Future of NASA's Aerosciences Capability

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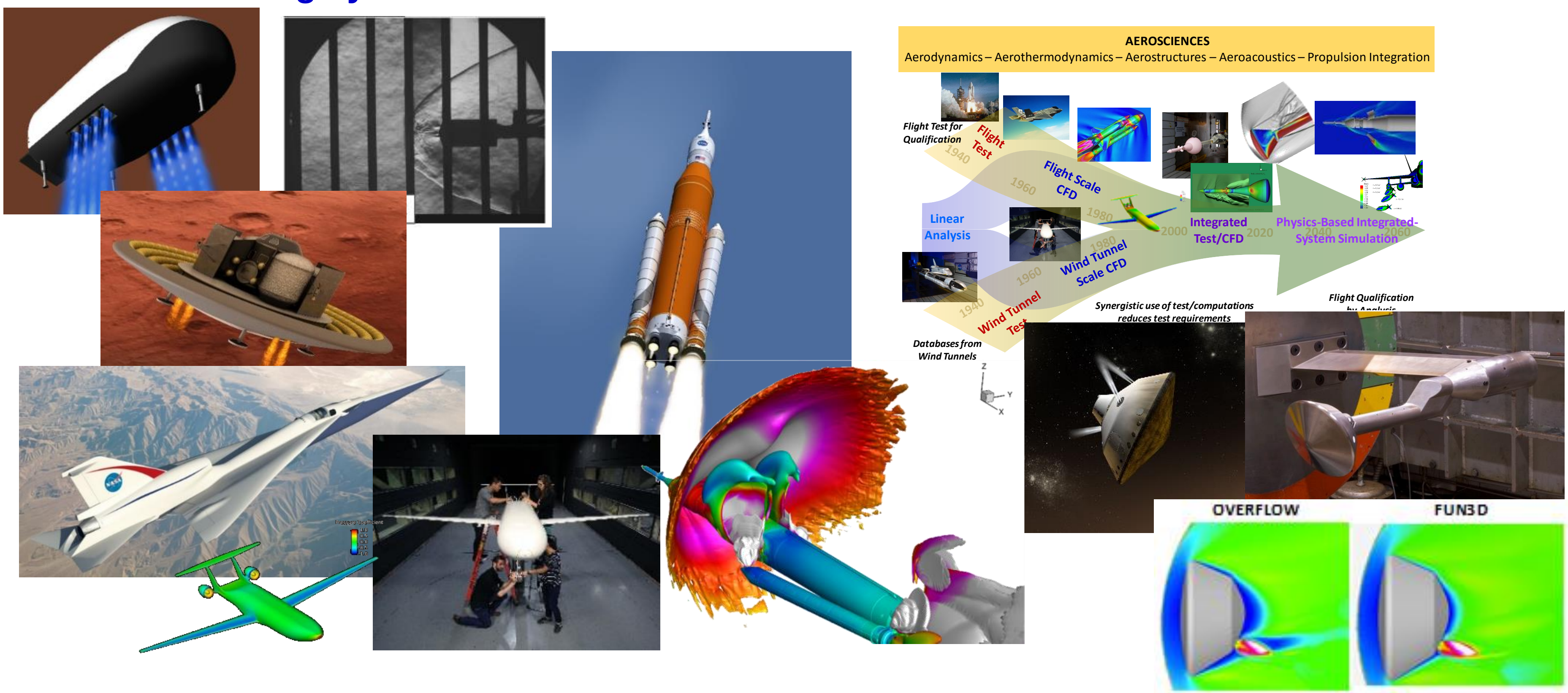


Thermal and Fluids Analysis Workshop
August 21 – 25, 2017

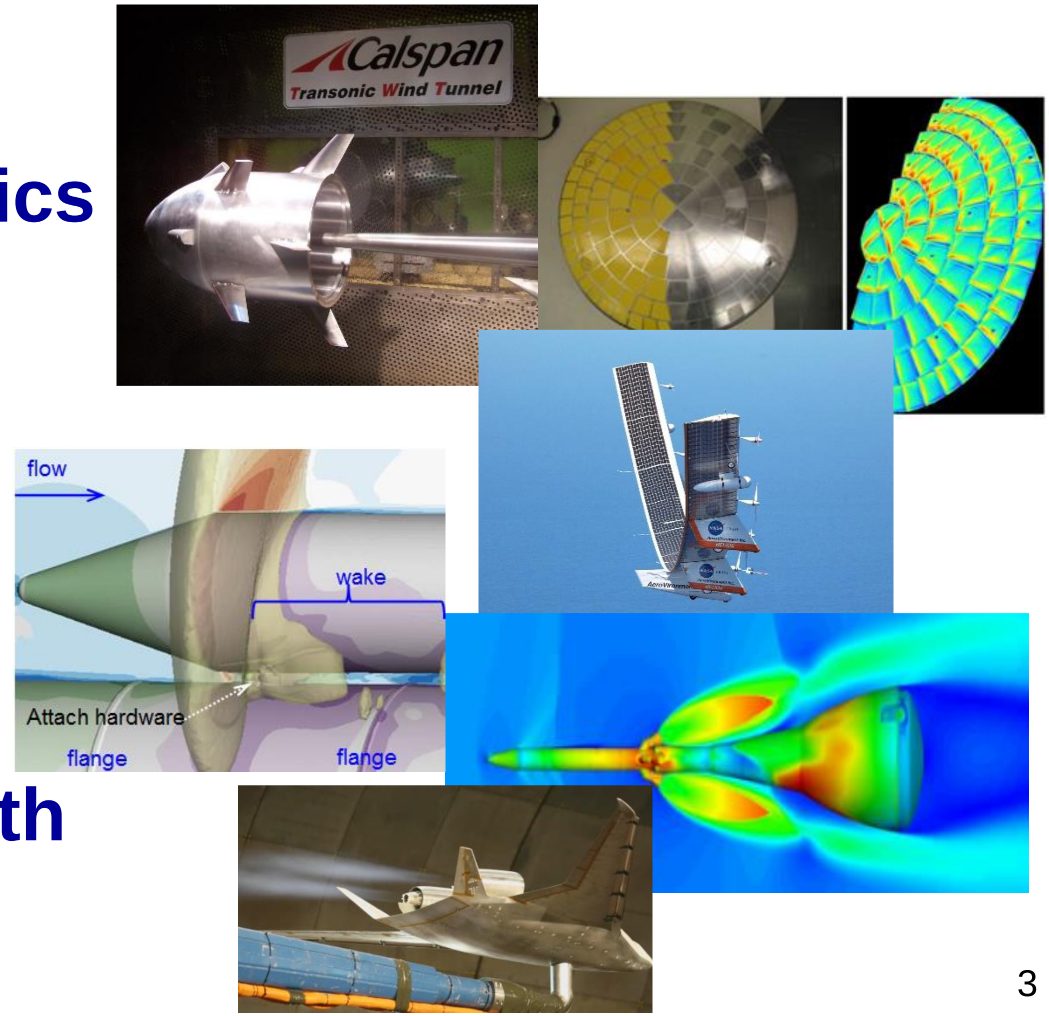
Outline

- Overview of the NASA Aerosciences Discipline
- Aerosciences Technical Discipline Team vs. Capability Leadership
- Strategic Vector
- Challenges: Technical and Capability
- Capability Stewardship and Initiatives
- Aerosciences Assessment Examples
- Questions and Discussion

NASA Aerosciences

Five broad categories:

- **Aerodynamics**
- **Aerothermodynamics**
- **Aerostructures (Aeroelasticity)**
- **Aeroacoustics**
- **Propulsion Flowpath and Interactions**



Capability Delivery

The Aerosciences discipline capability is delivered via four mechanisms:

1. *Analytical/Empirical Evaluations*
2. *Computational Analysis (CFD)*
3. *Ground Test (Wind Tunnel, Arc Jet, Ballistic Range, Water Channel, …)*
4. *Flight Test*

Aerosciences Leadership

At the Agency Level, the Aerosciences Discipline is supported and informed by two teams:

Aerosciences Capability Leadership Team (CLT)
Aerosciences Technical Discipline Team (TDT)

- Both the Aerosciences TDT and the CLT have the common goal of ensuring we have an Aerosciences capability that is ready to execute the missions of the Agency as well as the nation.
  - Aerosciences TDT – Technical Expertise, Review, Independent Assessment, and Project Support.
  - Aerosciences CLT – Management leadership to ensure appropriate human resource skills, facilities, and tools are available to meet the aerosciences challenges of the NASA missions.
    - Internal to NASA as well as external.

Role of Aerosciences TDT and CLT

- Functionally, the TDT and the CLT are two separate teams that answer to two separate authorities.
  - TDT – Responsible to the NESC Review Board.
    - Team members selected by the Technical Fellow
      - NASA Centers, government, industry, and academia experts.
  - CLT – Responsible to the Office of the Chief Engineer (and beyond).
    - Team members provided by the NASA Centers.
- We see the two functions as wholly dependent on the other.
  - The TDT cannot perform their job without the skills, expertise, facilities, and tools that are influenced by the CLT.
  - The CLT cannot effectively assess skills, expertise, facilities, and tools without the technical insight to the Agency's Aerosciences requirements and gaps afforded by the activities of the TDT and the NASA Aerosciences Community at large.

NASA Aerosciences

Philosophy and Approach

- Philosophy:
  - The Agency's Aerosciences goals, requirements, strengths, and weaknesses can be readily identified by examining the technical community's approaches to solving mission problems and the technical challenges encountered during execution of these approaches.
    - The insight of the TDT is a key resource here.
- Approach:
  - Examine and identify key aerosciences technical challenges uncovered during TDT activities.
    - Assemble TDT experience into a list of Top Technical Challenges.
    - Advocate for opportunities to address these challenges through NESC assessments, collaborations, and project support.
      - – Aerosciences CLT recommendations to Agency Leadership.
    - Continually evaluate, update and report on progress made toward solving these challenges.
  - Approach was the primary contributor to the previous State-of-the-Discipline
    - Capability Leadership has formalized the process for reporting on the SOD.

2017 Aerosciences TDT

Name	Center/Org.
Core Civil Service	
David Schuster, TDT Lead	LaRC
Craig Streett, TDT Deputy	LaRC
Adam Amar	JSC
Brian Anderson	JSC
Zac Applin	LaRC
Steve Bauer	LaRC
Mike Barnhardt	ARC
John Blevins	MSFC
Jennifer Cole	DFRC
Mark D'Agostino	MSFC
James Debonis	GRC
Ray Gomez	JSC
Jennifer Heeg	LaRC
Brian Hollis	LaRC
Tom Horvath	LaRC
Lawrence Huebner	MSFC
Cetin Kiris	ARC
Ben Kirk	JSC

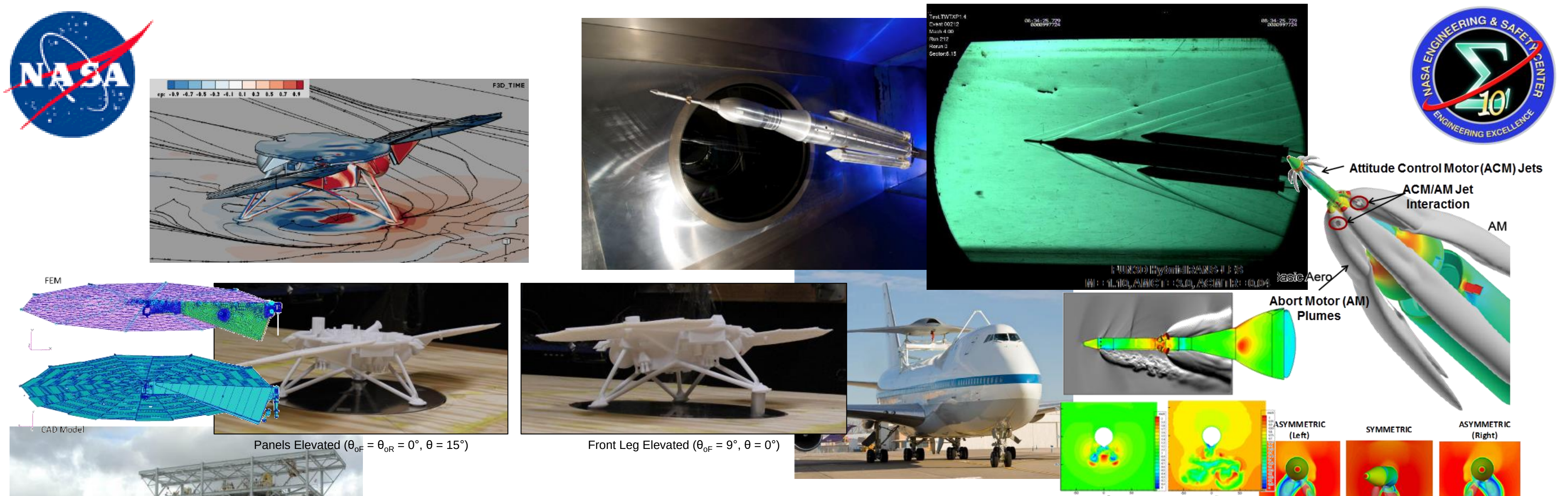
Name	Center/Org.
Core Civil Service	
Bil Kleb	LaRC
Jay Panda	ARC
James Ross	ARC
Mark Schoenenberger	LaRC
Jeff West	MSFC
Michael Wright	ARC
Core Industry/Academia	
Rick Barton	AMA, JSC ret.
Basil Hassan	Sandia National Lab
Michael J. Hemsch	NEAR, LaRC ret.
Fred Martin	AMA/NEAR, JSC ret.
Michael Mendenhall	AMA/NEAR
Peter Covell	AMA/NEAR, LaRC ret.
TDT Team Support	
John LaNeave	MTSO PA, LaRC
Jonay Campbell	Tech Writer, ATK
Pam Sparks	Proj. Coord, ATK

2017 Aerosciences Capability Leadership Team

Name	Center/Org.
David Schuster, ACLT Lead	LaRC
Mark D'Agostino, ACLT Deputy	MSFC
Dawn Schaible	OCE POC
Danny Allgood	SSC
Mike Carney	KSC
Jennifer Cole	AFRC
James Debonis	GRC
Lennie Duncil	KSC
Ray Gomez	JSC
Aga Goodsell	ARC

Name	Center/Org.
Lisa Griffin	MSFC
Cetin Kiris	ARC
Ben Kirk	JSC
Bil Kleb	LaRC
Mary Jo Long-Davis	GRC
Harry Ryan	SSC
Joel Simpson	GSFC/WFF
Christine Szalai	JPL
Tony Washburn	LaRC

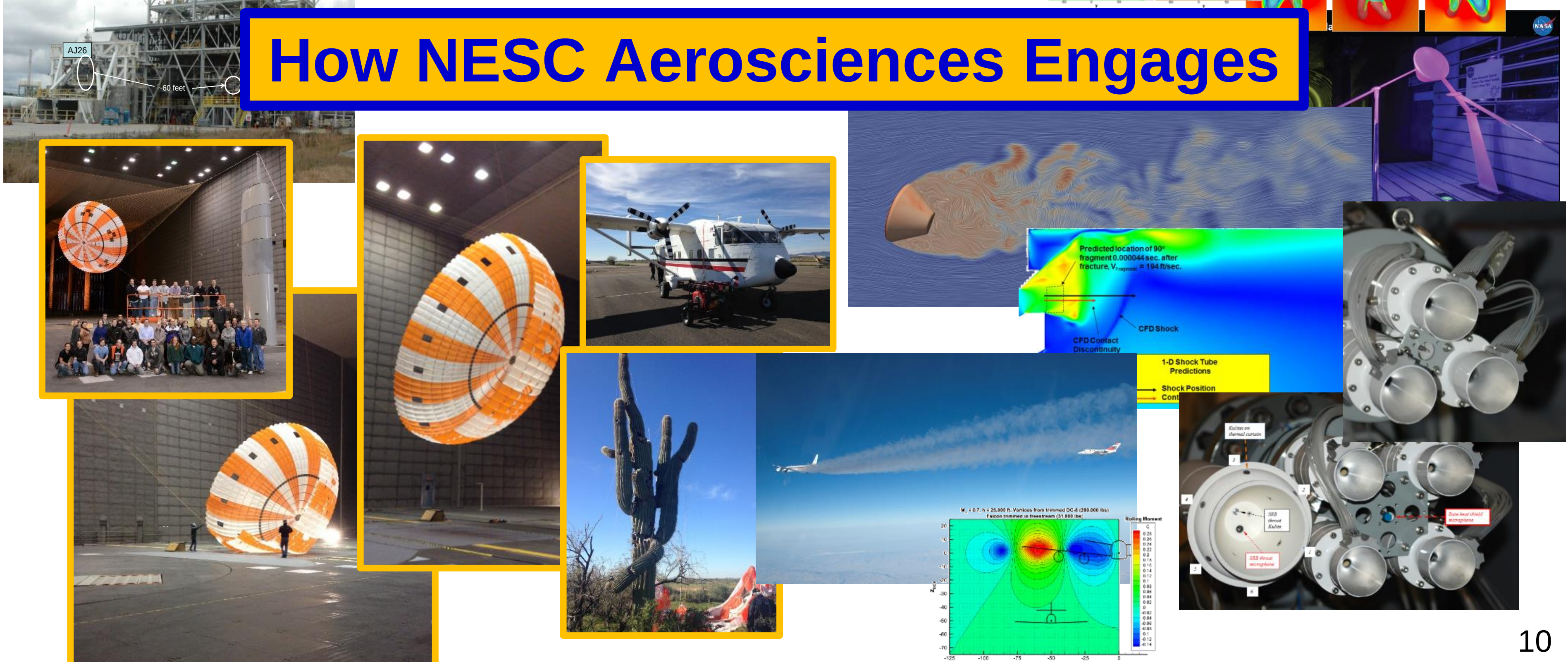
Yellow text indicates dual membership on TDT and CLT.



Panels Elevated ($\theta_{oF} = \theta_{oR} = 0°$, $\theta = 15°$)

Front Leg Elevated ($\theta_{oF} = 9°$, $\theta = 0°$)

How NESC Aerosciences Engages



Reviews, Technical Expertise and Aerosciences TDT Consultation

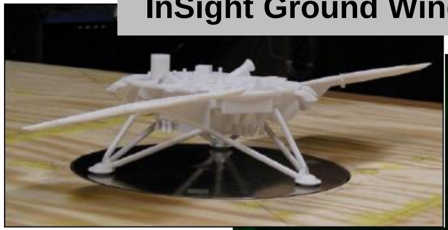
- NESC Aerosciences has established ongoing review and technical consultation of NASA Programs.
  - Standing review teams for MPCV, SLS, and CCP Aerosciences.
- MPCV initiated the present process as a request for formal, periodic peer reviews.
  - Supporting workload for program and review teams found to be excessive.
  - Present process:
    - Embed a member of the review team in program aerosciences regular meetings.
    - Full team participates in Project TIMs and data reviews, and provides findings and recommendations.
    - CCP process continues to be a more formal Peer Review.
- Numerous Technical interactions and even Independent Assessments have been spun off by this review process.

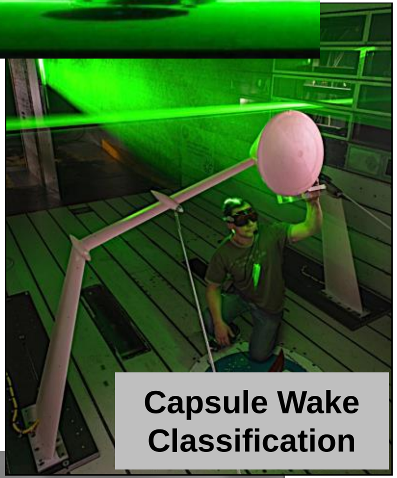
SLS Aerosciences Review

Aerosciences TDT Independent Assessment

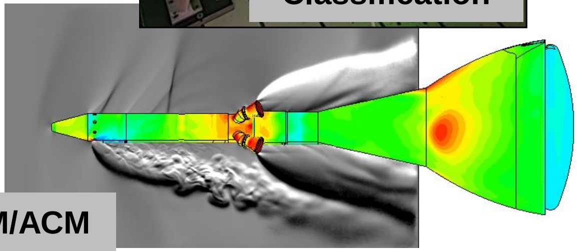
- **NESC Aerosciences has the ability to conduct assessments independent of program/project funding stream.**
  - **NESC funds the activity.**
  - **NESC assembles, leads, and manages the assessment team.**
  - **Stakeholder briefing and final report developed to document the effort.**
    - **Typically includes findings, observations and recommendations.**
  - **May include limited collaboration with the program/project to establish background and provide supporting data.**

InSight Ground Wind Loads





Capsule Wake Classification

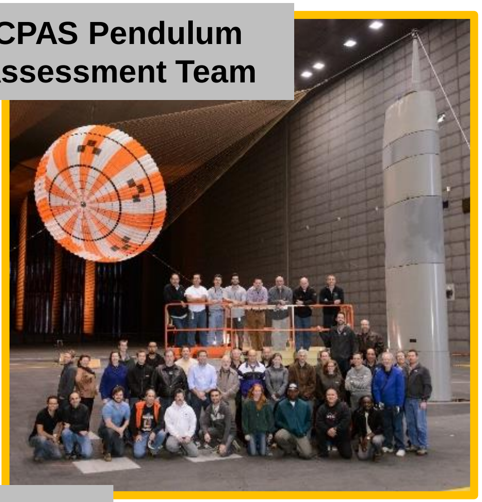


MPCV LAV AM/ACM Interaction

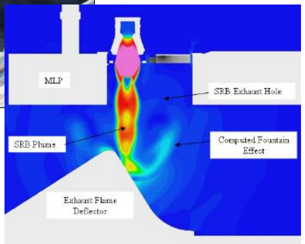
Aerosciences TDT Project Support

- **NESC Aerosciences regularly supports Tiger Teams and other program-led special projects.**
  - Program funds and leads the overall activity.
  - NESC Aerosciences provides and funds unique expertise applicable to the problem.
  - Program determines reporting and documentation.

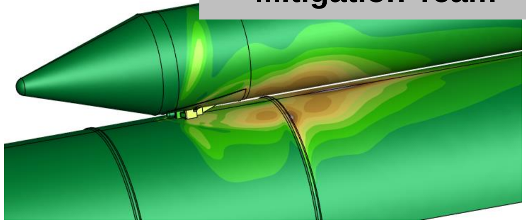
CPAS Pendulum Assessment Team



KSC Pad 39A Flame Trench Damage



SLS Buffet Loads Mitigation Team

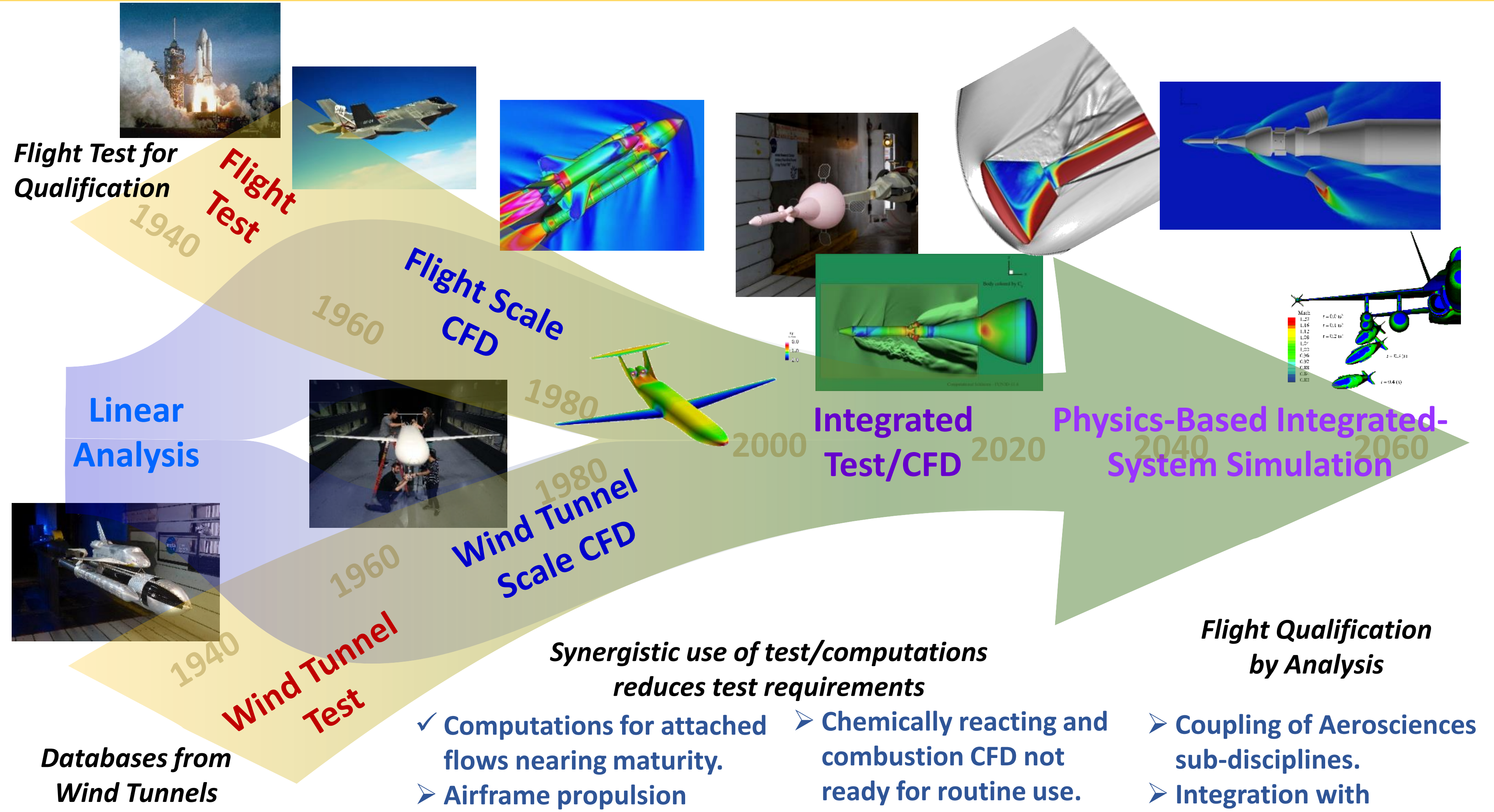


Products of Engagement

- Technical Review, Independent Assessment, and focused Project Support provides:
  1. A first-hand look at how the discipline is being employed to solve Agency problems.
  2. A clear picture of the readiness of the discipline to solve Agency problems.
  3. Specific Technical Challenges and Gaps that must be overcome to take the discipline forward.
  4. A Strategic Vector pointing to the future of the discipline.
- Across the board, programs/projects are stressing increased application of analysis over ground and flight test.
  - Probabilistic (as opposed to deterministic) analysis becoming more commonplace.
  - Encountering more flight conditions that cannot be reproduced in ground test.
  - Is SpaceX the exception to this trend?
- Over the last decade 4 distinct Aerosciences Technical challenges have emerged and continue to be in-play today.
  - Primarily informed by the Aerosciences TDT's State-of-the-Discipline.
- Aerosciences Capability Assessment has identified operational challenges and objectives that impact how effectively we are able to address these challenges.

AEROSCIENCES

Aerodynamics – Aerothermodynamics – Aerostructures – Aeroacoustics – Propulsion Integration



- ✓ Computations for attached flows nearing maturity.
- ➢ Airframe propulsion integration challenges test 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.

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

Aerosciences Technical Challenges

The top four challenges facing the Aerosciences discipline are understanding, predicting and managing:

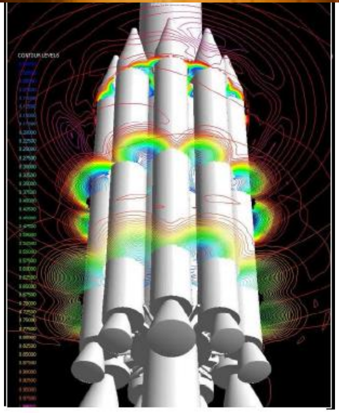
1. **Unsteady Separated Flow**
   - Flow behind capsules, abort systems, protuberances, and other bluff bodies across the speed regime from subsonic to hypersonic.
   - Juncture flows, landing gear, high lift systems.
2. **Aeropropulsive Interactions**
   - Integrated propulsion systems for sustained hypersonic flight, highly integrated efficient propulsion systems for aviation,
   - Reaction Control Systems (RCS) during entry, supersonic retro propulsion, launch abort vehicles, stage separation.
3. **Aerothermodynamic Environments and Interactions**
   - Shock radiation, coupled ablator performance (aerothermal/material response/shape change), high speed entry, CFD for turbulent aerothermodynamics.
4. **Parachute and Decelerator System Performance**
   - Subsonic and supersonic parachutes, inflatable and advanced low ballistic number decelerators, unsteady separated flow, aeroelsaticity of highly flexible structures.

Unsteady Separated Flow

- **Overarching gap that affects virtually the entire discipline**
- **Current state-of-the-art is prediction of steady attached flow using wind tunnel testing and Reynolds-Averaged Navier-Stokes (RANS) CFD**
  - **Unsteady wind tunnel testing can be accomplished, but at significantly increased cost over conventional wind tunnel testing.**
  - **Emerging, high-order unsteady CFD techniques have shown considerable promise but require extensive further development and validation.**
  - **Separated flows can be highly sensitive to scale effects making sub-scale testing uncertain.**

Unsteady Separated Flow
Launch Vehicle Aeroacoustics and Buffet

- **For over a decade, we have been addressing issues involving transonic separated flow on launch vehicles.**
- **2003 – 2005: Delta II Heavy Transonic Anomaly.**
  - **Large nozzle deflections in transonic flight due to unsteady separated flow in the booster interface region.**
  - **Control law modifications required to return to flight.**
- **2007: Ares I-X buffet testing identifies an unsteady and bi-stable separated flow mechanism at the CM/SM cone-cylinder junction.**
  - **No clear approach for how to model or otherwise incorporate these flow features in the flight simulations resulting in added control margin to cover the situation.**
- **2008 Ares I-X Aeroacoustic Tiger Team formed to investigate high environments near vehicle protuberances and boat-tail.**
- **2008 ARMD's Hypersonic Boundary Layer Transition (HyBoLT) project forms a Tiger Team to investigate high aeroacoustic environments at various vehicle locations.**



Unsteady Separated Flow
LV Aeroacoustics and Buffet (Cont'd)

- **2013 SLS Buffet Tiger Team formed to investigate high buffet loads encountered in buffet wind tunnel testing.**
  - **Similar in geometry and flow to Delta II Heavy anomaly.**
  - **Additional testing conducted as part of SLS aeroacoustic testing.**
- **2014 SLS retests buffet model with improved sensor coverage and flow fixes to refine buffet environments near booster interface.**
  - **Approximate cost to SLS: $2.1M for the test alone.**
  - **Buffet forcing functions reformulated, reducing environments.**
- **2014 SLS Aeroacoustics Tiger Team formed to investigate high environments derived from aeroacoustic wind tunnel testing.**
  - **Final resolution is still TBD.**

Unsteady Separated Flow
LV Aeroacoustics and Buffet (Final)

- **Each case involved similar physics: Unsteady separated flow, primarily in the transonic flight regime.**
- **Each case was resolved in a vehicle-specific manner.**
  - **Added design margin or unplanned tests to refine environments.**
  - **Impacts to schedule, budget, and vehicle performance.**
- **In each case, the Aerosciences technical community has recognized the need to conduct research and development to understand, predict and manage these types of flows.**
- **There is no Agency mechanism that allows the community to propose, formulate, and conduct these investigations.**

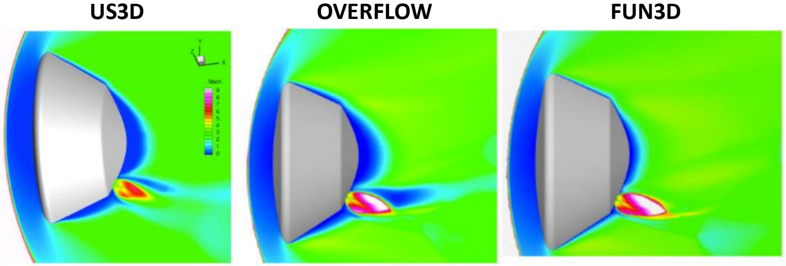
Aeropropulsive Interactions

- **Aero/Plume and Aero/Jet Interaction affect aerodynamic performance, control effectiveness, and heating**
  - **Prediction of combustor performance is also a key capability to engine development**
- **State-of-the-art is powered wind tunnel testing using air and occasionally other gases for the plume simulant**
  - **Typically cold plumes, some hot-plume testing has been accomplished at very high cost**
  - **Require new testing techniques to improve physical simulation and reduce extremely high test costs**
- **Chemically reacting Navier-Stokes CFD is the computational state-of-the-art.**
  - **Methodology is far from mature and development of algorithms and advanced physic-based tools needed for simulations.**

Aeropropulsive Interactions
Robotic Spacecraft RCS Development

- **Mars Phoenix predicted strong nonlinear aerodynamic interactions with their reaction control systems during portions of the vehicle entry.**
  - **Vehicle had sufficient stability margin to shut down RCS control in areas of high interaction uncertainty.**
  - **Without this margin, program cancellation was a probable consequence.**
- **MSL CFD predictions showed unacceptable Aero/RCS interaction during entry with original RCS placement and orientation.**
  - **Triggered a redesign and testing that moved and reoriented the thrusters to minimize interactions.**
- **Significant CFD code-to-code variation when analyzing RCS performance during entry.**
  - **Is CFD a good enough predictor to warrant a design change as in MSL?**
  - **Can we rely on CFD to determine RCS control margins that are suitably conservative for flight?**
- **There is no Agency mechanism that allows the community to propose, formulate, and conduct these investigations.**

Comparison of MSL Aero/RCS Interaction CFD Simulations



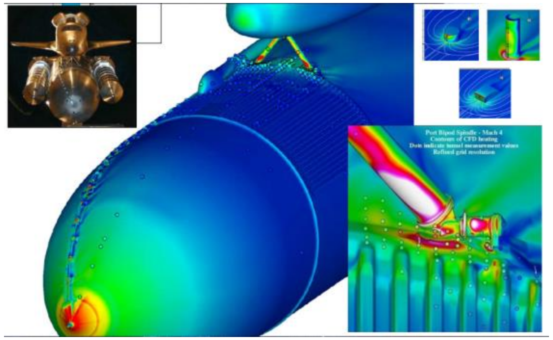
Aerothermodynamic Environments and Interactions - Radiation

- **High velocity entry involves heating mechanisms (shock layer radiation) that have not been significant since Apollo and are a critical component to any human mission beyond LEO.**
  - **Earth return is especially problematic due to higher velocities and thicker atmosphere, compared to Mars entry.**
  - **Thermal Protection System (TPS) mass is a substantial fraction of any human spacecraft designed for earth atmospheric entry.**
  - **Beyond Low Earth Orbit, shock layer radiation heating is a large component of the overall aerothermodynamic environment.**
    - **For Earth return from Mars radiation is the major contributor to the peak heating environment.**
- **Present ground test capabilities cannot reproduce the combined shock radiation and convective heating environments of high velocity entry.**
- **Present computational methods for predicting shock radiation heating can have uncertainties as high as 50%.**
  - **High uncertainties result in large TPS mass margins for missions beyond LEO, and may require the development of new materials.**
- **There is no Agency mechanism that allows the community to propose, formulate, and conduct the experimental and computational investigations required to attack this problem.**
- **Flight Test validation will be necessary to reduce risk of high-energy Earth return, and is not presently being pursued in the Agency.**

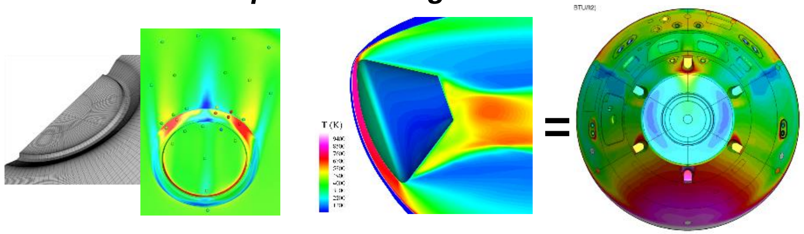
Aerothermodynamic Environments and Interactions – Details & Features

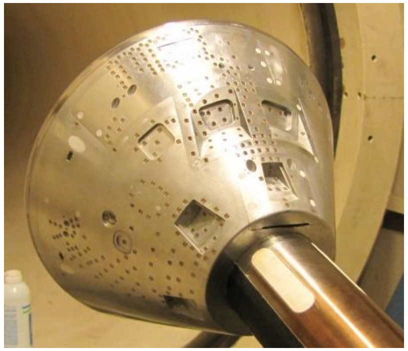
- **Flow interactions frequently result in severe localized heating augmentation.**
- **Computational techniques are challenged to accurately predict these phenomenon, especially for transitional & turbulent flows**
  - **Such phenomenon are increasingly important for high-energy entries that push the limits of existing TPS materials**
  - **Improved computational & experimental techniques are needed to improve beyond current state-of-the-art.**

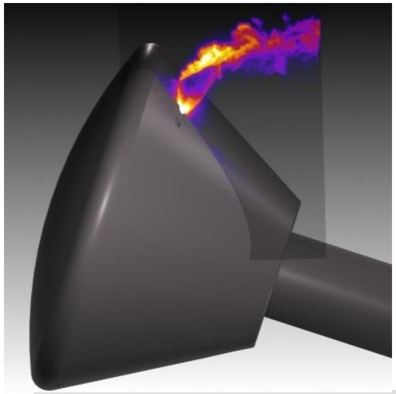
Ascent Environment Testing and CFD



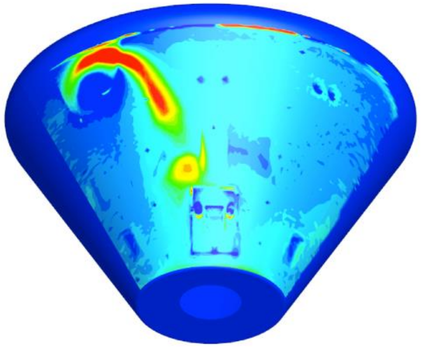
Feature Response & Integration

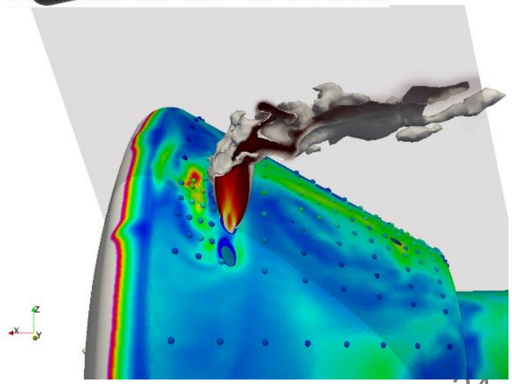






Orion has conducted 6 tests to develop RCS environments



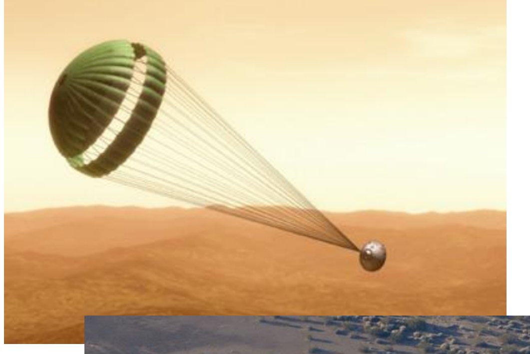


Parachute and Decelerator System Performance

- **Problem involves simulation of unsteady massively separated flow, strong aero-structural interaction, and complex geometry**
- **State-of-the-art for prediction is analytical/empirical analysis (often proprietary), some wind tunnel test, and drop testing**
- **CFD simulations just starting to be investigated by NASA**

Parachute and Decelerator System Performance
Parachute Performance Prediction

- **Prediction of parachute performance for capsule spacecraft generally involves the use of a combination of analytical and empirical tools that are often highly proprietary.**
  - **NASA applications routinely stretch the applicable range of these tools.**
  - **NASA engineers have little knowledge of the formulation or implementation of the tools making it difficult , if not impossible, to determine if appropriate physics for their problem are being modeled and simulated.**
- **As NASA missions increasingly challenge the capability of today's parachutes, new NASA-tailored tools will be required to predict decelerator performance.**
  - **NASA attempts to contract for the development of tools for internal use have also run into proprietary claims making the basic workings of the tools inaccessible to NASA engineers and researchers.**
- **Computational capability has improved to the point where CFD tools including fluid-structure interactions can start to be directed at this problem.**
- **There is no Agency mechanism that allows the community to propose, formulate, and conduct the experimental and computational investigations required to attack this problem.**



Capability Challenges

- So far, we have discussed where we want to go and the technical challenges ahead.
- What are some of the organizational and administrative challenges facing us?
- Aerosciences Capability Assessment identified the top impediments to moving on the top Aerosciences Technical Challenges.

Capability Challenge #1: Base Capability

- **Aerosciences research and development for Aeronautics applications is well-addressed by the Aeronautics Research Mission Directorate.**
- **As Space vehicle technical challenges are uncovered, there is no Mission tasked with addressing the R&D needed to address the technical issue.**
  - **Science Mission Directorate and Human Exploration Mission Directorate are hardware and operations focused and generally do not pursue long-term R&D efforts.**
  - **Aeronautics Research Mission Directorate views space applications as outside their sphere of responsibility.**
  - **Space technology Mission Directorate traditionally focuses on mid-TRL objectives, but have recently begun entertaining some proposals for low-TRL development. e.g. Entry System Modeling project.**

ACLT Recommendation:

Develop an <u>enduring</u> base capability <u>funding</u> mechanism to research, develop, and maintain the technical capability required to execute <u>NASA</u> Programs and Projects.

Capability Challenge #2: Computations vs. Test

- **Aerosciences ground test facilities (wind tunnels) are not fully funded at the Agency level resulting in a direct charge to programs using these facilities.**
- **High-end computing systems are fully funded at the Agency level and are "free" for use by programs, as needed.**
- **Charging discrepancy pushes programs and project, particularly small ones toward analysis and computations over ground testing.**
- **Aerosciences computational tools are not capable of replacing test in most critical flow regimes.**
  - **Artificially pushes programs to accept technical risk to control costs.**

ACLT Recommendation:

Reconcile charging differences between test and computations.*

**** This recommendation has been accepted by Agency leadership and we are now in the first year of operating our critical wind tunnels under a new Agency funding model. (Detailed later in this course)***

Capability Challenge #3: Supercomputing for Advanced Computational Method Development

- Present NASA high-end computing systems are fully utilized for project applications, research, and tool development.
- Many of NASA's present Aerosciences tools do not scale to envisioned computing systems utilizing up to millions of processors.
  - Cannot effectively dedicate all or large portions of NASA's high-end computing capability to developing tools that will run on future systems.
- Rapidly evolving computer technology makes it economically infeasible to invest in a separate high-end computing capability for tool development and research.
- DoD and DoE have already invested in these types of systems due to testing constraints that are forcing them into computational-based certification for some of their systems.

ACLT Recommendation:

NASA should pursue the development of partnerships and coalitions to access computational resources representative of envisioned future hardware and develop advanced computational methods on these systems.

Capability Challenge #4: Flight Data Opportunities

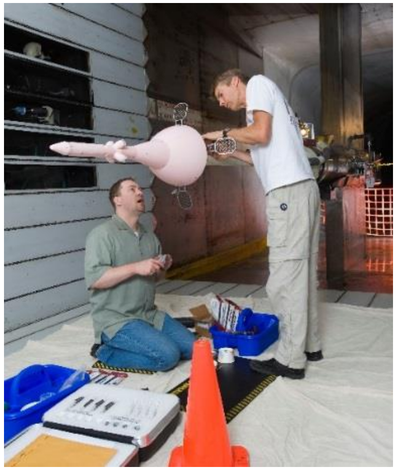
- **Flight data can be an important and even critical component to development advanced Aerosciences concepts and computational tools.**
- **Generally, Aerosciences requirements are not critical enough to warrant a flight test dedicated to acquiring aerosciences data.**
  - **Most flight testing focuses on integrated vehicle system, environment verification, GN&C, and flight mechanics data.**
- **NASA conducts numerous operational missions that involve flight through extreme aerodynamic and aerothermodynamic environments, data from which could prove invaluable to vehicle characterization and validation of computational tools and ground test techniques.**

ACLT Recommendation:
Require the evaluation of flight engineering data collection on all NASA programs and projects. Final decisions in implementation should be made at an Agency level.*

****** Recent solicitations for SMD robotics missions have expressly referenced the gathering of these types of data as a favorable factor in design selection.***

New Funding Model for Aerosciences Evaluation and Test Capabilities (AETC) Portfolio

Vision for NASA's New Aerosciences Ground Test Funding Model



One of the first NASA Capability Management recommendations was a New Funding Model (analogous to High End Computing) for Aerosciences ground test capabilities.

In FY17 the New Funding Model will fully cover the operational cost for NASA users of a key set of critical aeroscience ground test facilities. In addition, limited funds are available for capability advancements, new test technologies, and maintenance.

Starting in FY19 consumables (e.g. power, fuel, etc.) will also be covered.

EC-2015-06-001a Decision [July 28, 2015]

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. The New Funding Model will:

- 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

The NASA Aerosciences Evaluation and Test Capability (AETC) Portfolio will manage the aeroscience ground test capability portfolio for the Agency under this New Funding Model.

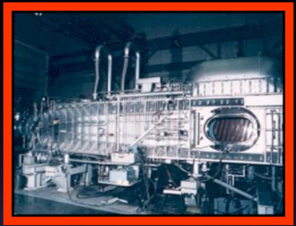
Facility Portfolio

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:

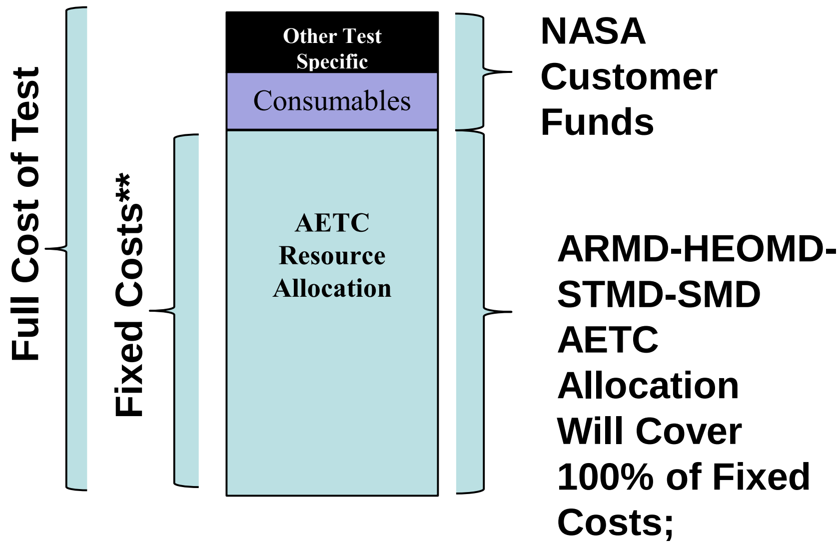
GRC Icing Research Tunnel
Aircraft Icing Condition Simulation

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

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

FY17+ New Funding Model

FY17-NASA Tests



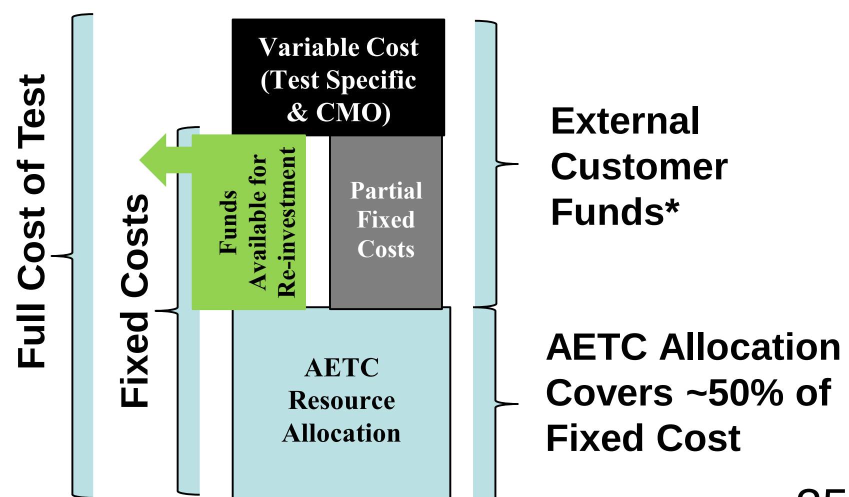
*Starting in FY19 there is a significant Uptick in MD allocation to cover consumables such as power

* International customers pay full cost of test
** Includes workforce to sustain set capacity

When reimbursable customers use AETC facilities:

- Reimbursable funds are <u>applied</u> to test specific and operations ("market rate") costs
- Once reimbursable funds are realized <u>AETC funds</u> slated for operations are <u>re-invested</u> the next Quarter into maintenance and capability advancements; need to burn down $500M+ maintenance backlog
- $9M reimbursable revenue will be realized by end of FY17 with some re-investment still occurring in 1QFY18.

FY17-Reimbursable Tests



AETC Governance

Currently governed by:

- ARMD Advanced Air Vehicles Program's (AAVP) Program Commitment Agreement signed (May 2016) by Robert Lightfoot and Jaiwon Shin and AAVP Plan defines AETC Project's (as well as other AAVP Projects) roles and responsibilities for the Agency
  - Established and managed by ARMD using appropriately modified NPR 7120.8 NASA R&T Program and Project Management Requirements
  - Has membership from 3 primary aeroscience ground test Centers: Ames, Glenn, and Langley Research Centers
  - Project Manager is allowed to reside at any of the AETC Centers (Ames, Glenn, and Langley Research Centers); Project Manager currently residing at Glenn Research Center

- NASA Executive Council Decision Meeting (PPBE FY17 Final Issue Paper July 28, 2015 (EC-2015-06-001a)), as part of the New Funding Model for Aeroscience Ground Test Facilities, provides expanded and additional roles and requirements for the AETC Project starting in FY17

- Aeroscience Test Advisory Board (ATAB)- provides guidance to and input for the ground test capabilities that are managed within the Aeronautics Research Mission Directorate (ARMD). Representing the major stakeholders (ARMD, HEOMD, SMD, STMD, Capability Leadership and Centers) of the aerosciences ground test capabilities, the ATAB serves as the main advisory board to the ARMD Aerosciences Evaluation and Test Capabilities (AETC) Project in the development and execution of plans and to support the facilitation of conflict resolution.

Future governance change:

- Future NASA Policy and Requirements Directives, currently being formulated and under stakeholder review, will further define AETC portfolio roles and responsibilities and governance to the rest of the Agency and establish Agency policy and requirements (i.e. NPD/NPR) for capability portfolio management. Anticipate NPD/NPR approval by April 2018.

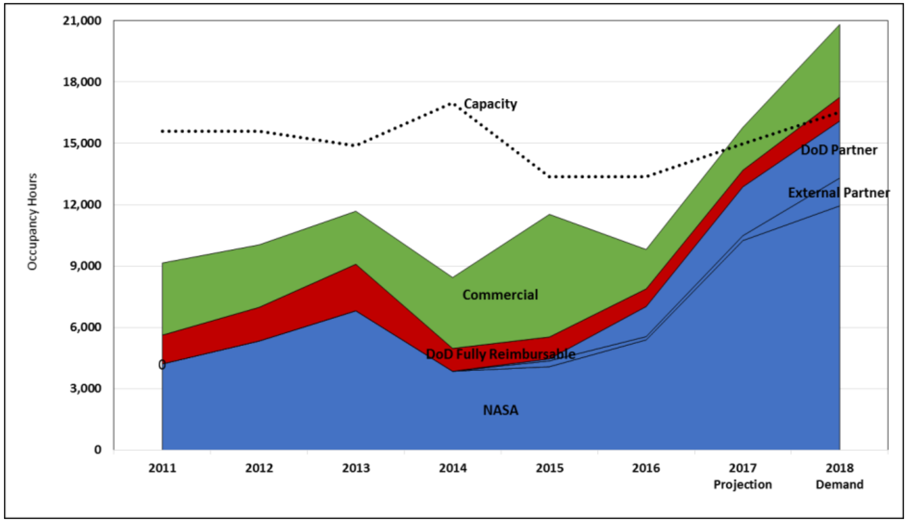
AETC Managing for the Benefit of the Agency

- **AETC has used the ATAB to ensure maximized benefit across the Agency and includes the following members**

Voting	
• Chair	Mike Mastaler, SETMO
• Deputy Chair, Representative for ACLT	Dave Schuster, Aeroscience Capability Leadership Team Lead
• Representative for AETC	Ron Colantonio, AETC PM
• Representative for ARMD	Rich Wahls
• Representative for HEOMD	Dan Hedin
• Representative for SMD	Jim Watzin
• Representative for STMD	LK Kubendran
Non-Voting	
• Technical Rep for Space Applications	Ray Gomez, JSC
• Technical Rep for Aeronautics Applications	Jim Ross, ARC
• Representative for Business Applications	Kathy Ferrare, LaRC
• Center Reps	

- **The ATAB meets quarterly and over the last year has**
  - Reviewed and commented on AETC performance and quality of work and new AETC processes (e.g. overcapacity)
  - Jointly developed measures and metrics
  - Reviewed and commented on upcoming implementation plans and new investments
  - Messaged the New Funding Model to respective Mission organizations
  - Reviewed the FY17 testing types and approved critical partnerships covered under the Model
- **Annual Test Demand Surveys conducted across all 4 Missions to collect next FY and beyond test needs and new capabilities or test technologies needed.**
- **Annual Capability Assessment conducted that includes figures of merits pertaining to all Mission Directorates- to be reviewed by ATAB; drives investment decisions**

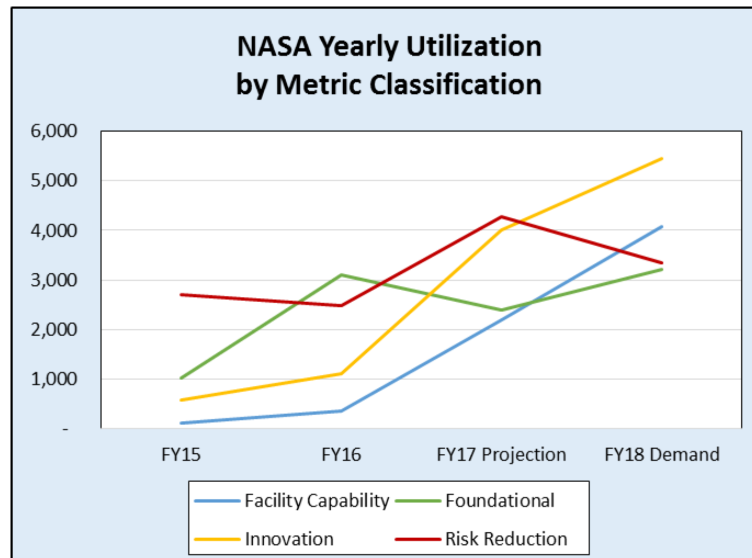
Aerosciences Facility Funding Model Resulting in Immediate Agency Utilization Improvement



- In FY17, aerosciences test demand has exceeded facility capacity for the first time in over a decade
- ***Increase in NASA utilization by over 50% in FY17***
  - NASA program/project utilization is up while commercial and DoD reimbursable testing remains level or is increasing
  - Reimbursable testing provides for critical maintenance ($500M+ maintenance backlog) and new capabilities - ***$9M reinvestment in FY17.***
- FY 18 Test Demand Survey asked NASA customers if proposed testing would be pursued without the New Funding Model
  Result: 50% of the 14,000 NASA testing hours would not have been requested

First 9 months of implementation has shown more robust user response than expected (Anticipated as much as a 3 – 5 year transition to realize full potential of the new funding model):

- ARMD showing substantial increase in Innovation testing with DoD and Commercial data sharing partnerships doubling
- HEOMD showing substantial increase in Risk Reduction testing
- Facility Capability testing (characterization, calibration, mature new test technologies, etc.) up 4-fold with crosscutting benefits to all Missions
- Projects employing innovative test techniques to risk reduction testing
  - University-developed Doppler Global Velocimetry flowfield measurements for SLS Booster Separation testing in LaRC UPWT
  - Dynamic pressure sensitive paint for SLS Buffet and Aeroacoustic testing at ARC UPWT this fall
  - Atmospheric turbulence generator spires and Earth boundary layer simulator blocks added to LaRC Transonic Dynamics Tunnel to evaluate ground wind loads on CCP launch vehicles



Note: FY18 Test Demand is preliminary and will continue to evolve throughout FY18

Innovation Cross-Over

Simplification of facility funding and advocacy for project-level testing is allowing engineers to investigate and incorporate innovative test techniques in their baseline and risk reduction testing.

- **University-developed Doppler Global Velocimetry flowfield measurement techniques for SLS Booster Separation testing in LaRC UPWT.**
- **Previous tests of dynamic pressure sensitive paint on a generic launch vehicle is being leveraged in SLS Buffet and Aeroacoustic testing at ARC UPWT this fall.**
- **Atmospheric turbulence generator spires and Earth boundary layer simulator blocks added to LaRC Transonic Dynamics Tunnel to evaluate ground wind loads on CCP launch vehicles.**

LaRC Transonic Dynamics Tunnel

Turbulence Spires and Boundary Layer Floor Blocks for CCP Ground Wind Loads Testing

ARC Unitary Plan Wind Tunnel

Dynamic Pressure Sensitive Paint Being Incorporated On Upcoming SLS Buffet Testing

FY17 Sample Testing Highlights

ARC Unitary Plan Wind Tunnel

- **HEOMD** 1.3% Scale Space Launch System (SLS) Ascent Aerodynamic Force and Moment Test
- **USAF-Lockheed** Joint Air-to-Surface Standoff Missile Test [Risk Reduction- Reimbursable]
- **Naval Air Warfare Center Weapons Division** High-Speed Anti-Radiation Missile (HARM) Test [Risk Reduction- Reimbursable]
- **Naval Air Systems Command** Next Generation Jammer (NGJ) Tests [Risk Reduction- Reimbursable]

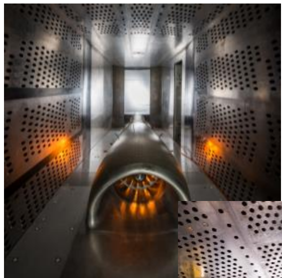
GRC Icing Research Tunnel

- **ARMD** Swept Wing Icing, Icing Roughness (Baylor NRA) and Bimodal Supercooled Large Droplet Tests [Foundational]
- **AETC** Winter Calibration and Liquid Water Content Repeatability Investigation Tests [Facility Capabilities]
- **General Atomics, Meggitt Polymers & Composites, Mitsubishi, Meggitt, Textron, etc.** Tests [Risk Reduction- Reimbursable]

GRC Propulsion Systems Laboratory

- **ARMD-GE-AFRL-FAA** GE F110 Power Extraction (Turbine Electric Hybrid Technology) Test [Innovation]
- **ARMD-AFRL-DARPA-Lockheed Martin** Water Injection Test (Hypersonics) [Innovation]

FY17 Sample Testing Highlights



GRC 9x15/8x6 Foot Wind Tunnels

- **ARMD** Boundary Layer Ingesting Inlet – Distortion Tolerant Fan (BLI2DTF) Test [Innovation]
- **ARMD** Quiet Supersonic Technology (QueSST) Test [Risk Reduction]
- **AETC** Major CoF start to Reduce Background Noise Levels for Future NASA Engine System Noise Measurements

GRC 10x10 Foot Supersonic Wind Tunnel

- **ARMD/DoD** Combined Cycle Engine-Large Scale Inlet Mode Transition Experiment (CCE-LIMX) - Phase 3C Testing [Innovation]

LaRC 14x22 Foot Subsonic Tunnel

HEOMD SLS Ground Winds/Liftoff Test [Risk Reduction]
ARMD Hybrid Wing Body Cross Tunnel Validation
Army Probe Calibration [Facility Capabilities- Reimbursable]

LaRC National Transonic Facility

- **ARMD** Fundamental Aerodynamic Subsonic Transonic – Modular Active Control (FAST-MAC) 3.0 Testing [Innovation]

LaRC Transonic Dynamics Tunnel

- **HEOMD** NASA Space Launch Systems (SLS) Block 1B Cargo Buffet Test [Risk Reduction]
- **HEOMD/NESC** Ground Wind Loads Space X/ULA Periodic Vortex Shedding Load Test [Risk Reduction]

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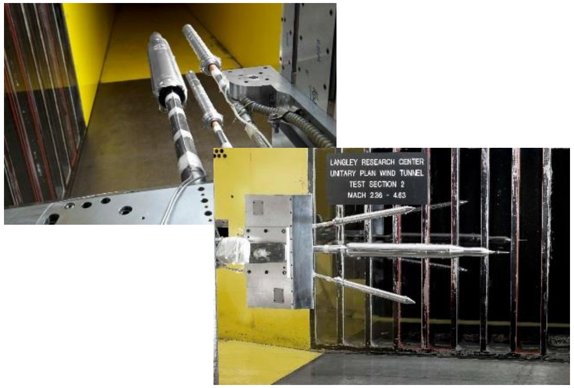
LaRC 8 Foot High Temperature Tunnel

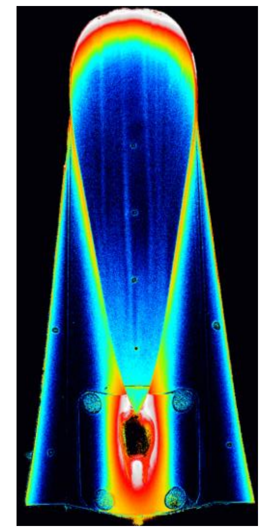
- **Missile Defense Agency** Classified Test [Risk Reduction-Reimbursable]
- **DoD** Classified Tests [Risk Reduction]

FY17 Sample Testing Highlights



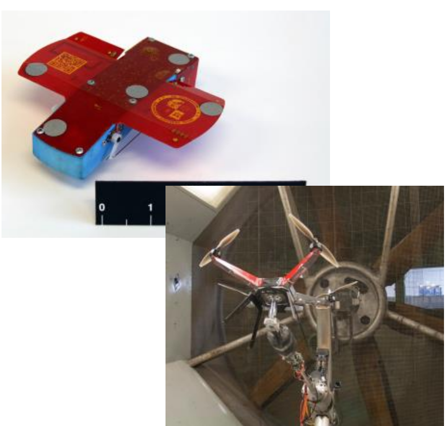
LaRC 4' Supersonic Unitary Plan Wind Tunnel

- **HEOMD** SLS Block 1B Booster Separation Test [Risk Reduction]
- **AETC** Check Standard Test [Facility Capabilities]



Langley Aerothermodynamics Laboratory (LAL)

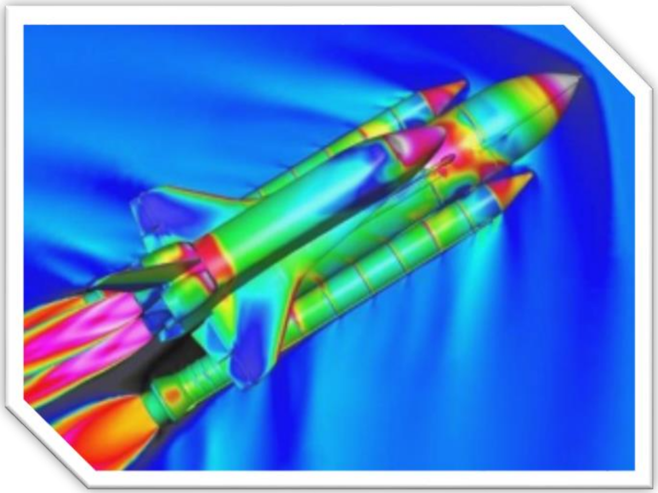
- **ARMD-DoD** HIFiRE 6 Flow Visualization Study [Foundational]
- **AETC-ARMD** Freestream Characterization Test [Facility Capabilities]

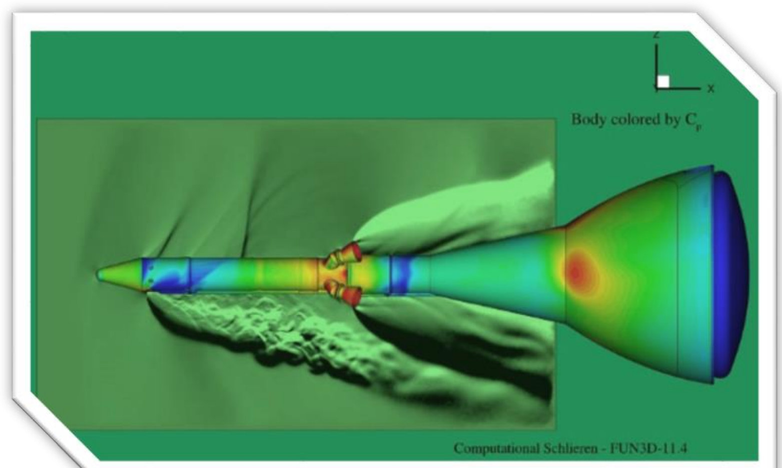


LaRC Flight Dynamics Research Complex

- **LaRC** CICADA Spin Mode Test [Innovation]
- **ARMD** Aerodynamic and Propulsion Models Testing [Innovation]
- **HEOMD/NESC** Commercial Crew Dynamic Stability Test [Risk Reduction]

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





Project Objective

To plan and execute a series of wind tunnel tests and associated CFD analyses to better understand potential Agency risk incurred by divesting of the LaRC Unitary Plan Wind Tunnel

- **CFD and test methodology validation**
- **Allows the Agency to make more informed ground test facility decisions**
- **Provides a guide for future CFD and ground test technique development**
- **Plan includes technical, cost, and schedule components – being reworked**
- **Plan can only account for known and foreseeable mission requirements**
  - **There will always be risk that unforeseen technical requirements could invalidate facility decisions**

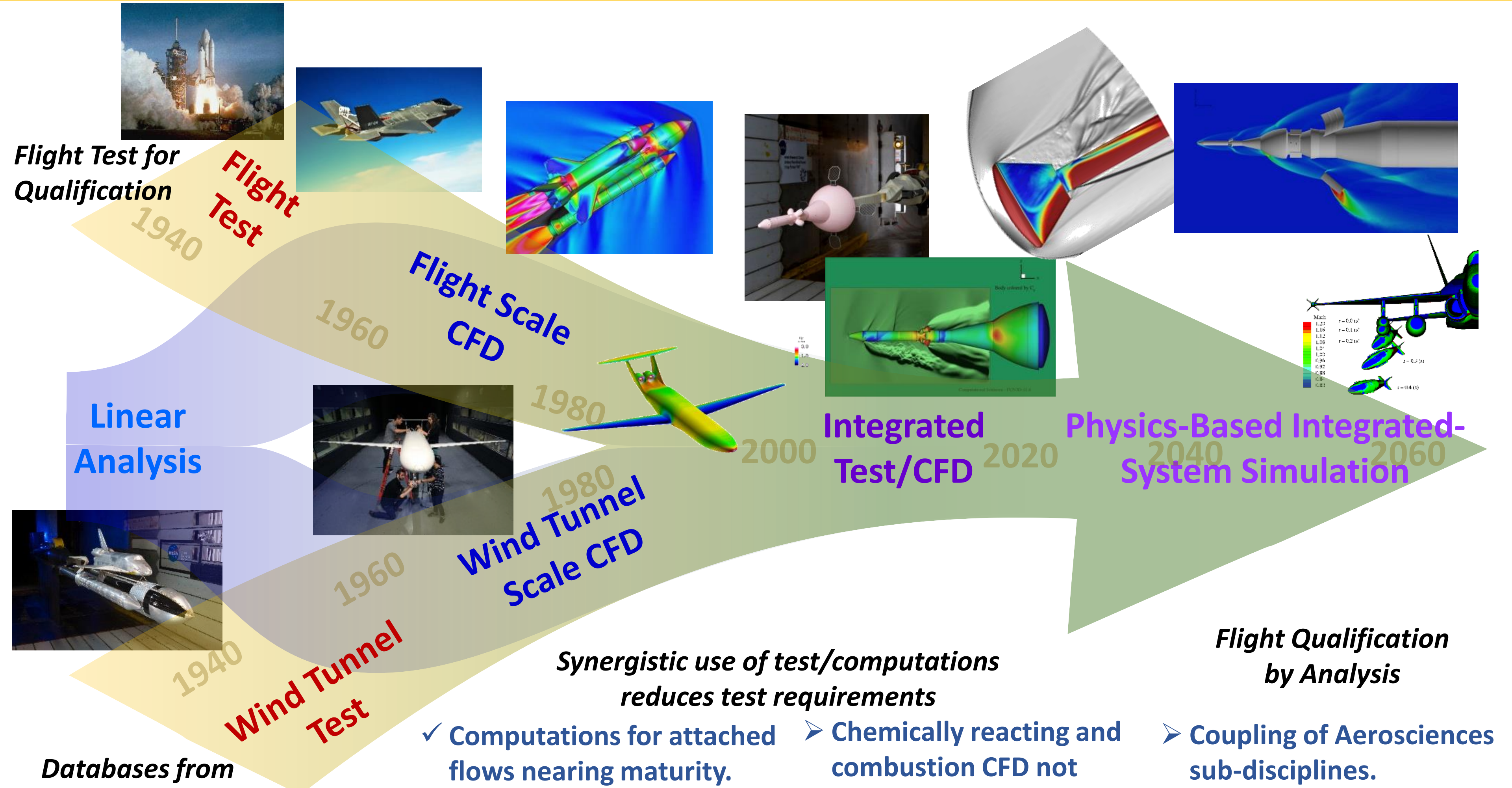
Project Scope

- Assess CFD capability to address NASA Aerosciences* prediction requirements in the Mach 2.5 – 6.0 range without an Agency wind tunnel
  - Evaluate accuracy of computational methods compared to wind tunnel testing for past, present, and future problems of interest
  - Evaluate efficiency of computational analysis compared to wind tunnel testing
    - Cost considerations
    - Schedule considerations

* "NASA Aerosciences" includes those requirements for which the non-NASA community depends on NASA capability

AEROSCIENCES

Aerodynamics – Aerothermodynamics – Aerostructures – Aeroacoustics – Propulsion Integration



Synergistic use of test/computations reduces test requirements

- ✓ Computations for attached flows nearing maturity.
- ➢ Airframe propulsion integration challenges test 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, …

Physics-Based Integrated System Simulation

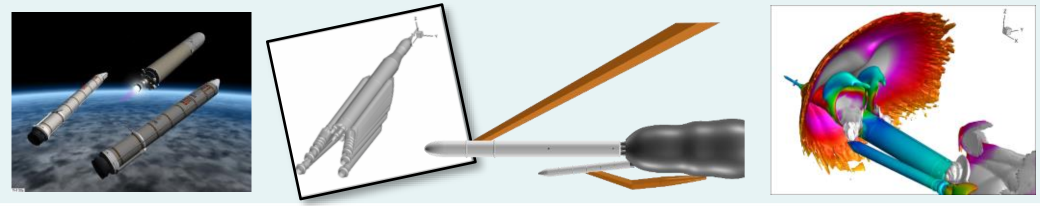
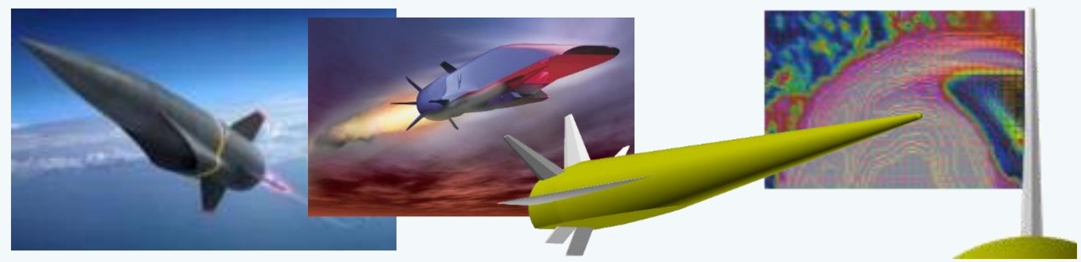
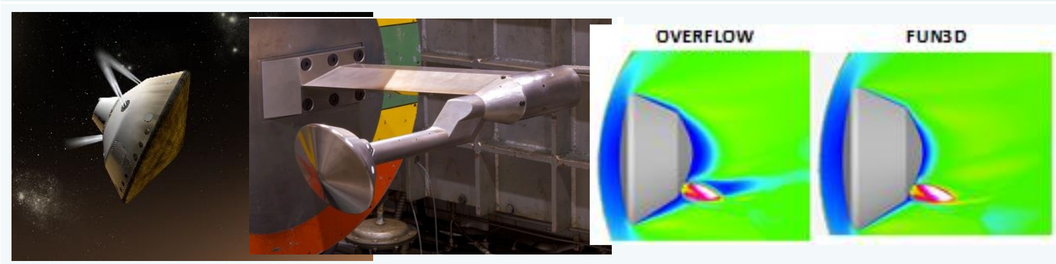
- **Why pursue this goal?**
  - **Eliminates reliance on configuration-specific empirical data and databases**
  - **Significantly reduces time to CDR**
  - **Improves accuracy of predicting system response to design changes**
- **How do we get there?**
  - **Development of models from the most fundamental physics principles possible/required**
    - **Computational Methods for Fluid Dynamics, Acoustics, Fluid/Structures Interactions, etc.**
    - **Test techniques: propulsion simulation, measurement of multibody interactions including shock/shock interactions and shock/boundary layer/shear layer interactions, etc.**
  - **Verification that the physics equations and models are solved/implemented as expected and document best practices**
  - **Validation that the physics and models reproduce flight/test observations**
    - **On- and Off-body flow measurement techniques (e.g., PSP, TSP, oilflow, schlieren, PIV, DGV)**

This test proposal baselines the state of the art in CFD and ground test for the high supersonic speed regime

General Team Observations

- **Present CFD study is a necessary first step to reducing our reliance on subscale ground testing**
  - **High Supersonic Flight regime appears to be most amenable to CFD analysis**
  - **Should not be confined to an isolated study, but should become a test philosophy across the speed range**
- **Unknown cost to develop vehicles solely by numerical simulation, especially for large changes in technology and configuration**
  - **Need a metrological framework or traceability for Computational Methods**
  - **Necessary before we can rely solely on analysis for vehicle design/qualification/certification**
- **Numerical modeling and simulation provides unique and powerful engineering capability for interactions, but can be weak in discovering unanticipated physics**
- **Recent interactions with AEDC and the National Partnership for Aeronautical Testing (NPAT) indicates that DoD Program testing is placing significant schedule pressure on the AEDC von Karman Facilities (Tunnel A, B, C) that is seen as increasing going into the future**
  - *"A lot of programs converging on AEDC and reducing the National Capability is not good. This* [reducing to one national facility] *would not be in the AF best interest. Sole reliance is not good. But we cannot tell another Agency what to do." Beth Emanuel,* ***Air Force*** *T&E*

Proposed Test Cases

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

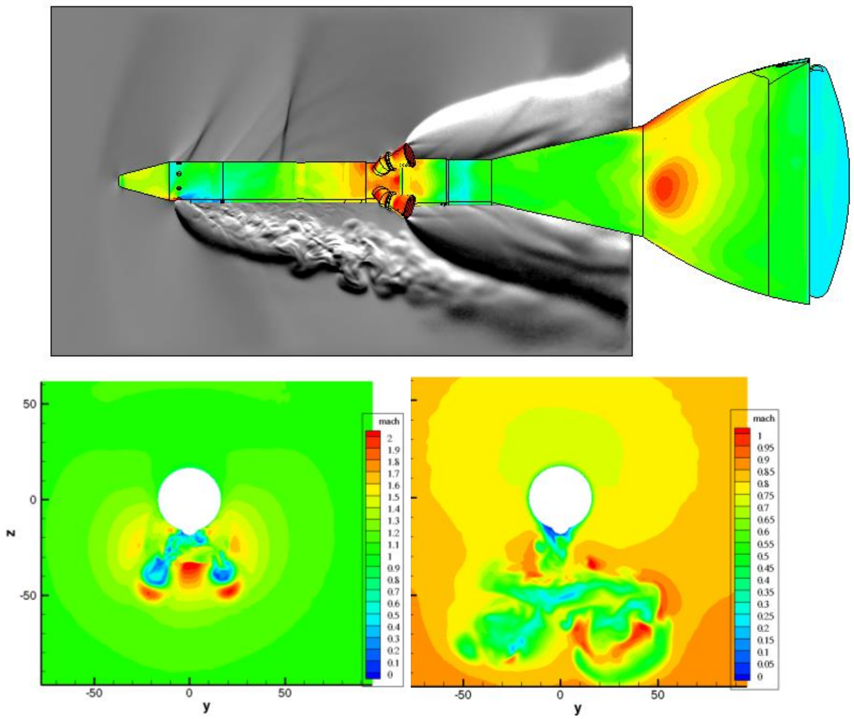
Cases focus on areas of highest uncertainty for CFD simulation in this speed regime

Examples of Aerosciences Assessments Pertinent to the Aerosciences Strategic Vector

Orion AM/ACM Jet Interaction

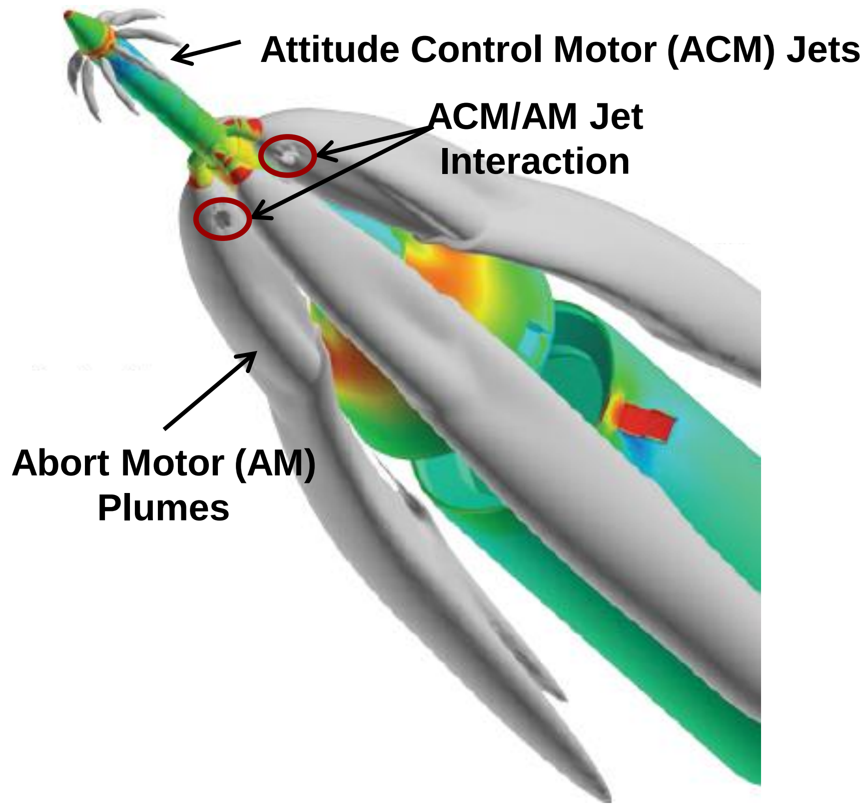
- **USM3D and OVERFLOW both predict Attitude Control Motor asymmetry at Mach 1.10.**
  - **Different code formulations, grid topologies, plume modeling verify issue as not numerical.**
  - **Both steady analyses.**
- **FUN3D has produced early hybrid RANS-LES simulations.**
  - **MSFC working to perform similar computations using Loci-Chem.**
- **Recent analyses of a jet-in-a-crossflow unit problem has demonstrated similar asymmetry and is proving to be a valuable test case on a much simpler configuration.**

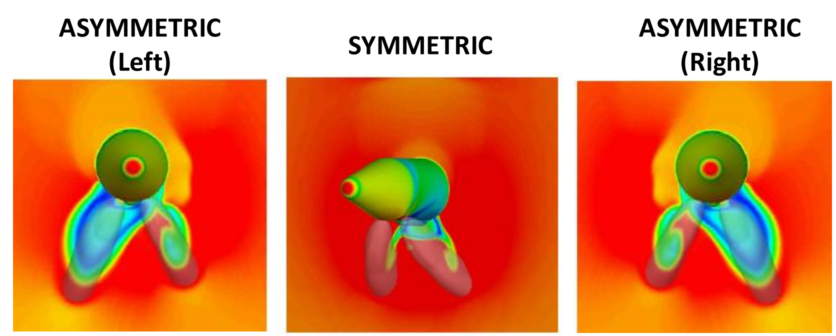
FUN3D Hybrid RANS-LES
M = 1.10, AMCT = 3.0, ACMTR = 0.04



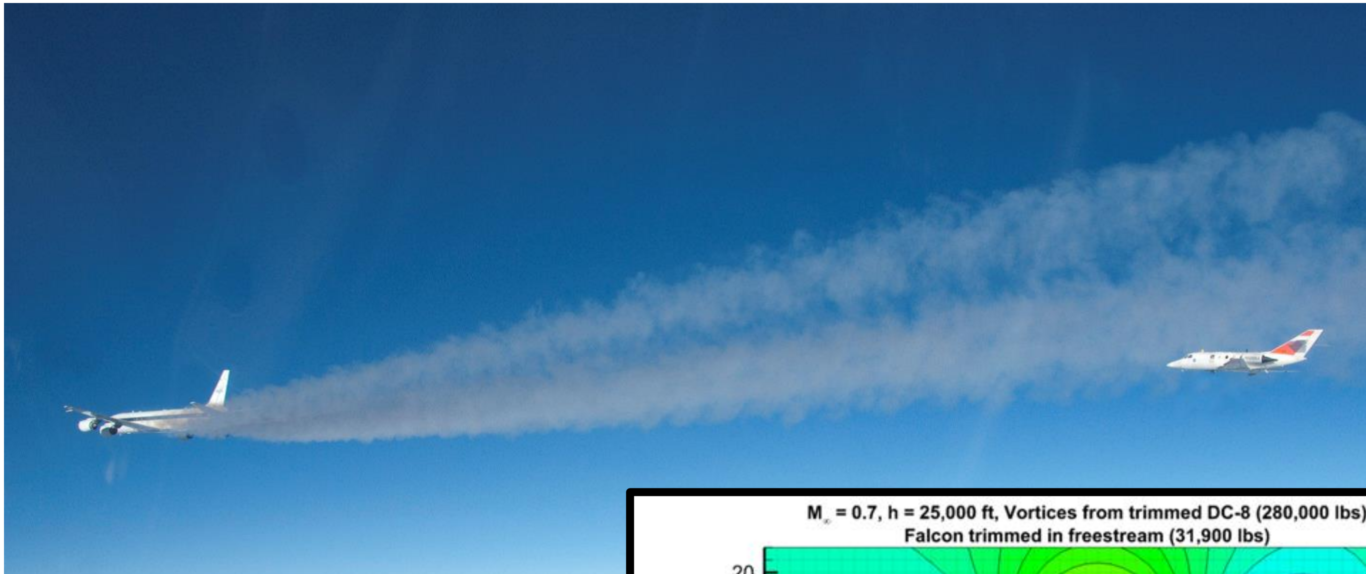
Orion LAV Plume Interaction

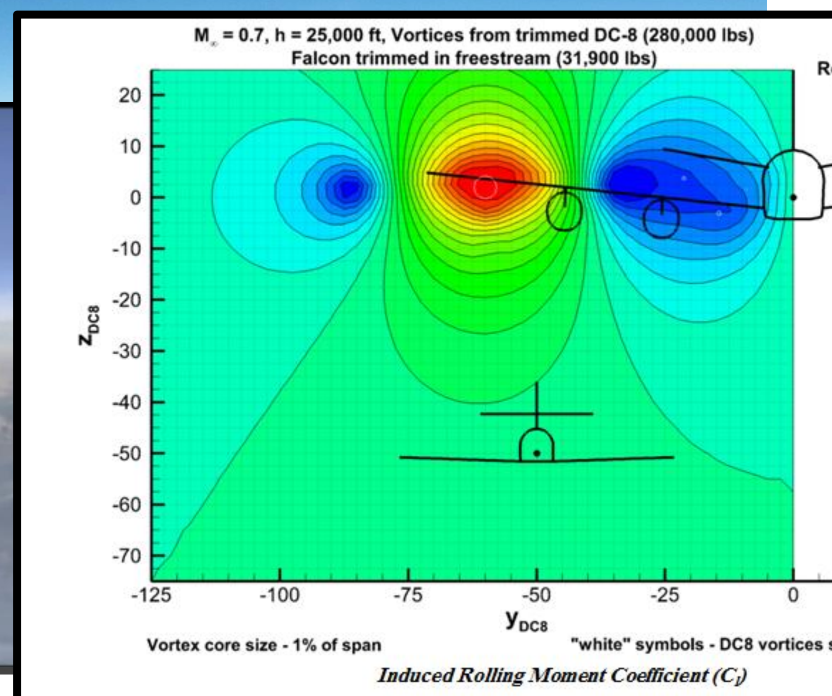
- **Problems involving high-speed, high-temperature, chemically reacting flows interacting with ambient complex attached and separated flowfields.**
  - **Large spread of length and time scales.**
- **Wind tunnel testing expensive and difficult.**
  - **Many questions concerning the validity of tests.**
  - **Hot-plume/cold-plume, plume gas simulant, plume scaling and similarity, measurement interference (blockage, balance fouling, etc.)**
- **Immature CFD.**
  - **Steady flow is the state-of-the-art, but flows are far from steady.**
  - **Turbulence modeling and flow chemistry are also large unknowns.**



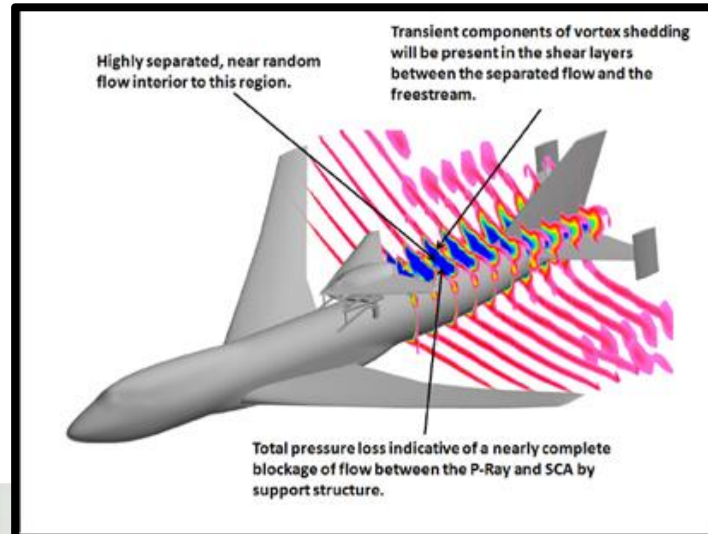


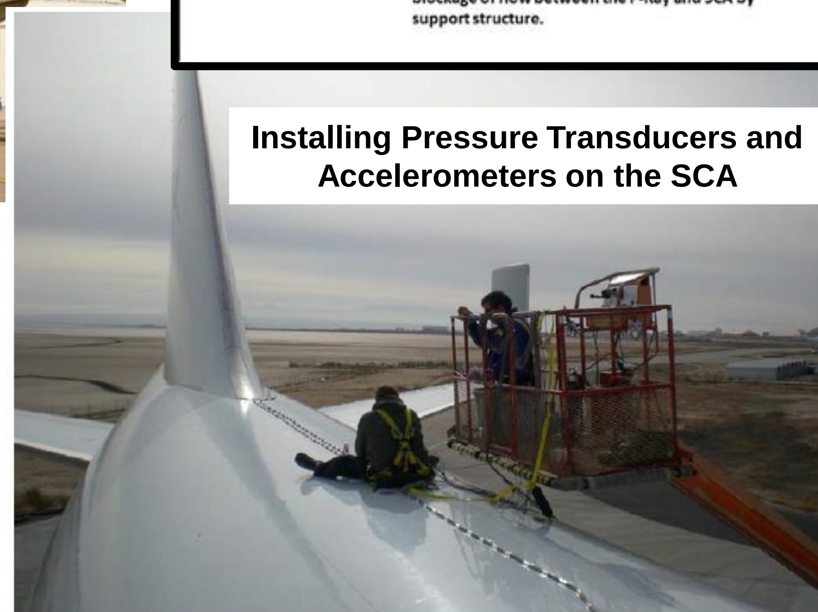
ACCESS Probing Aircraft Flight Test Hazard Mitigation





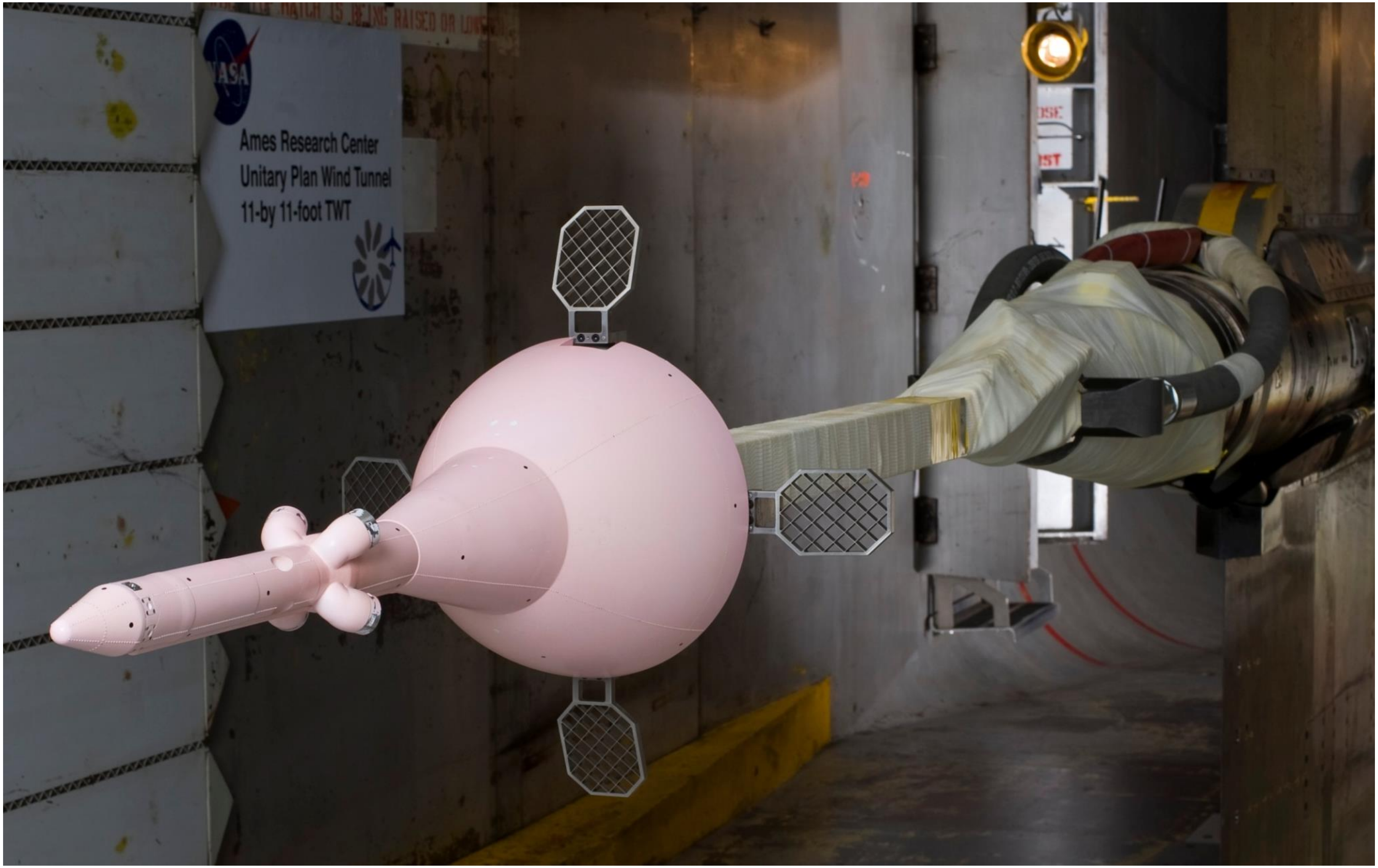
Boeing Phantom Ray Transport on Shuttle carrier Aircraft





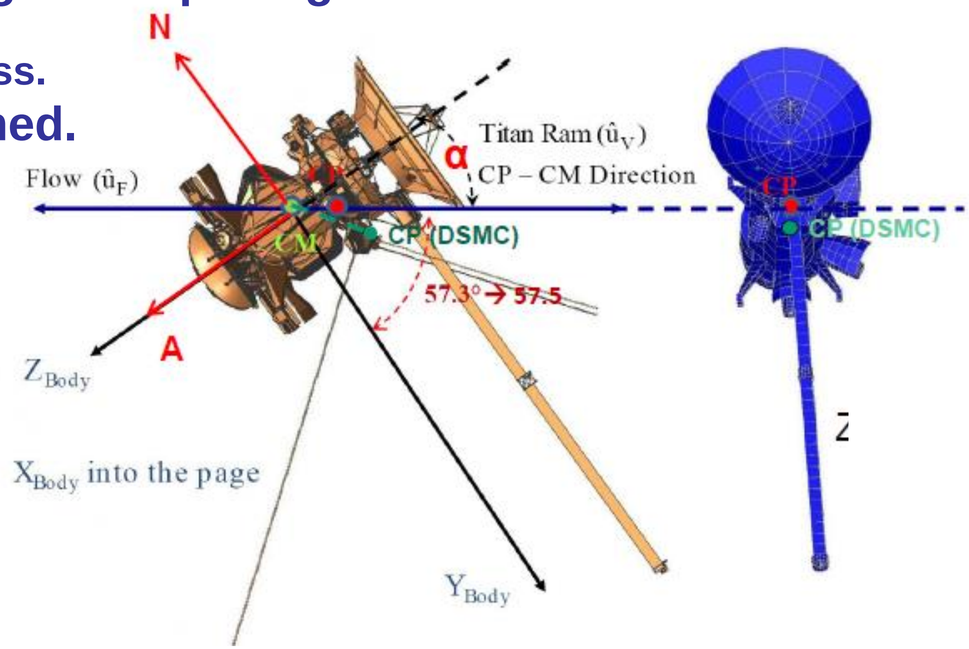
Installing Pressure Transducers and Accelerometers on the SCA

Grid Fin Aerodynamics for Launch Abort Vehicle Stability Augmentation



Cassini Titan -70 880 Km Flyby

- **Cassini passed through Titan's atmosphere at 880 Km altitude in June 2010.**
  - 70 Km lower than the lowest previous pass.
  - Concern over increased duty cycle of RCS.
  - Could cause a spacecraft tumble.
- **Free molecular flow used to predict aero for previous passes.**
  - Lower altitude results in transitional flow.
- **Direct Simulation Monte Carlo (DSMC) required for this type of flow.**
- **Atmospheric density modeling also a pacing issue.**
  - TitanGram adapted to modeling atmospheric density for this pass.
- **Thermal analysis also performed.**
- **Cassini flight analysis TIM held November 23, 2010.**
  - Data acquired and derived from June 20, 2010 flyby:
    - Minimum Altitude: 878 km Atmospheric density (Derived by two separate techniques) estimated to be 70% of that predicted prior to fly-by.
    - Z-thrusters duty cycle was over two times that predicted prior to fly-by.



SCIFLI: Scientifically Calibrated In-Flight Measurements

POC's: Thomas.J.Horvath@nasa.gov & Jay.H.Grinstead@nasa.gov (SCIFLI Co-PI's)

State of the art measurement and diagnostics:

- Launch/Abort
- Cruise
- Entry, Descent & Landing
- Breakup/Hazard zone

Characterization:

- Plume signatures
- Vehicle surface temperature
- Flowfield (emission/absorption)
- Telemetry/blackout

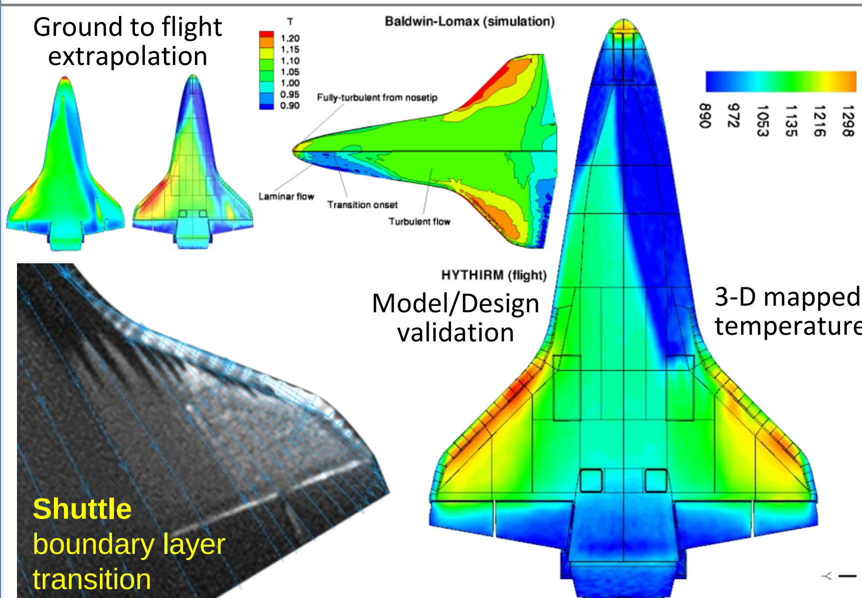
Host Platforms

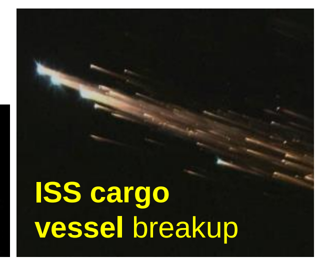
Ground-based | Sea-based | Air-based

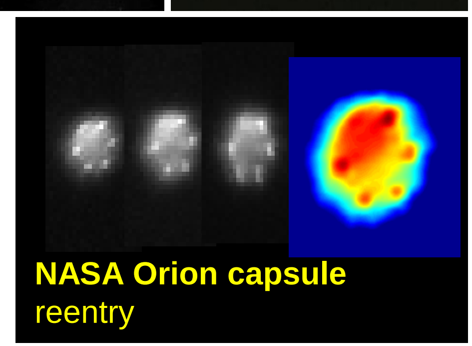
Electro-Optical Imagers

- Visible
- Infrared (NIR-SWIR, MWIR, LWIR)
- Spectral
- High Speed Tracking

Tailored for mission specific requirements

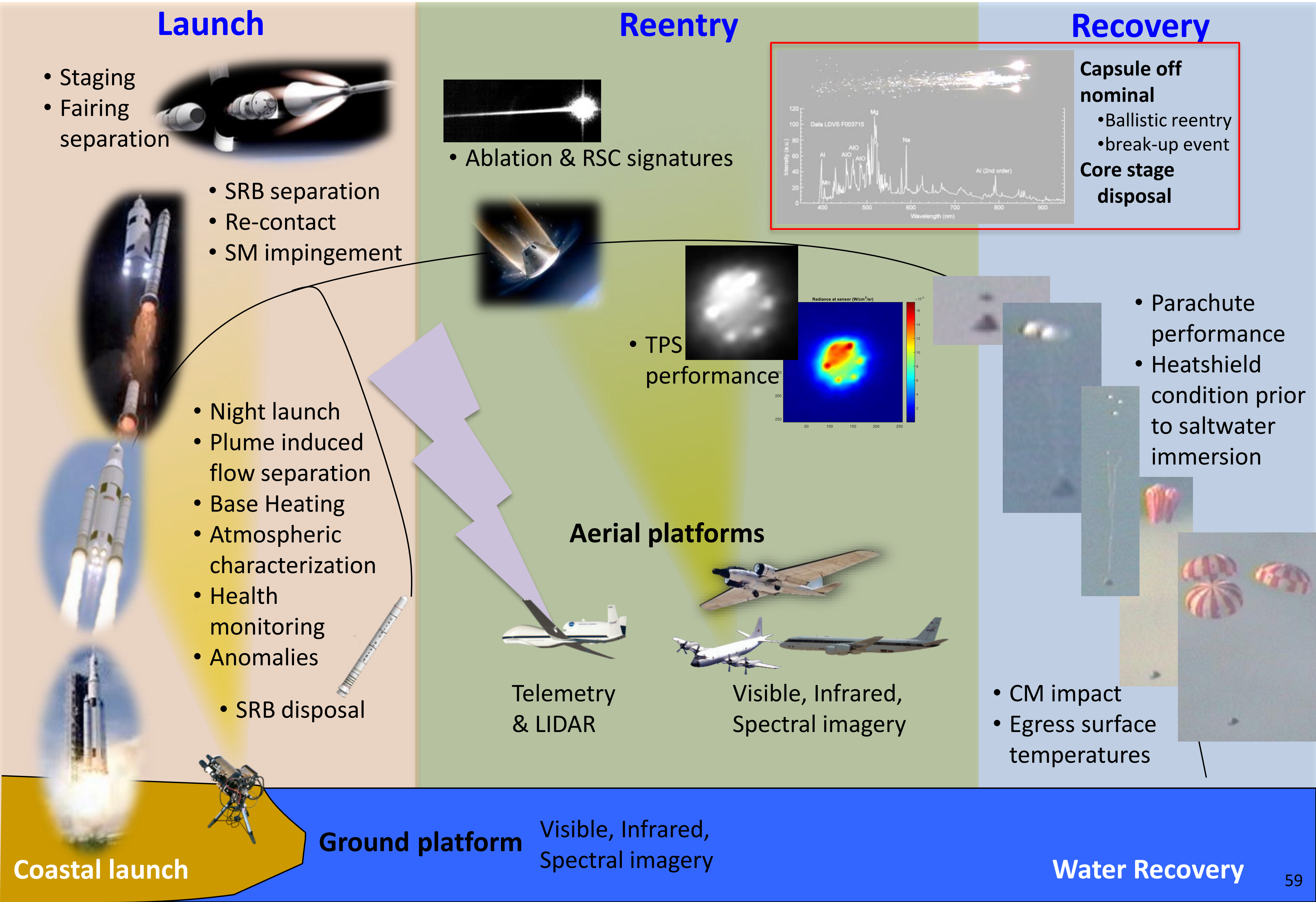






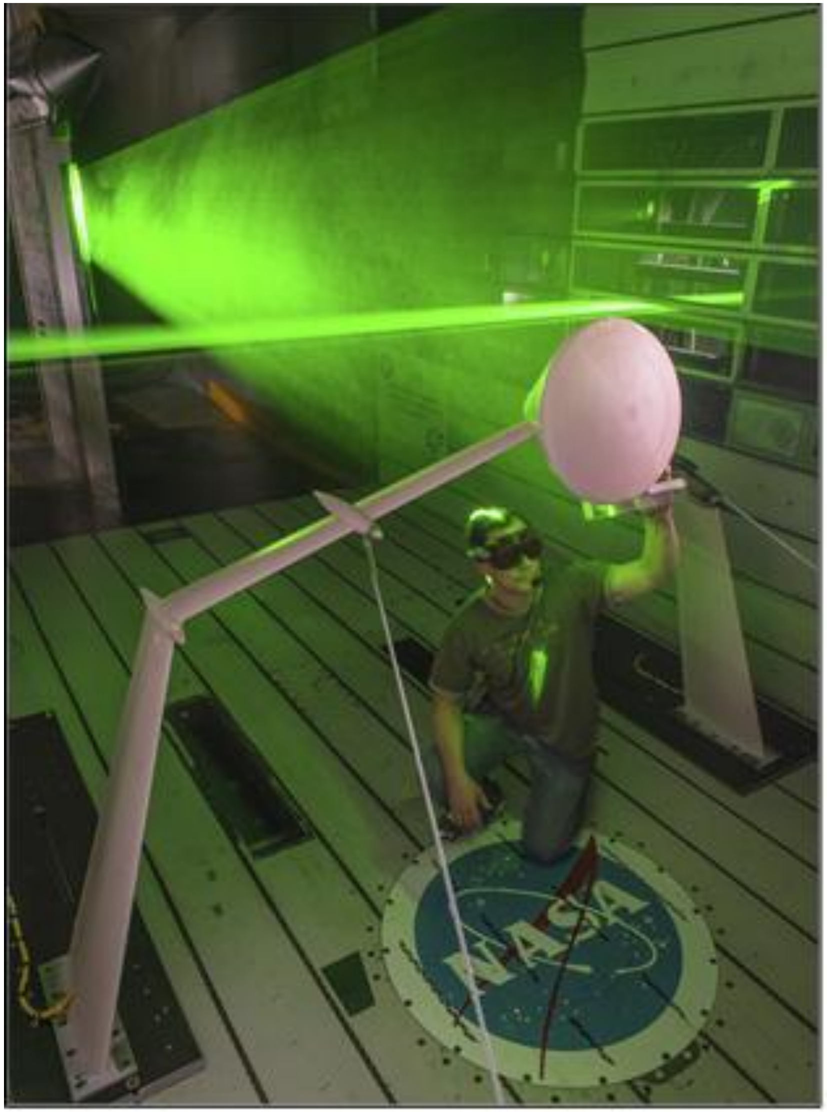
Johns Hopkins Applied Physics Laboratory · MARS · Southern Research Institute · NAVAIR · Spaceflight Meteorology Group · Stinger Ghaffarian Technologies · The Aerospace Corporation

Risk Mitigation and Support to SLS Flight Test Objectives



120-CA CPAS wake Deficit Test

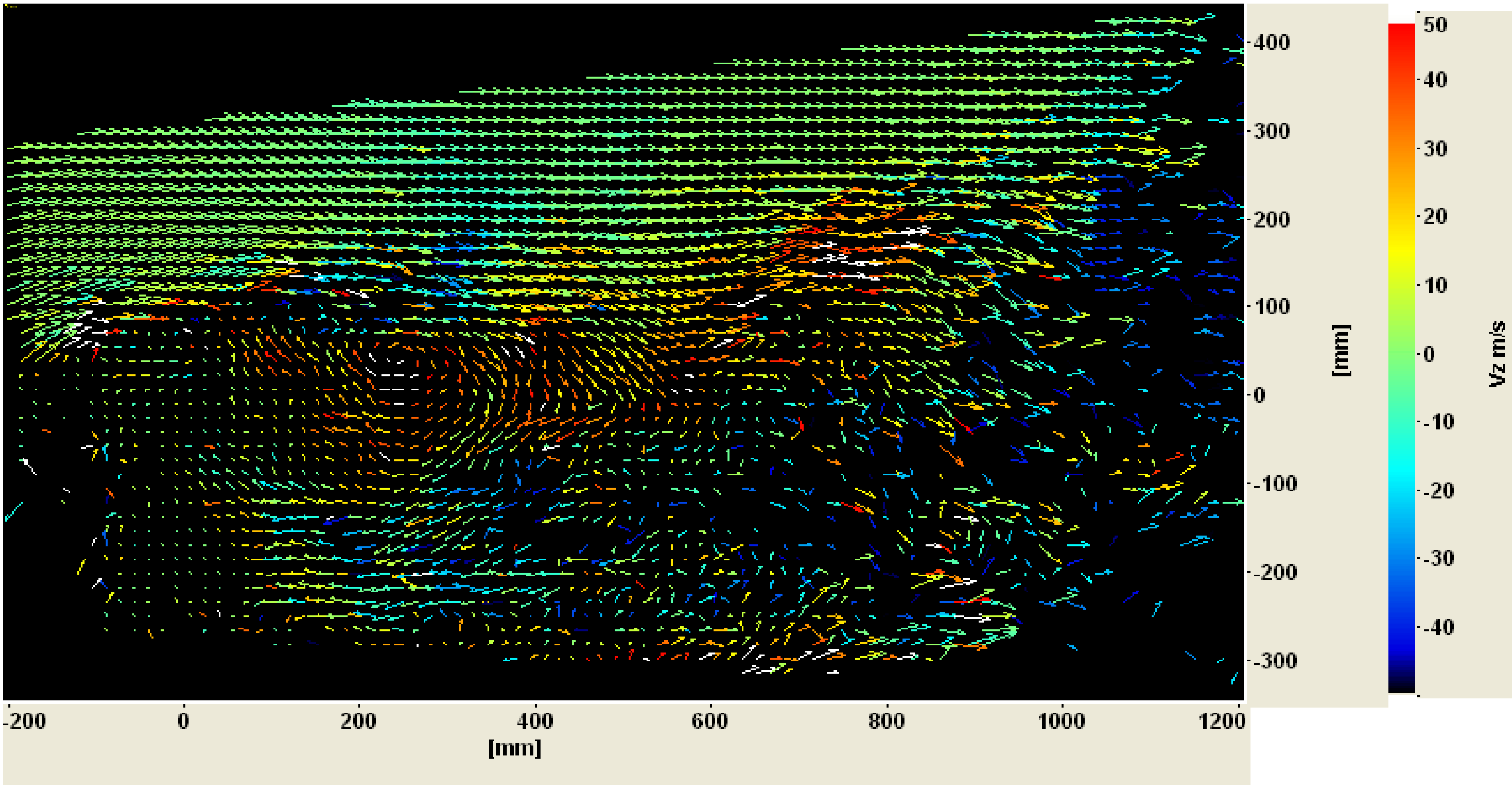
Laser Light Sheets for PIV



PIV at Mach 0.3, 15° - Upper Wide-View Image

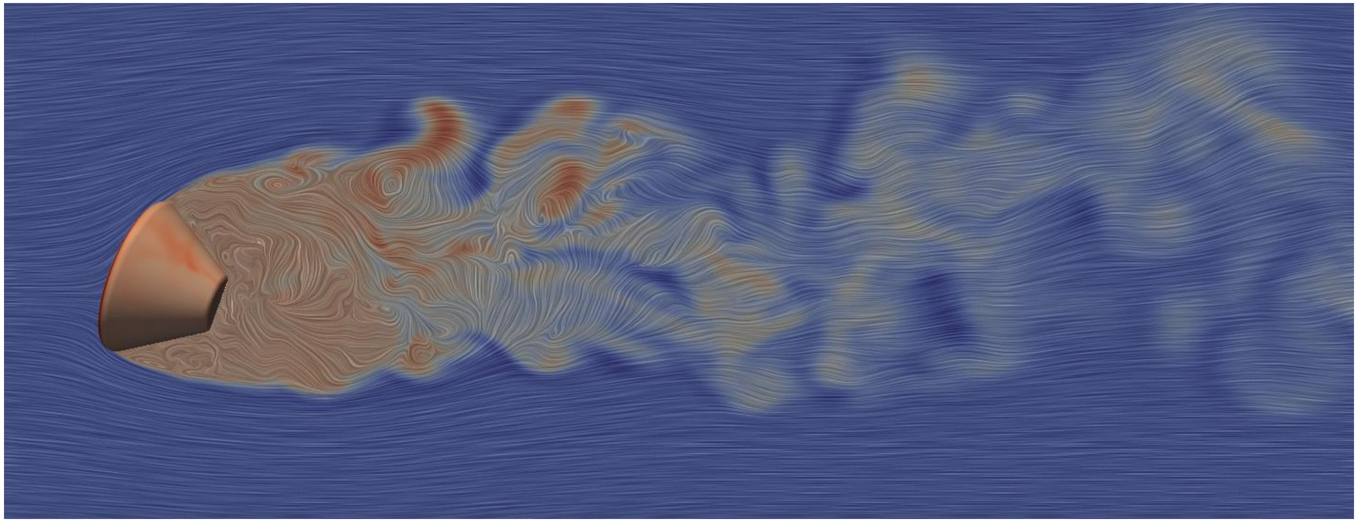
Presenter
D. Schuster

Date
October 18, 2012

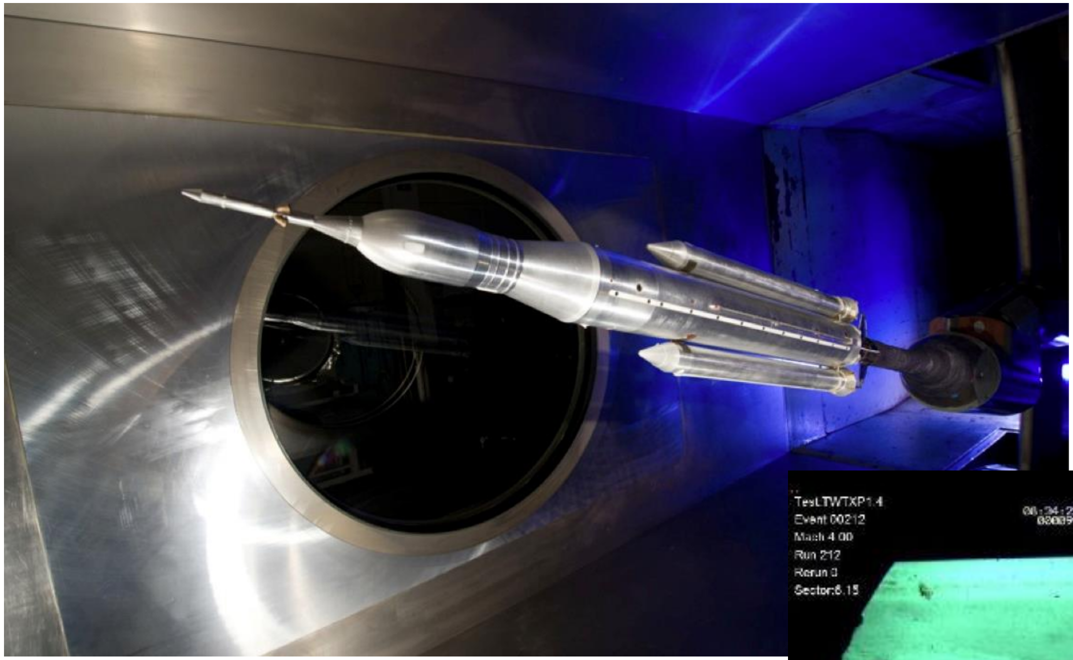


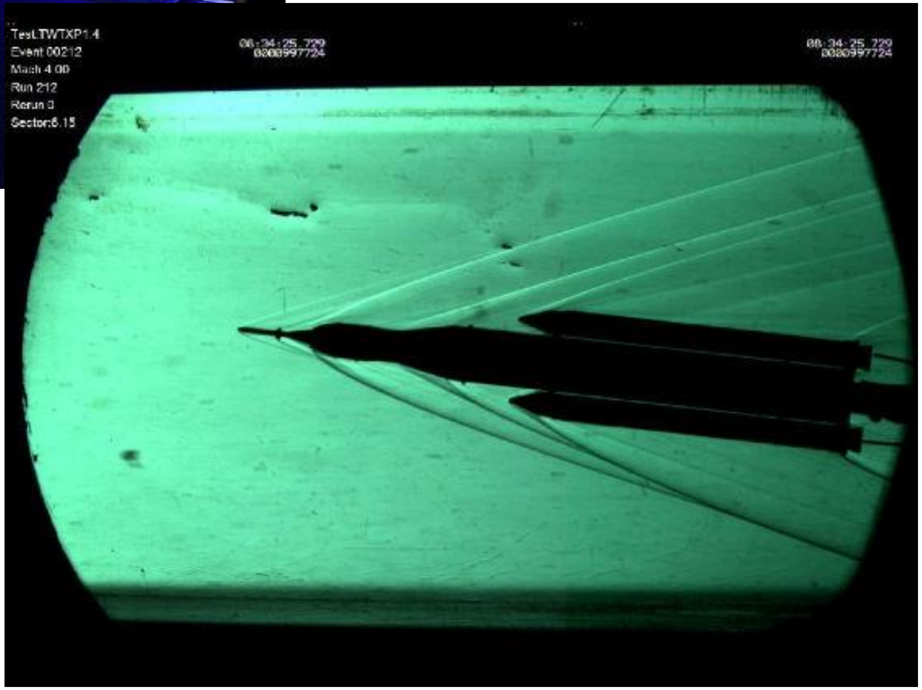
Unsteady Separated Flows

- Collaborating with ARMD's Revolutionary Computational Aerosciences Project make them aware of the Aerosciences SoD challenges.
  - Focus is on unsteady separated flow for a wide range of applications.
- AIAA Aeroelastic Prediction Workshop leveraging U.S. and international partners and data.
  - Initial focus is the prediction of unsteady, separated flow, eventually moving to structural coupling.
- Orion wake characterization testing.
- SLS buffet CFD analysis.



SLS Shock Reflection Testing



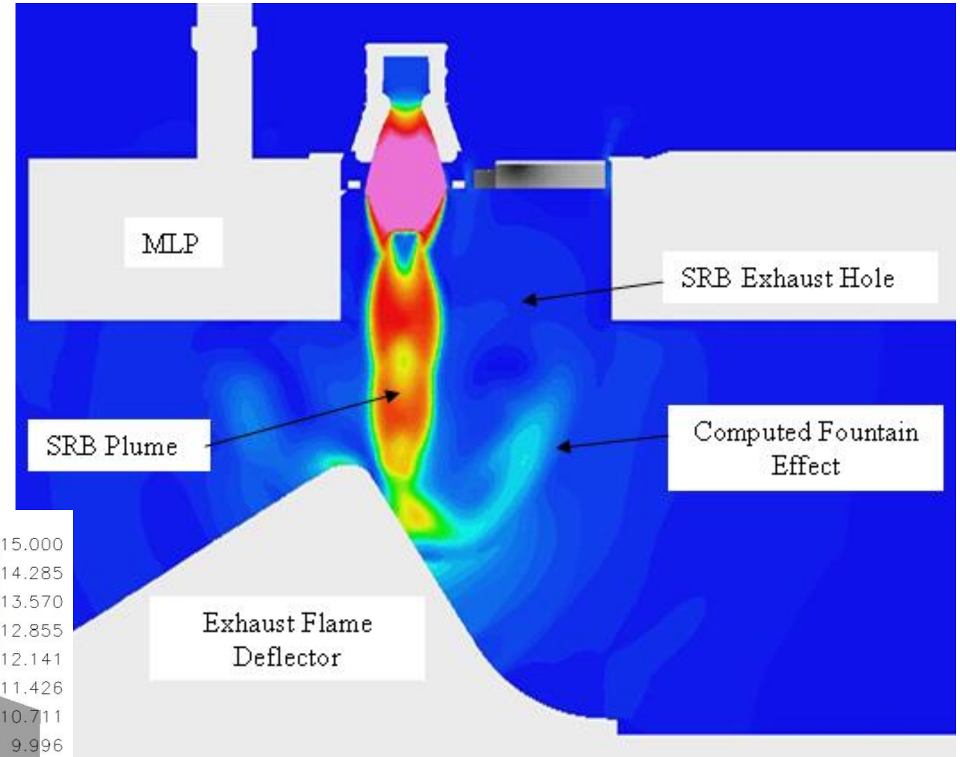


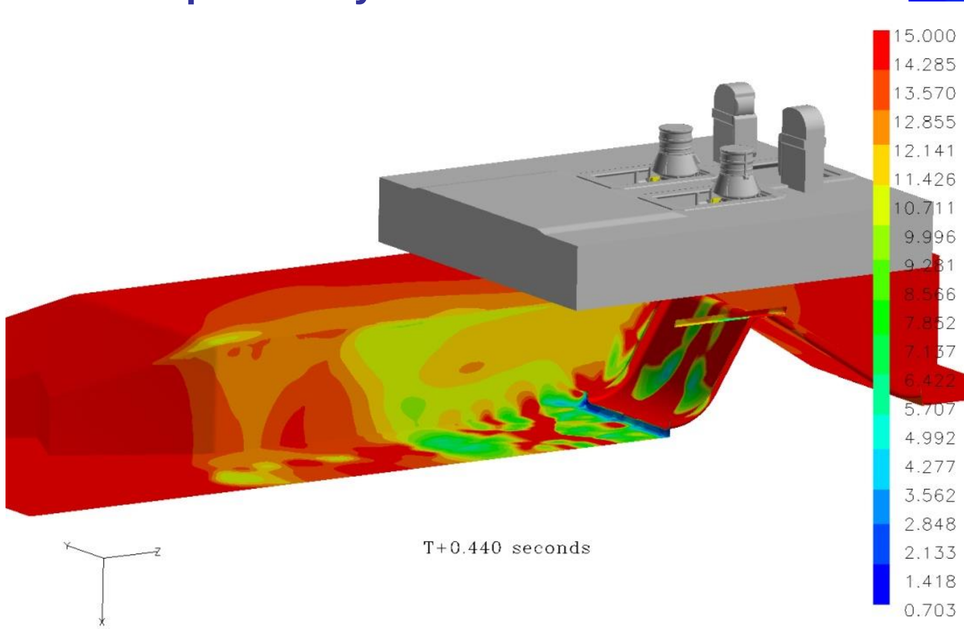
Background

- **Transonic aerodynamics are crucial for controller development. During ascent, the smallest control margins are in the transonic regime. We need to make sure that the data that is provided is as accurate as possible.**
- **Langley's Transonic Dynamics Tunnel had a window open for testing.**
- **Langley SLS, Research**
- **Directorate, and NESC collaborated to fund the test.**
  - **Test Team able to prepare and get in the wind tunnel within a couple days of getting the green light.**

Launch Pad Environments

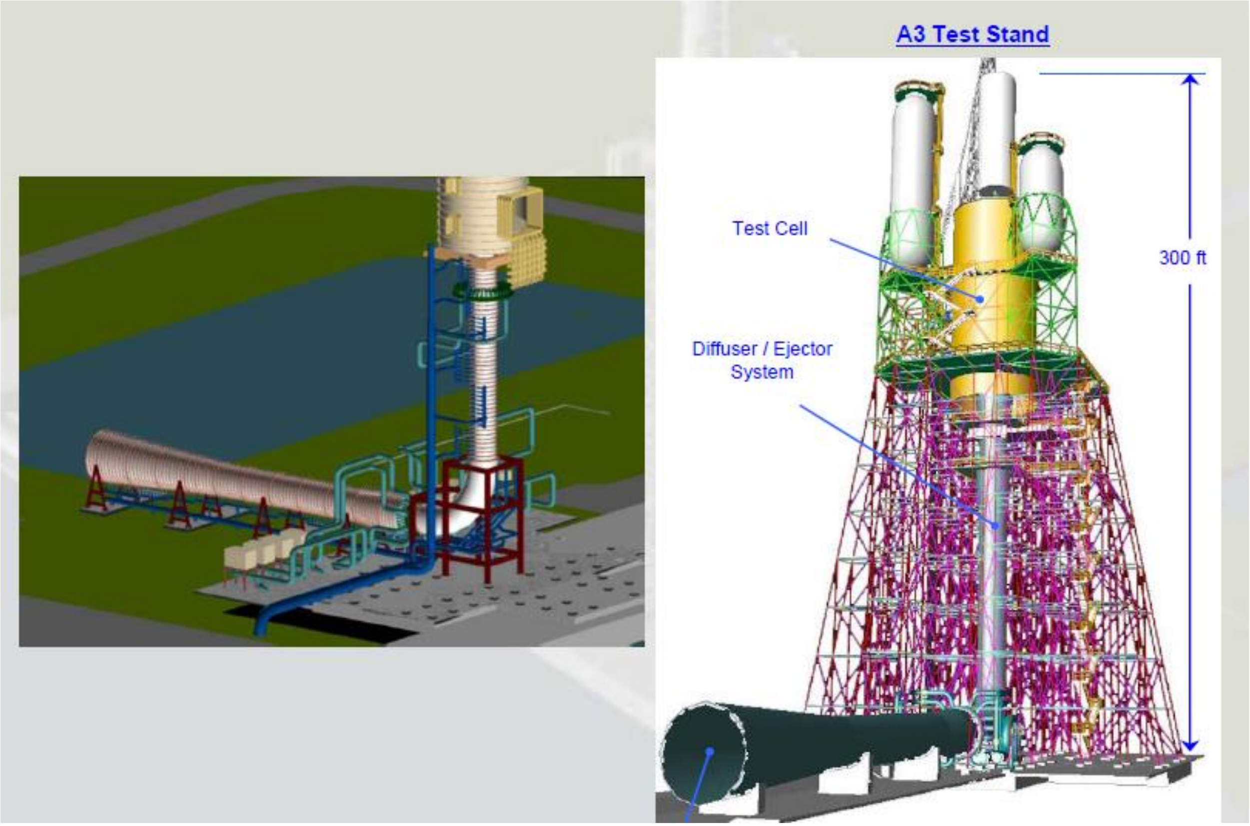
- NESC Aerosciences asked to review prediction of flame trench environments for investigation of STS-124 damage of Pad 39A
- High-energy, chemically reacting rocket plumes.
- Complex geometries.
- Multi-phase flows (water deluge for acoustic suppression).
- Pad surface loads for structural design.
- Flowfield characteristics for debris transport analysis.





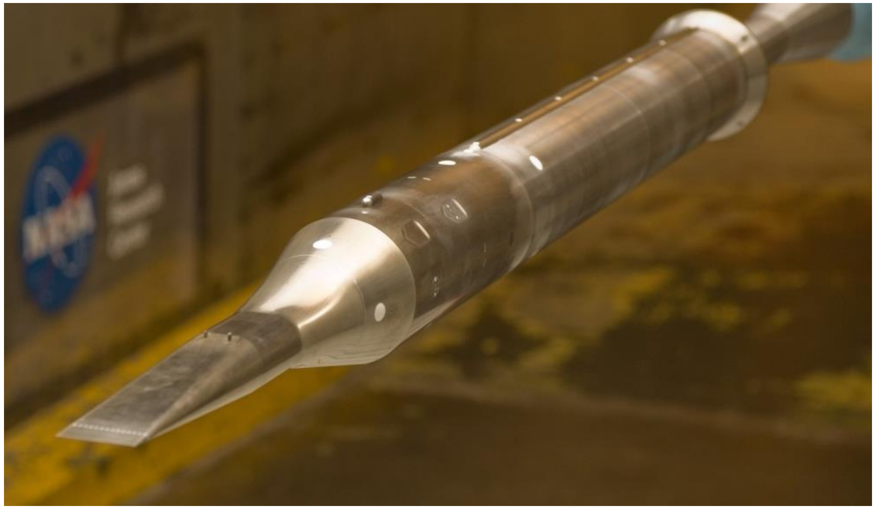
A3 Test Stand Loads Support

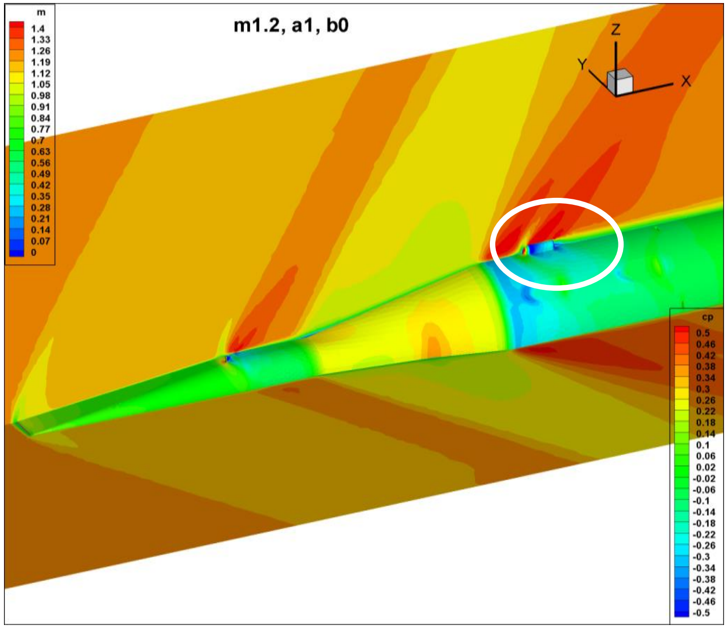
- One concern is Strouhal vortex shedding from tanks during hurricanes.
- How can we (efficiently) predict flows around a geometry this complex?
  - Can we even expect accurate results from our wind tunnels?
- Also requested to assess internal flow environments in support of operational dynamic loads.
  - Environments are being predicted by CFD.
  - Rocket plumes in ducts.



Hypersonic Boundary Layer Transition (HyBoLT) Aeroacoustics Assessment

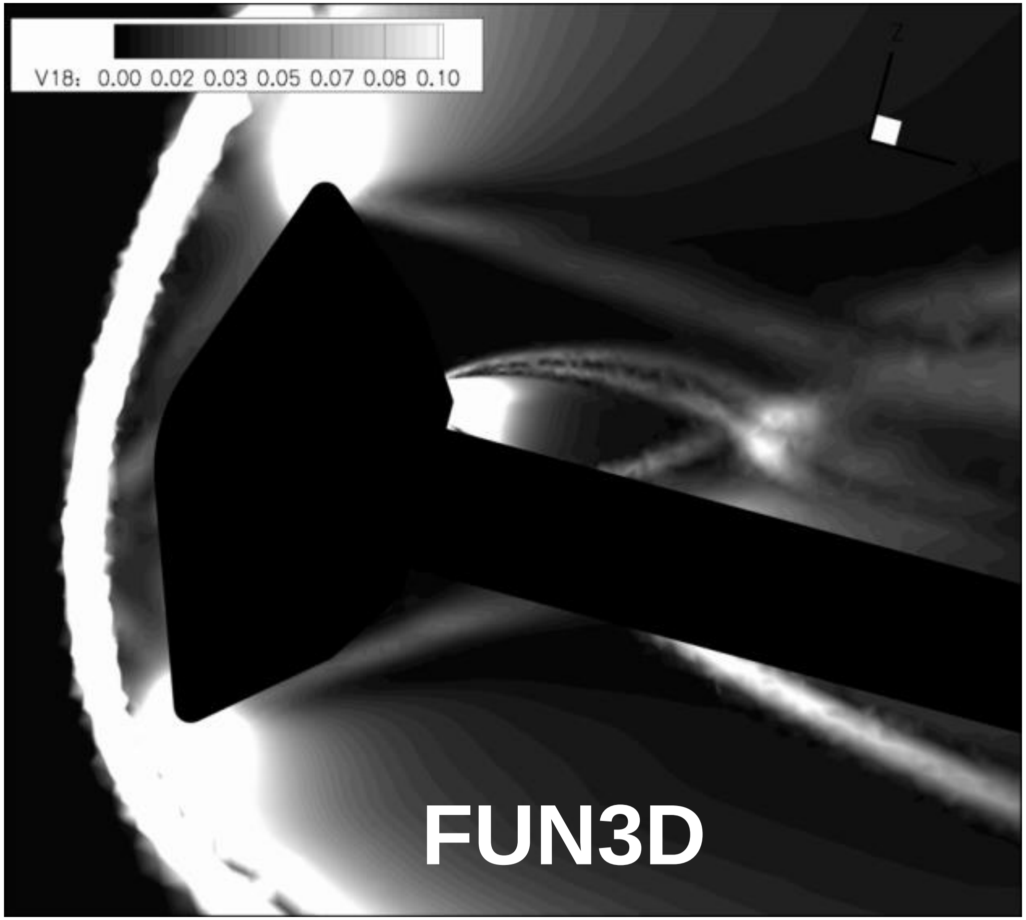
- Aeroacoustic assessment of the HyBoLT launch environment hampered by a limited set of wind tunnel aeroacoustic data, some contaminated by tunnel noise characteristics.
- State-of-the-art beyond wind tunnel is empirical prediction based on launch vehicle flight test and very limited operational data.
  - Applicability is challenged by non-similar geometries and flight conditions.
  - Steady CFD has been introduced to the process with some success to predict local flowfield characteristics such as local Mach, q, and boundary layer state.
  - Spectral content cannot be effectively addressed.
- Similar issues on Ares I-X and Orion PA-1 and can be expected to continue for future NASA launch vehicles and missions.



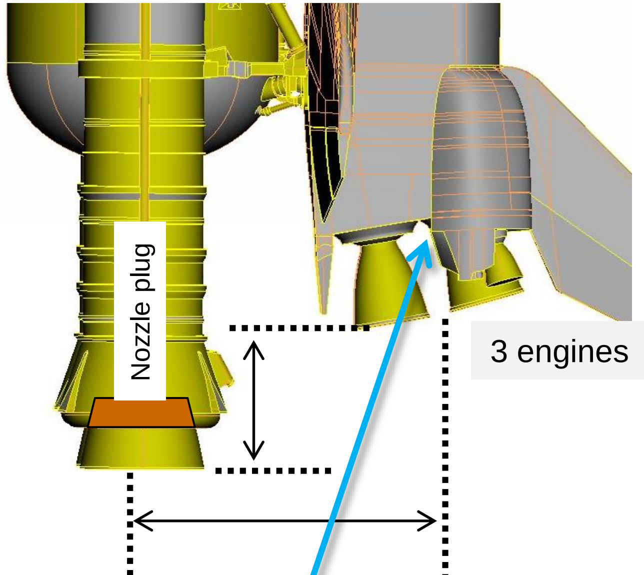


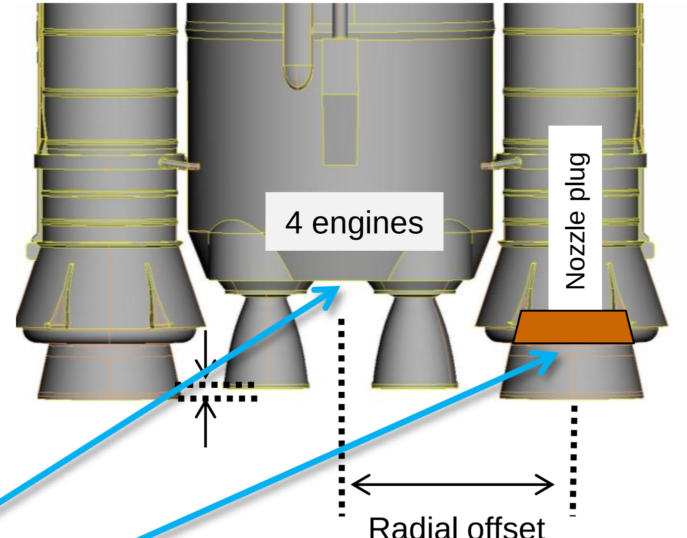
MSL Aero/RCS Jet Interaction

- Simulation of MSL capsule entering the Martian Atmosphere.
- Reaction Control System Jets firing into a separated flowfield in the spacecraft wake.
- Pitch, yaw, and roll control a strong function of the interaction of the RCS jet with the surrounding flowfield.



RS-25 Nozzle Flow Transient Assessment





Development work continues on the SLS booster nozzle plug: the current nozzle plug design meets launch load environments, but there are problems manufacturing the plug.

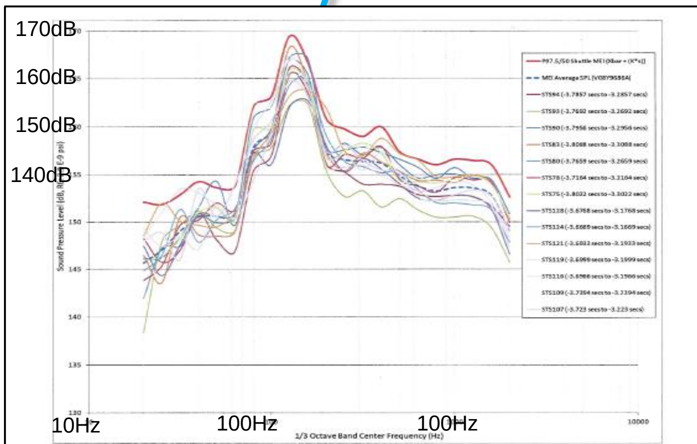


Figure 3 – SPL versus 1/3 Octave Band Center Frequency for V08Y9686A

Task Motivation:

-Obtain data to refine, possibly lower, the RS-25 NFT acoustics for the Booster nozzle plug.

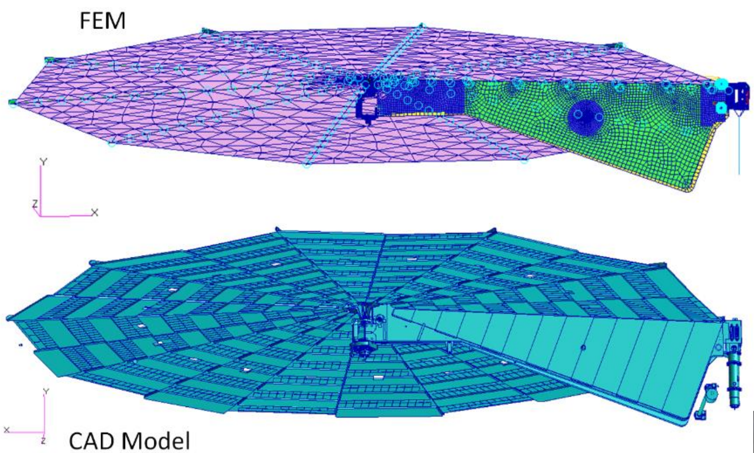
Keep the mass and density of nozzle plug to a minimum, reducing its risk as launch debris, SLS Risk 12172.

-Insure/verify the SLS launch RS-25 NFT acoustics loads are adequate as defined for the aft end of the SLS and Booster.

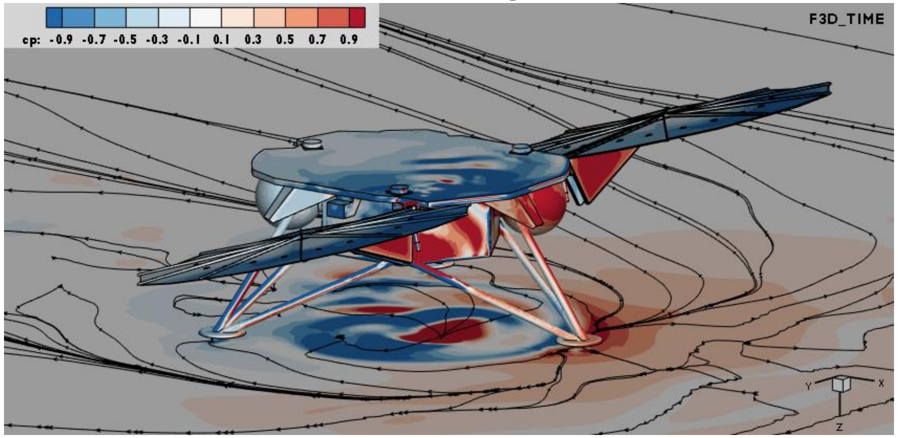
InSight Ground Wind Loads

- **Evaluation of Mars InSight Lander during a dust devil encounter.**
  - **Completed October 2014.**

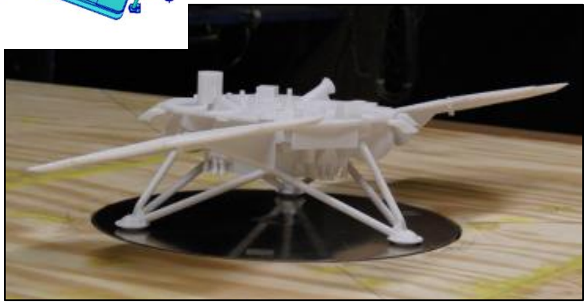
Structural Modeling



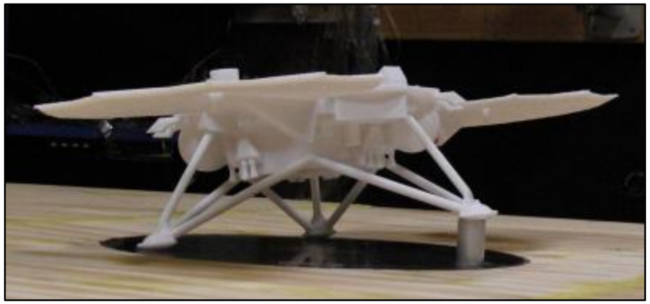
CFD Analysis



Wind Tunnel Testing



Panels Elevated ($\theta_{oF} = \theta_{oR} = 0°$, $\theta = 15°$)



Front Leg Elevated ($\theta_{oF} = 9°$, $\theta = 0°$)