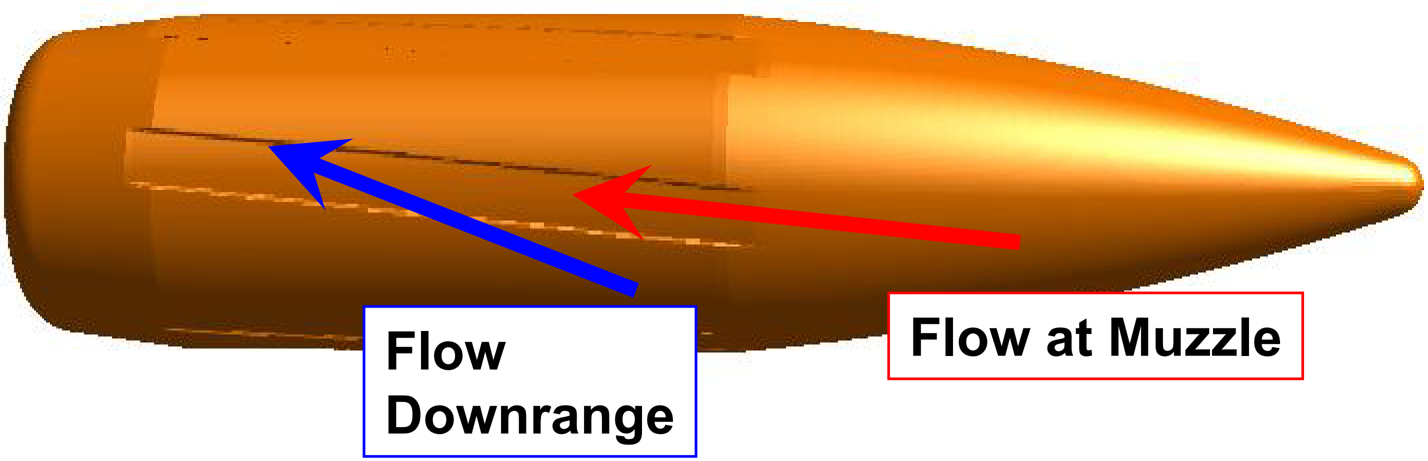


Pitch-Damping Moment Coefficient



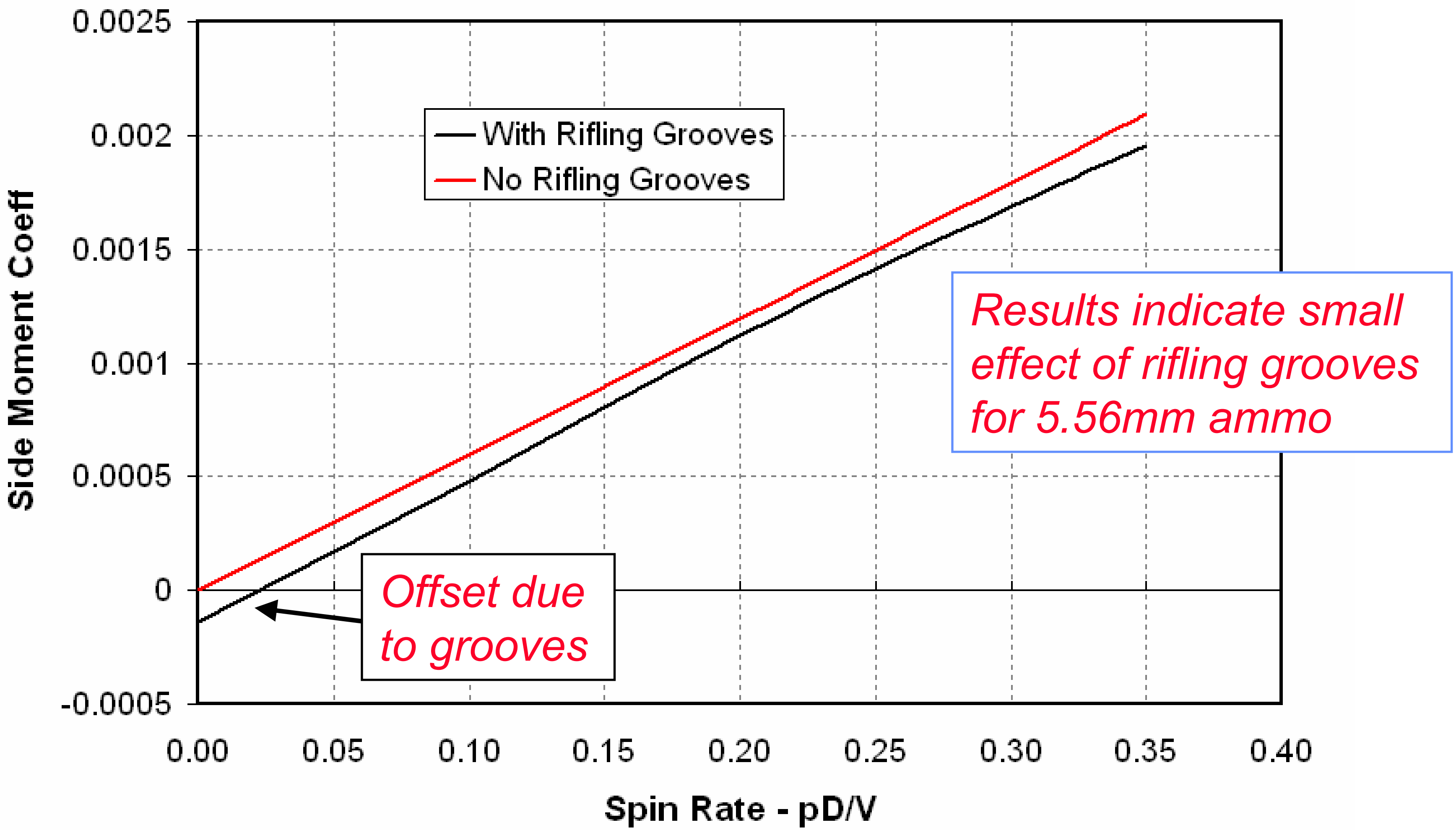
Rifling Groove Effect

- At muzzle - flow aligned with grooves
- Downrange - projectile velocity slows faster than spin rate
  - Projectile is "overspun"
  - Effects spin-sensitive Magnus moment

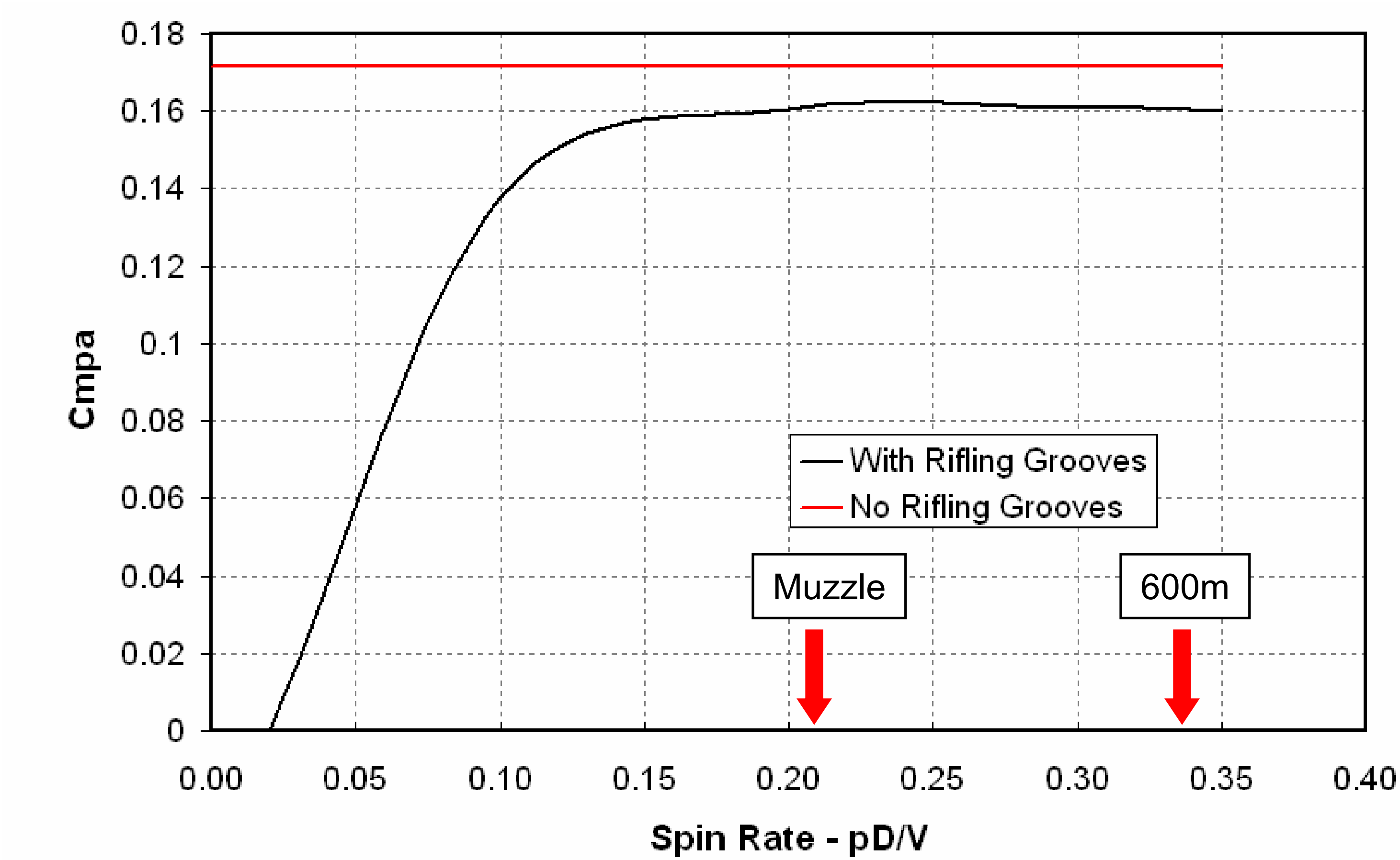


- An important focus: effect of engraving on aerodynamics

Effect of Grooves on Magnus Moment

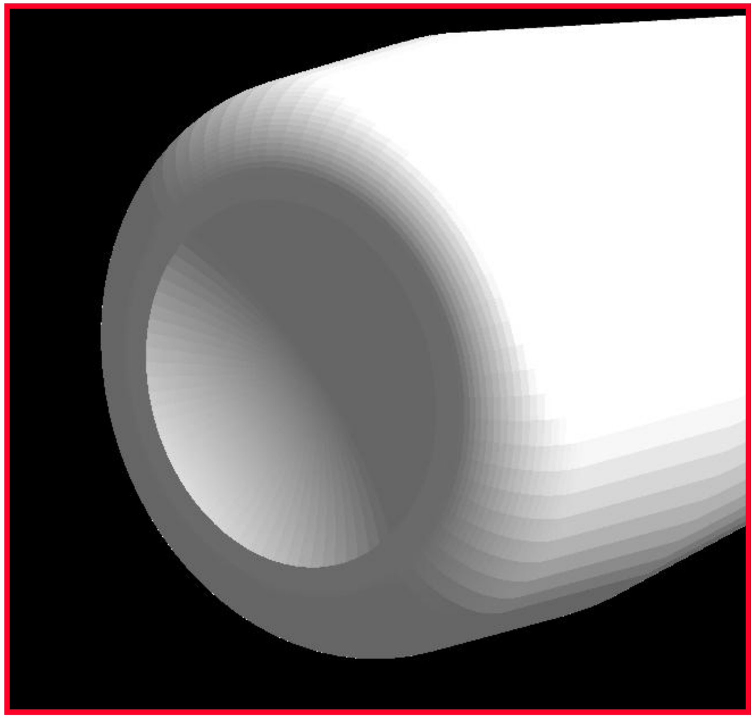


Effect of Grooves on "Effective" Magnus Moment Coefficient

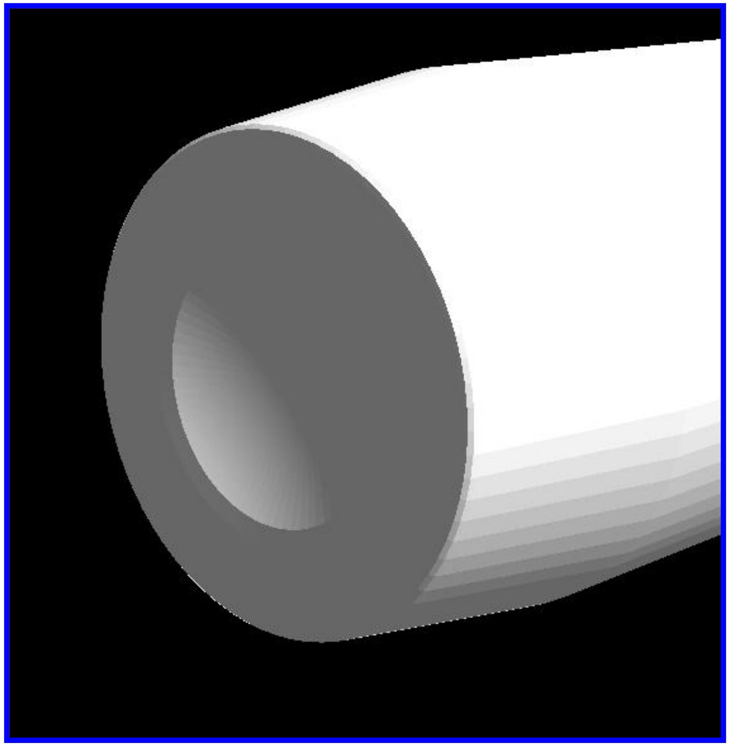


For 5.56mm ammo, slight offset in side moment affects Magnus moment only at low spin rates. Demonstrates that special twist rate guns (match spin) not required for aeroballistic testing!

Effect of Base Geometry on Magnus Moment/Trim Angles

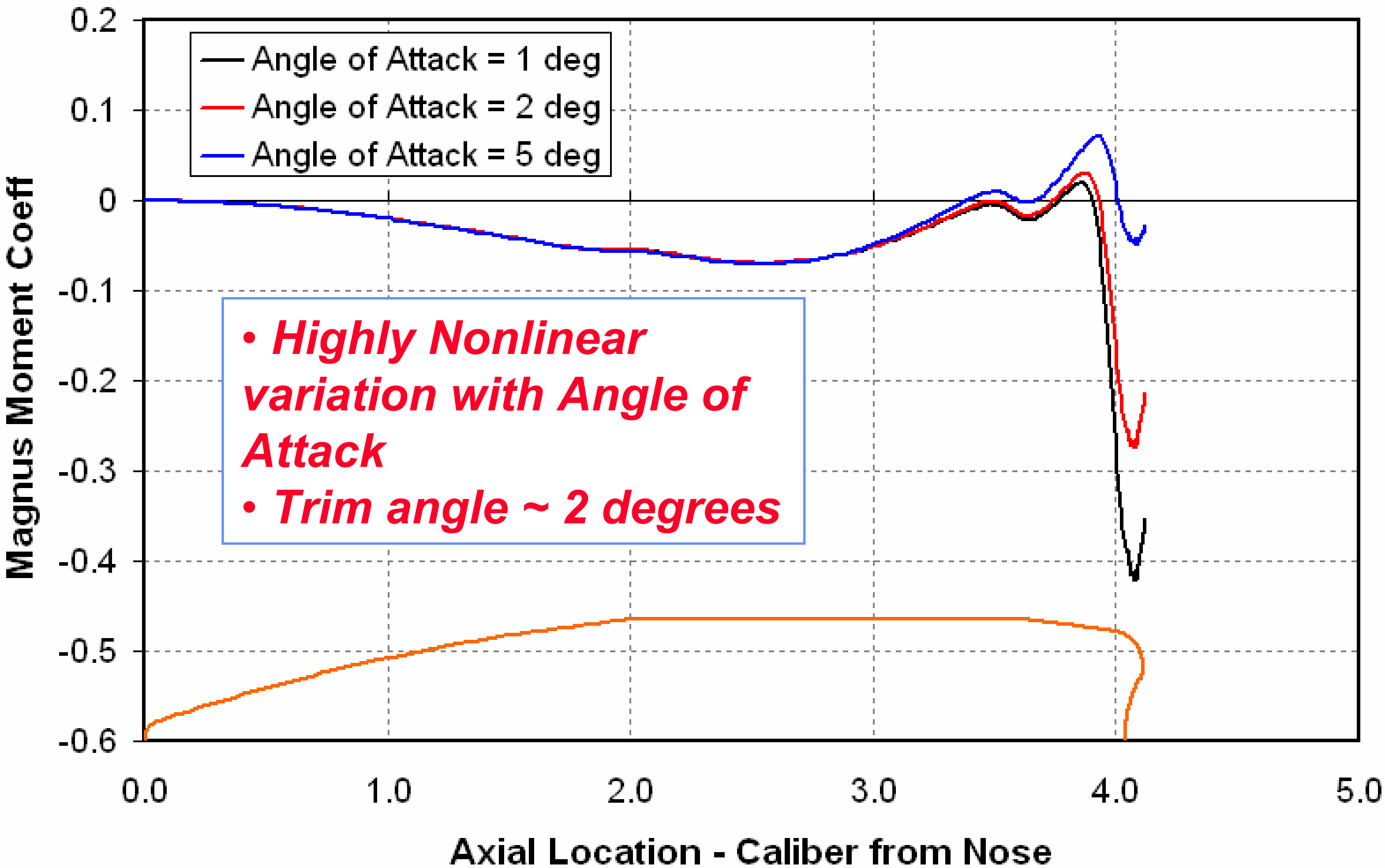


Traditional Rounded Base



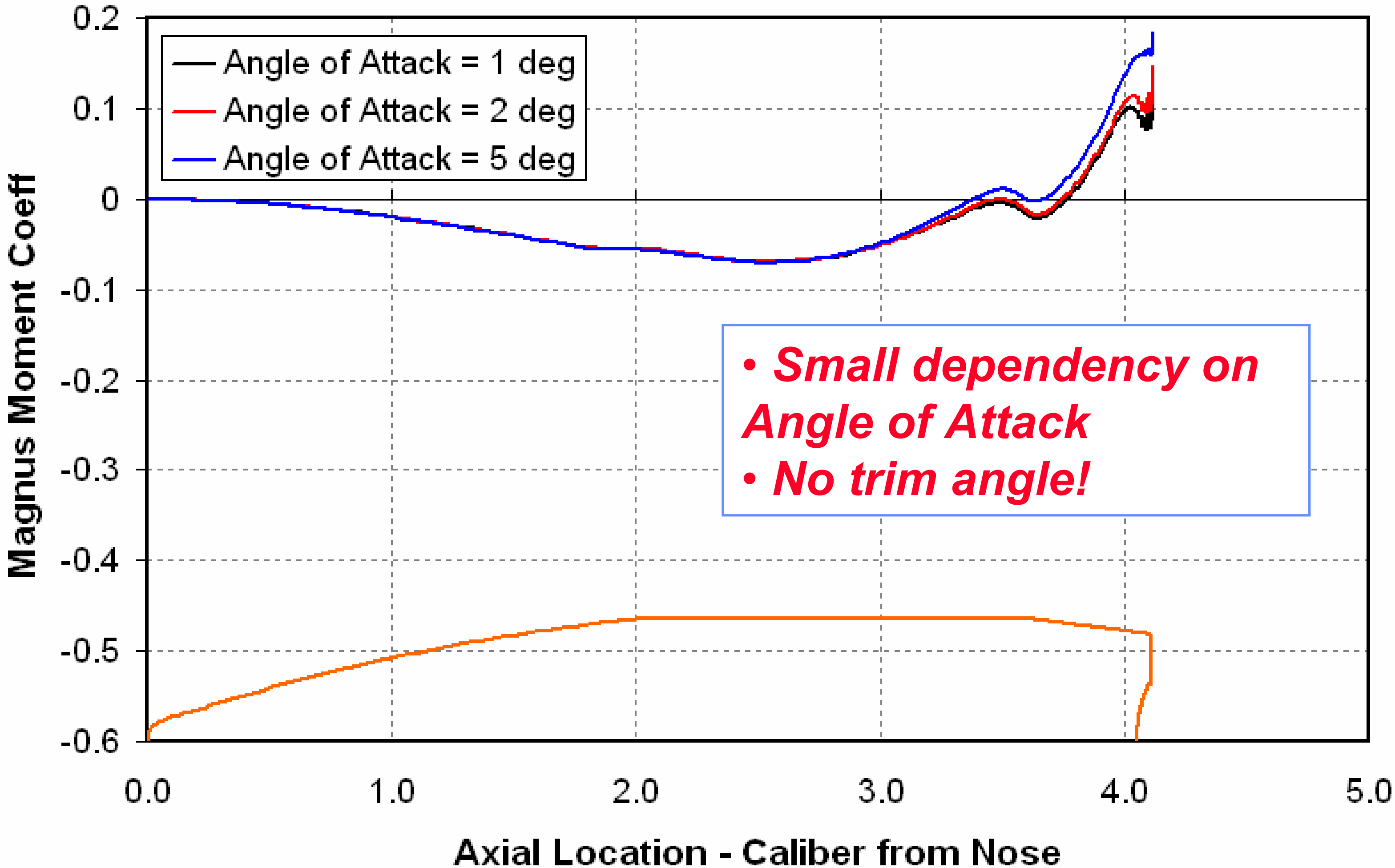
Square Base

Magnus Moment Distribution Along Body - Round Base



- Highly Nonlinear variation with Angle of Attack
- Trim angle ~ 2 degrees

Magnus Moment Distribution Along Body - Square Base



- *Small dependency on Angle of Attack*
- *No trim angle!*

Conclusions

- A fast and efficient methodology for aerodynamic prediction developed for small caliber ammo

- Method is easily extended to medium/large cal

- Technique has been used to advance understanding of small caliber aeroballistics
    - Rifling grooves
    - Base geometry

- Currently using approach within Green Ammo Program

Acknowledgement