A Vision of the NASA Aerosciences Discipline Under the Agency's New Operating Model

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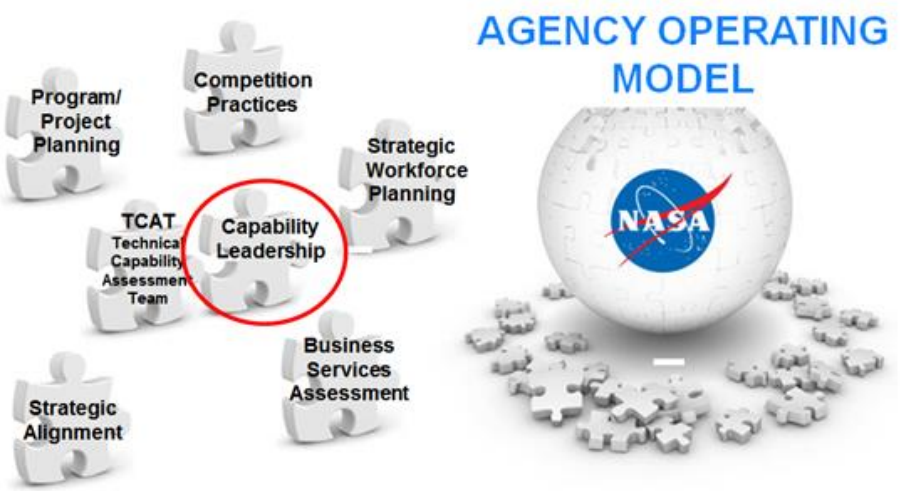
NASA's New Operating Model



IMPERATIVE: Establish a more efficient operating model that maintains critical capabilities AND meets current and future mission needs

Role of the Agency Capability Leaders:

- **Convey a regular (annual) status of their Capability.**
- **Define a Strategic Vector for their Capability.**
- **Advise on strategy to meet Capability needs.**
- **Identify gaps in their Capability to execute the NASA Missions.**
- **Recommend investments.**

- **Capability Leadership organized as Disciplines, Systems, Research, and Portfolio Management.**
  - **Each Composed of a Capability Leader, supported by a Capability Leadership Team with NASA Field Center and Mission Directorate Representation.**
  - **Each team conducts an initial baseline assessment (Aerosciences, 2014) and a re-baseline every 3 years with an annual Executive Summary.**
  - **Disciplines and Systems report to the NASA Engineering Management Board (EMB).**
    - **EMB carries discipline and system issues forward to Agency budget and program planning boards.**

NASA Capability Leadership Teams

Discipline Capabilities	Lead Org.	Over-sight	Lead
Aerosciences	**OCE**	**APMC**	**David Schuster**
Avionics	OCE	APMC	Oscar Gonzalez
Cryogenics	OCE	APMC	Michael Meyer
Electrical Power	OCE	APMC	Chris Iannello
Flight Mechanics	**OCE**	**APMC**	**Daniel Murri**
Guidance, Navigation & Control	OCE	APMC	Cornelius Dennehy
Human Factors	OCE	APMC	Cynthia Null
Instruments and Sensors	OCE	APMC	Upendra Singh
Life Support/Active Thermal	OCE	APMC	Henry Rotter
Loads and Dynamics	OCE	APMC	Joel Sills (interim)
Materials	OCE	APMC	Richard Russell
Mechanical Systems	OCE	APMC	Michael Dube
Non---Destructive Evaluation	OCE	APMC	William Prosser
Passive Thermal	OCE	APMC	Steven Rickman
Propulsion	OCE	APMC	Thomas Brown
Software	OCE	APMC	Michael Aguilar
Space Environments	OCE	APMC	Joe Minnow
Structures	OCE	APMC	Ken Hamm (interim)
Systems Engineering	OCE	APMC	Jon Holladay

System Capabilities	Lead Org.	Over-sight	Lead
Entry, Descent and Landing	**STMD**	**APMC**	**Michelle Munk**
In Situ Resource Utilization	HEOMD	APMC	Jerry Sanders (interim)
Rendezvous and Capture	STMD	APMC	Neil Dennehy (interim)
Autonomous Systems	STMD	APMC	TBA
ECLSS	HEOMD	APMC	Robyn Gatens
In-Space Transportation	STMD	APMC	TBD
Comm and Nav	HEOMD	APMC	TBD

Research Capabilities	Lead Org.	Over-sight	Lead
Earth Science Research	SMD	APMC	Jack Kaye
Heliophysics Research	SMD	APMC	Steven Clarke
Astrophysics Research	SMD	APMC	Paul Hertz
Planetary Research	SMD	APMC	Jim Green
Life Sciences Research	HEOMD	APMC	Craig Kundrot

Service Capabilities	Lead Org.	Over-sight	Lead
Aircraft Operations	MSD	APMC	Richard Schlatter
Mission Operations	Centers	APMC	Troy Leblanc (interim)

Capability Portfolio Management	Lead Org.	Over-sight	Lead
Aeronautics Evaluation and Test Capabilities (AETC)	**ARMD**	**MSC**	**Ron Colantonio**
High-End Computing (HEC)	**SMD**	**MSC**	**Tsengdar Lee**
Rocket Propulsion Testing Program (RPT)	HEOMD	MSC	Roger Simpson
Space Environments Testing Management Office (SETMO)	MSD	MSC	Mike Mastaler
Strategic Capabilities Assets Program (SCAP)	MSD	MSC	Mike Mastaler

Outline

- **The NASA Aerosciences Technical Discipline Assessment and Recommendations.**
- **NASA's Aerosciences Facility Funding Model and Year-one Experience.**
- **Pilot Project to Evaluate CFD as a Surrogate for Wind Tunnel Testing.**
- **The NASA Aerosciences Strategic Vector.**
- **Initiatives Addressing the Strategy.**

NASA's Aerosciences Capability

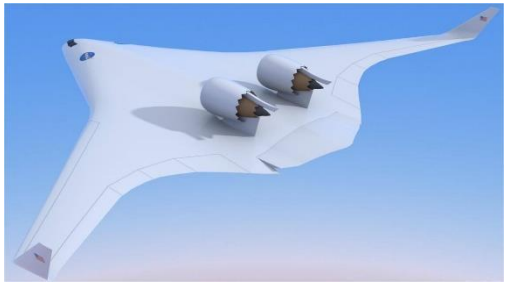
NASA Aerosciences Capability Assessed in 5 Sub-Disciplines

Aerodynamics

Aerothermodynamics

Aerostructures (Aeroelasticity)

Aeroacoustics



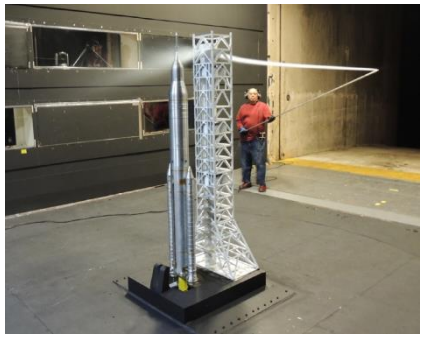
Propulsion Flowpath and Interactions

- **Capability delivered by: Analysis/Computations, Ground Test, Flight Test.**

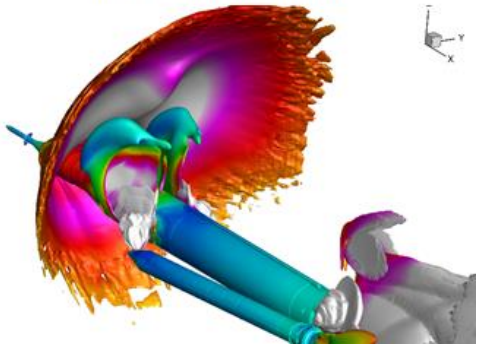
Aerosciences Technical Discipline Capability Assessment

- **Assessment informed by state of capability to execute NASA's Missions:**
  - **Aeronautics, Human Exploration and Operations, Science, and Space Technology.**
  - **Heavily influenced by technical challenges and issues addressed by Technical Fellows/Technical Discipline Teams.**

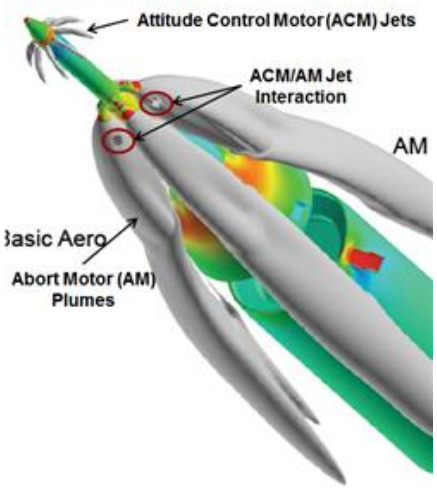
Launch Vehicle Ground Wind Loads/Liftoff Transition



SLS Booster Separation

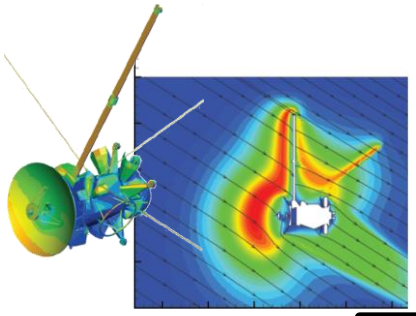


MPCV Launch Abort System

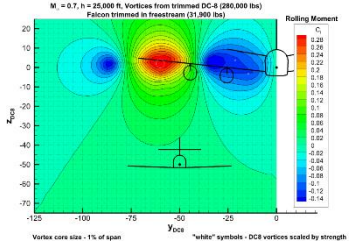


MPCV Parachute Pendulum Mode

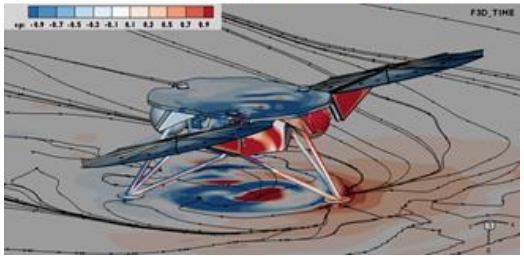
Cassini Titan Flyby



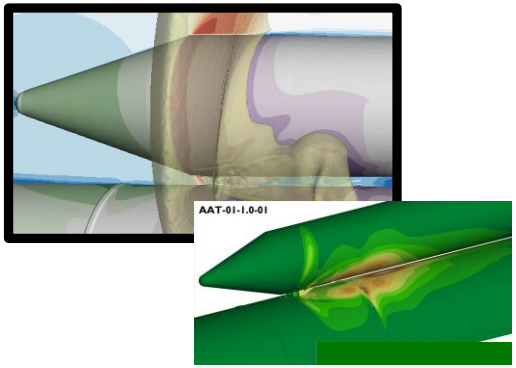
ACCESS Wake/Vortex Interaction



Mars INSIGHT Ground Wind Loads



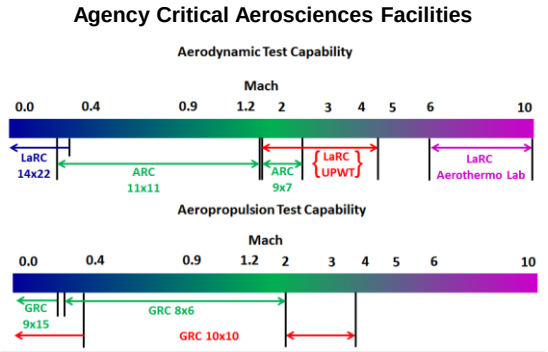
SLS Buffet and Aeroacoustics

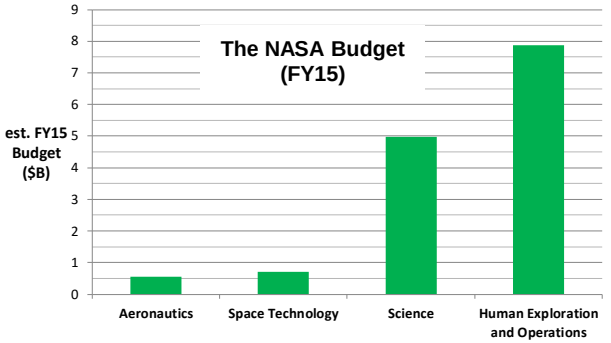


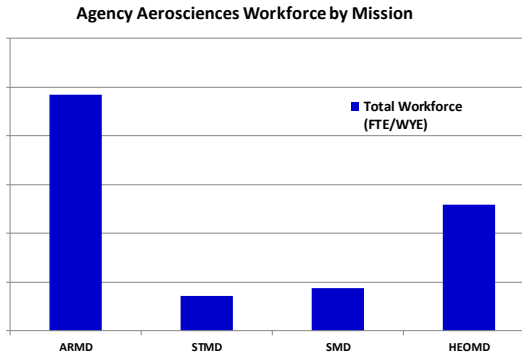
Assessment Findings and Recommendations.

- **Two primary findings from the assessment:**
  1. **NASA's inconsistent charging strategies for Aerosciences tools make computations significantly cheaper (no cost to programs) than ground test.**
     a. **Prematurely pushing us to a computational-based analysis and design approach.**
  2. **NASA's Human Exploration and Science Missions have high dependency on the Aerosciences discipline, exemplifying the need to recognize, lead, and manage the discipline as an Agency vital resource.**
     a. **NASA Aerosciences is recognized effectively as Aeronautics.**

- **Resulting in the following recommendations to Agency Leadership:**
  1. **Develop an enduring base capability funding mechanism to research, develop, and maintain the (Aerosciences) technical capability required to execute NASA Programs and Projects.**
  2. **Reconcile charging differences between test and computations.**







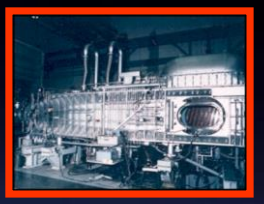
Facilities Covered by Funding Model

LaRC 14 x 22 Foot Subsonic Tunnel
Subsonic, Alternate Uses

LaRC National Transonic Facility
High Reynolds Number Flow

ARC Unitary Plan Wind Tunnels
11'x11' Transonic Wind Tunnel
9'x7' Supersonic Wind Tunnel

LaRC Unitary Plan Wind Tunnel (FY17 Portfolio)
Supersonic Speed Range



LaRC Aerothermodynamics Complex
Exploration Workhorse

Subsonic **Transonic** **Supersonic** **Hypersonic**

GRC 9'x15' Low Speed Wind Tunnel
Low-speed Propulsion Acoustic
GRC 8'x6' Supersonic Wind Tunnel
Transonic-propulsion

LaRC Transonic Dynamics Tunnel
Aeroelasticity & Flutter

GRC 10 x 10 Foot Supersonic Wind Tunnel
Large-scale Supersonics & Propulsion

LaRC 8-Ft High Temperature Tunnel
Large-scale Hypersonics & Propulsion

Specialty Tunnels:

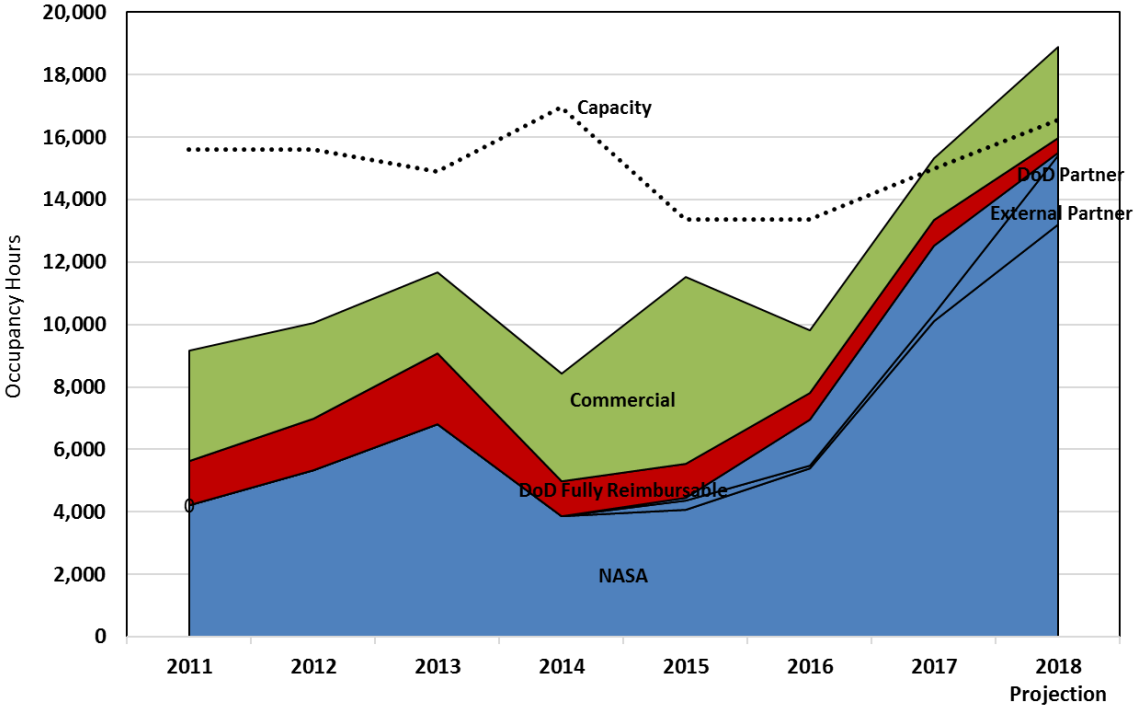
GRC Icing Research Tunnel
Aircraft Icing Condition Simulation

GRC Propulsion Systems Laboratory
Engine (and icing) Simulation at Altitude

LaRC 20-Foot Vertical Spin Tunnel (FY17 Portfolio)
Spin Characteristics & Dynamic Stability

Facility Funding Model Goals and Experience

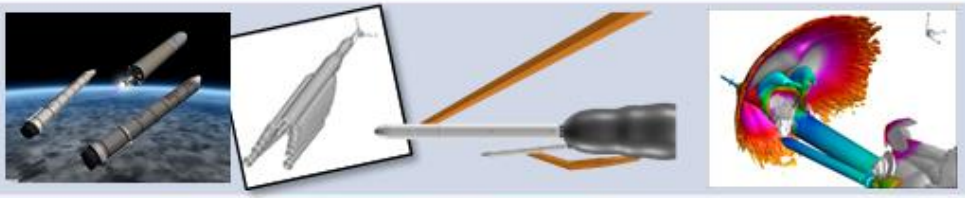
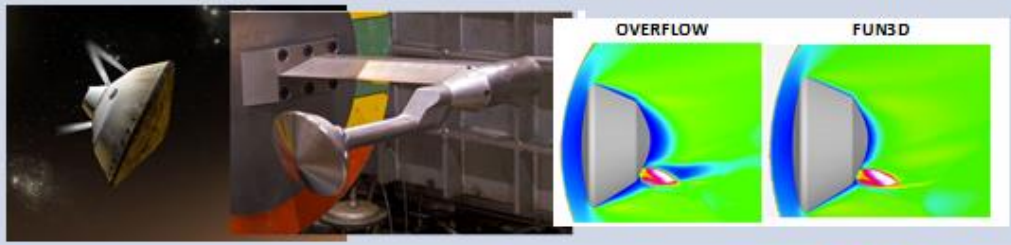
The primary objective of the New Funding Model is to improve access to our facilities, **putting them back in the hands of our NASA researchers and engineers to execute NASA's missions, programs, and projects.**



- **Enable technology innovation and risk reduction by providing easier access and remove cost bias that favors computation over test.**
- **Reinforce the role of facilities as a NASA centrally managed resource.**
- **Improve facility utilization.**
- **Enable capability and discipline sustainability.**
- **Provide an improved measure for facility decisions involving capability partnering, investment, and divestment.**

First-year experience shows the model to be an unqualified success in meeting these goals, and for the first time in over a decade NASA's wind tunnels are operating at full capacity.

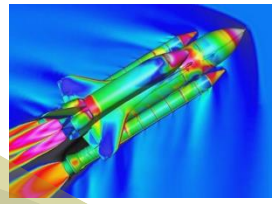
Evaluation of CFD as a Surrogate for High Supersonic Wind Tunnel Test
Proposed Test Cases

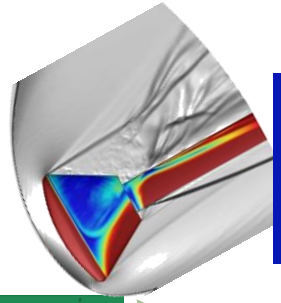
Case	
Multi-Body Aerodynamics for High Speed Separation Events.	
Aero/Propulsion Interaction for Supersonic Retro-Propulsion Deceleration.	
Aero/Reaction Control System Interaction for Entry Vehicle Control.	
Control Authority and Effectiveness for Aircraft and Missiles.	

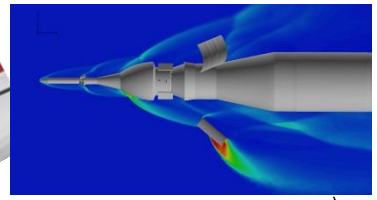
Cases focus on areas of highest uncertainty for CFD simulation in the Mach 2.5 – 6.0 speed regime.

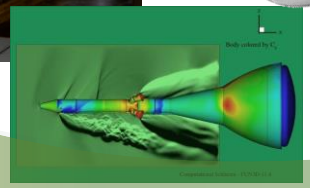
AEROSCIENCES

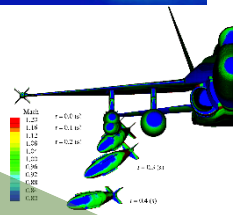
Aerodynamics – Aerothermodynamics – Aerostructures – Aeroacoustics – Propulsion Integration











Flight Test for Qualification

Flight Test

1940

Flight Scale CFD

1960

1980

2000

Integrated Test/CFD

2020

Physics-Based Integrated-System Simulation

2040

2060

Linear Analysis

Wind Tunnel Scale CFD

1980

1960

Wind Tunnel Test

1940

Databases from Wind Tunnels

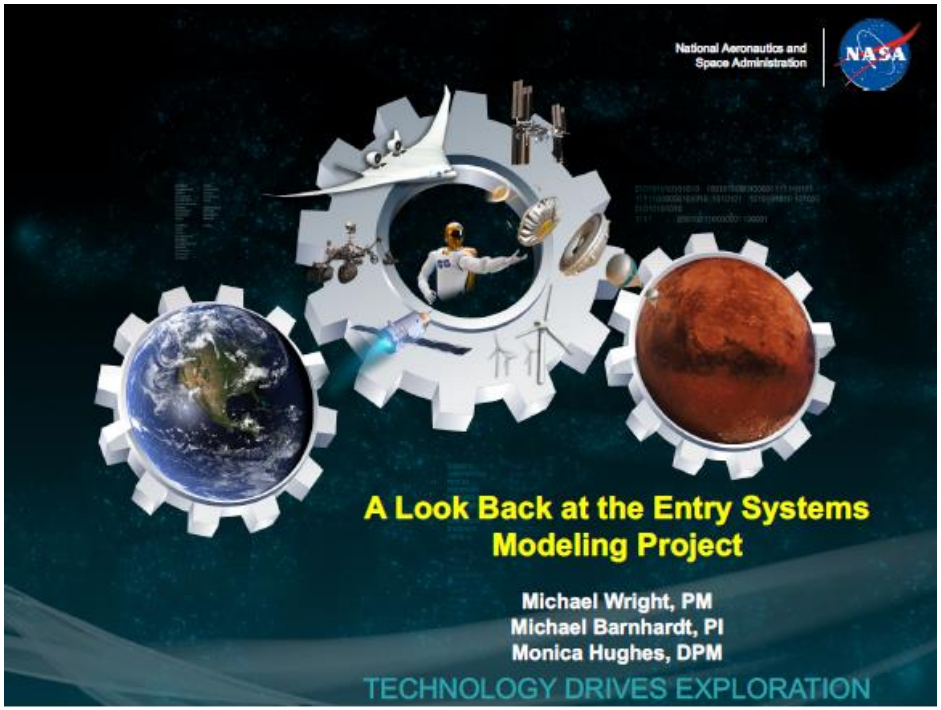
Synergistic use of test/computations reduces test requirements

- ✓ Computations for attached flows nearing maturity
- ➢ Airframe propulsion integration challenges tests and computations.
- ➢ Automated geometry modeling and adaptation require robust investment
- ➢ Chemically reacting and combustion CFD not ready for routine use
- ➢ Push toward unsteady separated flow CFD requires advanced algorithms and computer technology

Flight Qualification by Analysis

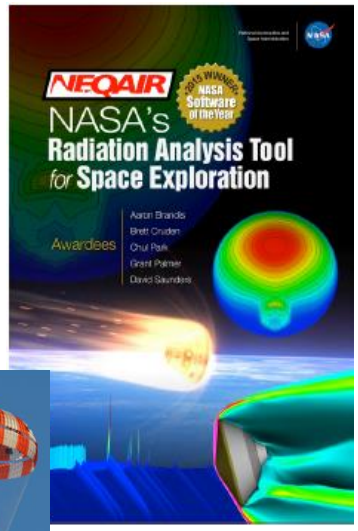
- ➢ Coupling of Aerosciences sub-disciplines
- ➢ Integration with complementary disciplines – Flight Mechanics, GN&C, Structures, Materials, Loads & Dynamics, …

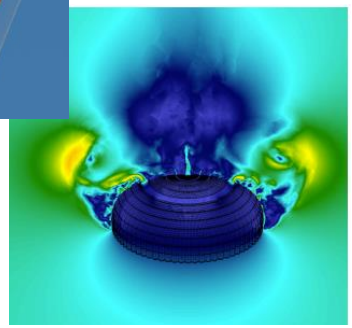
Base Research Reinvented?

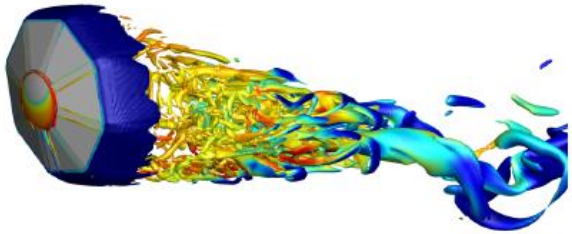


- **No specific Agency action to establish a base funding mechanism to research, develop, and maintain technical capability to support NASA's programs and projects.**
  - **Doesn't mean the message didn't get through.**
- **R&D targeting specific systems likely resonates better with NASA's Mission Directorate organizational structure.**
  - **Space Technology Mission Directorate's Entry System Modeling Project may be a good template for conducting the research and development supporting NASA's space programs and projects.**
  - **A sibling Ascent Systems Modeling project could support Launch Vehicle and Abort Vehicle R&D.**
- **With Aeronautics Research Mission Directorate's Transformational Tools and Technologies Project addressing the needs of NASA Aeronautics, we could piece together a pseudo base R&D clearing house covering the complete range of NASA aircraft, launch vehicles, and spacecraft programs and projects.**

CFD R&D in the ESM Project

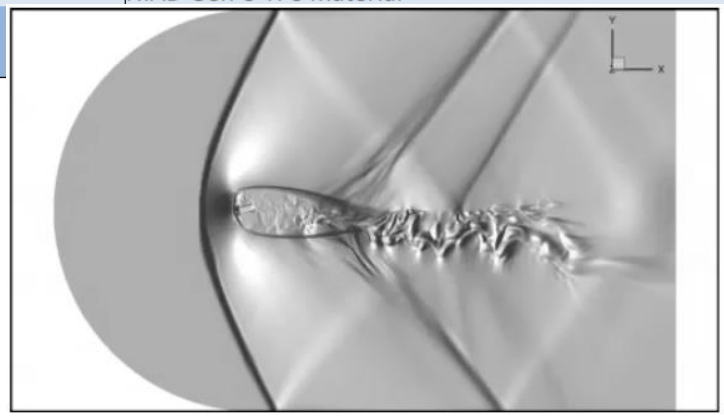






High-order resolution of unsteady flows

Technology	What is it?	Delivery
US3D	Unstructured 3D hypersonics CFD solver	2015
Hyp-Fun3D	Unstructured 3D hypersonics CFD solver	2015
MAP	Object oriented DSMC software	2016
Computational Dynamic Stability	Completed at supersonic, lower speeds in work	2017
Magnetic Suspension WT	Subsonic nearing completion	2017
Parachute Descent FSI	High fidelity model for parachutes and clusters	2018
Radiation Databases	Multiple delivered in air, CO2, Titan	ongoing
NEQAIR	Radiation emission and transport solver	2017
HARA	Radiation emission and transport solver	2017
Roughness Databases	LaL and HFFAF databases	2016
M-SAPE	Multi-mission systems analysis tool	2016
High Enthalpy Mars DB	CUBRC database and comparison to SOA simulation	2017
PuMA	Microstructural analysis tool	2017
PATO	High fidelity ablation response model	2016
Icarus	Engineering design tool for material response	2018
Coupling via LibMesh	Demonstration of CFD/AMR coupling using LibMesh	2016
High/Low Density Conformal	Conformal ablator in a range of densities	2014
Alternate Resin Conformal	Conformal ablator using resins other than phenolic	2016
50 W/cm2 Flexible TPS	HIAD Gen-2 TPS material	2015
75 W/cm2 Flexible TPS	HIAD Gen-3 TPS material	2016
CHIEFS		2018
Exo-Brake		2017



Simulated flight of ballistic range model

Top Aerosciences Technical Challenges

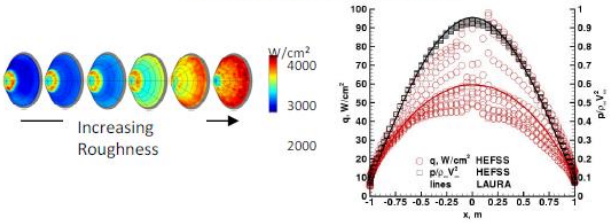
Aerosciences Discipline Assessment

Understanding, Predicting, and Managing:

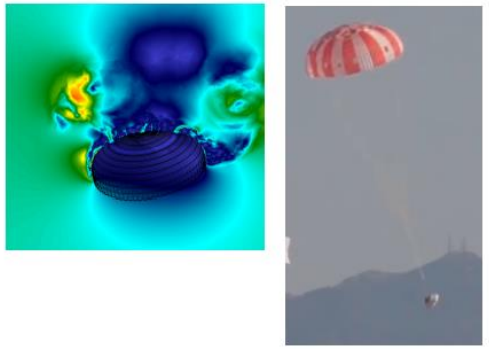
1. **Unsteady Separated Flow**
2. **Aeropropulsive Interactions**
3. **Aerothermodynamic Environments and Interactions**
4. **Parachute and Decelerator System Performance**

ESM Maps to the Top Aerosciences Challenges

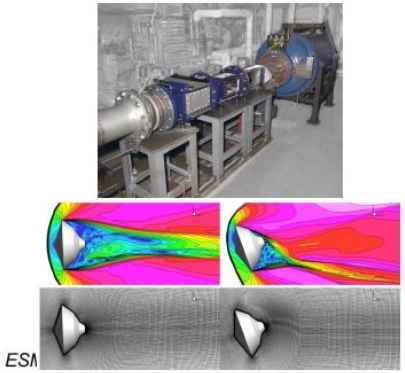
3 Improved Aerothermal Prediction:
DG methods attack largest remaining weakness in hypersonic CFD; roughness heating augmentation models



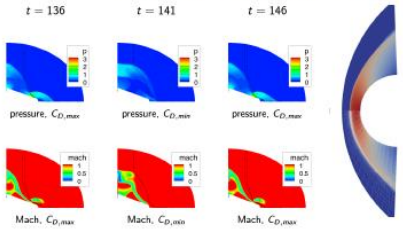
4 Parachute Aerodynamics:
FSI models for single chute and cluster; inflation via ESI-16 partnership

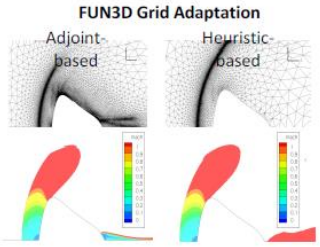


1 Unsteady Separated Flow
MSWT, dynamic free flight, multi-body separation dynamics



2 RCS/Jet Interactions
Advances in underlying methodology (DF, free flight, AMR, adjoint) will enable future work in this area





Riding the Vector

CFD 2030
This ain't your Granddaddy's CFD!

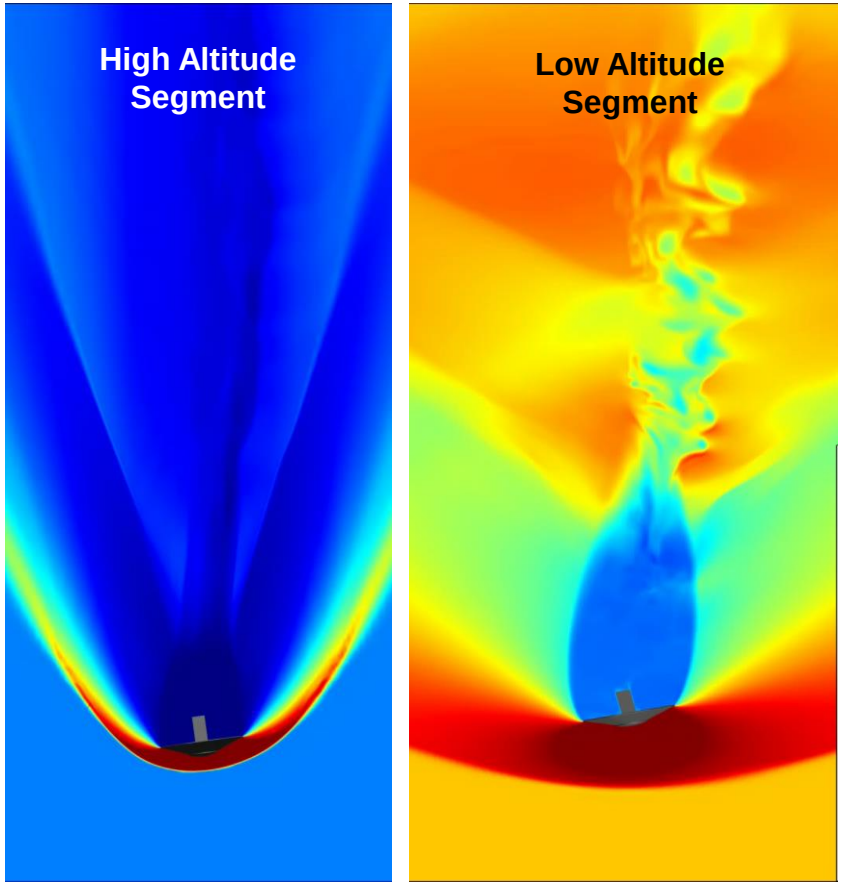
- **Physics-based integrated-system simulation is on a path to revolutionize vehicle research, development, and operation.**
  - **We're way beyond CFD mimicking and/or replacing wind tunnels.**
  - **We're talking about things we can't even dream about doing in a ground test facility.**

Full-scale, Full-environment, Nonlinear, Transient Flight System Simulation

Case in point:

- **NASA has spent over a decade building aerodynamic and aerothermodynamic databases to serve as input to flight simulation codes for MPCV.**
- **Replacing today's database with simulation-integrated CFD capability eliminates:**
  - **Linearization, interpolation, and extrapolation errors.**
  - **Uncertainties due to scale effects, test assumptions, propulsive simulants, quasi-steady assumptions.**
  - **Time and resources required to build databases, portions of which may never be exercised.**

ESM Hypersonic Entry
6-DOF Coupled CFD



Courtesy: Eric Stern, NASA ARC

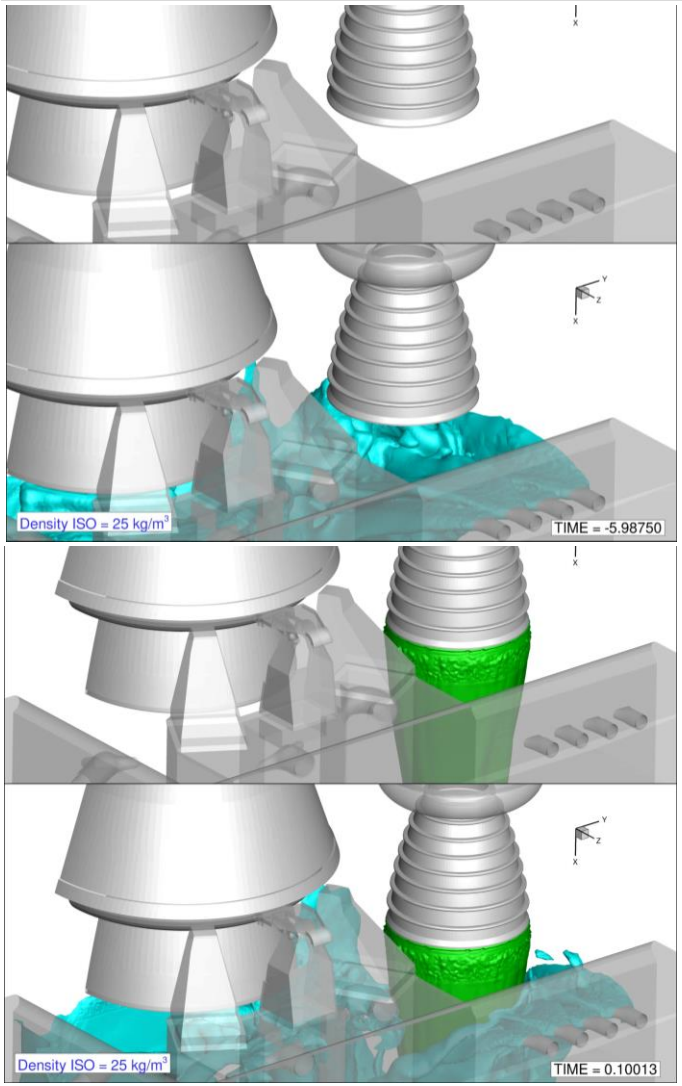
Riding the Vector – Part II

- **Programs are becoming increasingly dependent on computational capability to solve highly complex, time-critical technical problems.**
  - **NASA's Engineering organizations are leveraging program support and first-hand knowledge of technical requirements to develop, assemble, and validate computational capability to meet their vehicle development needs.**

Case in Point:

- **In 2008, MSFC began using CFD to simulate Space Shuttle SRB ignition and plume flow development around KSC Launch Complex 39A after damage resulting from the STS-124 launch.**
  - **Simulation included reacting flow plumes and the highly complex geometry of the Mobile Launch Platform and Pad 39A Flame Trench.**
  - **Water deluge acoustic suppression could not be simulated and was found to be a major contributor to the overall plume development and flow.**
  - **10 years of persistent development and application has seen the addition of the water deluge.**
  - **NASA is investigating the use the capability to evaluate launch pad environments during booster ignition.**

Notional Liquid Engine/Solid Rocket Booster Startup Including Water Deluge Acoustic Suppression Simulation



Courtesy: Jeff West, NASA MSFC

Get off the Stage

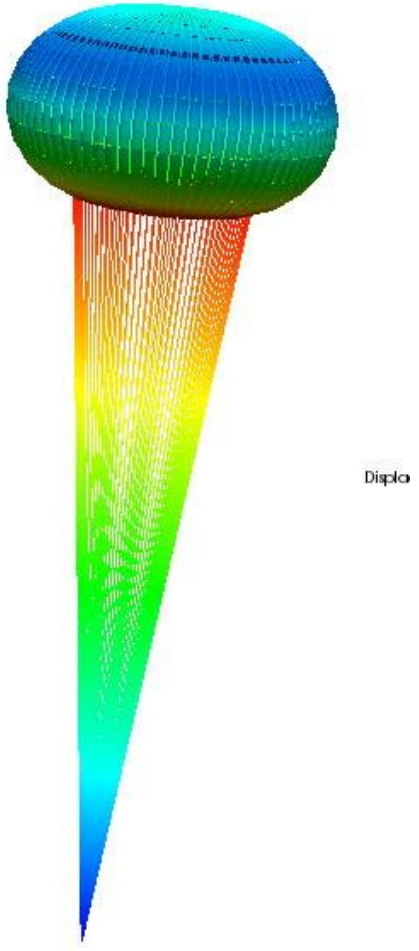
- NASA Capability Leadership serves as a bottom-up component of the Agency's operating model maintaining critical capabilities to meet mission needs.
- The Aerosciences Discipline Capability Leadership Team continually assesses the state-of-the-discipline, sets a strategic vector, and identifies top technical challenges facing the discipline.
- Programs are becoming increasingly dependent on computational analysis to solve complex, time-critical technical problems.
  - Must reinvent base R&D as a co-dependent effort among our Mission Directorates and Research and Flight Centers.
- Physics-based integrated-system simulation is on a path to revolutionize vehicle research, development, and operation.

- Where we need to focus:
  - Fast, robust, high-fidelity unsteady flow simulation, including separated flows.
  - Automated geometry processing and model development.
  - Error-based adaptation striving toward user-independent analysis.
  - Integration with current (flight) simulation tools.
    - Ref: LaRC/NESC/Georgia Tech Project to Couple FUN3D with POST.

      AFM-03, Monday Afternoon

      AIAA-2018-0291
      Coupling Computational Fluid Dynamics with 6DOF Rigid Body Dynamics for Unsteady, Accelerated Flow Simulations

ESM Parachute Disreefing Using OVERFLOW Environments



Courtesy: Paul Bauman (SUNY) /Scott Murman, (NASA ARC)