CFD Vision 2030 Roadmap: Progress and Projections in 2026

Andrew Wissink - HPCMP CREATE

Andrew Cary - Boeing

Nicholas Georgiadis – NASA GRC

Brian Smith - Lockheed Martin Corporation

Nick Wyman – Cadence Design Systems

Z.J. Wang – U. Kansas

Bill Gropp – U. Illinois

Karthik Duraisamy – U. Michigan

Nathan Wukie – Air Force Research Lab

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Objective

Roadmap subcommittee tracks progress of the objectives set in the 2014 "CFD Vision 2030 study: A path to revolutionary computational aerosciences"

High Performance Computing

- GPUs
- Quantum

Physical Modeling

- RANS
- Machine Learning
- Scale Resolving LES
- Scale Resolving WMLES & HRLES
- Boundary Layer Transition
- Chemically Reacting Flows
- Turbulent Thermal Modeling

Algorithms

- Accuracy / Efficiency / Robustness
- Uncertainty Quantification

Geometry Modeling & Mesh Generation

- Geometry advances
- Mesh Generation

Knowledge Extraction & Agentic Workflows

- Data driven Methods
- Agentic Methods

Multidisciplinary Design Analysis & Optimization

- Frameworks, Standards, and Benchmarks
- Transient and Chaotic Sensitivities
- Towards Full-Vehicle MDAO

Paper has 130 references outlining progress in each of these technical areas between 2021-2025

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High Performance Computing

MILESTONES

Exaflop milestone achieved (2022)

- Frontier system, Oak Ridge National Lab, May 2022
- General Purpose Graphical Processing Units (GPUs) by NVIDIA and AMD enabled these speedups
- Most commercial and govt CFD solvers now have GPU-enabled versions

Rise of AI/ML increasingly driving large HPC deployments

- xAI system uses 100,000 NVIDIA H100 GPUs – 2X number of GPUs in El Capitan

Upcoming flagship GPUs lack FP64 altogether and enhance performance through 8, 16, and 32 bit floating point arithmetic

- Impact on CFD unknown; potential area of study

PROJECTION

Quantum computing will impact CFD over the next five years

- 4000 logical cubit quantum computer could outperform today's Exascale computers
- Production quantum systems today have up to ~1200 cubits
- Scientists have assembled experimental arrays exceeding 6000 physical cubits

Frontier supercomputer debuts as world's fastest, breaking exascale barrier

https://www.ornl.gov/news/frontier-supercomputer-debuts-worlds-fastest-breaking-exascale-barrier

Atom Computing Announces Record-Breaking 1,225-Qubit Quantum Computer

https://www.forbes.com/sites/moorinsights/2023/10/24/atom-computing-announces-record-breaking-1225-qubit-quantum-computer/

AIAA

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Physical Modeling – Progress RANS - ML

RANS Modeling

- Progress has slowed – mostly model enhancements to extend range of applicability
- RS Closure models have not reached routine application – marginal improvements for additional computational effort (2023 Milestone)
- Advances in developing adaptive modeling approaches that preserve agreement with canonical flows but enable adjustable parameters to match empirical separation data
  - GEKO (Menter)
  - Constrained Recalibration (Bin, Huang, Kunz, Yang)

Machine Learning for Turbulence Modeling

- Significant activity – hope for a modeling breakthrough
- Fully data driven approaches have been relatively ineffective
  - Can violate established turbulent canonical flows
  - Training and inference can be computationally intensive
- Field Inversion Machine Learning (FIML) – demonstrated on moderately complex cases
  - Show promise but can violate established turbulence relations
  - Can provide a poor model without sufficient data
- Promise for ML training of constrained models (GEK0-type)

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Physical Modeling – Scale Resolving Methods

Wall resolved LES (WRLES)

- Computational capacity has enabled extreme levels of complexity and resolution for frontier applications
  - 865B DOF for high pressure turbine
  - 100B for open fan blade
- Useful for fundamental flowfield investigation, but impractical for engineering design

Wall Modeled LES and WMLES

- Significant demonstrated progress on High Lift Configuration
  - Significantly improved accuracy, both approaches compared to RANS in flows with large regions of separation
  - Challenges remain for accurate prediction of smooth body separation
- WMLES is less accurate in less challenging, mostly attached flow application than RANS

PROJECTION

Scale resolved methods applications will continue to grow

- GPU HPC systems enable expanded use with reasonable turnaround
- Improved modeling approaches for WMLES will enable more predictive capability
- WRLES and DNS on frontier problems reveal flow physics, enable new modeling approaches inc ML

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Algorithms

MILESTONES

Wall-modeled large eddy simulation demonstrated for high-lift configurations (2024)

- Multiple research teams with different numerical methods (FV, FD, LB, FR) successfully predicted maximum lift for the benchmark problems of HLPW5
- Most predictions achieved good agreement with experimental data in lift, drag, and pitch moment.
- Pizza-slice separation patterns observed in experiments were correctly predicted with WMLES.

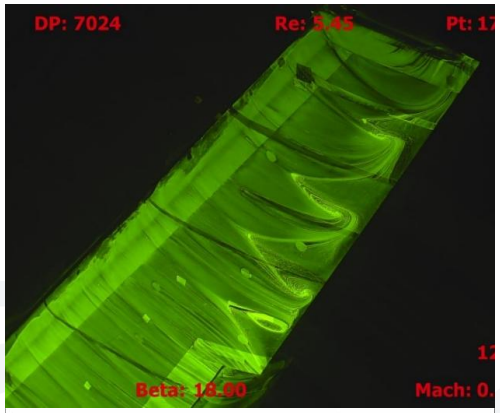
Wall-resolved large eddy simulation used for real-world flow problems

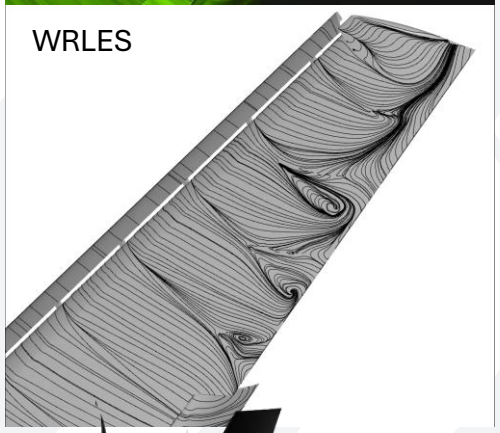
- GE Aerospace conducted noise predictions for an open fan at full flight scale on the 1st Exa computer, Frontier (2024).
- University of Kansas performed WRLES of high-lift Common Research Model on Summit. (2024)

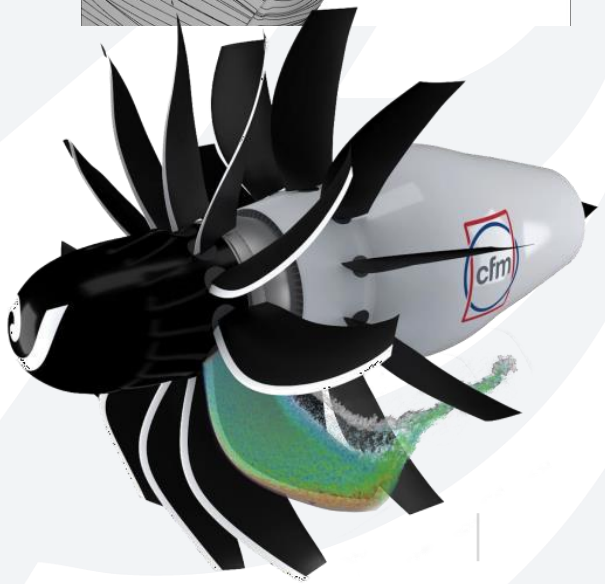
PROJECTION

More complex problems will be tackled & transition-resolving WMLES will be developed

- Full engine-wing integration at a flight Reynolds number will become feasible with WMLES
- WMLES approaches capable of resolving laminar-turbulent transition will be developed.







AIAA

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Uncertainty Quantification

MILESTONES

Multiple AIAA-sponsored activities have promoted UQ assessment of CFD/Aerospace

- FDTC UQ for Fluids DG sponsored 2 Community Challenge Problems presented at SciTech 2024 and SciTech 2026
- CbA Community of Interest hosting challenge for SciTech 2027
- APA/GT/Vision2030 ICE TAG-1 has been considering validation and error analysis
- Observing consistent conclusions/results from multiple methods at reasonable costs
-

Strong Solvers and Mesh Adaptation are driving out numerical uncertainty

- Model form uncertainty and parametric uncertainty still remain
- Multiple solutions add questions
- May need to look at approaches that do not decompose uncertainty

PROJECTION

AI/ML Surrogate models built upon CFD results will need to provide UQ estimates

- Already seeing some of this being done; many similar approaches between ML & UQ
- May push the overall CFD community to revisit errors and uncertainty

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Geometry and Mesh Generation

MILESTONES

Automated geometry preparation and meshing achieved (2022/2024)

- HighLiftPW-4/ Geometry-MeshGenerationW-3
  - Automated simulation preprocessing of complex CAD
  - RANS mesh families, High-Order, Hybrid RANS/LES, WMLES
  - RANS meshes in excess of 1B cells
- HLPW-5 demonstrated automated processing of 4 configuration build up models
- Massively parallel meshing algorithms for LES
  - Octree with immersed boundaries, clipped-Voronoi

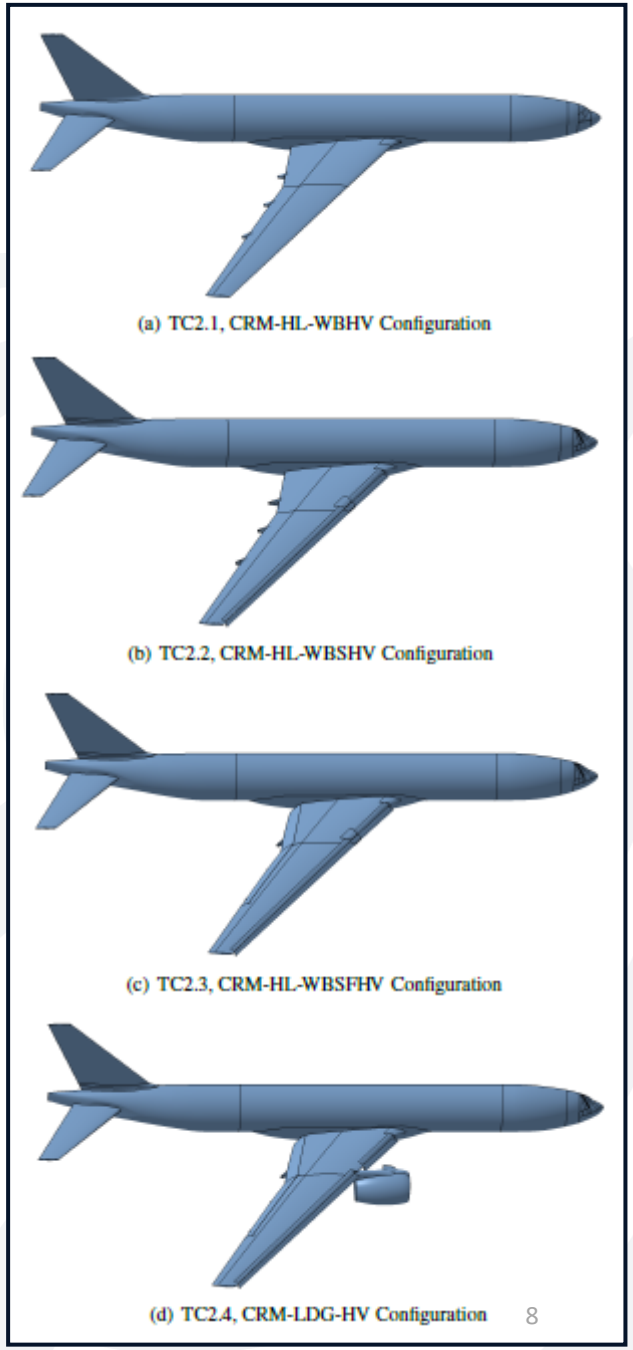
AI/ML influences

- Increased throughput needed to provide training databases
- AI assistants improve geometry and meshing tools UX
- Geometry definition compatible with generative AI
  - Implicit geometry / spatial occupancy

PROJECTION

AI/ML will significantly reduce TAT for geometry preparation and meshing

- Agentic tools now in late-stage development will provide point automation
- Agent of Agents will allow workflow automation



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Knowledge Extraction & Agentic Workflows

MILESTONES

Databases developed to promote AI-based reduced-order, data-driven, and physics-based models of common fluid-flow problems

- 2023 AIAA reduced complexity modeling repository – LES, DNS, PIV – U. Mich (12TB)
- 2025 UniFoil airfoil database – 500K RANS transitional and fully turbulent cases
- 2026 1800 WMLES cases of the CRM-HL model – available through AIAA HLPW

Agentic systems developed that automate workflows

- 2022 ChatGPT LLM released by OpenAI
- 2025 OpenFOAMGPT multi-agent system – Retrieval-Augmented Generation (RAG) planner, retrieval, executor, monitor, checker, and reporter
- Press releases and blogs from commercial CFD tools describe new agentic workflows

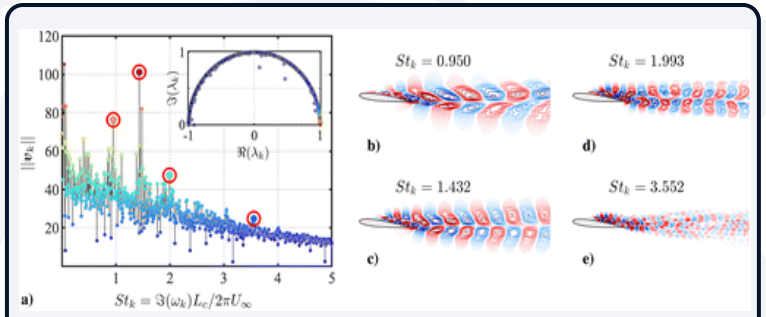
PROJECTION

CFD will increasingly become a key data generator for Physical AI

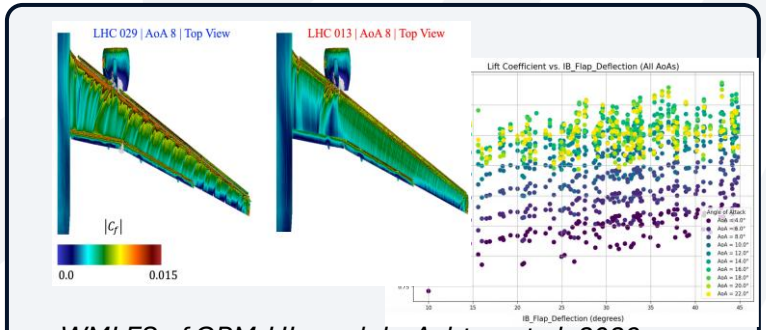
- High fidelity models will augment images and sensor input used today

Pace of progress in agentic CFD workflows will increase

- Multi-agent systems will support case setup, error recovery, post-processing, provenance capture, and database interrogation



Dynamic Mode decomposition – Towne et al, 2023



WMLES of CRM-HL model – Ashton et al, 2026

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Multidisciplinary Design Analysis & Optimization

MILESTONES

High-fidelity coupling techniques/frameworks (Target: 2017)

- Mphys: a Modular Multiphysics Library for Coupled Simulation and Adjoint Derivative Computation (Yildirim et al., 2025)
- FUNtoFEM: High-fidelity Aerothermoelastic MDAO (Kiviaho et al. 2017, Engelstad et al. 2023)
- AFRL & Northrop Grumman: High-fidelity, coupled sensitivities on industry relevant applications (Quantifying Utility of Aerospace Derivatives, 2023)

MDAO simulation of an entire aircraft (Target: 2025, Progress…)

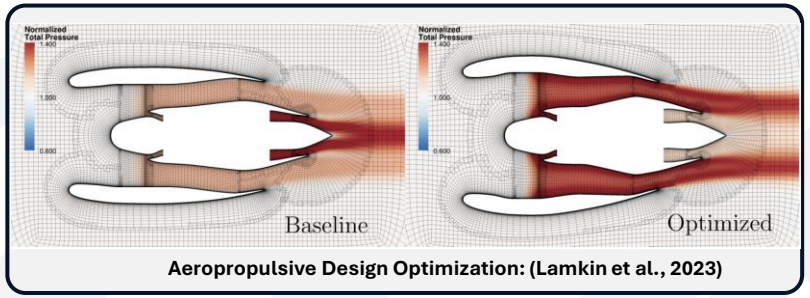
- **NASA ULI: Academia, Industry:** Large-scale distributed multidisciplinary design optimization of the NASA lift-plus-cruise air taxi concept (van Schie et al., 2025)

PROJECTION

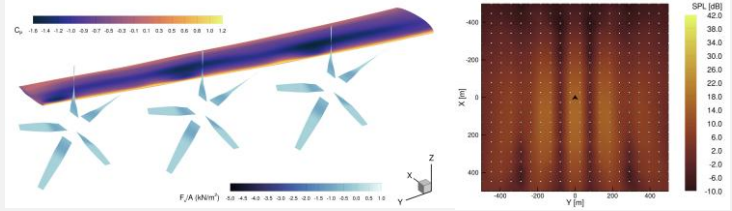
Standardization & industry adoption for recent MDO technologies will be critical areas of work over next 5-years

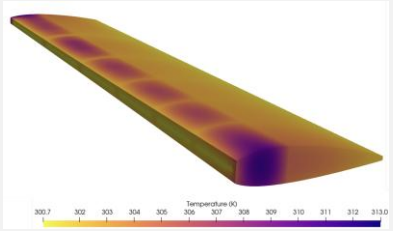
- AIAA MDO TC: Standard Analysis Interface Working Group
- AIAA MDO TC: MDO Benchmarks for Aircraft Design Working Group

Agentic-AI use-cases will emerge in a significant manner for MDO automation



Aeropropulsive Design Optimization: (Lamkin et al., 2023)


Aero-structural-acoustic: (Pacini et al., 2023)


Aero-thermo-elastic: (Kennedy et al., 2024)

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Concluding Remarks

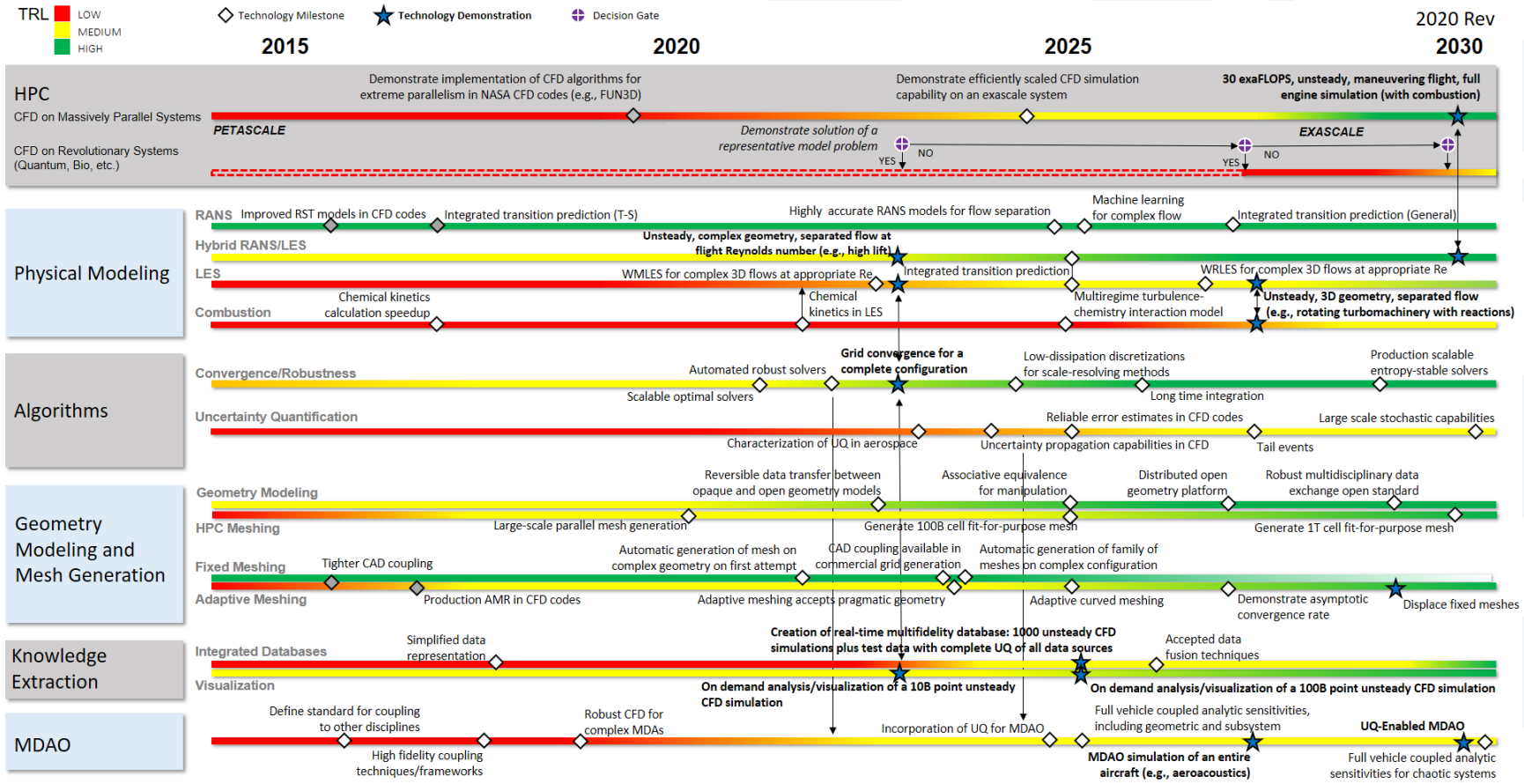
Paper has 129 references pointing to detailed descriptions of the developments described in this talk.

Annual roadmap updates

- https://cfd2030.com → Roadmap Updates

More Information

- aiaacfd2030@gmail.com



2020 revision of original Roadmap – published in "CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences" NASA/CR-2014-218178,

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Thank You

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