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Numerical Computations of Subsonic and Supersonic Flow Choking Phenomena in Grid Finned Projectiles

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Presentation Outline

- Introduction
- Model Configuration
- Numerical Modeling
- Results
- Analysis of Choking Phenomena
- Conclusion

Introduction

- Grid-fin configurations offer interesting alternative to classical fin designs :
  - Low Hinge Moment,Easy storage, Good performance at high AoA.
  - Drawback : Higher drag penalty
- Experimental studies conducted at DRDC (in collaboration with ISL) demonstrated an aerodynamic choking phenomena on two configurations :
  - Thick fin model : flow is choked over a large range of Mach numbers
  - Thin fin model : flow choking occurs at specific Mach numbers
- Choking effect has not been reproduced by CFD or wind tunnel tests.

Introduction

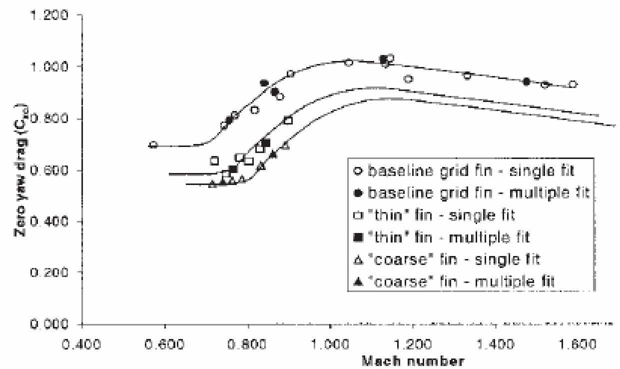


Figure 2. Zero yaw drag coefficient.

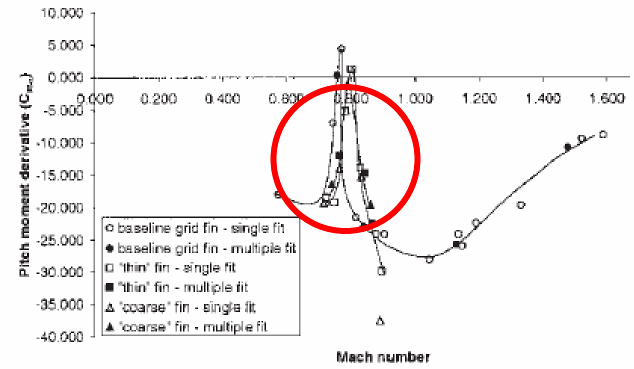


Figure 3. Pitch moment coefficient.

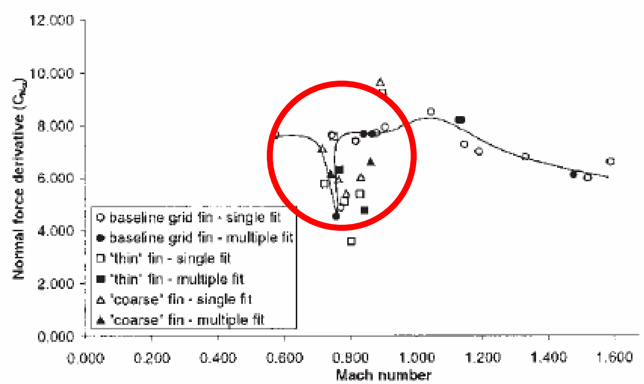


Figure 4. Normal force coefficient.

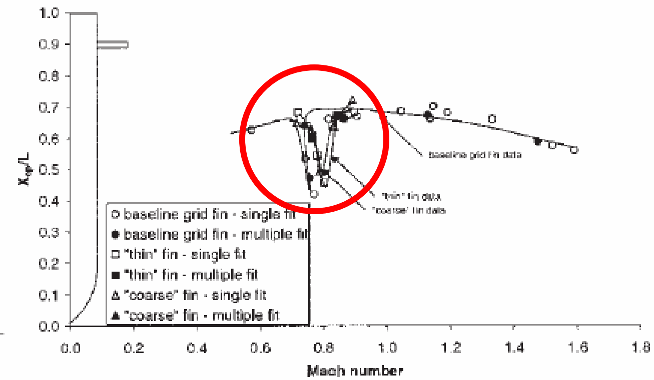
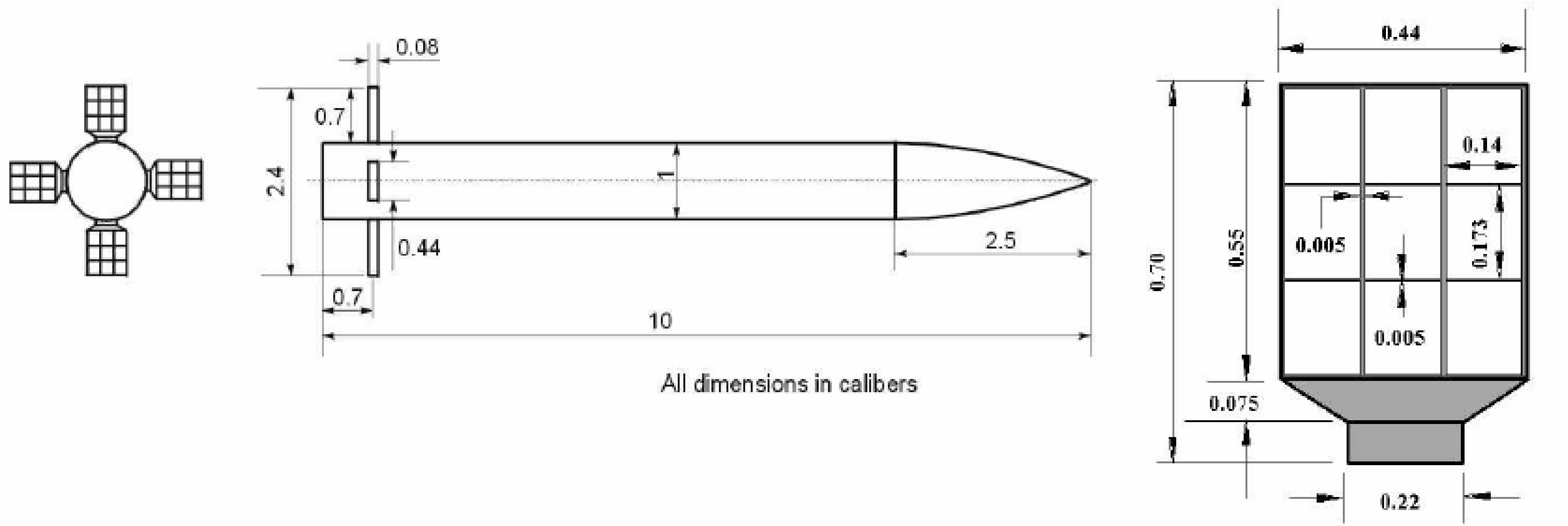


Figure 5. Center of pressure location.

⇒ Choking phenomena measured in aeroballistic range (Eglin AFB)

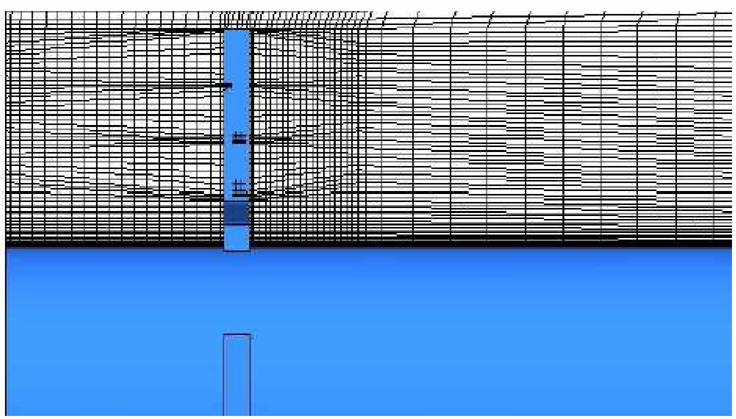
Model Configuration (Thin fins)

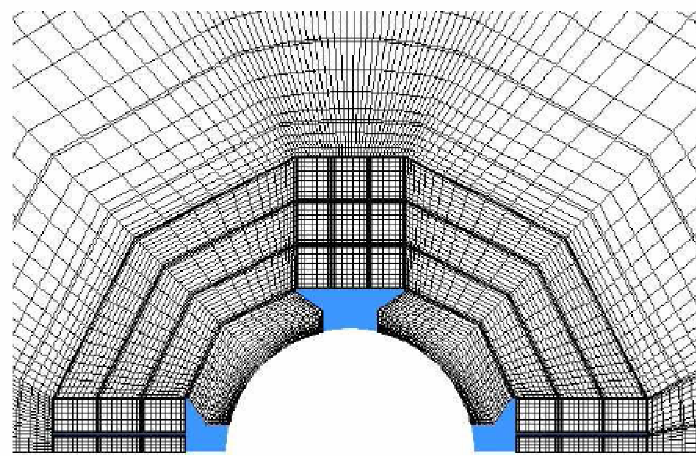


- Air Force Finner body, with four grid fins
- 9 grid cells per fin.
- No cant angle for fins
- 1 caliber = 20mm

Numerical Modeling

- CFD work done with ANSYS CFX 5.7
  - Navier-Stokes equations
  - 2nd order advection scheme
  - k-epsilon turbulence model was used
- Hexahedral mesh built with ANSYS ICEM CFD Hexa
  - 1.6 million elements for supersonic flow domain
  - 2.1 million elements for subsonic flow domain (with base flow)

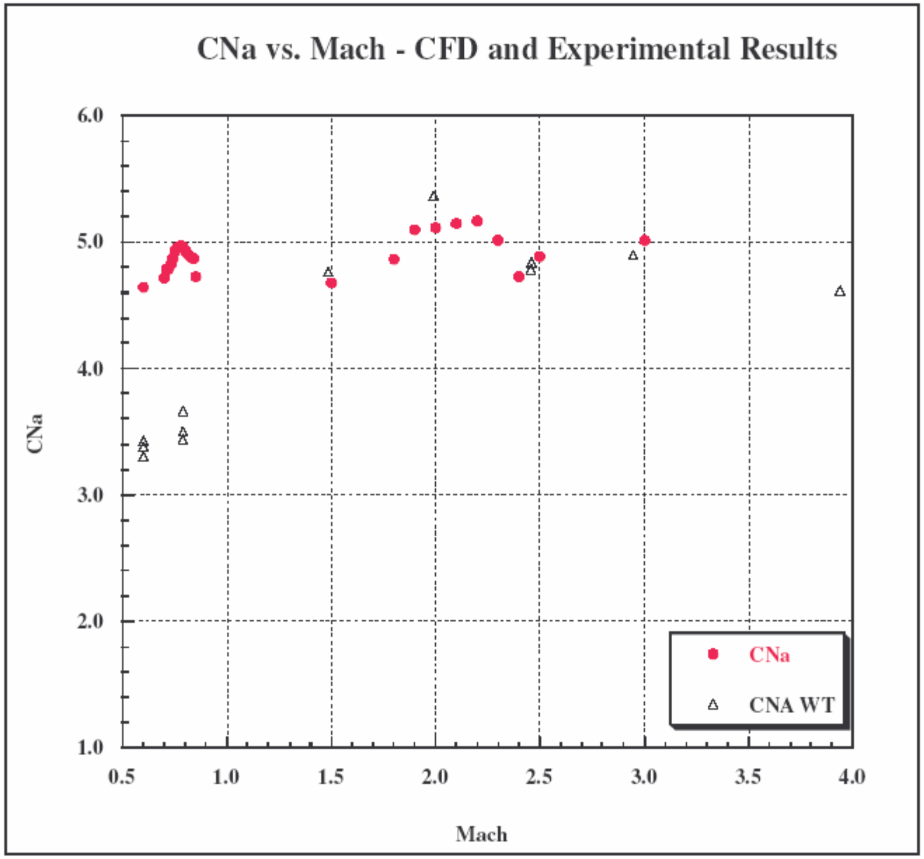




Numerical Modeling

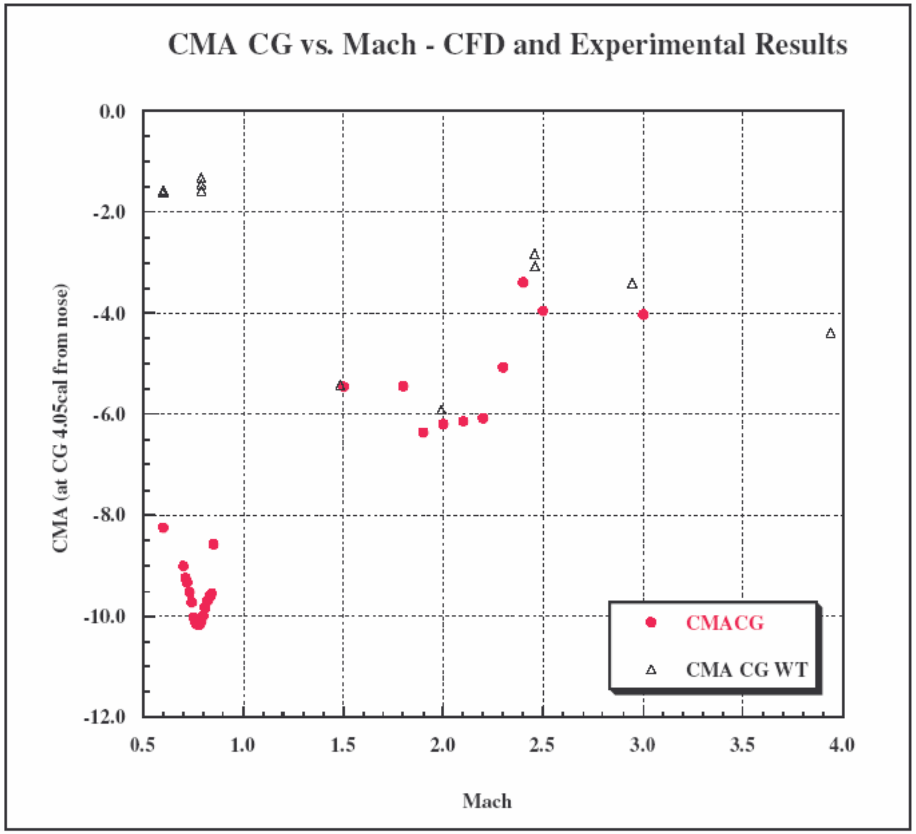
- CFD computations performed at following conditions :
  - Baseline Mach no. 0.6, 0.8, 1.5, 2.0, 2.5, 3.0
  - Subsonic runs conducted at small increments between Mach 0.7 and 0.85 for flow choking simulations
  - Supersonic runs conducted at small increments between Mach 1.8 and 2.5 to explain sudden change in aerodynamic coefficients.
  - All runs made a 2° angle of attack
  - Cx, Cn, Cm and Xcp aerodynamic coefficients computed

Results – Normal Force Coefficient



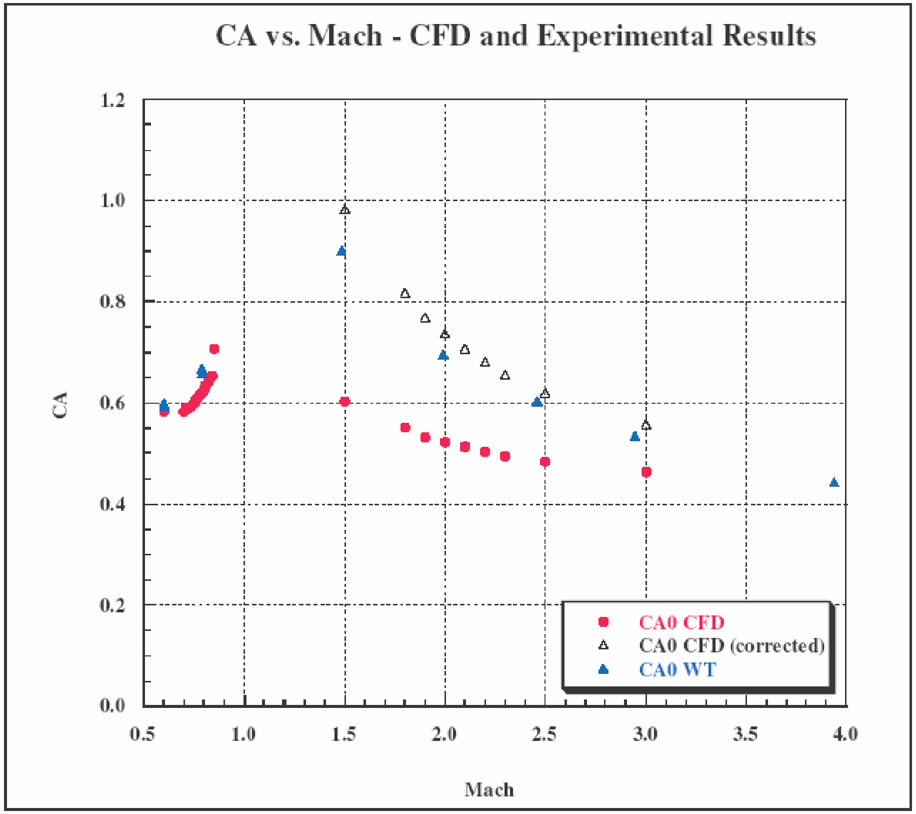
- Peak in CNa at M=0.78. Wind Tunnel results do not reproduce this peak.
- Theoretical Choking Mach for fin cells is M=0.744.
- Subsonic choking captured in CFD results.
- Discontinuous variation of CNa between Mach 1.8 and 2.4.
- Good agreement between CFD and Wind Tunnel results.

Results – Pitch Moment Coefficient



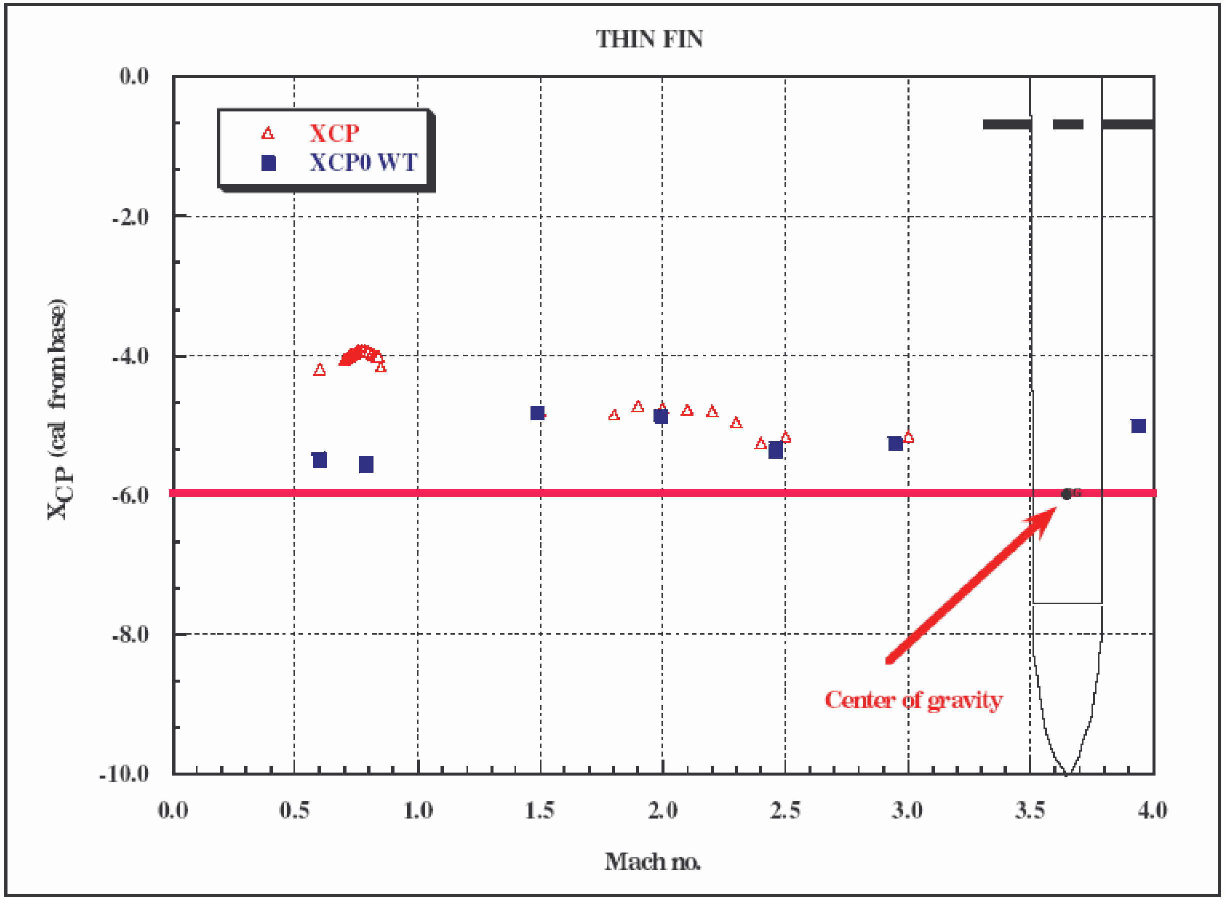
- Similar peak at M=0.78. Wind Tunnel results do not reproduce this peak.
- Effect of subsonic choking on CMa is to increase stability.
- Again, discontinuous variation of CMa between Mach 1.8 and 2.4.
- Good agreement between CFD and Wind Tunnel results.

Results – Axial Force Coefficient

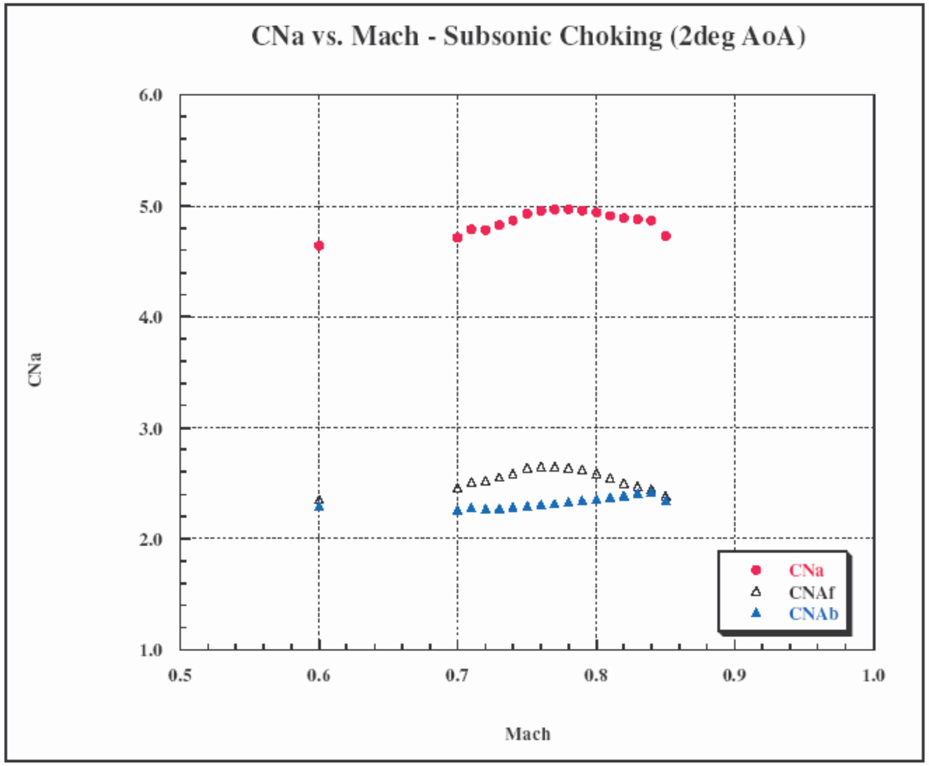


- Good agreement between CFD and Wind Tunnel results.
- CFD results in supersonic regime had to be corrected for base drag.

Results - Center of Pressure

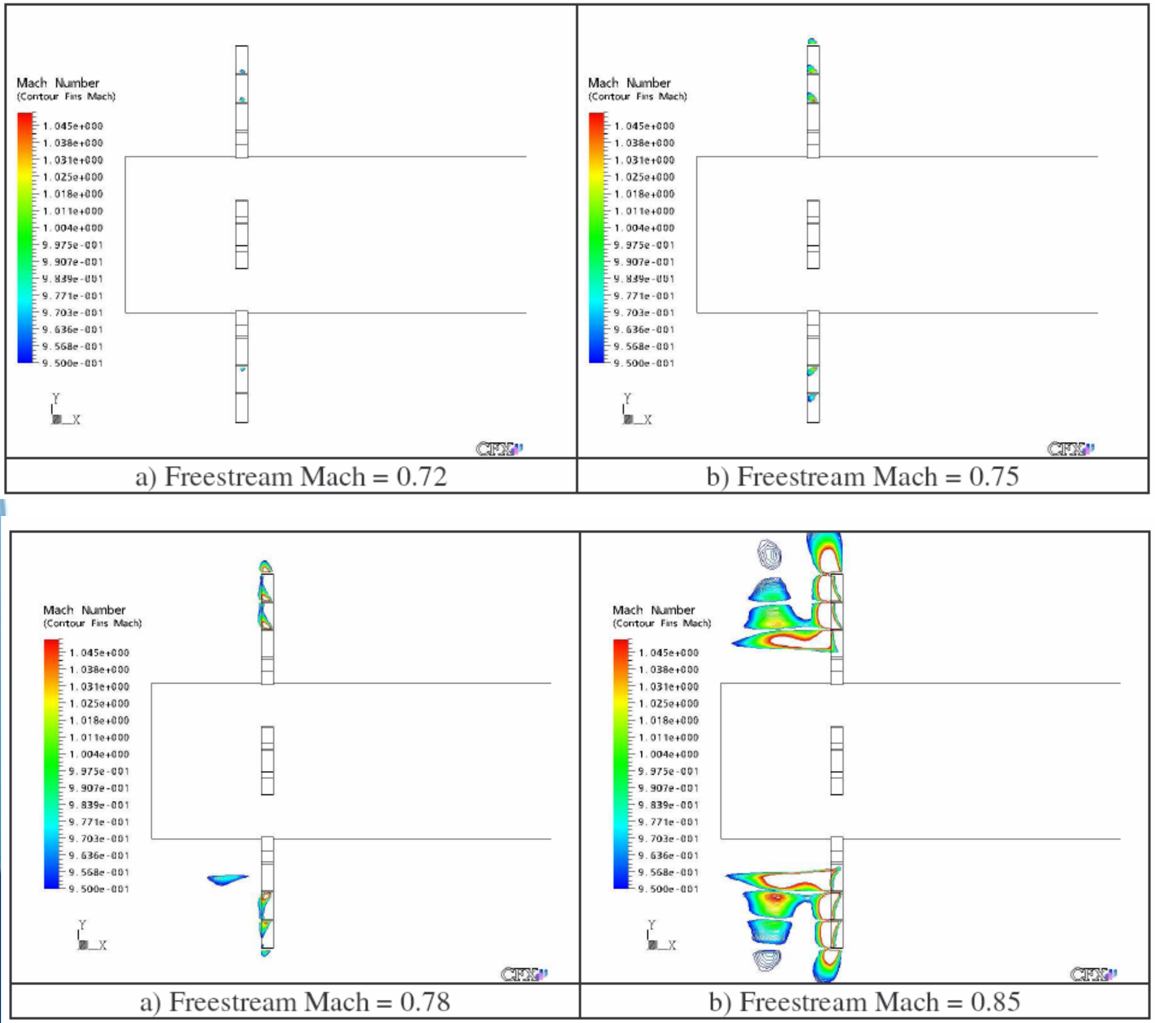


Analysis – Subsonic choking



- CNa contribution breakdown : peak effects come from fins.
- Peak value at Mach 0.78 due to choking effects.
- Confirmed by apparition of Mach waves inside fin cells.

Analysis – Subsonic choking

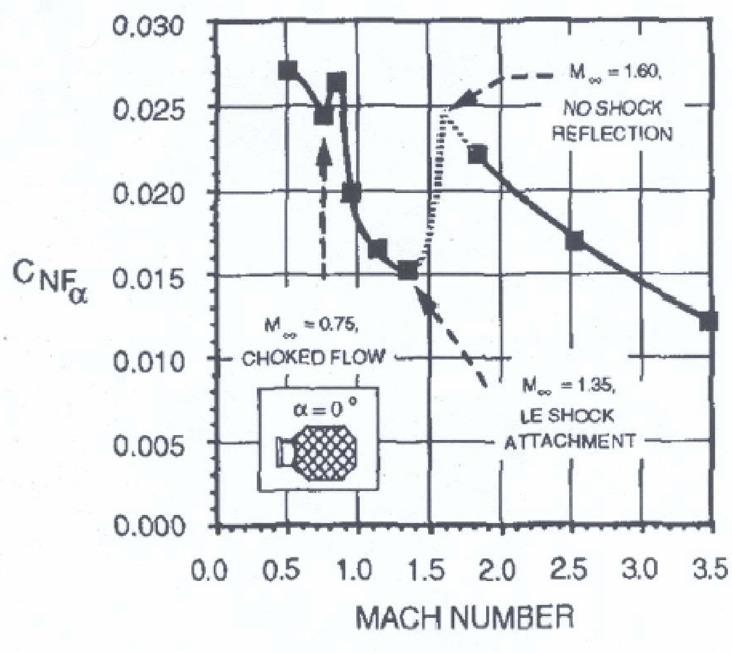


a) Freestream Mach = 0.72 b) Freestream Mach = 0.75

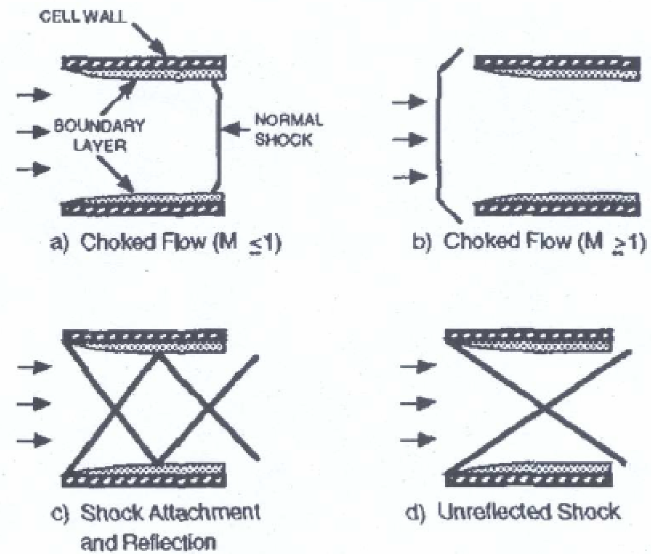
a) Freestream Mach = 0.78 b) Freestream Mach = 0.85

- Contour plots of sonic regions between Mach 0.95 and 1.05.
- As Mach number moves from 0.72 to 0.78, normal shockwaves appear in cells.
- Completely choked state reached at Mach 0.78.
- Good correlation between theoretical choking Mach number and CFD results.

Theoretical Grid Fin Flow Field Model



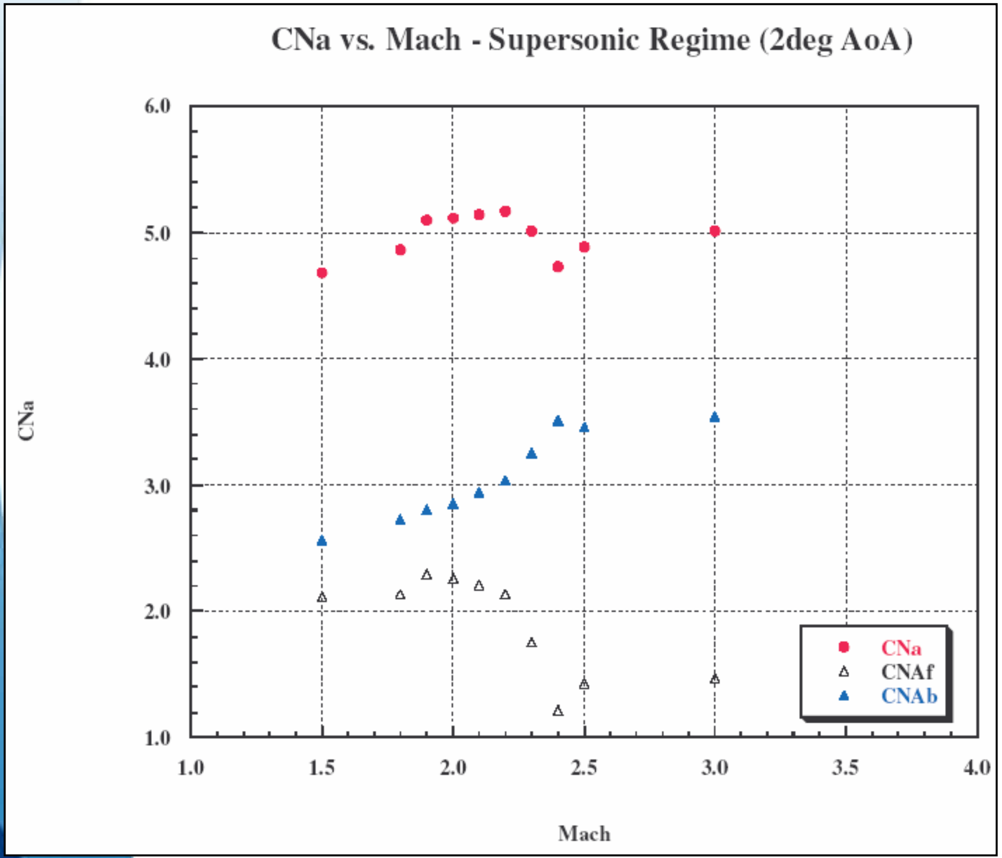
C_{NF_α} Versus Mach Number.



Grid Fin Flow Field.

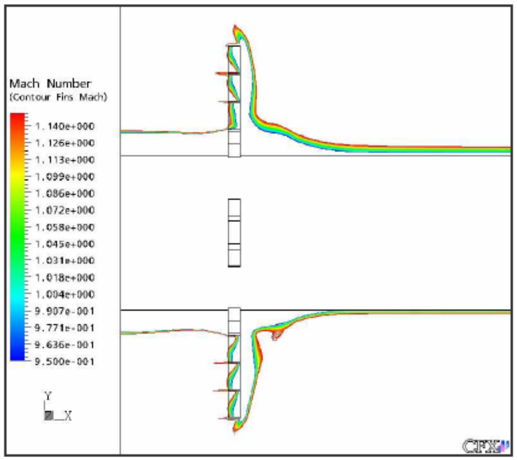
Ref. Washington et al.

Analysis – Supersonic choking

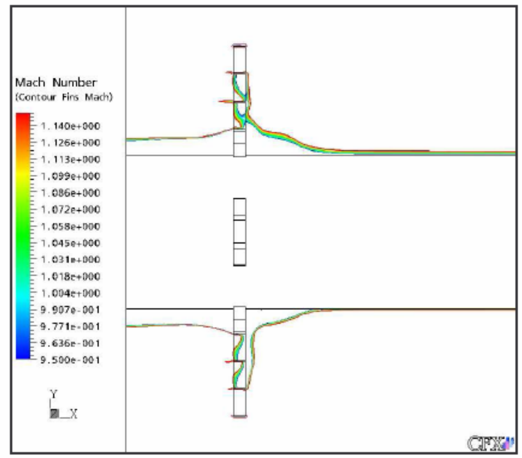


- CNa contribution breakdown : peak effects come from fins.
- Discontinuous behavior between Mach 1.8 and 2.4.
- Change in fin shock-wave configuration explains unusual variation in coefficients.

Analysis – Supersonic choking

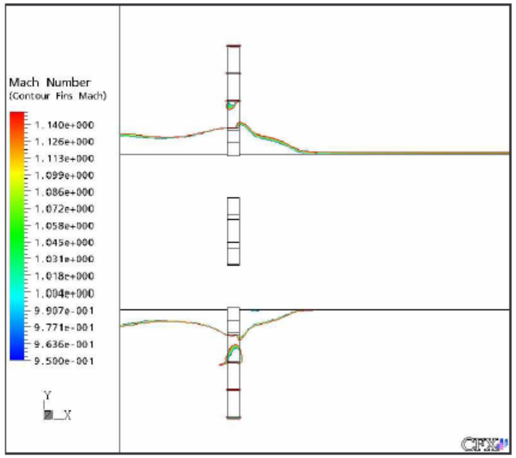


M = 1.50



M = 1.80

Contour plots of sonic regions between Mach 0.95 and 1.05



M = 2.30

- Flow completely choked at Mach 1.5, with transition to complete “unreflected” state at Mach 2.3.

- Irregular behavior between Mach 1.8 and 2.40 due to flow topology change from fully choked (shock outside of grid cells) to “non-reflecting” states.

Conclusion

- A detailed CFD analysis of flow inside grid fins gave insight on non-conventional behavior of the main aerodynamic coefficients.
- Flow choking effects successfully predicted in subsonic and supersonic flow regimes.
- Subsonic choking occurred at a specific Mach number. Important offset between wind tunnel and CFD results in subsonic regime.
- Supersonic flow transitions from fully choked to non-reflecting states over a large range of Mach numbers.

Conclusion

- Theoretical flow choking model by Washington (1993) demonstrated by CFD calculations.
- Experimental work Eglin AFB revealed loss of stability at subsonic choking conditions. With the present configuration, effect is opposite : gain in stability.
- CFD proved to be an essential tool in the study of this complex flowfield.

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Questions ?

References

REFERENCES

(1) Dupuis, A.D., and Berner. C., “Aerodynamic Aspects of a Grid Finned Projectile at Subsonic and Supersonic Velocities”, 19th International Symposium on Ballistics Interlaken, Switzerland, May 7-11, 2001.

(2) Dupuis, A.D., and Berner. C., “Aerodynamic Aspects of Fin Geometries on a Lattice Finned Projectile”, 20th International Symposium on Ballistics, Orlando, FL, USA, September 23-27, 2002.

(3) Bernier, A., and Dupuis, A.D., “Numerical Computations of Subsonic and Supersonic Flow for a Grid Finned Projectile”, 21st International Symposium on Ballistics, Adelaide, Australia, April 19-23, 2004.

(4) Washington, W.D., and Miller, M.S., “Grid Fins – A New Concept for Missile Stability and Control”, AIAA Paper 93-0035, 31st Aerospace Sciences Meeting & Exhibit, Reno, NV, January 11-14, 1993.

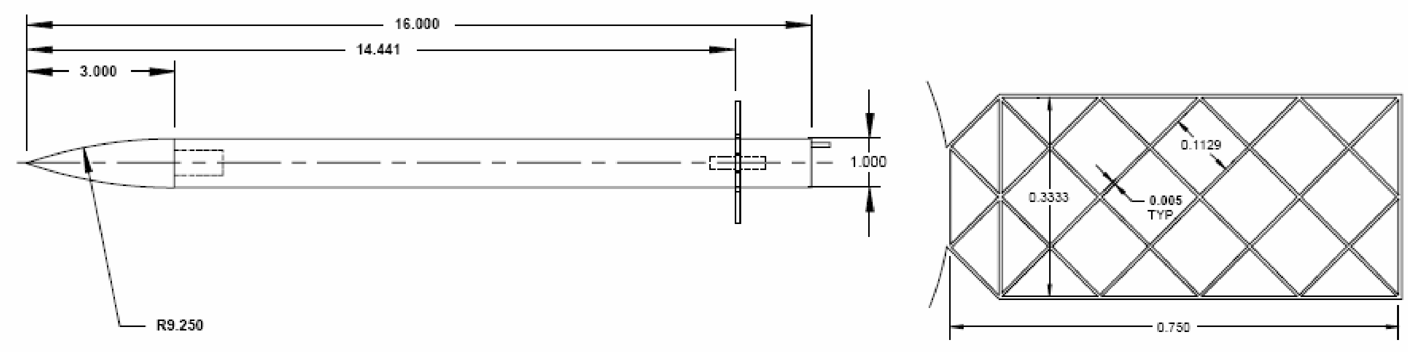

Figure 1 Generic tail control missile (GTCM) with grid fins