Fixing Poor Control Surface Performance on a Transonic Missile – A Case Study of Combining Cost-effective Wind Tunnel Testing and CFD Analysis

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Methods for Aerodynamic Design

Discrete methods with clearly defined boundaries?

- “Classical” exact analytical
- Semi-empirical database methods
- Computational Fluid Dynamics
- Wind-tunnel testing

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Combining CFD and Experiments

- “Conventional” view: use wind-tunnel to validate CFD, then use calibrated CFD to perform further studies
- Very slow, very expensive, very narrow view
- Why do CFD when good tunnel results already exist?

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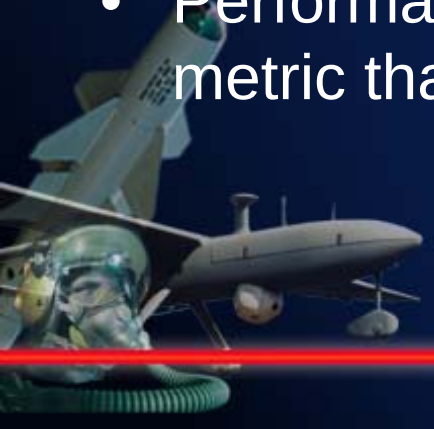
What Is “Quality”?

- CFD good practice stipulates measures to be taken to ensure good quality CFD
- Good quality CFD is very expensive. Is it always necessary?
- Does good quality CFD necessarily ensure good quality design?
- Quality vs. quantity trade-off, which will give better final design?
- Performance and quality of design is a more meaningful metric than quality of CFD analyses



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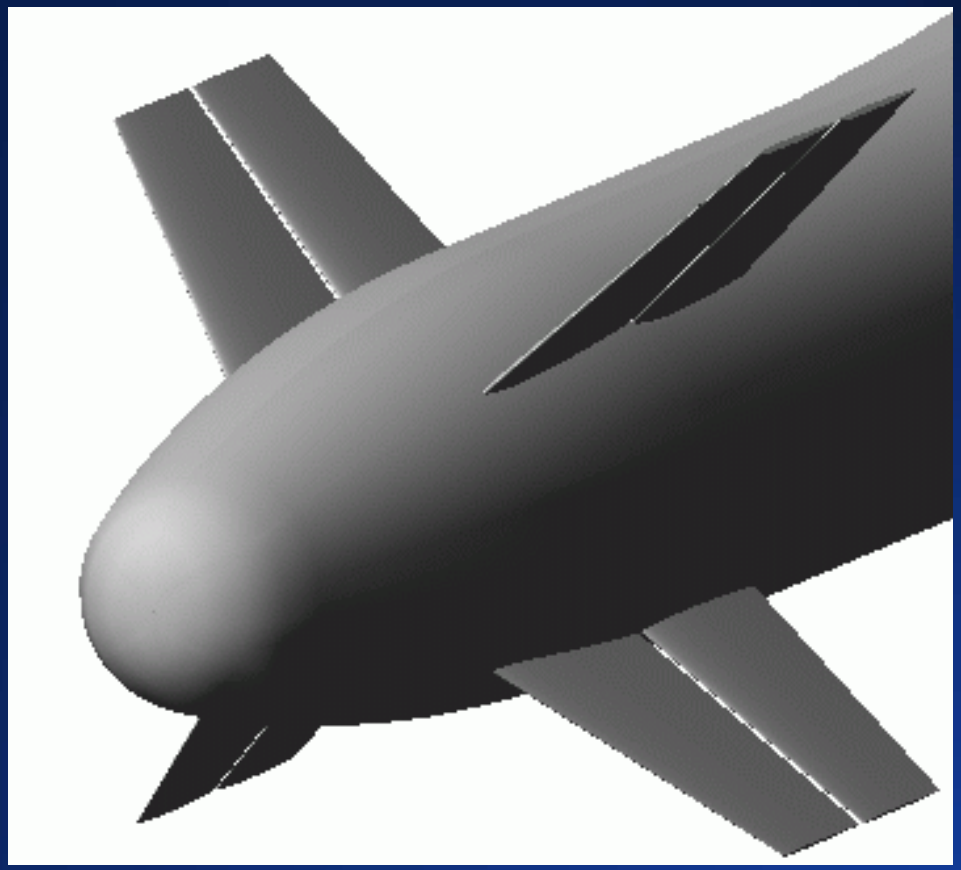
A Real Life Design Problem

- Transonic (mostly subsonic) missile with canard control
- User requirements:
  - Very high manoeuvrability
  - Strict packaging dimensions
  - Low hinge moments



Problem: Insufficient Elevator Power

- WT test in concept phase, 1:13 scale model in blow-down wind-tunnel, insufficient elevator effectiveness
- No CFD capability available, revise design empirically
- Performance improved, but still unsatisfactory
- Probable cause:
  - Low Reynolds number
  - Poor profile accuracy

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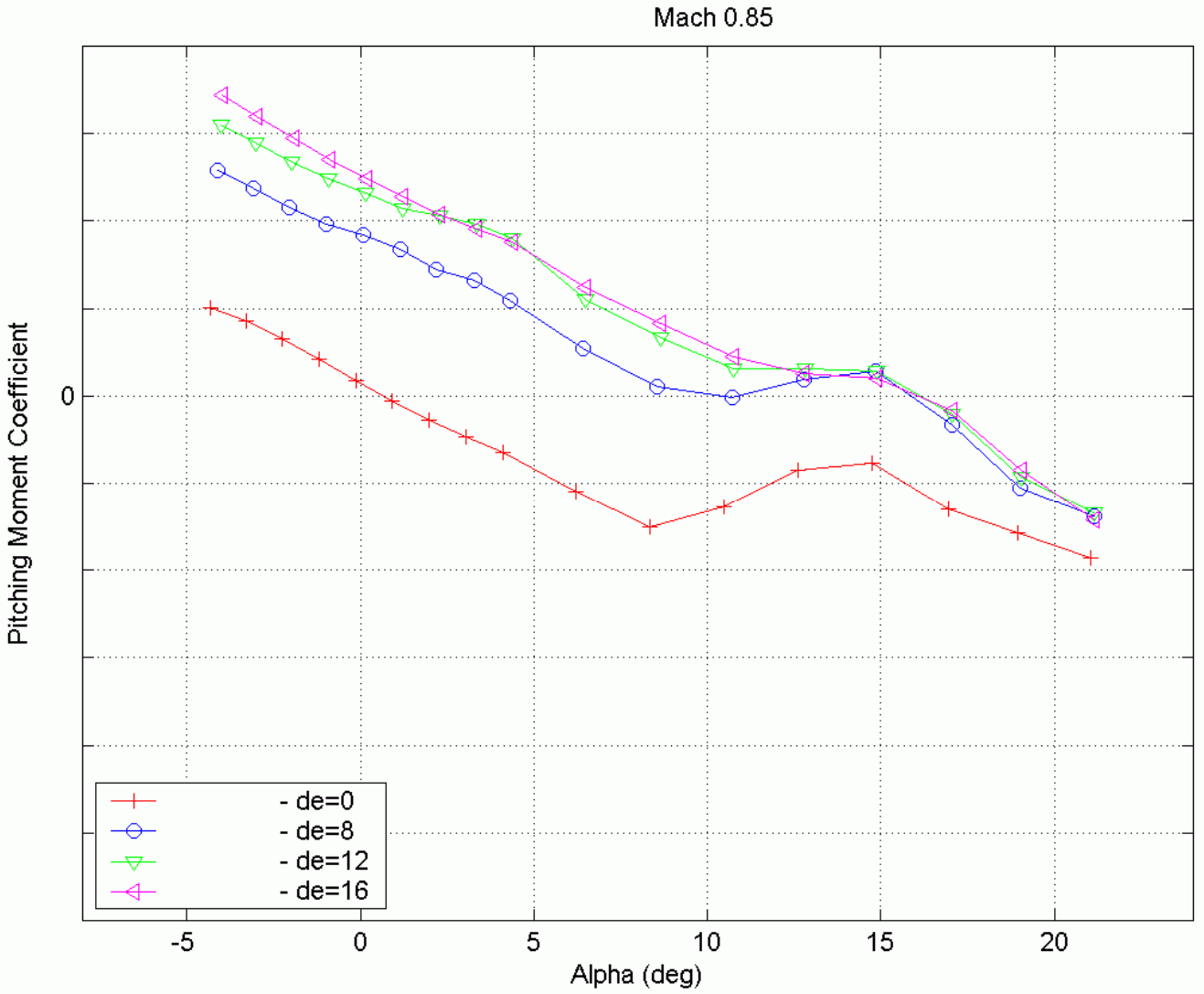
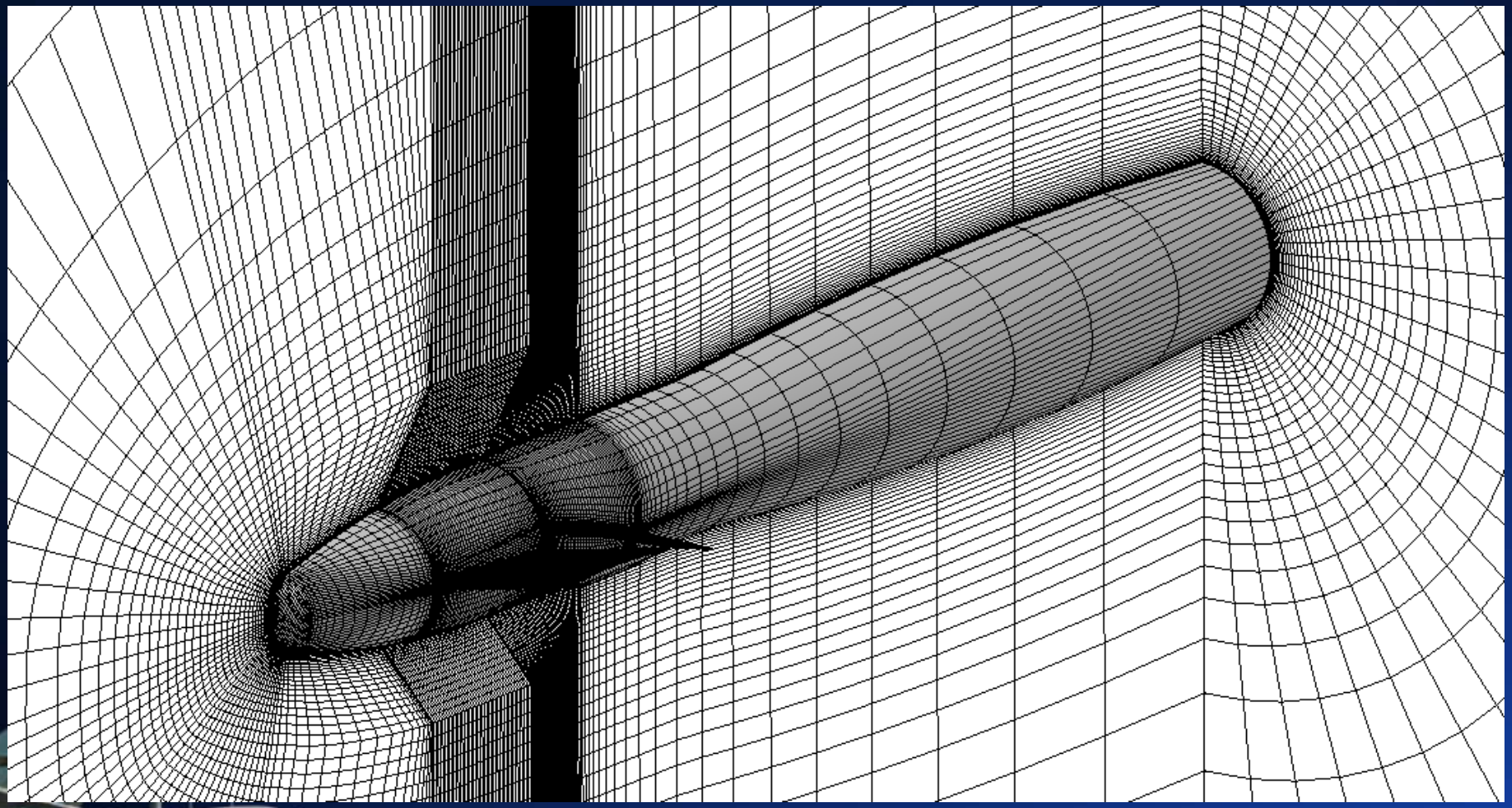
Problem: Design Flaw, Not Testing Artifact

Highly detailed test of 30% model in transonic tunnel



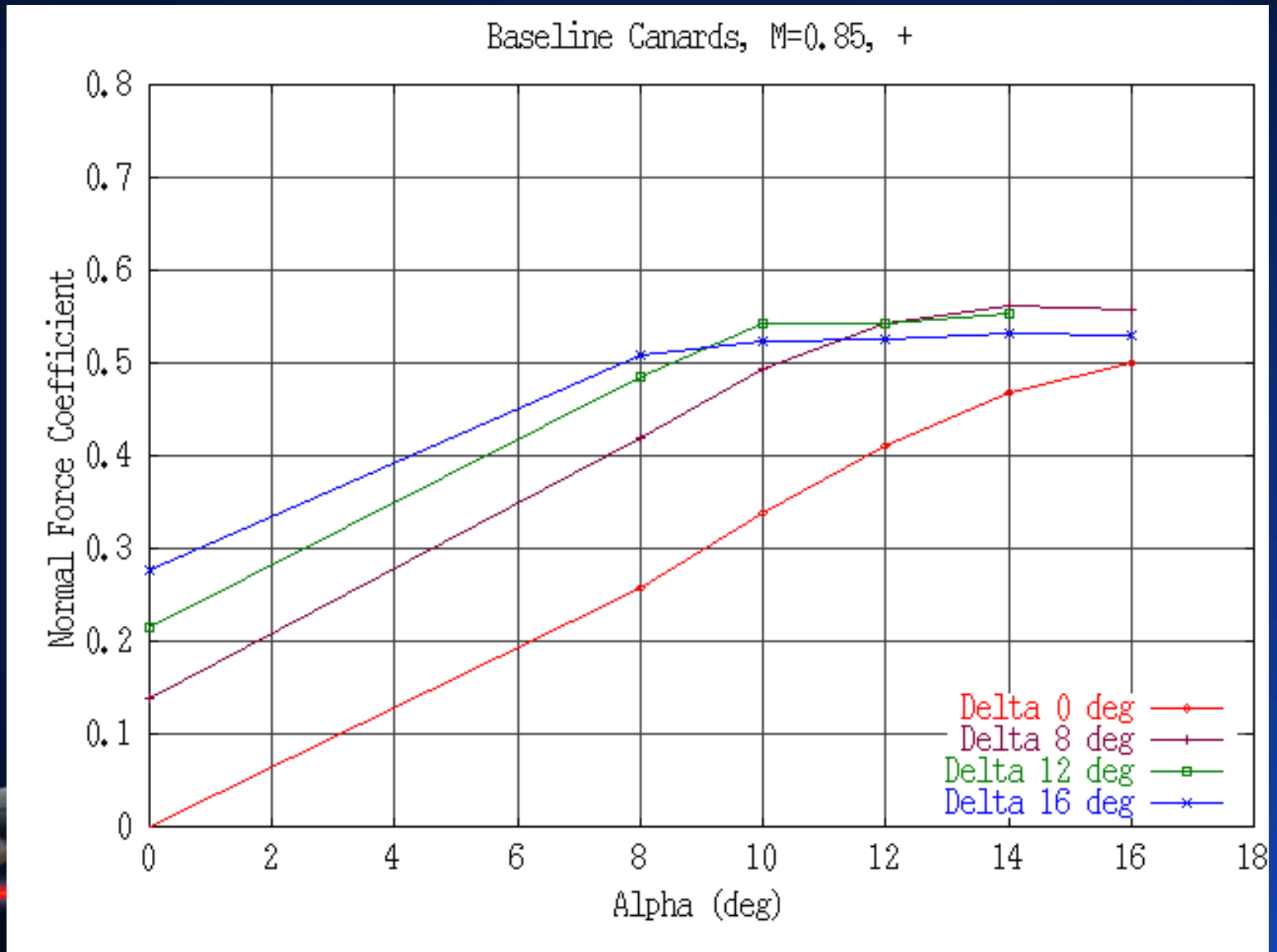
Understanding The Flow

Relatively “crude” simplified CFD-Fastran model, only 190 000 cells



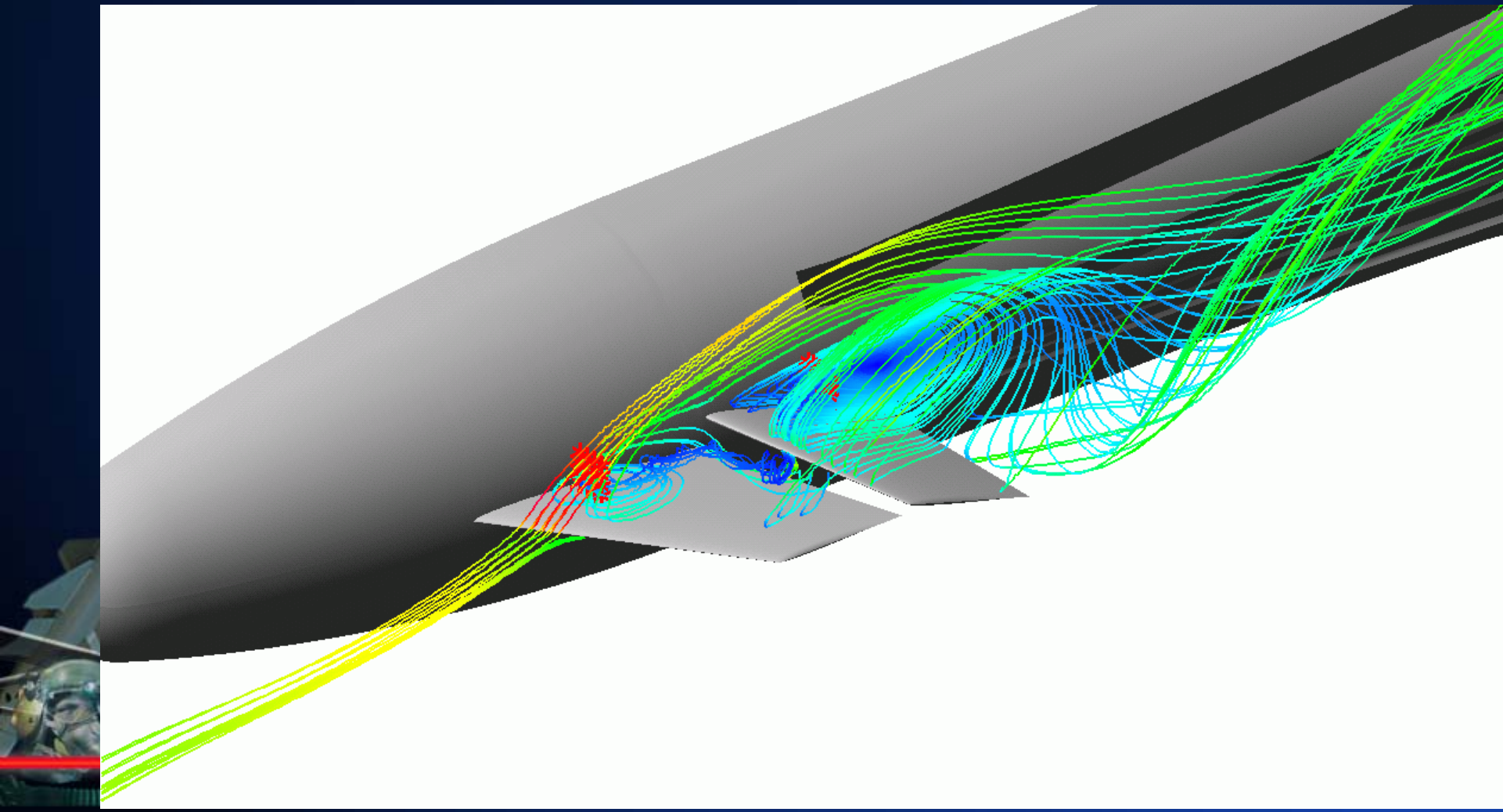
Baseline CFD Confirms Problem

Even much simplified CFD captures poor performance



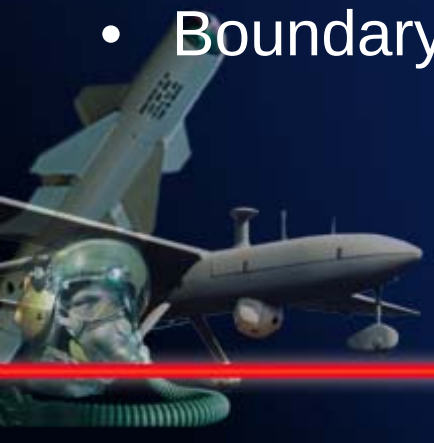
CFD Aids Understanding of Flow Problems

- Premature flow separation due to incidence and deflection
- Nose upwash aggravates separation
- Interference due to close spacing



Fixing the Problem

- Thanks to improved understanding, mostly from qualitative inspection of CFD flow fields, design is easy to improve
- Design tweaked to get better looking picture
- Increase control surface leading edge sweep angle
- LE sweep reduces adverse interference on fixed canard
- Increased gap also reduces interference
- Boundary layer fence on fixed canard helps



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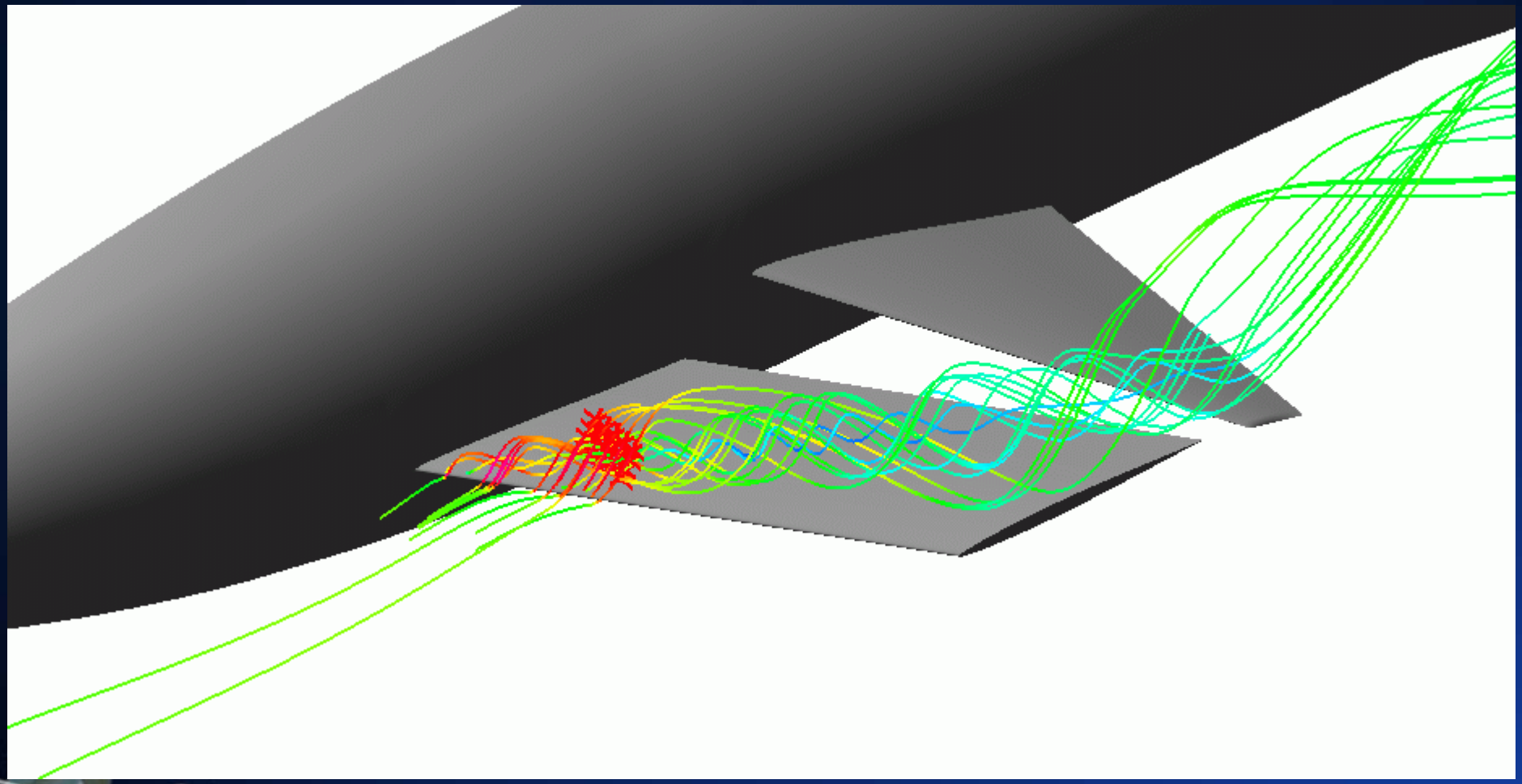
Much Prettier CFD Pictures After Mods



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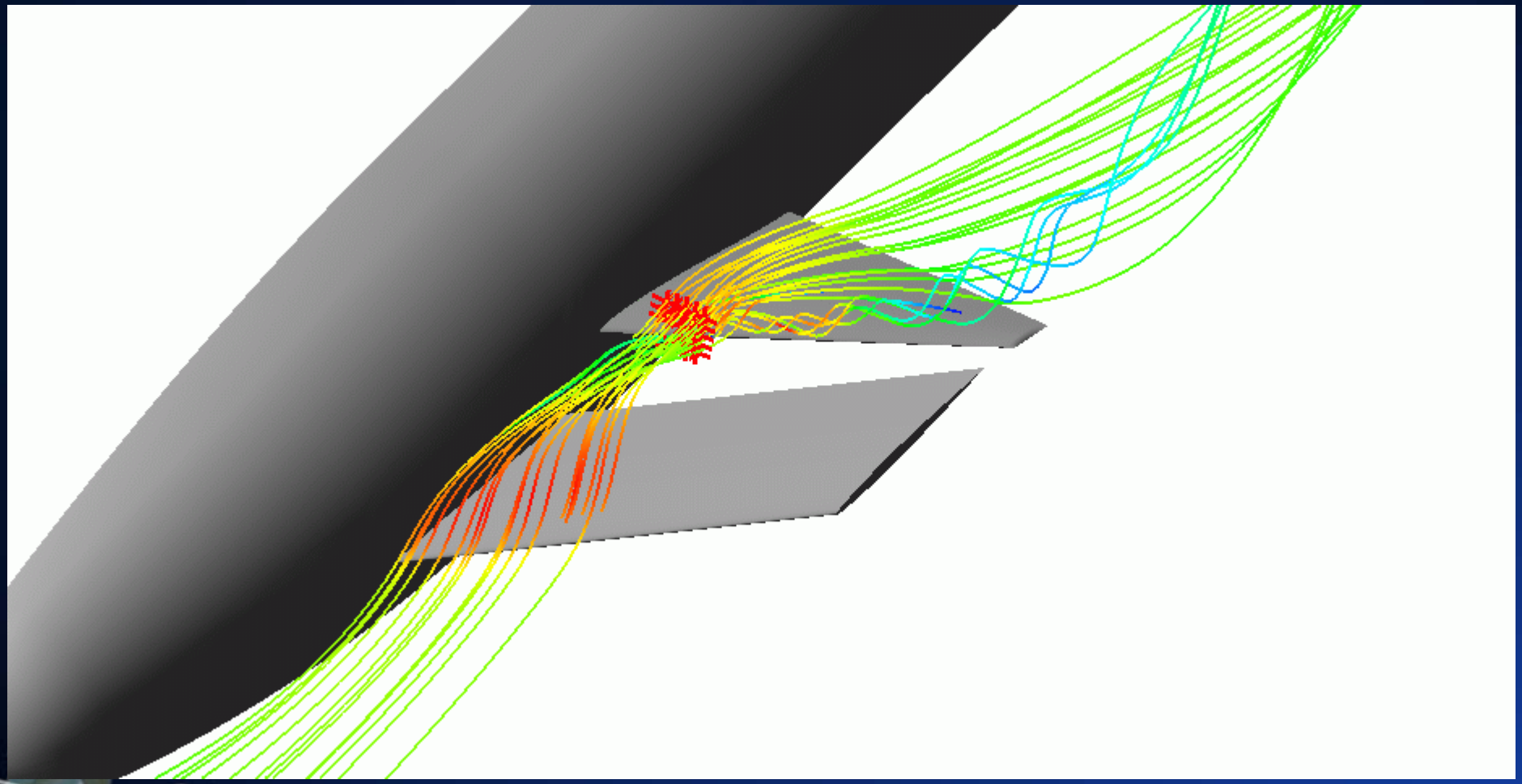

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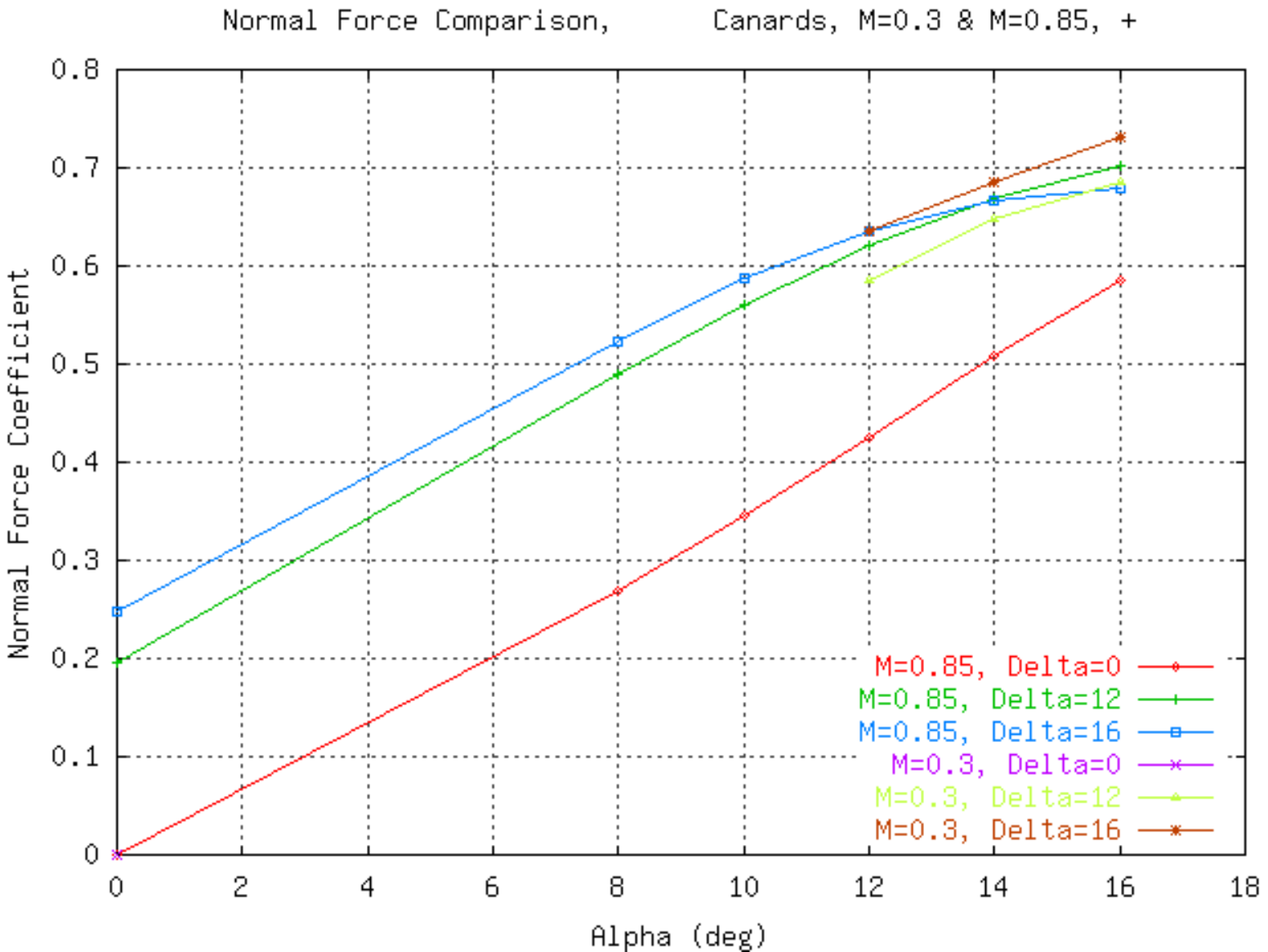
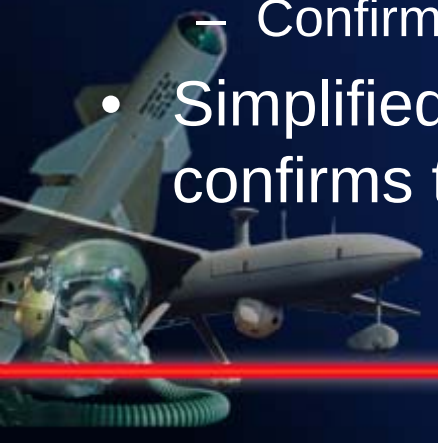
But Pretty Picture Also Gives Better Forces



Confirm With “Crude” Low-speed WT Test

- Big chances taken with simplified CFD
- Need to confirm independently
- CFD suggests non-subtle flow, try cheap WT test
- WT approximations suggested by CFD:
  - Low Mach-number (cheaper tunnel)
  - Simplified aerofoils
  - “Coke tin & aluminium tape” model modifications
- Simplified CFD and WT test only practical because of:
  - Cross-confirmation
  - Confirmation from later detailed test, which acts as a “Safety Net”
- Simplified test indicates BL fence was a bad idea, CFD confirms this



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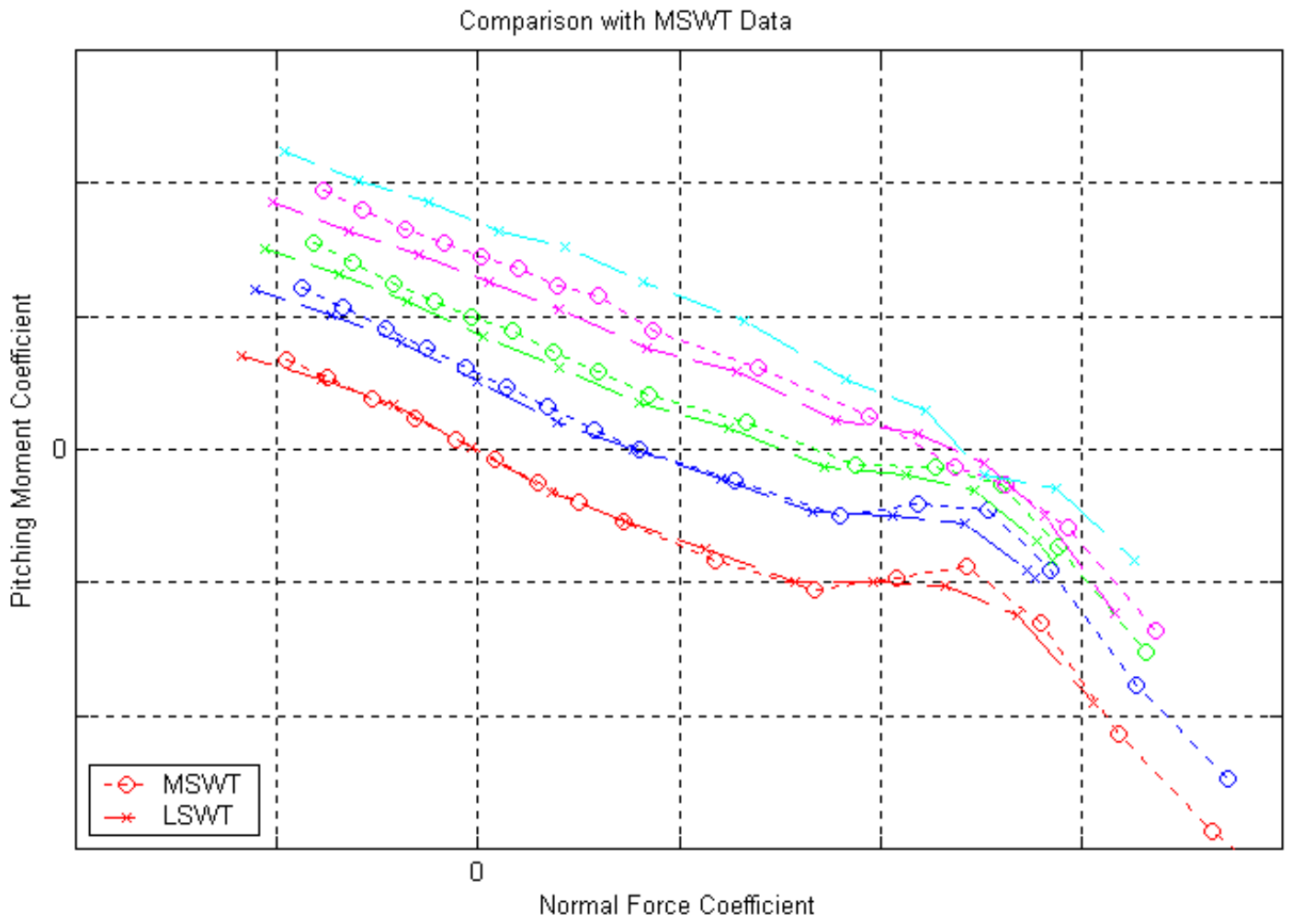
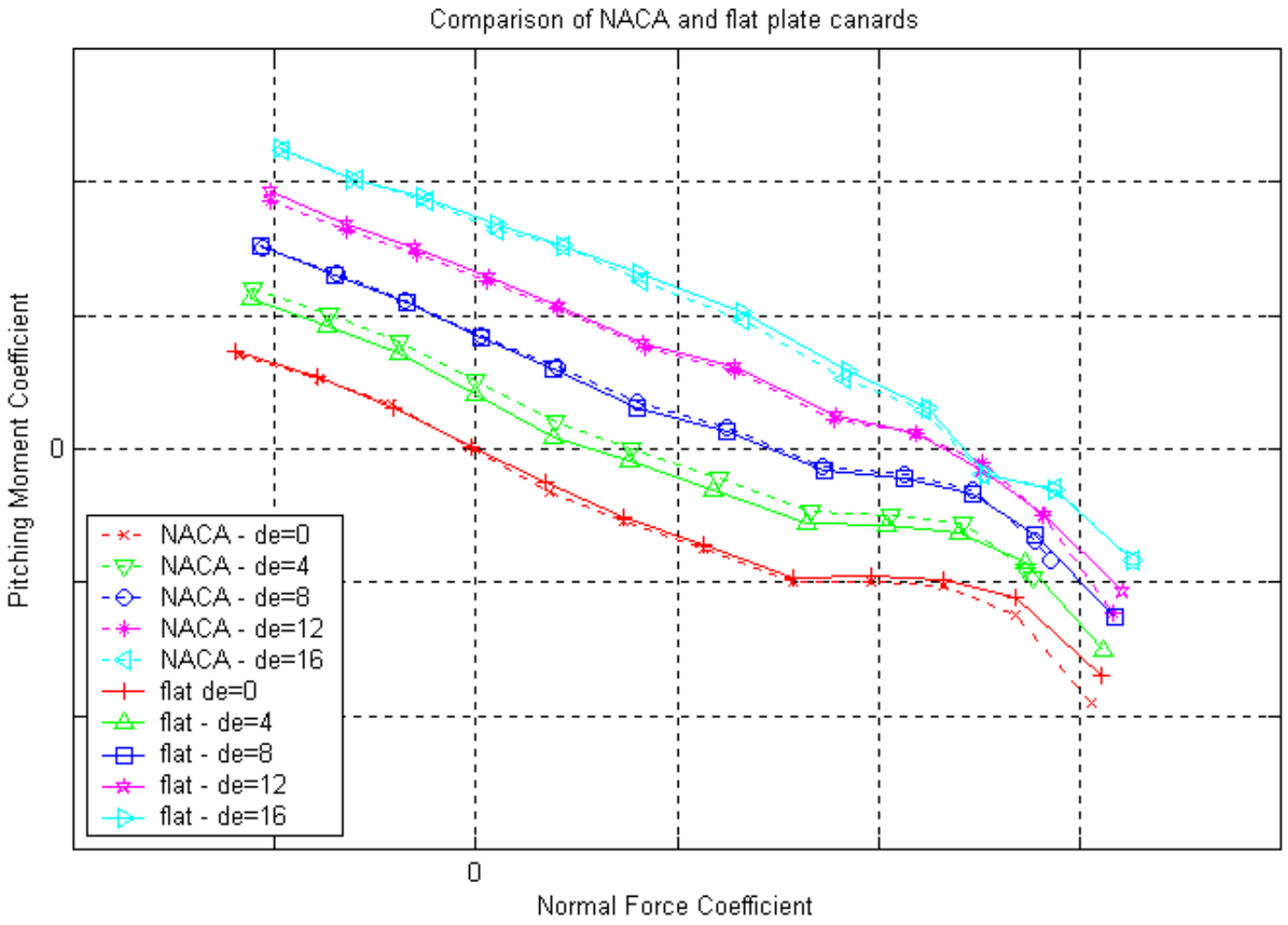
Low Mach Number Can Be OK

Check validity with CFD before WT testing

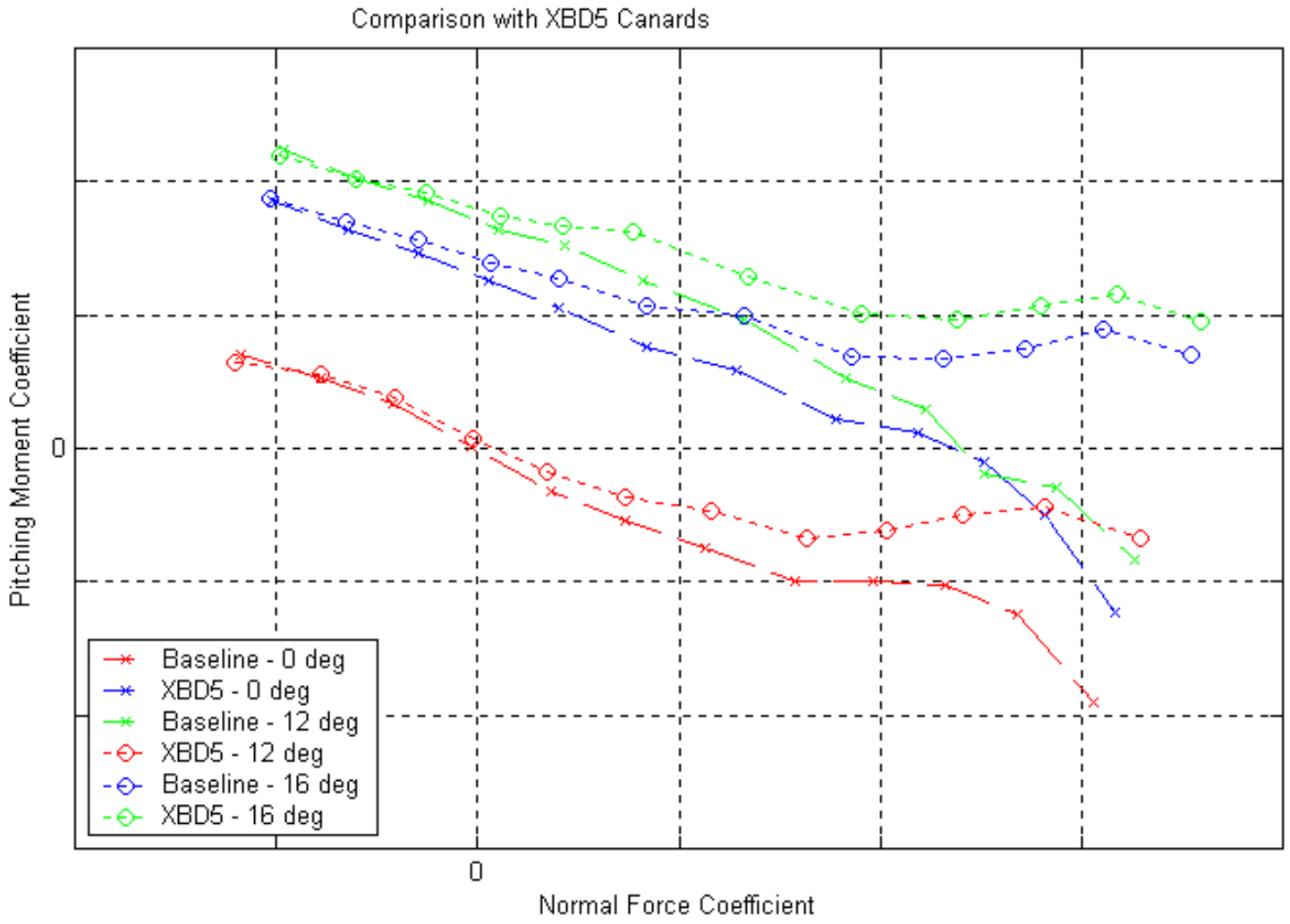


Simplified Aerofoils OK at Low AR

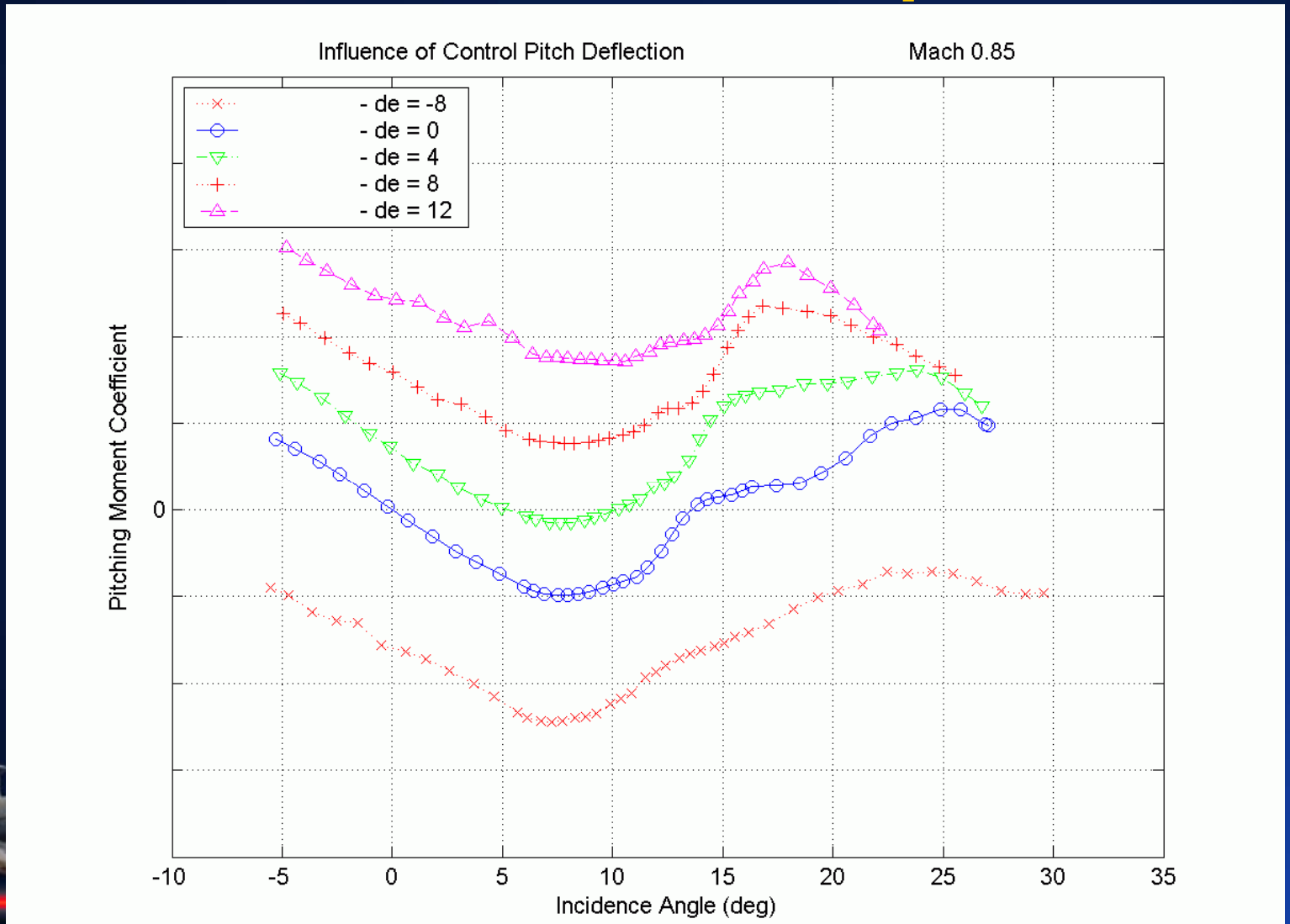
Check validity with CFD before WT testing



Low Speed Test Confirms Improvement



Detailed Transonic WT Test Gives Further Confirmation of Improvement



Conclusions

- Rough WT testing can mislead, use CFD to check
- Rough CFD can capture most important characteristics of a complex flow field – this **may** be sufficient
- Qualitative CFD is very valuable for understanding complex flows, very good for improving designs
- Characterisation WT test makes a good quality “safety net”, allows earlier CFD and WT testing to take short-cuts
- Increased quality risk may be more acceptable if CFD and experimental work is integrated
- Aerodynamic designer, WT test engineer and CFD practitioner need to work ver closely together
- CFD can lead down blind alleys, even rough WT testing can rectify this
- Only quality of the final design matters

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