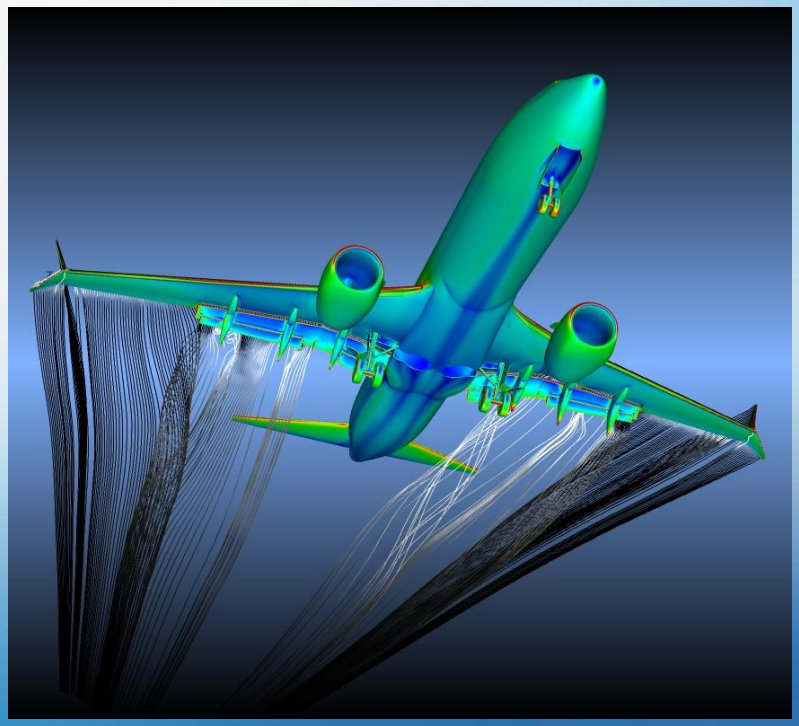
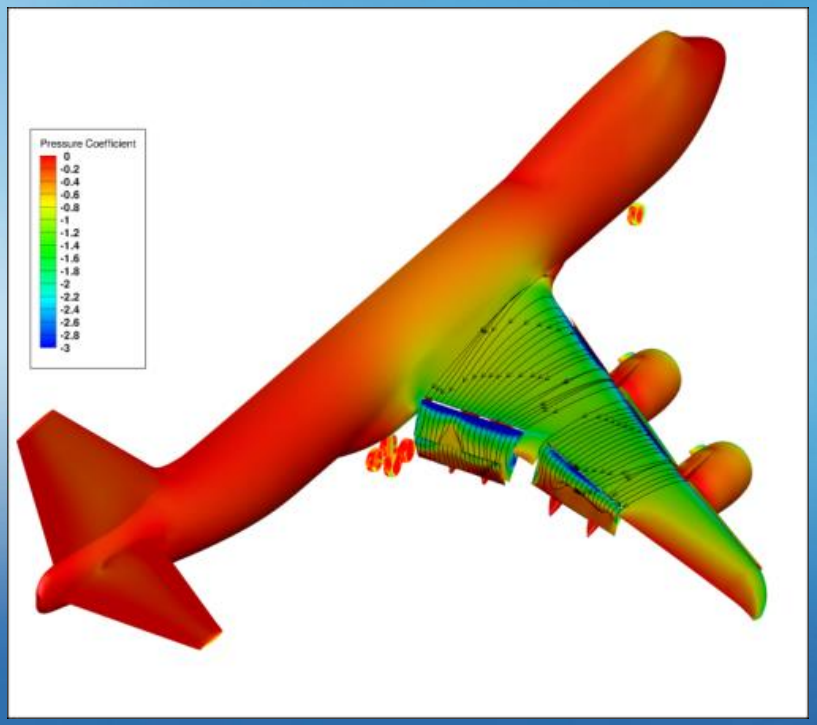




Welcome to Overset Grid Symposium

Robert Gregg – BCA Chief Aerodynamicist

Oct 18, 2016

Some Initial Comments …

- **In a celebrated 1975 paper*, Chapman, Mark and Pirtle postulated that**

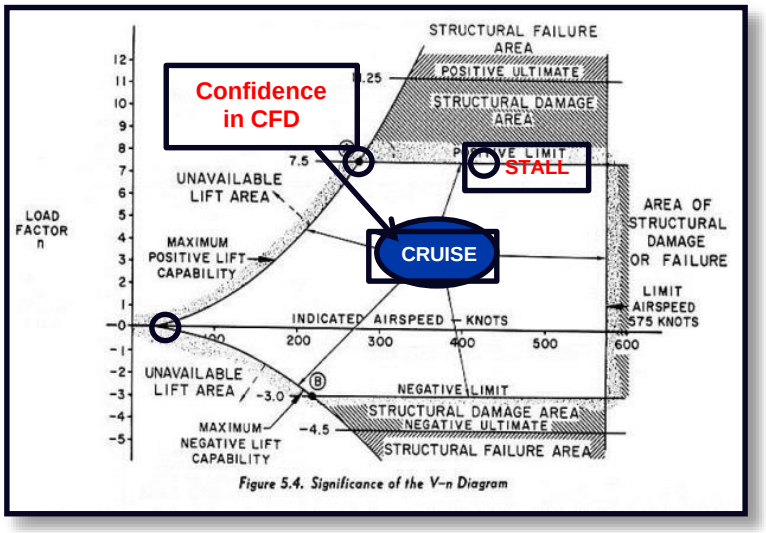
  "[…] future aerodynamic studies will chiefly rely on computational data provided by the computer […] in the mid 1980s."

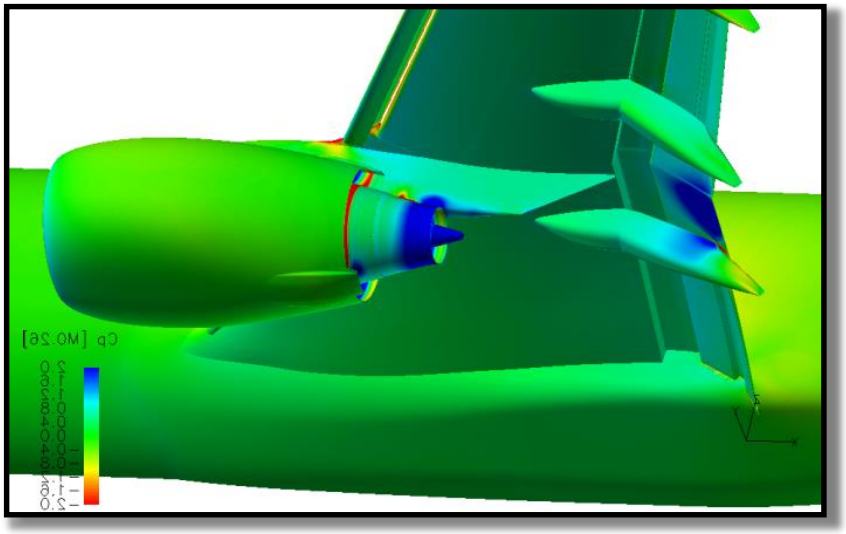
- **Although, arguably, their prediction missed reality by some 30 years, their vision is now becoming a reality**
  - **But only in some parts of the operating envelope…**

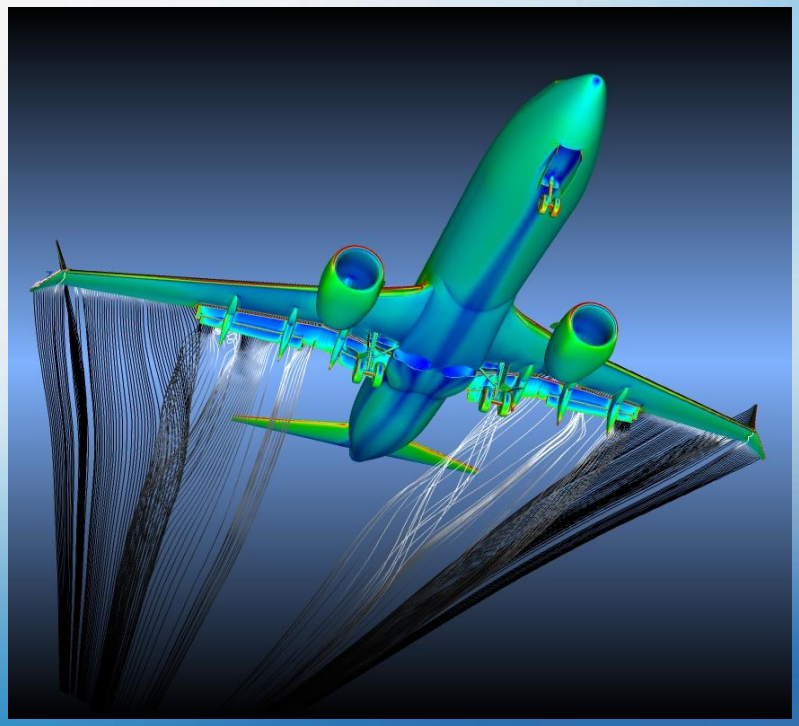
* Chapman, D. R., Mark. H., Pirtle, M. W., "Computers vs. wind tunnels for aerodynamic flow simulations", Astronautics & Aeronautics 13(4):22-30, 35, 1975

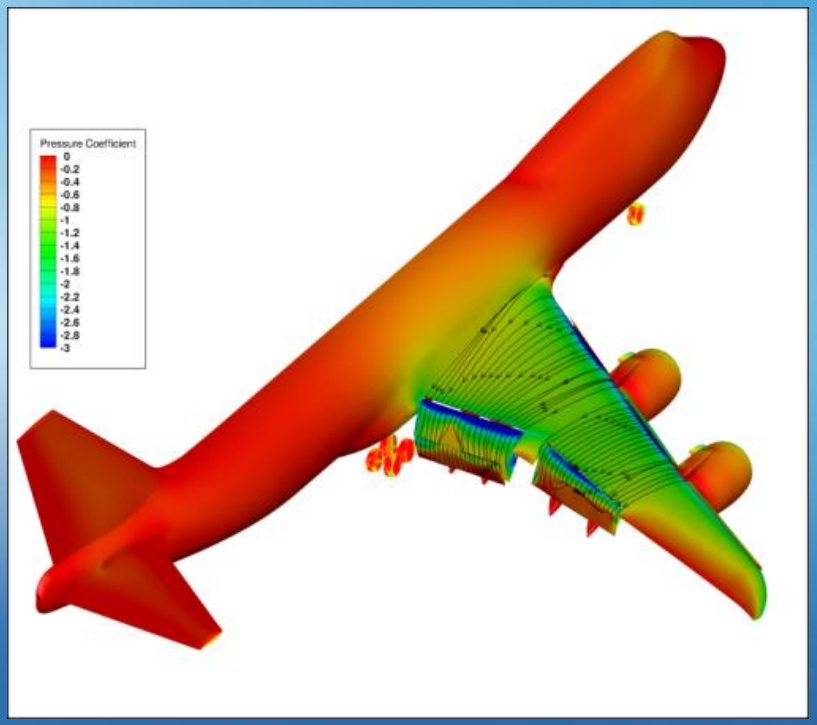
Additional Thoughts

- Use of CFD to reduce program risk and accurately predict characteristics across the flight regime provides large value
- Overset Grids important to not only Boeing but the broader aerospace community
- Great to see friends of Overset from Academia, Government and Industry
- I look forward to the material to be presented and the discussions during the week
- Enjoy the symposium!









The Challenges of Certification by Analysis

Robert Gregg

Oct 18, 2016

Some Initial Comments …

- **In a celebrated 1975 paper*, Chapman, Mark and Pirtle postulated that**

  "[…] future aerodynamic studies will chiefly rely on computational data provided by the computer […] in the mid 1980s."

- **Although, arguably, their prediction missed reality by some 30 years, their vision is now becoming a reality**
  - **But only in some parts of the operating envelope…**

- **This presentation discusses views of what the future might bring for Certification and Qualification by Analysis (CQbA)**

* Chapman, D. R., Mark. H., Pirtle, M. W., "Computers vs. wind tunnels for aerodynamic flow simulations", Astronautics & Aeronautics 13(4):22-30, 35, 1975

What is CQbA?

- **Commercial aircraft are certified to show compliance with government regulations**
  - The FAA certifies commercial aircraft in the US
  - While most FAA rules are the basis for foreign regulations, there are differences
- **Military aircraft use qualification to demonstrate that the aircraft meets specification requirements**
- **Certification/Qualification by Analysis**
  - Showing that a vehicle is in compliance with a regulation or specification using analysis without flight test or to supplement flight test results for a specific requirement
  - Analysis is not just CFD

Some Initial Comments … (II)

- **We think of CQbA in two separate but complementary ways:**
  - **As a sequence of steps, processes, and methods that can incrementally satisfy requirements using computations alone (a sort of *technology push* view) – R. Gregg**
  - **As a series of requirements to be met before any certification / qualification requirement can be considered to be satisfied by analysis (a sort of *technology pull* view) – J. J. Alonso**
- **Our views combine operational and research perspectives into a single presentation**
- **We hope not to miss the mark by 30 years as well, but:**

  "Prediction is difficult, especially when dealing with the future". . .Danish Proverb

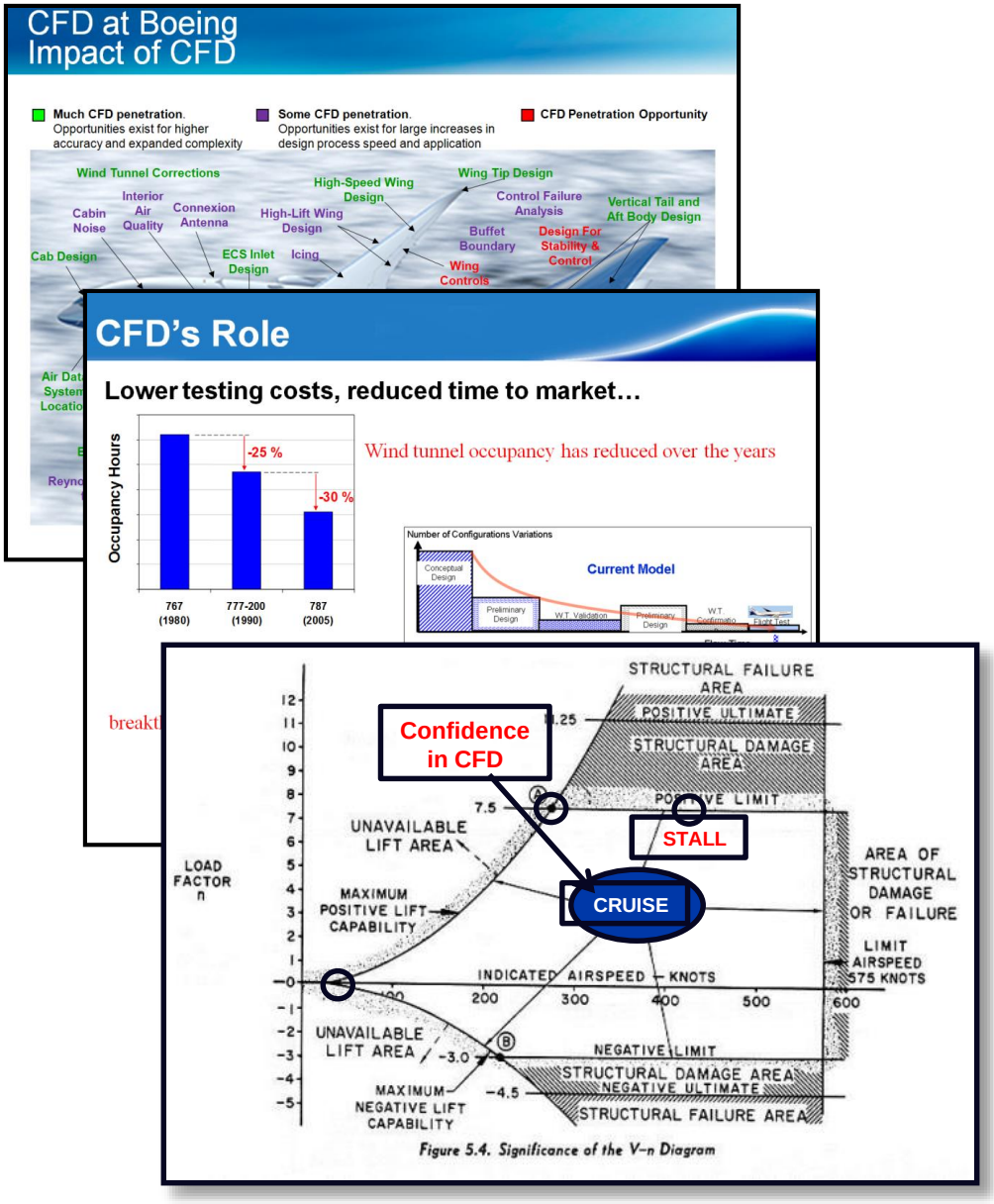
Some Initial Comments … (III)

- **Although CQbA was not discussed in detail in the NASA Vision 2030 CFD report†, the main objectives of that study included:**
  - **Physics-based, predictive modeling**
  - **Automated management of errors and uncertainties**
  - **Effectively leveraging the best HPC hardware**
- **These are fundamental premises for CFD use in CQbA**
- **CQbA goes hand-in-hand with the realization of key elements of the "NASA Vision 2030 CFD"**

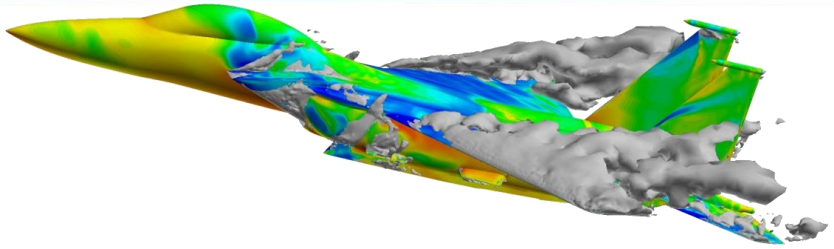
† Slotnick, J., Khodadoust, A., Alonso, J. J., Darmofal, D., Gropp, W., Lurie, E., Mavriplis, D., "CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences", NASA/CR-2014-218178, 2014.

Computational Fluid Dynamics

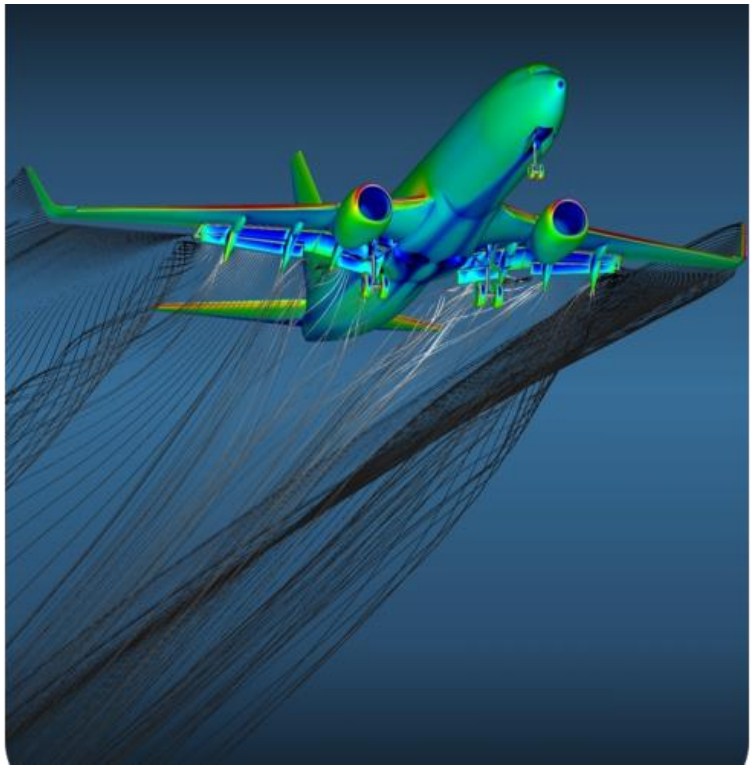
- CFD plays a key role in designing innovative and efficient new aircraft/vehicles
- CFD influences almost every exterior surface of our products
- The primary focus of CFD has been to reduce both design cycle time and design risk
- Still areas still needing improvement (e.g. high-lift CLmax, flap optimization, S&C, distributed h/l loads, control surface effectiveness, etc)
- Gridding automation, grid adaptation, turbulence models, and higher order models will continue to need development



CFD Considerations

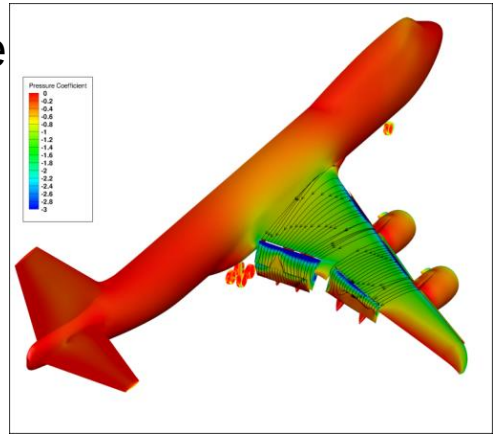


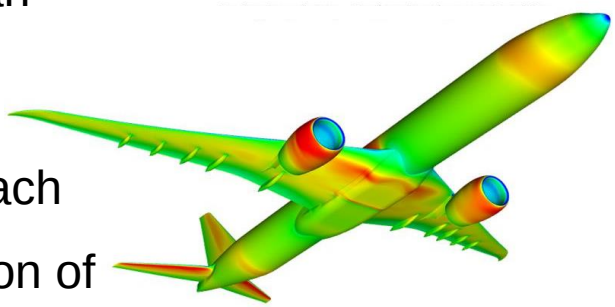
- CFD can be used to reduce design cycle time ***and*** be leveraged to reduce test costs if used smartly
- When CFD is used properly, we have had very good results (e.g. cruise drag)
- With more trusted results across the flight regime, FT & Program risks will be minimized
- Use of CFD at the corners of the flight envelope will require more use of unsteady analysis and improved physical models (need to accurately predict effects of separated flow)
- Continued CFD improvements and validation are critical to getting significant reductions in flight test costs



Challenges for Overset Grid CFD

- Overset grid technology has an advantage in computational efficiency compared to unstructured grid solutions
- There appears to be no inherit solution accuracy advantage if grid is adequately resolved relative to unstructured grids
- Set-up of Overset grids is the long pole in getting solutions quickly – particularly on complex geometries to be evaluated
- Unstructured grid generation currently has an advantage in set-up time
- For large databases, the computational efficiency of an Overset approach can overcome long set-up times
- Adaptive unstructured grid technology could erode computational efficiency advantage of Overset approach
- Need Overset tools that can generate grids in a fraction of the current time
- More automated processes will enable even wider use of Overset grids





Certification/Qualification by Analysis (CQbA)

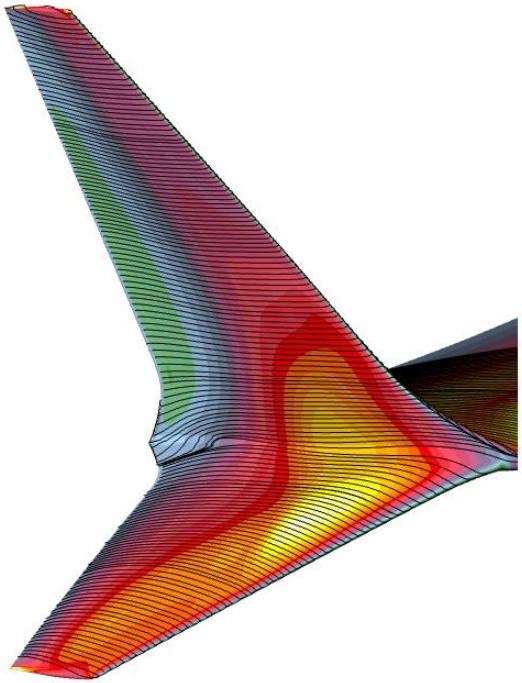
- **Certification/Qualification today is based on flight test data as an accepted means of analysis (e.g. wind tunnel data corrected to flight conditions)**
- **FAA allows for alternate Means of Compliance**
  - Must obtain FAA approval
- **CFD data should be treated like WT data for CQbA**
  - Analysis can supplement FT by thinning matrix of conditions, correct FT data for differences (e.g. CG) or be used to replace FT for specific characteristics called by FAR rules (if substantiated)
  - Incremental adjustments for configuration differences have a different standard than absolute levels on a major derivative / all new vehicle
- **Any CQbA process needs validation to gain trust by regulators and/or Authorized Representatives**

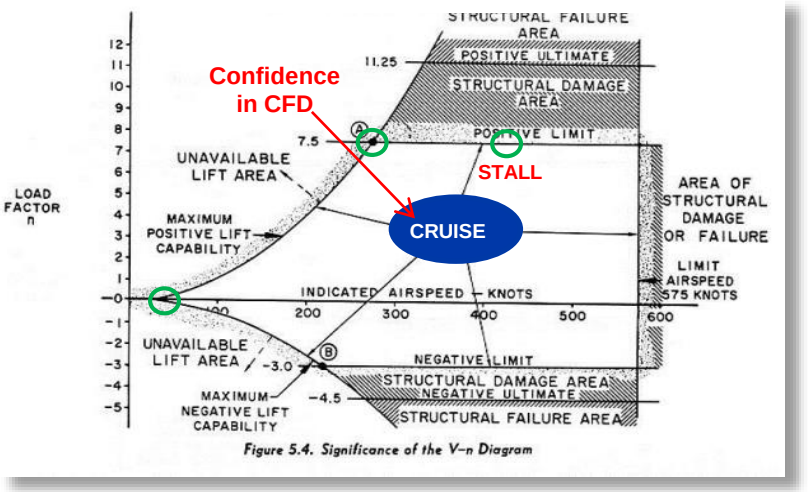
CFD must be performed by trained CFD users following a disciplined, validated, and traceable process

CFD CQbA Process Elements

In addition would include:

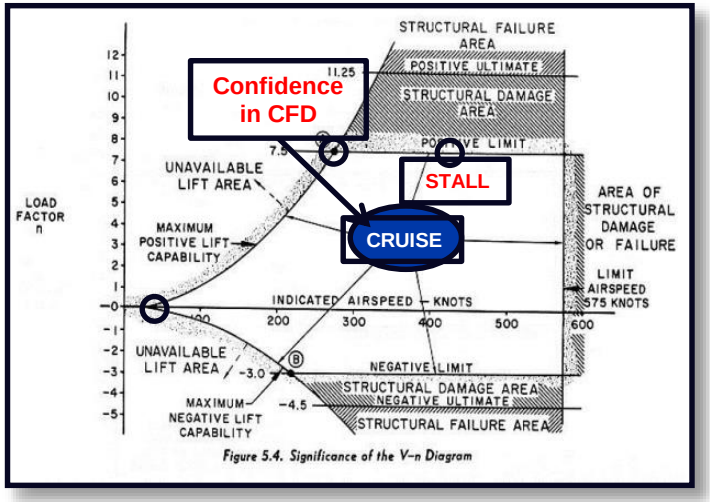
- Configuration management - Airplane geometry is controlled & represents FT article
- Common tools/best practices - Can we trust the results?
- Software version control – Are the process and results repeatable?
- Expert Audits - Are you following the best practices and an established CFD plan?
- Skill requirements and training – Can we trust the results and is this a repeatable process?



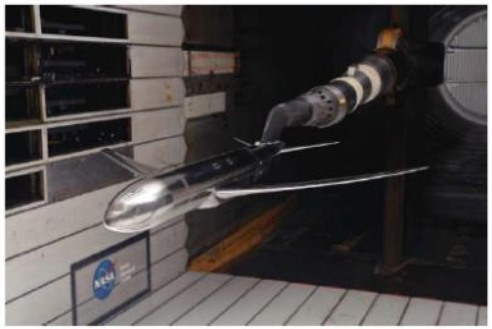


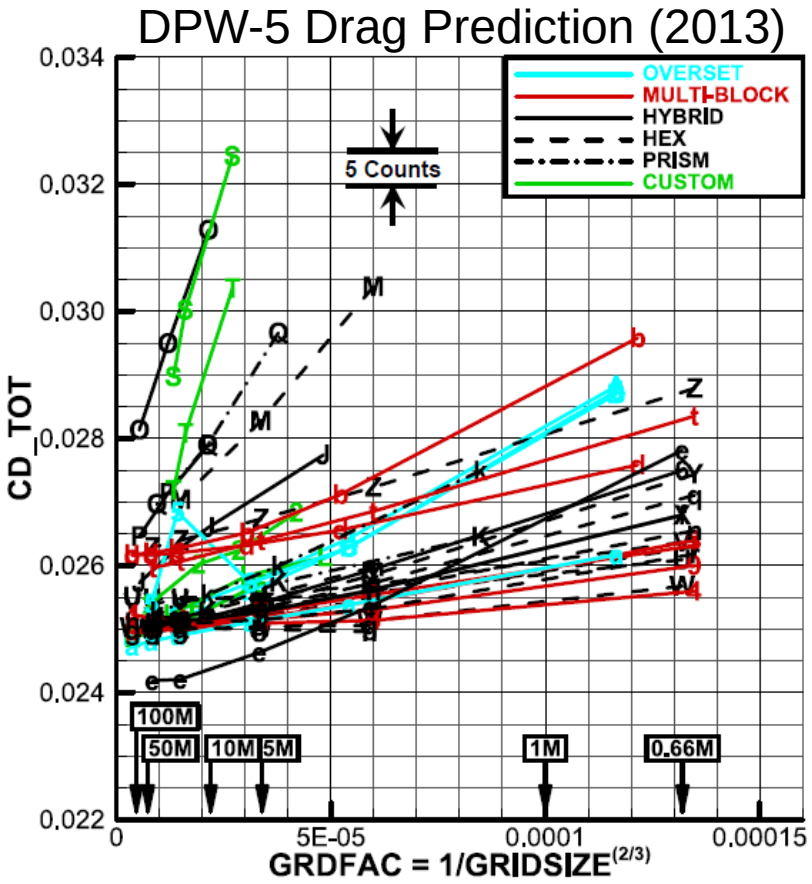
CQbA Challenges for Overset Grid CFD

- **Vehicle geometric definition must represent the airplane that comes out of the factory**
- **Consistency and validation of CFD solutions**
  - Multiple configurations (flaps, slats, control surfaces, tail setting, symmetric and asymmetric, with and without power)
  - From 0.1M to Mdive (0.97M for 747)
- **Engine/nacelle/exhaust modeling, including correct mass flux, in CFD**
- **Separated flows including smooth surface**
  - From minimal separation at cruise to massive separation
  - From essentially steady state to unsteady flows
- **Creating a database including 1000's of conditions and configurations**
- **Useable by significant number of CFD users**



Results From 5th AIAA Drag Prediction Workshop





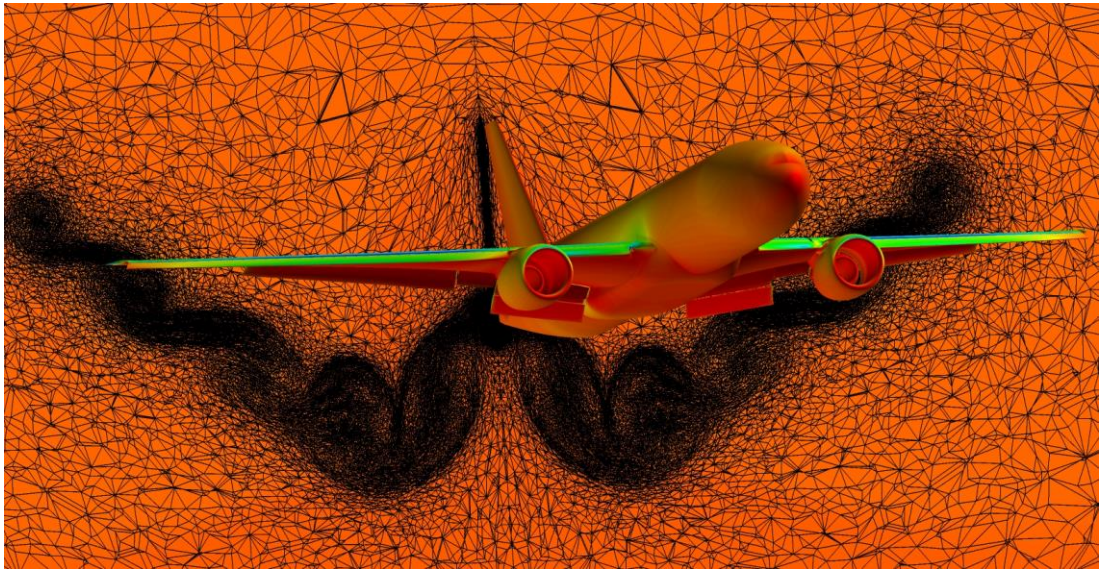
Inconsistency limits use of CFD for certification and increases risk during design

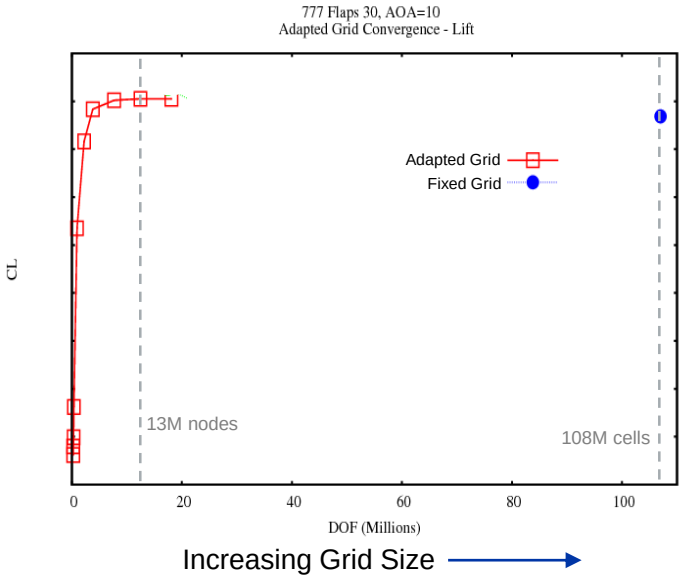
Summary

- CQbA will make a huge impact is reducing costs associated with Product development
- Continued focus on advancing CFD technology will enable and expand the use of CQbA across all product categories
- Overset grid CFD has played, and will continue to play, a critical and pivotal role in assessing our current and future predictive simulation capabilities in addressing CQbA opportunities
- Boeing remains committed to overset grid technology at all levels, including internal development, collaboration with trusted partners, and interactions with the broader CFD community

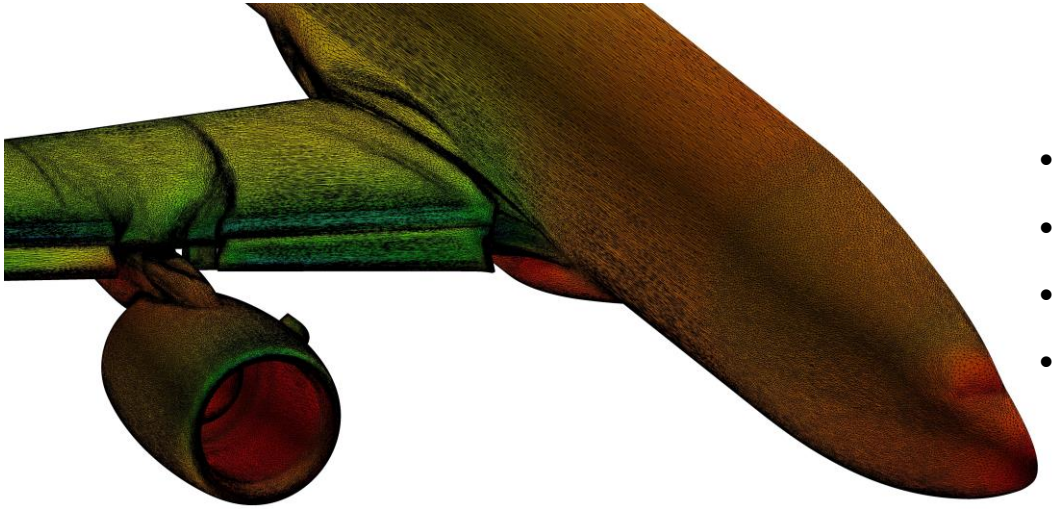

BOEING

Solution Adaptive Grids Provide Similar Accuracy On Reduced Grid Size





Increasing Grid Size →



777 Landing Configuration, RANS solution

- Boeing GGNS finite element solver
- Adapted to Mach Hessian
- Tetrahedral mesh
- ~ 13 million grid nodes to convergence