# Requirements in Computational Simulation to Enable Certification by Analysis

Robb Gregg

6 January 2018

# Outline

- **Industry Trends**
- **Emerging Technologies for Aircraft Development**
- **Certification by Analysis (CbA)**
- **Role/Impact of CFD**
- **CbA Opportunity Development**
- **Example**
- **CFD Requirements and Shortcomings**
- **External Engagement Strategy**

# Major Industry Trends

- **Car manufacturers have digitally integrated their design and build processes**
  - **Driven by the fast pace of market demand and scale of production**
  - **Resulting in increased use of manufacturing automation**
  - **Enabled by Engineering tools use of S/W based analysis**

- **Aerospace Environment**
  - **Need to be able to respond quickly to changes in market demand and continued need to reduce fuel burn and emissions**
  - **Competitive market with new manufacturers**
  - **Increased use of manufacturing automation to improve efficiencies**
  - **Investing in Enterprise-wide Engineering S/W to integrate “design to build” processes**
  - **Processes enabled by use of physics based analysis and simulation in Engineering tools**
  - **Increasing use of Certification using analysis and simulation to shorten cycle times and reduce Flight Test effort**

# Emerging Technologies for Aircraft Development

- Future State – Commercial transport aircraft **flight characteristics will be accurately simulated electronically**:
  - Aerodynamics (including aeroelastics)
  - Stability and Control (including handling qualities)
  - Systems / Flight Controls
  - Engine/ Propulsion
  - Etc.

- Today Boeing is on a path towards fully utilizing Model Based Engineering to simulate our products (including integration of Certification requirements) – ***Digital Twin.***

- Use of validated **physics based models** will improve the understanding and safety of our products, and is key to this digital transformation:
  - Gain greater insight into flow physics and the effects on aircraft response
  - Can assess aircraft characteristics over wider range of cases under controlled conditions
  - Can simulate critical conditions and failure modes, and determine key flight conditions to test (reduced matrix)
  - Can help avoid surprises during flight testing

- Moving to **analysis-based aircraft certification process** is consistent with this overall strategy.

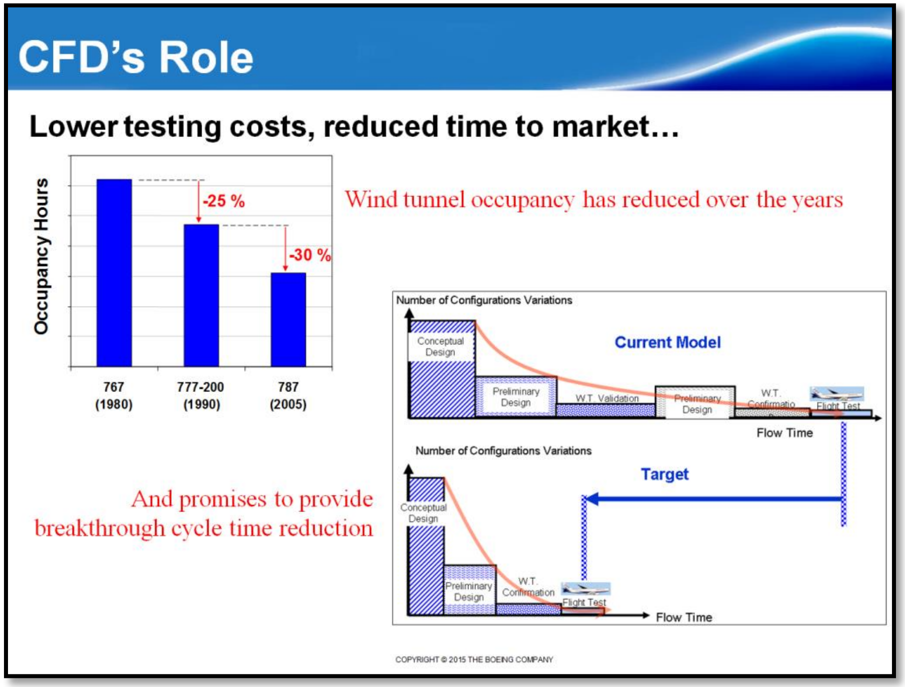
# Certification by Analysis

- Airplane certification is one of the largest non-recurring cost drivers in a commercial airplane development program.
- Today, certification is an intense, approximately year long process involving many aircraft (~4) and a large team of people for aircraft and technical support. **Cost of effort is >$1B**
- Currently, flight testing and flight representative ground testing are accepted means to show compliance with regulatory requirements.
- **Alternate means of compliance (MOC) using analytic methods** are considered, and have been accepted, on a case by case basis.
- **Computational Fluid Dynamics (CFD)** is expected to play an increasingly significant role in achieving dramatic reductions in flight testing through Certification by Analysis (CbA).

# CbA using CFD

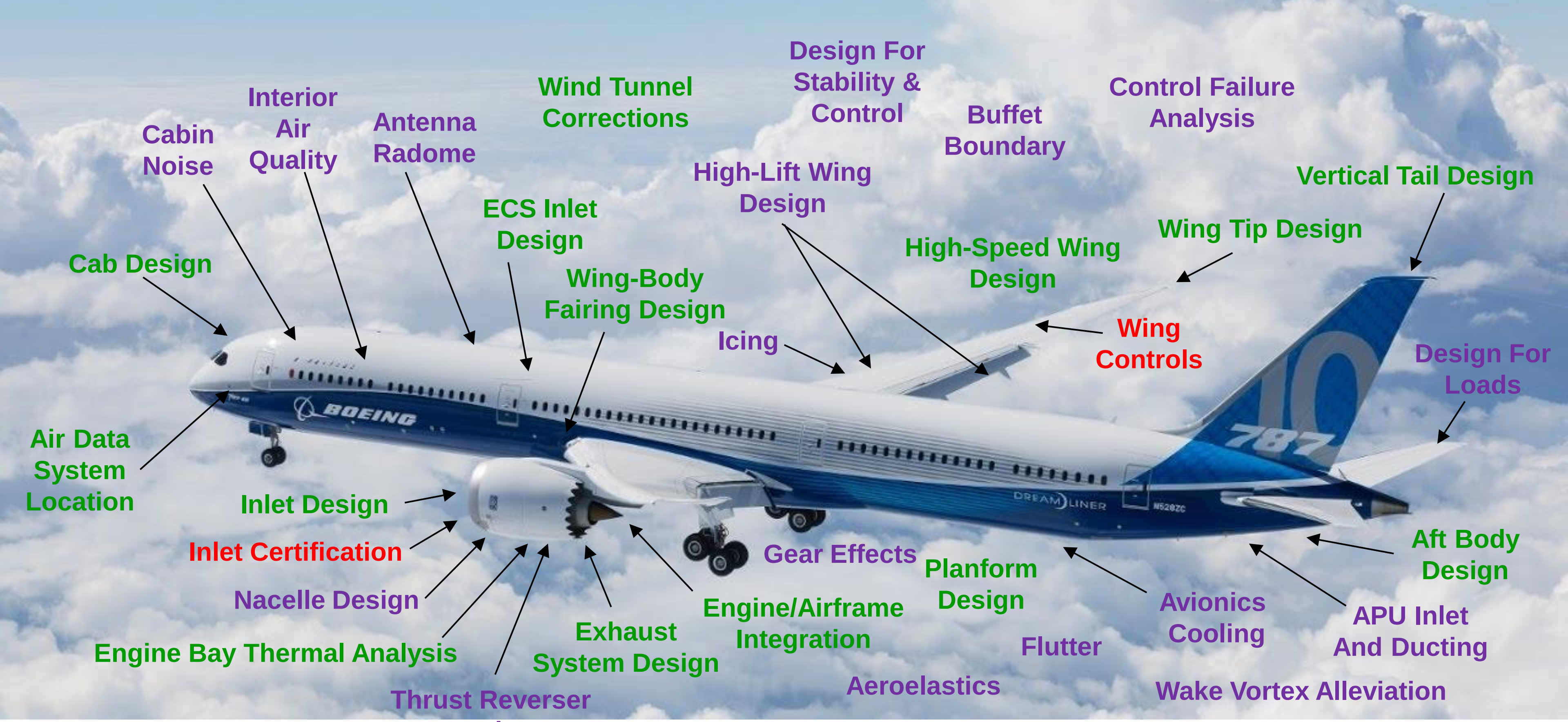
- Generally speaking, **“analysis”** includes **any method that provides data that is at the same level of accuracy as flight test data**, and is used to **ensure an equivalent level of safety (ELOS).** Data from handbook methods, WT data, and computationally-derived data (like CFD) all classify as analysis data.

- Arguably, CFD has the largest potential to impact the reduction of flight test costs:
  - CFD has been used to define just about every exterior component of commercial airplanes
  - The primary focus of CFD has historically been to reduce both design cycle time and design risk, but **new focus is on reducing non-recurring cost and schedule**



# CFD Impact at Boeing

- **Much CFD penetration.** Opportunities exist for higher accuracy and expanded complexity
- **Some CFD penetration.** Opportunities exist for large increases in design process speed and application
- **CFD Penetration Opportunity**




Reynolds Number Corrections for Loads and S&C

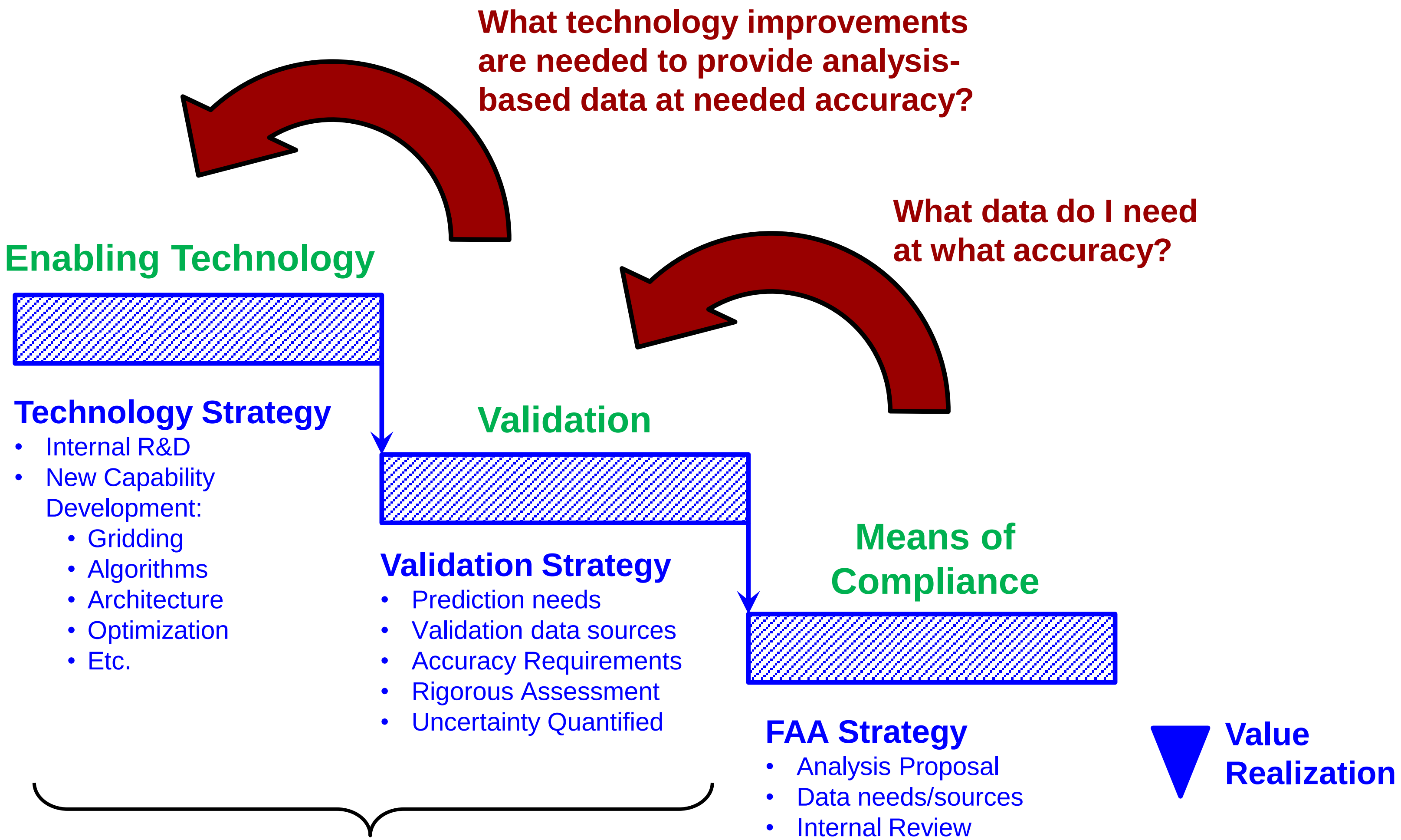
Design for FOD Prevention

Community Noise

APU and Propulsion Fire Suppression

Vortex Generator Placement

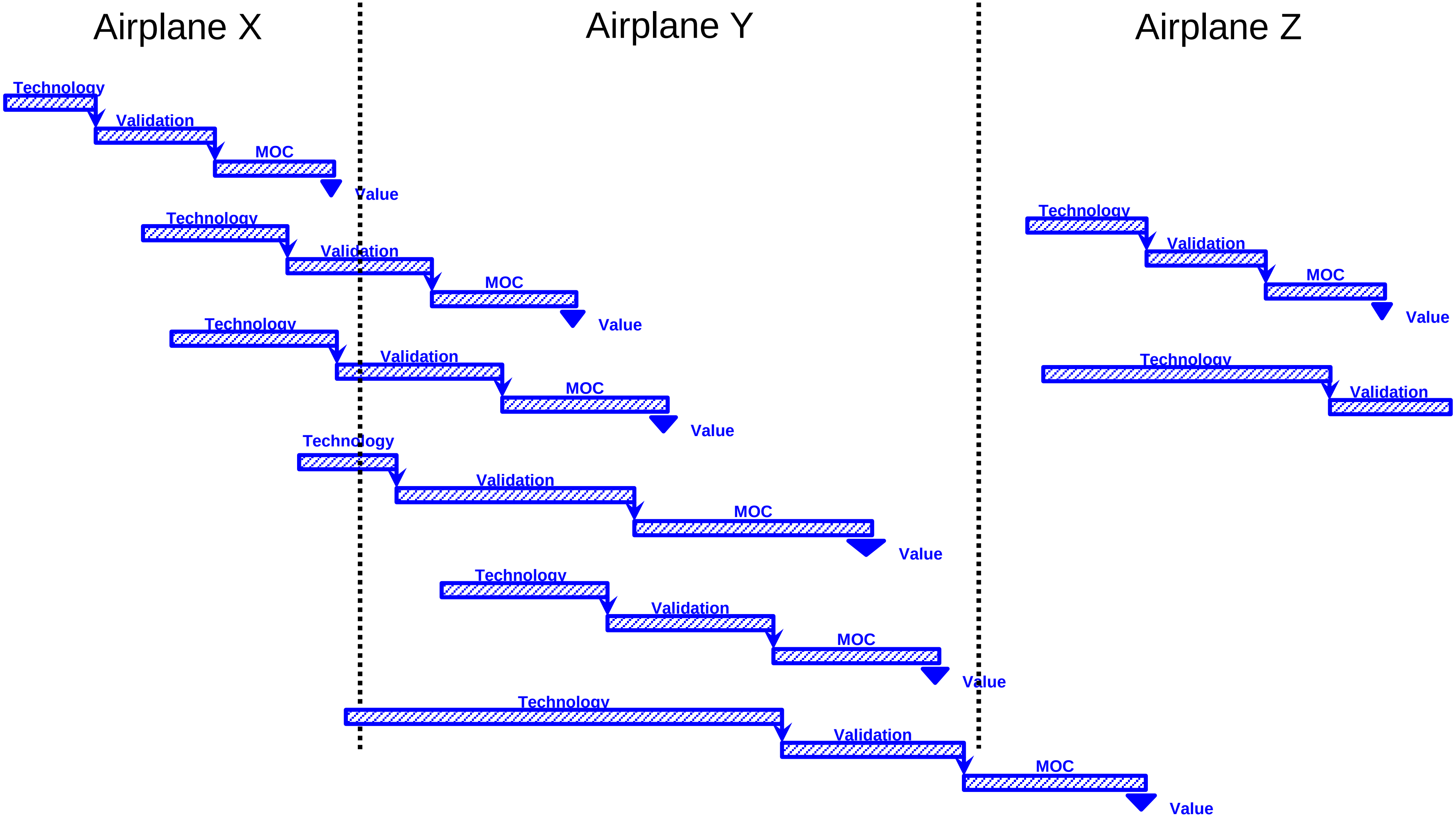
# Opportunity Development for CbA




**Mature Boeing CFD Tools & Processes**

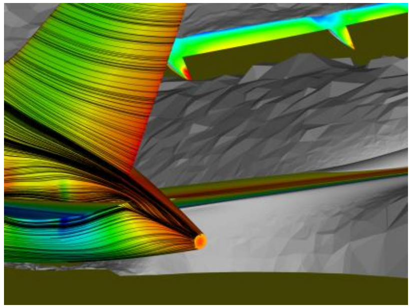
**Leverage Community Development – CFD Vision 2030**

# CbA Realization for Airplane Programs



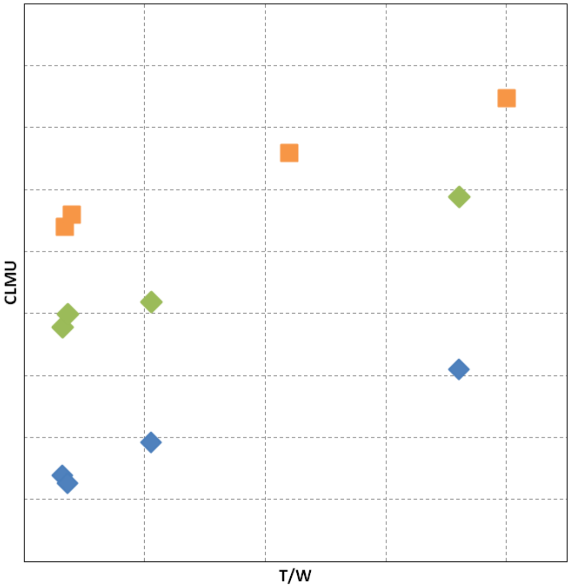
# Example
# Minimum Unstick Speed (VMU)

**14 CFR 25.107(d)** *VMU is the calibrated airspeed at and above which the airplane can safely lift off the ground, and continue the takeoff. VMU speeds must be selected by the applicant throughout the range of thrust-to-weight ratios to be certificated. These speeds may be established from free air data if these data are verified by ground takeoff tests.*

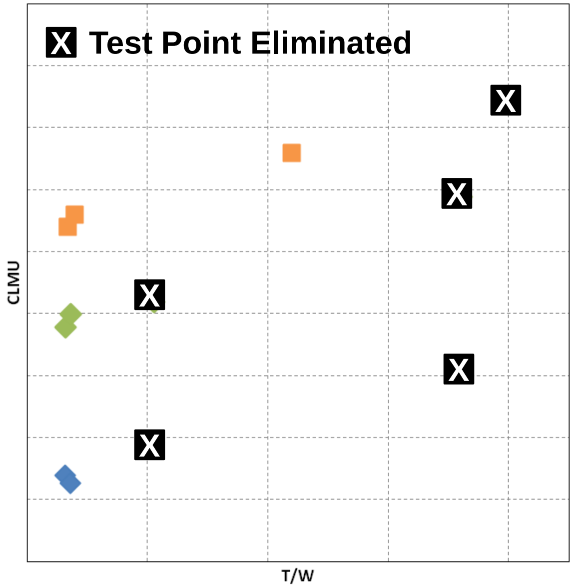


**OBJECTIVE: Show regulatory compliance replacing (particularly high risk) VMU flight testing with analysis-based data**

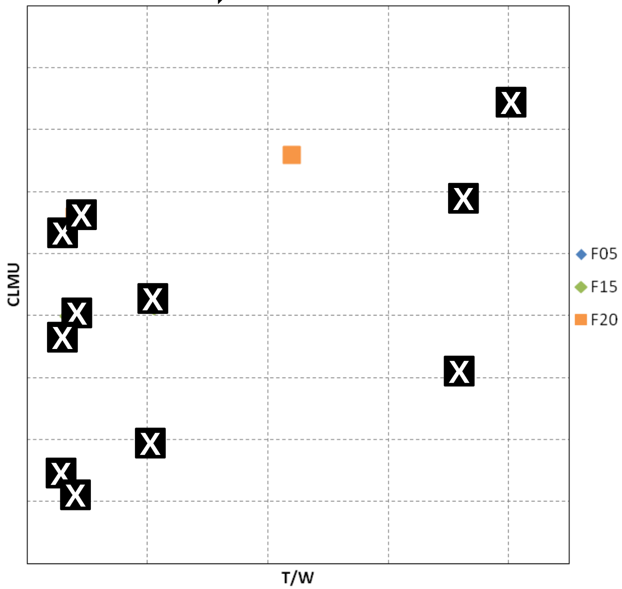
**Improvements to CFD predictive capability**




Notional flight test matrix




Elimination of some test points calibrating analysis (RANS CFD) to previous data




Matrix completely generated with analysis and **verified** at selected flight condition

# CFD Challenges for CbA

- To fully exploit CFD for airplane certification, coordinated progress in several technical areas, as detailed in the CFD Vision 2030 report, is needed…

## CFD Challenges…

| Vision 2030 recommendations | Challenge |
|---|---|
| 1, 2, 5 | Consistent predictive results for critical design and/or certification conditions –<br>• Source of **CFD error** not well understood (e.g. turbulence model, grid resolution, numerics, etc.)<br>• **Complex flow physics**, typically at extreme corners of the envelope |
| 1, 3, 5, 6 | **Computational efficiency** with throughput & resource constraints<br>• Expertise and level of effort vary amongst tools<br>• Extremely large models required for airplane-level analysis<br>• Large database coverage required |
| 1 | Manipulating **geometry** and developing appropriate **grid models** in a timely manner for complex airplane configurations |
| 1, 4 | Consistent **best practices** for complex configurations<br>• Turbulence models and settings<br>• Solver settings<br>• Gridding strategies |
| 1, 4 | Adequate **CFD validation datasets** that target relevant flow physics (e.g., high lift, etc.) |

## …are addressed in CFD Vision 2030

**Recommendations (NASA should…)**

1. …develop, fund, and sustain a base **research and technology (R&T) development** program for **simulation-based analysis and design technologies**.
2. …develop and maintain an **integrated simulation and software development infrastructure** to enable rapid CFD technology maturation.
3. …**utilize and optimize HPC systems** for large-scale CFD development and testing.
4. …develop and execute **integrated experimental testing and computational validation campaigns**.
5. …develop, foster, and leverage improved **collaborations** with key research partners and industrial stakeholders across **disciplines within the broader scientific and engineering communities**.
6. …attract world-class engineers and scientists.

# Strategy
## External Engagement

- **CbA Working Group formed** with representation from Boeing, Airbus, NASA, DLR, FAA, and EASA (from Forum 360 discussion at Aviation 2017)
  - White Paper (available January 2018) details motivation and proposed approach
- Objectives:
  - Build advocacy to **promote streamlined acceptance of CbA with regulatory agencies**
  - Establish an **AIAA Community of Interest (CoI)** to help develop a CbA **Best Practices** document
- Leverage **outside technology and funding sources** to accelerate progress where possible –
  - **CFD development –** Methods, turbulence modeling, etc.
  - **CFD validation** –
    - **High Lift Common Research Model (HL-CRM)**
    - Experiments targeting smooth body separation (NASA hump, Boeing proposed "Speed Bump", etc.

**CFD Vision 2030**

# Example CFD Validation Experiment
## High Lift Common Research Model (HL-CRM)

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Configurations** | Body<br>Wing (cruise)<br>Vert tail | Body<br>Wing (cruise)<br>Vert tail<br>Nacelle/pylon | Body<br>Wing (HL, cTE)<br>Vert tail<br>Slat (FS, brackets) | Body<br>Wing (HL)<br>Vert tail<br>Slat (FS, brackets)<br>Flap (FS, fairings) | Body<br>Wing (HL)<br>Vert tail<br>Slat (brackets)<br>Flap (fairings)<br>Nacelle/pylon | Body<br>Wing (HL)<br>Vert tail<br>Slat (brackets)<br>Flap (fairings)<br>Nacelle/pylon<br>Landing gear | Body<br>Wing (HL)<br>Vert tail<br>Slat (brackets)<br>Flap (fairings)<br>Nacelle/pylon<br>Chine | Body<br>Wing (HL)<br>Vert tail<br>Slat (brackets)<br>Flap (fairings)<br>Nacelle/pylon<br>Horiz tail | Body<br>Wing (HL)<br>Vert tail<br>Slat (brackets)<br>Flap (fairings)<br>Nacelle/pylon<br>Wingtip |
| | **Purpose** → | Validate CFD predictive capability on simplified configuration | Validate CFD predictive capability for engine installation effects on simplified configuration | Validate CFD predictive capability on slat-extended configuration | Validate CFD predictive capability on TO and landing configuration | Validate CFD predictive capability for engine installation effects on TO and landing configuration | Validate CFD predictive capability on TO and landing configuration with gear extended | Validate CFD predictive capability for engine chine effects on TO and landing configuration | Validate CFD accuracy for longitudinal stability on TO and landing configuration | Validate CFD accuracy for wingtip effects on nominal TO and landing configuration |
| | **Data** → | 1 2 3 4 5 | 1 2 | 1 2 3 4 | 1 2 3 4 | 1 2 3 4 5 6 | 1 2 3 4 | 1 2 3 4 5 | 1 2 3 4 | 1 2 3 |
| **CFD Studies** | **1** | Basic aero – Reynolds number effect, UQ | Basic aero – Reynolds number effect | Basic aero – Reynolds number effect | Basic aero – Reynolds number effect, TO and landing | Basic aero – Reynolds number effect, TO and landing, UQ | Basic aero – Reynolds number effect, TO and landing | Basic aero – Reynolds number effect, TO and landing | Basic aero – Reynolds number effect, TO and landing | Basic aero – Reynolds number effect, TO and landing |
| | **2** | Mounting effects | | | Mounting effects | Wing breakdown at stall | Landing gear noise | Wing breakdown at stall | Wake effects on tail | Slat trims/tip breakdown at stall |
| | **3** | T&I/Wall effects | | | T&I/Wall effects | | | | | |
| | **4** | | | Slat positioning inc | | Slat/flap positioning inc | | | | |
| | **5** | | | Inboard slat trim effects, strakelets | | Slat/flap trim effects | | | | |
| | **6** | | | | | Optimum positioning +/- dev | | | | |
| | **7** | | | | | Transition effects | | Transition effects | | |

TE = Trailing edge
cTE = cruise TE
FS = full-span
HL = high lift
H = horizontal

V = vertical
alt = alternate
Inc = increments
dev = deviation
UQ = uncertainty quantification

1 Forces/moments
2 Surface pressures
3 Surface flow viz (oil, tufts)
4 Off body velocity (QWSS, PIV)
5 Transition
6 Model deformation

**LONGER TERM STUDIES**
- Effects of icing
- Wake vortex
- Effect of Vortex Generators
- Effects of skin fasteners on Clmax
- Chine, wingtip design
- Wing buffet/high angle-of-attack
- Flow control

**DRAFT** 22 Oct 2017

BOEING