Advancing CFD Vision 2030

Progress and Future Plans within the Aerospace Community

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53rd Fluid Dynamic Conference / 39th Aerospace Numerical Simulation Symposium
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Outline

- **CFD Vision 2030**
- **Current Landscape**
- **AIAA CFD2030 Integration Committee**
- **Activities**
  - **Progress Towards CFD Vision 2030**
  - **CFD Grand Challenges**
- **Community Collaboration Opportunities**
  - **High Lift Common Research Model (CRM-HL) Ecosystem**
  - **High Lift Prediction Workshop**
  - **Certification by Analysis (CbA)**
- **Summary**

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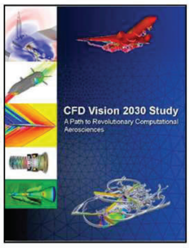
CFD Vision 2030

- **Emphasis on physics-based, predictive modeling**
  Transition, turbulence, separation, unsteady/time-accurate, chemically-reacting flows, radiation, heat transfer, acoustics and constitutive models
- **Management of errors and uncertainties**
  Quantification of errors and uncertainties arising from physical models, mesh and discretization, and natural variability
- **Automation in all steps of the analysis process**
  Geometry creation, meshing, large databases of simulation results, extraction and understanding of the vast amounts of information
- **Harness exascale HPC architectures**
  Multiple memory hierarchies, latencies, bandwidths, programming paradigms and runtime environments, etc.
- **Seamless integration with multi-disciplinary analyses and optimizations**
  High fidelity CFD tools, interfaces, coupling approaches, the science of integration, etc.



Slotnick, et al., "CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences," NASA/CR-2014-218178, 2014

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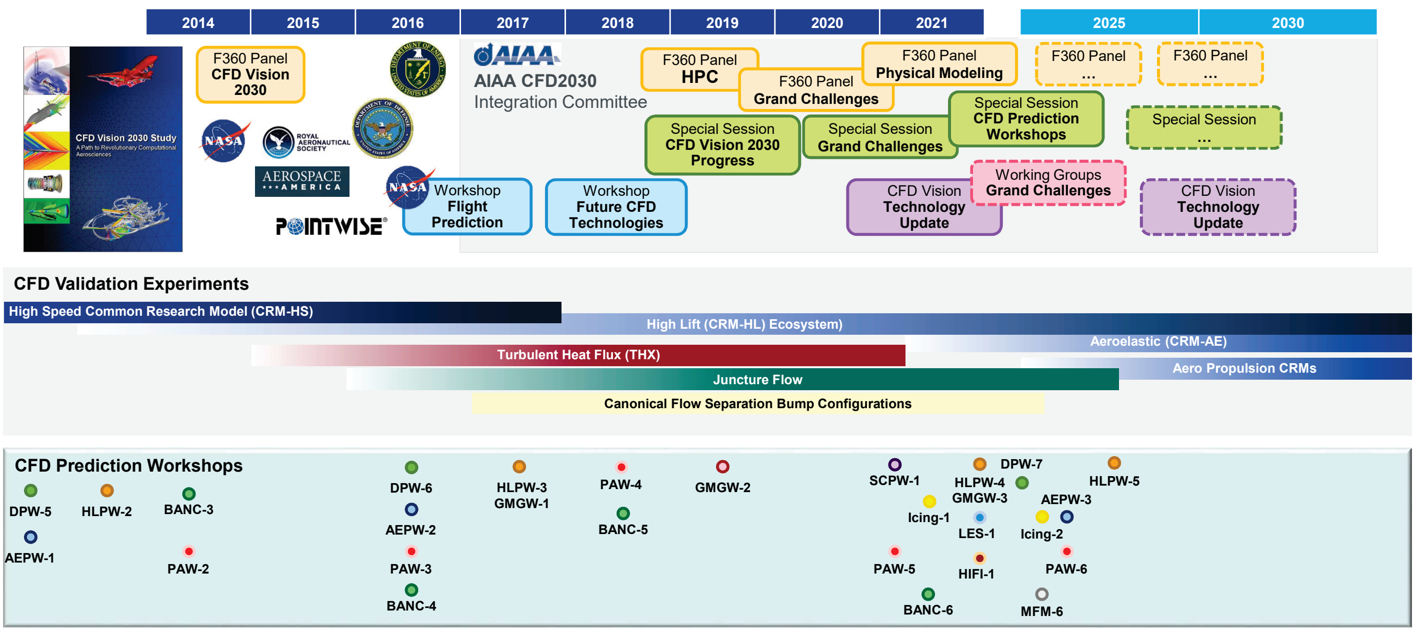
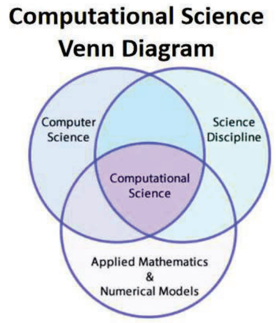
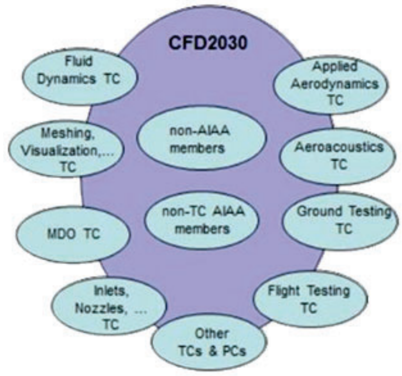
Landscape



CFD2030 Integration Committee (IC)

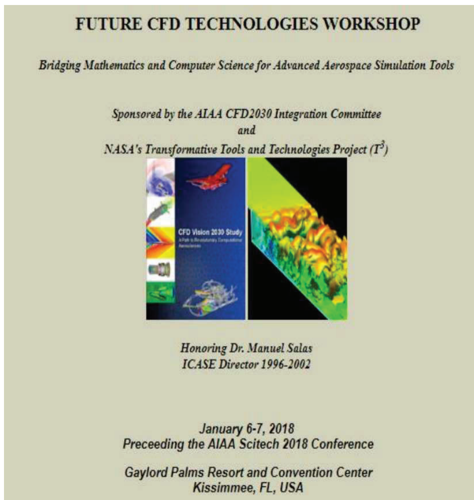
- Established in 2017
- Hosted by AIAA
- Paid membership in AIAA is not required for participating as a member of IC
- Objective: *Promote a **community of practice** engaged in developing methods, models, physical experiments, software, and hardware for revolutionary advances in **computational simulation technologies** for analysis, design, certification, and qualification of aerospace systems*
- http://www.cfd2030.com/index.html
- Chair: Dimitri Mavriplis, Univ. of Wyoming
- 44 current members (48% government, 36% industry, 16% academia)
  - All US-based, but the IC is open to international participation





Future CFD Technologies Workshop

- January 6-7, 2018 – Proceeded AIAA SciTech conference
  - **First event hosted by CFD2030**
- Objectives:
  - Bridging **fundamental disciplines** for advanced aerospace simulation tools:
    - – Applied Mathematics/Computer Science/Physical Modeling
  - **Coordination/collaboration/interaction** with government agencies/professional societies/technical communities
  - Raise awareness of importance of intersecting disciplines in Aerospace community
- Multiple sessions held over 2 days:
  - Basic research
  - Application drivers
  - Math/algorithmic drivers
  - Technology drivers
  - HPC
  - Emerging Technologies



Progress Towards CFD Vision 2030

Special Session: Progress Towards CFD Vision 2030

2019 (Aviation)

John Cavolowsky (NASA-TAC Program)
Jeffrey Slotnick (Boeing)
Gorazd Medic (UTRC)
Eric Nielsen (NASA-LaRC)
Scott Morton (CREATE-AV Program)
Dimitri Mavriplis (Univ of Wyoming)
John Chawner (Pointwise) / Nigel Taylor (MBDA)
Philippe Spalart (Boeing) / Michael Strelets (NTS)

Discussion Topics

- Role of NASA Aeronautics
- Industry (airplane/propulsion) perspectives
- Importance of HPC
- Geometry and Mesh Generation
- Turbulence prediction

Roadmap Update

Forum 360: HPC

2020 (SciTech)

Jeffrey Slotnick (Boeing, Moderator)
Roy Campbell (DoD-HPCMP)
Doug Kothe (DoE-ECP Program)
Eric Nielsen (NASA-LaRC)
Scott Morton (CREATE-AV Program)

Discussion Focus

- Drivers: Virtual testing, streamlined product acquisition
- Hardware: Shift to exascale, GPUs, load/system balancing, capability vs capacity
- Software: Toolkits→ stacks→ apps, strategic/long-term code refactoring,
- Algorithms: Asynchronous communication, concurrency, strong scaling, mixed-precision

Forum 360: Physical Modeling

2021 (Aviation) – *Planned*

Brian Smith (Lockheed Martin, Moderator)
Florian Menter (Ansys)
Oriol Lehmkuhl (BSC)
Meelan Choudari (NASA)
Venkat Raman (Univ of Michigan)

Discussion Focus

- Scale-resolving simulations and high-fidelity modeling of combustion and flow transition
- Error control and UQ
- Use of AI/ML and data fusion with limited test data
- CFD validation requirements

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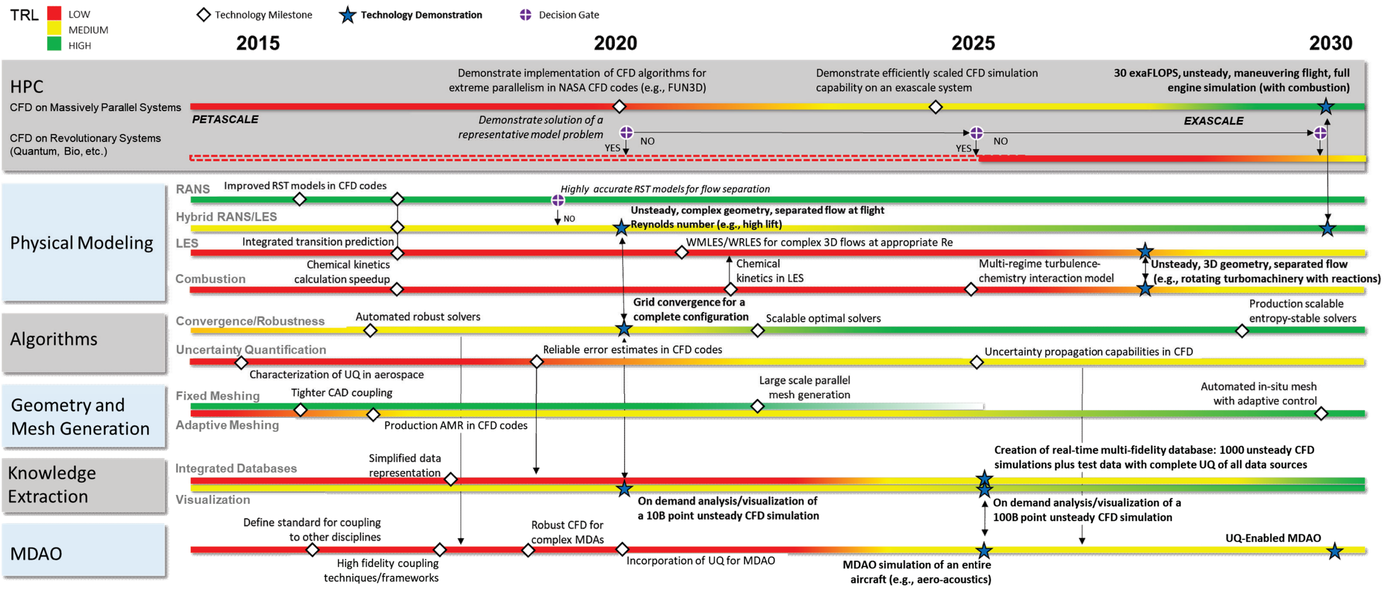
Original CFD Vision 2030 Roadmap (2014)



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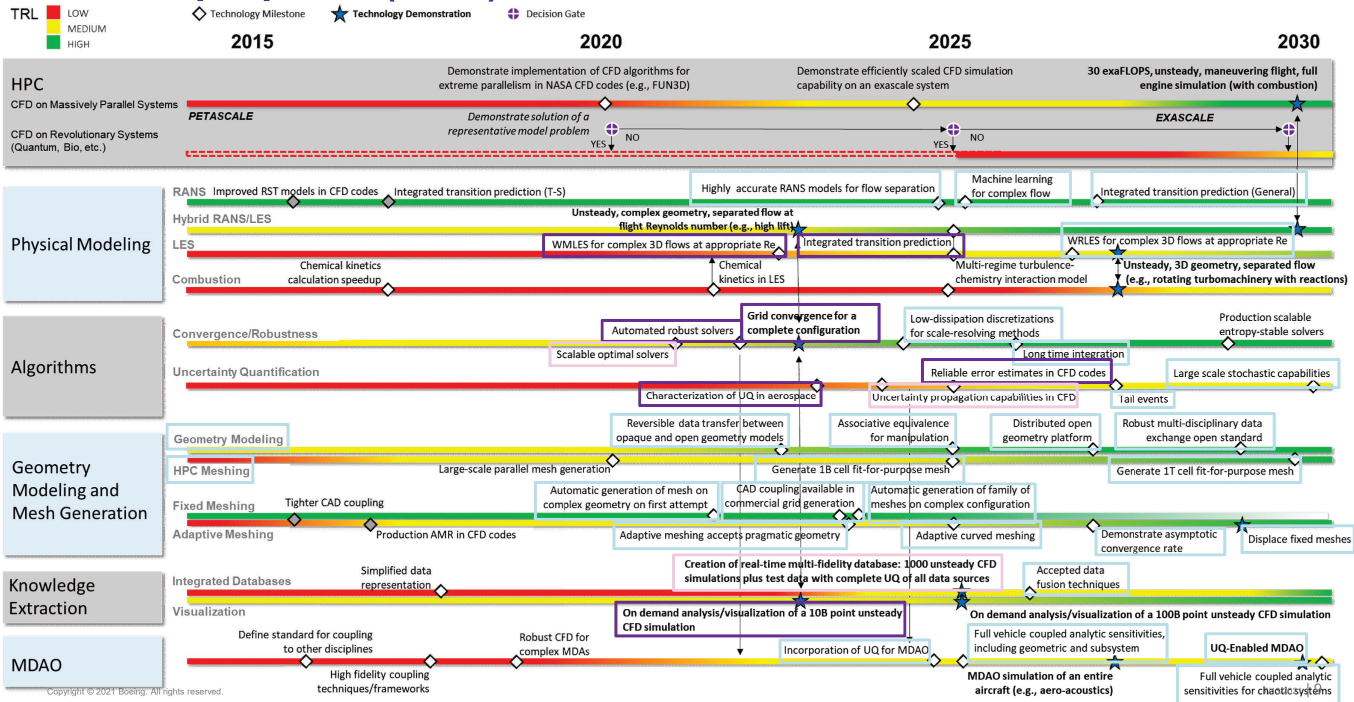
Roadmap Update (2021)

Milestone achieved
Deferred/reformulated
Accelerated
New



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CFD Grand Challenges

F360: Aerospace Grand Challenge Problems for Revolutionary CFD Capabilities

2020 (Aviation)

Juan Alonso (Stanford, Moderator)
John Cavolowsky (NASA-TAC Program)
Ray Gomez (NASA-JSC)
Micah Howard (Sandia)
Om Sharma (UTRC)
Steve Wells (Boeing)

Discussion Focus
- Need and value of Grand Challenge (GC) problems to drive technology innovation
- Overview of 4 GCs described: high-lift, full engine simulation, space access, and hypersonics
- Highlights key technical obstacles and the quantified benefit to industrial product development in overcoming those obstacles.

Special Session: CFD 2030 Grand Challenge Problems for Numerical Simulation in Aerospace Engineering

2021 (SciTech)

Jeffrey Slotnick (Boeing)
David Schuster (NASA-LaRC)
M. S. Anand (Rolls Royce)
Michelle Munk (NASA-LaRC)
Robert Meakin (CREATE-AV Program)
Doug Kothe (DoE-ECP Program)

Discussion Topics
- Described details of 3 GCs: high-lift, full engine simulation, and space access
- Highlighted key technical obstacles, and the quantified benefit to industrial product development in overcoming those obstacles.
- Experience with GCs within research and government labs

Working Groups
Grand Challenges

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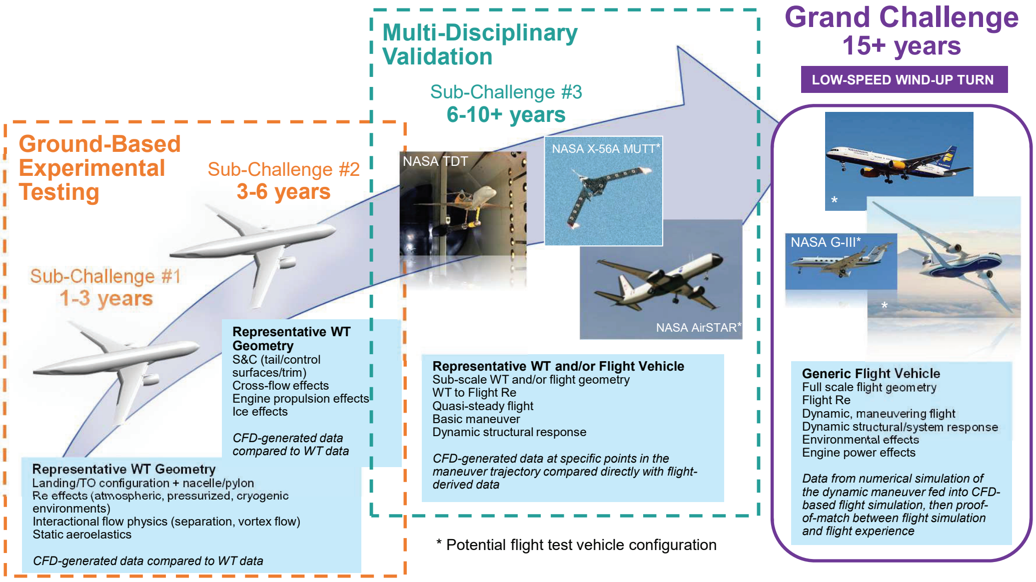
Advancing High Lift Aerodynamic Prediction
Series of Technical Challenges



Slotnick, J., and Mavriplis, D. "A Grand Challenge for the Advancement of Numerical Prediction of High Lift Aerodynamics", AIAA 2021-0955, https://doi.org/10.2514/6.2021-0955

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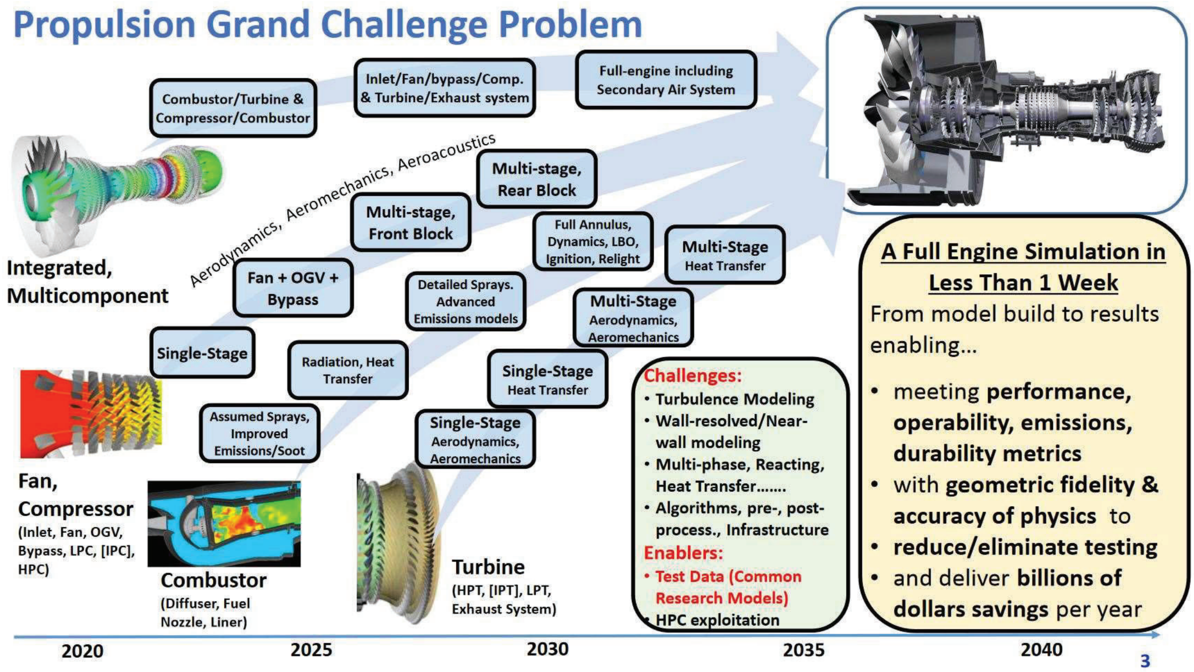
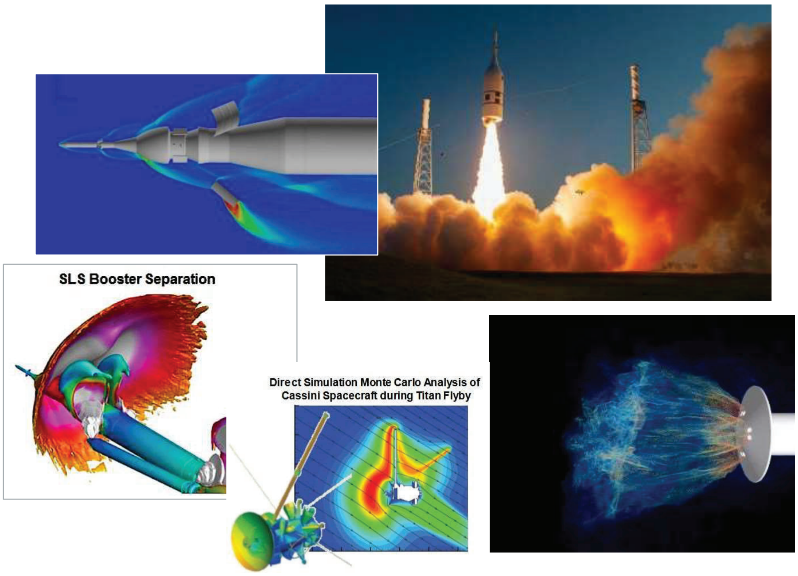
Propulsion Grand Challenge Problem



Anand, M. S., et al.,. "Vision 2030 Aircraft Propulsion Grand Challenge Problem: Full-engine CFD Simulations with High Geometric Fidelity and Physics Accuracy", AIAA 2021-0956, https://doi.org/10.2514/6.2021-0956

CFD-in-the-Loop Monte Carlo Flight Simulation for Space Vehicle Design

- Detailed analysis is required in two primary flight phases for space vehicles: **Ascent/Abort** and **Entry Descent and Landing (EDL)**.
  - Vehicles not optimized for aerodynamics.
  - Prediction of unsteady flows, plume/surface/aerodynamic interaction, shock effects, heating, and vehicle flight stability are prime requirements.
- Designers regularly deal with unsteady flow –
  - Steady CFD is prone to large variations.
  - Community increasingly turning to DES and LES-based methods for select cases.
- **CFD-in-the-loop MC simulation** has potential to significantly reduce design development time and lessen the cost and schedule impact of vehicle design changes and/or block upgrades
- Challenges to realizing this capability are significant and well-aligned with the goals proposed in the CFD Vision 2030 Study.
- The grand challenge is partially scalable and could be initially **demonstrated on only a segment of a flight simulation**.
  - EDL may be a good choice for demonstrating capability; several initial efforts in free-flight CFD EDL analysis are underway.
- **ROM** and **Machine Learning** techniques may be required for near-term implementation of CFD tools capable of simulating space vehicle flows of interest.



Schuster, D. "CFD 2030 Grand Challenge: CFD-in-the-Loop Monte Carlo Flight Simulation for Space Vehicle Design", AIAA 2021-0957, https://doi.org/10.2514/6.2021-0957

Community Collaboration Opportunities

Success requires **coordinated collaboration** within **engineering and simulation communities**

Courtesy NASA

Courtesy DLR

CFD Validation Partnerships

- Encourages pooling of critical resources (people, time, $) to develop appropriate configurations and/or platforms (e.g. CRM-HL)
- Drives community consensus on data requirements (type, location, etc.)
- Enables joint sharing of data and lessons learned
- Establishes steering of future CFD validation activities

CFD Prediction Workshops

- Growing number within aerospace community – several (e.g. HLPW) directly address issues associated with Grand Challenges (e.g. high lift GC)
- Focuses attention on specific problems of interest
- Encourages newcomers to get involved
- Increasingly tied to the development and testing of common research models (e.g. CRM-HL)

Future Activities

- Increasing emphasis on engine/propulsion simulation technologies → CRMs, workshops
- Integration of simulation and test data to enhance/accelerate product development
- "Digital Flight" workshops focusing on multi-disciplinary coupling strategies using building block approaches
- Formation of Grand Challenge Working Groups

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High Lift Common Research Model (CRM-HL) Ecosystem

- **Community-sourced** collaboration of international partners established in 2018
- **Partners fund activities** within the ecosystem (e.g. building/testing wind tunnel models, providing flow measurement technology, etc.) and **share the results** (e.g. test data, CFD results, etc.)
- Partners decide if/when to make any of the **data publically available** (e.g. for community workshops)
- **~12 organizations** from industry, government, and academia, representing 5 countries (US, UK, France, Germany, Japan)
- Serves as an **effective example** for future community collaboration efforts

Lacy, D. and Sclafani, A, "Development of the High Lift Common Research Model: A Representative High Lift Configuration for Transonic Transports" AIAA-2016-0308, https://doi.org/10.2514/6.2016-0308.

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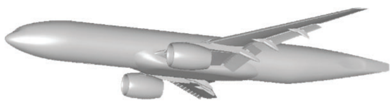
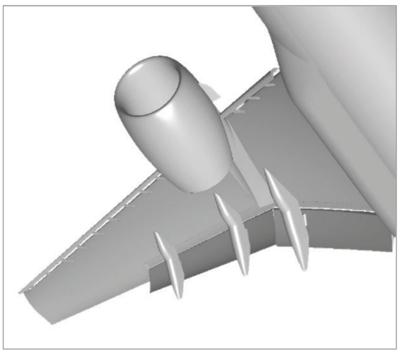
High Lift Common Research Model Ecosystem – Benefits





- Provides **industry-relevant** configuration(s) and consistent models.
- Enables **direct assessment and comparison** between CFD flow solvers and modelling approaches.
- Provides a **common standard** to assess the predictive capabilities of emerging computational tools.
- With proper controls, enables the design and fabrication of nearly **identical models in multiple facilities** (for data repeatability).
- Provides a challenging open-source configuration(s) to demonstrate **advanced measurement and sensing techniques**
- Provides a **freely-sharable geometry**, which enables new, and strengthens existing, partnerships to accelerate technology development.
- Provides a geometrically-relevant testing platform to jointly develop, assess, and share **pre-competitive aerodynamic technology** (e.g. Active Flow Control, noise, etc.) with external partners (e.g. NASA, etc.)
- Drives development of enabling technologies which provide indirect benefits, like improved **test facility capability/utilization** and **workforce development** (e.g. industry/university collaboration).

High Lift Common Research Model Ecosystem – Test Plan

June 2021

NASA 10% SS (14x22/Q, 1atm / 3atm)
- Confirm CRM-HL design features
- Data for reference configurations
- NASA research (AFC, noise)
- Tie in to NTF-derived Re # trend data

NASA 5.2% SS cryo (NTF/ETW/others)
- Primary model for Re # trends
- SS/FS model issues deemed Re # dependent
- Wall effects
- NASA research (Flow measurements, AM, others)

NASA 2.7% SS/FS cryo (NTF/ETW/others)
- SS/FS model issues deemed Re # dependent
- NASA research (Flow measurements, AM, others)

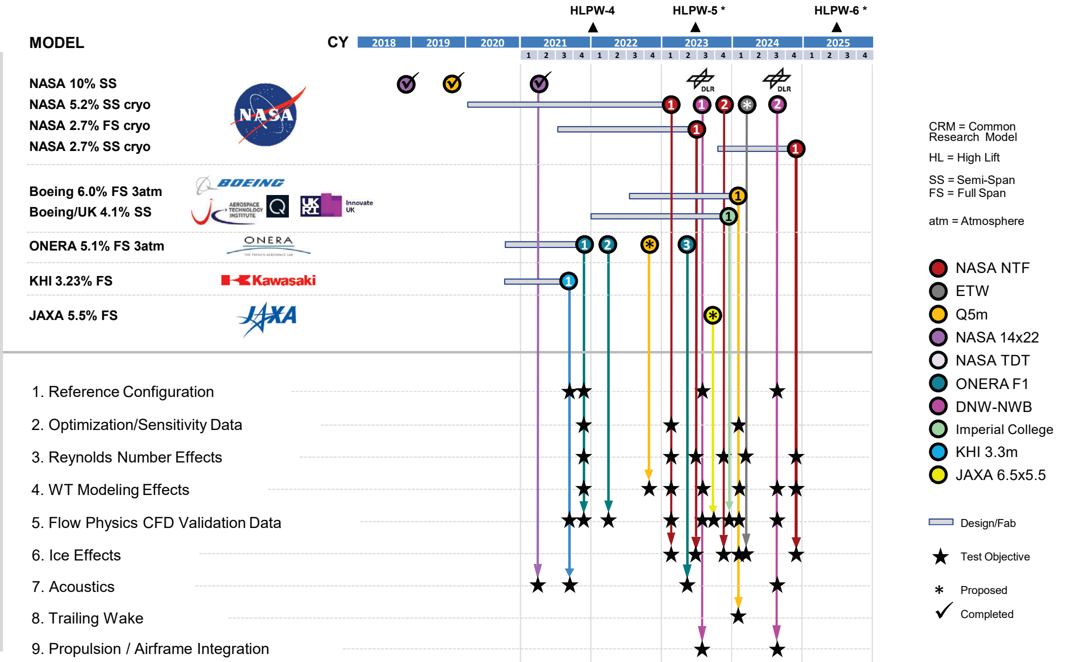
Boeing 6.0% SS/FS 3atm (Q/F1/others)
- Configuration variation data
- SS/FS model issues
- Tie in to NTF-derived Re # trend data
- Mounting system effects (T&I)
- Wall effects (collaboration with ONERA)
- Configuration-level PIV data

Boeing/UK 4.1% SS (Academic)
- Flow measurement technology development
- Platform for UK aerodynamic research

ONERA 5.1% FS 3.85atm (F1/Q)
- Wall effects (collaboration with QinetiQ)
- Exploit unique data collection opportunities
- Tunnel Standard Model

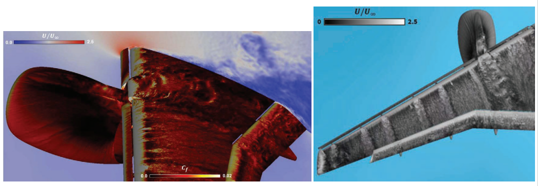
KHI 3.23% FS
- Aerodynamic and noise research
- Tunnel Standard Model

JAXA 5.5% FS
- CFD validation
- Aerodynamic research
- Tunnel Standard Model



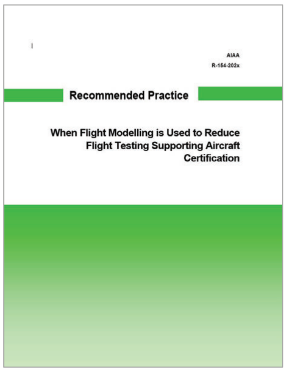
4th High Lift Prediction Workshop (HLPW-4)

- Closely aligned with geometry/mesh generation community (GMGW)
- First in series to utilize CRM-HL configuration data **directly from ecosystem testing**
  - NASA 10% semi-span model tested in QinetiQ in 2019
  - Test cases focus on flap effectiveness, CLmax
- New approach – accelerate learning through collaborative **Technology Focus Groups (TFGs)**
  - Geometry
  - Fixed Grid RANS
  - Adaptive Meshing RANS
  - Higher-order CFD
  - Hybrid RANS-LES
  - WMLES
- Emphasis on in-tunnel simulations using "more complete" WT facility CAD definitions and run procedures



https://hiliftpw.larc.nasa.gov

Certification by Analysis – Recent Community Efforts



AIAA-hosted Community of Interest (CoI)

- Started in 2018
- Report published in 2021
- International participation between industry, government research labs, academia, and regulatory agencies (50+ contributors)
- 6 recommended practices identified

American Institute of Aeronautics and Astronautics, "**When Flight Modelling Is Used to Reduce Flight Testing Supporting Aircraft Certification**," Reston, VA, R-154-2021.

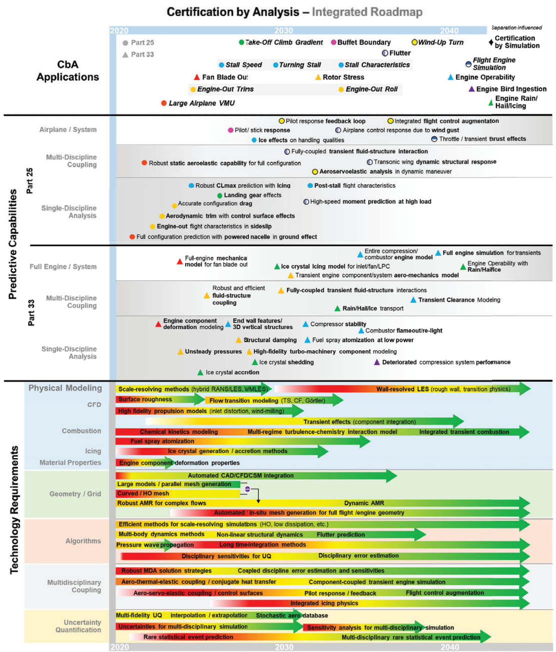
NASA Research Announcement (NRA) – "CbA2040"

- Awarded to Boeing in 2018
- Report published in 2021
- Coordination between industry, government research labs, academia, and regulatory agencies through online survey and technical workshop
- Technology roadmap developed
- 9 technical / logistical / programmatic recommendations

https://ntrs.nasa.gov/citations/20210015404

CbA Vision 2040

- The ability to numerically simulate the **integrated system performance and response of full-scale airplane and engine configurations** in the flight and/or ground-test environment in an accurate, robust, and computationally efficient manner.
- The development and implementation of quantified **flight and engine modeling uncertainties** to establish appropriate confidence in the use of numerical analysis for certification.
- The rigorous **validation of flight and engine modeling capabilities** against full-scale data from critical airplane and engine testing.
- The use of flight and engine modeling to enable **Certification by Simulation**.



Summary

- An **AIAA Integration Committee (CFD2030)** has been established to promote and advance the findings and recommendations from the CFD Vision 2030 report.
- CFD2030 actively **engages the aerospace community** through **AIAA-sponsored panel discussions and special sessions** on topics directly related to CFD Vision 2030 goals.
- The CFD Vision 2030 roadmap has been **updated to reflect progress to date**.
- Several **Grand Challenges (GCs)** in key focus areas have been developed and published. Working groups to drive progress towards the GCs will be forming in the near future.
- **CFD validation** collaborations, in combination with **CFD prediction workshops** and focused **technology roadmap development (CbA)**, are being established to accelerate learnings and progress.

- The CFD2030 IC steering committee **strongly encourages international participation** to help shape and drive efforts to advance CFD simulation technology
  - Desire to leverage **specialized expertise and knowledge**
  - Desire to promote **cross-fertilization of ideas**
  - Desire to assist with **national activities (e.g. Japan CFD Vision 2040)**

BOEING