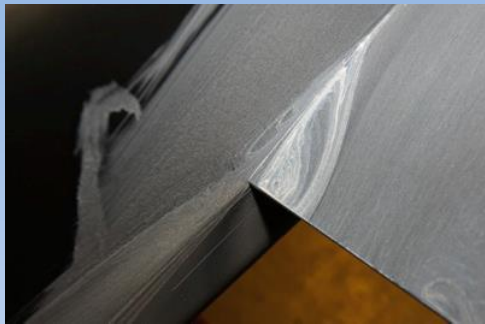
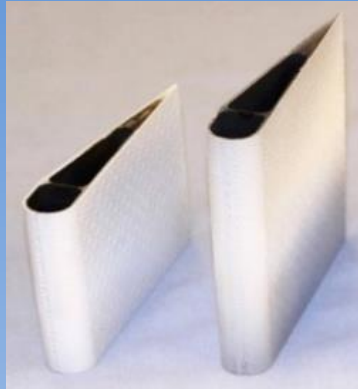
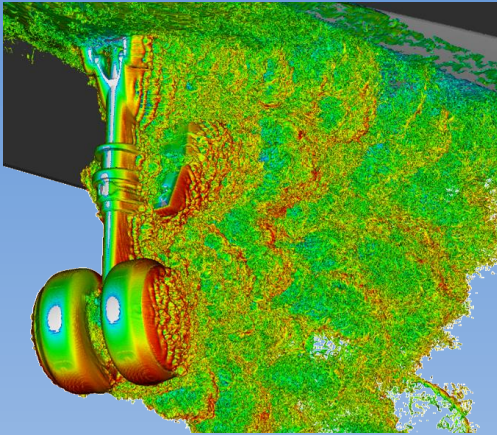
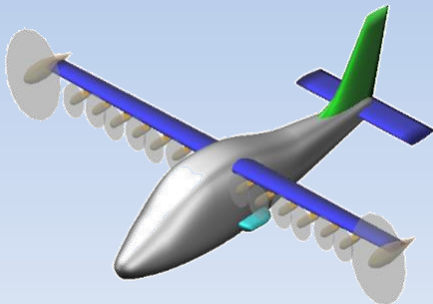
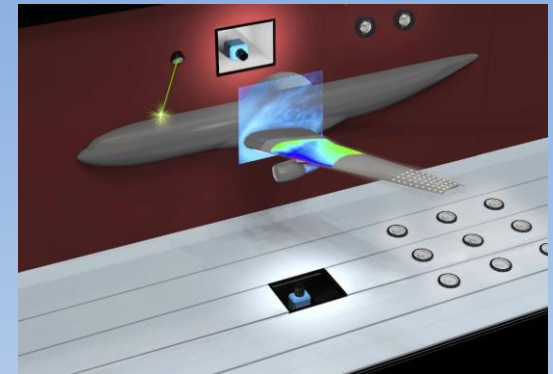




Transformational Tools and Technologies (T³) Project



Future CFD Technologies Workshop January 7, 2018



Michael M. Rogers, Project Manager
Dale Hopkins, Deputy Project Manager
Joe Morrison, Associate Project Manager



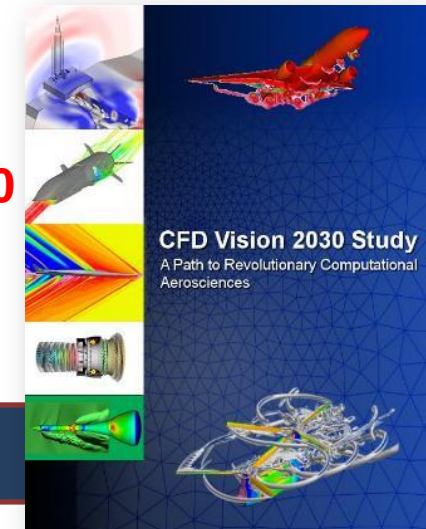
Host Center: Glenn

Partner Centers: Ames, Armstrong, Langley



Revolutionary Tools and Methods

- Physics-based Predictive Methods for Improved Analysis and Design
- Improved CFD Models and Algorithms
- MDAO/System Analysis Tools
- Materials and Structures Modeling and Simulation **Vision 2040**
- Combustion Modeling
- Validation Experiments



Critical Aeronautics Technologies

- High-temperature Engine Materials
- Multifunctional Materials and Structures
- Combustion Technologies
- Propulsion Controls
- Advanced Flight Controls
- Innovative Measurements



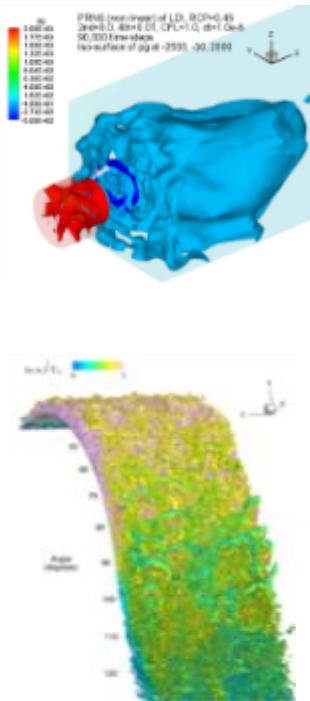
EBC-Coated CMC Vane



NiTiHf Shape Memory Alloy
torque tube actuators for UAV
flight demo

RCA Technical Challenge – Completes May 2018

Technical Challenge	Milestones
<p>Physics-Based Turbulence Models & Simulations:</p> <p>Identify and downselect critical turbulence, transition, and numerical method technologies for 40% reduction in predictive error against standard test cases for turbulent separated flows, evolution of free shear flows, and shock-boundary layer interactions on state-of-the-art high performance computing hardware.</p>	<p>FY17: 1. Evaluate advanced RANS and scale-resolving simulations capability for prediction of shock-boundary layer interactions. 2. Juncture Flow Experiment to obtain CFD validation data (complete first test entry of the 8% scale juncture flow model - slipped).</p> <p>FY18: 1. Evaluate large-eddy simulation codes for high Reynolds number flow separation prediction. 2. CFD Prediction Assessment Workshop. 3. Complete juncture flow experiment to obtain CFD validation data (second entry).</p>



Technical Areas and Approaches

- Development of more accurate physics-based methods (e.g. higher-moment closure, LES, hybrid approaches)
- Advanced numerical methods
- Transition prediction and modeling
- Validation experiments (Juncture Flow, THX, HL-CRM, Aeroelasticity,...)
- Multidisciplinary analysis and design (high fidelity)

What's Next?



Technology Development Roadmap

TRL ■ LOW
■ MEDIUM
■ HIGH

◇ Technology Milestone ★ Technology Demonstration + Decision Gate

2015

2020

2025

2030

HPC

CFD on Massively Parallel Systems

PETASCALE

Demonstrate implementation of CFD algorithms for extreme parallelism in NASA CFD codes (e.g., FUN3D)

Demonstrate efficiently scaled CFD simulation capability on an exascale system

30 exaFLOPS, unsteady, maneuvering flight, full engine simulation (with combustion)

CFD on Revolutionary Systems (Quantum, Bio, etc.)

Physical Modeling

Improved RST models in CFD codes

Highly accurate RST models for flow separation

Hybrid RANS/LES

Unsteady, complex geometry, separated flow at flight Reynolds number (e.g., high lift)

LES

Integrated transition prediction

WMLES/WRLES for complex 3D flows at appropriate Re

Combustion

Chemical kinetics calculation speedup

Chemical kinetics in LES

Unsteady, 3D geometry, separated flow (e.g., rotating turbomachinery with reactions)

Algorithms

Convergence/Robustness

Automated robust solvers

Grid convergence for a complete configuration

Multi-regime turbulence-chemistry interaction model

Production scalable entropy-stable solvers

Uncertainty Quantification (UQ)

Characterization of UQ in aerospace

Reliable error estimates in CFD codes

Uncertainty propagation capabilities in CFD

Large scale stochastic capabilities in CFD

Geometry and Grid Generation

Fixed Grid

Tighter CAD coupling

Large scale parallel mesh generation

Adaptive Grid

Production AMR in CFD codes

Automated in-situ mesh with adaptive control

Knowledge Extraction

Integrated Databases

Simplified data representation

Creation of real-time multi-fidelity database: 1000 unsteady CFD simulations plus test data with complete UQ of all data sources

Visualization

On demand analysis/visualization of a 100B point unsteady CFD simulation

On demand analysis/visualization of a 100B point unsteady CFD simulation

MDAO

Define standard for coupling to other disciplines

High fidelity coupling techniques/frameworks

Incorporation of UQ for MDAO

MDAO simulation of an entire aircraft (e.g., aero-acoustics)

UQ-Enabled MDAO



Some thoughts captured from workshop talks

CFD Vision 2030

- Strong community support – consensus helps advocacy
- AIAA CFD2030 Integration Committee
- CFD Vision 2030 roadmap updates? Machine Learning, Big Data, New Computing Technology (e.g., Quantum Computing, Neuromorphic)

Future Drivers

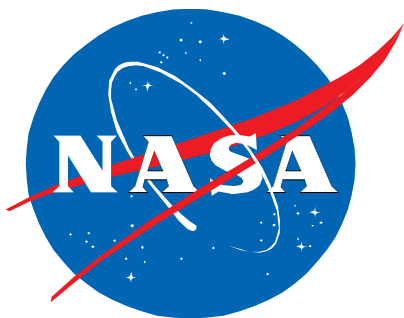
- Certification by Analysis, Prediction of full flight envelope
- Changing HPC architectures – Significant impact to CFD in the near future; Are we looking far enough ahead?
- System focus (or even System of Systems Focus?)

Road Blocks

- False prophets (but still working LES, HO DG, etc. – and LB)
- End of Moore's Law

Needs/Challenges

- MDAO, physics-based integrated-system simulation
- Integration of new advanced work from different fields into advanced computational frameworks
- Some familiar challenges (separation, transition, aeroelasticity, hypersonics)
- Time concurrency – $O(N \log N)$





Vision 2040 for Integrated, Multiscale Materials and Structures Modeling/Simulation NRA



Key Element Domains

- | | |
|--|---|
|  1. Models and Methodologies |  6. Data, Informatics, & Visualization |
|  2. Multiscale Measurement & Characterization Tools and Methods |  7. Workflows & Collaboration Frameworks |
|  3. Optimization & Optimization Methodologies |  8. Education & Training |
|  4. Decision Making and UQ |  9. Computational Infrastructure |
|  5. Verification & Validation | |

2040 Vision State

*A cyber-physical-social ecosystem that impacts the supply chain to **accelerate** model-based concurrent design, development, and deployment of materials and systems throughout the product lifecycle for **affordable, producible** aerospace applications*

Needed to overcome various gaps and challenges to achieve the fully integrated 2040 Vision end state

 Pratt & Whitney A United Technologies Company	NEXIGHT GROUP	 esi get it right®	 BlueQuartz Software
 BOEING	 Rolls-Royce	 UCSB UNIVERSITY OF CALIFORNIA SANTA BARBARA	 United Technologies Research Center

Phase II

Phase I

CFD Validation Experiments

- **Juncture Flow Experiment**

- Prediction of trailing edge corner separation a challenge
- First 14'x22' WT entry in November 2017
- Second entry in March 2018

- **Turbulent Heat Flux Experiment**

- Need experimental data for CFD of turbulent heat transfer

- **Shock Wave/Boundary Layer Interaction**

- Mach 2.5 Axisymmetric SWBLI (attached and separated)
- Mean and turbulent stress data

- **2D Flow Separation**

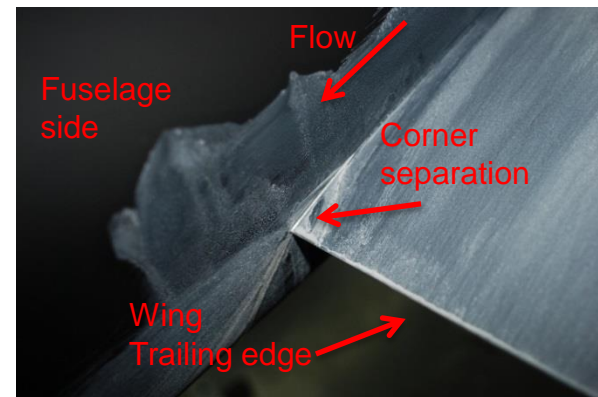
- NRA to Notre Dame (Flint and Corke)
- Data for attached and separated (incipient, small, large) flow

- **2D Compressible Mixing Layer**

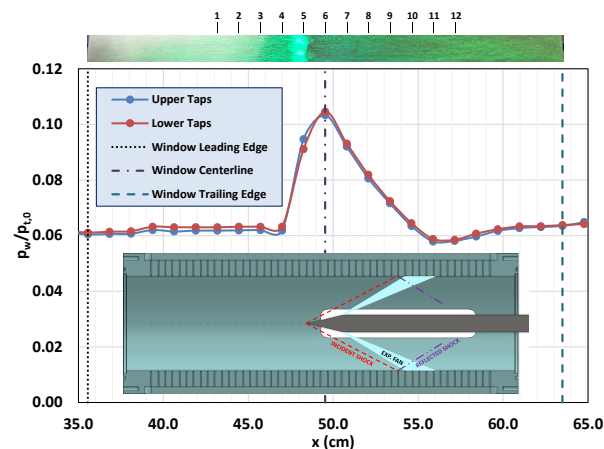
- NRA to U-Illinois (Dutton and Elliott)
- Full documentation of BC and mean/turbulence data

- **CRM in Fluid Dynamics Lab**

- Characterize on-body (e.g., skin-friction) and off-body (wake) flow field



Experimental surface flow visualization



Axisymmetric SWBLI – 13.5° Cone Angle

Each set of fringes is a C_f data point.

