# Numerical Investigation of Lateral Jet Interaction on a Fin-Stabilized Projectile

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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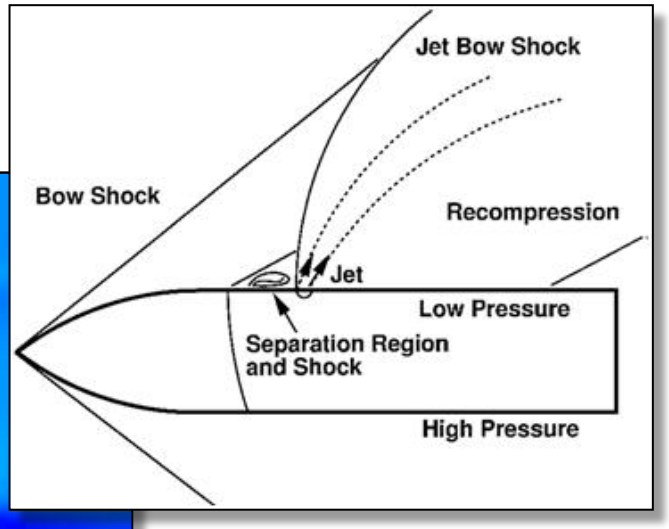
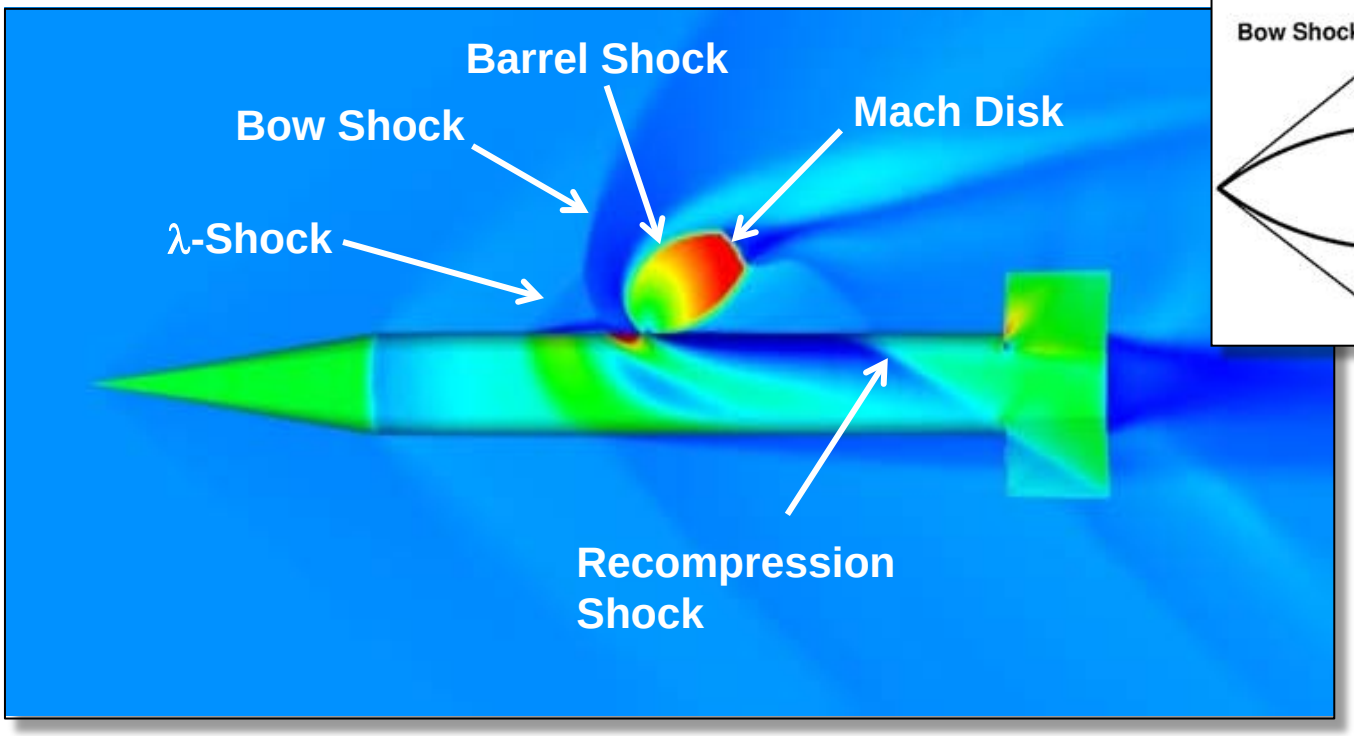
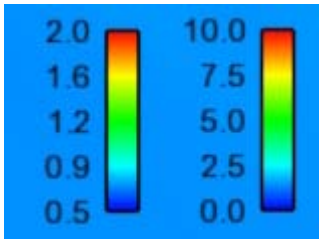
# Basic Features of Jet Interaction (JI) Flow (2)

*M* ≤ Jet Issuing From Body of Revolution into *M* > 1 Crossflow

From **Graham** and Weinacht, 2000




- Sonic Jet
- PR=340
- Mach 1.5 Crossflow

# Objective and Approach

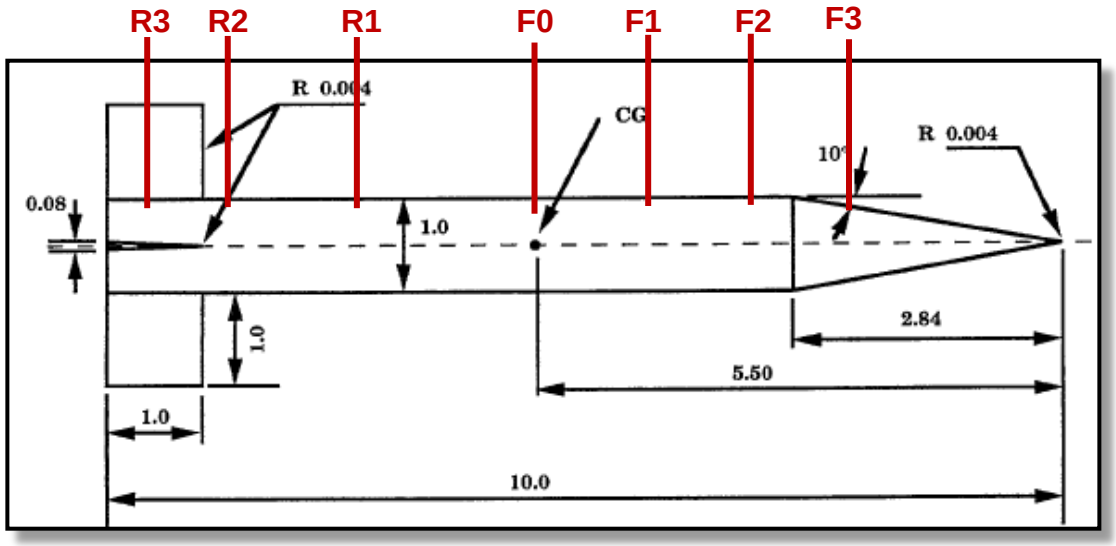
- Use computational fluid dynamics (CFD) to investigate the effect of lateral reaction jet control (RJC) nozzle location and resulting jet interaction (JI) effects on control forces and moments on a generic, fin-stabilized projectile.
- Parameters fixed:
  - Jet total pressure to freestream static pressure ratio (PR), $p_{0j}/p_{\infty}$ = 340
  - Sonic nozzle, 2.54 mm diameter
- Parameters varied:
  - Jet location along projectile axis
  - Mach number ($M$ = 1.5, 2.5)

# Numerical Approach

- CFD++ (v10.1), from Metacomp Technologies, Inc.
  - Finite-volume, point implicit formulation
  - Second-order, upwind HLLC Riemann solver
  - TVD flux limiter
  - Multigrid W-cycle method (4 cycles, 20 grid levels)
- Menter's Shear Stress Transport (SST) turbulence model, based on 2-equation, $k$-$\omega$ model was used.
- High performance computer systems used:
  - SGI Altix ICE 8200 Supercomputer (HAROLD) and Linux Networx Advanced Technology Cluster (MJM) at Army Research Laboratory DoD Supercomputing Resource Center (DSRC), Aberdeen proving Ground, MD.
  - Cray XE6 (RAPTOR) at Air Force Research Laboratory DSRC at Wright-Patterson Air Force Base, OH.

# Model Geometry
## Army-Navy Finner

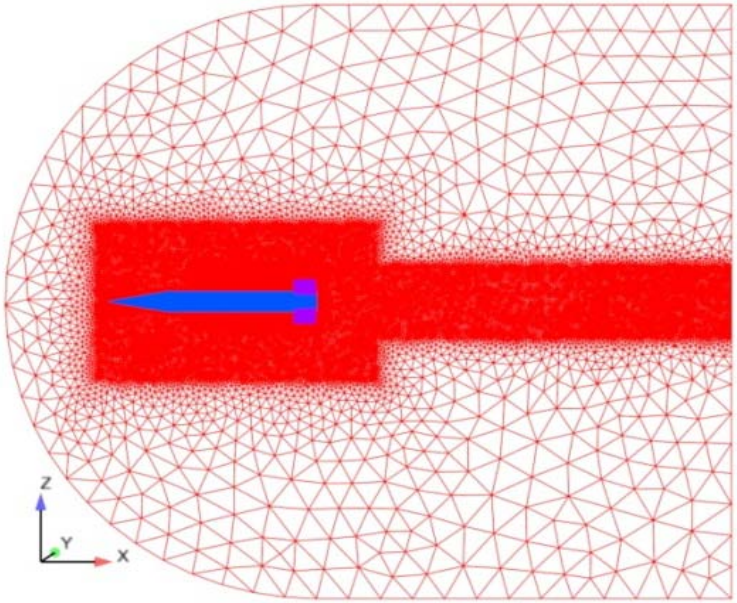
- Army-Navy Finner (ANF) missile—a reference configuration reported extensively in the archival literature.
  - 2.84 cal. conical nose
  - 10 cal. total length
  - 1-cal., square planform fins mounted flush with base
  - Center of gravity (c.g.) located 5.5 cal. from nose
- 7 jet locations on top surface, as indicated in figure.
- No lateral reaction jet validation data.

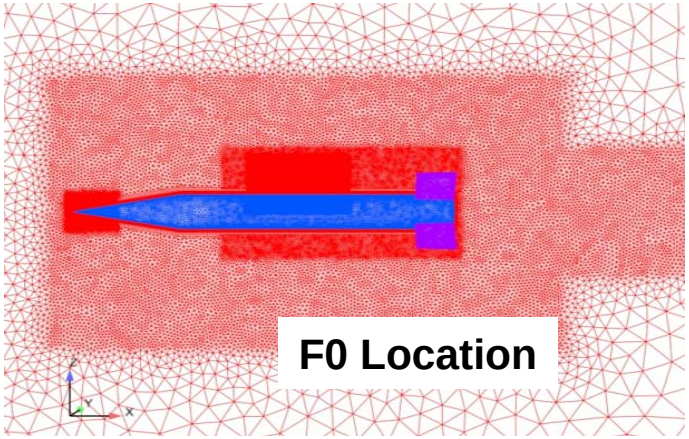


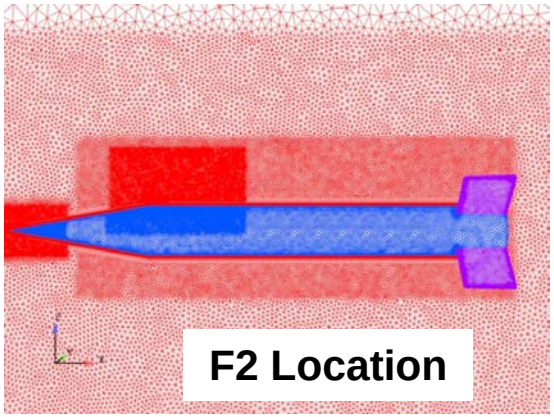

| Label | Location from nose (mm) | Location from nose (cal.) | Location from c.g. (mm) | Location from c.g. (cal.) | Description |
|---|---|---|---|---|---|
| F3 | 65.0 | 2.17 | -100.0 | -3.33 | On conical nose |
| F2 | 90.0 | 3.00 | -75.0 | -2.50 | Just rearward of cone |
| F1 | 127.5 | 4.25 | -37.5 | -1.25 | Between cone and c.g. |
| F0 | 165.0 | 5.50 | 0.0 | 0.00 | At c.g. |
| R1 | 215.0 | 7.17 | 50.0 | 1.67 | Between c.g. and tail fins |
| R2 | 265.0 | 8.83 | 100.0 | 3.33 | Just ahead of tail fins |
| R3 | 290.0 | 9.67 | 125.0 | 4.17 | Between tail fins |

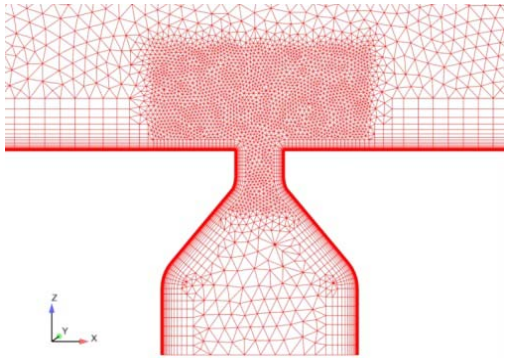
# Army-Navy Finner Meshes

- MIME, from Metacomp Technologies, Inc.
  - 8.8 to 10.2 M cells
  - Prism layers on solid boundaries
  - Half domain modeled
- Computational domain
  - 5 cal. forward, 20 cal. behind
  - 14.5 cal. radially from body
- Adiabatic walls, y+ ≤ 1.0
- Freestream $M$ = 1.5, 2.5 at $p_\infty$ = 101.3 kPa and $T$ = 288 K
- Stagnation conditions ($p_0$, $T_0$) at nozzle plenum inlet



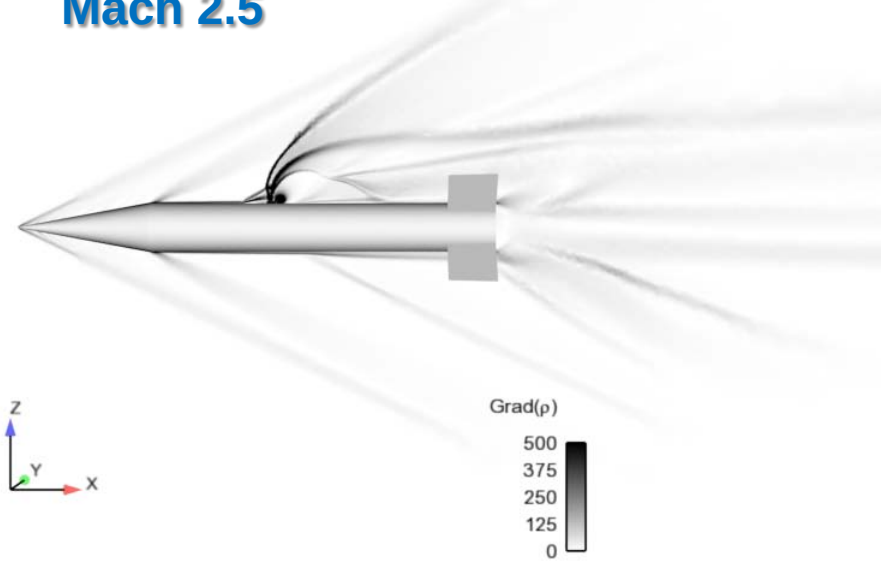



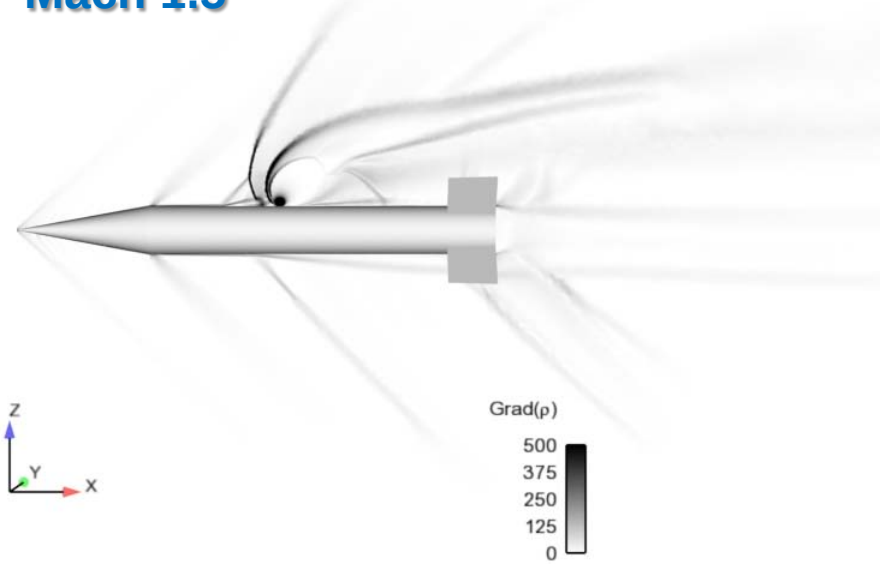
# Example Flowfield
## Army-Navy Finner (PR=340)

**Numerical Schlieren**

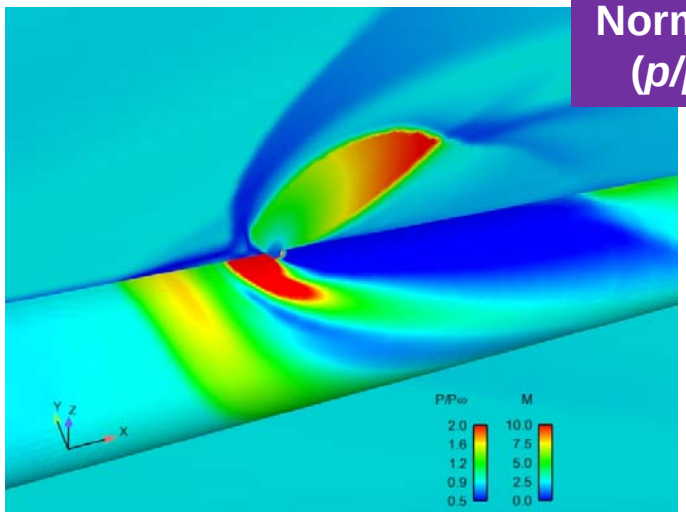
**Mach 2.5**



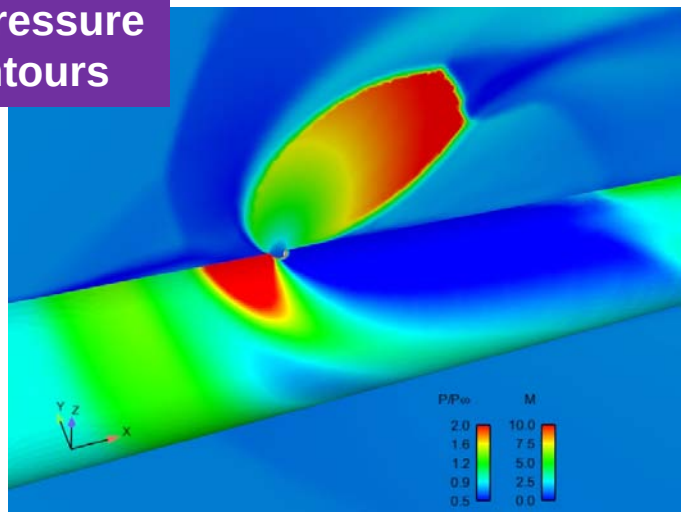

**Mach 1.5**




**Normalized surface pressure ($p/p_\infty$) and Mach contours**

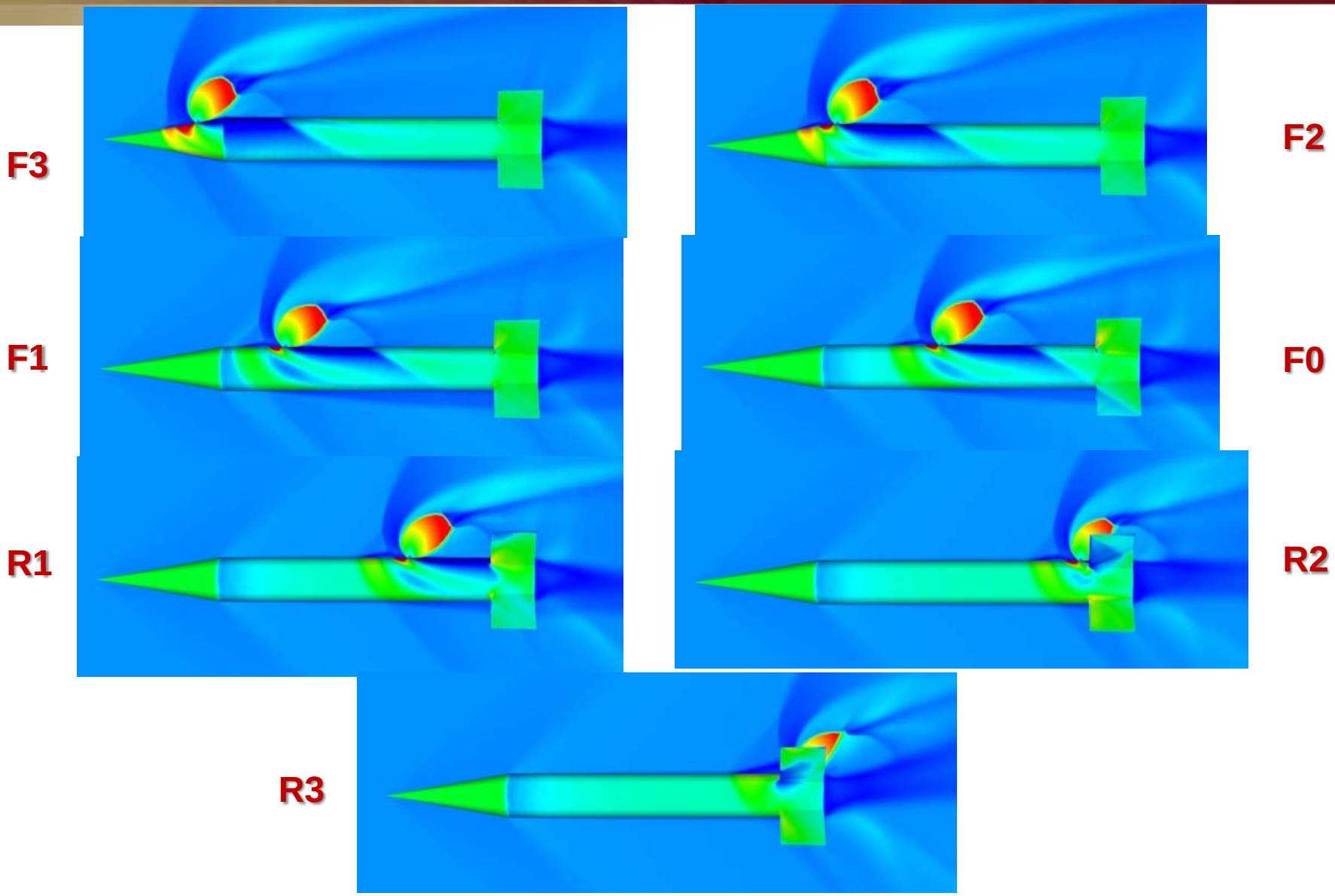



**F0 Location**



# Mach 1.5 Flowfield

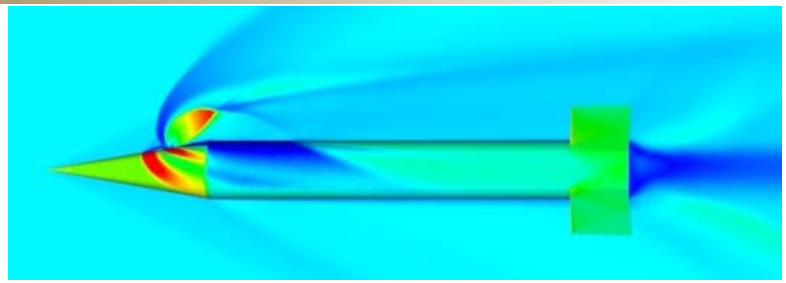
*p*/*p*$_\infty$ contours on projectile and Mach contours on symmetry plane (PR=340)



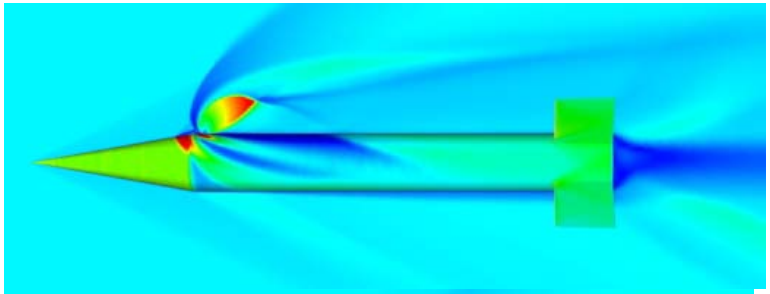
# Mach 2.5 Flowfield

*p*/*p*$_\infty$ contours on projectile and Mach contours on symmetry plane (PR=340)

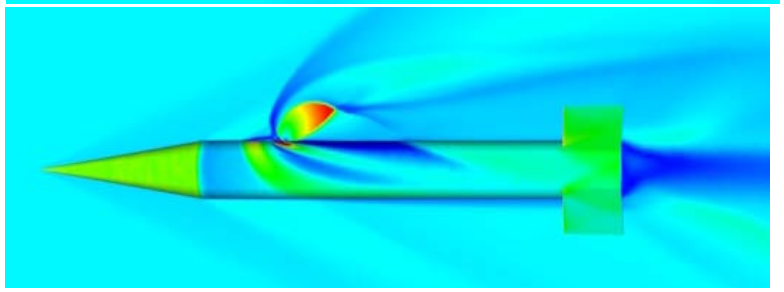
F3



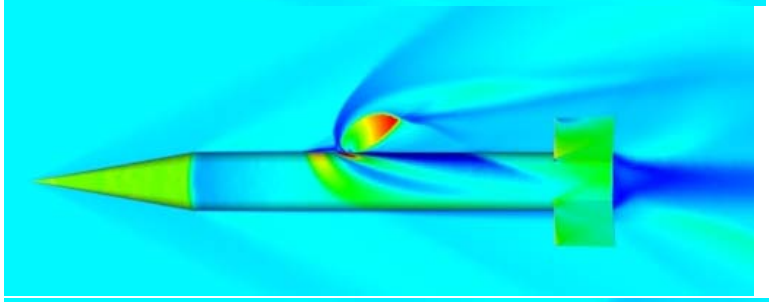
F2



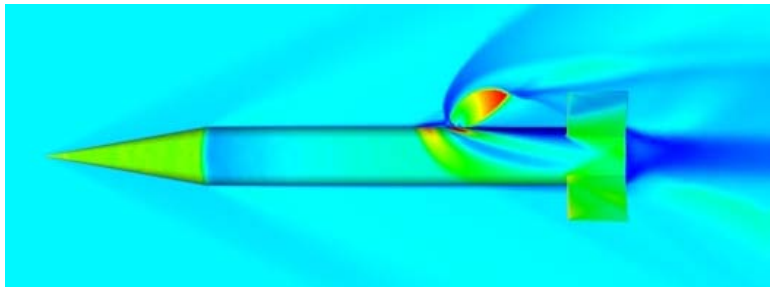
F1



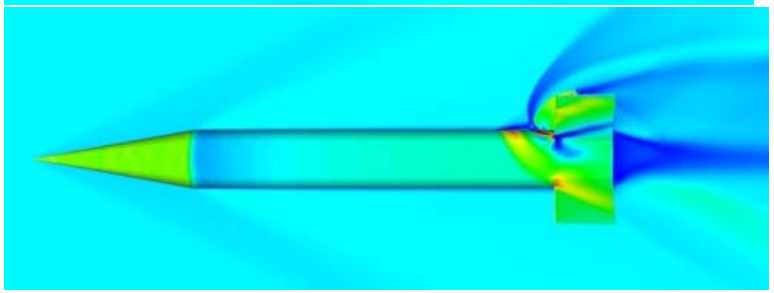
F0



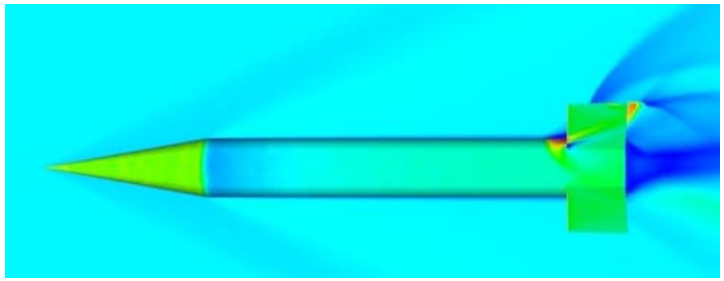
R1



R2



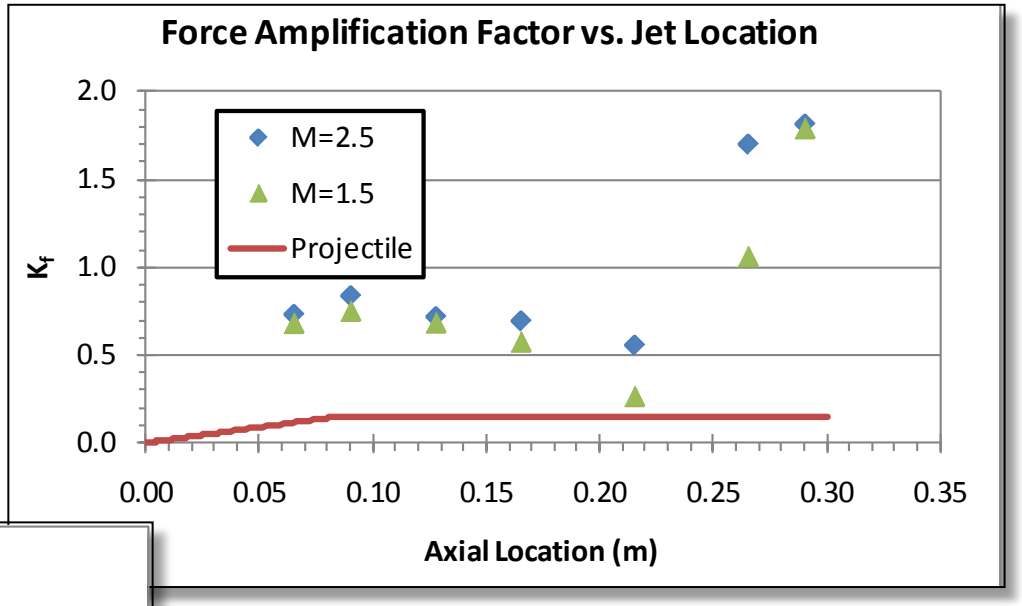
R3

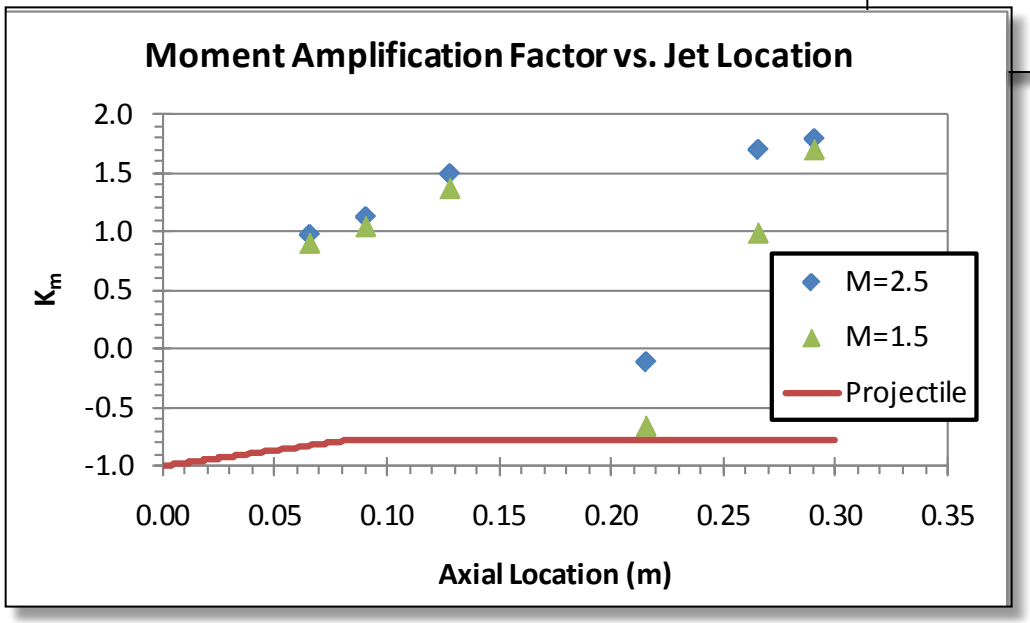


# Jet Amplification Factors
## PR=340

$$K_f = \frac{C_{N_j} + C_{N_{ji}}}{C_{N_j}} \qquad K_m = \frac{C_{m_j} + C_{m_{ji}}}{C_{m_j}}$$

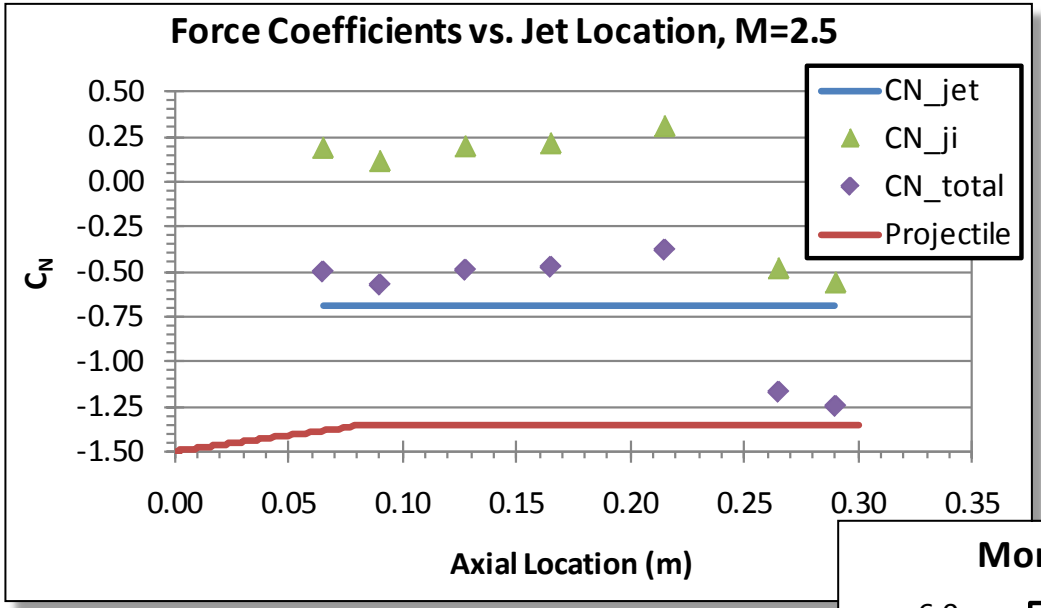
- Measure of JI effect.
  - > 1 → amplification
  - < 1 → attenuation
  - < 0 → effect opposite jet thrust



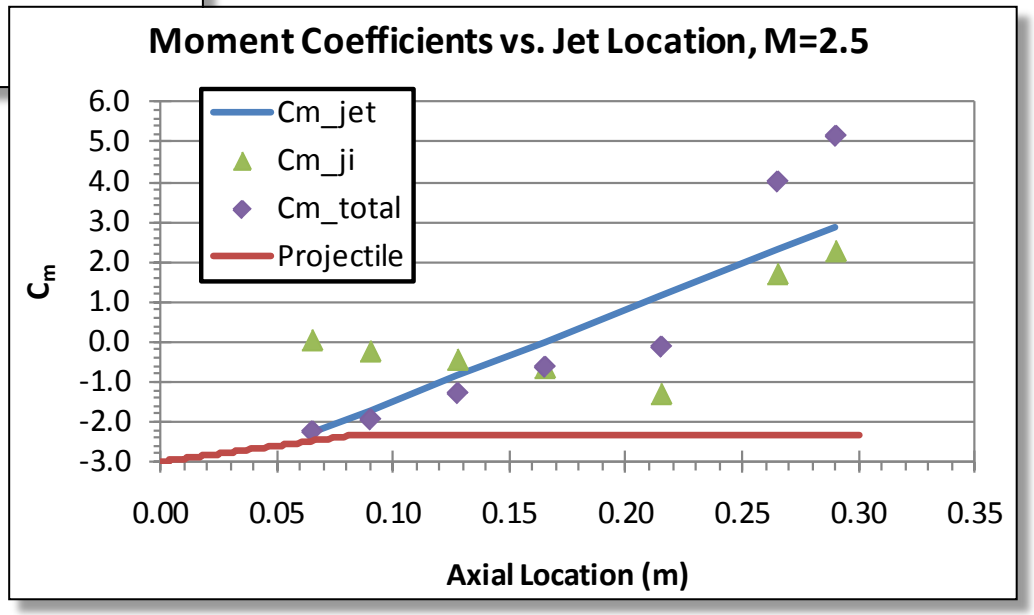




- Jet force attenuated at forward five locations.
- Jet force amplified at rear two locations.
- Moment due to jet thrust amplified at most locations.
- $K_m < 0$ at the R1 location.

# Force & Moment Coefficients
## PR=340




- Jet force constant
- JI force > 0 opposes jet thrust
- "Total" force
  - Magnitude < jet force indicates attenuation
  - Magnitude > jet force indicates amplification

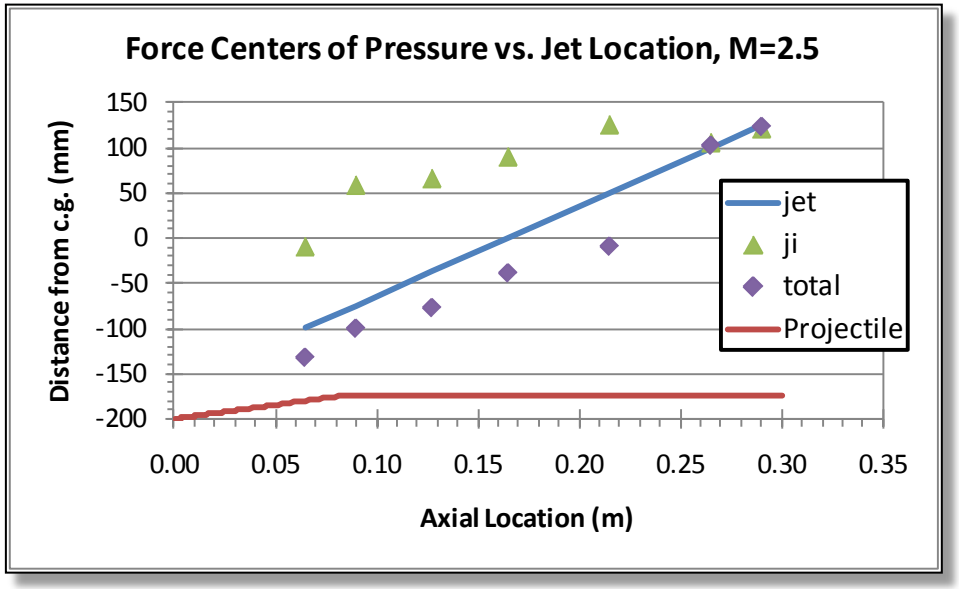


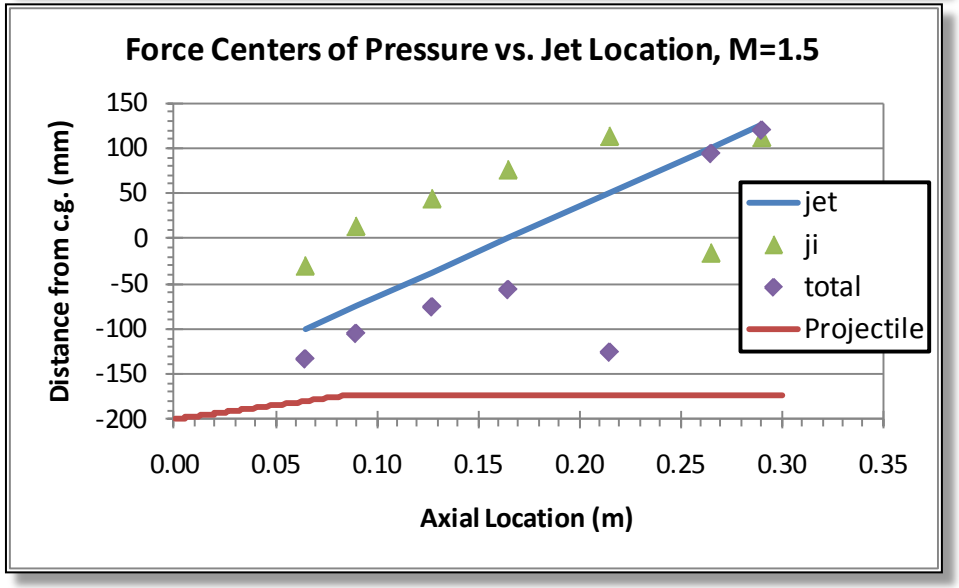

- Moment varies linearly with jet location.
- "Total" moment approaches moment due to jet thrust as location moves toward nose
  - JI moment goes to zero
  - $K_m$ goes to zero
- "Total" moment at R1 opposite that due to jet thrust

# Force Centers of Pressure
## PR=340

$$x_{cp} = -\frac{C_{m_k}}{C_{N_k}}$$

- Resultant force center of pressure (RFCP, "total") varies nearly linearly with jet location from c.g. and forward.
- At R1, RFCP is well forward at Mach 1.5.
  - 125 mm forward
  - Interaction with tail fins
  - Negative $K_m$ at R1
- Neither $C_{m_total}$, nor RFCP, are zero when jet located at c.g.



# Summary and Conclusions

- Effects of lateral reaction jet location on the forces and moments imparted to basic fin-stabilized projectile were investigated.
- Features of JI flowfield compared well with those presented in archival literature.
- Jet thrust was attenuated at forward five locations
  - 15-45% at Mach 2.5
  - 25-75% at Mach 1.5
- Jet thrust amplified up to 80% when located just forward or between tail fins.
- Locating jet near the tail of projectile can minimize the traditional JI effects that are due to interactions in the jet wake.
- However, the near-jet flowfield interaction between jet and fins must be taken into account.

# Future Work

- These results and additional flat plat investigation results presented at the 29th AIAA Applied Aerodynamics Conference, Honolulu, HI, June 2011.
  - DeSpirito, J., “Factors Affecting Reaction Jet Interaction Effects on Projectiles,” AIAA-2011-3031, June 2011.
- Plan to extend study to include
  - Higher Mach number
  - Effects of variation of projectile angle of attack
  - Effects of transient jet pulse
  - Effects of projectile rotation
- Also plan investigations in subsonic crossflow.

# Acknowledgments

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