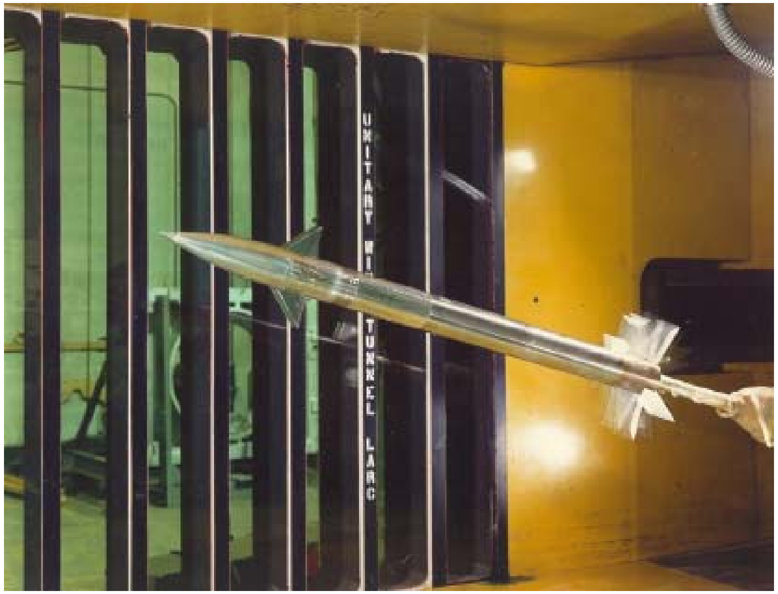
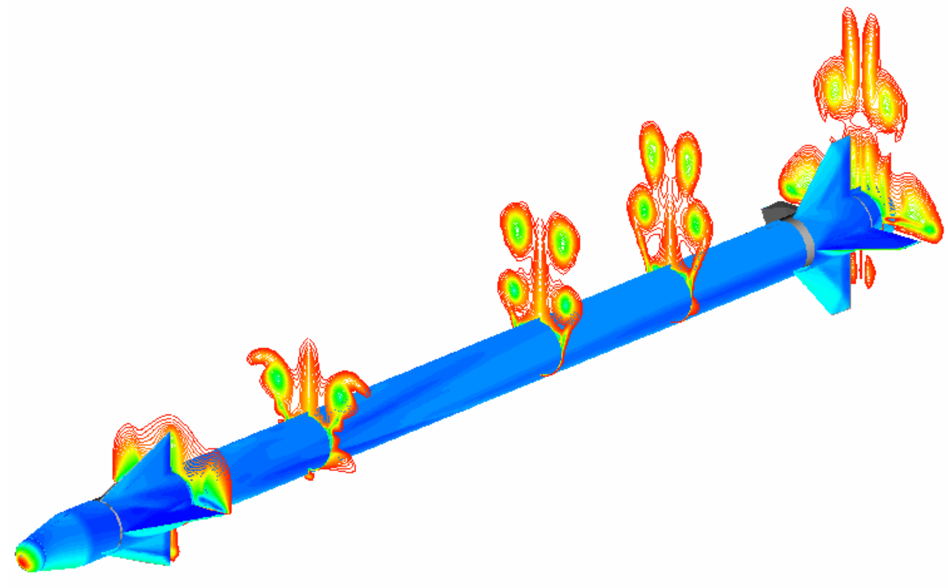
 

INTEGRATING EXPERIMENTS AND CFD IN WEAPON AERODYNAMICS

T J Birch

12 July 2007

Dstl is part of the Ministry of Defence

Contents

- Introduction to weapon aerodynamics
  - Airframe design and aerodynamic data requirements
- Aerodynamic data sources
  - Engineering methods, CFD, Wind tunnel and flight testing
- Examples of integration
  - Improving the credibility of CFD solutions
  - Improving wind tunnel experiments
- Conclusions

Weapon design

- Like most design - is a compromise
- Unlikely that the the external configuration of a missile will be designed solely by an aerodynamicist
- Many other systems have an impact on the external shape
  - Sensors, propulsion & launch platform
- Lateral and longitudinal accelerations not limited by a human pilot
- Aerodynamic efficiency is not the primary goal

Airframe design objectives

- Satisfy mission requirements
  - range, speed, stability, manoeuvrability
- Efficient and simple configuration
  - minimise development time & cost
  - reliability
- Efficient and precise aerodynamic controls
  - low actuator loads
  - simplify guidance & control
- Efficient packaging of internal components

Weapon aerodynamics

- A specialised activity
- Concerned with the understanding and prediction of :
  - a wide range of configurations (to meet different requirements)
  - over a wide range of flight conditions (M, σ, λ)
- Relevant flow physics include:
  - Shock waves
  - Boundary layers (attached and separated)
  - Vortical flows
  - Plumes
  - etc.

Aerodynamic data requirements

- Overall forces and moments
  - Vehicle stability & control
  - Performance models (3 DoF, 6 DoF)
- Component loads
  - Control actuator design
- Surface pressures/Load distributions
  - Structural design
- Temperature/heat transfer data
  - Structure
  - Sensors performance
  - IR signature

Performance modelling

- Mathematical models enable the designer to anticipate and solve many problems
- In the past flight tests were used to solve development problems in addition to validating system performance
- No matter how successful modelling and simulation studies a flight demonstration programme will always be required

Aerodynamic data sources

- Historical data / experience
- Engineering prediction methods
- Computational fluid dynamics
- Wind tunnel testing
- Flight testing

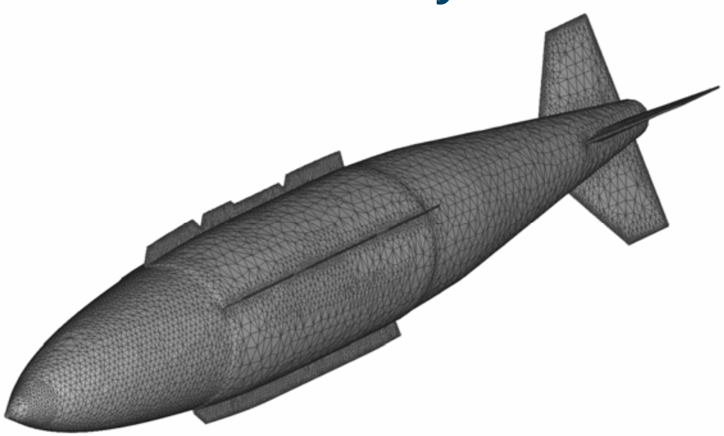
↓ Increasing cost/data point

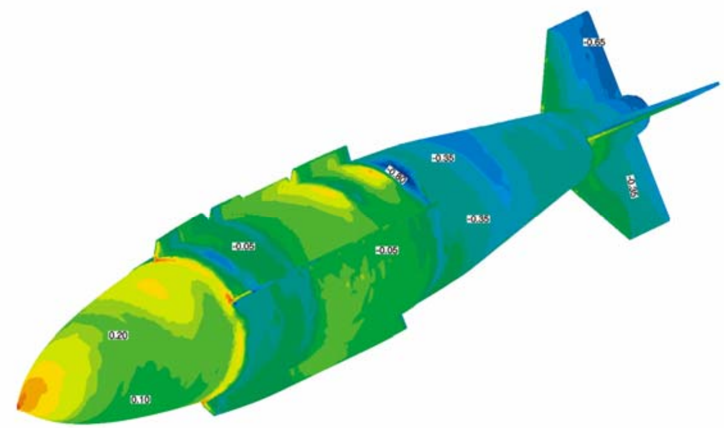
Engineering prediction methods

- Component build-up
  - body+wing+tail+interference
  - Linear theory + empirical data
- Missile Datcom (USAF), Aeroprediction Code (US Navy)
- Very economical to run - seconds for complete polars
- Forces and moments only
- Used mainly for conceptual design
- Limited by methods & databases
  - circular bodies, planar fins etc.

Computational Fluid Dynamics

- Euler and RANS
  - Time-marching & space-marching
- Wide range of configurations and flow conditions
- Complete description of the flowfield
  - Not just forces & moments
- Can be costly to run





Development wind tunnel testing

- Objectives
  - To confirm the aerodynamic estimates - not a design exercise
  - To improve the accuracy of the evolving performance models by providing “real” aerodynamic data
- Wind tunnels are not perfect
  - Can be time consuming and costly to operate
  - Scale effects, blockage etc.
  - Not able to measure everything of interest

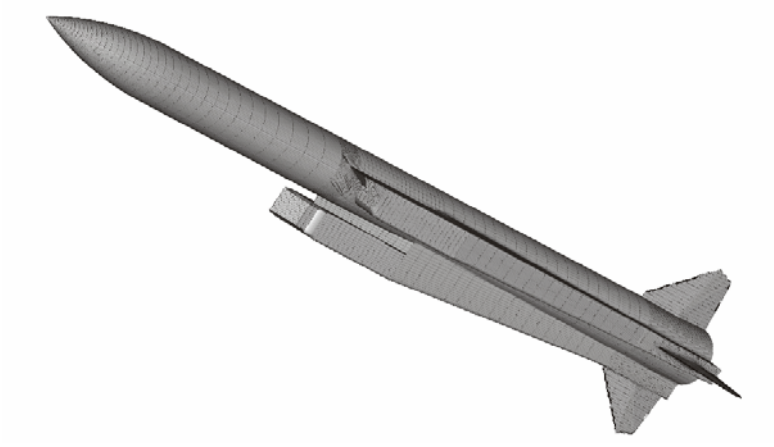
Flight testing

- Objectives
  - To evaluate all aspects of the weapon system
  - Convince the customer it works
- The most realistic and expensive test
- Very difficult to extract useful aerodynamic data

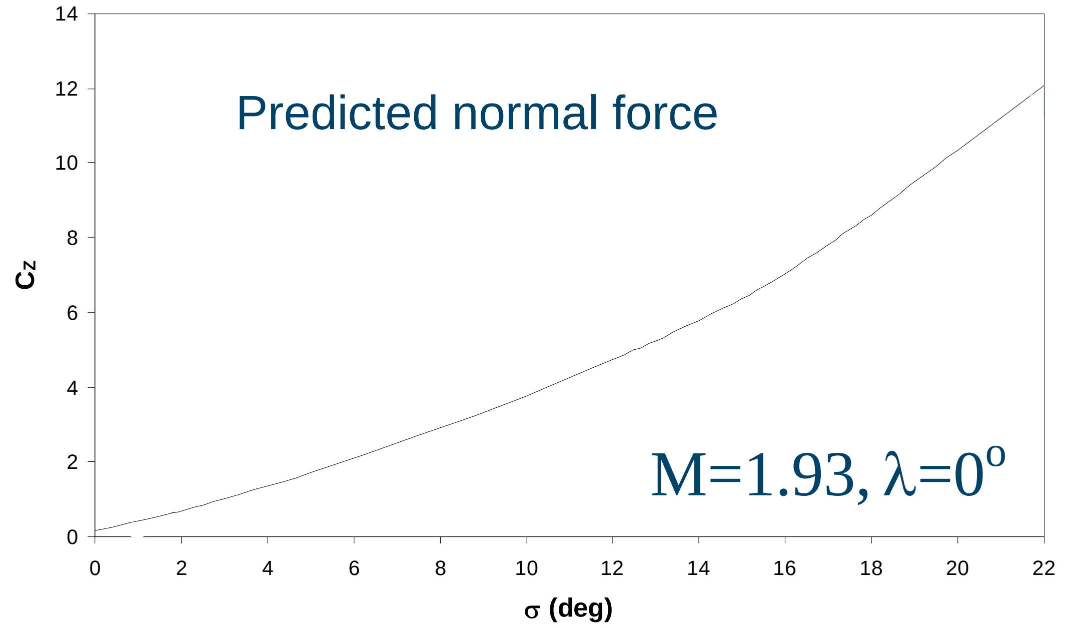
Examples of integration

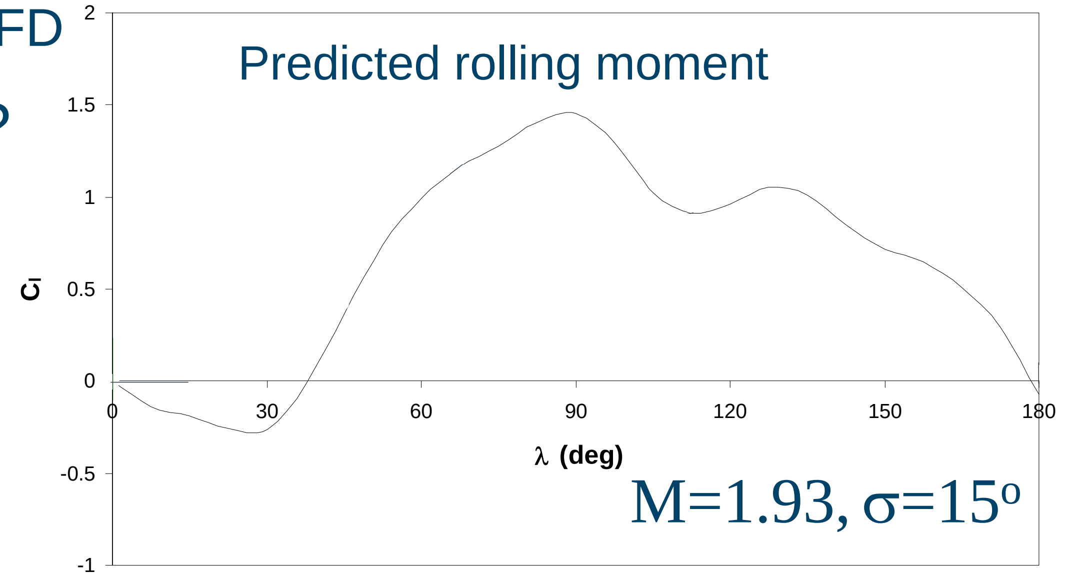
- Improving the credibility of CFD
- Better wind tunnel experiments
- Improving engineering prediction methods

Improving the credibility of CFD



- Complex missile design
  - M=1.93
  - Forces & moments from CFD
- Do we trust these results?
  - How accurate are they?
  - Suitability of equations?
  - User induced errors?





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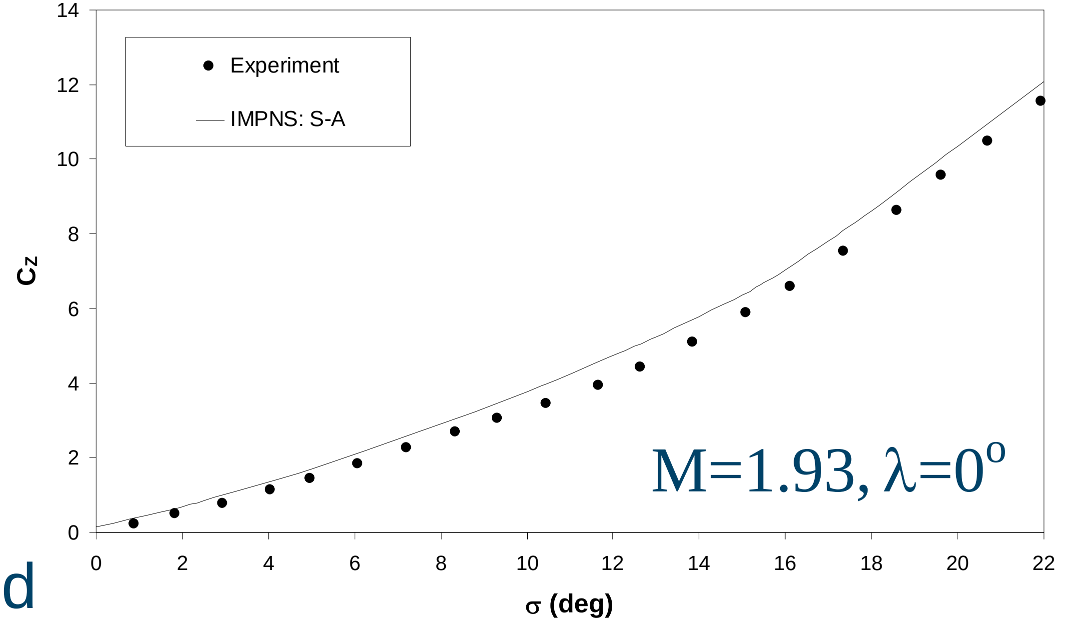
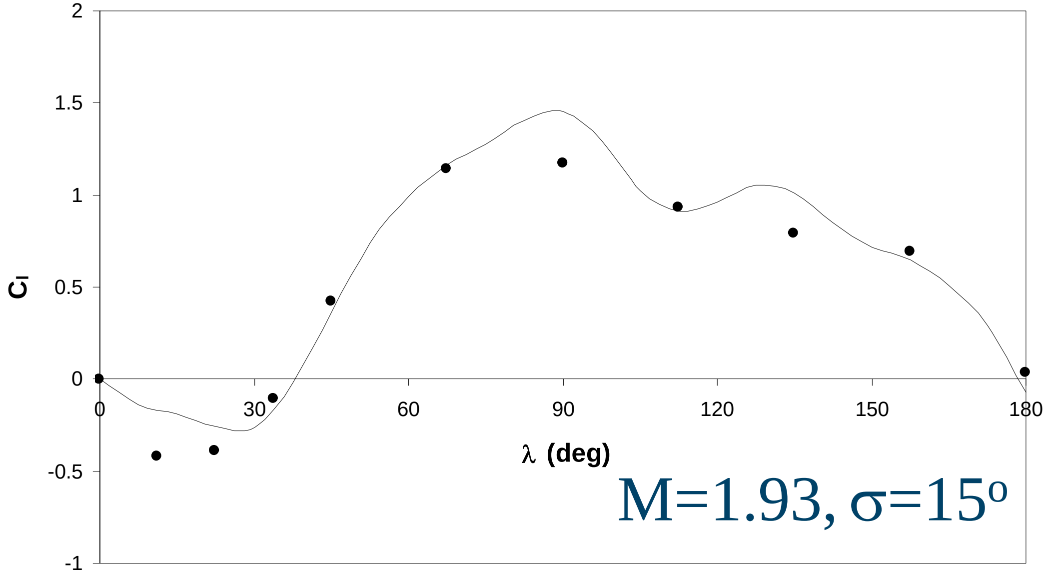
Building confidence





- Verification, validation, and certification
- Availability of some WT data boosts confidence
- But how accurate are the experiments?

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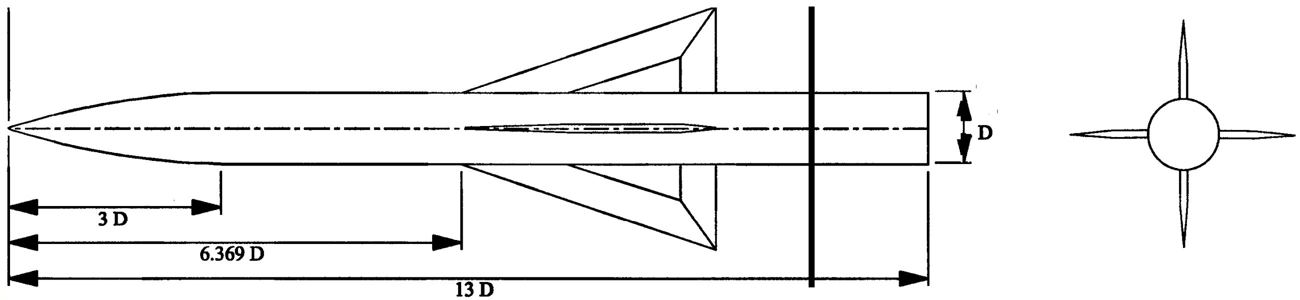
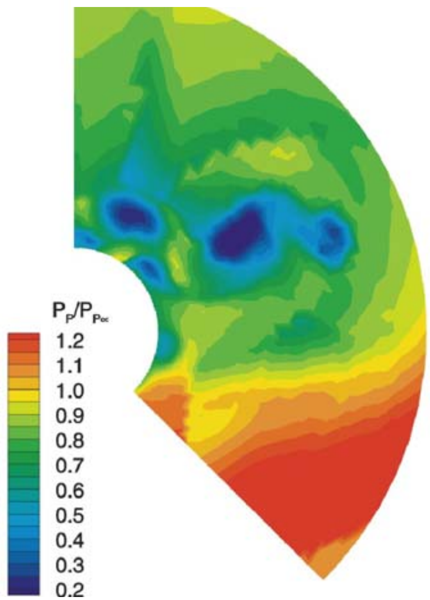
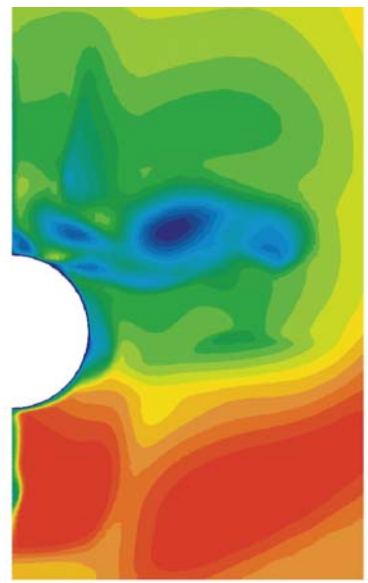
Calibration of turbulence models

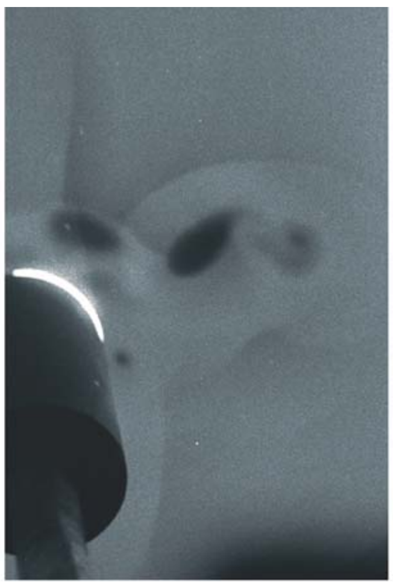




Measured flowfield



CFD (S-A)



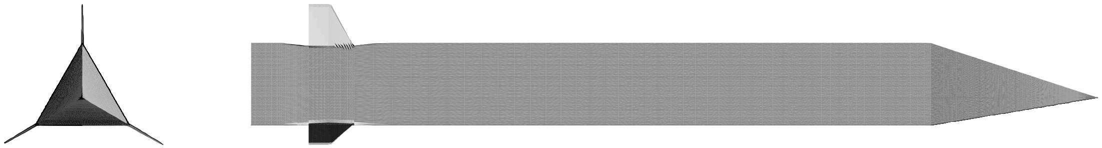
Laser vapour screen

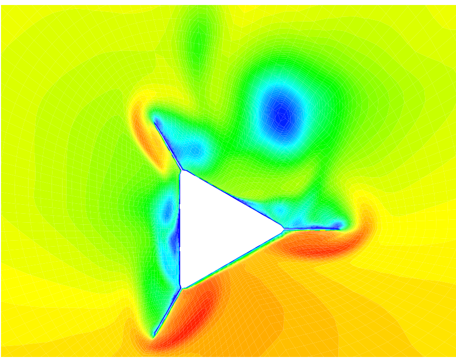
$M=2.5, \sigma=14^o$

Better WT experiments with CFD

- Wind tunnel experiments can be expensive
  - Model design & manufacture, instrumentation, manpower and power consumption
- Careful planning at the outset can save time & money
- CFD can help in many ways
  - Designing the experiment - selection of config & test matrix
  - Support model design & instrumentation selection
  - Monitor progress of experiment
  - Supplement wind tunnel data
    - improve understanding of physics, extend test matrix
    - provide results that are difficult to measure

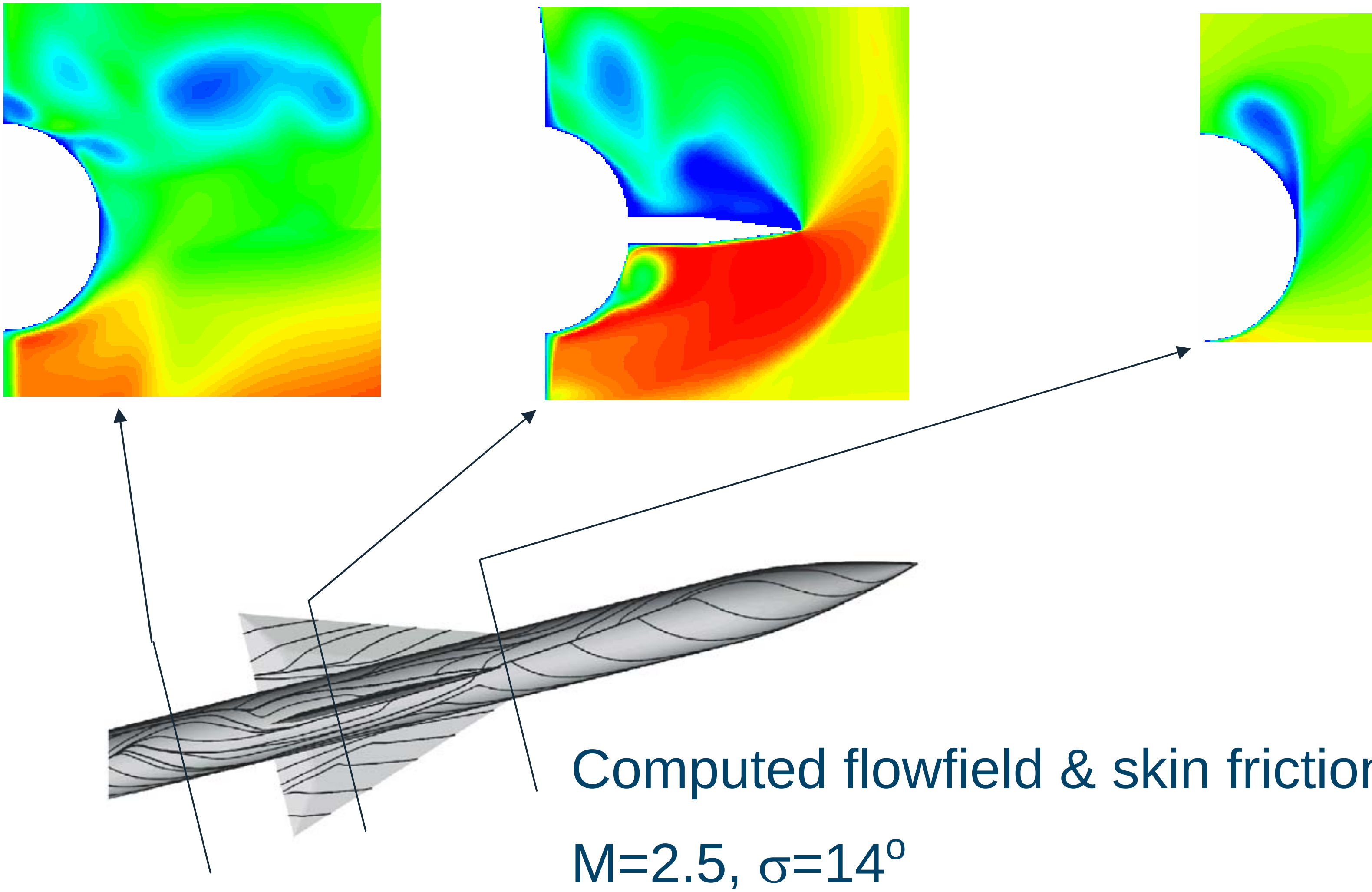
CFD study of novel missile designs





- Aerodynamic characteristics computed for a range of novel designs
- Best design has subsequently been tested in a wind tunnel
- CFD loads used for WT model design and selection of balance
- CFD results used on-line during test

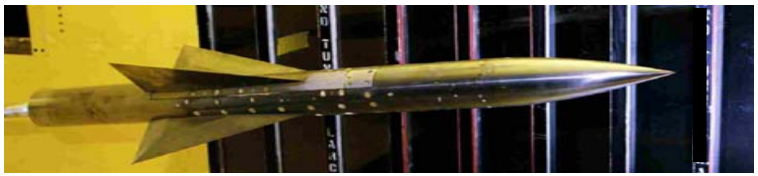
Understanding flow physics

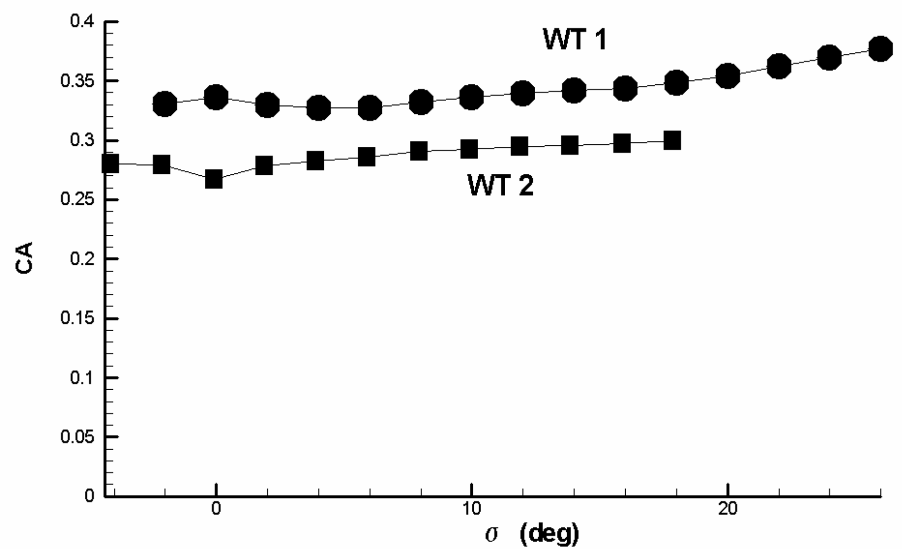


Computed flowfield & skin friction lines

$M=2.5, \sigma=14^{o}$

Enhancing WT results with CFD

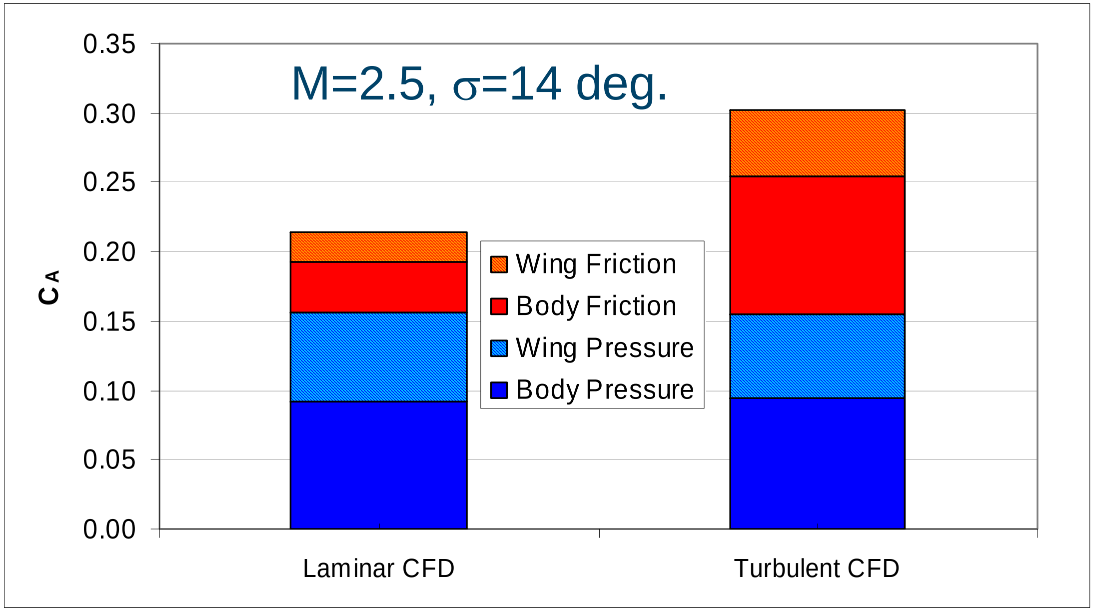




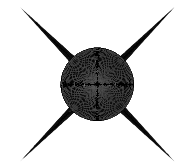
- Axial force discrepancy
- Measured in two comparable tunnels
  - Testing the same missile model at same conditions - M=2.5
  - WT 2 C_A ~12.5% lower than WT1
- Used CFD to try to understand differences

Enhancing WT results with CFD

- Axial force components computed using CFD
  - Laminar & turbulent (S-A)
- Experimental discrepancy found to agree well with additional wing skin friction for turbulent case
- Turned out transition not fixed on wings in WT2

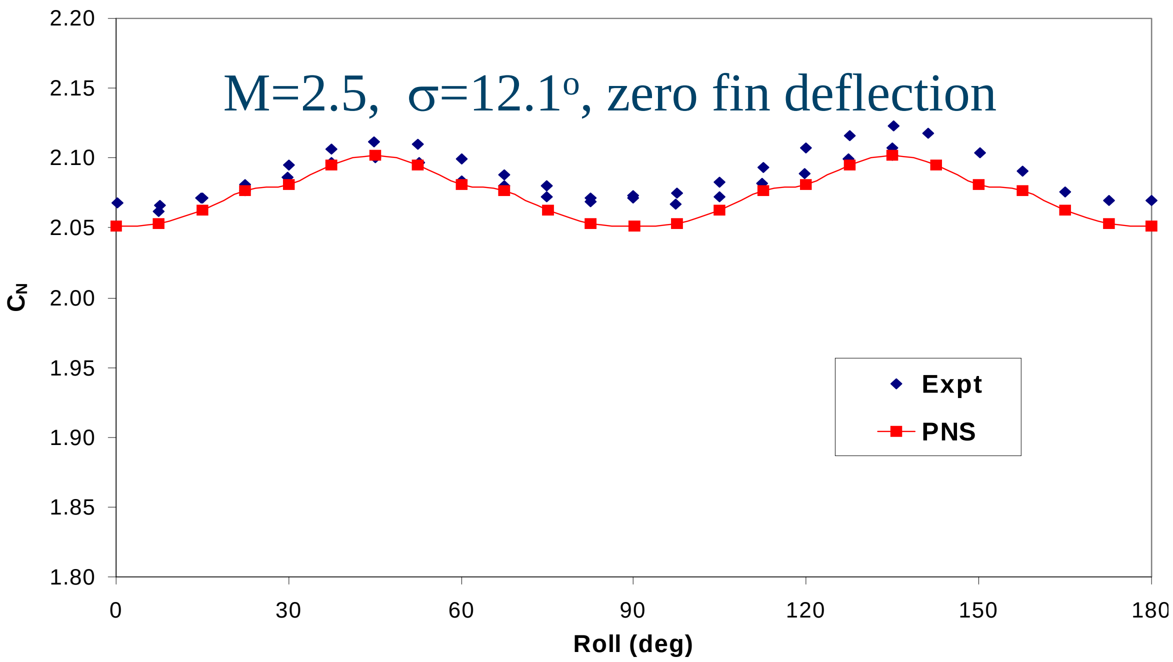


Autopilot designed using CFD data



- CFD results used to supplement limited wind tunnel results
- Approximately 500 CFD runs completed
- Computing forces and moments
  - As a function of incidence, roll and aileron deflection
  - Calculations completed using PNS solver
    - ~ 1.2 million cell grid
    - ~ 3 hrs /point on PIII 1.8MHz

Some issues



- Ambitious application of CFD
- Difficulty handling large number of calculations
  - Keeping track of jobs and storage requirements
- Need for data fusion to join wt and CFD datasets

CFD & engineering prediction methods

- Engineering methods are the principal tool of the weapon aerodynamicist
  - Used primarily for conceptual design studies
- But many new configurations have features that cannot be accurately modelled with these methods
  - Non-axisymmetric bodies, intake ducts, close-couple controls
- Extension of the methods via systematic WT tests is prohibitively expensive
- CFD is now also being used to enhance engineering methods

Conclusions

- The use of CFD and the use of wind tunnels is not an either/ or situation
- It is folly to favour one to the exclusion of the other
- It is foolish to stand on one foot when you have two

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