Engineering, Operations & Technology
Boeing Research & Technology

Boeing Unstructured Grid Results for Drag Prediction Workshop VI

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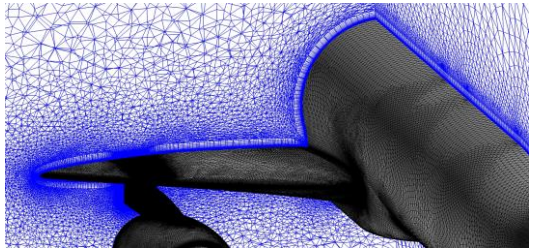
Boeing Unstructured Grid DPW VI Study Summary

- **BCFD (Boeing CFD)**
  - 2nd order cell centered finite volume discretization
  - SA-RC turbulence model (also ran SA-RC-QCR, SST)

- **GGNS (Generalized Geometry Navier-Stokes)**
  - 2nd order node centered SUPG finite-element discretization
  - SA-RC turbulence model
  - Strong solver – machine precision residual convergence

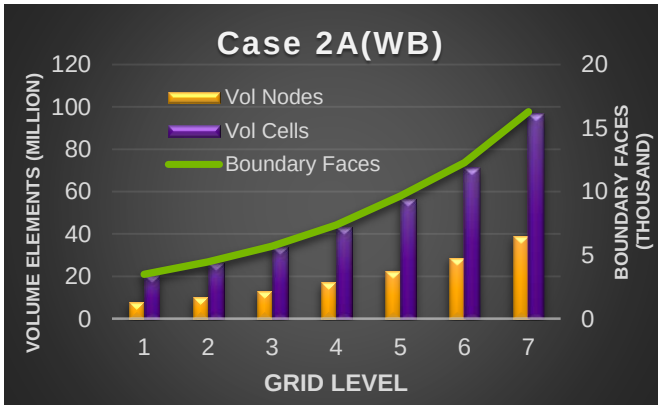
Case	Grids	Geometry	Flow Solver	Turbulence
1	Family II NASA TMR, adapted	NACA 0012	BCFD, GGNS (adapted)	SA
2A	Boeing - 7 levels	CRM WB	BCFD, GGNS	SARC, SARC-QCR, SST
2B	Boeing - 7 levels	CRM WBNP	BCFD	SARC
3	Boeing Med Grid (level 3) One for each AE deformation	CRM WB (7 deformed)	BCFD	SARC
4	Adapted	CRM WB, WBNP	BCFD, GGNS	SARC

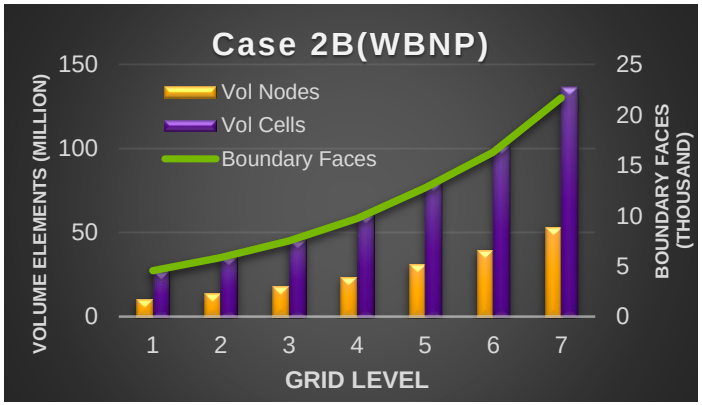
Boeing Custom Grids



- **Toolset : MADCAP*/AFLR****
- **Process**
  - Utilized STEP geometry files and followed DPW VI sizing guidelines
  - Created mesh sizing template for WBNP case
  - Global scaling applied with template to generate 7 grid levels
  - Removed Nacelle/Plyon and filled hole in grid for WB cases
  - Aeroelastic grids generated on 7 geometry models (same sizing field)

Mixed Element Grid Sizes (converted to tets for GGNS)

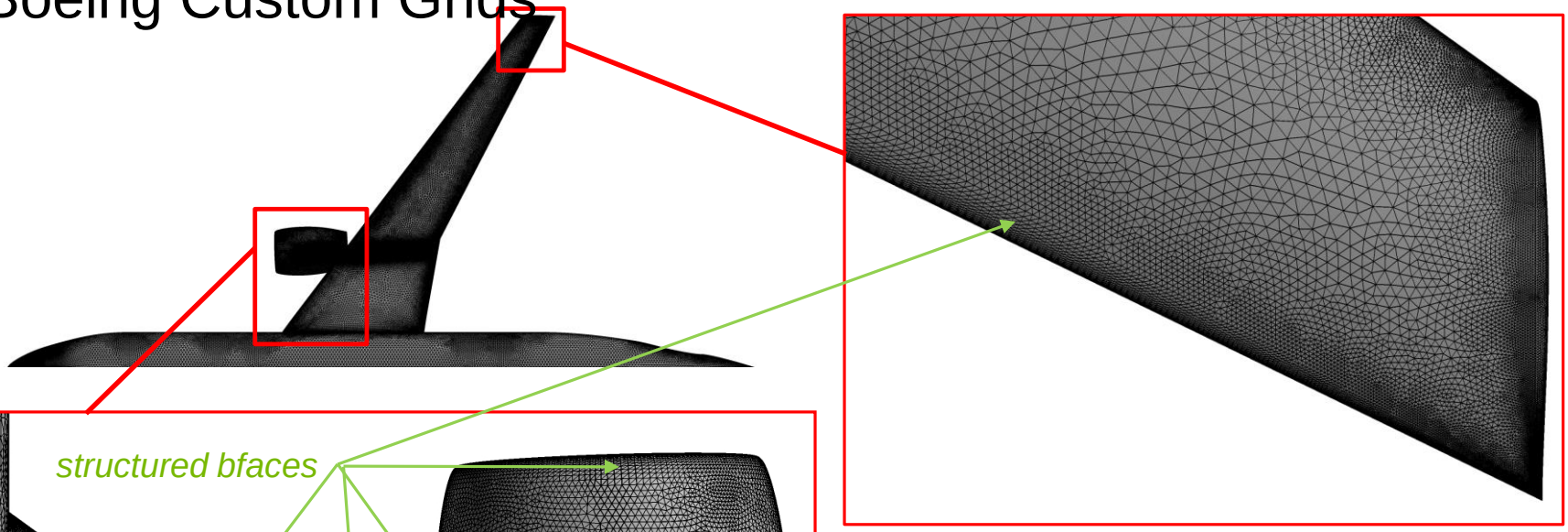


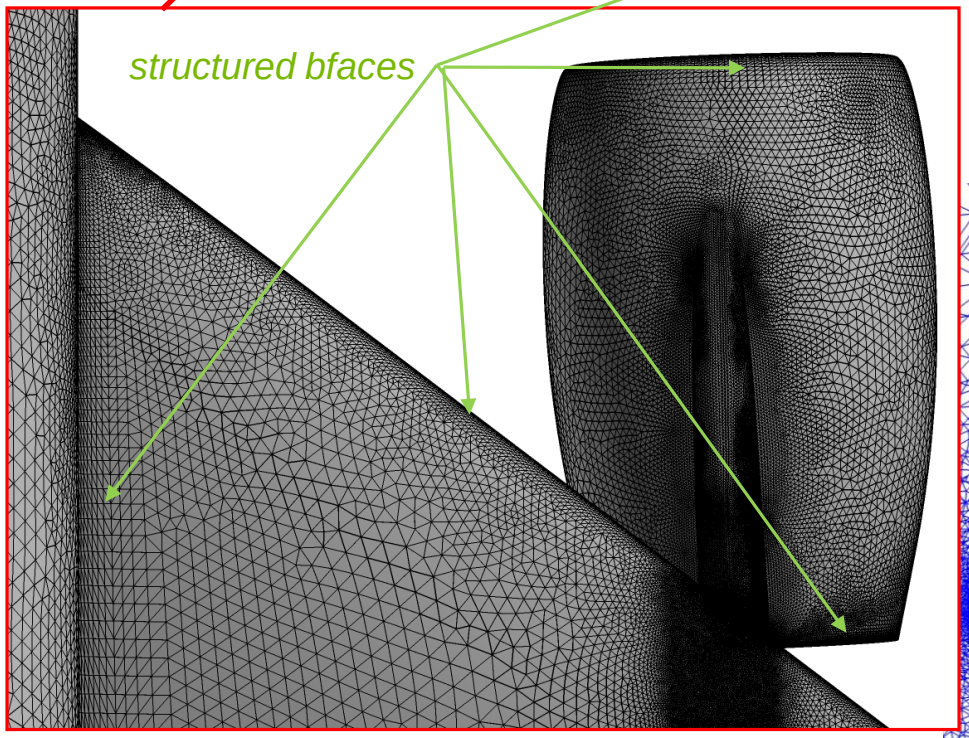


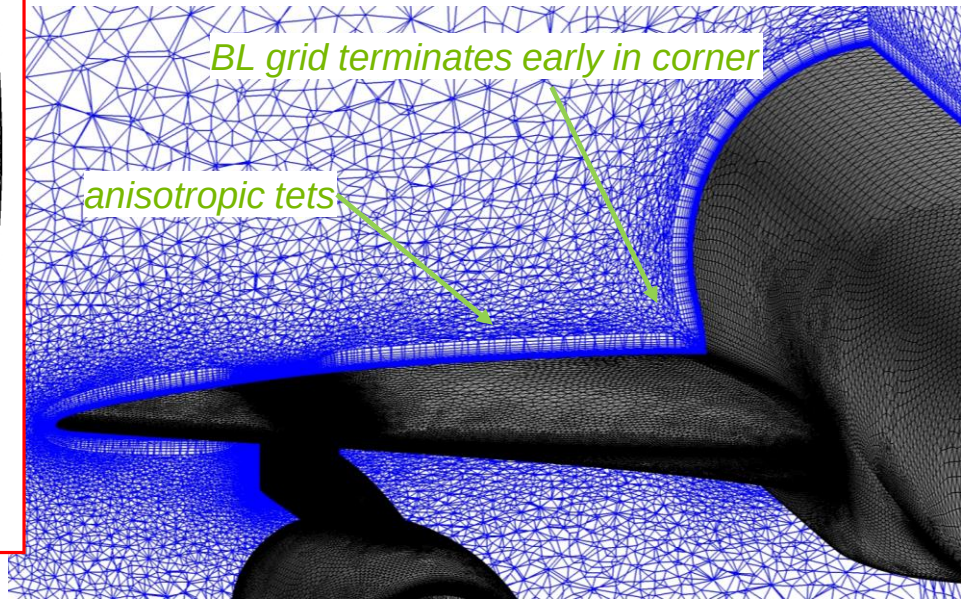
* Modular Aerodynamic Computational Analysis Process - Boeing unstructured grid process

** Advancing Front with Local Reconnection – Developed by D. Marcum, Mississippi State University, modified by Boeing

Boeing Custom Grids





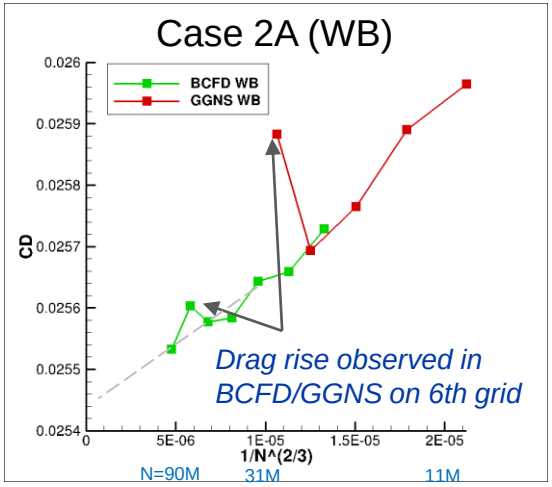


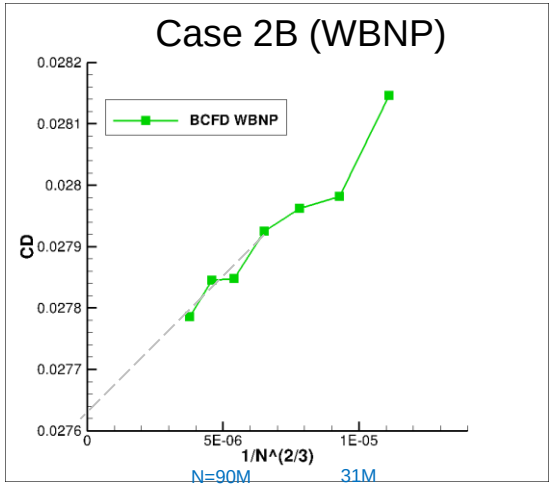
CASE 2 – Grid Convergence Study WB and WBNP
Drag Increment at Constant CL=0.5

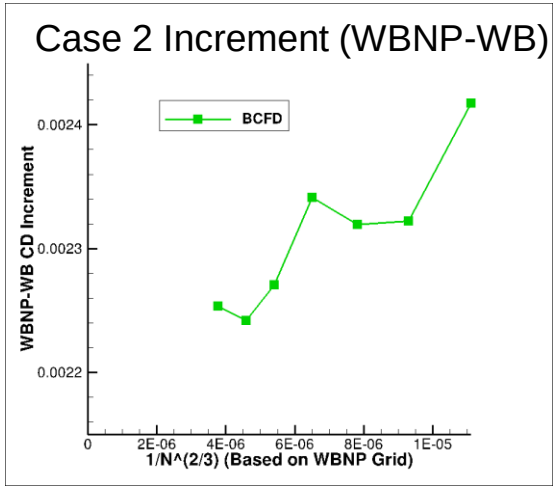
- **CASE2A (WB) - BCFD (Grids 1-7) and GGNS (Grids 2-6)**
- **CASE2B (WBNP) - BCFD (Grids 1-7), no GGNS results**

- **0.5 to 2 count drag rise observed with Grid 6 in BCFD and GGNS results**

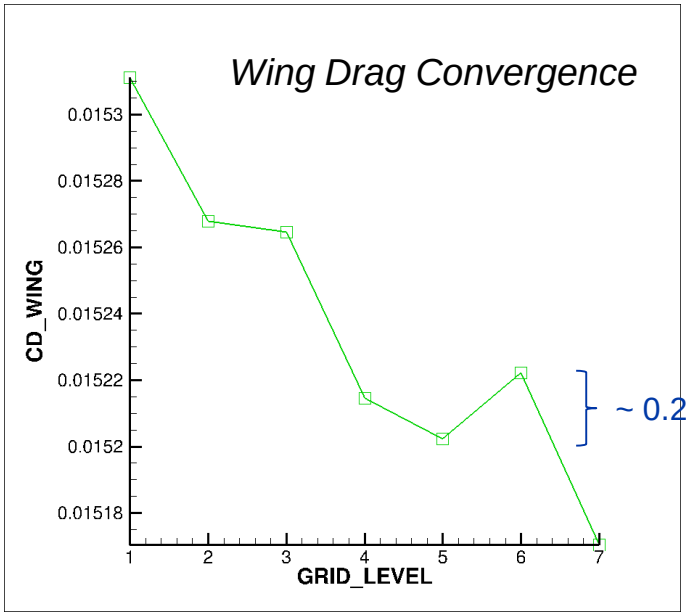
- **Removing grid 6, BCFD and GGNS extrapolated drag very similar**

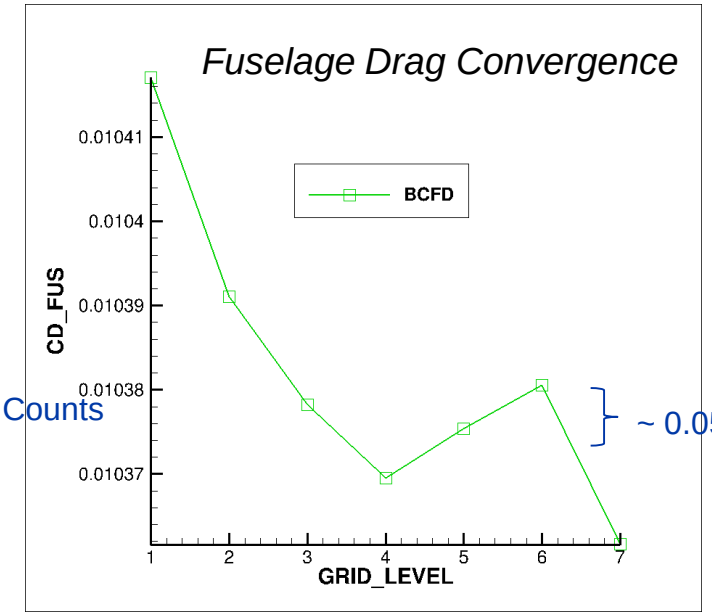


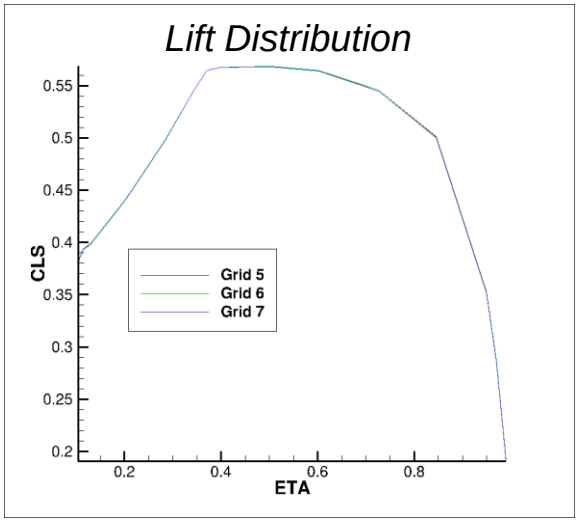


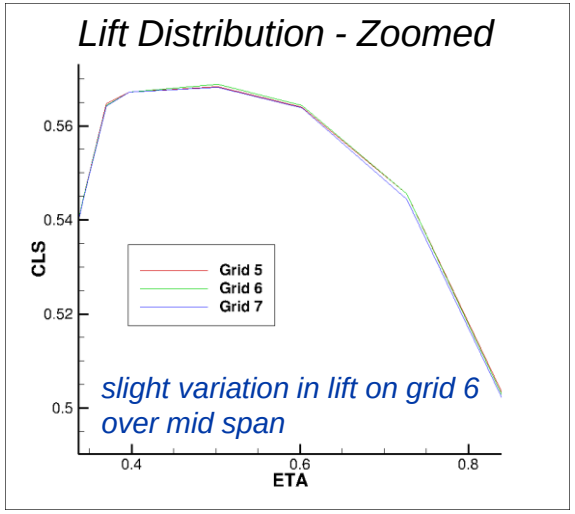


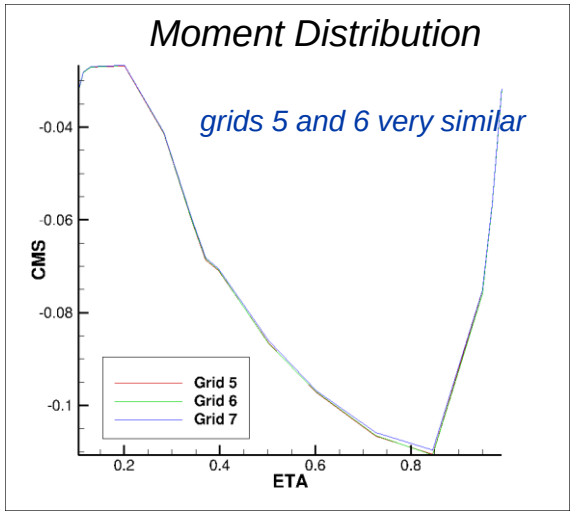
BCFD Investigation of Drag Rise on 6th Grid



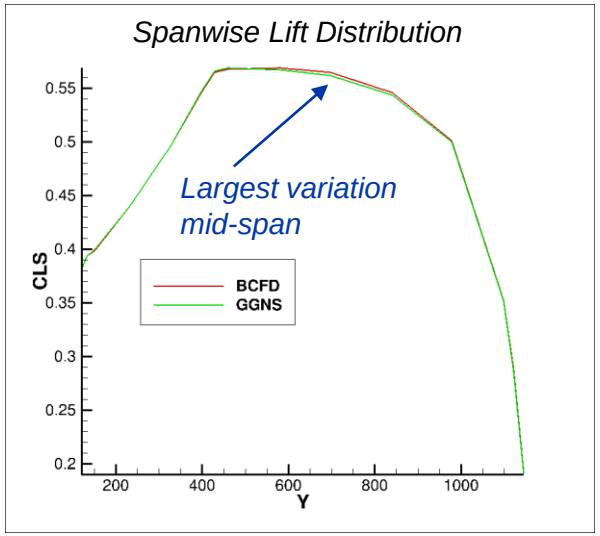


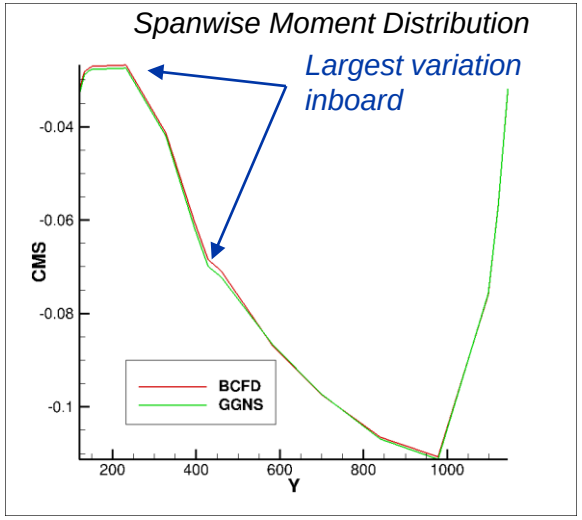


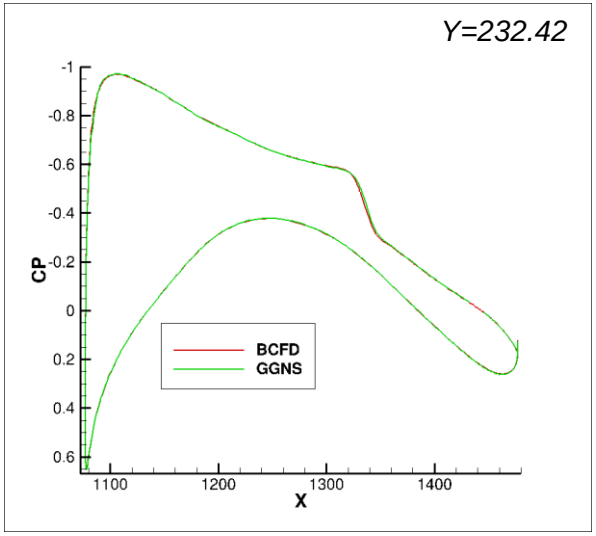


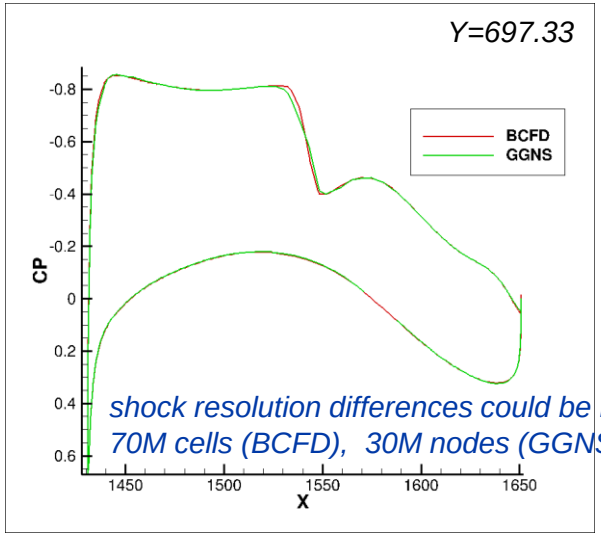


BCFD/GGNS Comparison – Grid Level 6





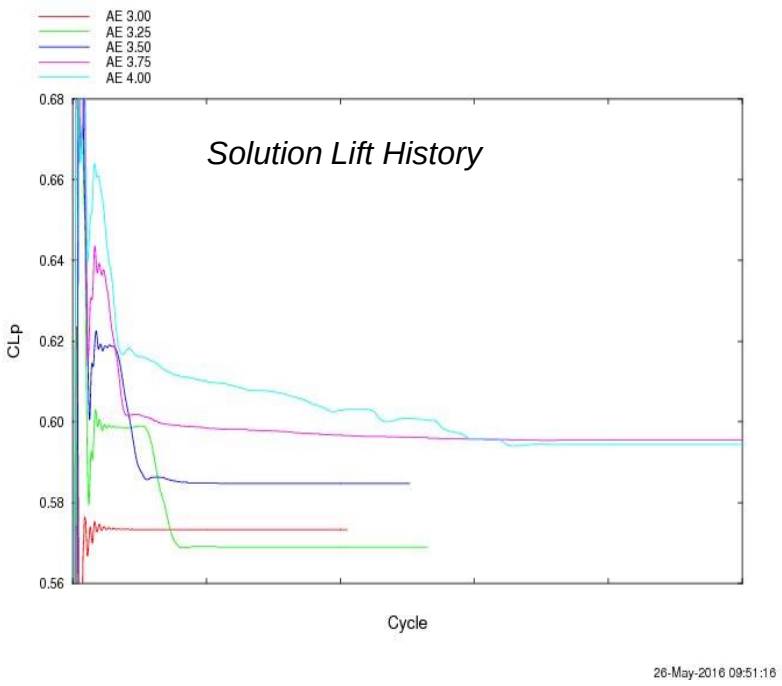


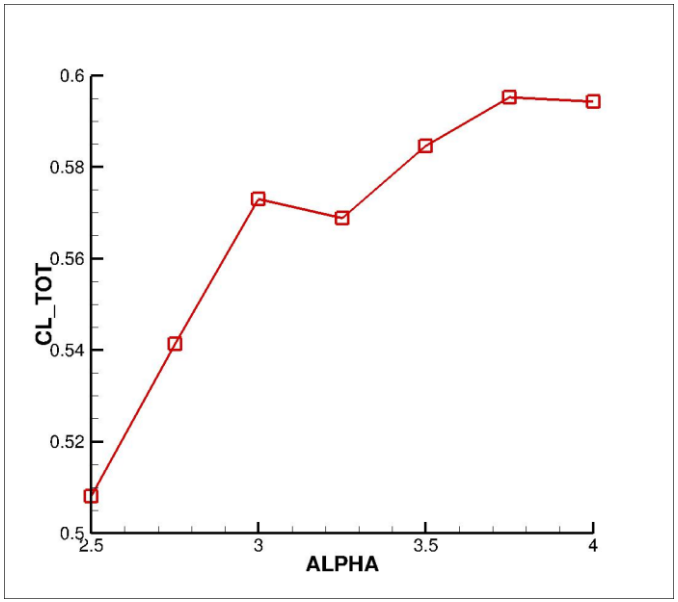


shock resolution differences could be DOF related
70M cells (BCFD), 30M nodes (GGNS)

CASE 3 – Aeroelastic Deformation Study WBNP

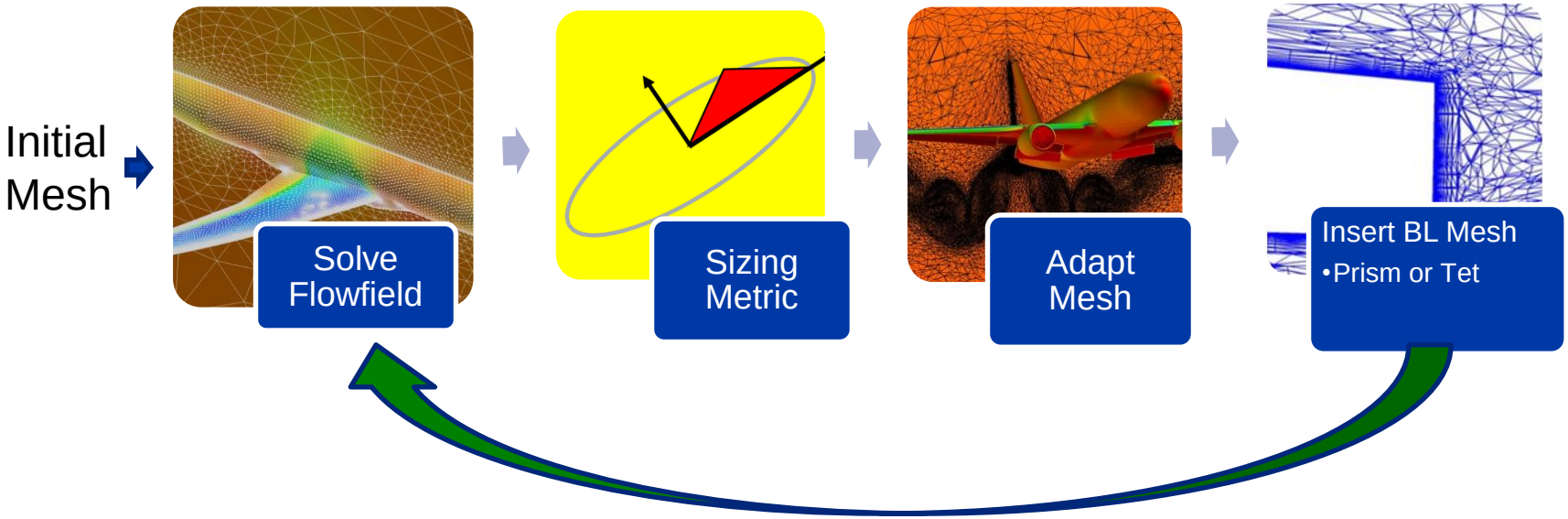
- Ran on medium grid level (~50M cells) for all 7 angles of attack
- SA-RC turbulence model
- Solutions above AoA=3.0^{o} initially attracted to unstable high-lift solution and then converge on lower-lift solution
- Inboard separation introduces non-linear lift curve at AoA=3.25^{o}



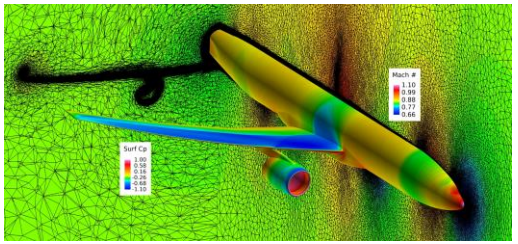


Adaptive Grid Generation

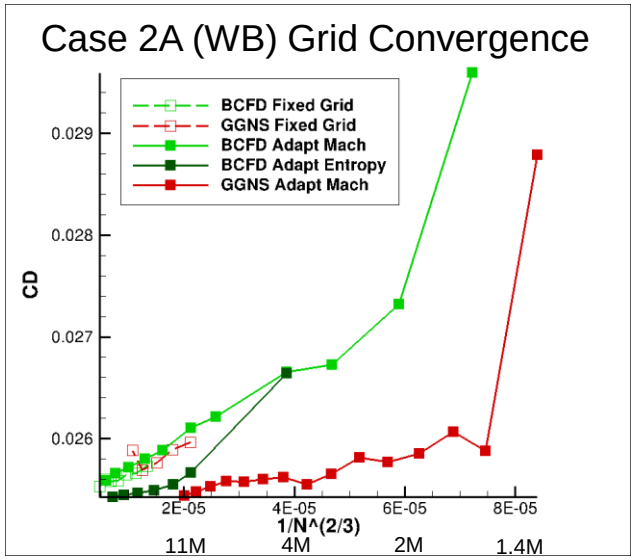
- **EPIC (Edge Primitive Insertion Collapse) Adaptive Grid Tool**
  - Utilizes edge based operators to coarsen/refine surface and volume mesh to match a target metric field
  - Adaptation performed on tetrahedral mesh with optional post BL prismatic grid insertion (normal spacing based on solver estimate of y+)
  - Sizing metric derived from Mach Hessian or Entropy Adjoint error estimate
- **Adaptation Process**



CASE 4 – Adapted Grid Study

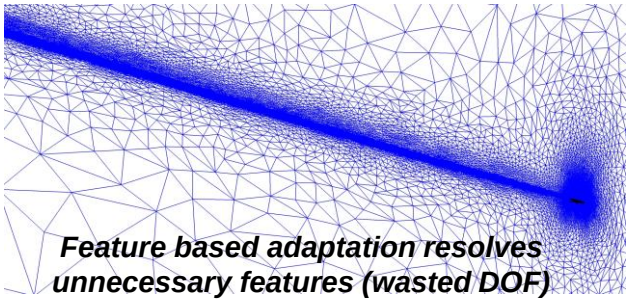


- **WB and WBNP configurations with GGNS and BCFD flow solvers**
- **Initial grid (559K cells, 205K nodes)**
- **Adapted on tetrahedral grid with BL grid insertion (prisms BCFD, tets GGNS) – BL grid not fully adapted**
- **Mach Hessian and Entropy adjoint error indicators**
- **Multiple runs to investigate impact of initial grid size/type, BL mesh, adapt growth rate, error estimate/metric choices**

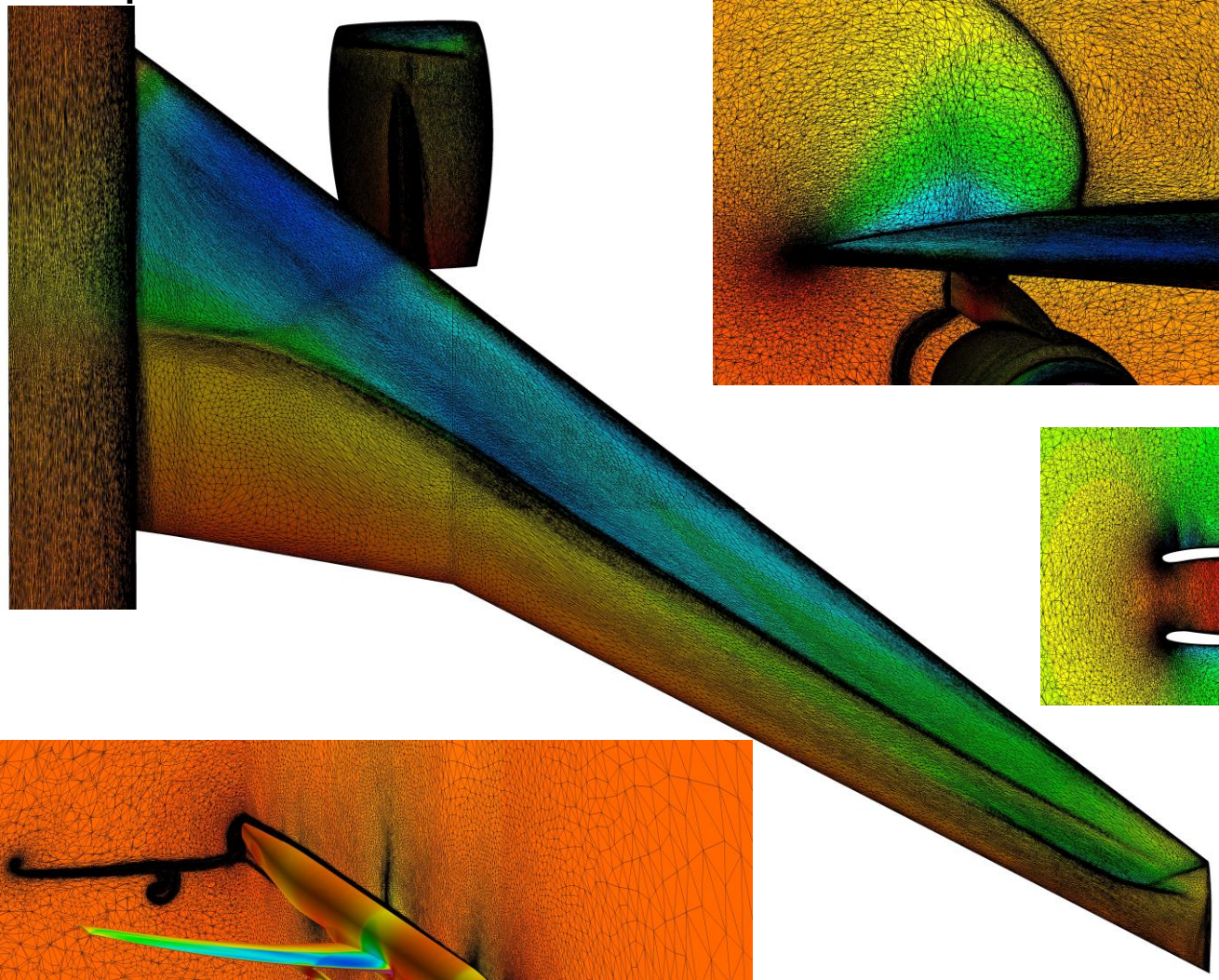


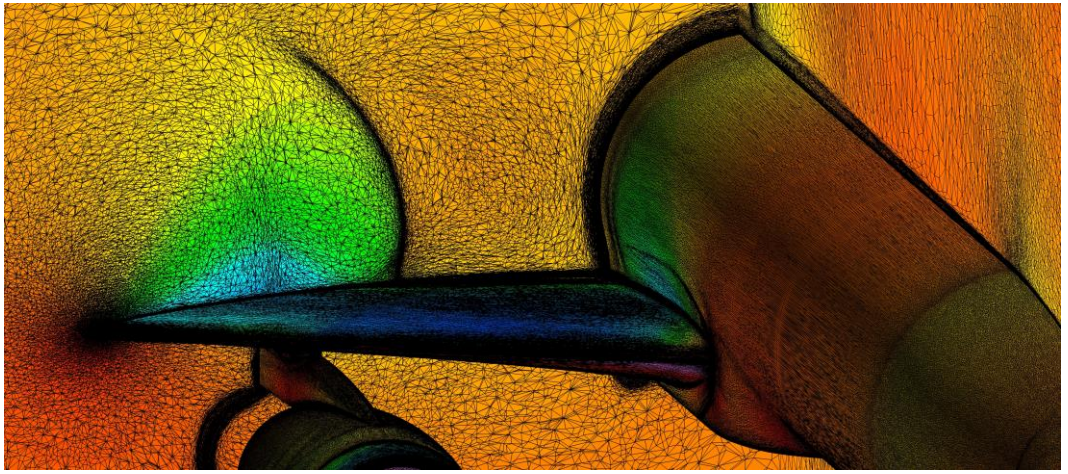
Adapted Grid Convergence Rate

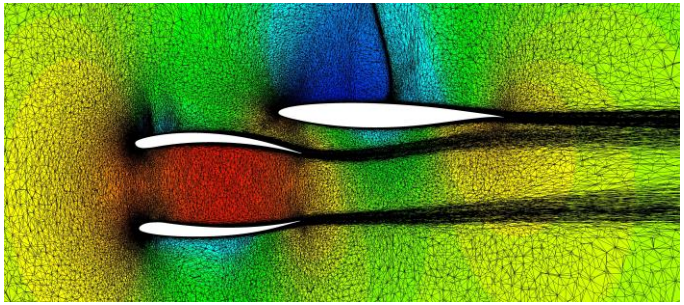
- BCFD (Mach) convergence comparable to fixed grid
- GGNS (Mach) better than fixed grid
- BCFD (Entropy) improves rate



GGNS/EPIC Final Solution and Grid Adapted to Mach Hessian

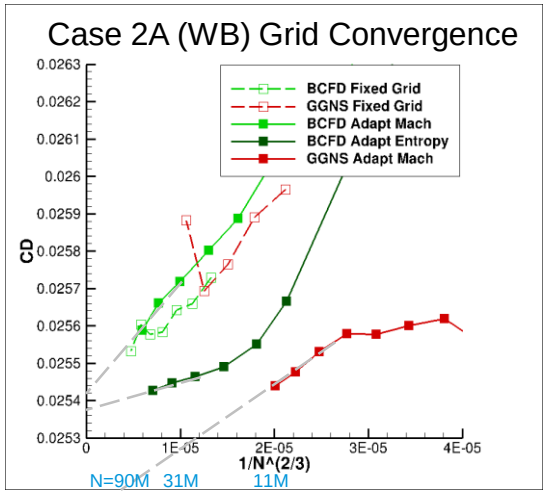




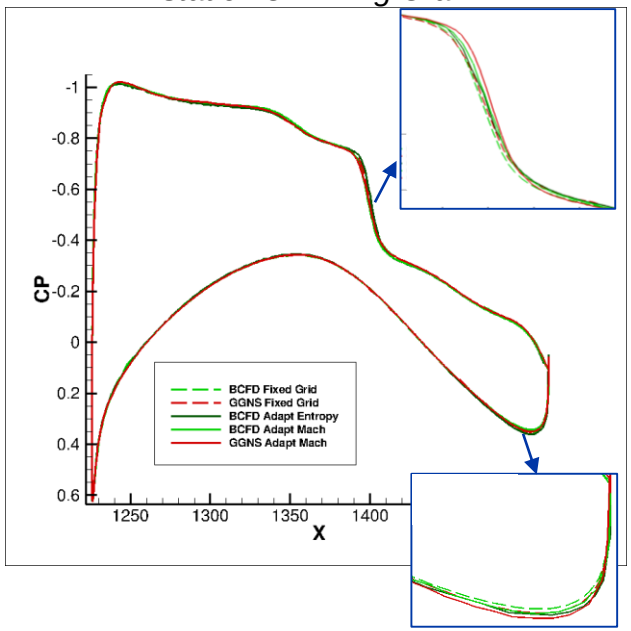


CASE 4 – Adapted Grid Study
Adapted Grid Comparison – WB Configuration

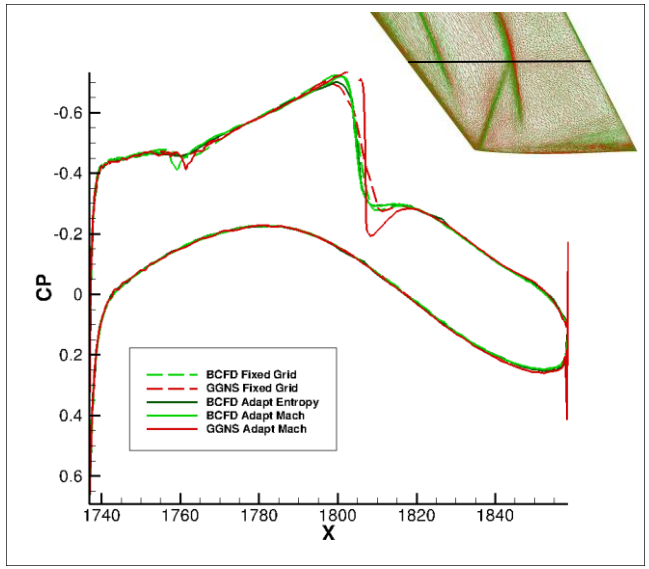
- **BCFD adapted grid drag consistent with fixed-grid**
- **GGNS adapted grid drag lower than fixed-grid estimate**
  - Problems matching CL – resulted to running with fixed alpha on larger grids
- **Adapted grid pressure distributions generally consistent**
  - Adapted results: better resolution of shocks, lower surface near trailing edge
  - Large difference in adapted results near wing outboard lambda shock



station 8 – Wing Crank



station 14



Conclusion/Summary

- **Fixed Grid Results**
  - Seemingly benign variations in the grid topology or stretching rate can introduce drag variations comparable in magnitude to the drag increment between grid levels.
  - Complicates use of Richardson extrapolation to predict grid converged drag

- **Adapted Grid Results**
  - Drag predictions generally comparable to fixed-grid
  - Choices in adaptation strategy (*i.e*. error-estimate) have large impact on grid convergence rate
  - Demonstrated grid convergence to within ½ to 2 counts of drag
  - Absolute grid converged results will require very large grids, or output-based error-estimates