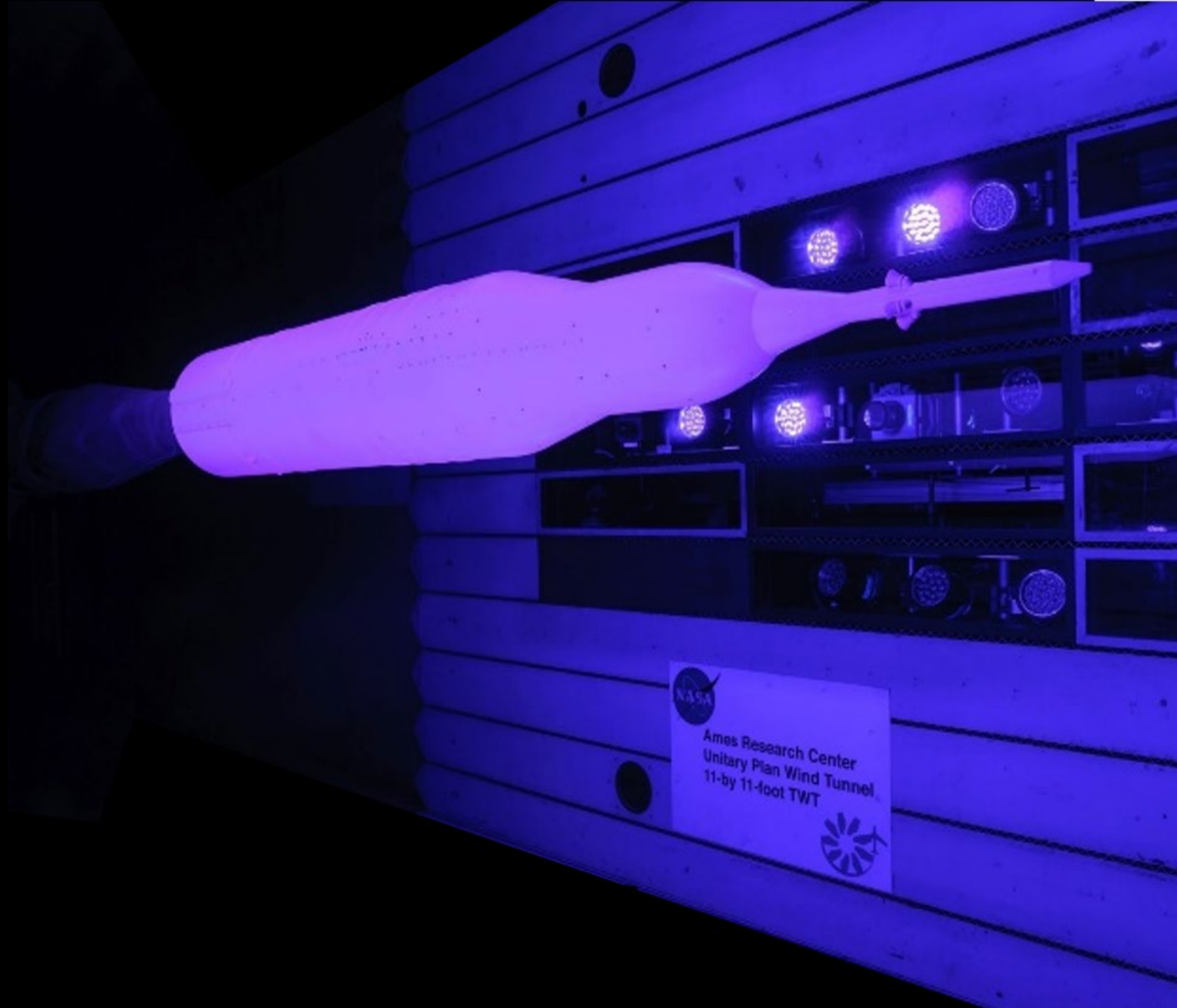
Painting a Picture of Pressure

How Pressure-Sensitive Paint Reveals the Forces that Shape Flight

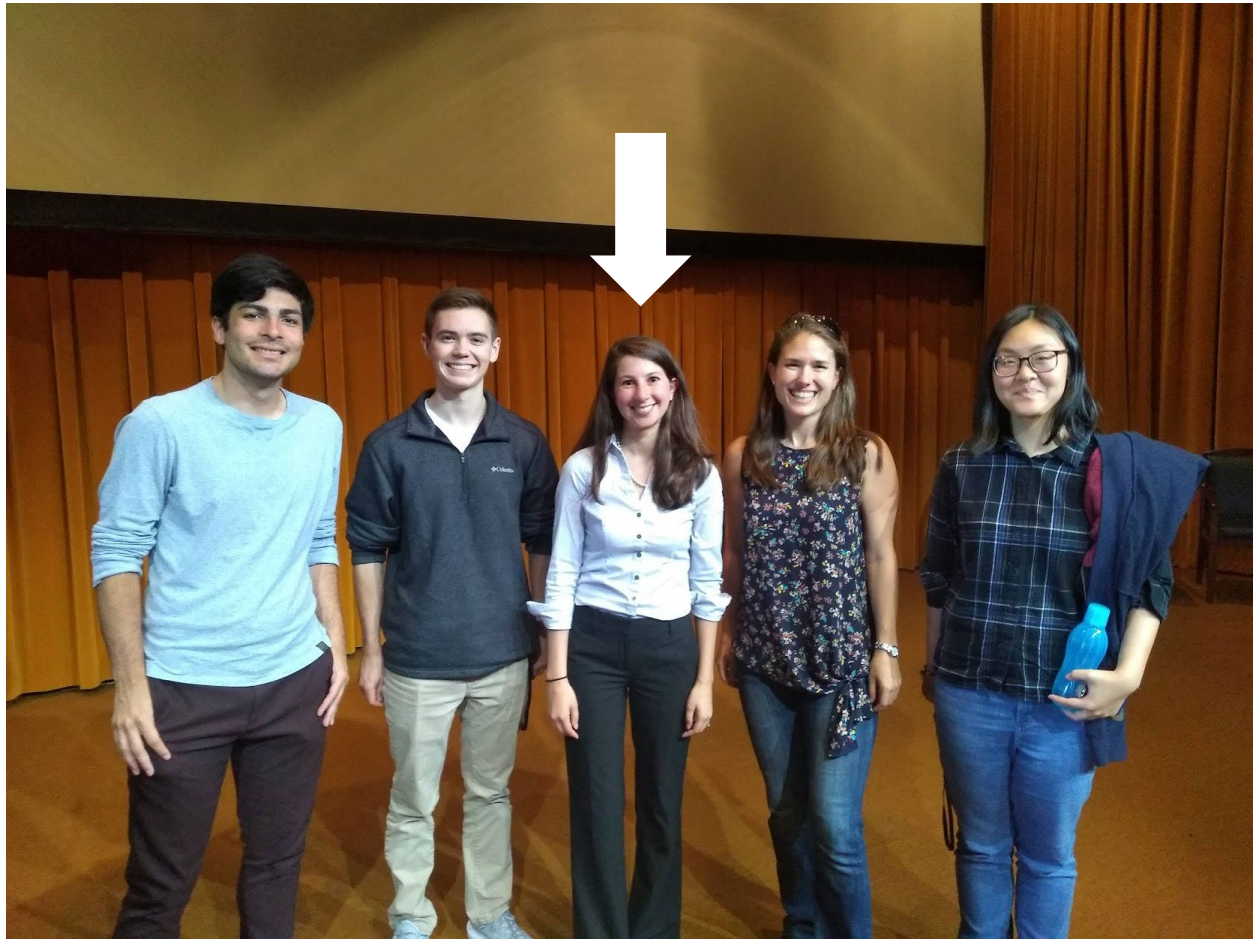
E. Lara Lash

NASA Ames Research Center
Summer Series

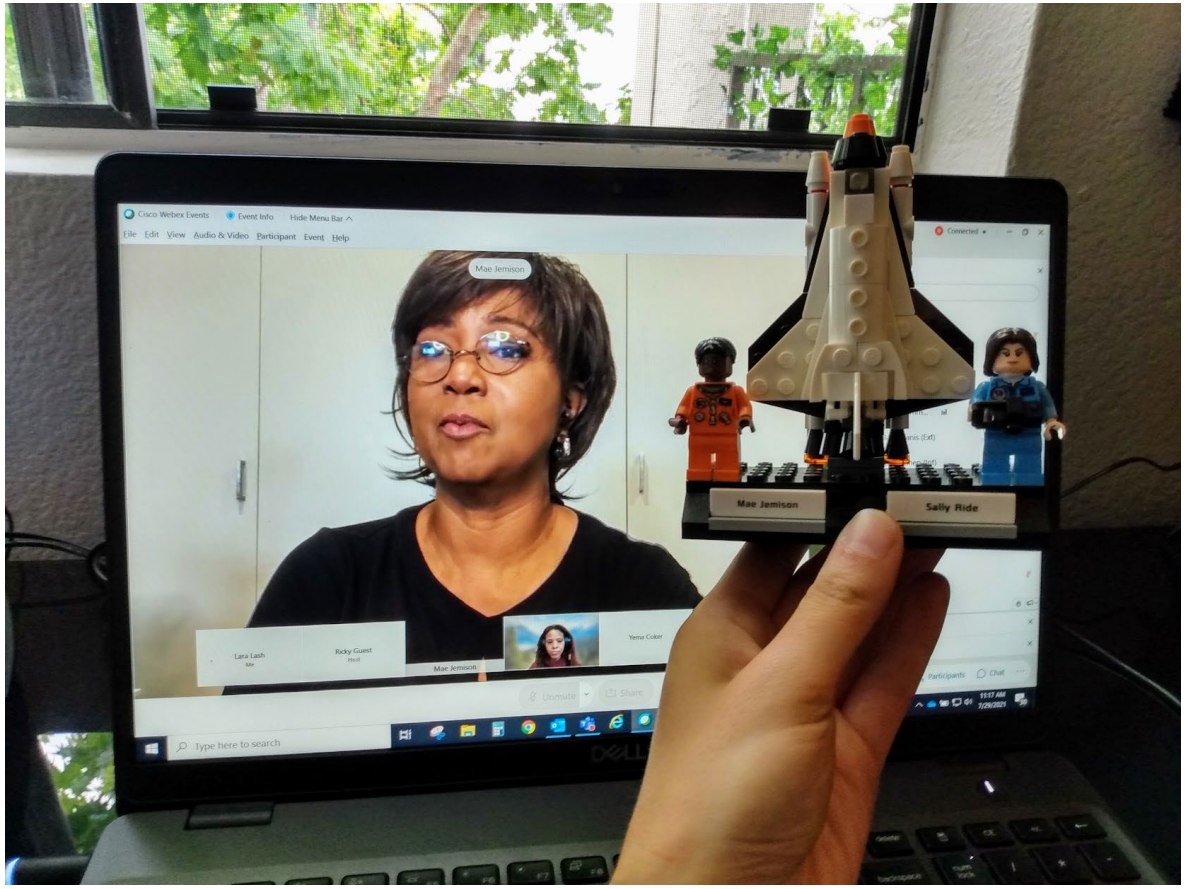
26 June 2025



Ames Summer Series

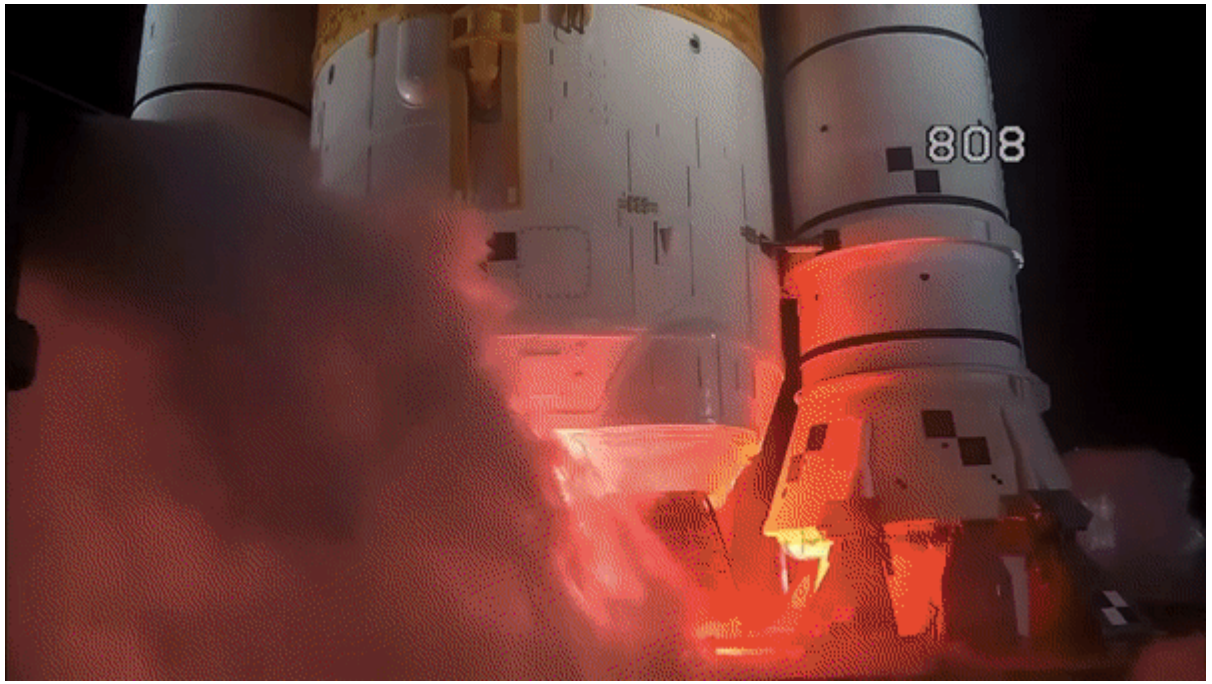


Summer 2019: Dr. Katie Bouman



Summer 2021: Dr. Mae Jemison

Our Role in the NASA Mission



Artemis I: November 16, 2022

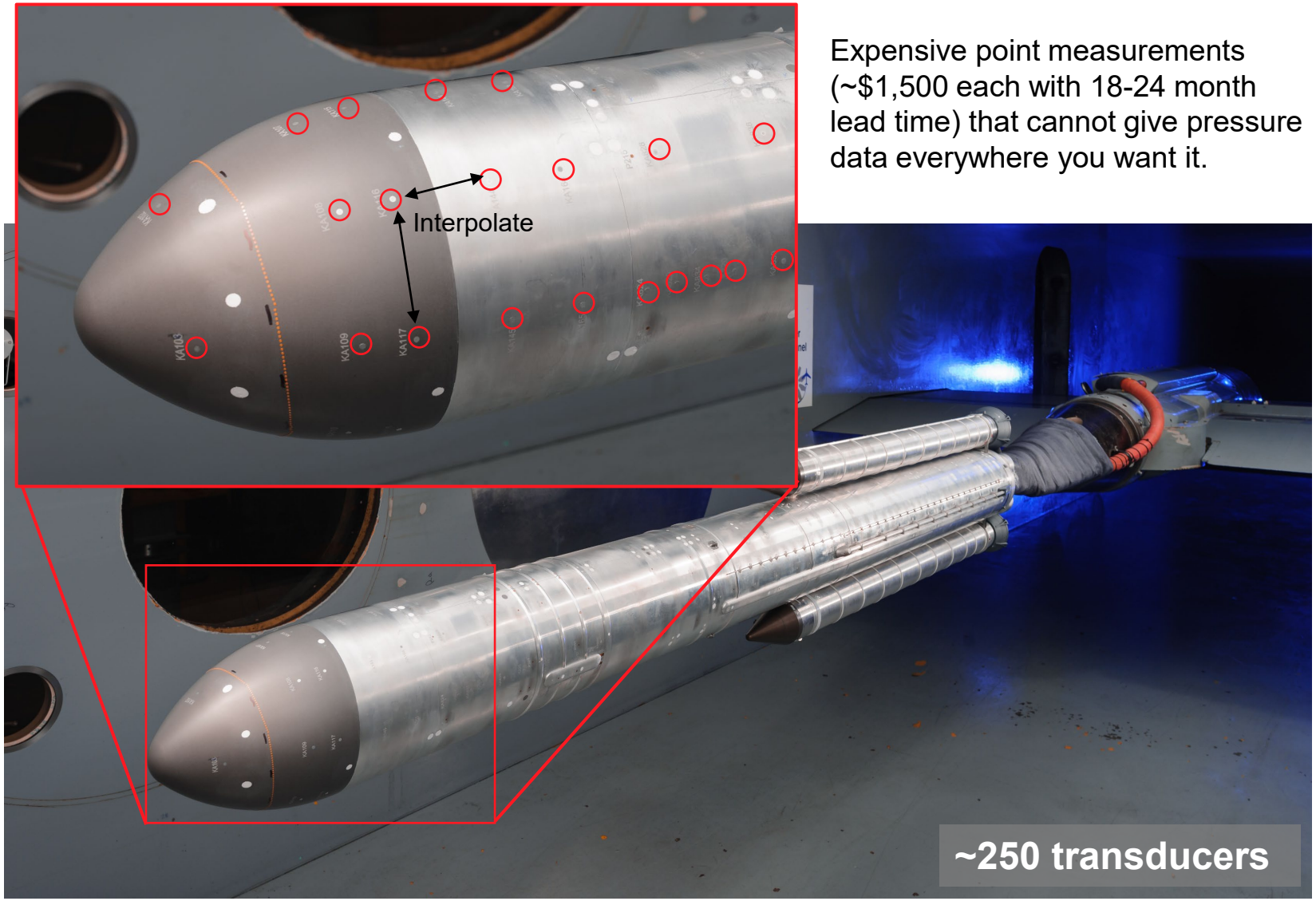
- Extremely high-profile NASA event
- 1st flight of an entirely new vehicle
- *Performed wonderfully!*

How? *Extensive* analysis, simulation, **wind tunnel testing**

- Provide data on aero-acoustic environment during critical flight phase (ascent)
- Unsteady Pressure-Sensitive Paint (uPSP) ***system revolutionizes*** this process

A Need for Innovation

Expensive point measurements (~$1,500 each with 18-24 month lead time) that cannot give pressure data everywhere you want it.



NASA ARC Unitary Plan Wind Tunnel (UPWT) Supersonic 9-by 7-ft



NASA ARC Unitary Plan Wind Tunnel (UPWT) Transonic 11-by 11-ft

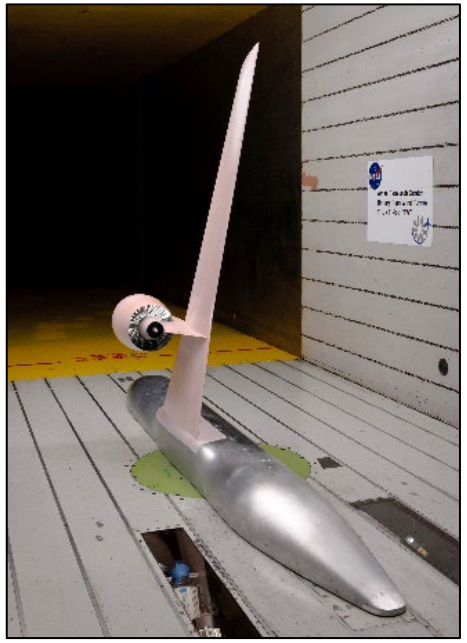
Past Applications of Steady PSP

NASA X-planes

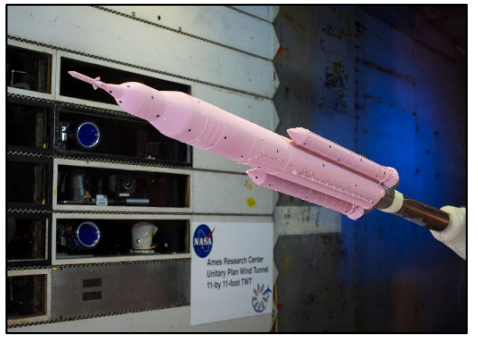


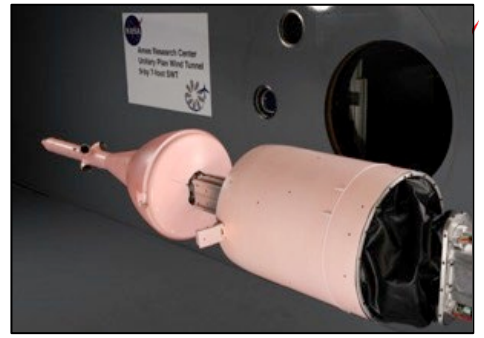
NASA ERA



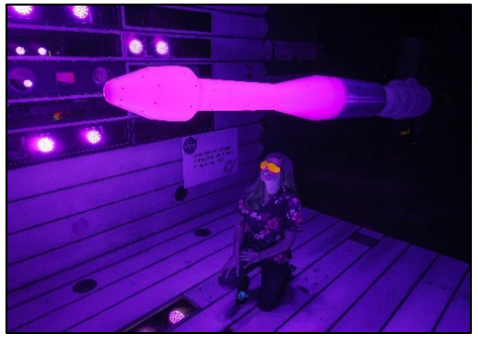


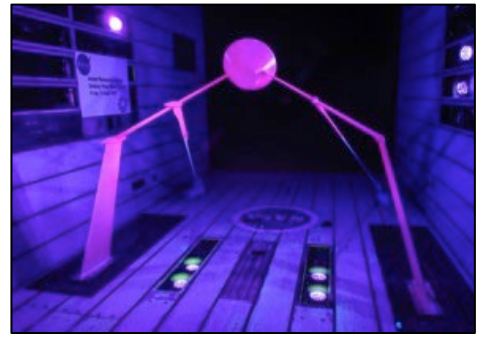
NASA HEOMD





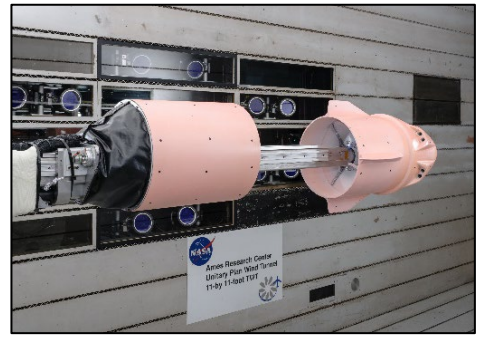
NASA NESC



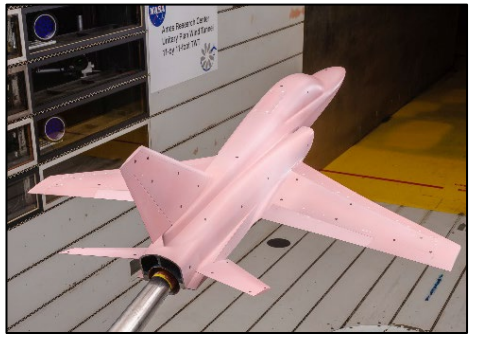


Commercial Crew





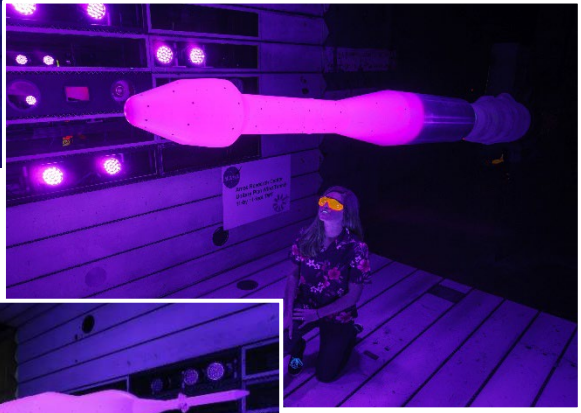
Reimbursable

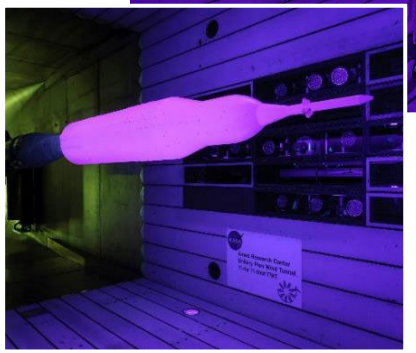




What is uPSP?





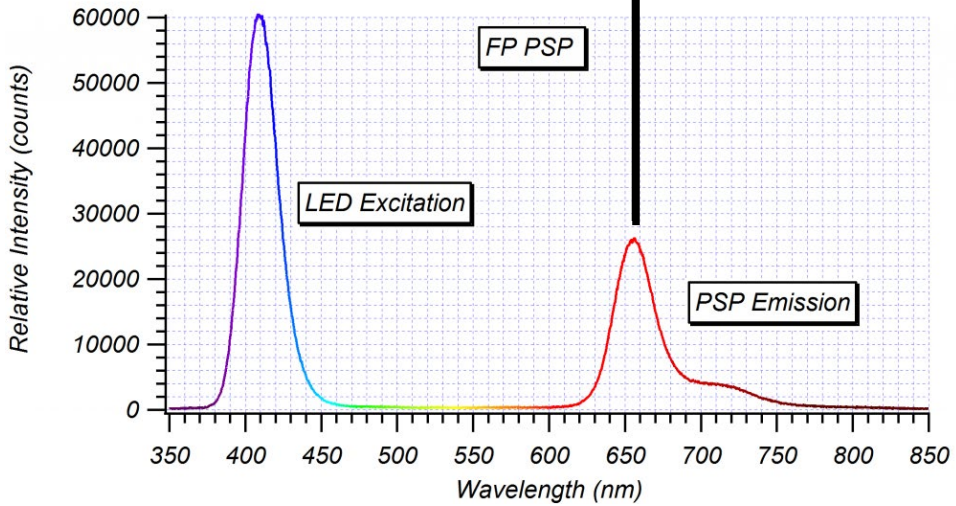


Unsteady Pressure-Sensitive Paint

1. Apply porous, fast-response PSP to model
2. Illuminate paint with 400 nm light source
3. Paint emission intensity is a function of pressure
4. Measure emission with high-speed cameras



Reproduced with permission from ISSI





Reproduced with permission from Vision Research, Inc.

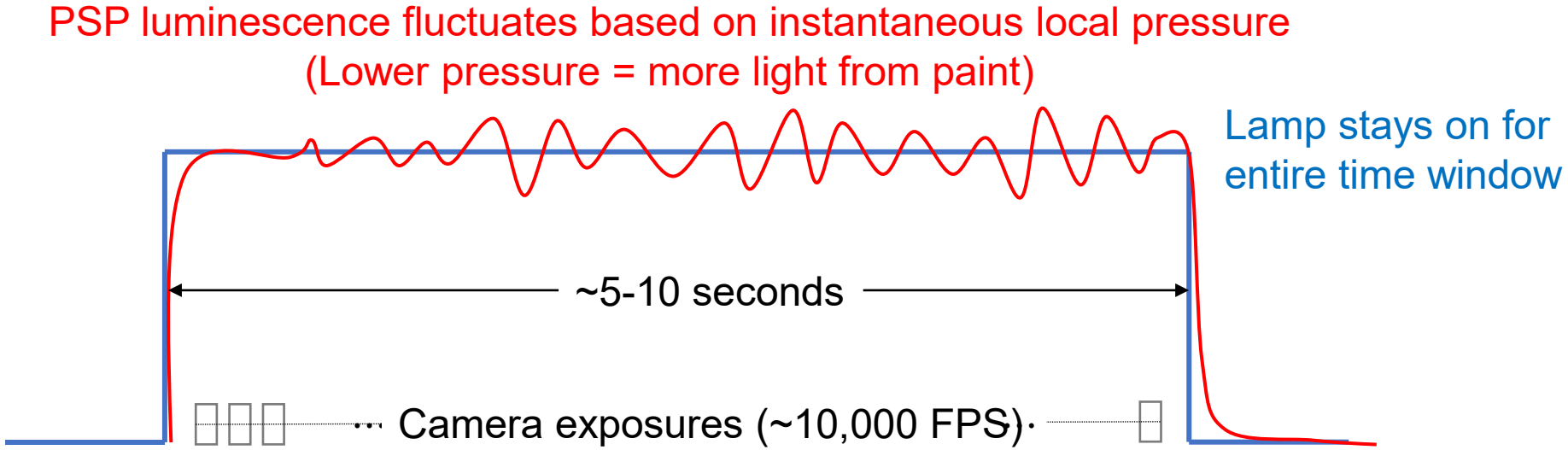
-8 high-speed cameras
-10k fps acquisition
-40 lamps

35 F – 150 F
0 psf – 4100 psf

How do we use the paint?

There are (2) common methods to use PSP to measure pressure.

Technique #1: "Intensity" Mode



Challenge: How do we know what measured light intensity corresponds to what pressure?

- Common solution: ratios relative to a known "wind off" condition.
- But paint degrades over time!

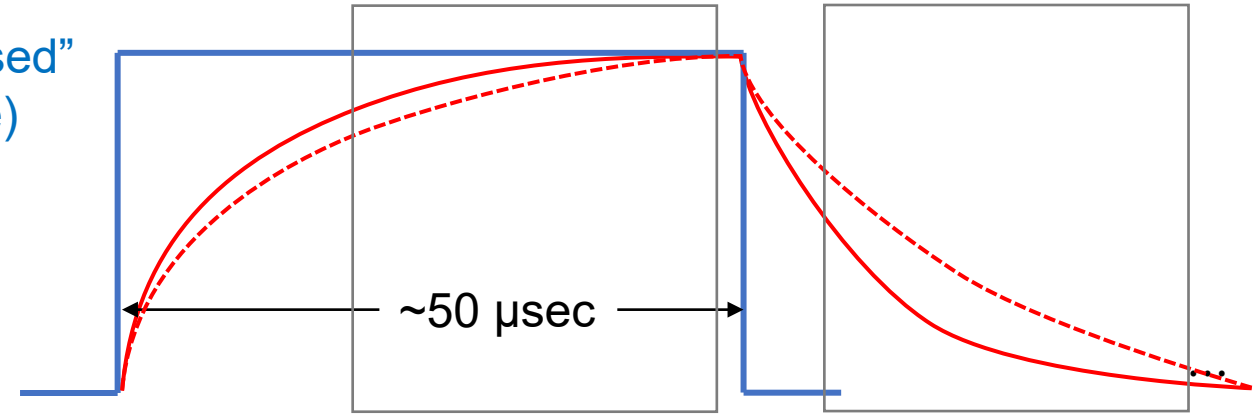
How do we use the paint?

There are (2) common methods to use PSP to measure pressure.

Technique #2: "Lifetime" Mode

PSP luminescence decay **time constant** changes based on instantaneous pressure

Lamps are "pulsed" (step impulse)



Two Camera exposures
- "Gate 1" and "Gate 2"
- Ratio G1/G2 proportional to time constant

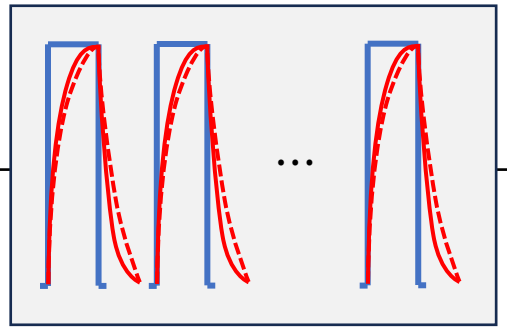
- More robust to paint degradation (+ less degradation)
- Downside: "Gate 2" is really dark → low SNR
- Workaround: average many G1/G2 's to get good data → useful for **average** surface pressure

How do we use the paint?

Our approach is a HYBRID. (Credit: Air Force + paint vendor collab)

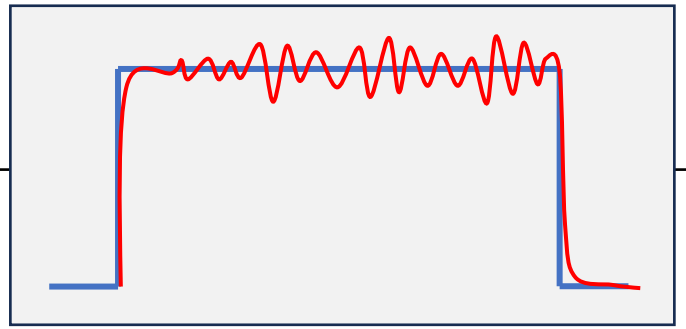
Total acquisition timeline ~ 10-20 seconds

Lifetime Mode



Measures the average pressure, $\overline{p}$

Intensity Mode



Measures fluctuating intensity

Paradigm Shift: New State-of-the-Art **System**

World-Class Transonic Wind Tunnel Leveraging World-Class High-Performance Computing

NASA Ames UPWT - 11 x 11-ft Test Section (Transonic)







NASA Advanced Supercomputing Division (NAS)



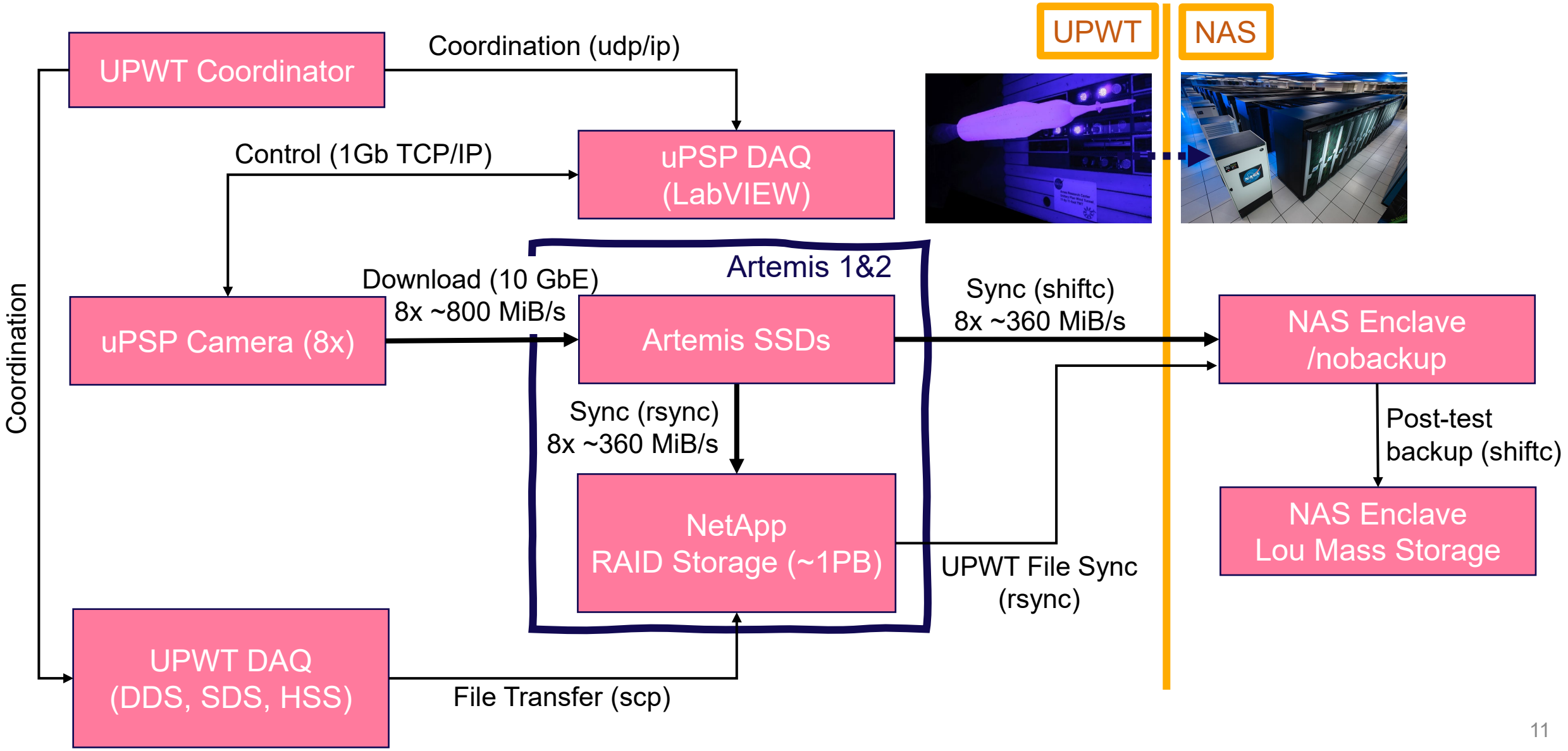
Single-mode fiber

"This is a **paradigm shift** from how ground testing has historically been executed."
–Dr. Ron Colantonio, NASA Director of AETC

DARWIN Project, 1990s

Koga, D., Korsmeyer, D., and Schreiner, J., "DARWIN Information System of NASA – An Introduction", AIAA Advanced Measurement and Ground Testing Conference, New Orleans, LA, June 1996. https://doi.org/10.2514/6.1996-2249

Project: Red Rover 2.0



uPSP Processing Software

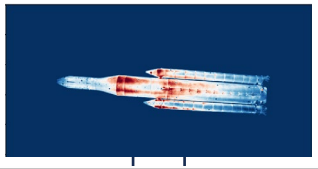
Raw video frames

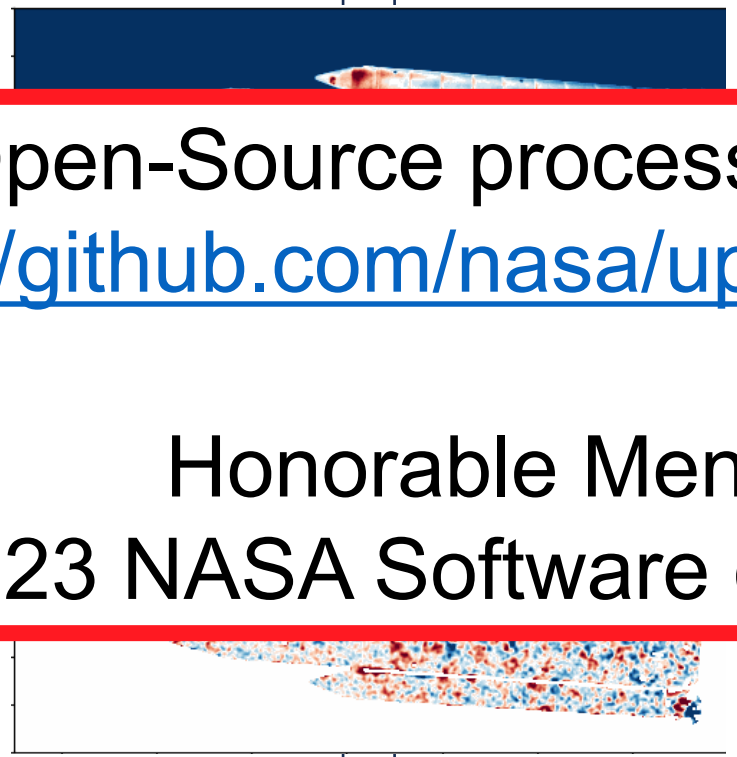
Registration
Mitigate frame-to-frame vibration

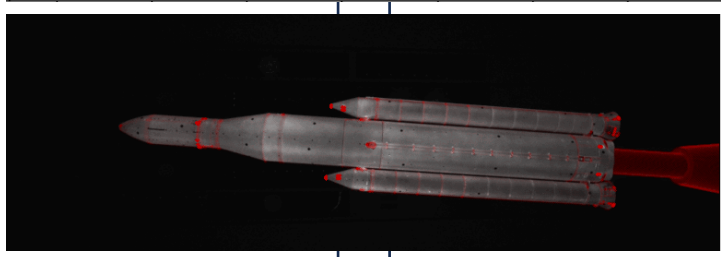
Intensity
R[k] = Counts$_{me}$
(R ∝ Surface

Denoi
Image fi

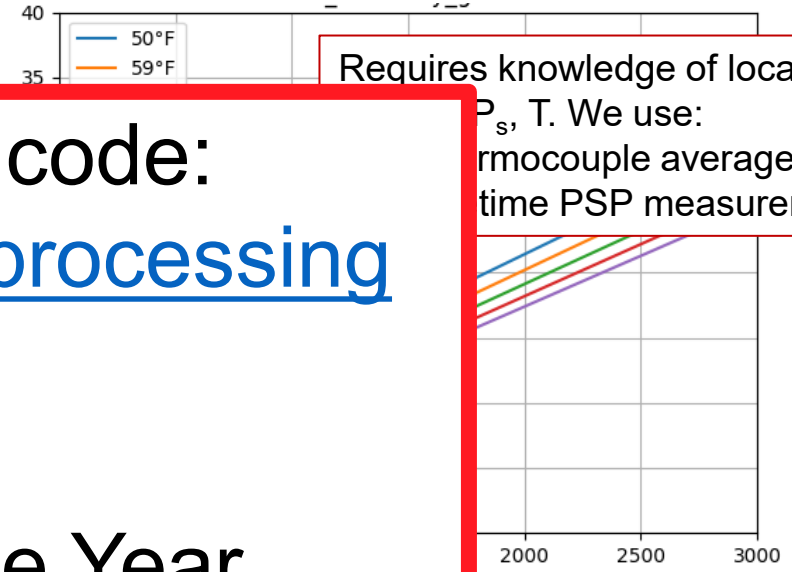
3D Projection
2D-3D correspondances



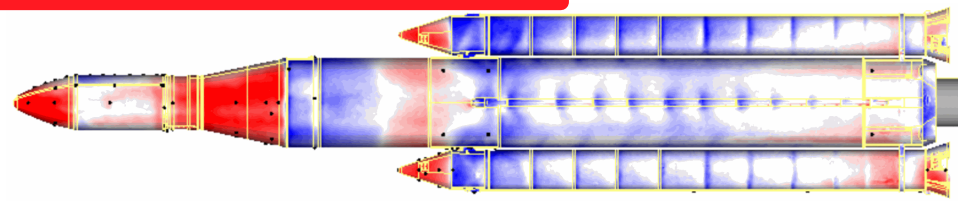




3D Surface Pressure
P[k] = Gain(P_s , T) x R[k]



Requires knowledge of local
P_s, T. We use:
rmocouple average
time PSP measurement

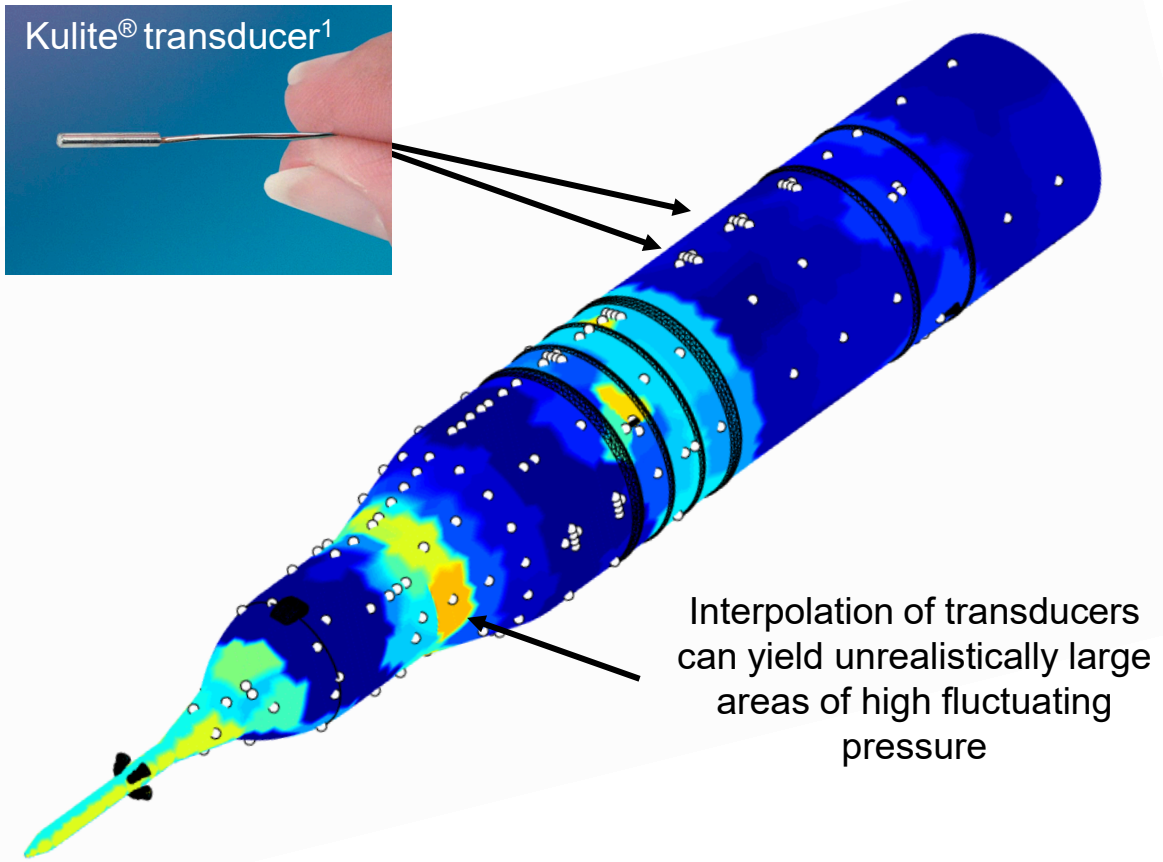


Open-Source processing code:
https://github.com/nasa/upsp-processing

Honorable Mention
2023 NASA Software of the Year

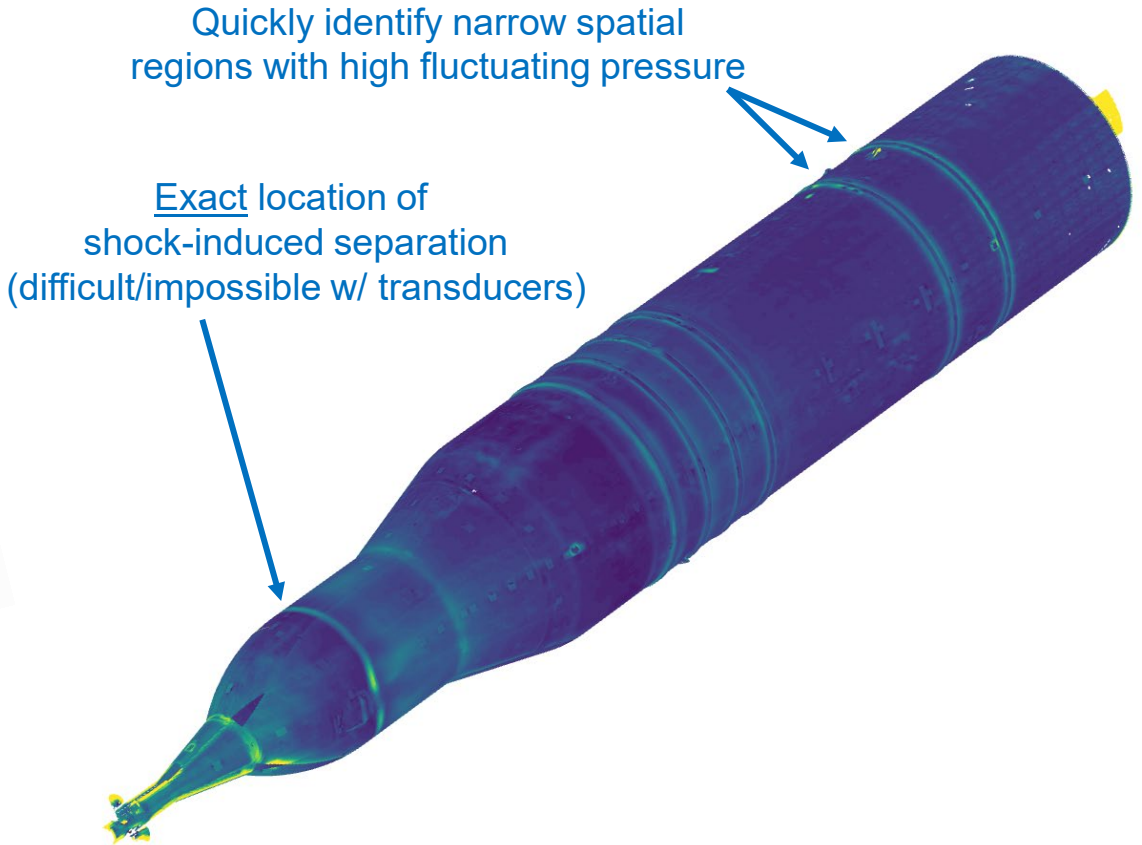
What's Better About uPSP?

Transducer-based dB level (**measured + interpolated)**
(courtesy T. Steva, NASA Marshall)



Current State-of-the-art
("100's of measurements")

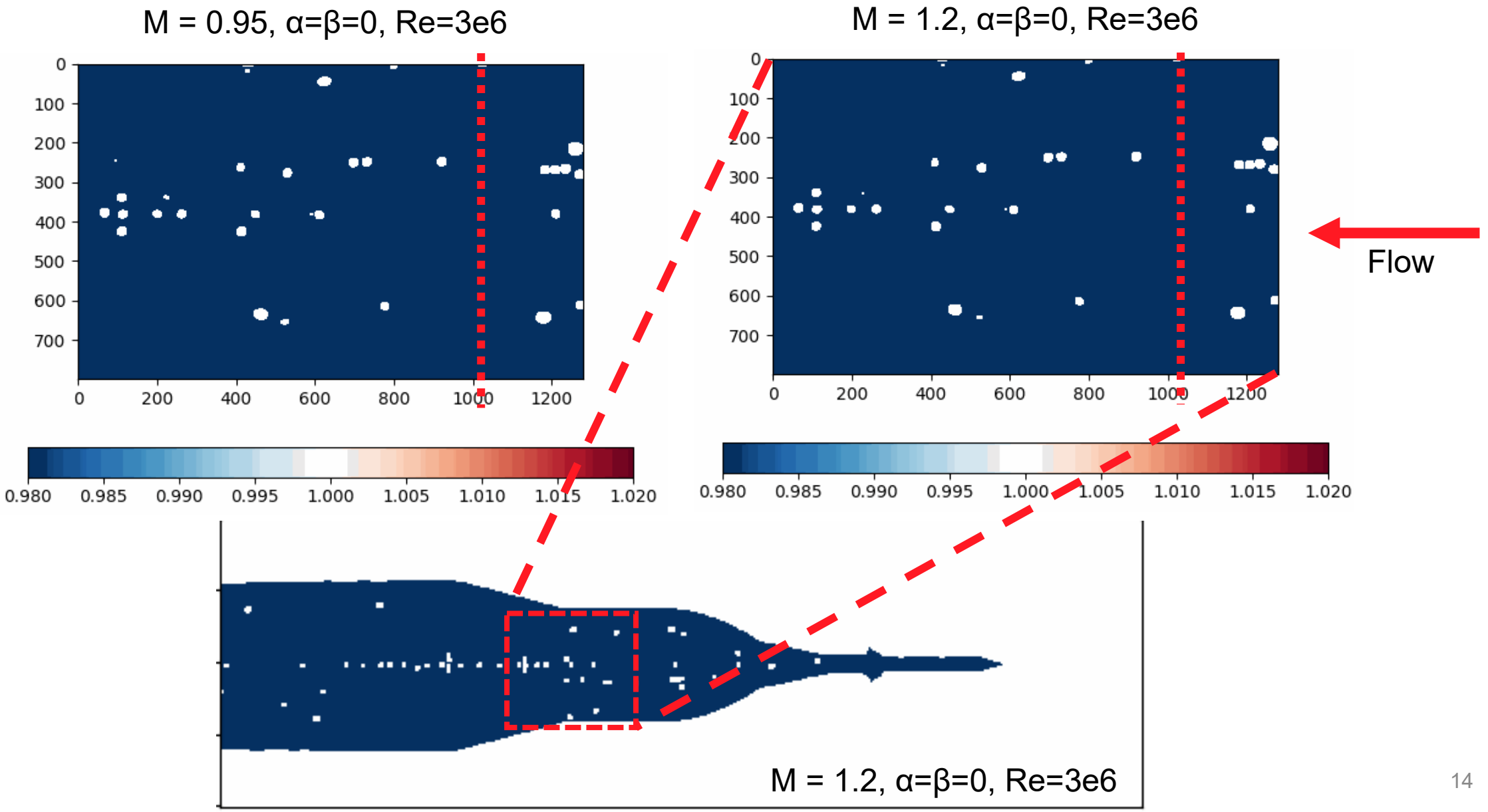
Unsteady PSP dB level (**measured)**



Future State-of-the-art
("1 million measurements")
Spatial Resolution Increased 10,000 X

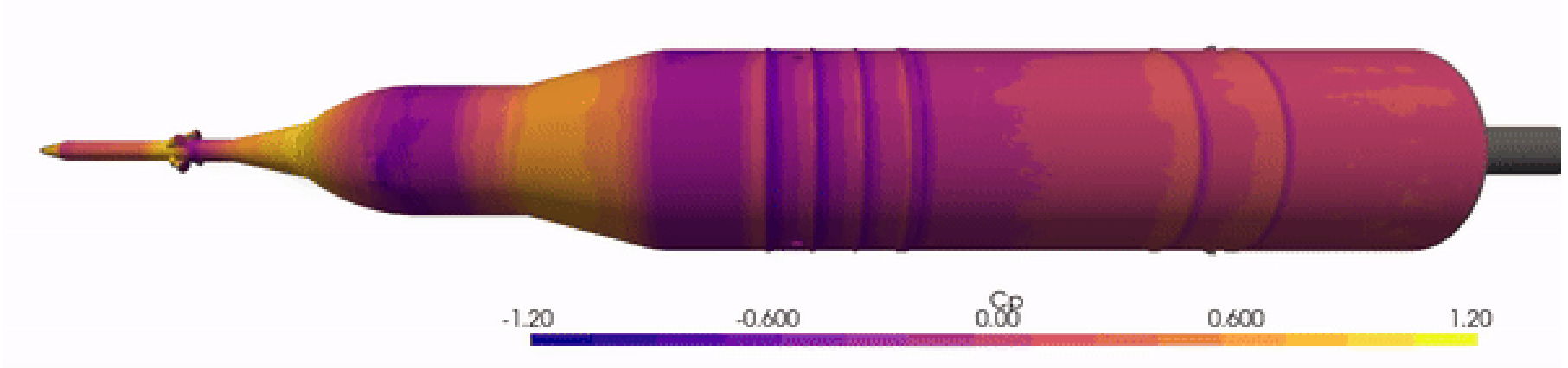
[1]*Reproduced with permission from Kulite Semiconductor Products, Inc.*

uPSP Data: Fluctuating Pressure



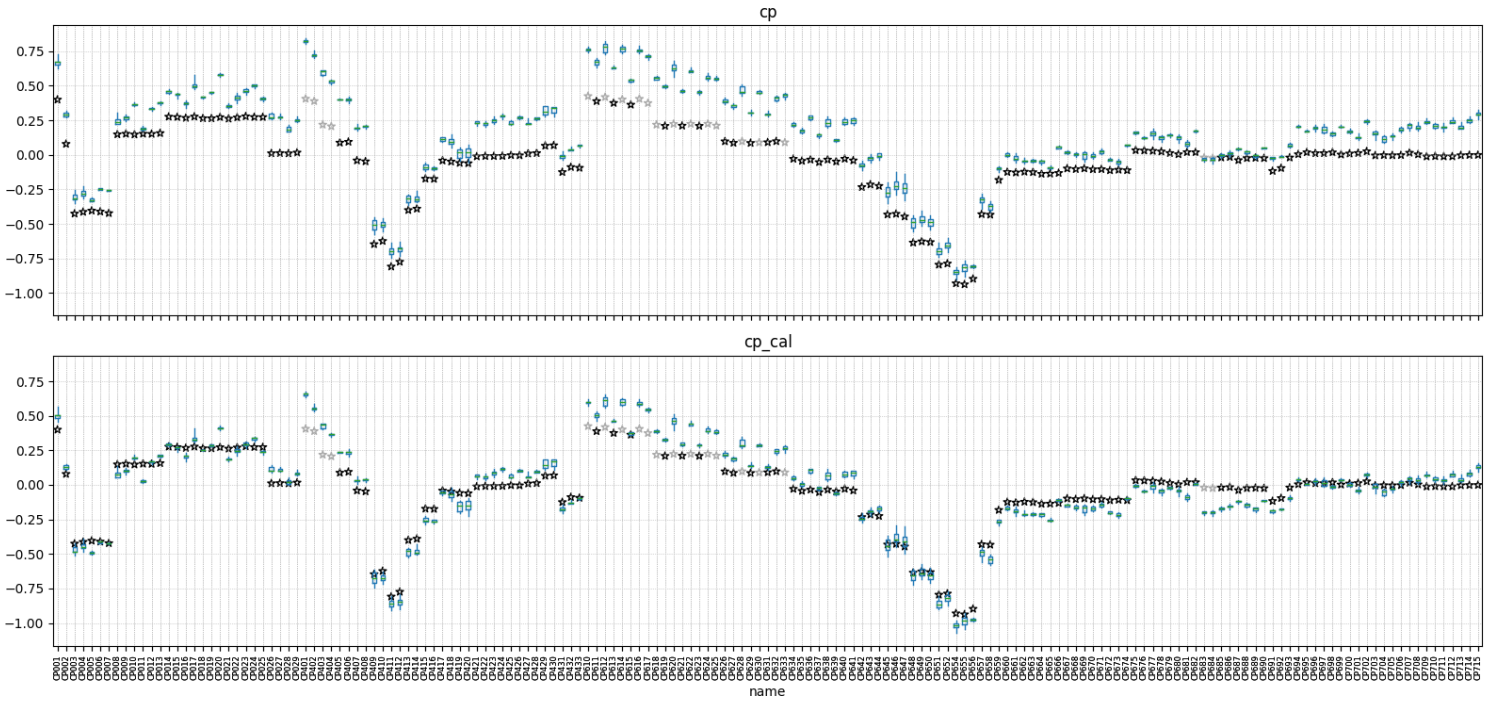
uPSP Data: High-Speed Lifetime

Mach 1.2
$\alpha = \beta = 0$



Flow

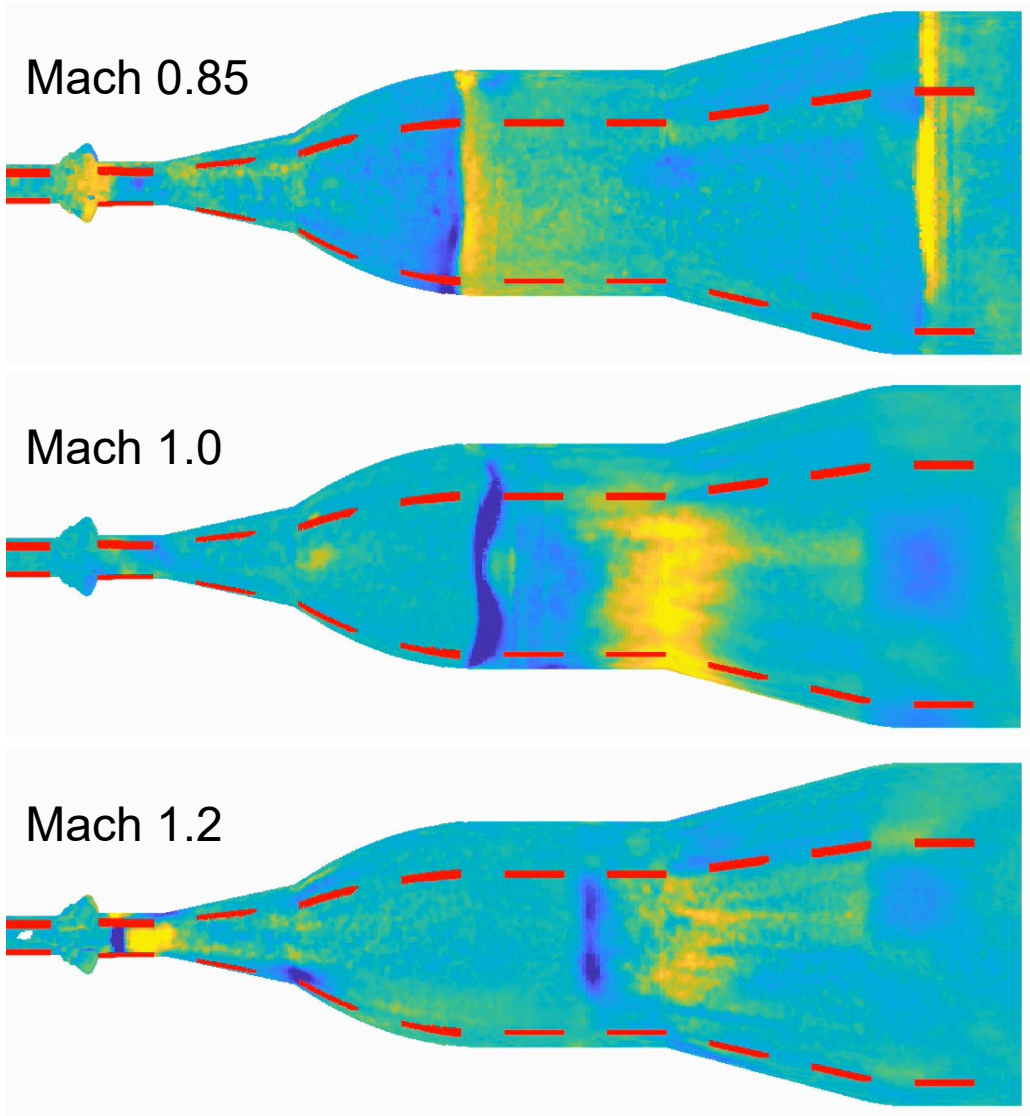
Mach 0.8
$\alpha = \beta = 0$



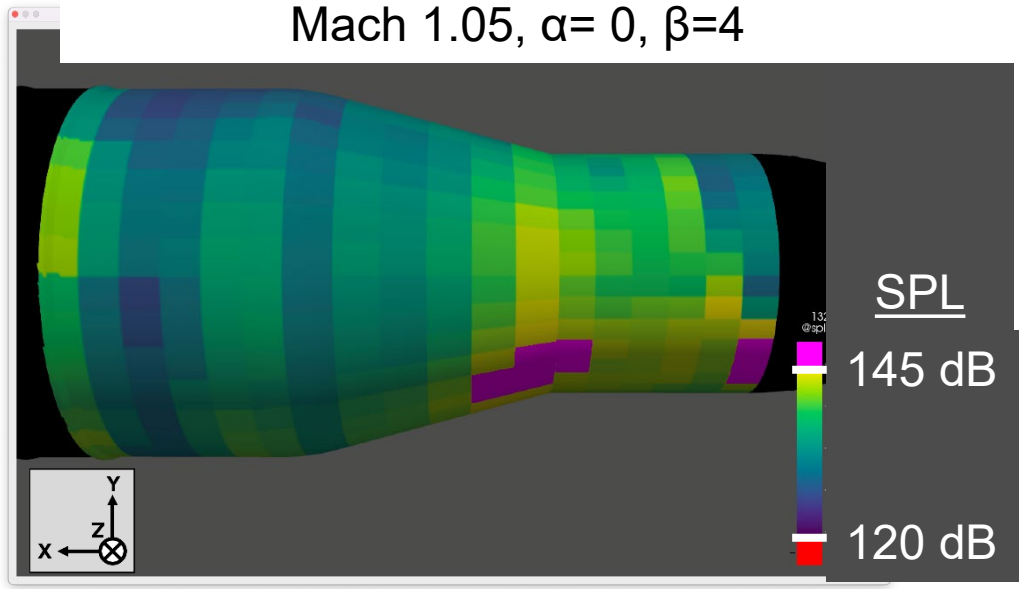
uPSP Data: Spectral POD

- High spatio-temporal resolution
- Easily evaluate both dominant and non-dominant features
- Isolate frequencies
- Evolution in phase and time

- 1st SPOD mode at the same frequency
  - Animated in phase
  - Wake from the launch abort nozzles
  - Unsteady shock footprint
  - Pockets of turbulent separation

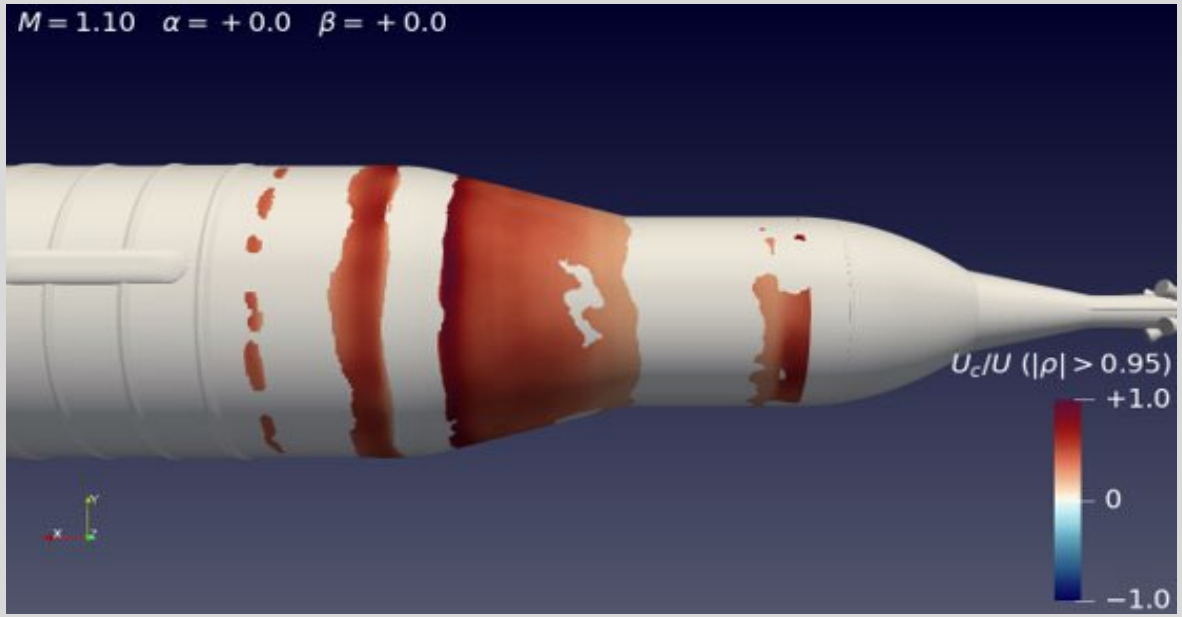


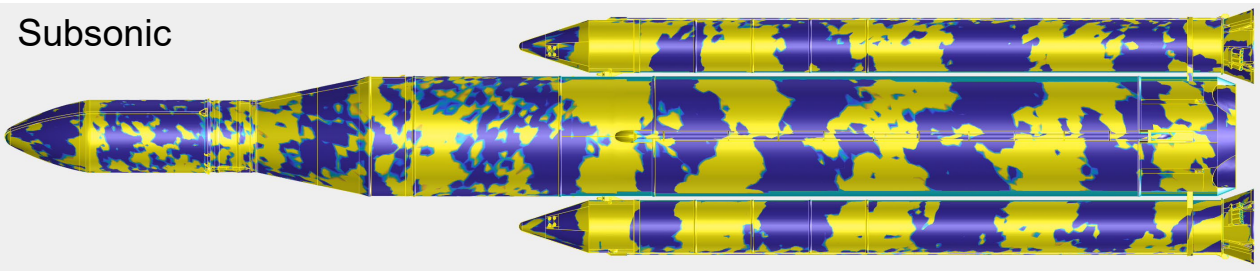
uPSP Data: Additional Data Products

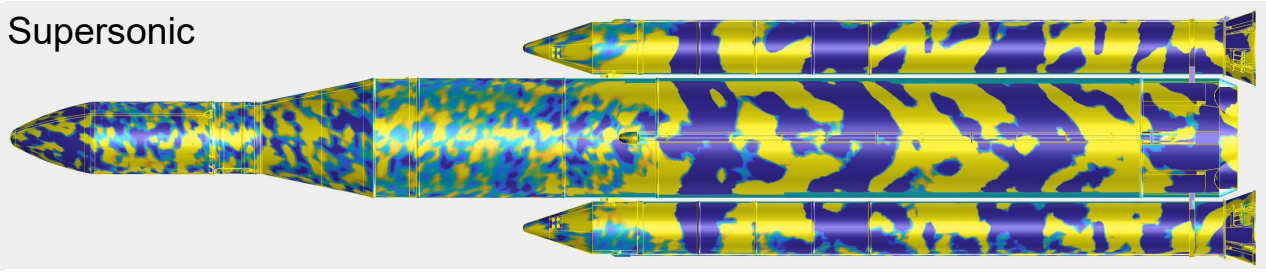


Patch-Integrated force vs. time for input into structural models.

Surface map of TBL convective speed
Does not rely on amplitude cal (uses CSD)
(normally requires a transducer pair @ each location)







DMD mode visualizations across entire model.



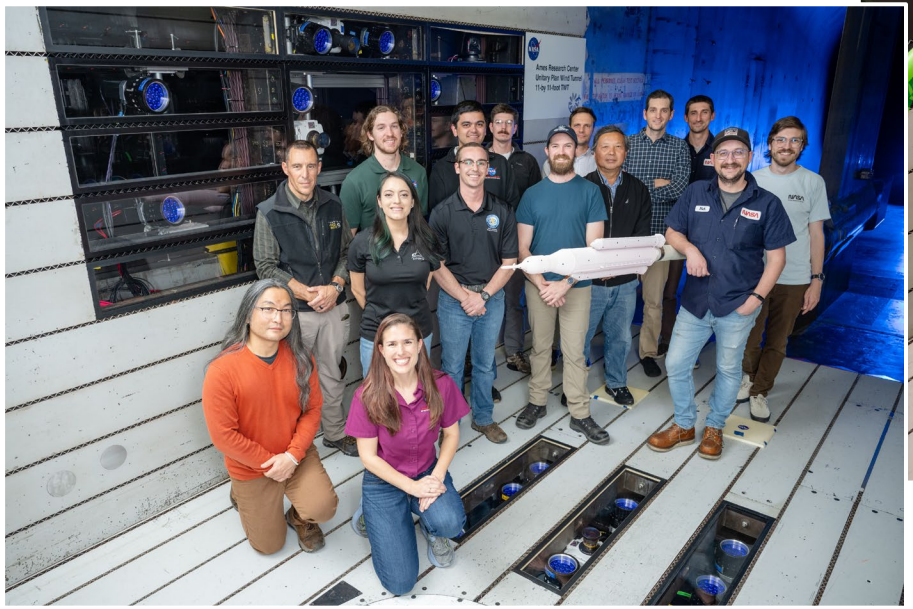






What's Next?

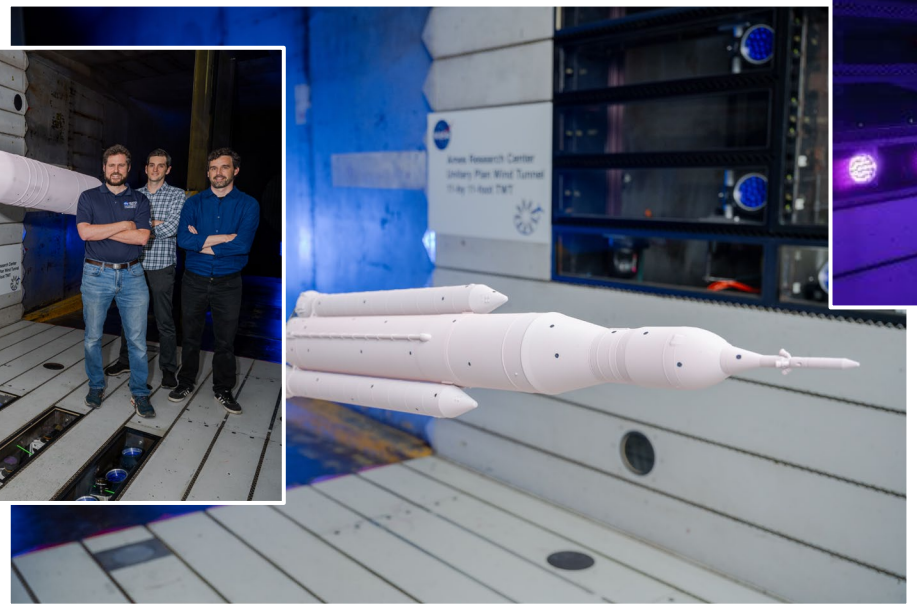


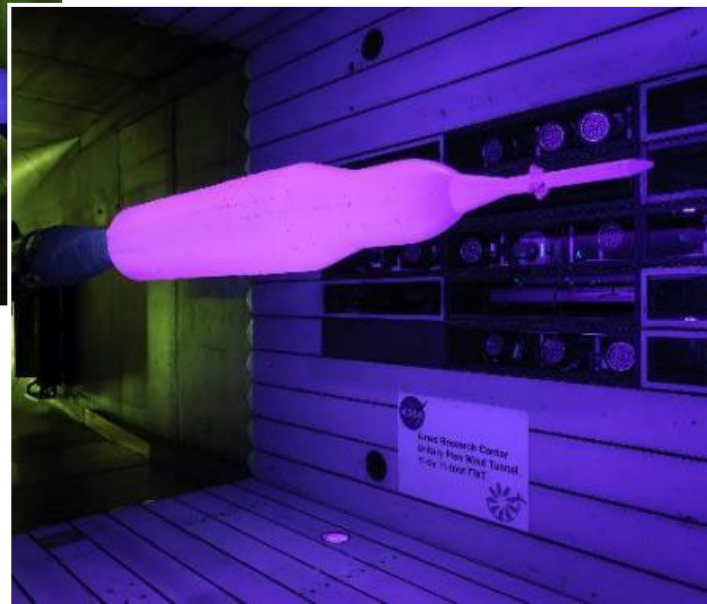






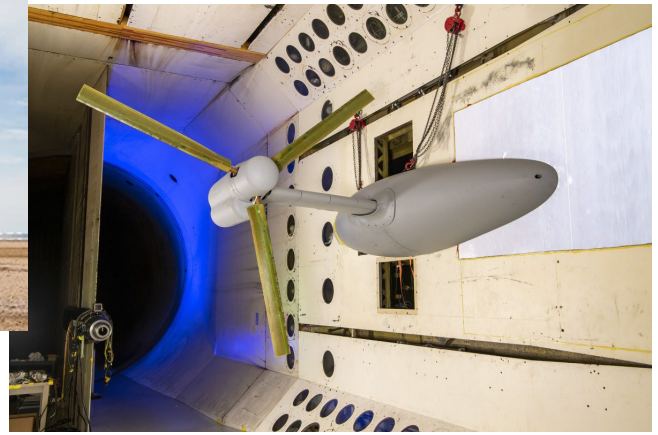




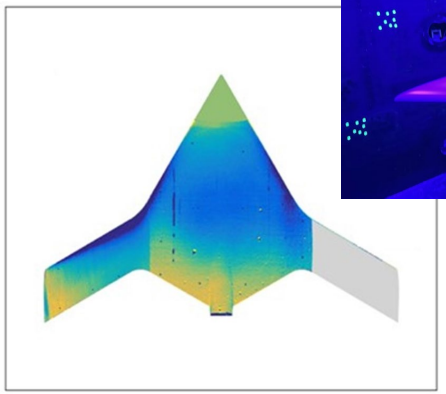


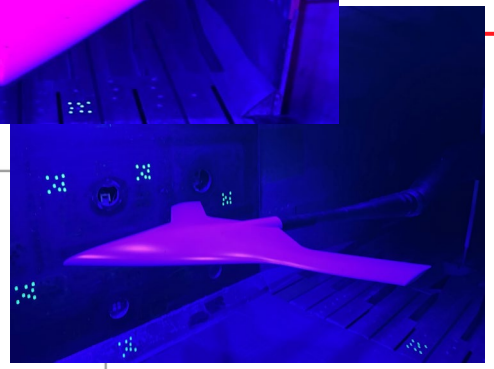
What's Next?

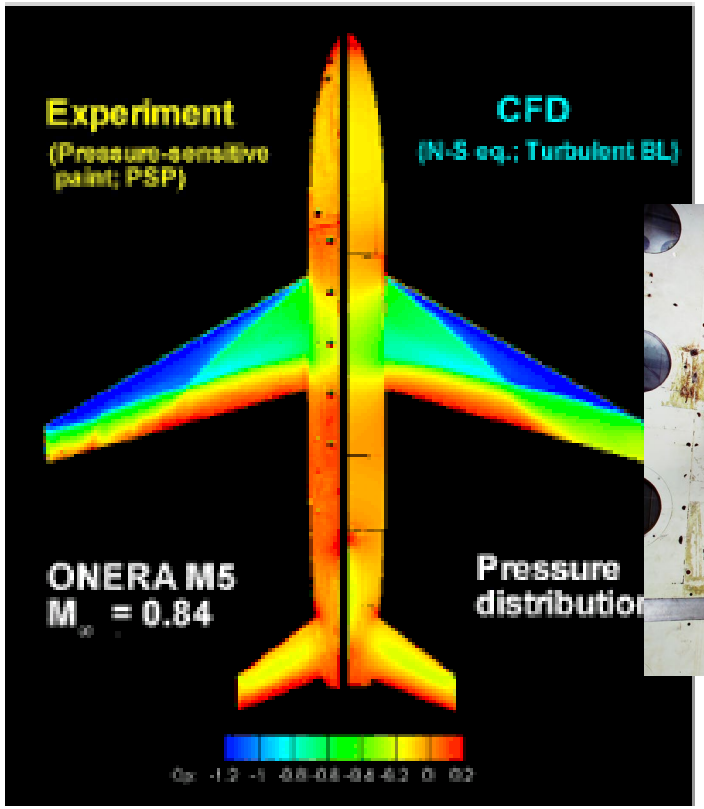

Joby
N542JA

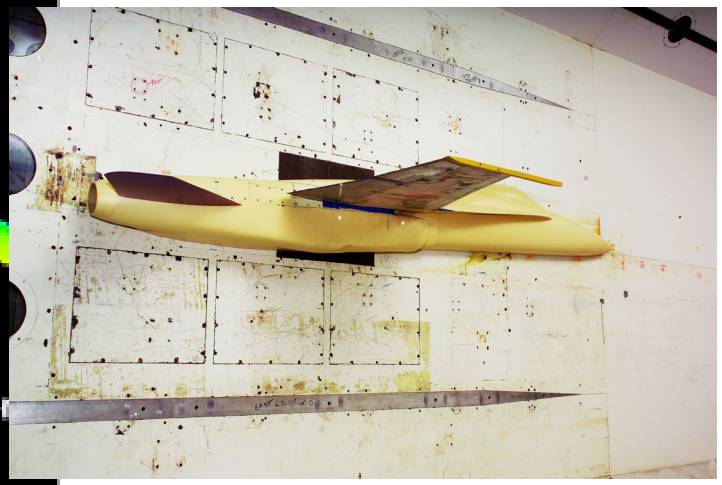









Experiment
(Pressure-sensitive paint; PSP)
CFD
(N-S eq.; Turbulent BL)
ONERA M5
M∞ = 0.84
Pressure distribution







The Work of Many Hands

ARMD AETC
Ron Colantonio
Chris Mouring
Steve Helland
David Stark
Lynne Sahay
Lori Arnett
Erik Lopez

Ames Aeronautics Office:
Huy Tran
Bill Van Dalsem
Jeff McCandless
Suzie Cisneros
Bimal Aponso
Parimal Kopardekar

NASA Advanced Supercomputing
Piyush Mehrotra
Donovan Mathias
Mahmoud Hanafi
Scott Murman
Bob Ciotti
Bill Arasin
Tawni Wills
Paul Kolano
Celeste Banaag
Derek Shaw
Nichole Boscia
Chris Henze
Dave Ellsworth
Tim Sandstrom
Bron Nelson
Nina McCurdy
Pat Moran
Patricia Ventura-Diaz
Katsutoshi Ishisoko
Ted Manning
Blaise Hartman
Jeffery Becker
Theodore Bohrer
Andrew Michaelis

Ames UPWT
Christina Ngo
Jennifer Baerny
Tom Volden
Ross Flach
Matt Krackenberg
Ted Garbeff
Jim Ross
Kurt Long
Colin Davis
Mike Treece
Bill Browning
Jay Panda
Nate Burnside
David Sanchez
David Keil
David Stathatos
James Brown
Bob Gisler
Rita Eick
Don Morr
James Bell
Rabi Mehta
Frank Kmak
Maureen Delgado
Jon Bader
Jen Everett
John Kemp
Pilar Gutierrez
Jerry Williams
John Salisbury
Michele Foster
Chris Harder
James Carolino
Bee Keil
Hannah Spooner
Adam Parrish
Harold Reimer
Nick DeLurio
Nestor Rostran
Albert Correa
Lauren Knowles
Noah Listgarten
Avraham Gileadi
James Gaudinez
Lindsey Drone
Bill VanZuylen
Andrew Kathner
Joseph McMinn
Nathan Mills
Taylor Warson

Air Force AEDC
Marvin Sellers
Wim Ruyten
Mike Nelson
Zach Lowry
Autumn Gardner
Scott Peltier

ISSI:
Jim Crafton
Steve Palluconi

Sierra Nevada Corp
Mike Jeffries

uPSP Team
E. Lara Lash
Kenny Lyons
Jie Li
David Murakami
Sofia Tafolla
Nathan Eller
Evan Crowe
Nettie Roozeboom
Marc Shaw-Lecerf
Larry Hand
Nick Califano
Paul Stremel
Jennifer Baerny
Christopher Barreras
Blair Mclachlan
Stephanie Morse
Lucy Tang
Kathryn Chapman
Kenji Kato
Jack Ortega

Interns
Kenneth Nguyen
Aiden Szeto
Nathan Strasser
Jack Ortega
Zion Amador
Nick Califano
Joe Adamson
Autumn Gardner
Kate Stamper
Lara Lash
Steve Claughtery
Joe Burces
Nick Huesen
Willy Wang
Varda Ahmed
Gail Romer
Michelle Noguez
Emmanuel Nava

Johnson Space Center
Jessie Powell
Ray Gomez

Marshall Space Flight Center
Thomas Steva
Bruce Laverde
Victoria Pollard
Ryan Connelly
AC Richardson
John Blevins
Paul Bremner

HECC
Tsengdar Lee
Bill Thigpen

ARC Intern Office
Haley Fleck
Abel Morelos
Krisstina Wilmoth
Janet Cabrera

Ametek
Mark Doerfler
Kevin Gann

Langley Research Center
Neal Watkins
Dan Reese
Dave Piatak
Martin Sekula
Francesco Soranna
Patrick Heaney
Mike Ramey
Ian Giles
Oleg Goushcha
Craig Streett
Jeremy Pinier
Dave Schuster

Glenn Research Center
Mark Woike
Jonathan Ponder
Tim Bencic
Chris Bialko

Boeing:
Alan Landmann
Jeff Iqbal
Adam Clark

Contract Companies
Amentum
Jacobs Technology
Metis Flight Research Associates
Aerospace Computing Inc
Science & Technology Corp.
AeroHydro Plus
ASRC Federal

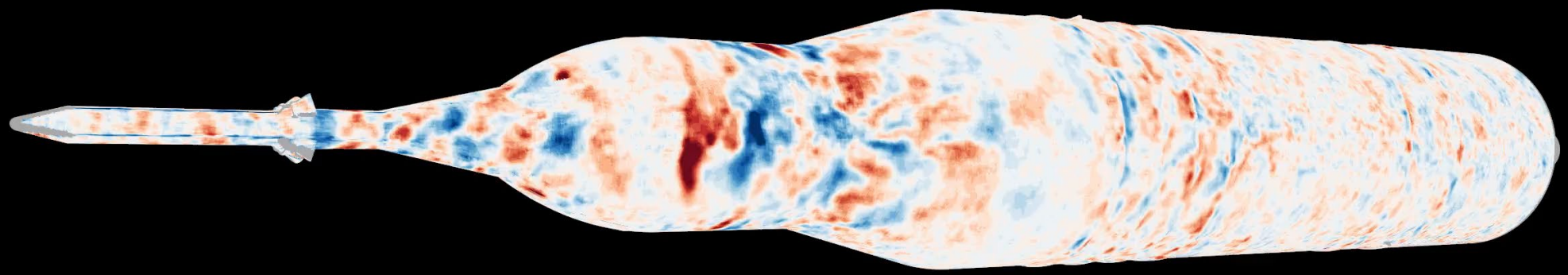
NASA Programs

NASA Aeroscience and Test Capabilities (AETC)
NASA Space Launch System (SLS) Program
NASA Multipurpose Crew Vehicle (MPCV) Program
NASA ARC Wind Tunnel Division
NASA ARC Fluid Mechanics Lab
NASA ARC Advanced Supercomputing Division
NASA High End Computing Capability (HECC)
NASA Engineering and Safety Center (NESC)
NASA ARC Office of Chief Scientist
NASA ARC Office of Chief Technologist

Thank you!

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It's not CFD, it's PSP!



M=0.95, α= 2, β=0

"All in all, for someone who was immersed in, fascinated by, and dedicated to flight, I was disappointed by the wrinkle in history that had brought me along one generation late. I had missed all the great times and adventures in flight."
~ Neil Armstrong (1947)