Boeing Defense, Space & Security (BDS)

Focus Session on Simulation at Aeronautics Test Facilities

October 15, 2014

Overview of Presentation

- Questions to be addressed during presentation
  - How has the ability to do increasingly accurate modeling and simulation (M&S) changed the way aeronautics test and evaluation (T&E) facilities are used? How has it changed the way we do flight test?
  - From a T&E standpoint, are U.S. M&S capabilities sufficiently mature and reliable? How well are NASA facilities meeting the needs of industry regarding advanced M&S capabilities for aeronautics T&E?
  - How well is NASA working with other government entities and academia to enhance M&S capabilities for aeronautics T&E?
- Background for presentation
  - This presentation will treat M&S as synonymous with CFD and T&E as synonymous with ground test facilities, specifically wind tunnels

Effects of Increasingly Accurate M&S Capabilities

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- Utilization of CFD has become prevalent on programs primarily because of improved accuracy and efficiency
  - Algorithm improvements
  - Turbulence model improvements
  - Availability of increased computational power is a key enabler
    - Enables faster turn-around
    - Enables higher-fidelity modeling via discretization refinement
    - Enables database development, i.e. population of large run matrices
  - Example for a similar launch vehicle configuration:
    - 1991 – 0.5M grid point model, 30 days/case, 1 case at a time, UCLA supercomputer
    - 2014 – 10M grid point model, 45 minutes/case, 25 cases at a time, in-house Linux cluster
      - Improved accuracy based on grid resolution enhancement of 20x, plus improved accuracy due to algorithm and turbulence model improvements
      - Improved efficiency of 480000x per grid point, or 24000x per solution

Effects of Increasingly Accurate M&S Capabilities (cont'd)

- Trend is to introduce high-fidelity CFD methods in early design cycles along with a corresponding reduction in wind tunnel testing
  - Geometry is often in a state of flux which makes computational approach more appealing
  - Fabrication of wind tunnel models and availability of test facilities are often pacing items during early, short-duration design cycles
  - Access to rapid and accurate CFD methods enables reduction in design cycle duration and reduced reliance on third-party schedules (WT model vendors, WT test facilities, etc)
- Heavy reliance on wind tunnel testing (along with CFD) for final design and verification activities
  - Desire is to reduce reliance on wind tunnel testing further, but is this feasible in the near term?

Airborne Launch Assist Space Access

M&S Maturity and Reliability

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- For some configurations, M&S capabilities are sufficiently mature and reliable to reduce reliance on wind tunnel testing
  - However, this is not true for every configuration, as indicated on the next slide
- M&S capabilities often fall short when flow separation, boundary layer transition, turbulent mixing, etc., are 1st-order contributors to the parameters of interest
  - Users of data must understand limitations of M&S methods
    - Improper reliance on poor quality M&S data can have severe adverse impacts to a program
      - Design issues not identified until late in the design or verification cycles cause significant cost and schedule issues
  - Ground test facilities (wind tunnels) are required to develop the "truth" data needed to gage adequacy of M&S methods
    - Users must also understand limitations of ground test data

M&S Maturity and Reliability (cont'd)

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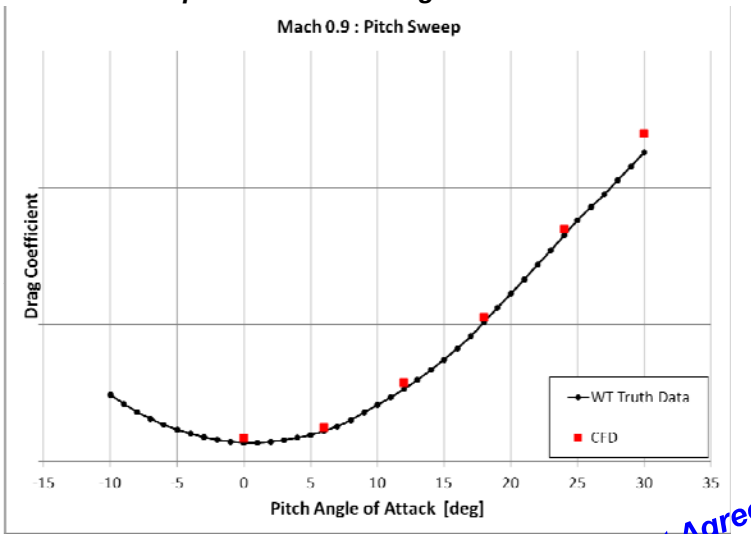
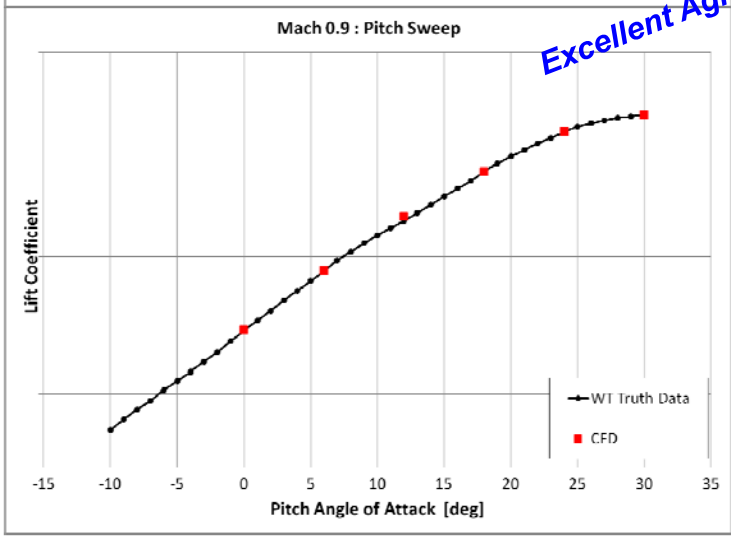
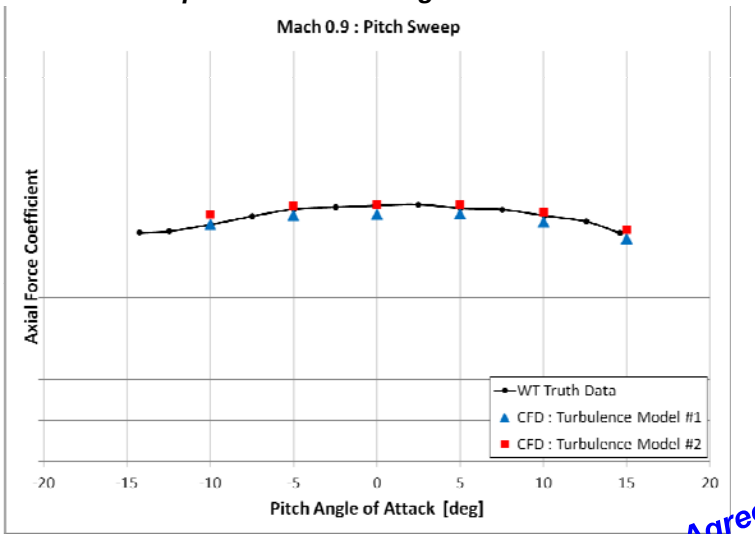
Space Access Configuration #1

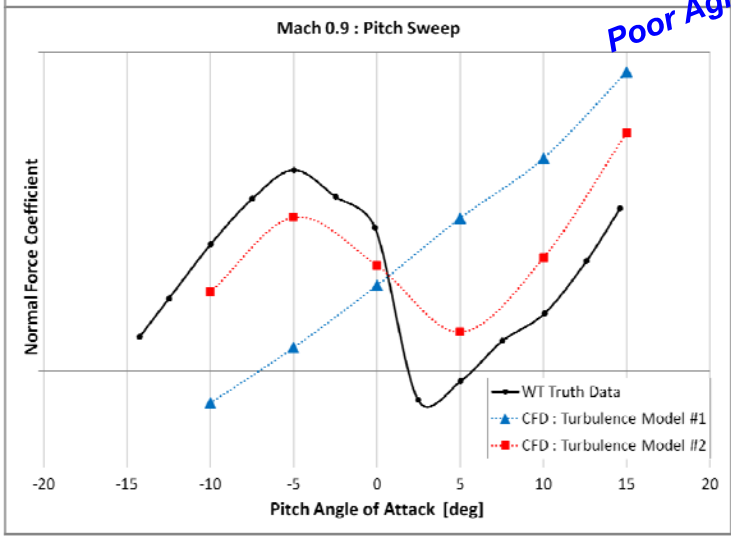




Excellent Agreement

Space Access Configuration #2





Poor Agreement

Challenge Problems

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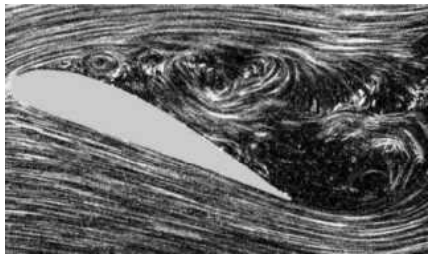
- CFD methods are relatively immature for tackling the most difficult problems often encountered
- One example – massive flow separation leading to aerodynamics, aeroacoustics, and/or buffet issues
  - The #1 program risk on several recent high-profile development programs
  - Steady and unsteady RANS modeling is inappropriate and insufficiently accurate for these simulations
    - Hybrid models, such as DDES, offer an improvement over URANS, but accuracy remains marginal
  - Unsteady CFD simulations on full-scale vehicle platforms with sufficient grid resolution to capture the flow physics remain "grand challenge" problems
    - These simulations are performed routinely with less-than-desired grid resolution
      - Consume tremendous computational resources and calendar time
      - Data accuracy is typically good enough for trends, insufficiently accurate for design
      - Does not even scratch the surface in terms of database coverage (Mach / alpha / beta)
  - In spite of these deficiencies, CFD can be used to help resolve these types of issues
    - Aero shape optimization to eliminate massive flow separation
    - Development of aerodynamic devices for flow control



- Other challenge examples – boundary layer transition, turbulent mixing and chemical kinetics, etc.
- Reliance on test facilities will be required for the foreseeable future to address these challenge problems
  - Provide final design and verification datasets prior to flight
  - Provide high-quality validation datasets to support development of improved computational models

NASA Collaboration with Government and Academia

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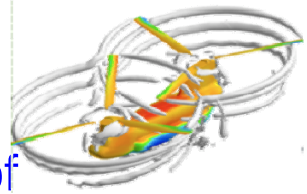
- Branches of the DoD are collaborating in the development of the next generation of computational tools for aerospace application
  - CREATE-AV Project
    - Full coordination across DoD to produce next generation of physics-based computational methods for DoD acquisition engineering
    - Significant investment commitments by DoD for a long-duration computational sciences development effort



- Computational science development efforts within NASA appear to be less coordinated across the agency
  - Per recommendations of the recent NASA-funded Vision 2030 CFD study report prepared by Boeing-led team of CFD experts, a long-term base research and development effort coordinated across the agency must be initiated to address CFD technology gaps and enhance CFD capabilities
  - Increased collaboration between NASA and DoD would also be beneficial

** CREATE-AV images obtained from publicly released CREATE-AV presentation*

Closing Comments

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- Sustained and coordinated investments in the computational sciences will continue to pay huge dividends
  - Efficiency and accuracy improvements continue to be realized
    - Automated solution adaptive gridding
    - Improved algorithms and turbulence / transition modeling
    - Improved aero shape optimization and MDAO methods
    - Reduction in reliance on “CFD expert” to ensure quality – enhancing the availability of reliable and accurate computational methods
- Wind tunnel facility advancements should remain high priority
  - A couple of examples from recent aeroacoustics test experiences
    - Fast Pressure Sensitive Paint (Fast PSP) capability promises to enable characterization of high-frequency fluctuating pressures (aeroacoustics) over the surface with greatly improved resolution relative to models instrumented with pressure transducers only
    - Improved data acquisition systems allow for collection of large volumes of higher-frequency data required to characterize these environments
- The few remaining wind tunnel test facilities are national assets, and continued advancement of WT test technologies is critical for the continued success of the US aerospace industry


NASA SLS