

Steady Surface Pressure Measurement via the Lifetime Method with High-Speed Cameras in NASA's Unitary Plan Wind Tunnel

Kenneth R. Lyons¹

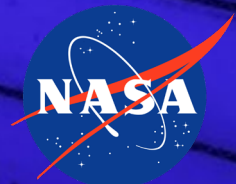
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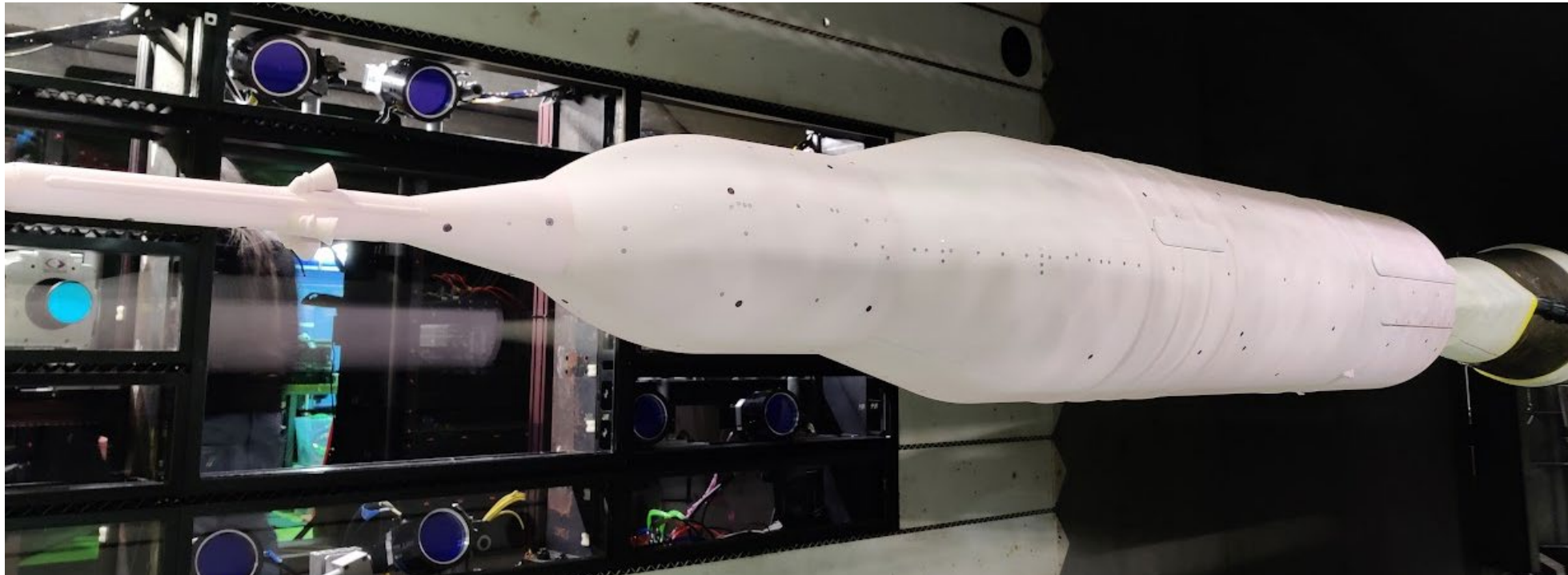
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Launch Vehicle Demonstration Test (LVDT)



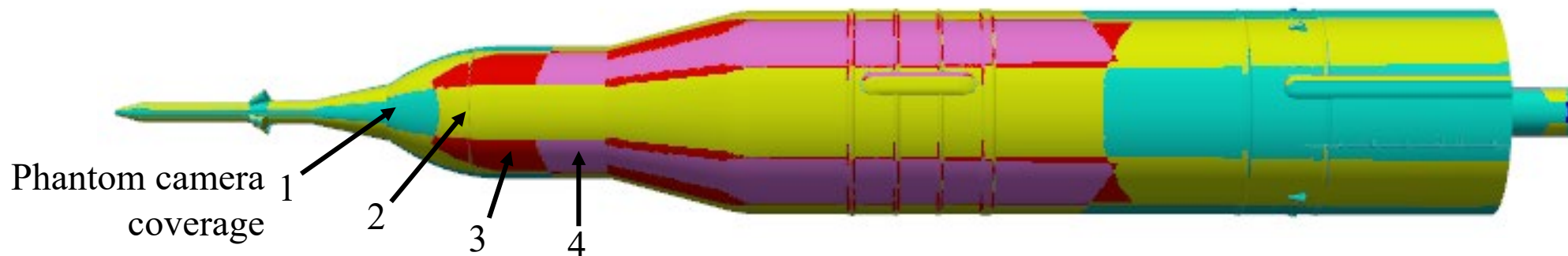
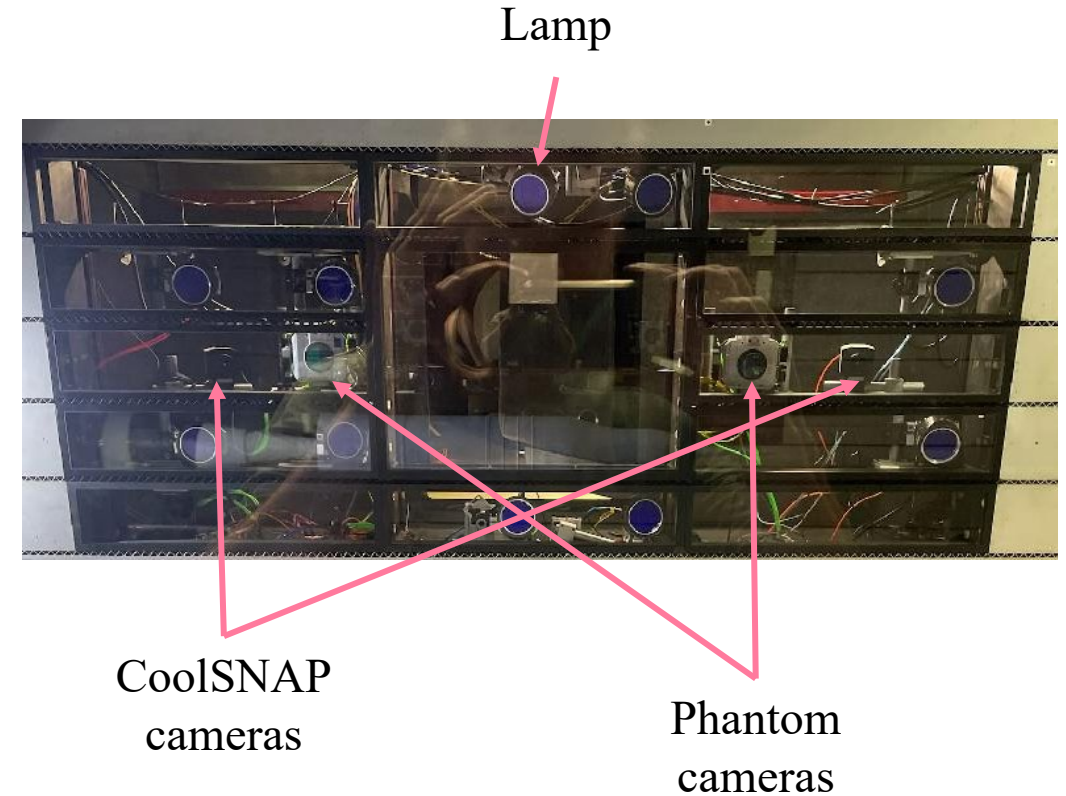
- SLS Block 1B 4% Crew Config
- Model instrumentation:
 - 119 pressure transducers
 - **176 static pressure ports**
 - 6 thermocouples
- NASA Ames UPWT 11-by 11-foot
- Same model & tunnel used in 2017 Ascent Unsteady Aerodynamics Test (**AUAT**)



PSP Instrumentation



- “High-speed system”:
 - 8 Vision Research Inc. Phantom[®] v2512 high-speed cameras
- “Legacy system”:
 - 8 Photometrics[®] CoolSNAP[™] K4 cameras
 - Modified for on-chip accumulation
 - Separate, opaque computing infrastructure
- 40 400nm LED lamps
- ISSI porous fast-response paint

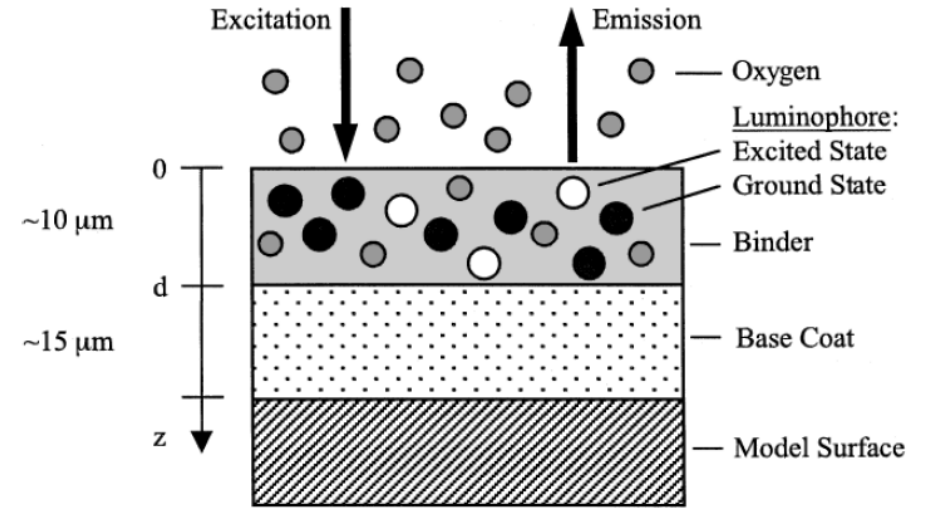


Background: PSP



Paint consists of two primary components:

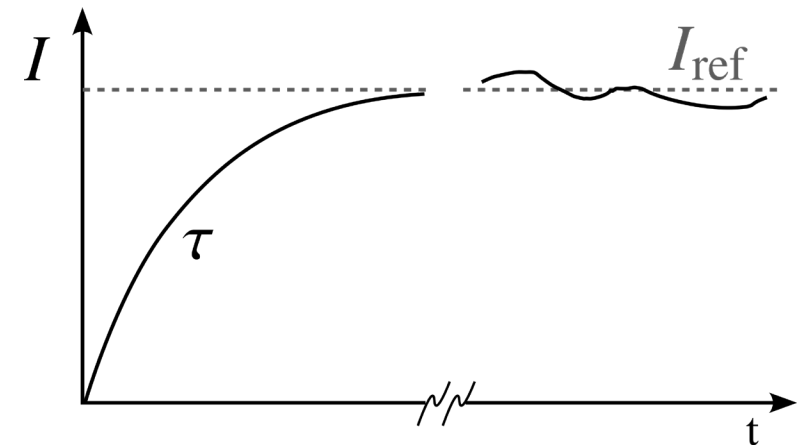
- Luminophores Luminesce processes quenched by oxygen
- Binder Oxygen-permeable matrix



Bell et al., "Surface Pressure Measurements Using Luminescent Coatings," 2001.

Two main methods to estimate pressure:

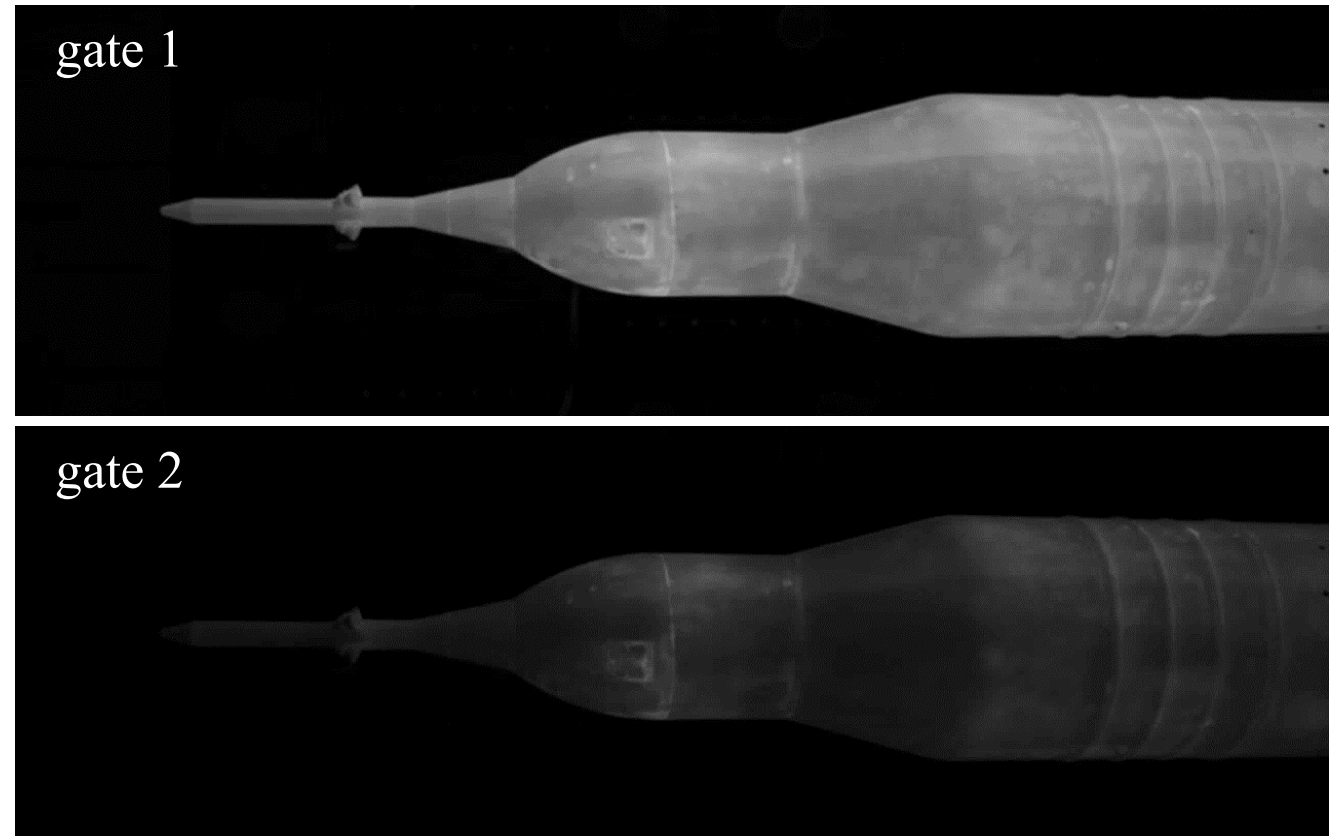
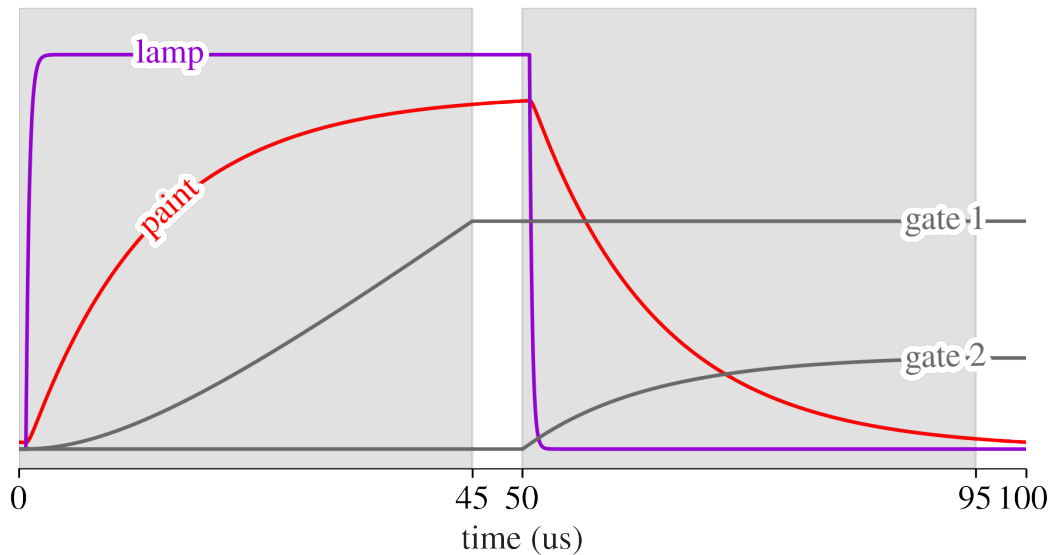
- Lifetime** Relate dynamic response to pressure
→ steady-state pressure
- Intensity** Reference to steady intensity
→ fluctuating pressure



Background: Lifetime Method

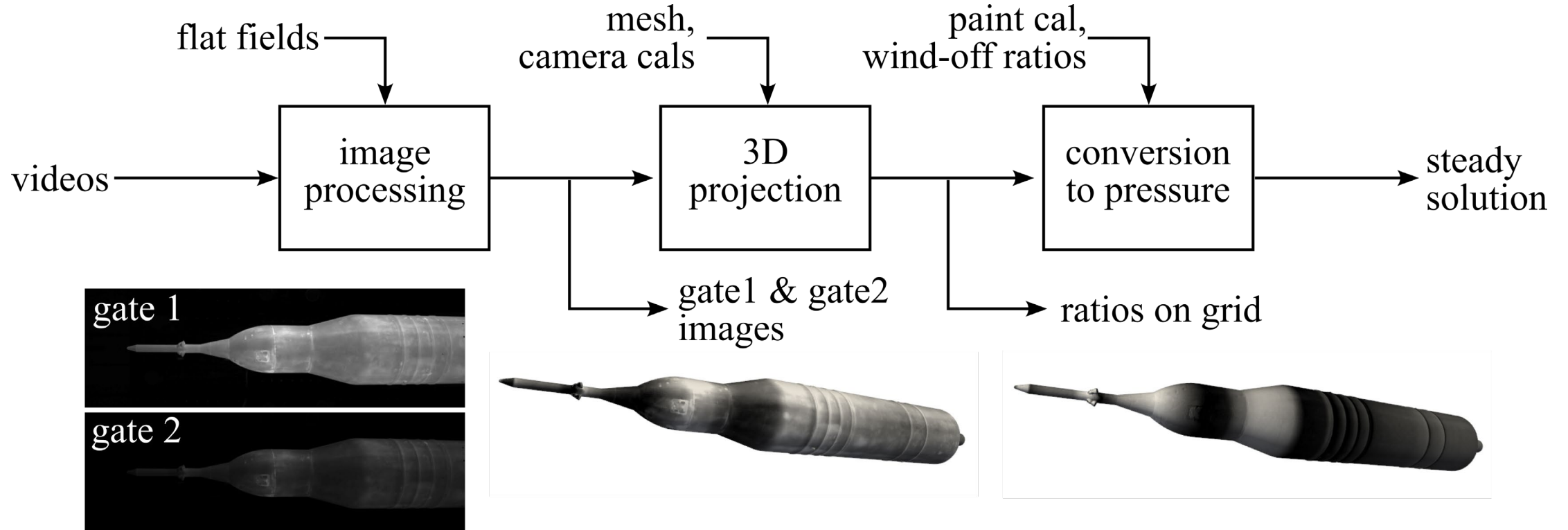


- Acquire images (gates) with exposures precisely timed with respect to pulsed illumination
- Relate gate ratio to pressure and temperature



brightness +50%

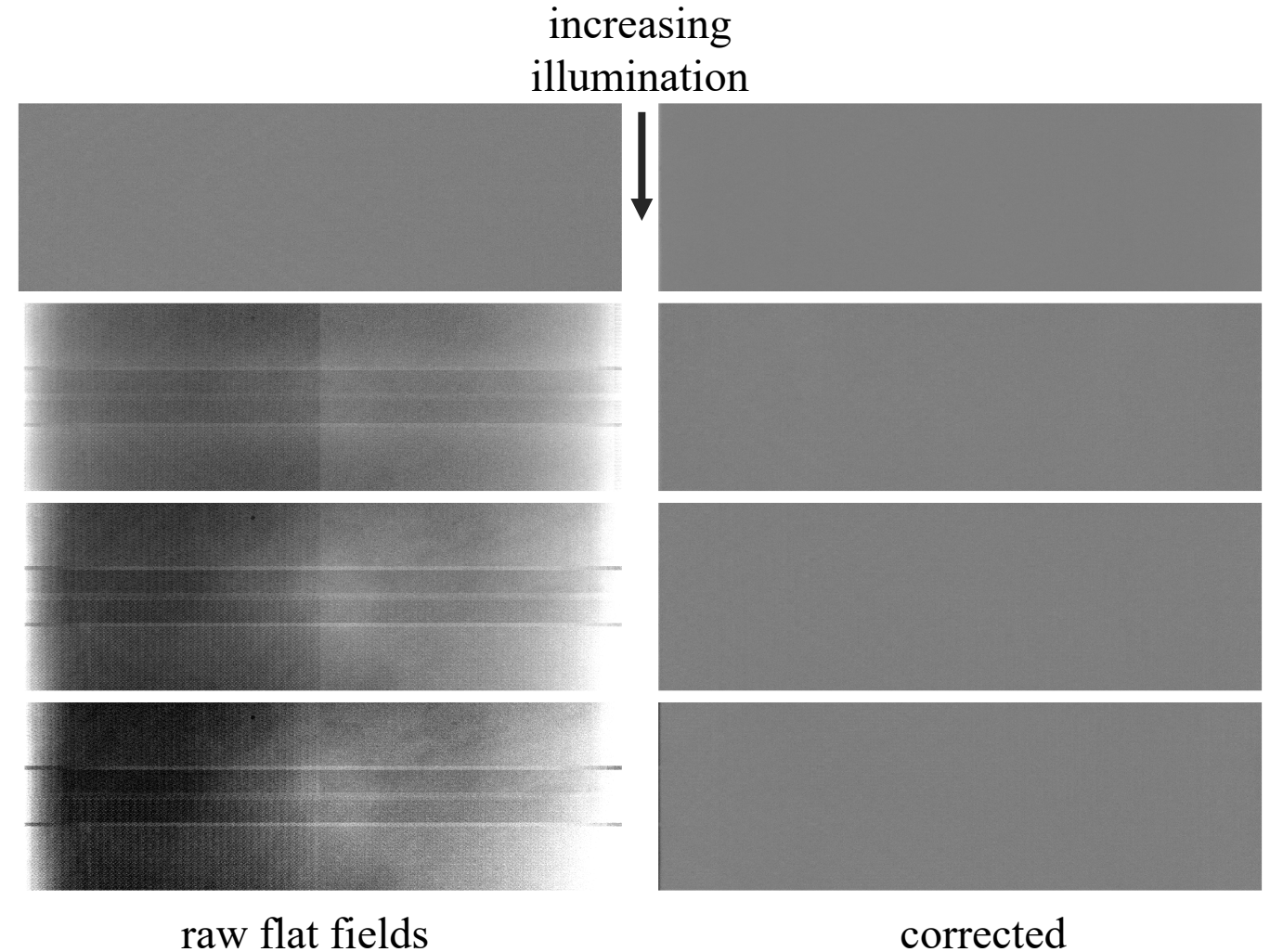
Data Processing



Data Processing: Image Processing



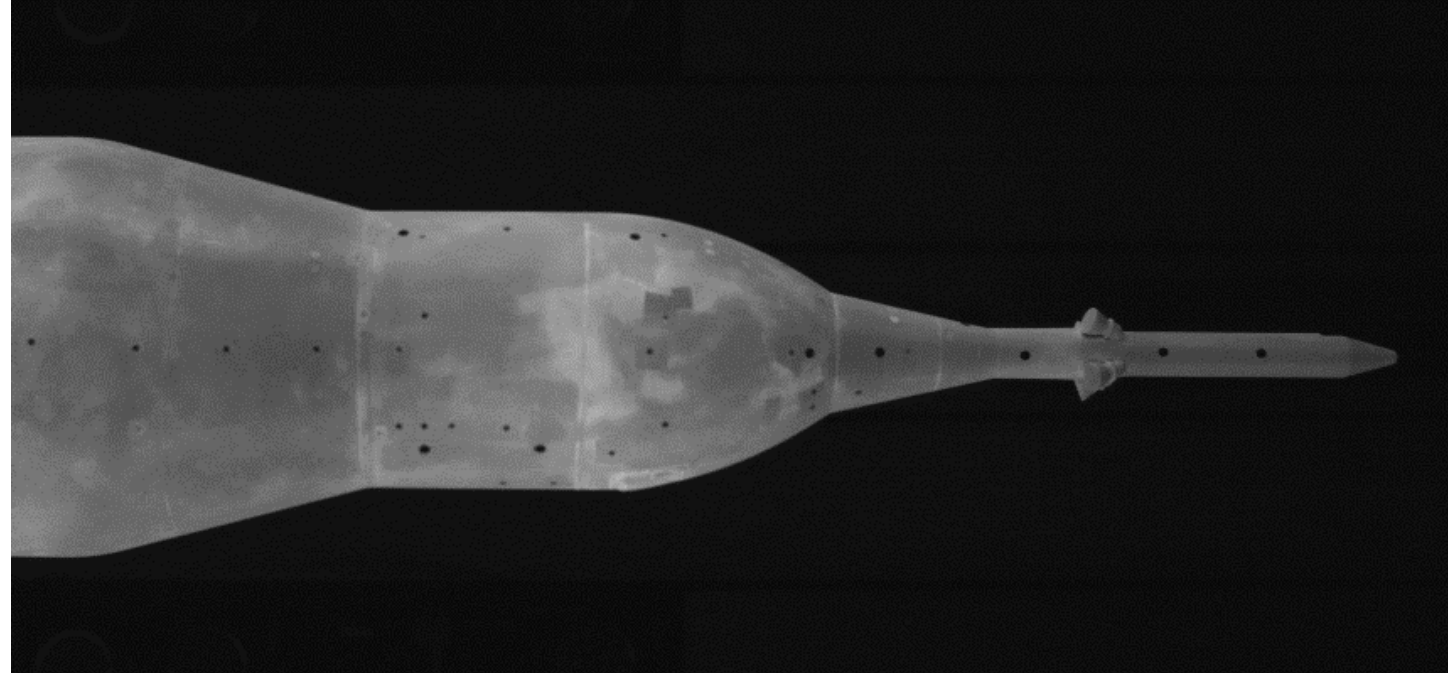
- Black level correction
- **Flat field correction**
- Image registration
- Time averaging
- Interpolate over unpainted patches
- Spatial filter
- Ratio gate 2 / gate 1



Data Processing: Image Processing



- Black level correction
- Flat field correction
- **Image registration**
- Time averaging
- Interpolate over unpainted patches
- Spatial filter
- Ratio gate 2 / gate 1

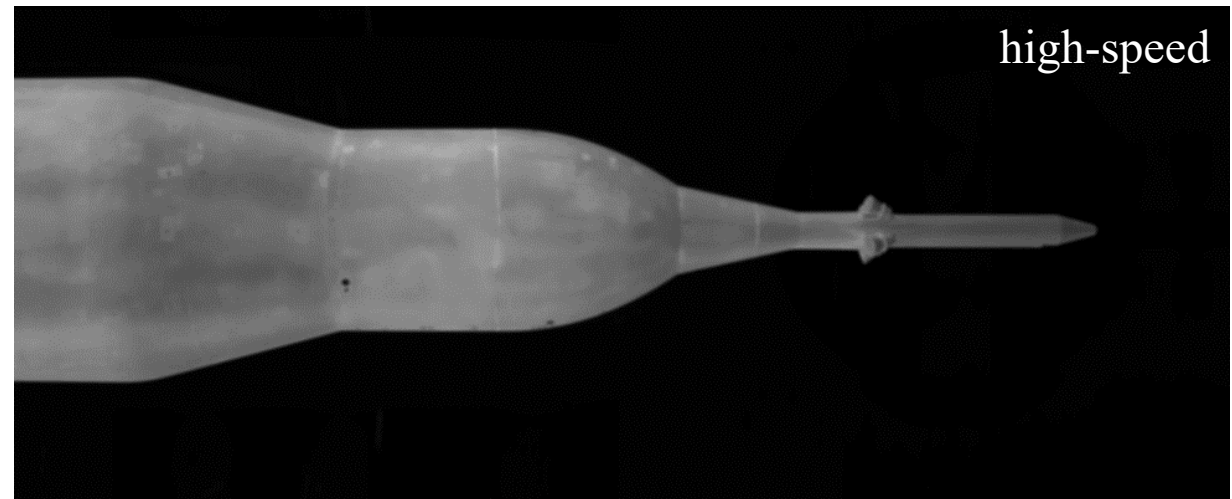
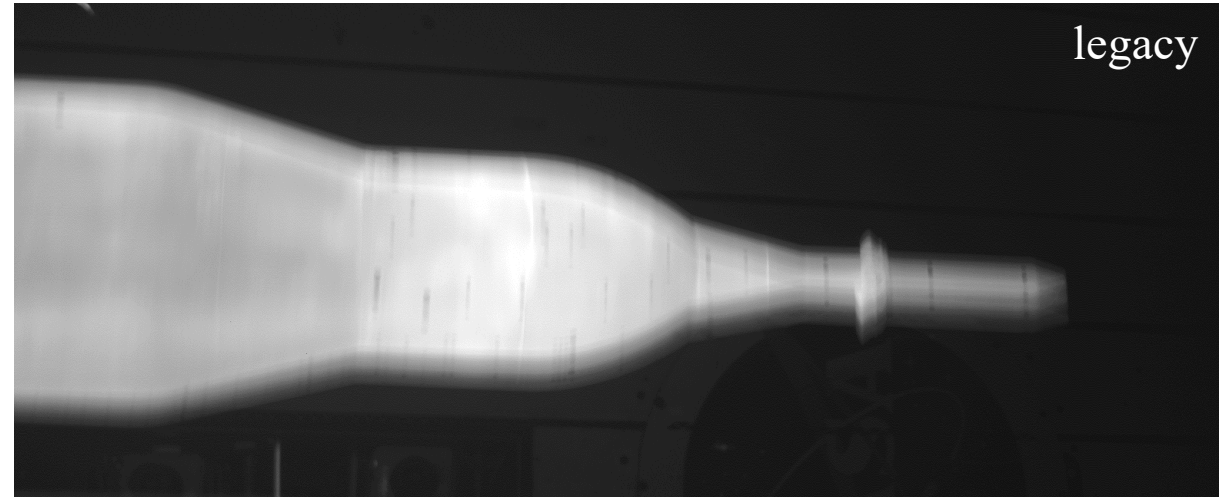


2 images during Mach 1.4 datapoint

Data Processing: Image Processing



- Black level correction
- Flat field correction
- **Image registration**
- Time averaging
- Interpolate over unpainted patches
- Spatial filter
- Ratio gate 2 / gate 1

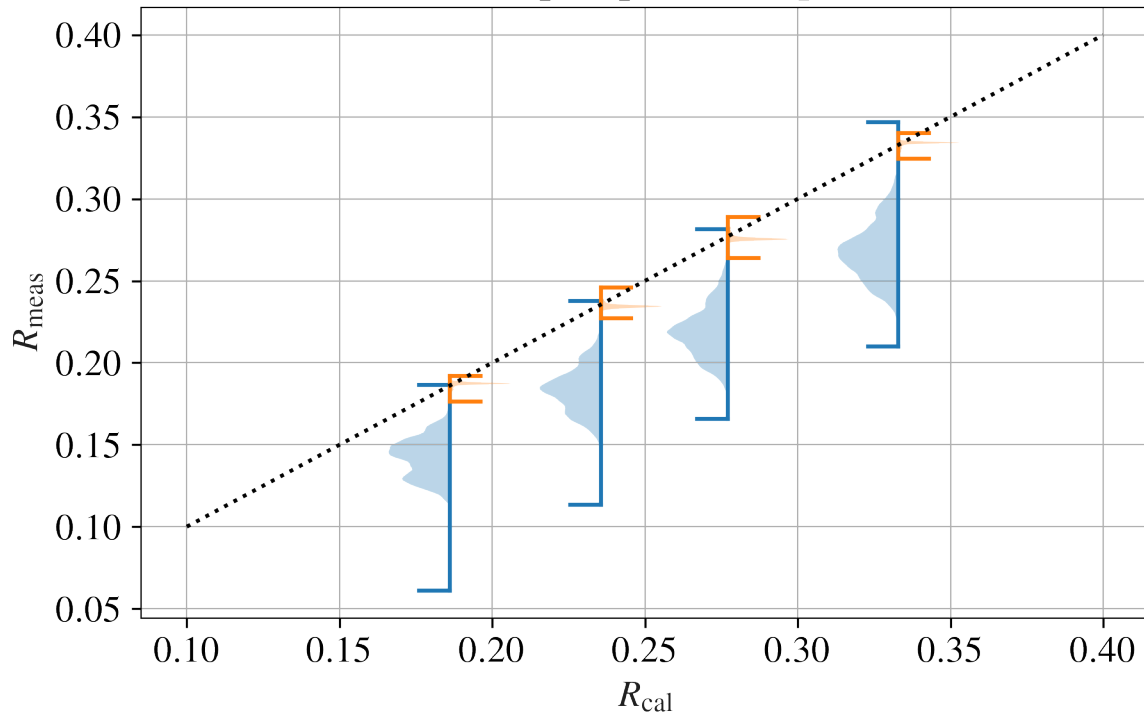


Data Processing: Ratio to Pressure



- **Non-uniformity correction**
- Lookup pressure from paint cal $P(T, R)$
- Convert pressure to C_p
- Anchor to static pressure taps (offset or affine)

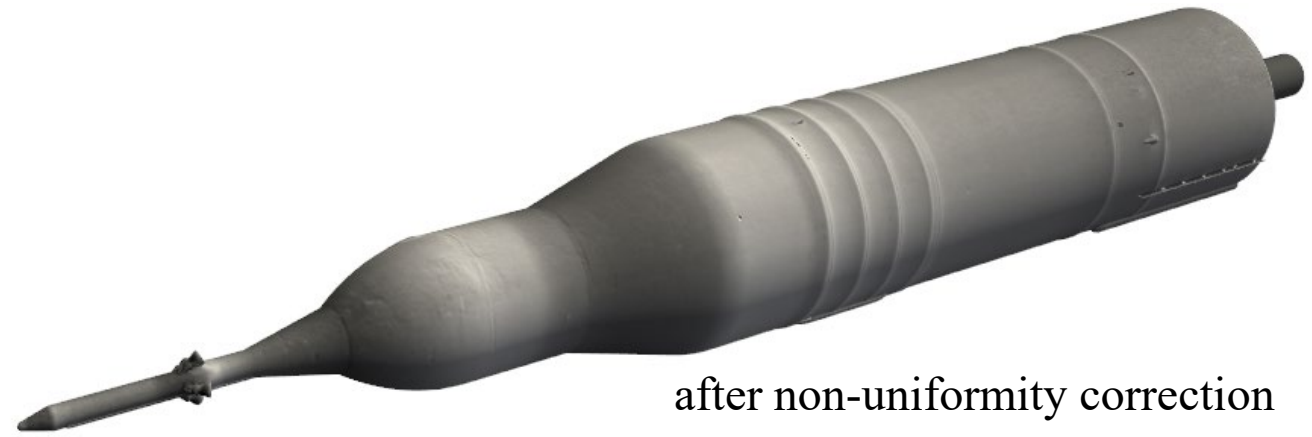
wind-off pumpdown sequence



Mach 1.2



before non-uniformity correction

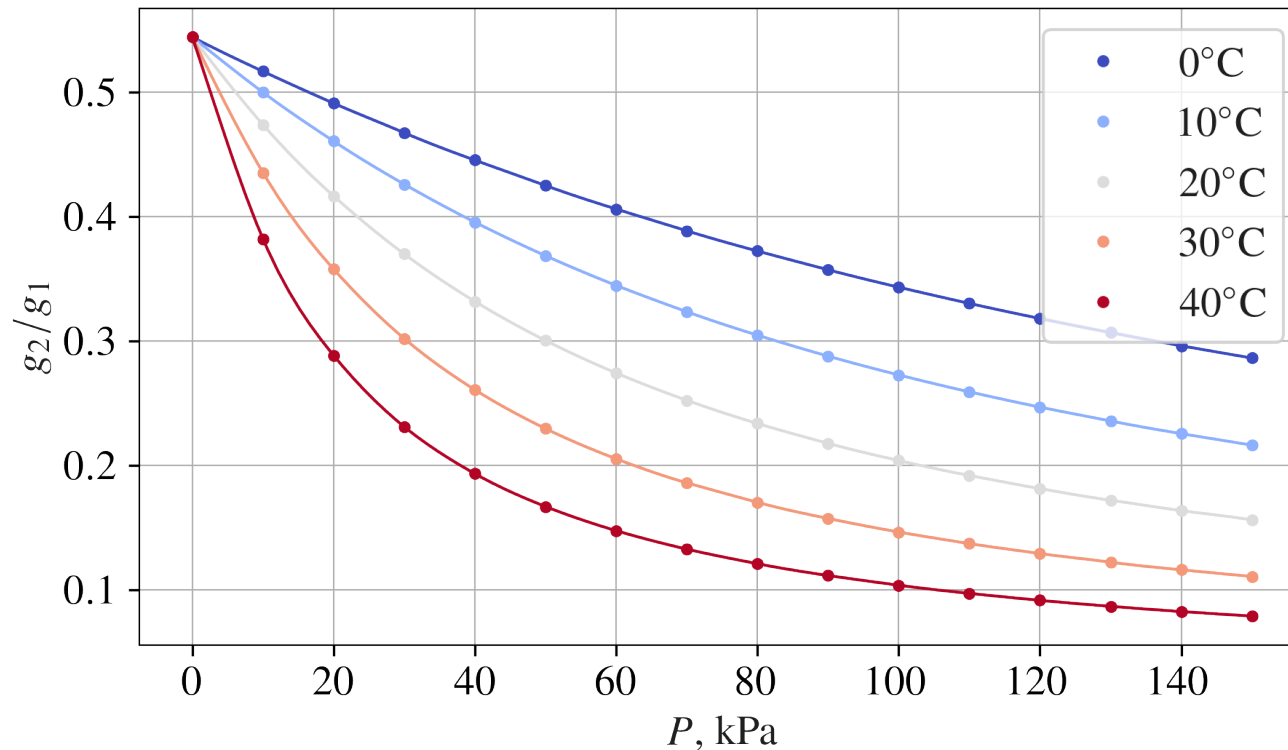


after non-uniformity correction

Data Processing: Ratio to Pressure



- Non-uniformity correction
- **Lookup pressure from paint cal $P(T, R)$**
- Convert pressure to C_p
- Anchor to static pressure taps (offset or affine)



First-order paint response model

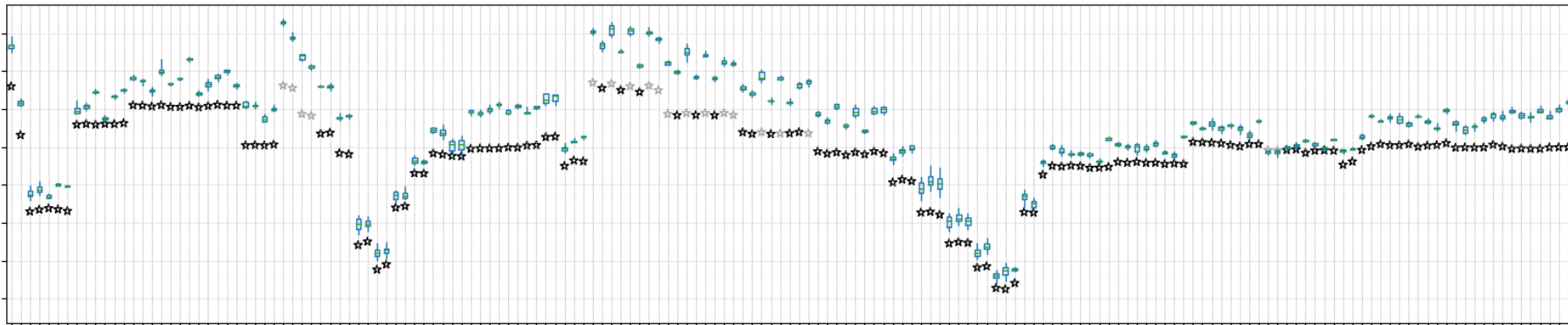
$$\tau = \frac{\tau_0}{1 + \tau_0 P e^{k_1 + k_2 T}}$$

Data Processing: Ratio to Pressure

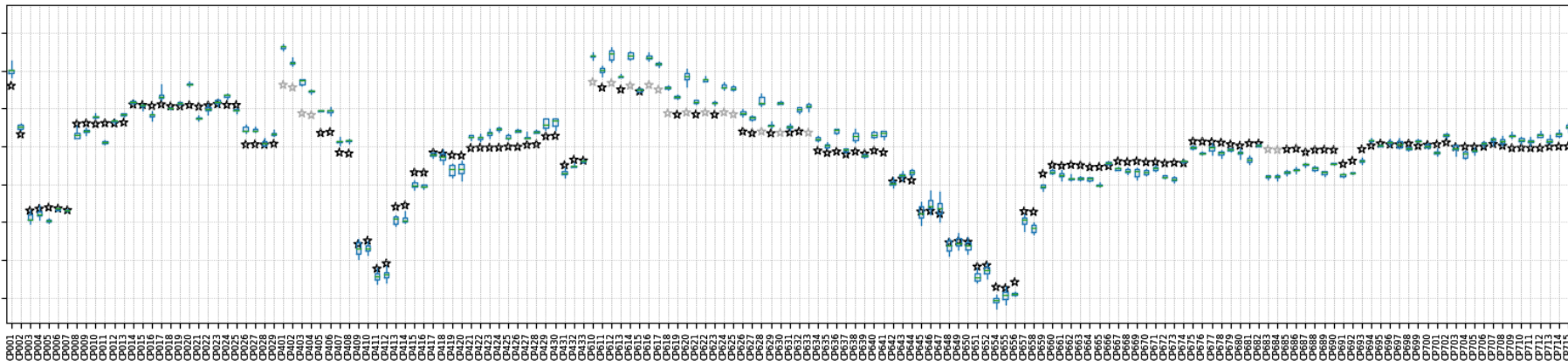


- Nonuniformity correction
- Lookup pressure from paint cal $P(T, R)$
- Convert pressure to C_p
- **Anchor to static pressure taps (offset)**

uncorrected



corrected



Comparison to Legacy System: 3D View



Mach 0.8, $\alpha = \beta = 0$

high-speed system (LVDT)



legacy system (AUAT)



Comparison to Legacy System: 3D View



Mach 1.2, $\alpha = \beta = 0$

high-speed system (LVDT)



legacy system (AUAT)



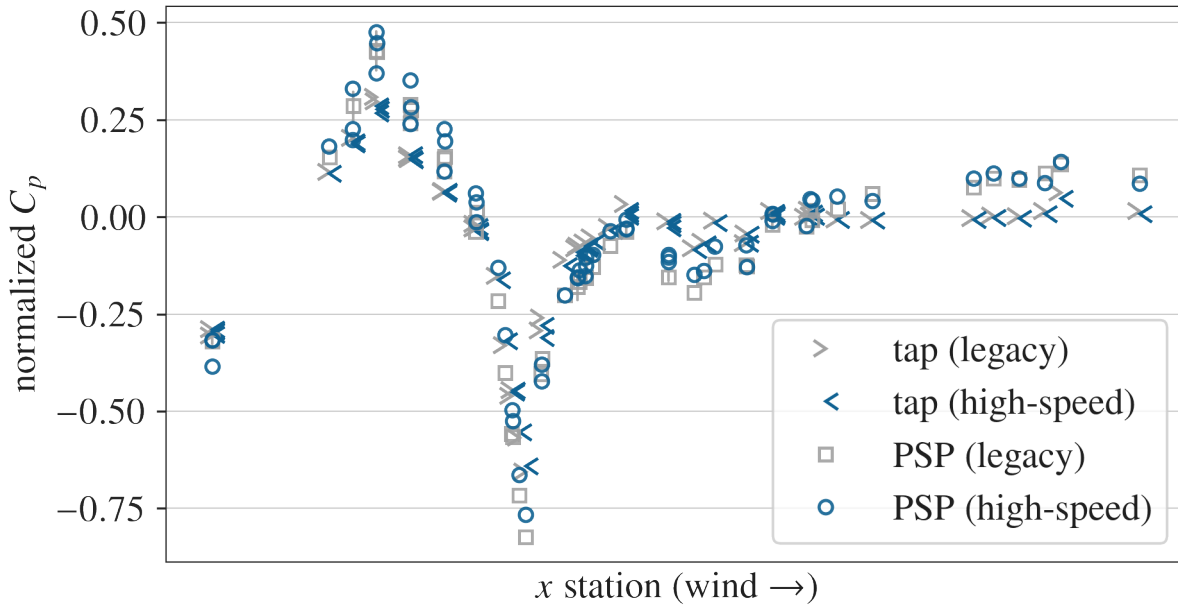
normalized C_p



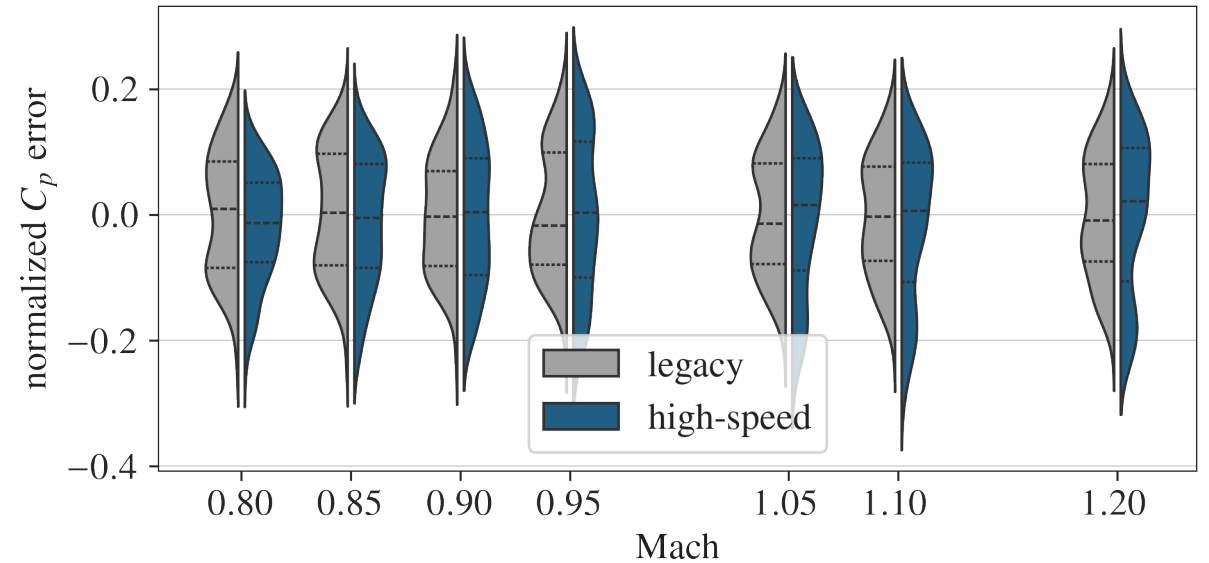
Comparison to Static Taps



Mach 0.8 pressure tap comparison



Error distribution over a Mach sweep



Same neighbor selections for LVDT and AUAT, but independent anchoring

Conclusions



- High-speed system is performing about as well as the legacy system
 - Errors with respect to static taps comparable following similar offset anchoring
 - Overall 3D solutions look similar to “matched” AUAT datapoints
- Single set of cameras is operationally advantageous
 - Simpler installation and data acquisition
 - Processing pipelined for steady solution → unsteady gain
- Individual exposures are...
 - ...critical for handling model motion
 - ...a burden to store and process – terabytes of data
- Future work:
 - Explore data acquisition timing and camera noise, paint dynamics
 - Full-resolution flat fields for non-zero α and β
 - Handle non-rigid motion