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
30 June 2021
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
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.

# Landscape

## CFD Validation Experiments

**High Speed Common Research Model (CRM-HS)**

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<th>Aerospace</th>
<th>Turbulent Heat Flux (THX)</th>
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<td>High Lift (CRM-HL) Ecosystem</td>
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## CFD Prediction Workshops

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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
- 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

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
# 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

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**Working Groups Grand Challenges**
Advancing High Lift Aerodynamic Prediction
Series of Technical Challenges

Sub-Challenge #1
1-3 years
Representative WT Geometry
Landing/TO configuration + nacelle/pylon
Re effects (atmospheric, pressurized, cryogenic environments)
Interactional flow physics (separation, vortex flow)
Static aerelastics
CFD-generated data compared to WT data

Sub-Challenge #2
3-6 years
Ground-Based Experimental Testing
Representative WT Geometry
S&C (tail/control surfaces/trim)
Cross-flow effects
Engine propulsion effects
Ice effects
CFD-generated data compared to WT data

Sub-Challenge #3
6-10+ years
Multi-Disciplinary Validation
Representative WT and/or Flight Vehicle
Sub-scale WT and/or flight geometry
WT to Flight Re
Quasi-steady flight
Basic maneuver
Dynamic structural response
CFD-generated data at specific points in the maneuver trajectory compared directly with flight-derived data

Grand Challenge
15+ years
Generic Flight Vehicle
Full scale flight geometry
Flight Re
Dynamic, maneuvering flight
Dynamic structural/system response
Environmental effects
Engine power effects
Data from numerical simulation of the dynamic maneuver fed into CFD-based flight simulation, then proof-of-match between flight simulation and flight experience

* Potential flight test vehicle configuration

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.

### Community Collaboration Opportunities

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

#### 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
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

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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

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1. Reference Configuration
2. Optimization/Sensitivity Data
3. Reynolds Number Effects
4. WT Modeling Effects
5. Flow Physics CFD Validation Data
6. Ice Effects
7. Acoustics
8. Trailing Wake
9. Propulsion / Airframe Integration

**Test Objective**

- **HLPW-4**
  - NASA 10% SS
  - NASA 5.2% SS cryo
  - NASA 2.7% FS cryo
  - Boeing 6.0% FS 3atm
  - Boeing/UK 4.1% SS

- **HLPW-5**
  - ONERA 5.1% FS 3.85atm

- **HLPW-6**
  - KHI 3.23% FS
  - JAXA 5.5% FS

**Proposed**

- NASA NTF
- ETW
- Q5m
- NASA 14x22
- NASA TDT
- ONERA F1
- DNW-NWB
- Imperial College
- KHI 3.3m
- JAXA 6.5x5.5

**Design/Fab**

- **HLPW-4**
  - CRM = Common Research Model
  - HL = High Lift
  - SS = Semi-Span
  - FS = Full Span
  - atm = Atmosphere

**Completed**

- NASA NTF
- ETW
- Q5m
- NASA 14x22
- NASA TDT
- ONERA F1
- DNW-NWB
- Imperial College
- KHI 3.3m
- JAXA 6.5x5.5

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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


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)**