Numerical Predictions of Magnus of Spin-Stabilized Projectiles

James DeSpirito and Sidra I. Silton
U.S. Army Research Laboratory
Aberdeen Proving Ground, Maryland

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

24th International Symposium on Ballistics
New Orleans, Louisiana
22–26 September 2008

Introduction

- Nonlinear Magnus moments
  - Observed for nearly all spin-stabilized projectiles in subsonic and transonic flight.
  - Accurate prediction important to predict dynamic stability and trim angles.
- Prediction capabilities
  - Steady-state RANS provides accurate results in supersonic and high transonic flight regimes, as demonstrated in 1980s.
  - Recent work found issues in subsonic and transonic flight regimes for some projectile configurations.
    - Predictions too high at these flight speeds.
    - Time-accurate hybrid RANS/LES simulations can lead to more accurate results.

Steady-State RANS

M910 Projectile
Mach 0.6

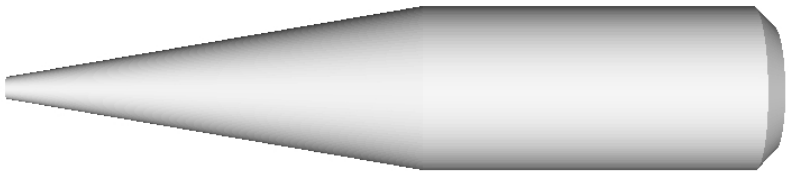
Unsteady RANS/LES

Numerical Approach

- Full 3-D Navier-Stokes calculations
- CFD++, Metacomp Technologies, Inc.
  - Implicit, dual time-stepping
  - Unstructured, finite-volume discretization
- Second order space/time accuracy
- Steady-state RANS simulations
  - Goldberg's three-equation k-ε-R turbulence model
  - Two-equation realizable k-ε turbulence model
  - Two-equation cubic k-ε turbulence model
- Unsteady hybrid RANS/LES
  - Batten-Goldberg turbulence model
    - Cubic k-ε in RANS region (handles anisotropy)
    - Anisotropic form of the Smagorinsky model in LES regions
- y^+ values <0.5

Configurations Investigated

M910 Target Practice Round



D=16.2 mm
L=4.7 cal.

*DeSpirito and Heavey, 2004
*DeSpirito, 2007

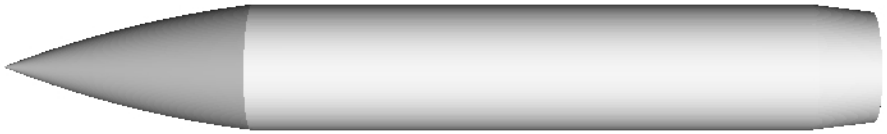
0.50-caliber round

D=12.7 mm
L=4.55 cal.

*Silton, 2005

U.S. Army-Navy Spinner Rocket (ANSR)

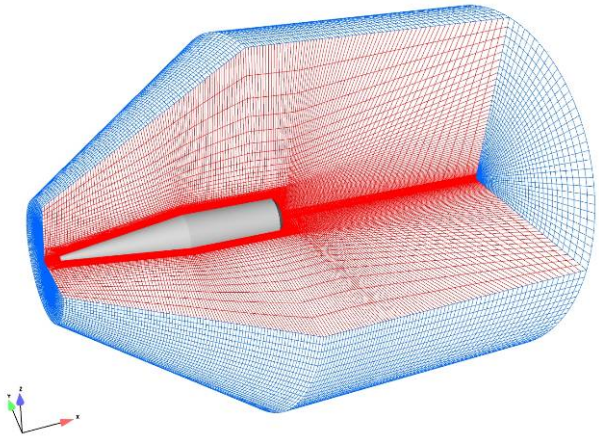
D=20.0 mm
L=7 cal.



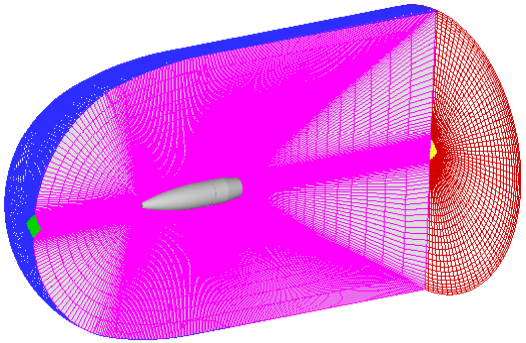
*DeSpirito, 2008

Computational Meshes

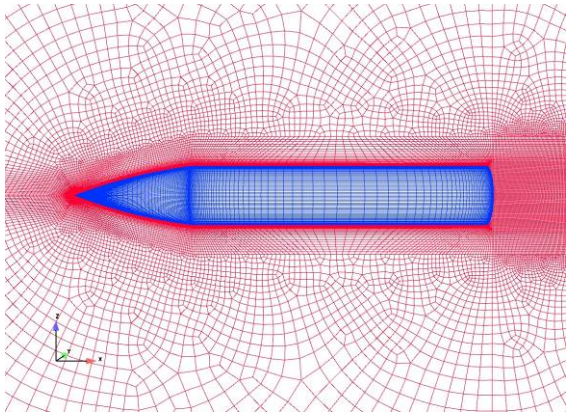
M910

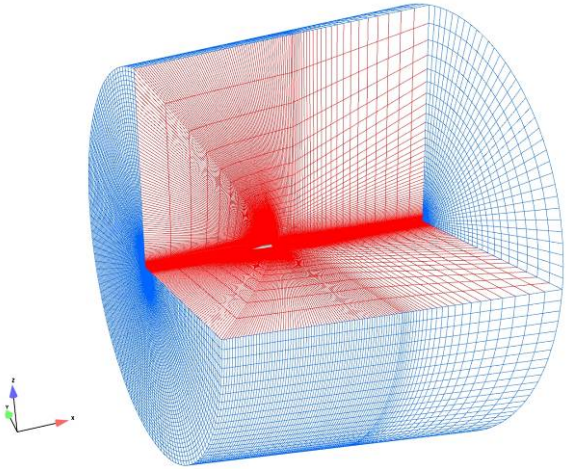


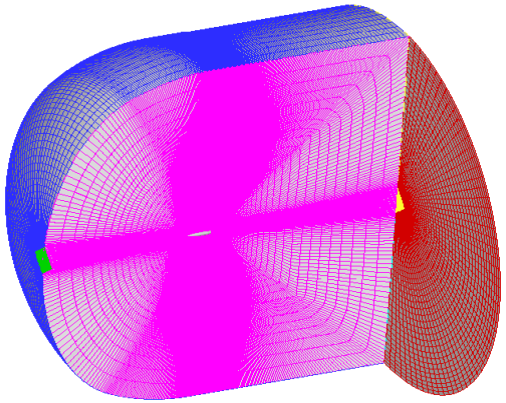
0.05-cal

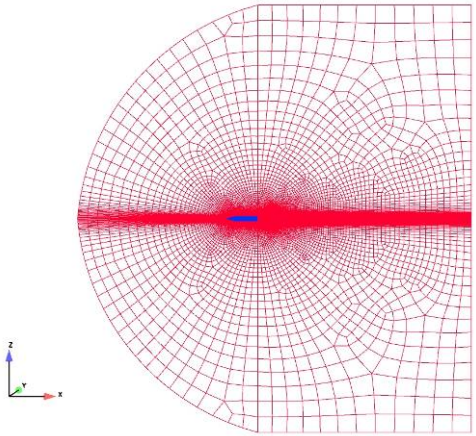


ANSR

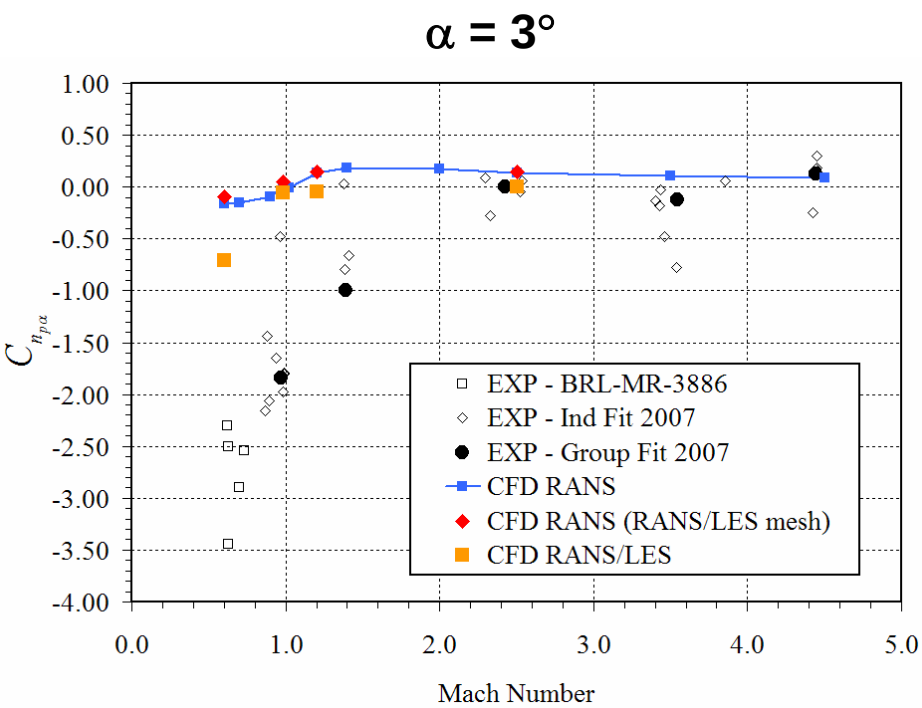


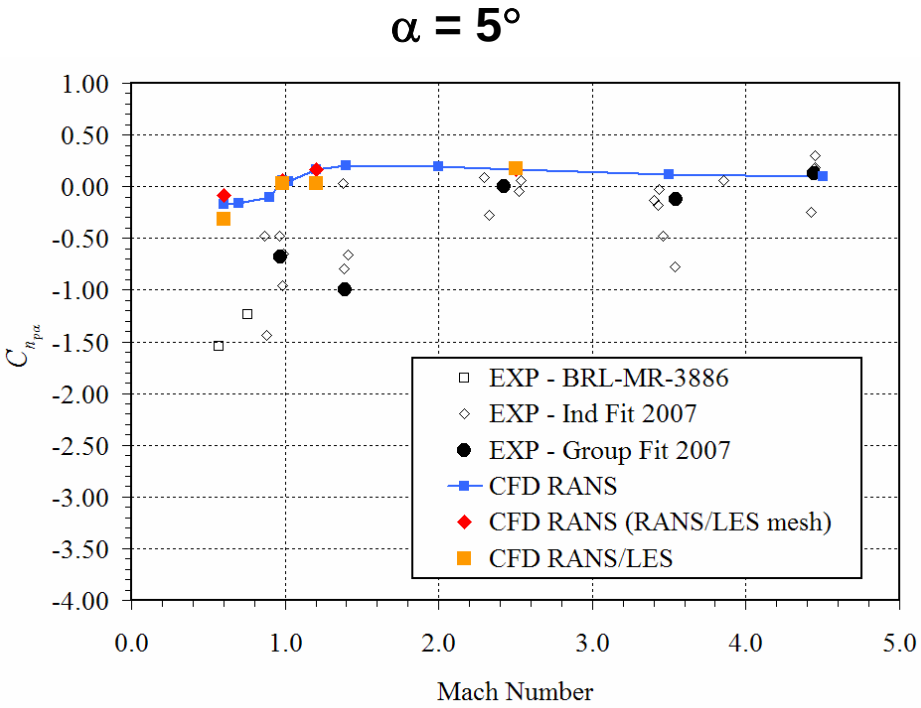






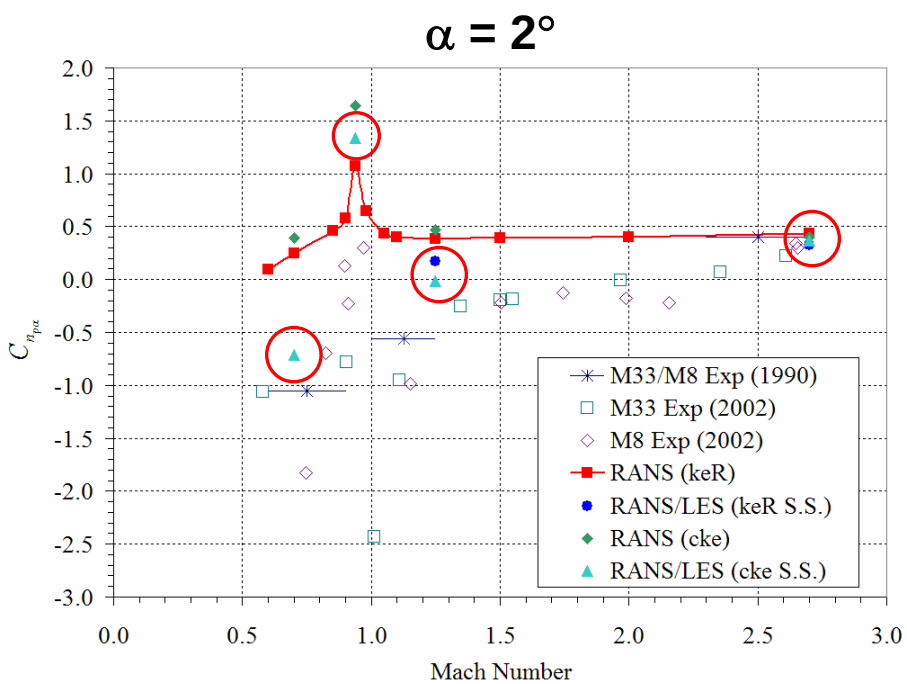
M910 Results

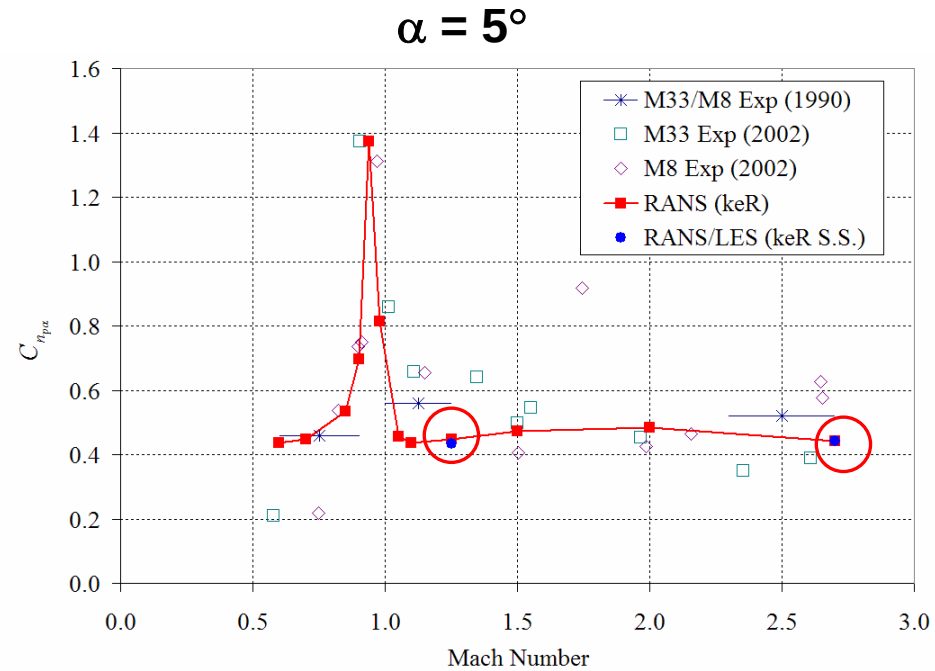




- Steady-state RANS accurate in supersonic regime.
- Time-accurate RANS/LES
  - More accurately predict negative trend at lower Mach numbers (though not as sharp a decrease).
  - Predicts nonlinearity with α, not observed in steady-state RANS simulations.

0.50-cal. Results

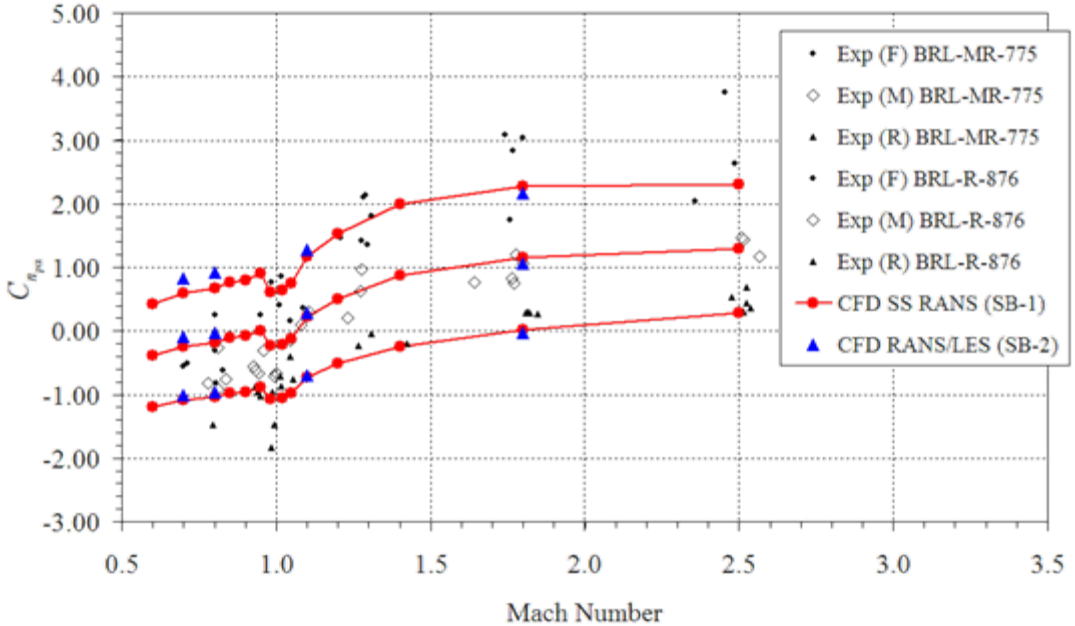




- Critical behavior in transonic region predicted by both solution methods.
- At α=5° RANS predictions compare well with experimental data.
  - Magnus moment under predicted as Mach 1 approached from above.
  - Over predicted in subsonic range.
- At α=2° time-accurate RANS/LES (circled) more accurate.
- RANS turbulence model has small effect on Magnus moment but did not improve prediction in subsonic range.

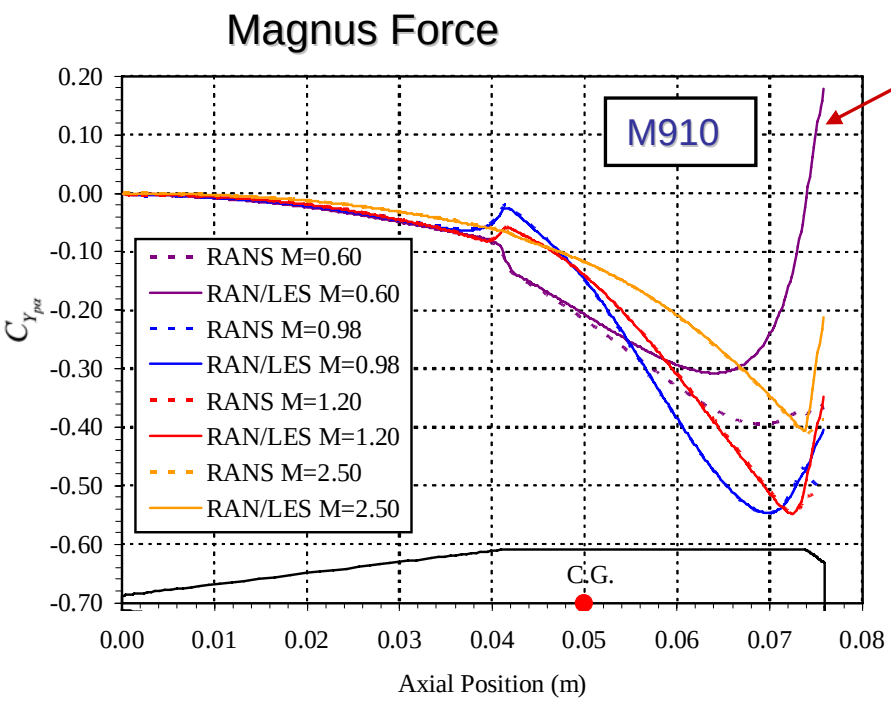
ANSR Results
Square-base, no boattail

$\alpha = 2^\circ$

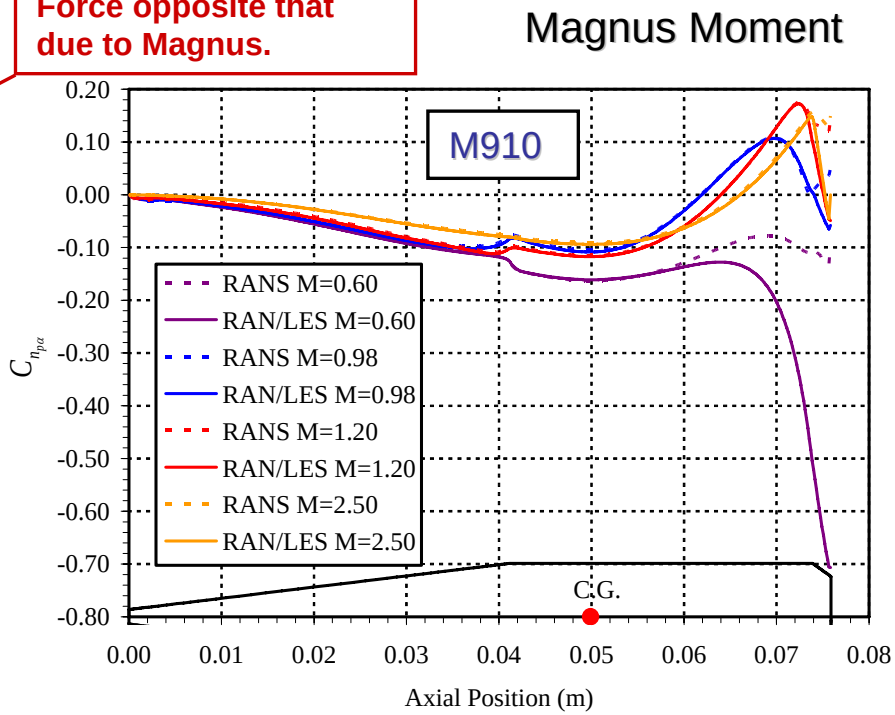


- Sharp edge on base, unlike rounded 0.50-cal. and chamfered M910.
- 3 c.g. locations.
- Little difference between RANS and RANS/LES (regardless of Mach number or c.g. location).
  - Excellent agreement for $M \geq 0.98$.
  - Slightly over predicted in subsonic range but not a great as 0.50-cal or M910.
- Similar result for 0.5-cal, 7° boattail ANSR configuration.
- Results indicates that a sharp edge (corner) on base of projectile may inhibit impact of unsteady flow phenomena on accuracy of steady-state RANS solution.
  - Weinacht (2007) previously found sharp edge reduces nonlinear Magnus effect.

Magnus Distribution on Projectile
M910

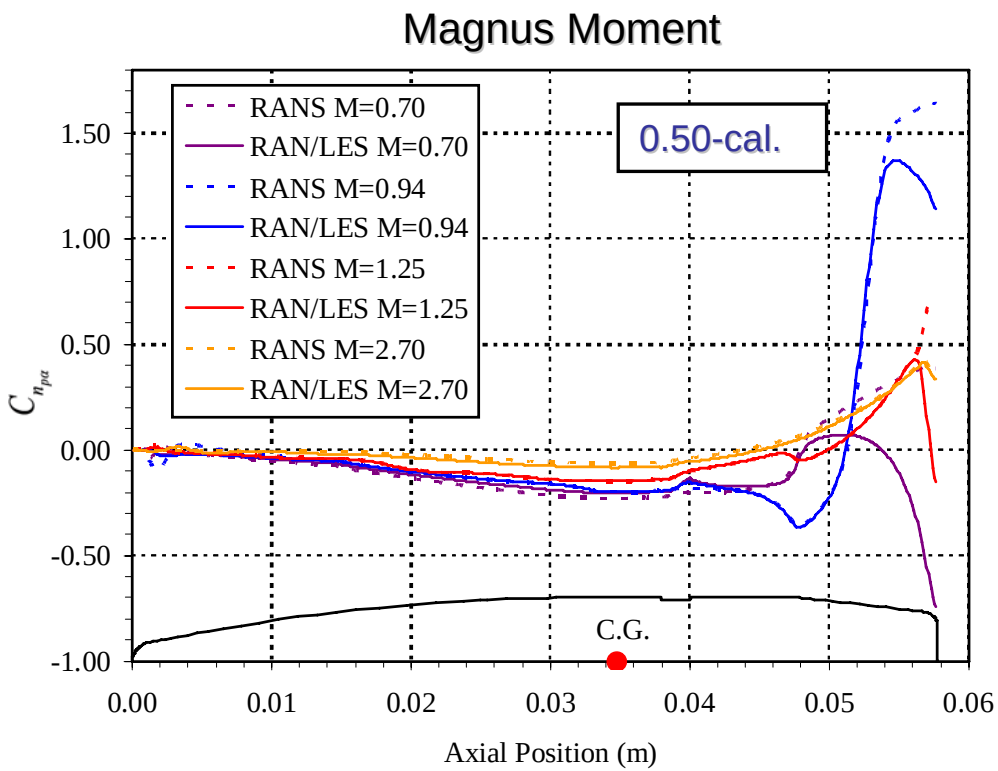


Force opposite that due to Magnus.



- Effects of Magnus confined to rear end of projectile.
- RANS vs. RANS/LES differences
  - Small for transonic and supersonic Mach numbers and confined to chamfer region.
  - Large difference at Mach 0.6 and begins farther forward on projectile.
- Subsonic (Mach 0.6) Magnus
  - Positive force indicates flow interactions have overtaken Magnus effects.
    - Magnus force usually negative (normal pointing to port side for right hand spin).
  - Magnus force center of pressure has moved rear of c.g.

Magnus Distribution on Projectile
0.50-cal.



- Virtually no difference between RANS and RANS/LES at Mach 2.7.
- As Mach number decreases
  - Difference between simulation methods increases.
  - Difference between the two distributions diverge farther forward.

(ANSR results showed only minor differences in Magnus distributions for the two simulations methods.)

M910 Flow Field
RANS vs. RANS/LES

Mach 0.6

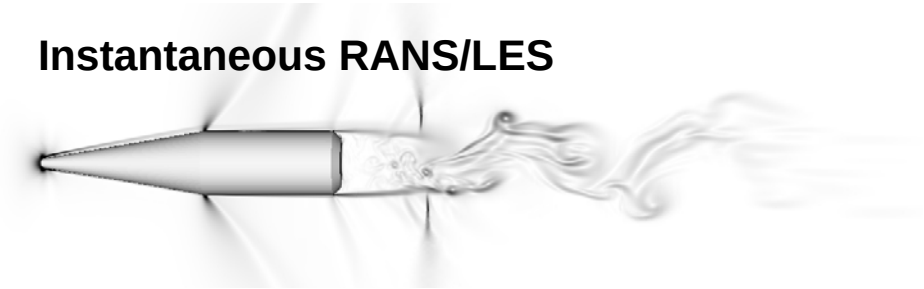
Instantaneous RANS/LES

Time-averaged RANS/LES

Steady-state RANS

Mach 0.98

Instantaneous RANS/LES



Time-averaged RANS/LES

Steady-state RANS

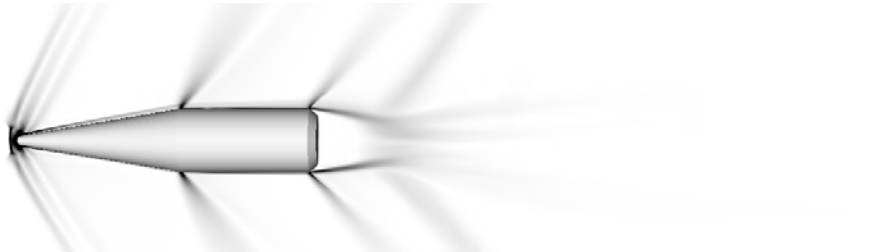
Numerical Schlieren Visualizations, $\|\nabla\rho\|$

M910 Flow Field
RANS vs. RANS/LES

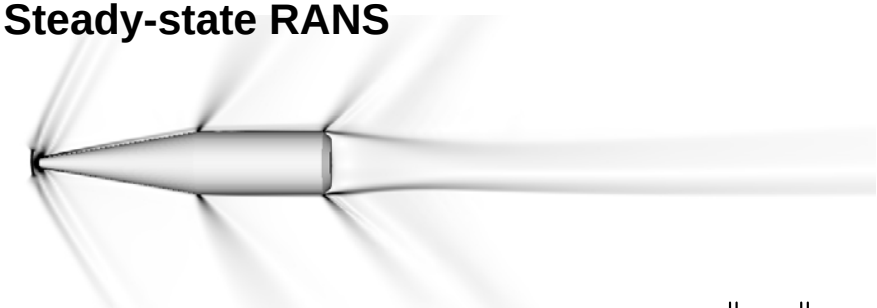
Mach 1.2

Instantaneous RANS/LES

Time-averaged RANS/LES

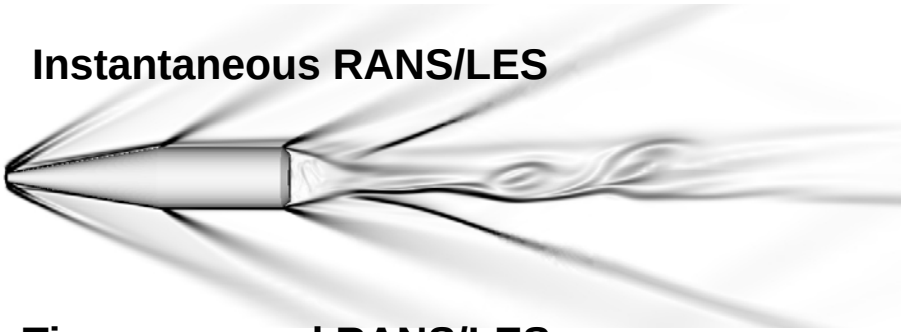


Steady-state RANS

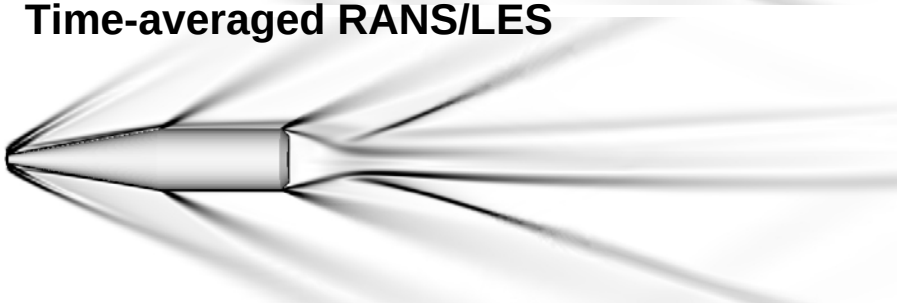


Mach 2.5

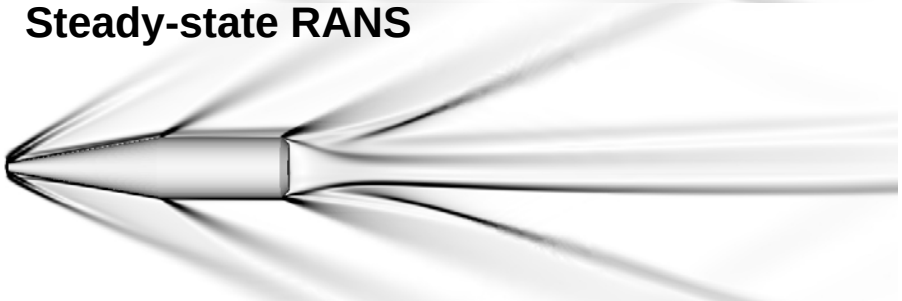
Instantaneous RANS/LES



Time-averaged RANS/LES



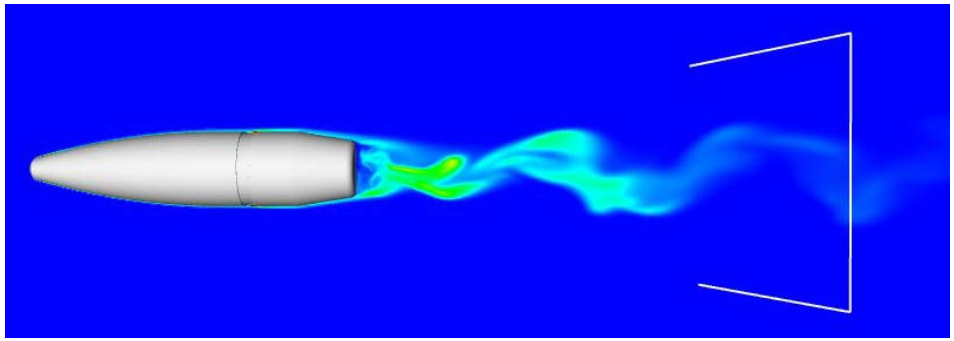
Steady-state RANS



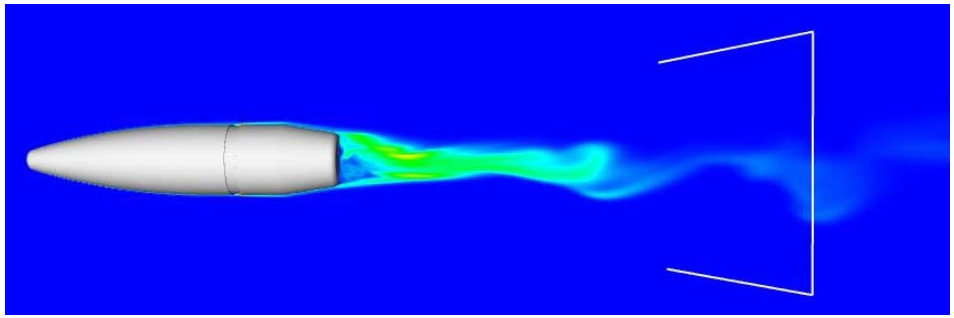
Numerical Schlieren Visualizations, $\|\nabla\rho\|$

0.50-cal. Flow Field
Turbulent Kinetic Energy

Mach 0.7



Mach 1.25



- Similar flow field results for 0.50-cal. and ANSR (not shown).

Conclusions & Future Work

- Projectile base shape is an important parameter.
  - Rounded or chamfered bases
    - Time-accurate RANS/LES simulations improve the Magnus moment prediction.
    - Higher nonlinear Magnus effects (Weinacht, 2007).
  - Sharp cornered base leads to less nonlinear Magnus and improved steady-state RANS predictions.
- Turbulent eddies resolved in RANS/LES simulations impact the pressure distribution on projectile at lower Mach numbers.
- Future work
  - More detailed analysis of unsteady flow field.
    - Separation
    - Pressure distribution
  - Higher angle of attack simulations ($5° \leq \alpha \leq 15°$).

This work was supported in part by a grant of high-performance computing time from the U.S. Department of Defense High Performance Computing Modernization program at the ARL Major Shared Resource Center, Aberdeen Proving Ground, Maryland.

Contact Information

Dr. James DeSpirito

U.S. Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5069

410-306-0778

james.despirito@us.army.mil