



Predicting Buffet Onset on the Transonic Truss-Braced Wing

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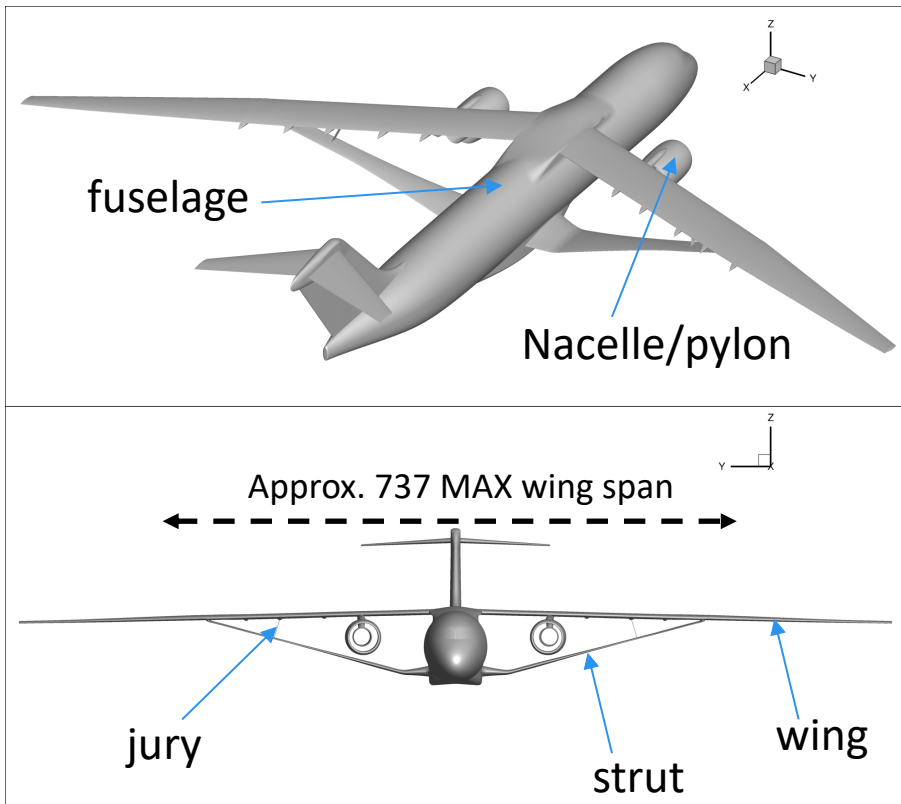
Transonic Truss-Braced Wing: Motivation



- NASA and Boeing are collaborating to develop a Transonic Truss-Braced Wing (TTBW) aircraft concept design, which contains advancements in technology that have the potential to improve fuel efficiency for commercial aircraft.
- The unconventional configuration of the TTBW—which includes a high aspect ratio wing, in addition to wing and jury struts—leads to complex flow phenomena such as transonic buffet, separated flow, and a turbulent wake.
- Current industry best practices tend to employ Reynolds-Averaged Navier-Stokes (RANS)-based computational fluid dynamics (CFD) analysis for buffet onset prediction. To accurately predict the onset of buffet more accurate scale resolving CFD simulations may be required.
- NASA's Advanced Air Transport Technology Project launched a collaborative multi-center effort to develop new methods for simulating the TTBW to better predict its performance and that of similar truss-braced wing configurations.



Transonic Truss Braced Wing

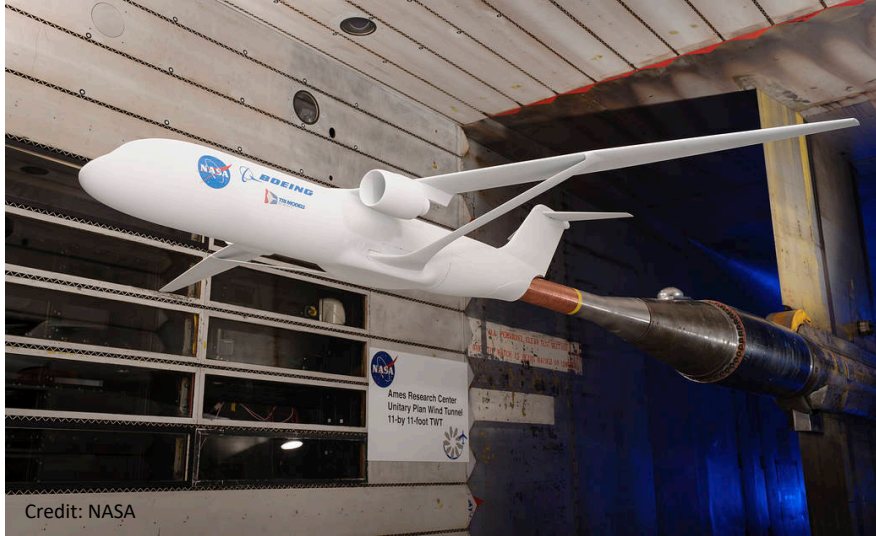
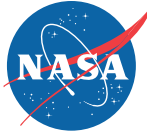


The Transonic Truss Braced Wing (TTBW) is one of several concepts for a next generation of efficient commercial travel. NASA has been running simulations for the wind tunnel configuration of the TTBW; the goal being to develop the best practices for representing the tunnel's flow dynamics for this complex geometry.

Some advantages of the TTBW design over conventional designs (e.g. 737):

- Thinner wing and reduced sweep – allows for natural laminar flow control to be employed – low friction drag
- Wing truss provides external structural support to reduce wing weight - significant increase in wing span – leads to reduction in drag due to wing tip vortices (reduction in portion of wing affected by wing tip vortex)

Transonic Truss Braced Wing: Experiments



Credit: NASA

A wind tunnel experiment of a half-span model of a TTBW was conducted in the NASA Ames Unitary Plan 11- by 11-foot Transonic Wind Tunnel in January 2022, and large angle-of-attack sweeps at different Mach numbers were run. This data is being used to validate the simulations, with a goal to be able to accurately reproduce experimental results using CFD.



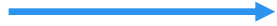
Credit: NASA



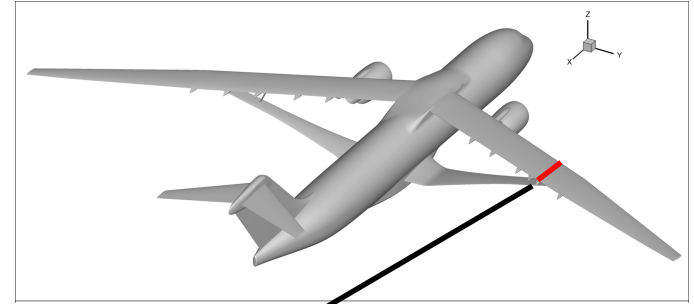
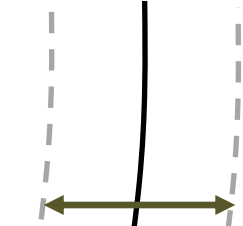
Transonic Buffet

Schematic of transonic buffet phenomena

Mach Number = 0.8

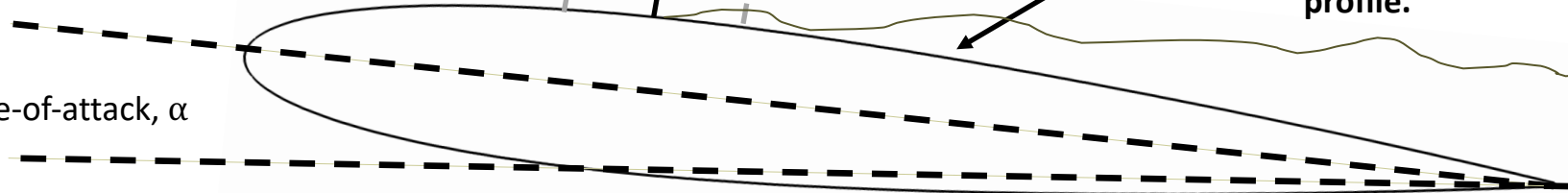


Oscillating shock



2D profile of wing, **Note:** representative wing profile, not TTBW wing profile.

Angle-of-attack, α



Unsteady wake

The shock buffet phenomenon is a low frequency instability occurring at certain angles-of-attack and flow conditions around wings. It is characterized by the interaction of the shock with the turbulent boundary layer and shock induced flow separation. At certain angles-of-attack the shock starts to oscillate back and forth and causing large fluctuations of the aerodynamic loads.

Moving Towards Scale-Resolving Simulations to Capture Buffet Onset

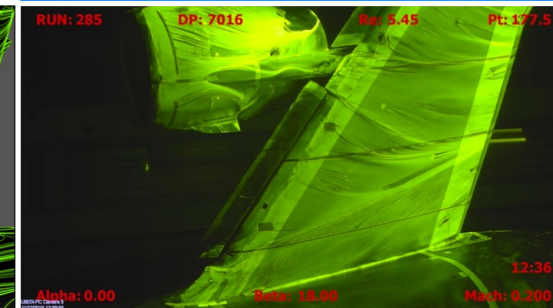
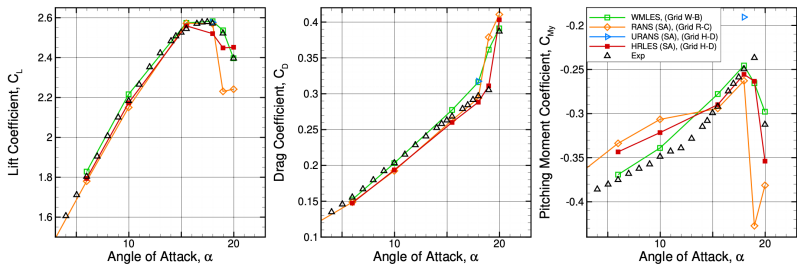


- The Launch, Ascent, and Vehicle Aerodynamics (LAVA) team at NAS selected Hybrid RANS/Large Eddy Simulations (HRLES) as the initial choice for the scale-resolving simulation approach. As the name suggests, this hybrid method models turbulence inside the boundary layer to solve the RANS equations, while the turbulence is resolved outside the boundary layer with LES. The dominant transonic buffet phenomena can largely be captured by steady-state RANS or unsteady RANS.
- However, neither is suitable for investigation of the phenomena in the turbulent wake (including deep stall and high-lift configurations) due to excessive dissipation of turbulent motion, and the team has demonstrated that RANS is an unreliable tool when simulating the maximum value of lift (CL_{max}) and the onset of stall.
- Scale resolving simulation approaches like HRLES are better able to resolve the turbulent content and enable more accurate predictions.

Moving Towards Scale-Resolving Simulations to Capture Buffet Onset

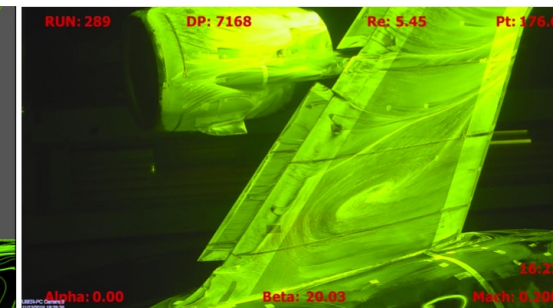


QinetiQ tunnel experiments <https://hilftpw.larc.nasa.gov>



(a) HRLES

(b) Oil Flow



(a) HRLES

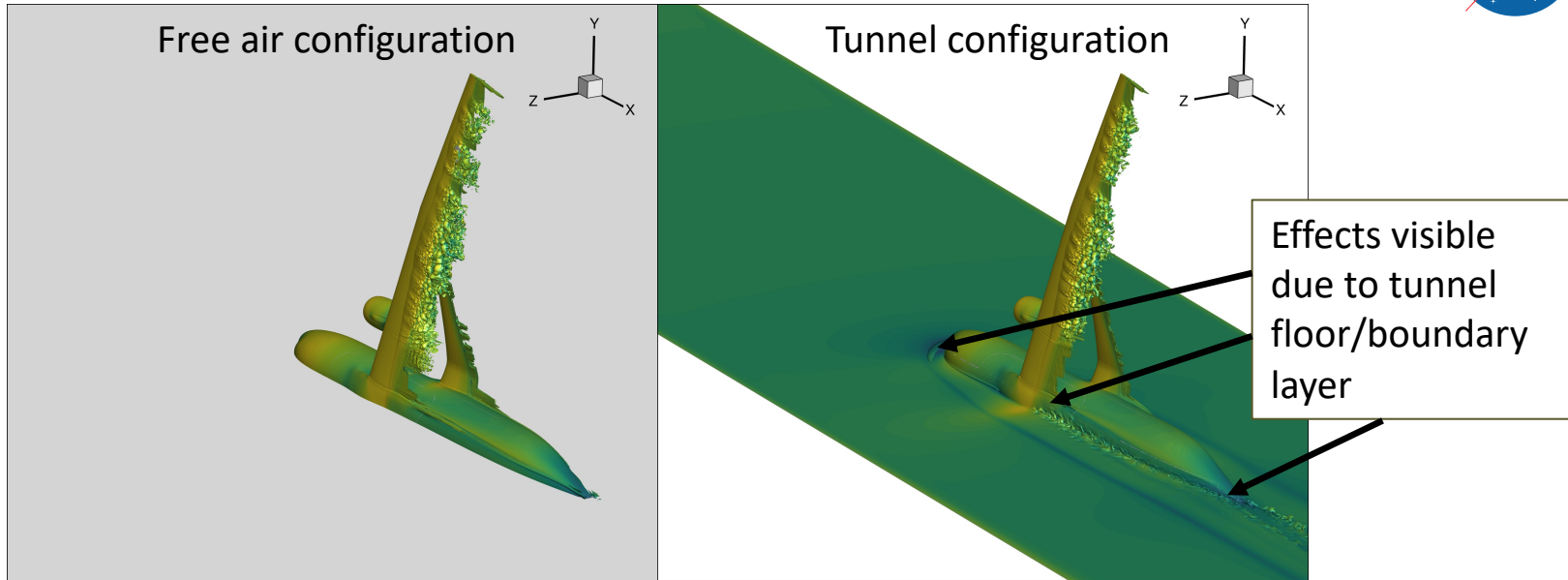
(b) Oil Flow

- LAVA Hybrid RANS/LES (HRLES) scale-resolving simulations in the High Lift Prediction Workshop 4 (HLPW4) showed success at predicting CL_{max} , onset of stall and break in pitching moment for the High-Lift Common Research Model (CRM-HL),
- Next stages in the project will move to high-lift configuration of the TTBW and onset of deep stall where scale resolving simulations may be needed to accurately capture the flow physics.
- Establishing best practices for meshing and numerical scheme for HRLES has been conducted for the cruise configuration before moving to abovementioned more challenging configurations.

[1] O. M. F. Browne, J. A. Housman, G. Kenway, A. S. Ghate, C. C. Kiris. Investigation of a Hybrid RANS-LES Approach for CL_{max} Prediction on NASA High-Lift Common Research Model. Accepted for publication in AIAA Journal

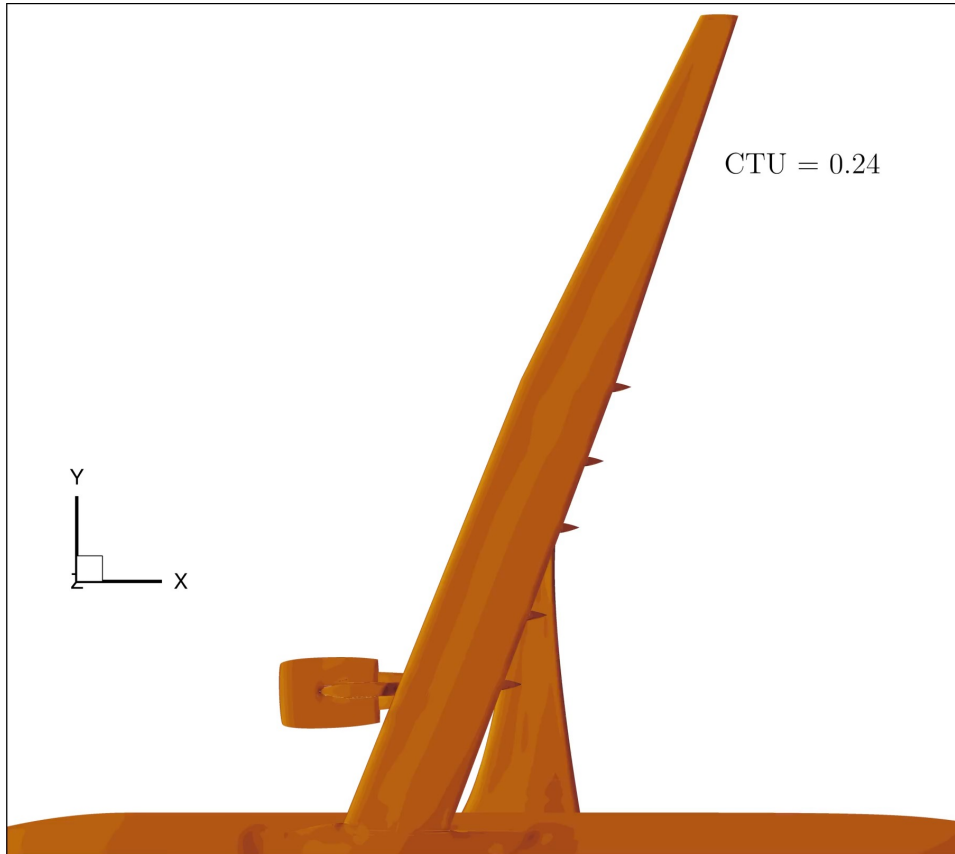
[2] O. M. F. Browne, J. A. Housman, G. Kenway, A. S. Ghate, C. C. Kiris. A Hybrid RANS-LES Perspective for the High Lift Common Research Model Using LAVA. AIAA Aviation 2022 Forum, AIAA Paper 2022-3523, 2022

Transonic Truss Braced Wing



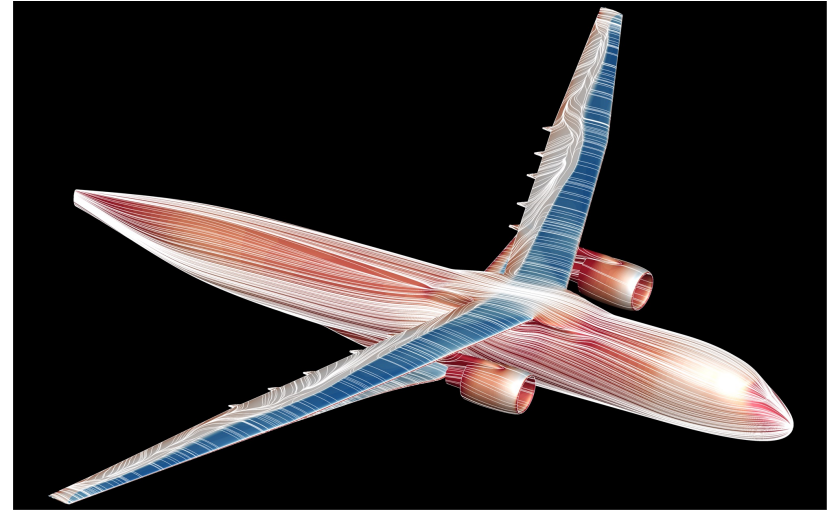
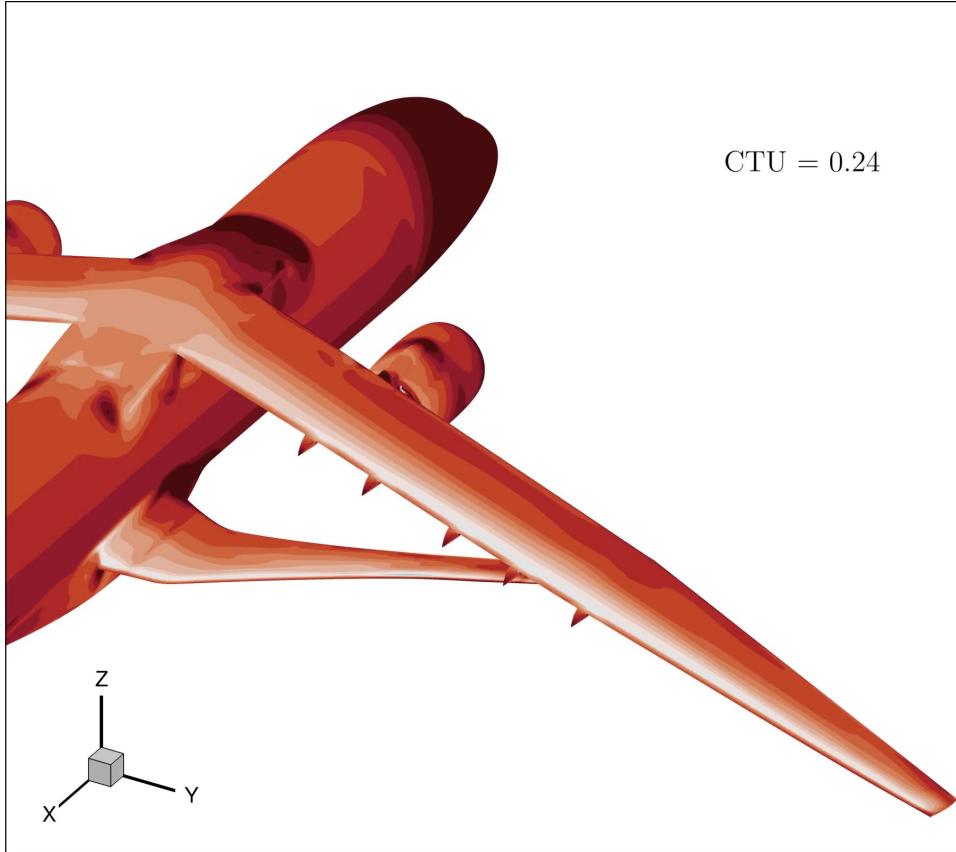
- To validate the CFD simulations, we compared with both a free air configuration and the wind tunnel configuration – the free air experimental results are a corrected set of wind tunnel results.
- The incoming boundary layer on the wind tunnel floor needs to be accurately modeled to ensure a high fidelity simulations is obtained.
- Visualization of the instantaneous vorticity showing large regions of separated flow across the wing span.

Transonic Truss Braced Wing

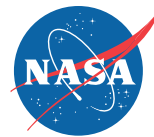


- Movie of instantaneous x-component of surface skin friction coefficient (c_{fx}) for the TTBW in the free-air configuration from a freestream initial condition.
- The surface skin friction coefficient has been clipped for $c_{fx} < 0$ to show regions of separated flow.
- The flow remains largely attached on the strut but there are regions of separated flow downstream of the shock along almost the entire wing span.

Transonic Truss Braced Wing

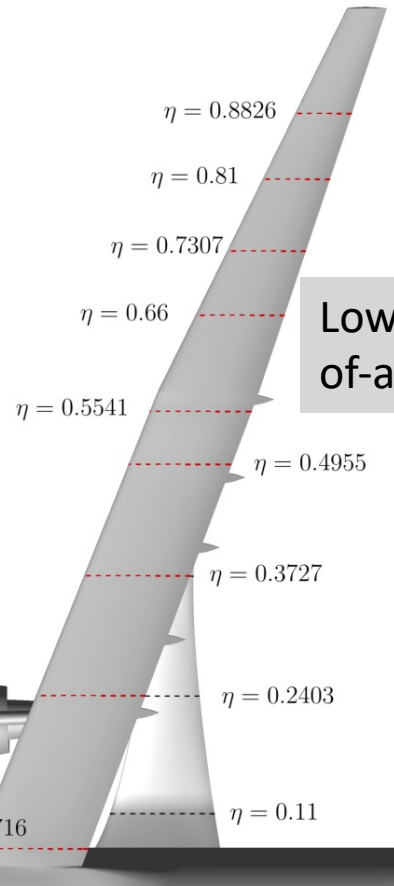


Movie of instantaneous surface pressure coefficient (c_p) contour for the TTBW in the free-air configuration from a freestream initial condition. Unsteady shock motion and cross-flow can be visualized along almost the entire extent of the wing span.

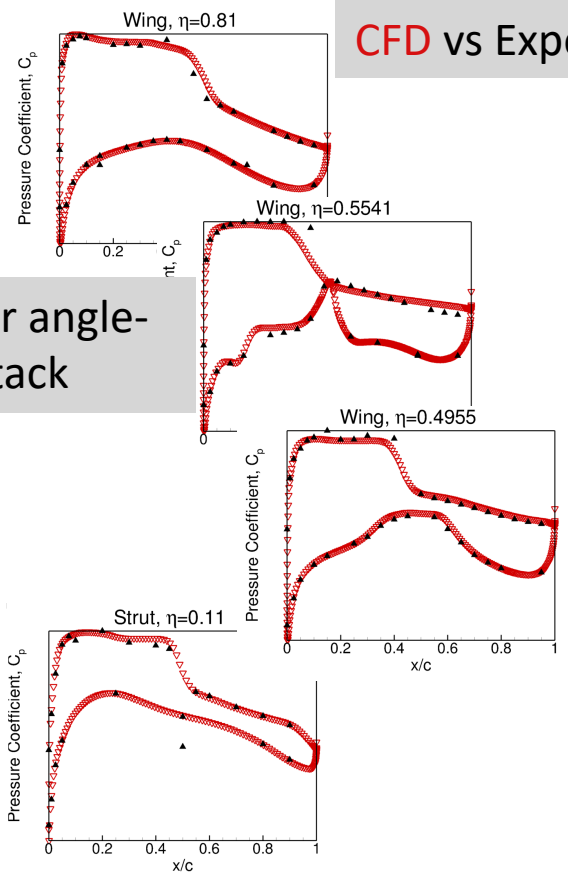


Transonic Truss Braced Wing

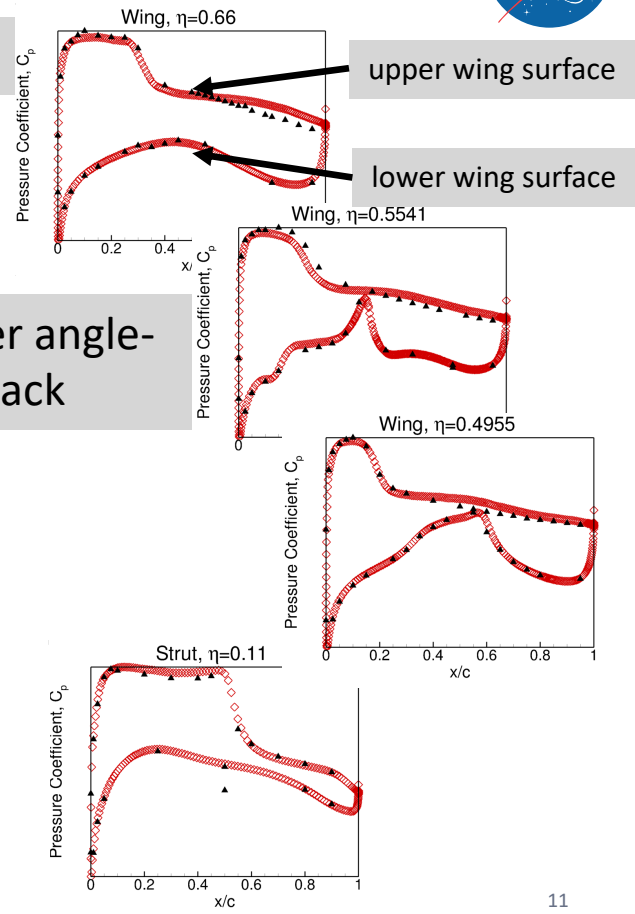
CFD vs Experiment



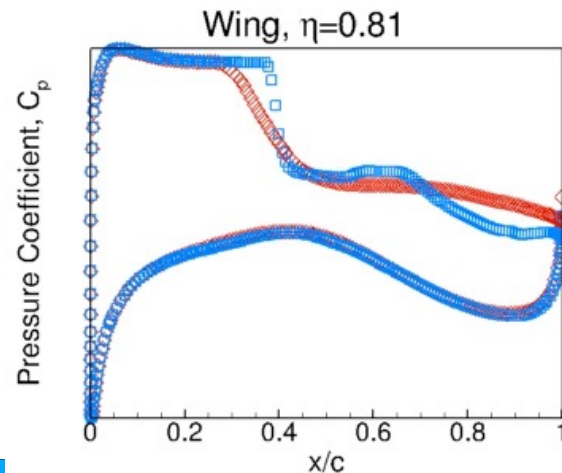
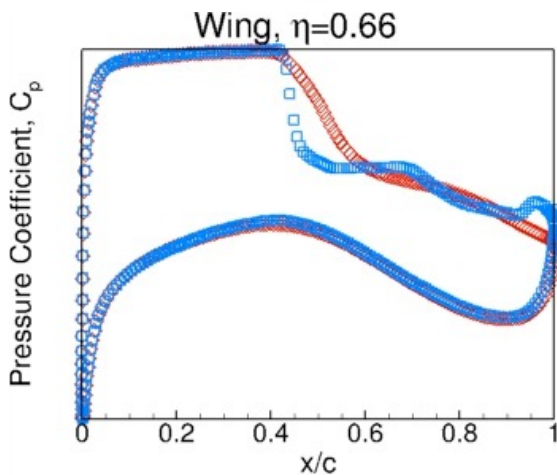
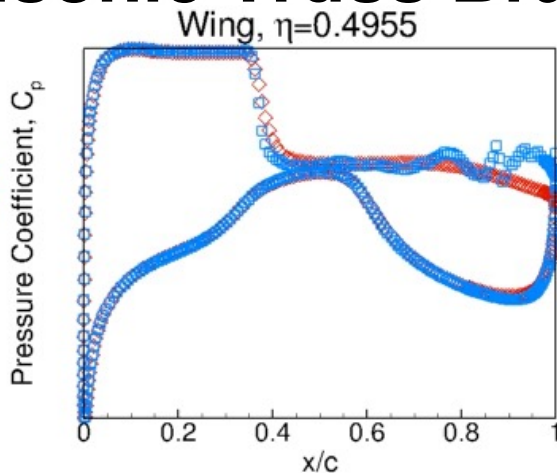
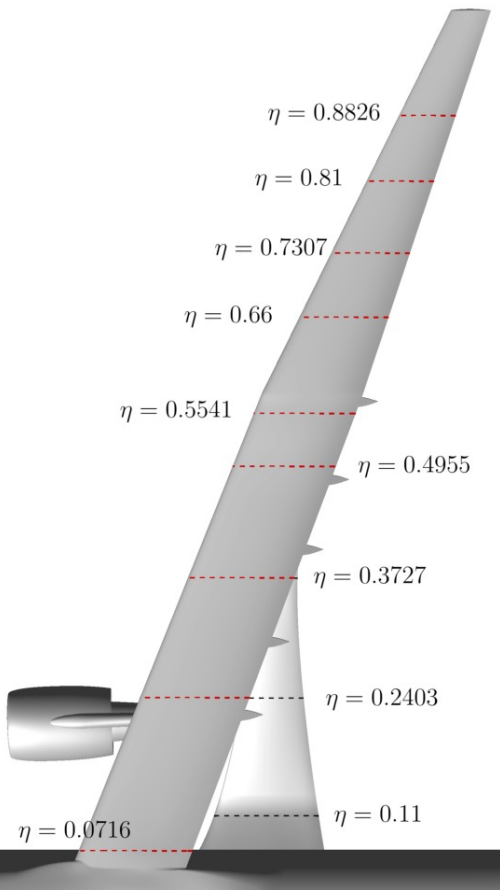
Lower angle-of-attack



Higher angle-of-attack



Transonic Truss Braced Wing



- Visualization of the **time averaged** vs **instantaneous** surface pressure with the scale resolving CFD simulations at different locations along the wing span.
- Shock can be seen oscillating back and forth while downstream the flow is very unsteady.

NASA Ames High Performance Computing



Credit: NASA

- The high-performance computing resources at NAS have made it possible to run the HRLES simulations within a short turnaround time.
- Scale-resolving simulations are computationally expensive due to the small timestep size and grid cell sizes needed to resolve the unsteady turbulent flow,
- HRLES approaches have a lot of tuning parameters. Being able to run a parameter study to test their sensitivity using the efficient throughput provided by NAS systems enabled quick decision-making and accelerated the development of simulation best practices.

NASA Ames High Performance Computing



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Thank you for
listening, any
questions or
comments?

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For more information on LAVA HRLES work:

https://scholar.google.com/citations?user=M_gcZh4AAAAJ&hl=en

