

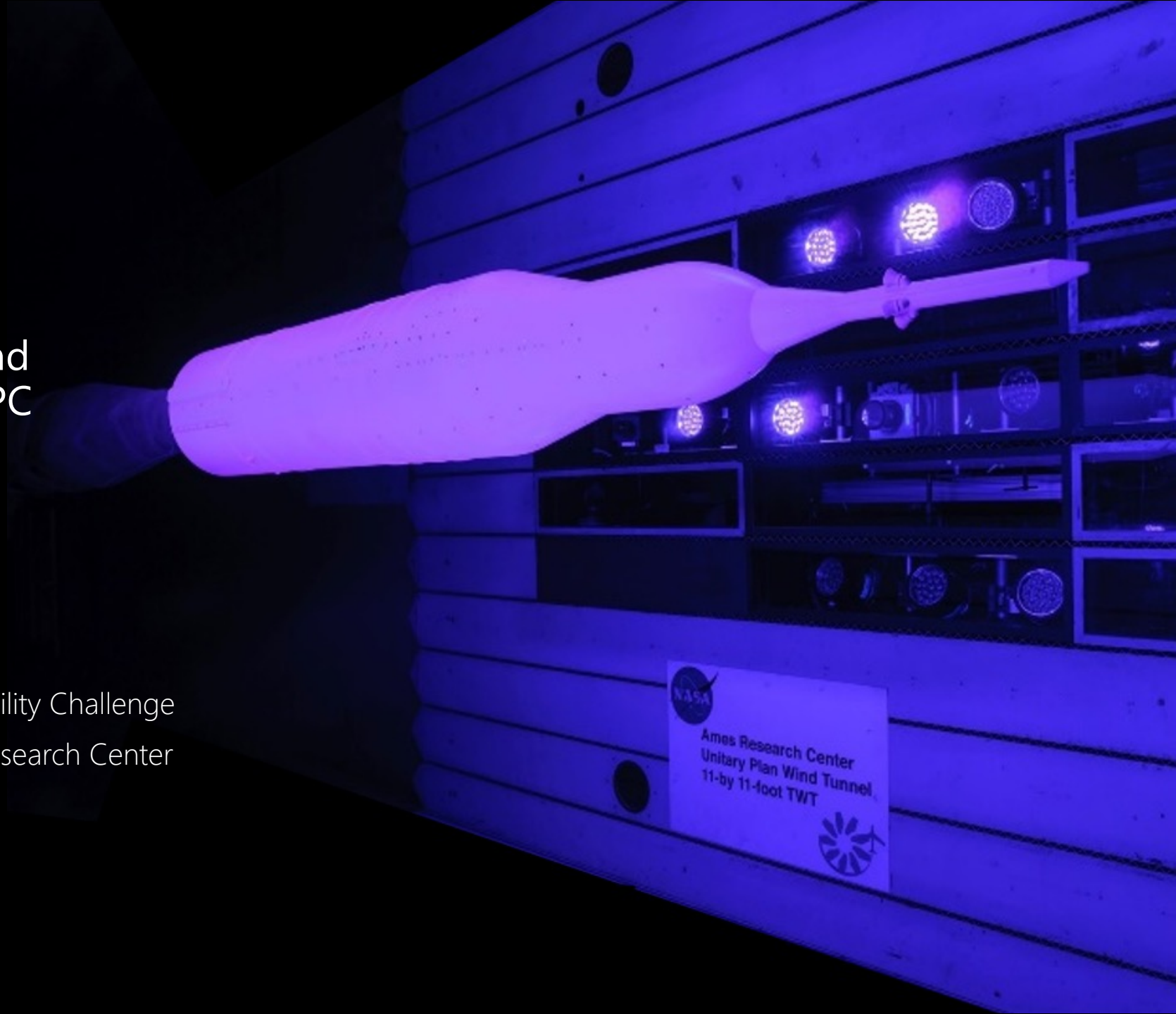
Enabling Next-Generation Wind Tunnel Tests with uPSP and HPC

May 2022 LaRC HPCC Talk

Marc Shaw-Lecerf

Software Lead, uPSP Test Technology Capability Challenge

Fluid Mechanics Laboratory, NASA Ames Research Center



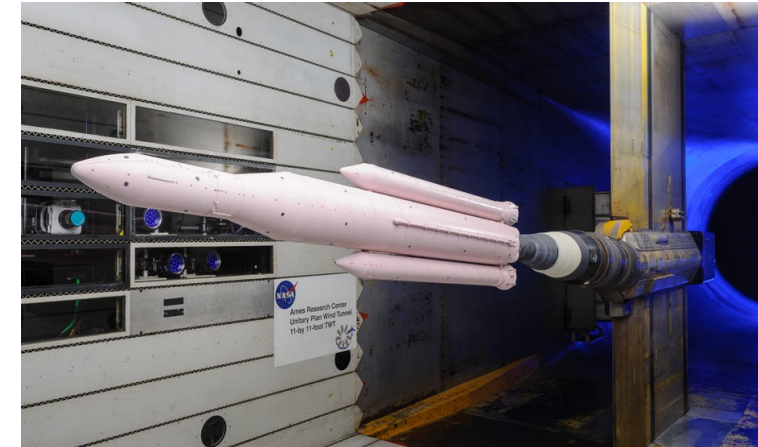
- **What is a uPSP system?**
- Overview of uPSP system deployed at NASA Ames
- Overview of uPSP data processing software
- Lessons learned [software-centric]
- Future and ongoing work
- Conclusion

What is a uPSP system?



Unsteady Pressure-Sensitive Paint

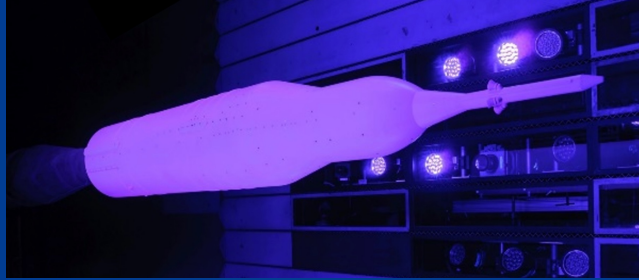
1. Apply porous, fast-response PSP to subject
2. Illuminate paint with UV light source
3. Paint emission is a function of pressure
4. Measure emission with high-speed cameras



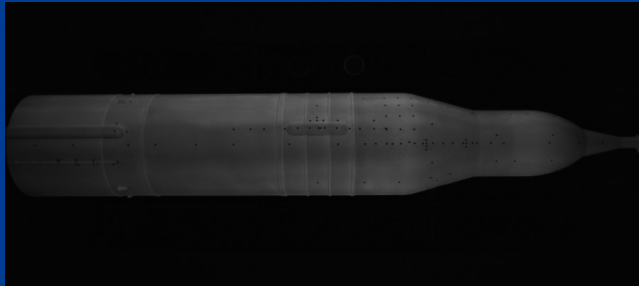
What is produced by a uPSP system?



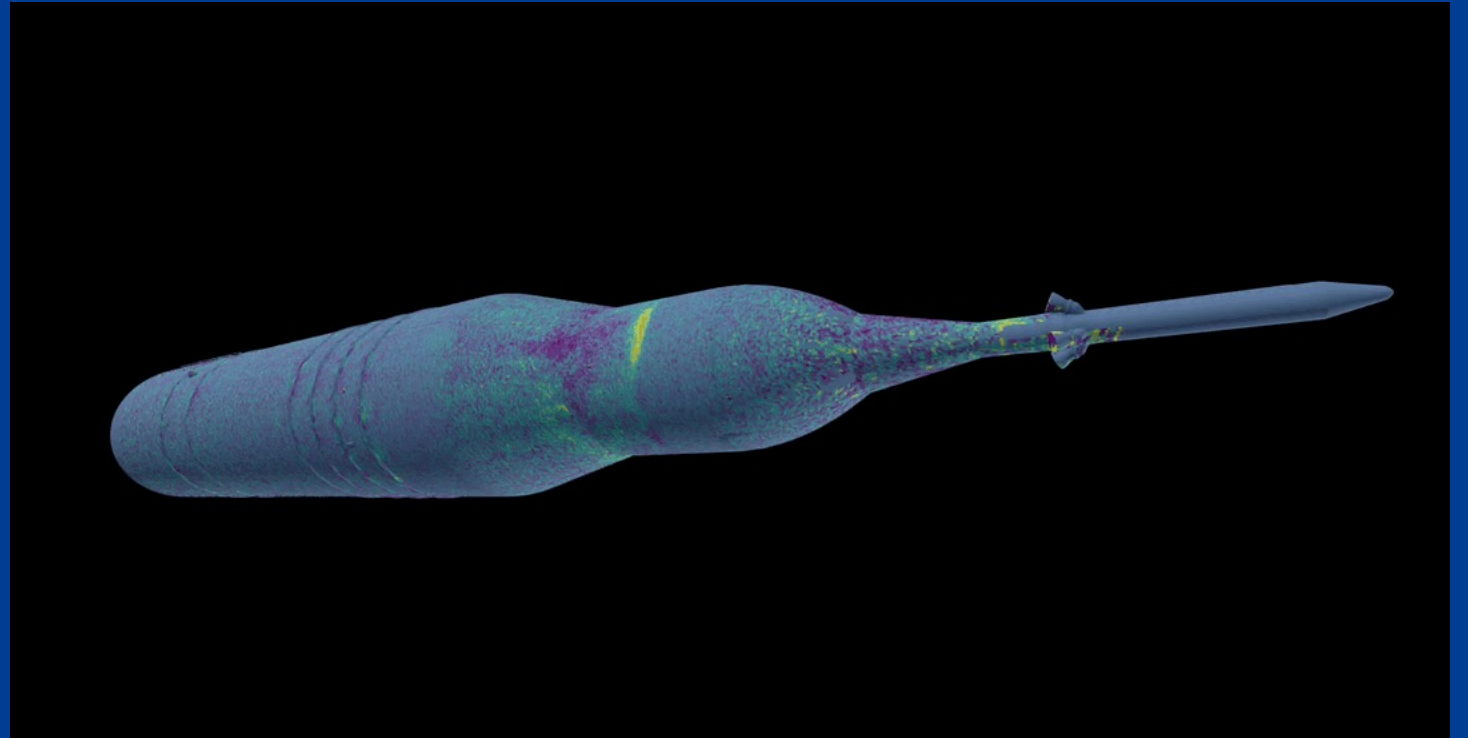
Wind Tunnel Test DAQ



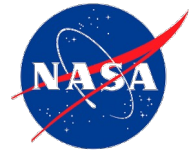
High-Speed Video Frames



Fluctuating Surface Pressure (10k FPS, playback @ 30 FPS)



What is produced by a uPSP system?

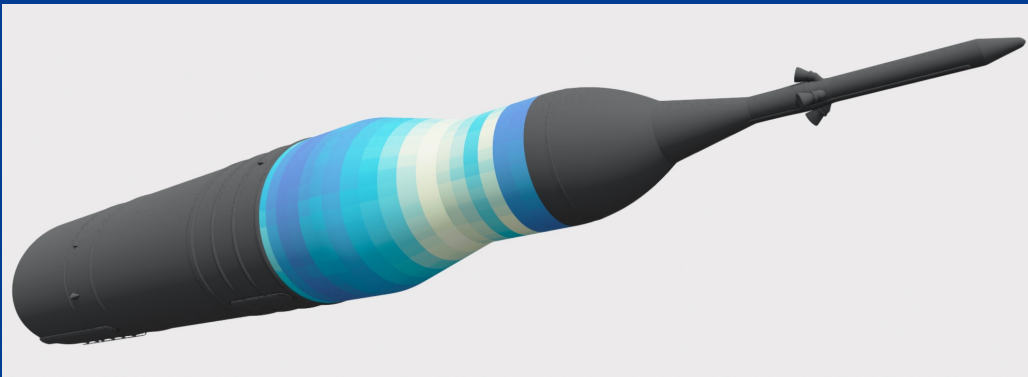


Example data products relevant for launch vehicle loads analysis

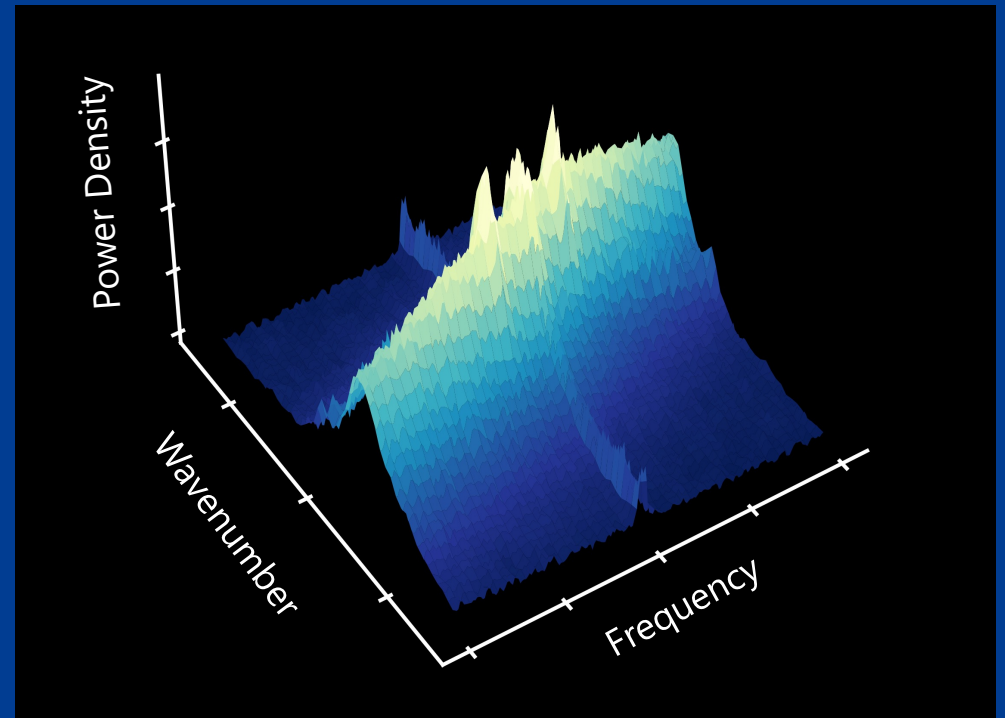
Turbulent BL Convective Speeds



Area-Averaged Surface Loads



Wavenumber-Frequency Pressure Spectrum

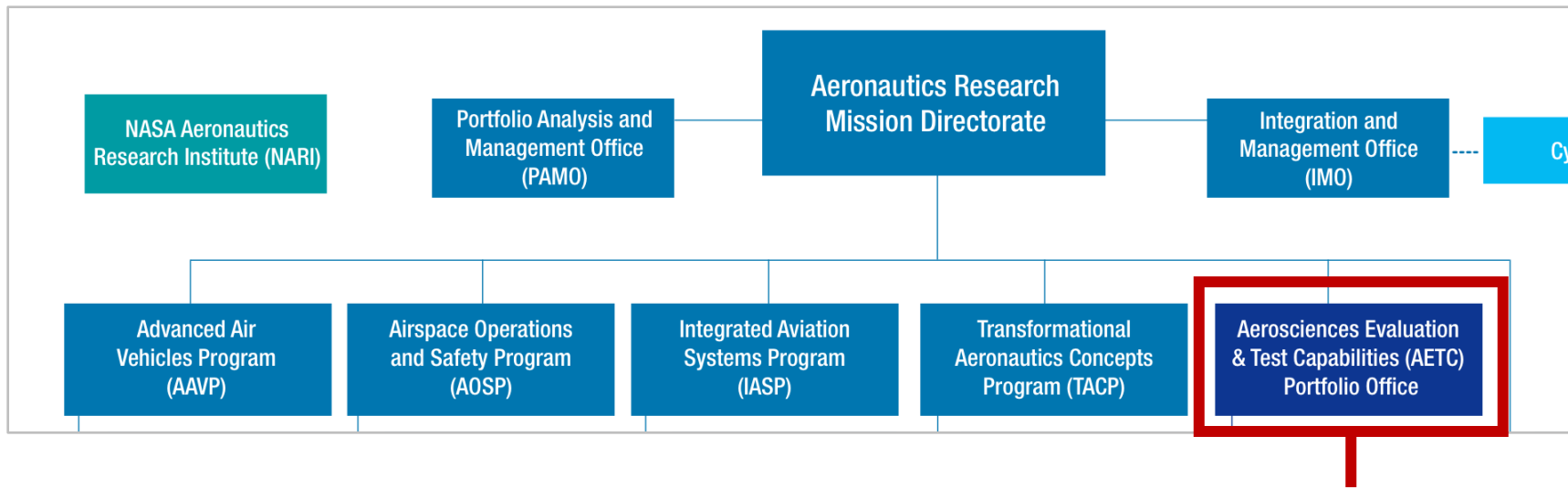
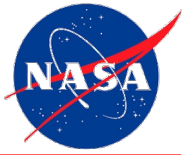


Outline



- What is uPSP?
- **Overview of uPSP system deployed at NASA Ames**
- Overview of uPSP data processing software
- Lessons learned [software-centric]
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uPSP Test Technology Capability Challenge



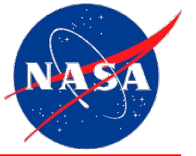
- **Aerosciences Evaluation & Test Capabilities (AETC) Portfolio Office**

Executes strategic efforts to preserve and enhance research and test capabilities for NASA's world-class portfolio of National Wind Tunnel facilities.

- **uPSP Test Technology Capability Challenge**

*Develop a state-of-the-art system to **measure, assess, and visualize** unsteady aerodynamics for advanced and complex aerospace vehicles at **high-resolution** and **unprecedented data turn-around times ("months" to "minutes")***

ARC Facilities enabling uPSP capability



Ames Unitary Plan Wind Tunnel Complex (UPWT)



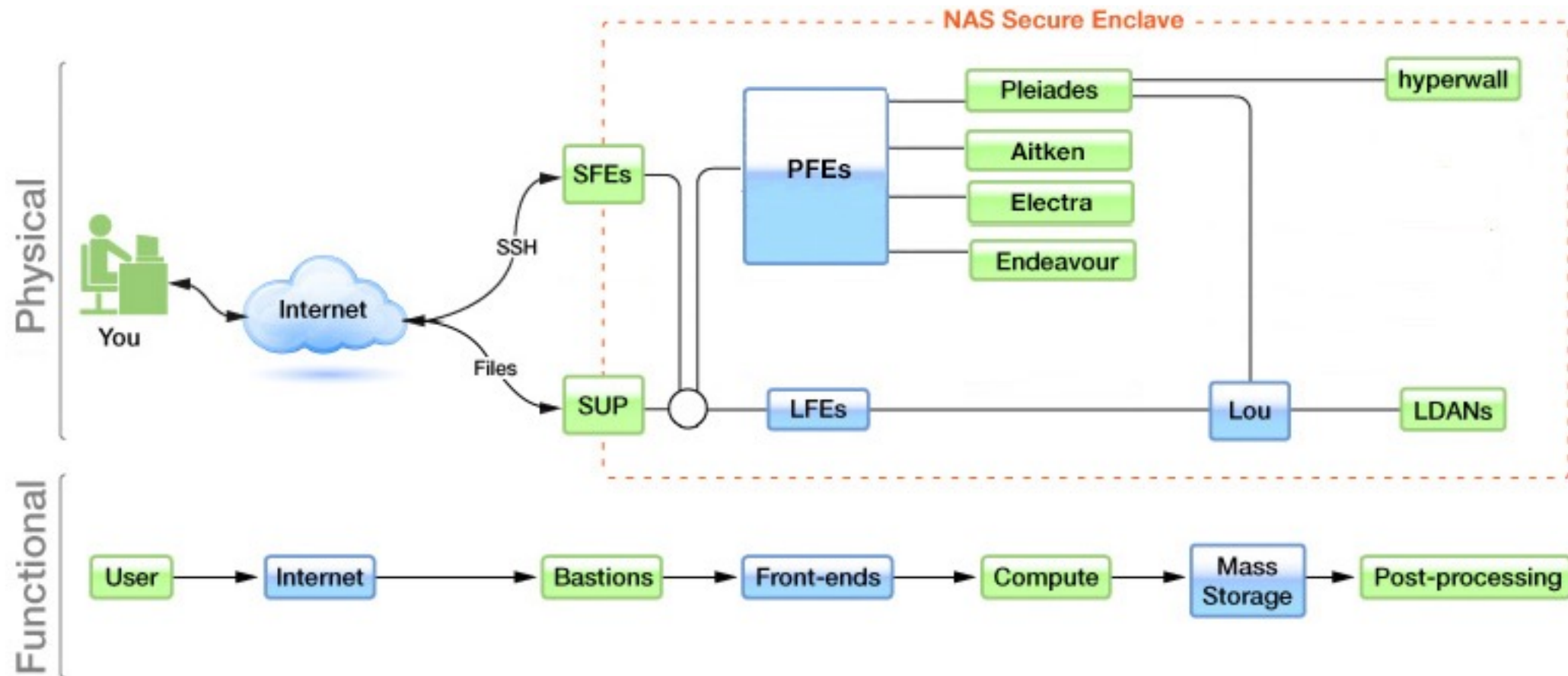
NASA Advanced Supercomputing (NAS) Division



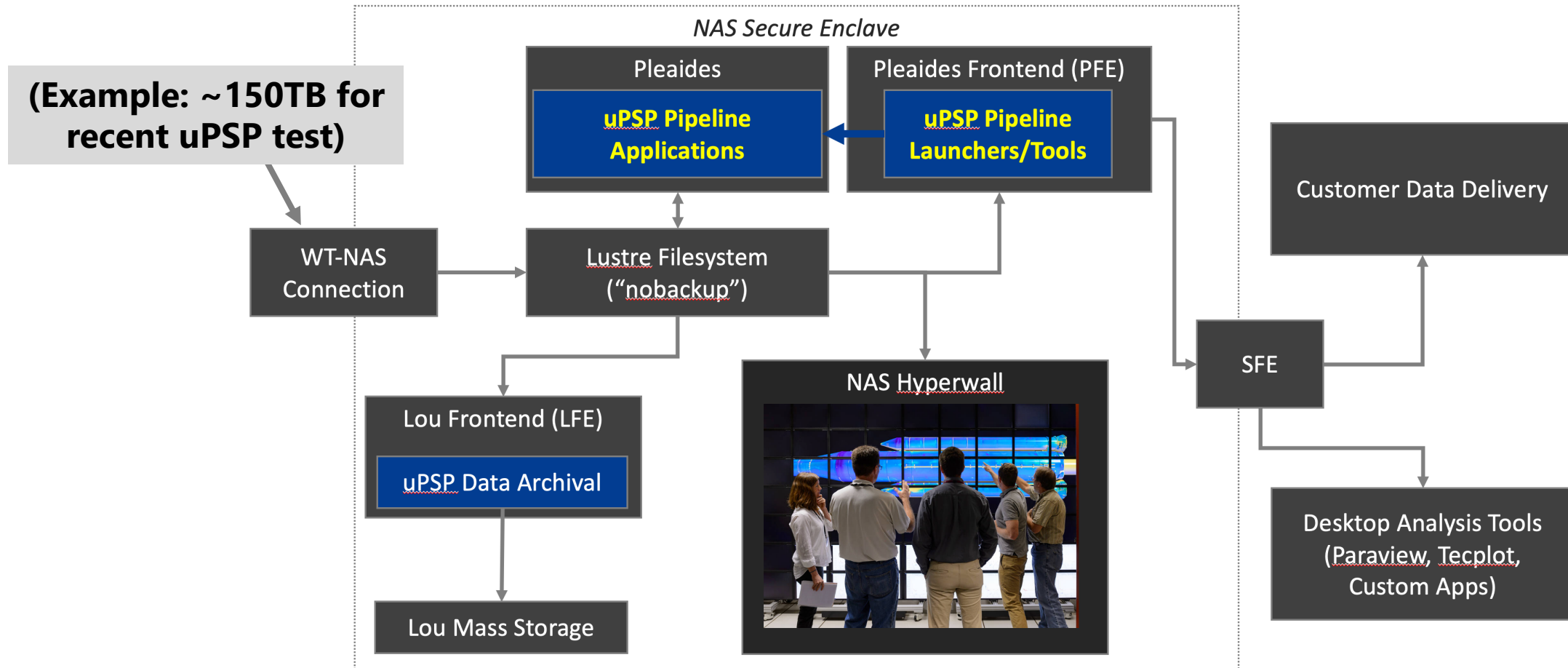
Fiber Optic Connection



NAS HPC Environment



uPSP @ NAS HPC Environment



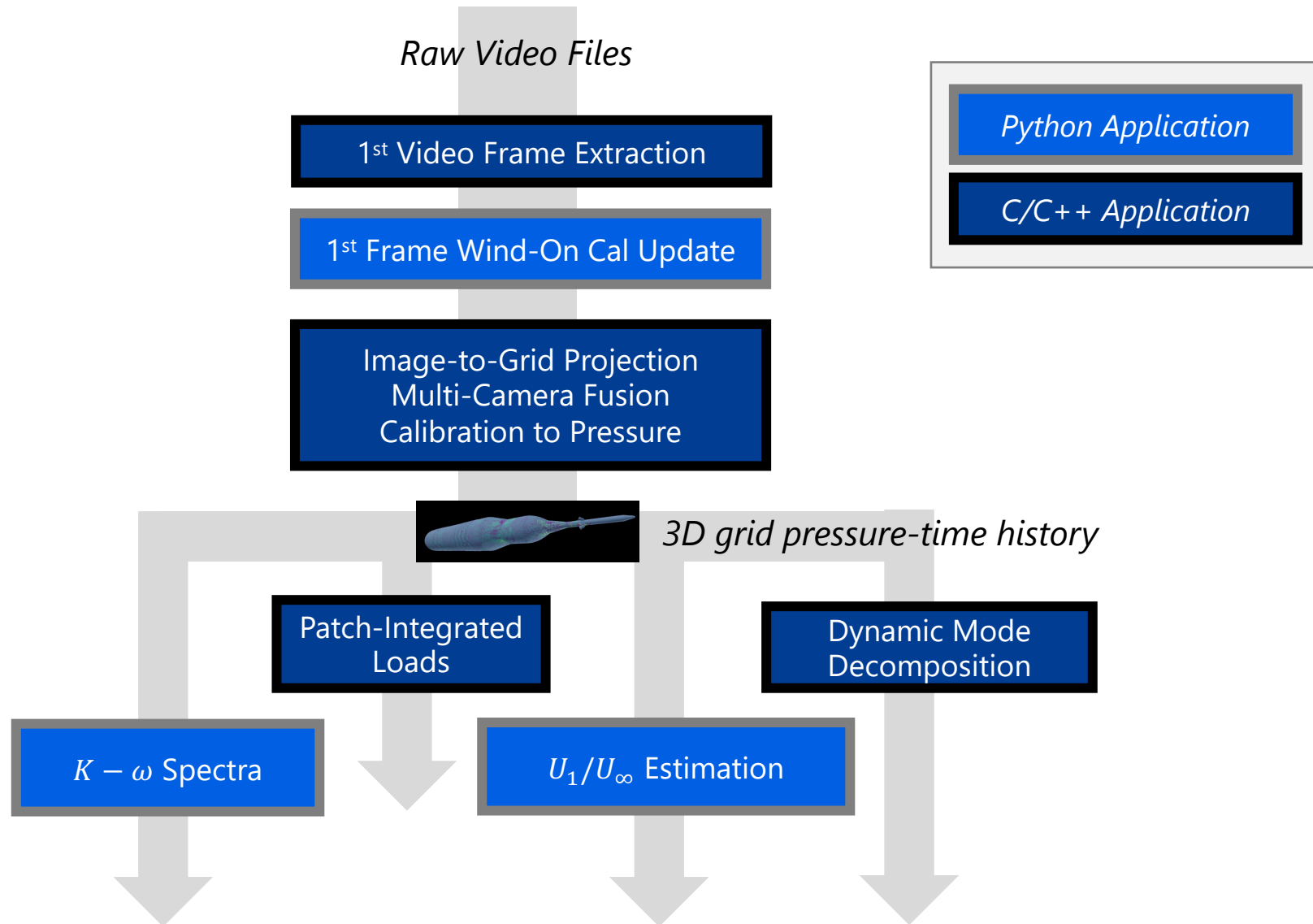
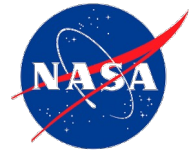
“Rethinking the hard drive” for WT customer data delivery
NAS resources enable on-demand/just-in-time processing and analysis

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uPSP Data Processing Pipeline



uPSP Data Processing Pipeline

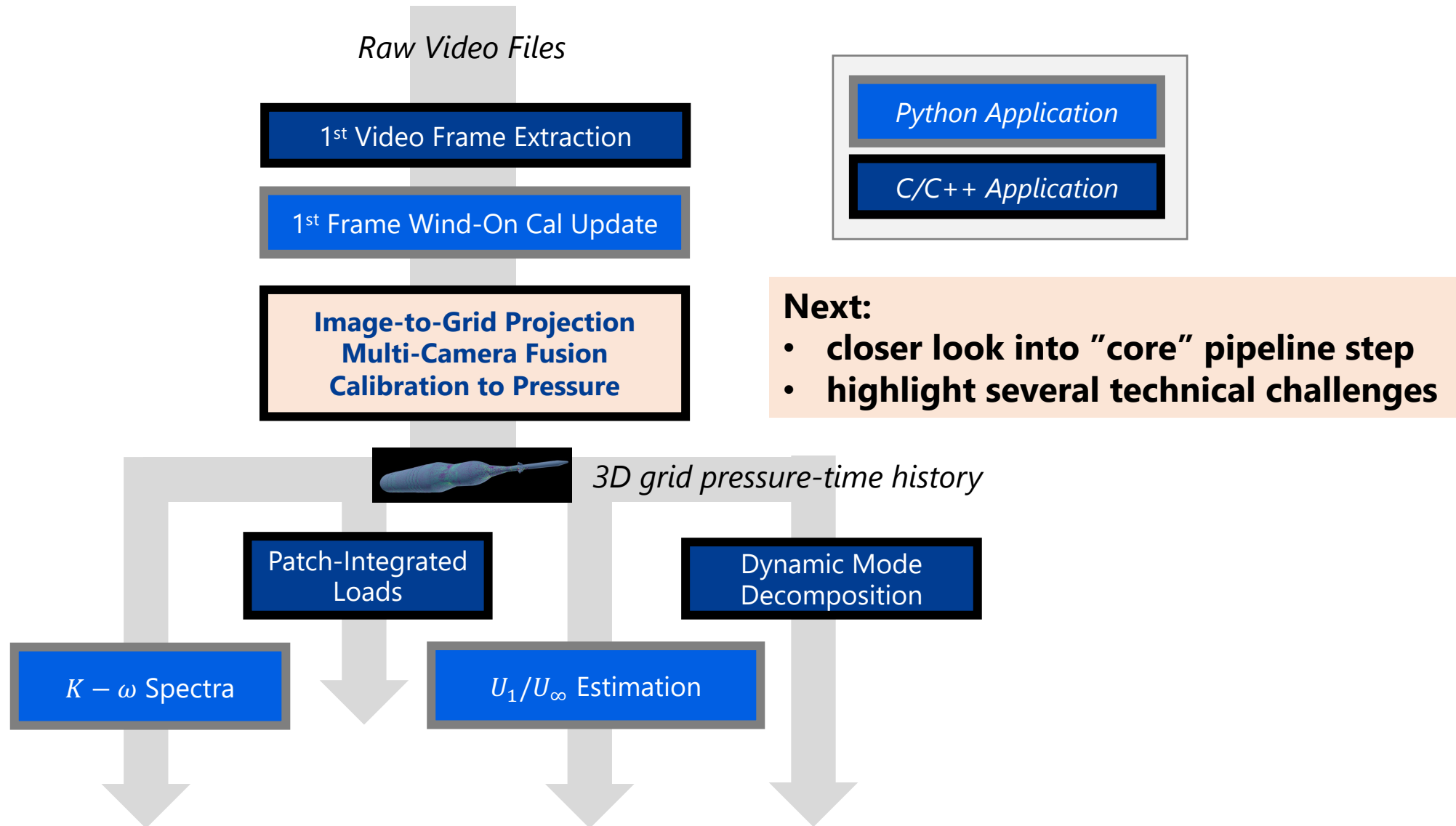
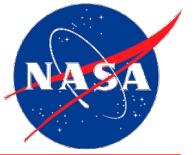
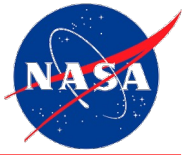
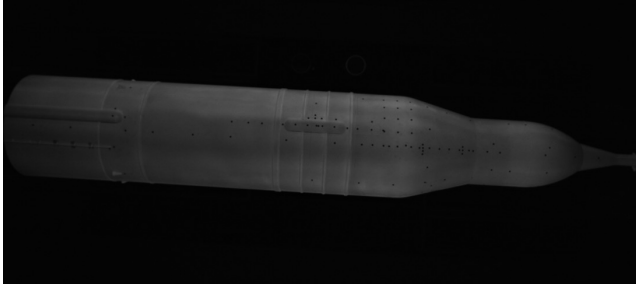


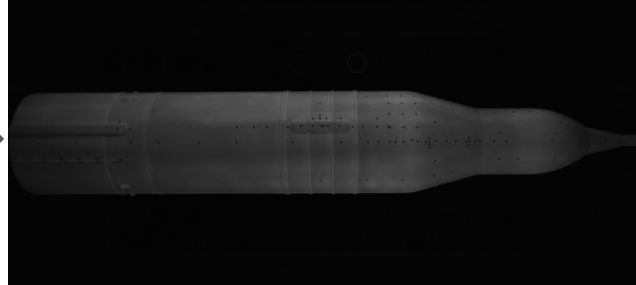
Image-to-Grid projection leveraging HPC



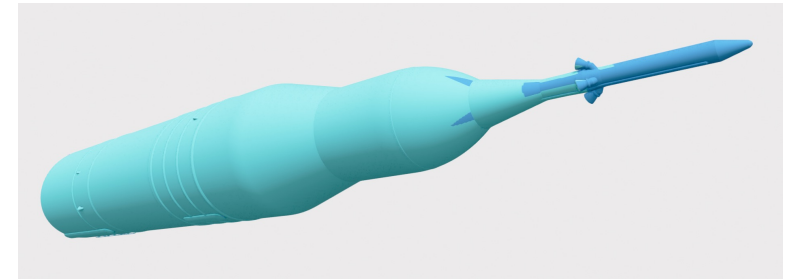
Frame 'k'



Frame 'k', aligned to Frame 0
(tform assumed small, affine)



1. Image registration aligns each frame to first frame
2. Projection built for model position in first frame
3. Projection accounts for visibility (via raycast)
4. Linear combination of value from each camera



MPI Communicator

Rank 1

Frame Chunk 1



Grid Intensity Chunk 1

Rank 2

Frame Chunk 2



Grid Intensity Chunk 2

...

Rank R

Frame Chunk R



Grid Intensity Chunk R

Challenge 1: [1M verts x 50K frames] =
~200GB total memory

Grid Intensity Chunk

t1 Intensity[v]

t2 Intensity[v]

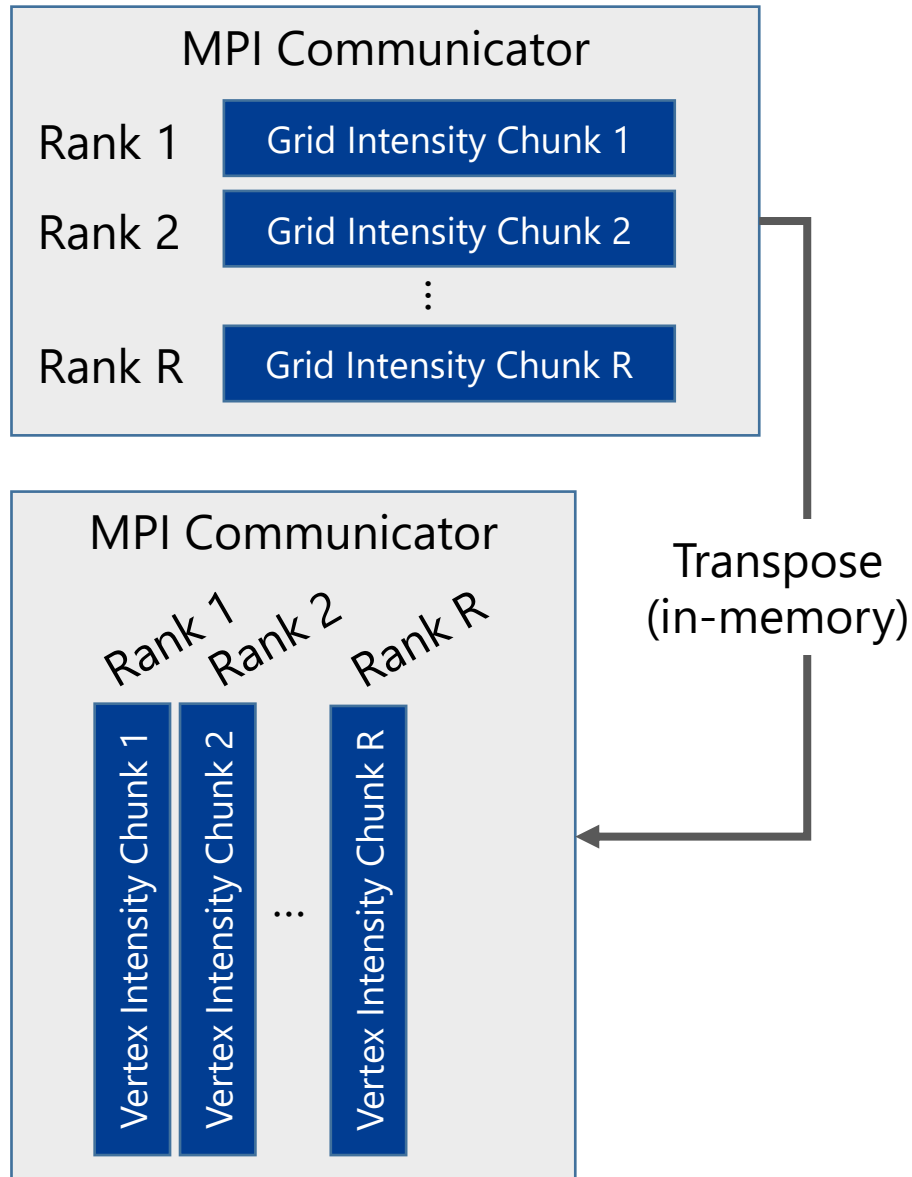
⋮

tM Intensity[v]

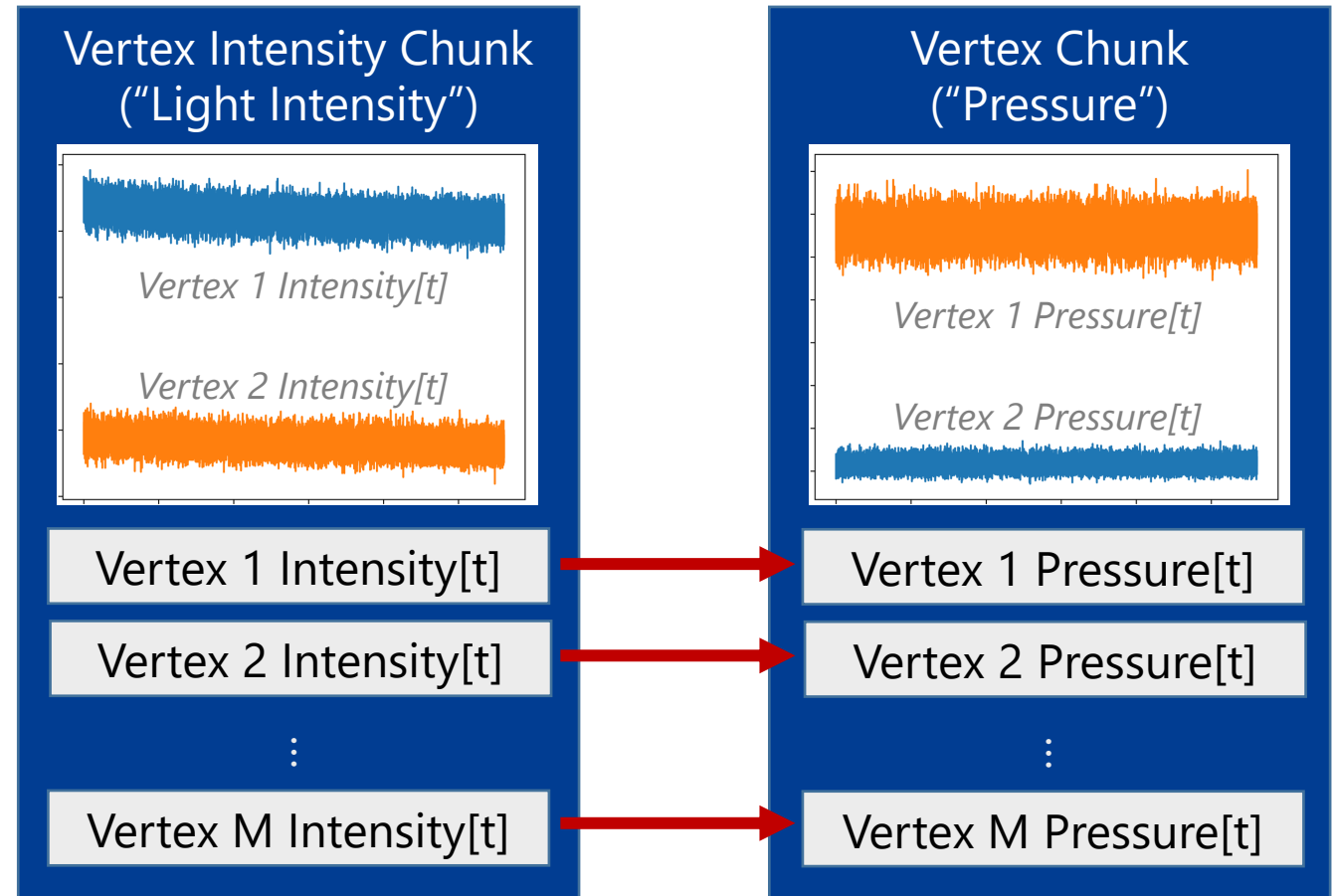
Calibration to Pressure leveraging HPC



Challenge 2: 3D Projection scales across ***time***
Pressure calibration scales across ***space***



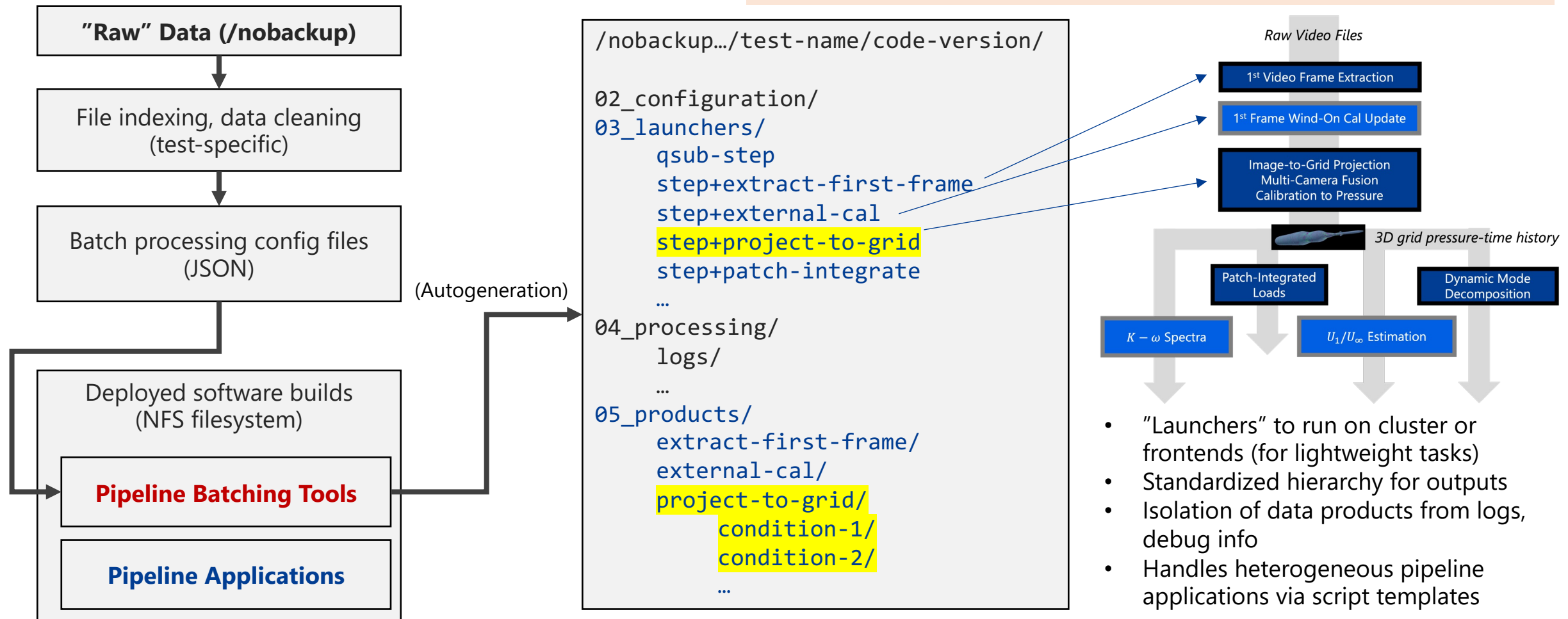
(Detrending + in-situ & lab-based calibration)



Software Tools deployed to HPC systems



Challenge 3: Manage data from multiple customers and iterative SW development

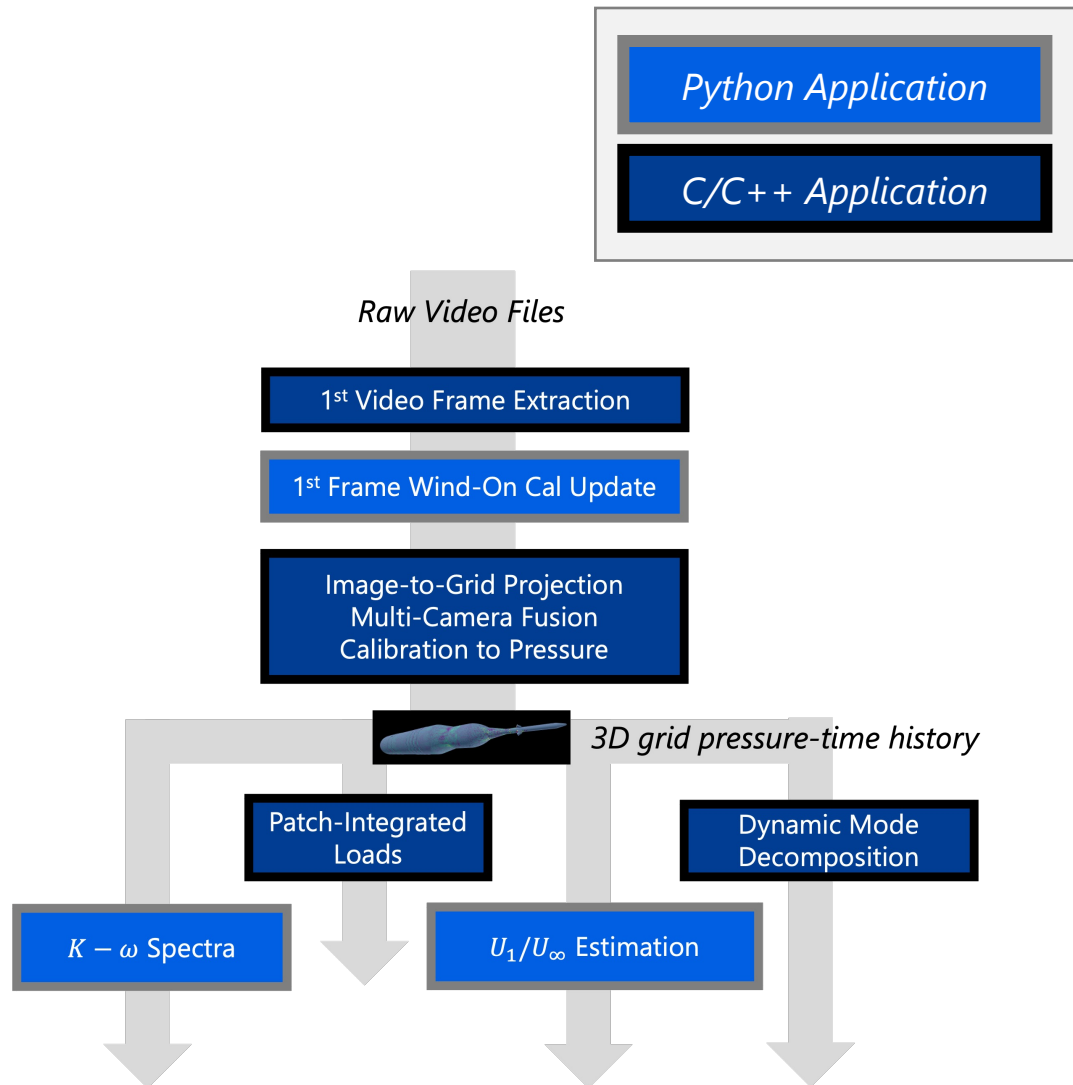
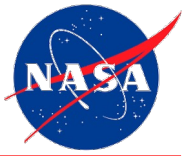


Outline



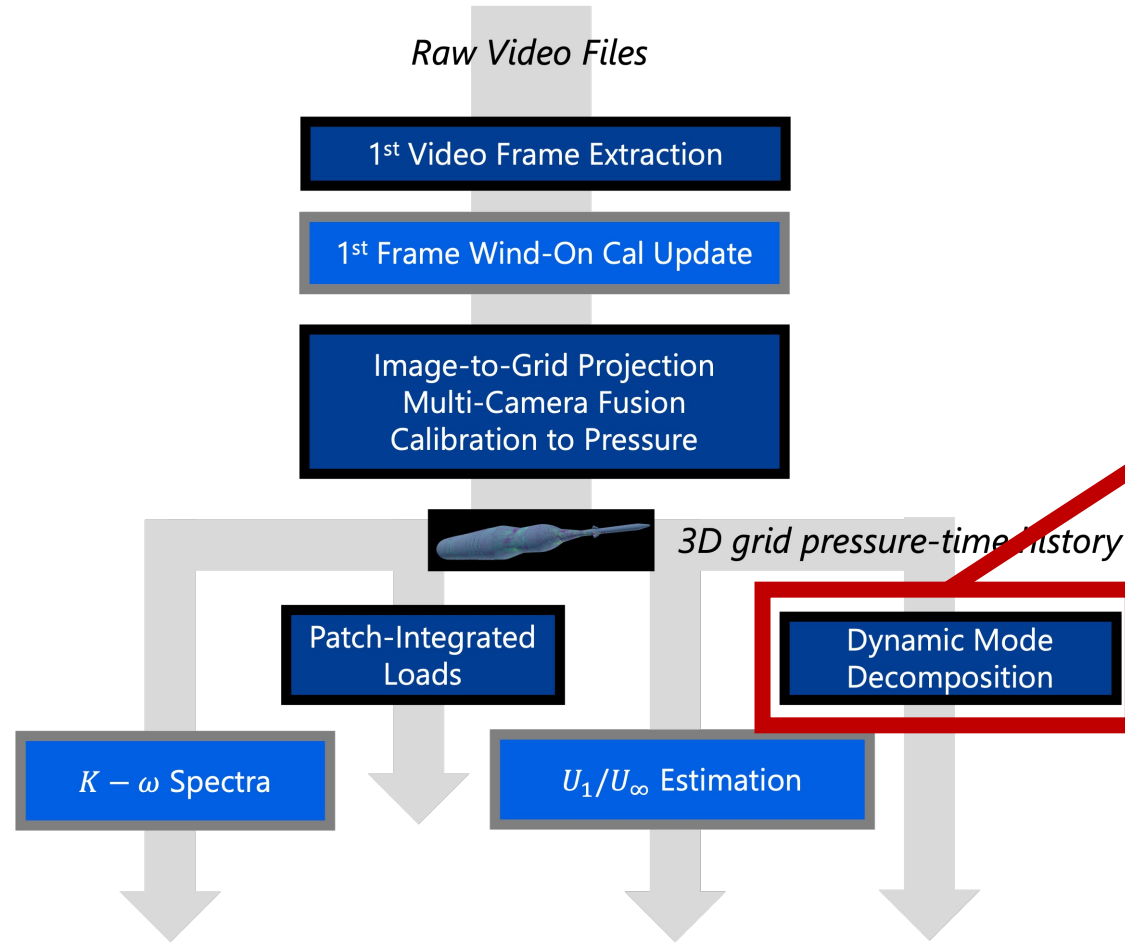
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Lessons learned during development

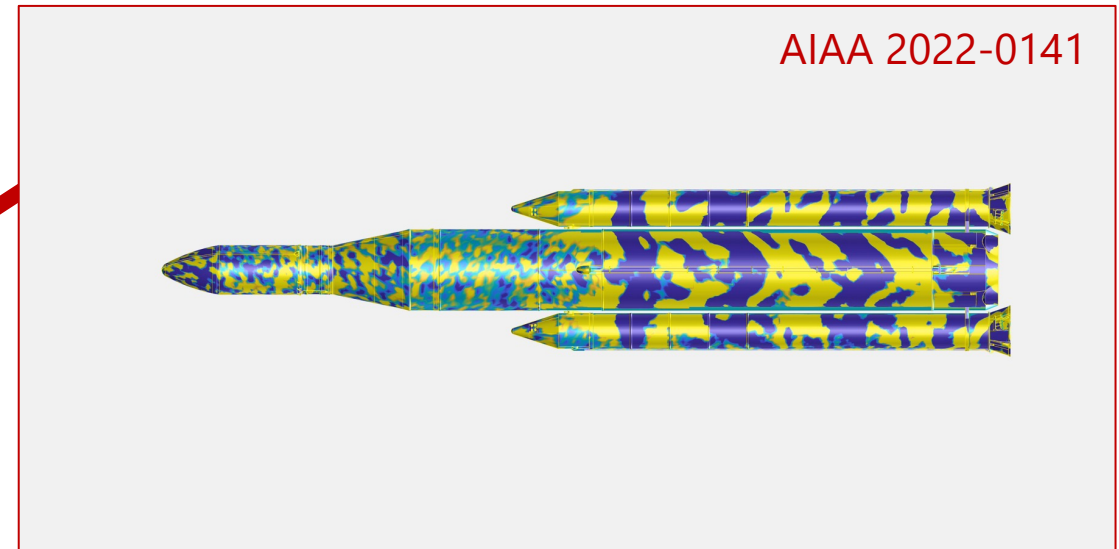


- **Version control is essential**
 - Accurately track code version + data products
 - >30 contributors to-date (back to ~2015)
- **Real test data is messy**
 - “Data cleaning” steps are mandatory
 - Leave room for the human in SW design
- **Multiple language support**
 - Use bindings to share functionality (pybind11)
 - Accommodate diverse team skillsets
- **Modern build+deploy tools improve portability**
 - cmake, vcpkg, miniconda3
 - Dockerfile for local dev environment

Learn by Doing - NAS GPU Hackathon 2021

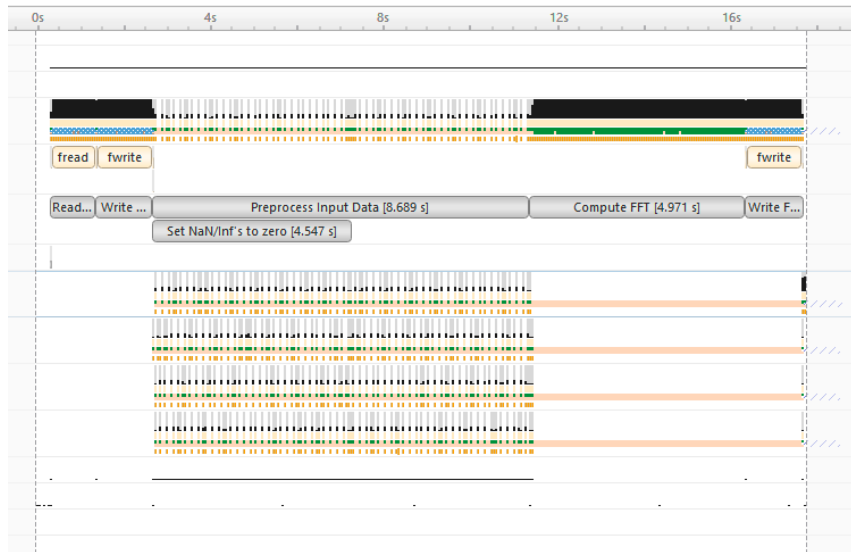


- Create "mini-app" from DMD pipeline step

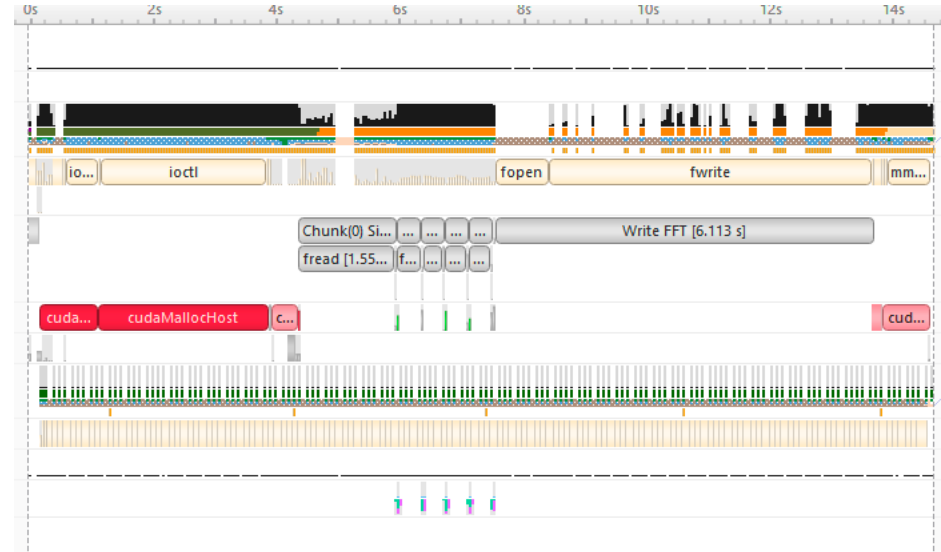


Working towards **on-demand generation** of uPSP data products

- **~14 sec** for math routines on CPU



- ~50 msec for math routines on GPU
- ~350 msec for GPU-host IO
- ~4 sec for host pinned memory allocate



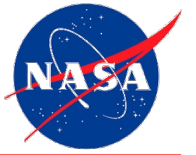
Hands-on practice with **NVIDIA® Nsight™ Systems**

Outline



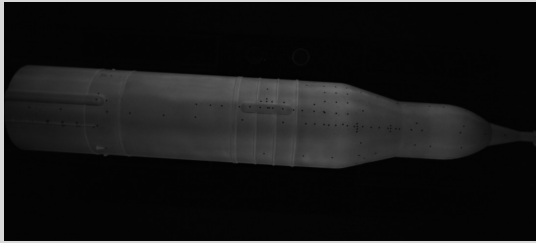
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Improving uPSP 3D projection step

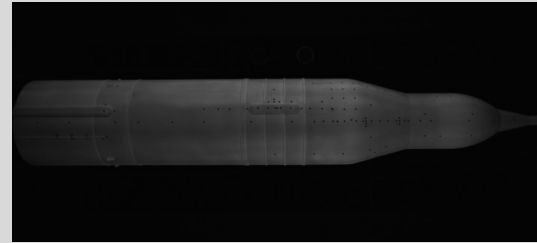


Current Approach

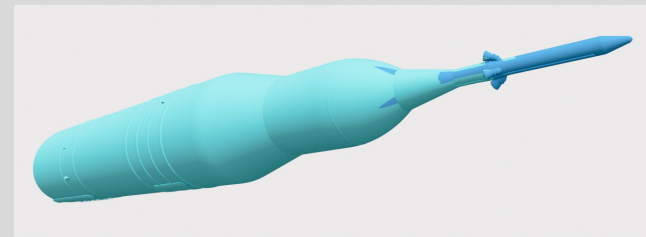
Frame 'k'



Frame 'k' aligned to Frame 0
(tform assumed small, affine)

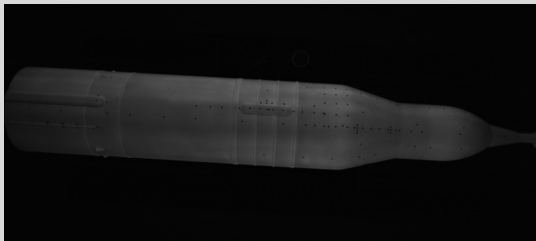


3D Projection based on
external calibration of Frame 0

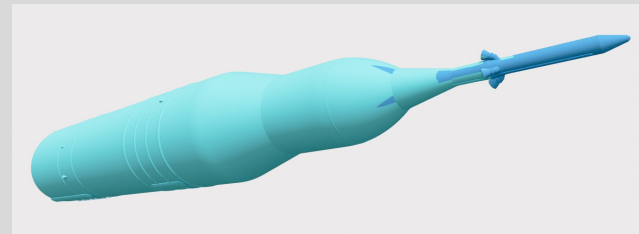


Improved Approach (In progress)

Frame 'k'

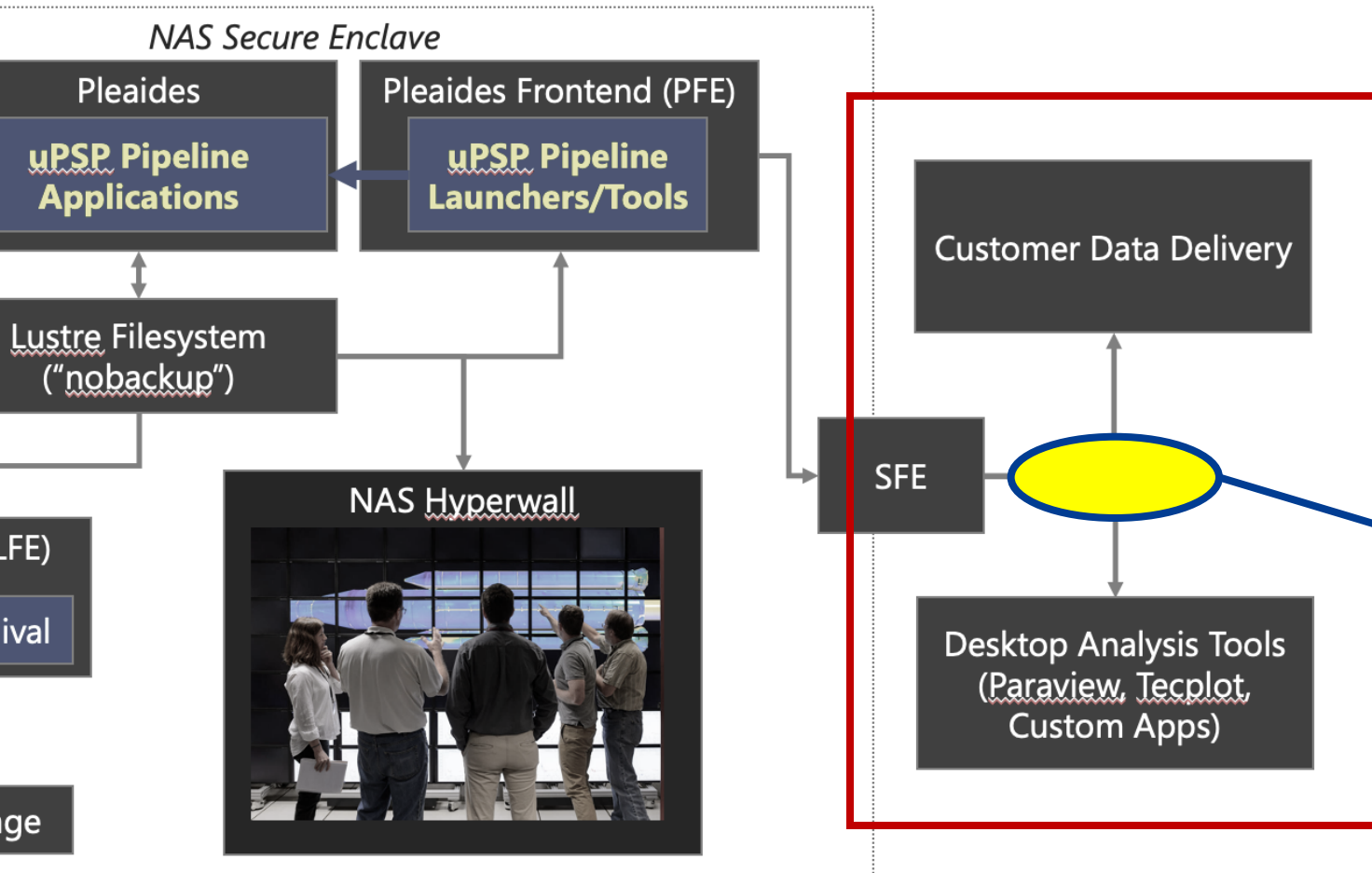


Grid Projection based on
external calibration of Frame 'k'



- Improved fidelity vs Frame 0 registration
- Facilitates Uncertainty Quantification (UQ)
- Facilitates handling model deformation
- Facilitates model motion tracking

Simplifying uPSP data access for end users



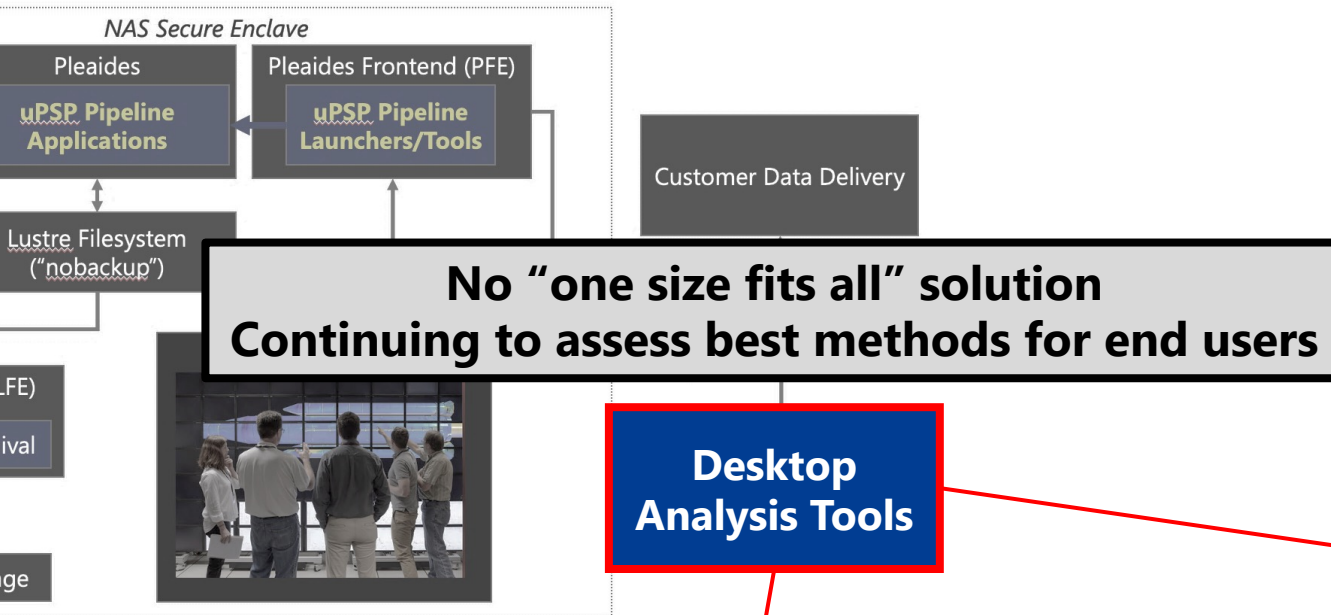
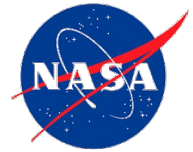
Current data access limitations

- SSH connection required
- All users must have NAS accounts

Ongoing work

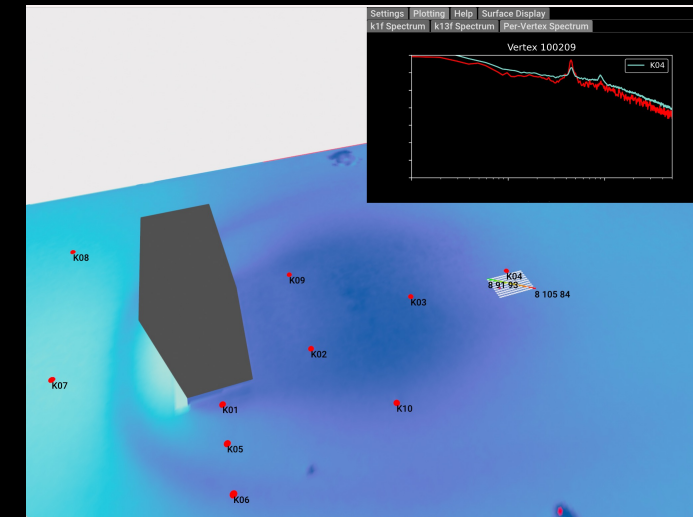
- Additional service(s) to mediate with NAS
- Compliance with latest NASA IT standards
- Flexible endpoint for multiple applications

uPSP analysis toolkit buildup

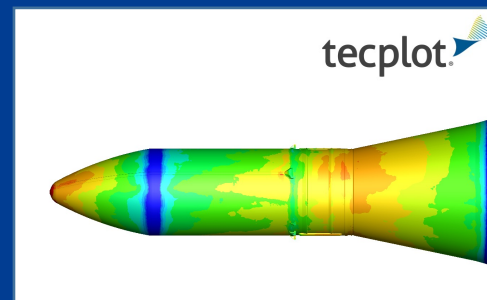
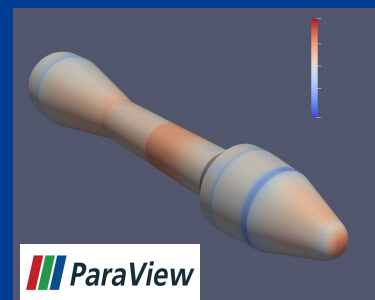


Custom uPSP Applications

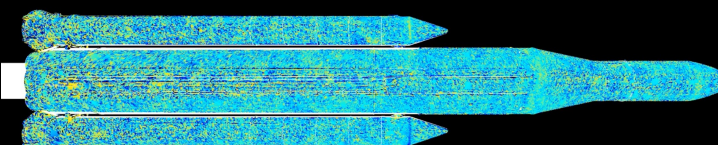
On-Demand Spectral Decomposition



General-Purpose Engineering Analysis



AR/VR-Capable



Ongoing collaboration and outreach



- Supporting **uPSP capability at LaRC** (SW deployment)
- Working towards **open-source distribution** (end of FY23)
- Close collaboration with **SLS program**
 - Ascent Unsteady Aerodynamics Test (AUAT), 2017
 - Ascent Transient Aerodynamics Test (ATAT), 2019

Outline



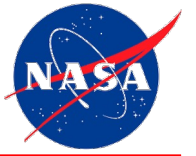
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Conclusion



- uPSP → **Next-generation** wind tunnel data products
- UPWT + NAS → **On-demand uPSP data analysis + delivery**
- Eager to promote collaborations between **experimental** + **computational** capabilities to advance aerospace technologies

Thank You!



Heartfelt thanks to teams and organizations that made this possible

- ARMD + AETC Portfolio Office
- SLS Program (MSFC, LaRC, JSC)
- HEC Program, ARC NAS Division
- ARC Wind Tunnel Division
- ARC FML Staff
- uPSP TTCC Team
- Open Source Initiative (OSI)
- ... and many others!

