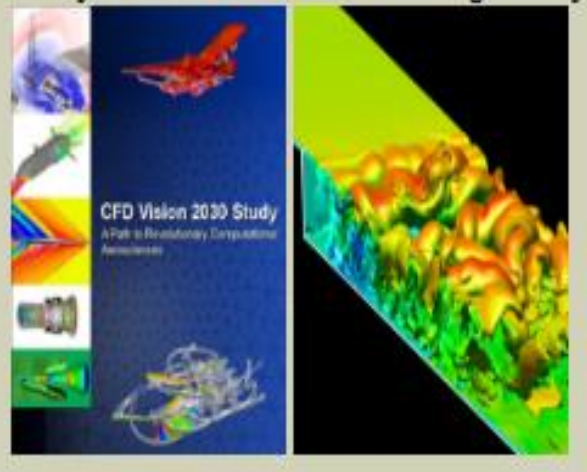
FUTURE CFD TECHNOLOGIES WORKSHOP

Bridging Mathematics and Computer Science for Advanced Aerospace Simulation Tools

Sponsored by the AIAA CFD2030 Integration Committee
and
NASA's Transformative Tools and Technologies Project (T^3)



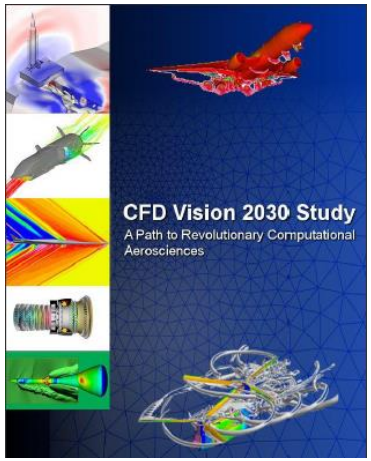
Honoring Dr. Manuel Salas
ICASE Director 1996-2002

January 6-7, 2018
Preceeding the AIAA Scitech 2018 Conference

Gaylord Palms Resort and Convention Center
Kissimmee, FL, USA

Motivation

- CFD2030 Integration Committee
  - Integrate activities across AIAA TCs and with outside institutions
- Formed in response to CFD2030 Vision Report and recommendations



AIAA
The World's Forum for Aerospace Leadership

June 5, 2017

CFD Vision 2030 Integration Committee (CFD2030 IC) Proposal

Points of Contact:

CFD Vision 2030 Study Sponsor, *Mujeeb Malik*, mujeeb.r.malik@nasa.gov
CFD Vision 2030 Study Project Manager, *Abdollah Khodadoust*, abdollah.khodadoust@boeing.com
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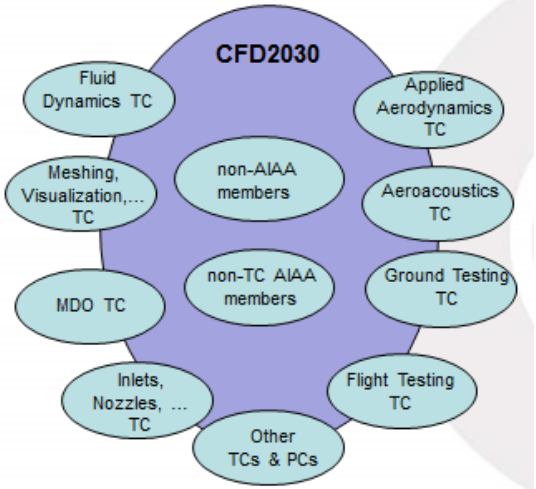
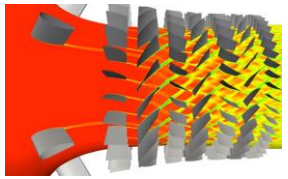
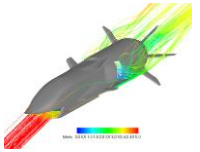
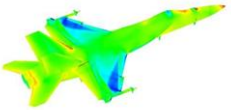
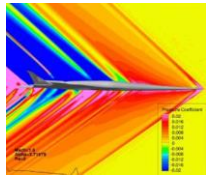
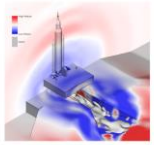
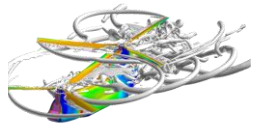
CFD Vision 2030 Study Subject Matter Expert, *Dimitri Mavriplis*, mavripl@uwyo.edu
CFD Vision 2030 Study Subject Matter Expert, *Dave Darmofal*, darmofal@mit.edu
CFD Vision 2030 Study Subject Matter Expert, *Juan Alonso*, jjalonso@stanford.edu



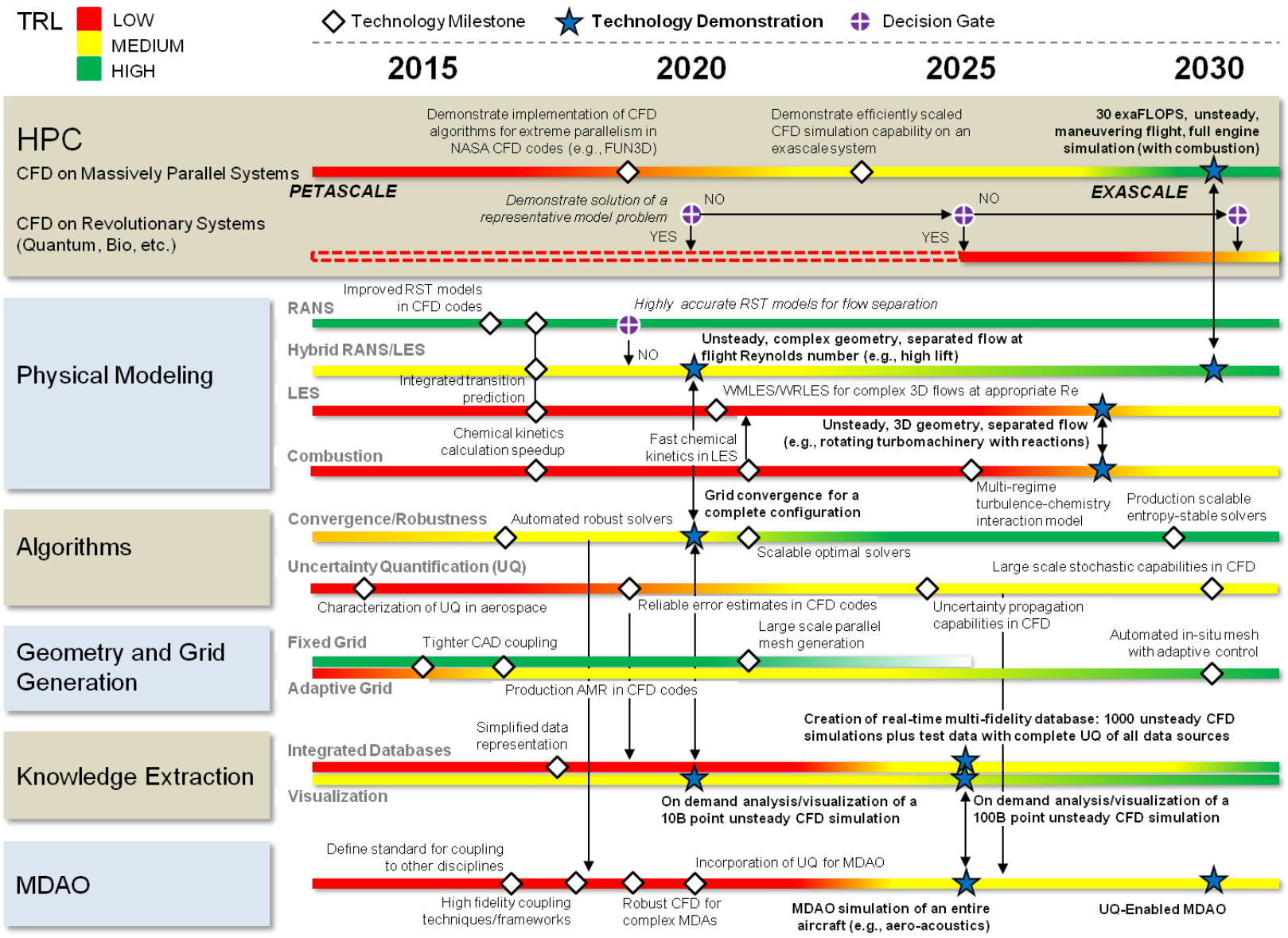
Vision of CFD in 2030

- **Emphasis on physics-based, predictive modeling**
  Transition, turbulence, separation, unsteady/time-accurate, chemically-reacting flows, radiation, heat transfer, and constitutive models, among others.
- **Management of errors and uncertainties**
  Quantification of errors and uncertainties arising from physical models (epistemic), mesh and discretization, and natural variability (aleatory) and their effect on important engineering quantities of interest.
- **A much higher degree of automation in all steps of the analysis process** Geometry creation, mesh generation and adaptation, large databases of simulation results, extraction and understanding of the vast amounts of information generated with minimal user intervention.
- **Ability to effectively utilize massively parallel, heterogeneous, and fault-tolerant HPC architectures that will be available in the 2030 time frame** Multiple memory hierarchies, latencies, bandwidths, programming paradigms and runtime environments, etc.
- **Flexible use of HPC systems**
  Capability- and capacity-computing tasks in both industrial and re environments.
- **Seamless integration with multi-disciplinary analyses**
  High fidelity CFD tools, interfaces, coupling approaches, etc.

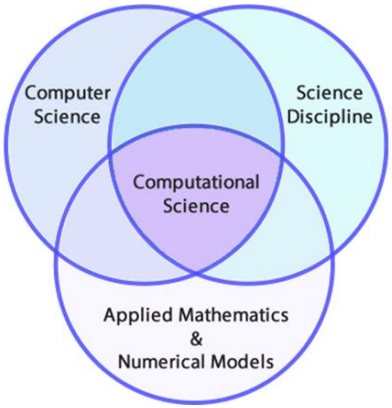





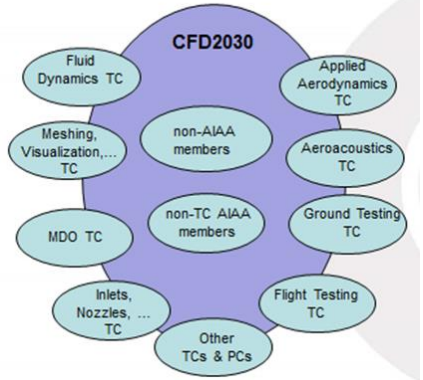



Technology Roadmap



CFD2030 IC





- Incredibly broad
  - Fundamental disciplines
  - CFD centric technologies
  - Aerospace needs and requirements

Physical Modeling
Validation Expts.
Applied Math
Computer Science
Machine Learning
Quantum Computing

Mesh Generation
AMR
Discretizations
Solvers
HPC

Practical CFD Codes
RANS, DES, LES
DPW, HLPW, AePW
Optimization
MDAO
UQ

Ground Testing
Flight Testing
Certification
Digital Twin

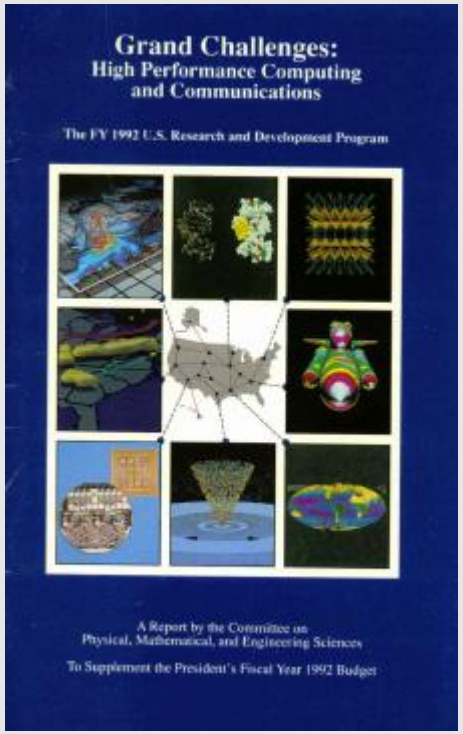
- Workshop focuses on contributions of fundamental disciplines

Workshop Objectives

- Bridging Fundamental Disciplines for Advanced Aerospace Simulation Tools
  - Applied Mathematics
  - Computer Science
  - Physical Modeling
  - Coordination/Collaboration/Interaction with
    - Other government agencies
    - Other professional societies
    - Other technical communities
- Raise awareness of importance of intersecting disciplines in Aerospace community

National/International Importance

- Important implications of Computational Science and Engineering (CSE)
  - Economic competitiveness
  - National Security
  - Scientific discovery
- Repeatedly addressed through national reports, thrusts and initiatives over the years



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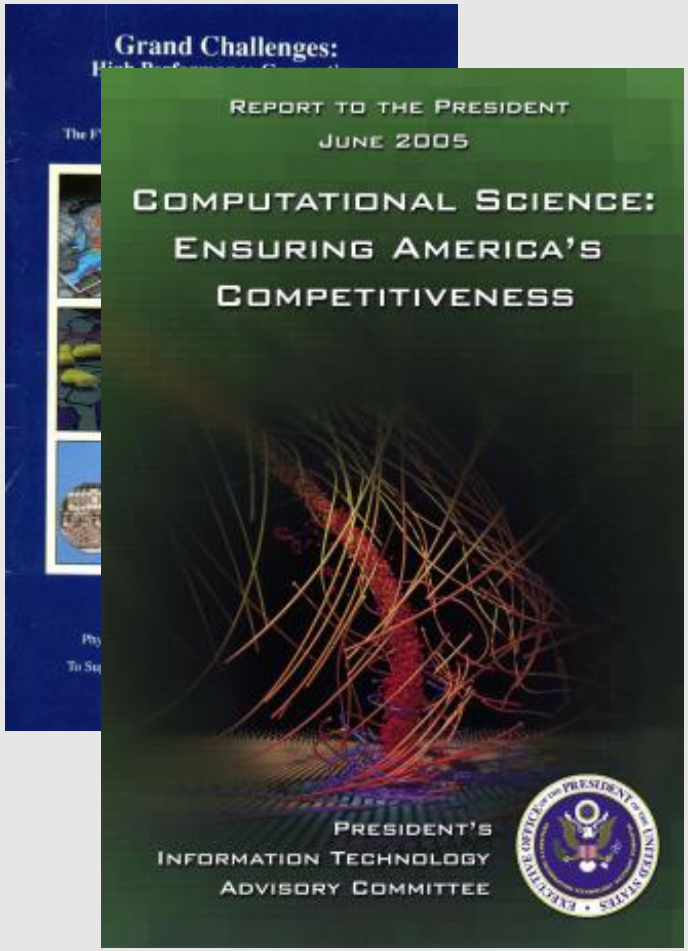

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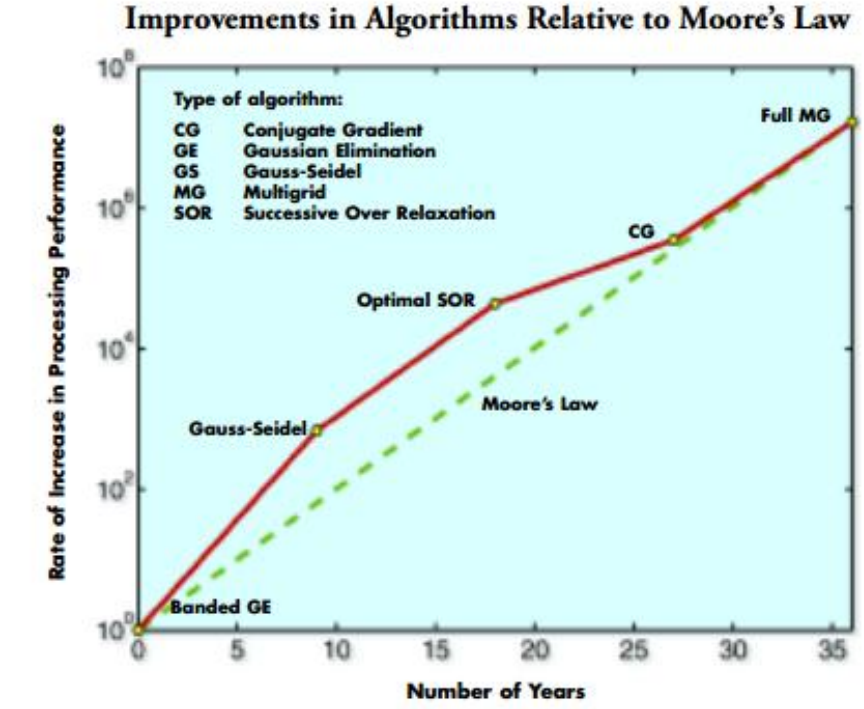
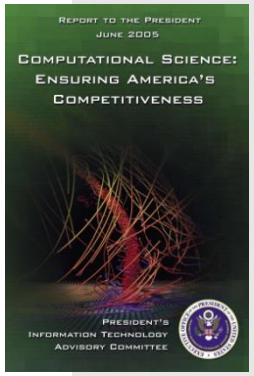
Develop Exascale Computer (1000 times faster than 2010) by 2020

Using Mathematics to Improve Simulation Capability



The relative gains in some algorithms for the solution of an electrostatic potential equation on a uniform cubic grid compared to improvements in the hardware (Moore's Law).



2005 PITAC Report

Moore's Law: Computer hardware speed doubles every 18 months

- **Algorithmic/Mathematical advances have improved simulation capability at similar rate as advances in computer technology**

National/International Importance

- Important implications of Comp. Sci. a
  - Economic
  - National S
  - Scientific
- Repeatedly through na thrusts and the years

The Lax Report (1982)

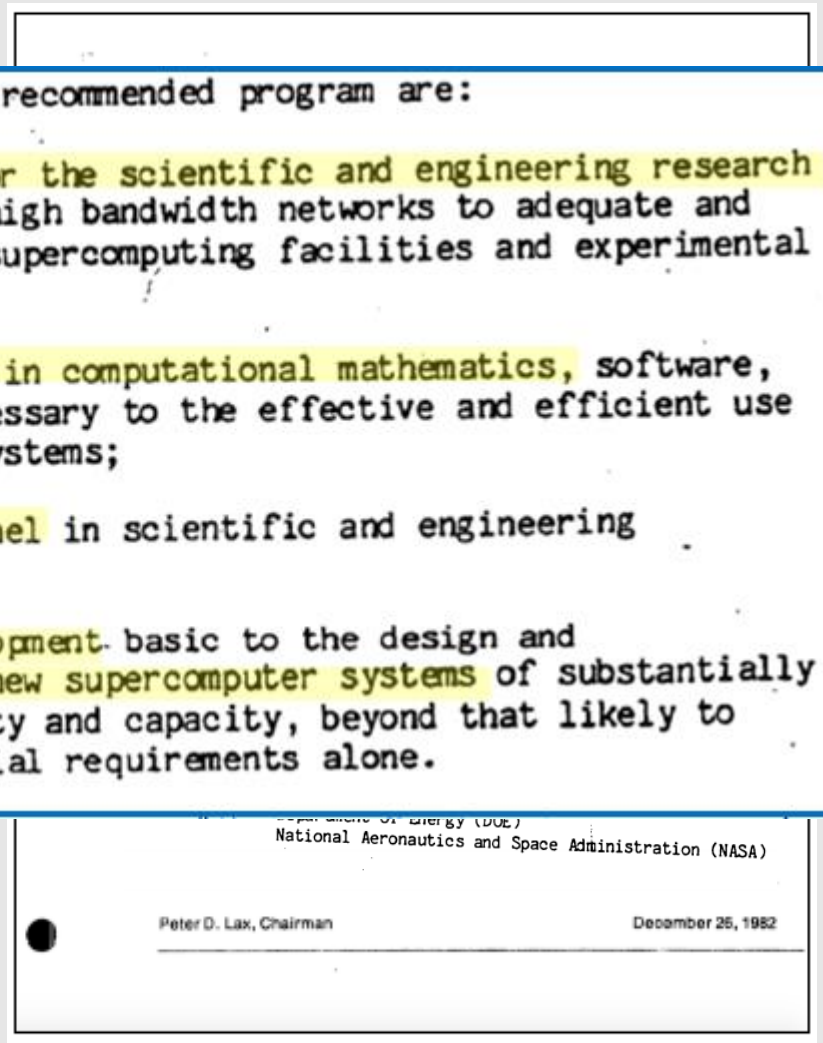
The four components of the recommended program are:

1. Increased access for the scientific and engineering research community through high bandwidth networks to adequate and regularly updated supercomputing facilities and experimental computers;

2. Increased research in computational mathematics, software, and algorithms necessary to the effective and efficient use of supercomputer systems;

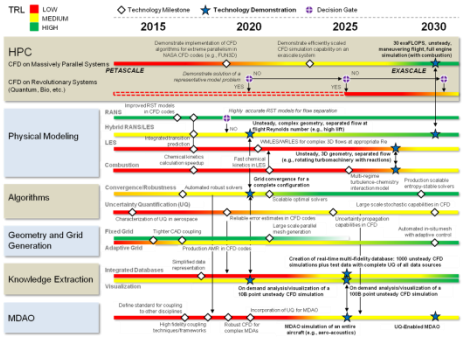
3. Training of personnel in scientific and engineering computing; and

4. Research and development basic to the design and implementation of new supercomputer systems of substantially increased capability and capacity, beyond that likely to arise from commercial requirements alone.



Challenges

- Maturation of CFD Capabilities leading to complacency
  - RANS plateau
  - Stagnation of capabilities (HLPW/DPW)
- Increasing segregation between Application (Aerospace Eng.) and fundamental science communities
- Significant investments outside of Aerospace not fully leveraged
  - DOE, NSF, NIST, International
- Current and upcoming challenges
  - Heterogeneous computing
  - Larger scale (asymptotic)
  - Multidisciplinary
- Updating CFD2030 RoadMap
  - Machine Learning
  - Big Data
  - Quantum Computing



Learning from Past Experiences

- A tribute to ICASE (1972-2002) which was exemplary in accomplishing these objectives in the past
  - Well aligned with the Lax Report
  - Highly successful at bridging fundamental research with aerospace objectives
  - Manny Salas ICASE Director, 1996-2002
- How to be long-term forward looking in a mission-focused (NASA) environment

Quotes

For the past 25 years ICASE has been one of the very few places where one could engage in “strategic” research—the type of scientific inquiry which has all the attributes of basic research but which has an application horizon in the not-very-far future. As a result ICASE has left its mark in many areas of aero-space applications**.** **--Saul Abarbanel, June 1997**

I wanted to add my own two cents about how significant ICASE was. To this day it is still the best example for the interaction of staff scientists and engineering and visiting faculty. With a robust visitors program, frequent seminars, and everyone sitting together, amazing things were accomplished. To me personally it showed me the best environment to work in. I am really grateful to my own advisor (Joe Oliger) who got me involved as a graduate student and then post-grad. **--Marsha Berger (December 2017)**

Summary

- Present broad range of technologies and include diverse points of view
  - Government program manager perspectives
  - Industry application and needs perspectives
  - Expert researcher technological perspectives
- Attempt to cover diverse set of emerging technologies
  - Representative talks for different areas
  - Cannot cover all aspects and include all major contributors
- Expect workshop to be unique in scope

Day 1: Saturday, 6th January 2018	
07:15 - 08:00	Continental Breakfast
08:00 - 08:30	Introduction and Workshop Objectives: Dimitri Mavriplis (University of Wyoming) and Mujeeb Malik (NASA Langley)
	Session 1: Application Drivers and Basic Research Session Chair: *Mujeeb Malik*
08:30 - 09:00	**"Future Directions in Computational Simulation to Enable Certification and Qualification by Analysis"** Abstract *Rob Gregg III and Jeff Slotnick (Boeing Commercial)* Bio
09:00 - 09:30	**"A Vision for the NASA Aerosciences Discipline Under the Agency's New Operating Model"** Abstract *Dave Schuster (NASA)* Bio
09:30 - 10:00	**"Towards Overcoming the LES Crisis"** Abstract *Rainald Lohner (Geroge Mason University)* Bio
10:00 - 10:30	Break
	Session 2: Math/Algorithmic Technology Drivers Session Chair: *Dimitri Mavriplis*
10:30 - 11:00	**"Implicit positivity-preserving high order discontinuous Galerkin methods for conservation laws"** Abstract *Chi-Wang Shu (Brown University)* Bio
11:00 - 11:30	**"Multigrid solvers in space and time for highly concurrent architectures"** Abstract *Rob Falgout (Lawrence Livermore National Laboratory)* Bio
11:30 - 12:00	**"Contributions of Applied Mathematics to Meshing Technologies and their Applications to Aerospace Simulations "** Abstract *Frederic Alauzet (INRIA)* Bio
12:00 - 01:30	Lunch on own (not provided) (Restaurant List)
	Session 3: Application Drivers Session Chair: *Jeff Slotnick*
01:30 - 02:00	**"The Virtual Product Next Generation Simulation for Future Aircraft Design"** Abstract *Cord Rossow (DLR)* Bio
02:00 - 02:30	**"Challenges and Opportunities for CFD at ONERA"** Abstract *Vincent Couaillier (ONERA)* Bio
02:30 - 03:00	**"Turbomachinery CFD @ GE"** Abstract *Brian Mitchell (GE)* Bio
03:00 - 03:30	Break
	Session 4: Technology Drivers Session Chair: *Venkat Venkatakrishnan*
03:30 - 04:00	**"Lattice Boltzmann Methods (TBD)"** Abstract *Li-Shi Luo (Old Dominion Universirty)* Bio
04:00 - 04:30	**"Cross-Platform Computational Fluid Dynamics at Petascale with Python"** Abstract *Peter E. Vincent (Imperial College)* Bio
04:30 - 05:00	**"Data to Decisions: Computational Methods for the Next Generation of Aerospace Systems"** Abstract *Karen Willcox (MIT)* Bio
05:00 - 05:30	**"On the Creation of ICASE: A Personal Retrospective View"** Abstract *Manny Salas* Bio
05:45 - 07:00	Reception

Day 2: Sunday, 7th January 2018	
07:15 - 08:15	Continental Breakfast
08:15 - 09:00	**Plenary Talk:** **"InfoSymbioticSystems - The Power of Dynamic Data Driven Applications Systems (DDDAS)"** *Frederica Darema* *Director, Air Force Office of Scientific Research (AFOSR)*
	Session 1: Application Drivers Session Chair: *Boris Diskin*
09:00 - 09:30	**"A Ten-Year Retrospective on Building CREATE Air Vehicle Tools Consistent with Much of the CFD2030 Vision"** Abstract *Scott Morton (CREATE-AV/DoD)* Bio
09:30 - 10:00	**"Exascale Computing Projects at the DOE (TBD)"** Abstract *Doug Kothe (DoE ECP)* Bio
10:00 - 10:30	**"Status and future prospects of turbulence modeling in CFD"** Abstract *Chris Rumsey (NASA)* Bio
10:30 - 11:00	Break
	Session 2: HPC Session Chair: *Manny Salas*
11:00 - 11:30	**"High Performance Computing (HPC) in the Service of Aeroscience"** Abstract *Piyush Mehrotra (NASA)* Bio
11:30 - 12:00	**"Recent and Expected Advances in HPC"** Abstract *Josip Loncaric (Los Alamos National Laboratory)* Bio
12:00 - 12:30	**"Algorithmic Adaptations to Extreme Scale Computing"** Abstract *David Keyes (KAUST)* Bio
12:30 - 02:00	Lunch on own (not provided) (Restaurant List)
	Session 3: Emerging Technologies Session Chair: *Li-Shi Luo*
02:00 - 02:30	**"Model Validation and Uncertainty Quantification: Recent Advances and Opportunities for Aerospace Applications "** Abstract *Sankaran Mahadevan (Vanderbilt University)* Bio
02:30 - 03:00	**"Prospects for the Application of Data-driven Methods for Computational Physics Modeling"** Abstract *Karthik Duraisamy (University of Michigan)* Bio
03:00 - 03:30	**"The Tail Wags the Dog – How In-Situ Processing and Data Modeling Will Enable Knowledge Extraction at Scale to Address the 2030 CFD Vision"** Abstract *Steve Legensky (Intelligent Light)* Bio
03:30 - 04:00	Break
04:00 - 05:30	Discussion/Panel *Panelists : Mike Rogers (NASA), Fariba Fahroo (DARPA),* *Durrell Rittenberg (Siemens PLM), Sharath Girimaji (Texas A&M)* *David Keyes (KAUST)*

Workshop Sponsors

- CFD2030 Integration Committee
  - Fluid Dynamics TC
- NASA T^3 Project (Transformative Tools and Technologies)
- Reception Sponsors
  - Intelligent Light
  - Pointwise
  - Siemens PLM
  - University of Wyoming
- Organizing Committee
    - Dimitri Mavriplis, University of Wyoming
    - Mujeeb Malik, NASA Langley Research Center
    - Venkat Venkatakrishnan, Siemens PLM
    - Boris Diskin, National Institute of Aerospace
    - Li-Shi Luo, Old Dominion University
    - David Keyes, KAUST

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Shaping the Future of Aerospace

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