Particle Seeding System Upgrades in the NASA GRC 1’×1’ Supersonic Wind Tunnel

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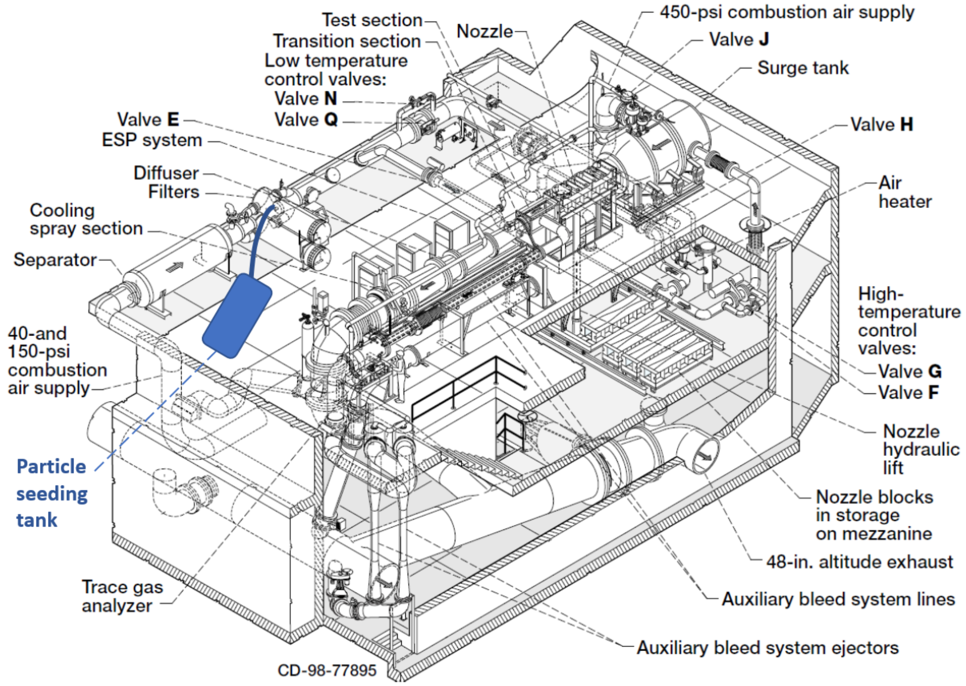
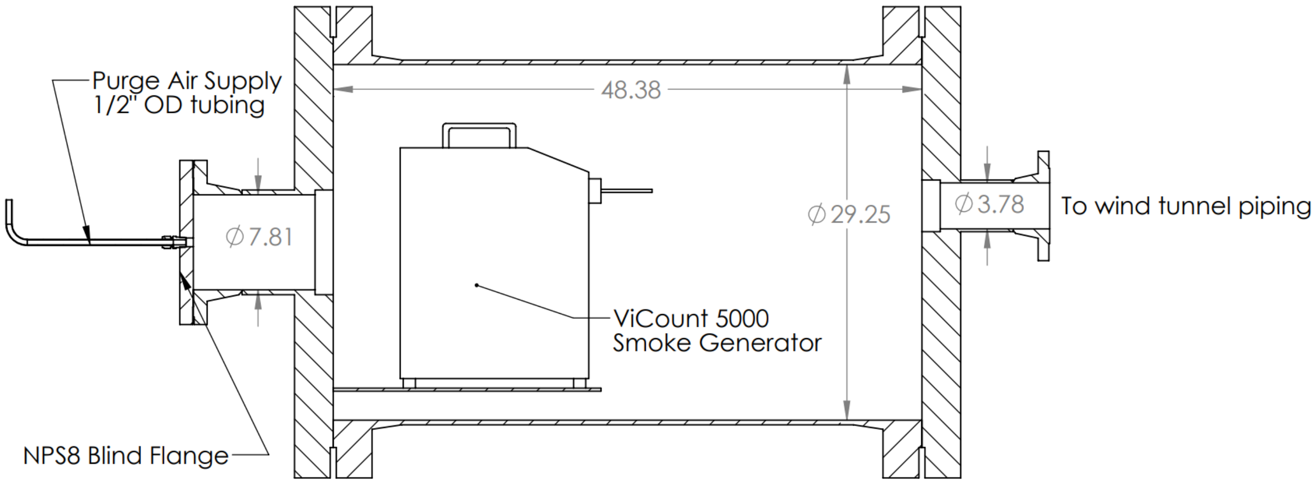
Introduction

- **GRC 1’×1’ Supersonic Wind Tunnel**
  - Fundamental research in supersonic vehicle aerodynamics
  - Mach 1.3 – 6.0 with discrete nozzle blocks
  - Continuous operation over large Re range
  - High temperature capability requires global seeding introduced far upstream of test section
  - Particle seeding system historically used for PIV and LDV was suspected to have issues with particle agglomeration

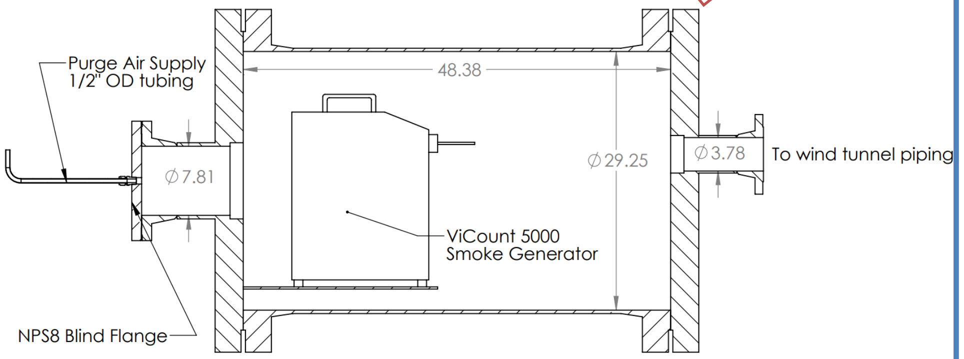


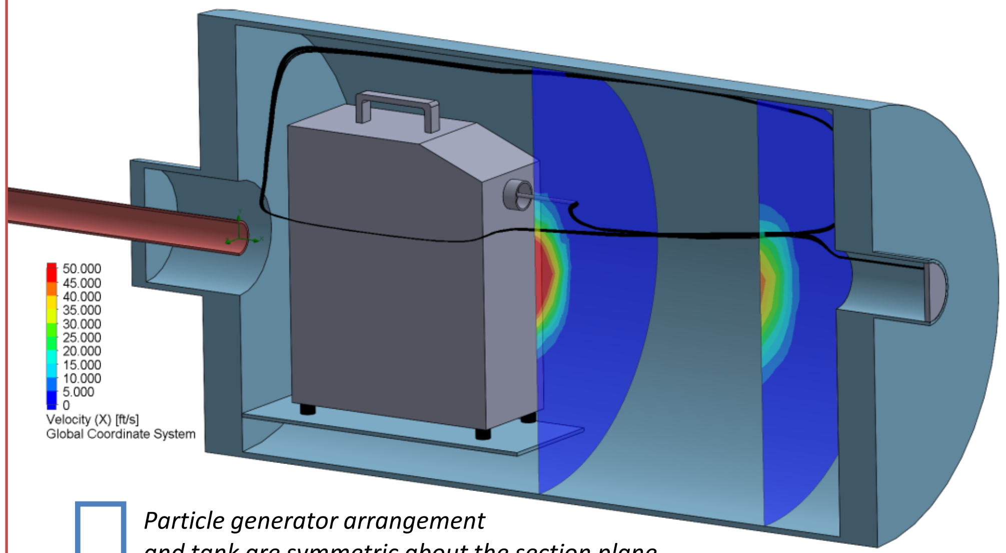


- **Legacy particle seeding tank**
  - 37” long section of 30” NPS pipe with flanged ends installed in basement
  - 2 ViCount 5000 particle generators inside
  - Shop air supplied through ½” line to drive oil droplet seed into main facility air supply

Particle Seeding Tank Purge Upgrade

- **Investigated possible design changes to purge particles from tank more rapidly**
  - Increase purge flow rate
  - Better distribute purge air to thoroughly expel particles
- **RANS CFD through Solidworks® Flow Simulation**

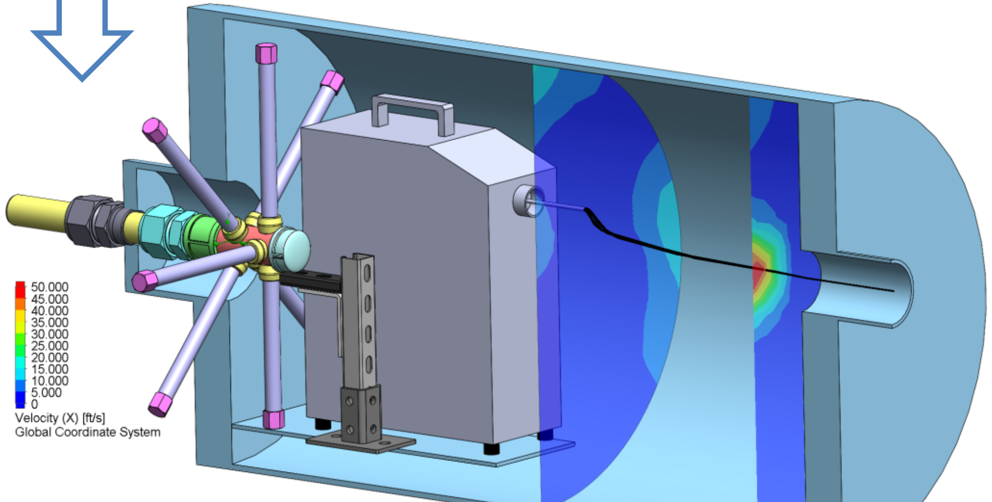




Particle generator arrangement and tank are symmetric about the section plane.

<u>Revision 1:</u>
Increase diameter of purge air supply piping to 2"

<u>CFD Result:</u>
Particles not well entrained into central jet passing through vessel



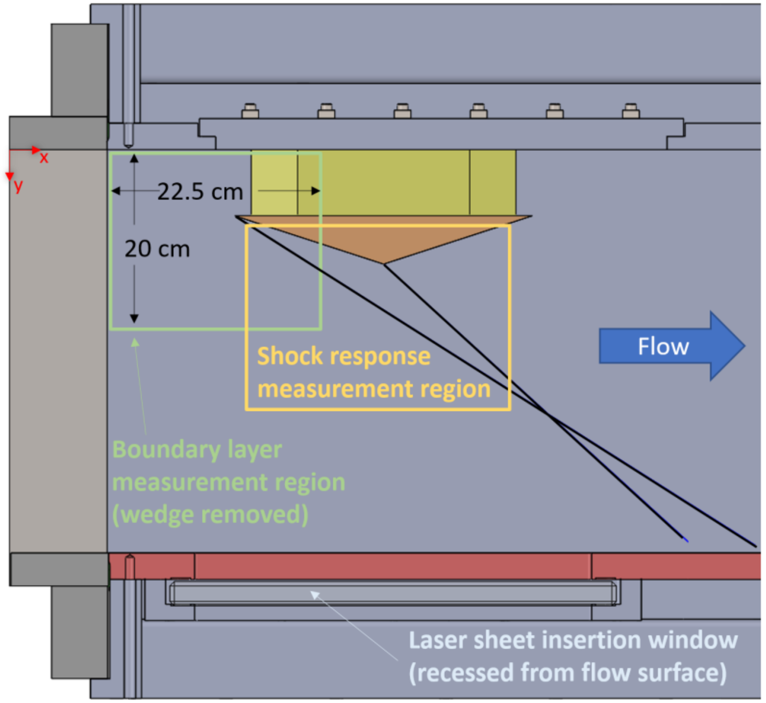
Particle generator arrangement and tank are symmetric about the section plane.

<u>Revision 2:</u>
Fabricate "wagon wheel" to provide uniform purging

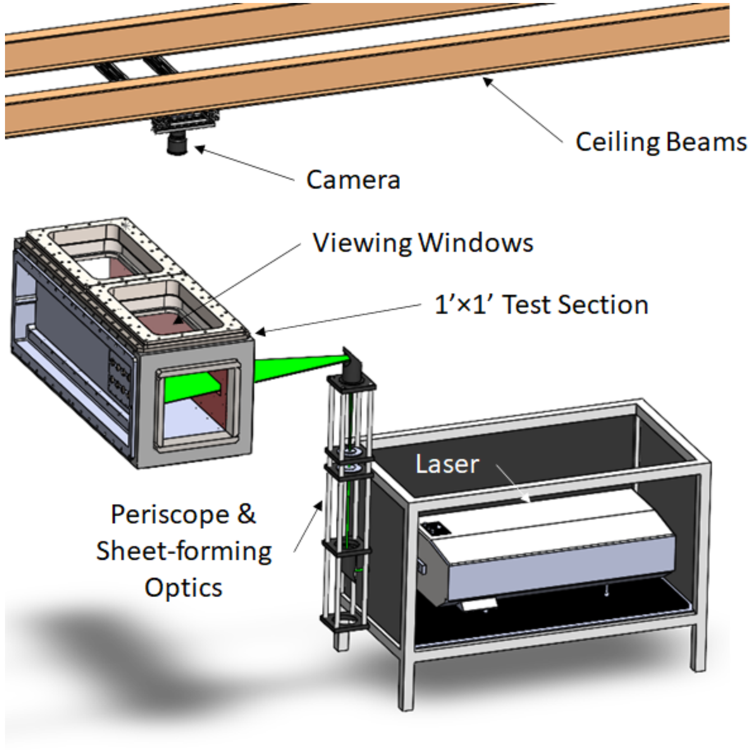
<u>CFD Result:</u>
Particles not well entrained into central jet passing through vessel

Apparatus

- **Particle size quantified by making PIV measurements across oblique shock**
  - 18° wedge model
  - Measurements made at mid-span
- **Test section sidewall boundary layer height assessed by moving PIV measurement region to wall and as far upstream as possible**

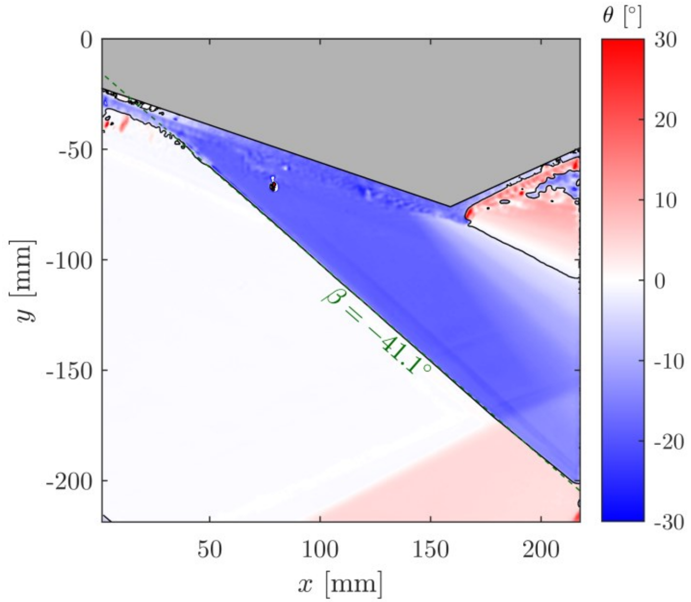


- **PIV system:**
  - 380 mJ/pulse at 532 nm
  - Sheet thickness ~1mm, focused beyond measurement region
  - 2048×2048 CCD sensor with 85mm lens
  - Custom shutter system to account for mismatch in operating frequencies

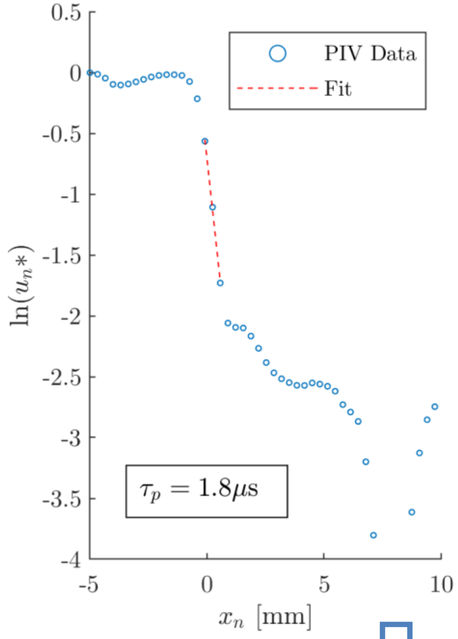


Particle Size Assessment

- **PIV datasets collected over range of inputs to particle seeding tank**
  - Purge air pressure sets flow rate through tank
  - Particle generator N_2 supply controls quantity and size of droplets
- **Velocity snapshots used to build ensemble statistics for particle response time**



Shock-normal reference frame



Compile ensemble of line profiles

400 vector fields
300 profiles per field

- **Vector spacing must be small enough to accurately fit decay profile**
- **For fixed vector spacing, 16×16 windows were smallest which had adequate particles/window**

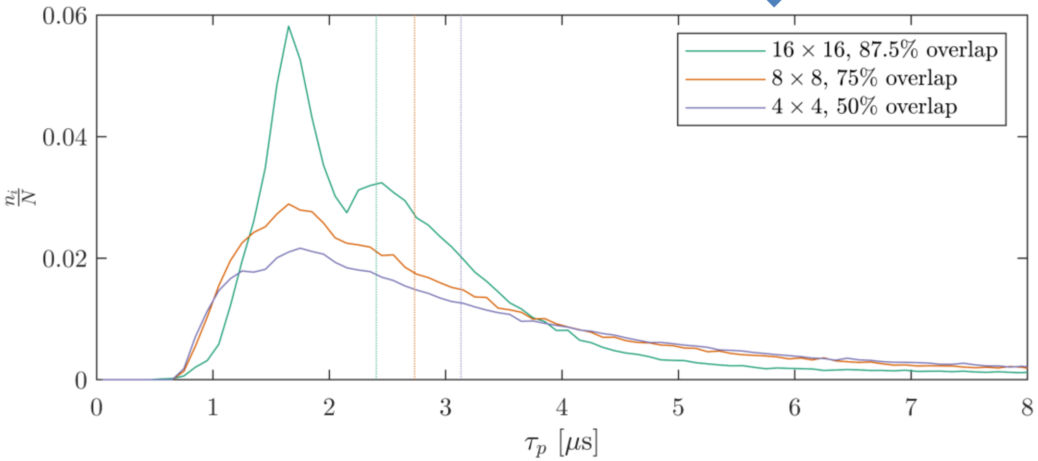


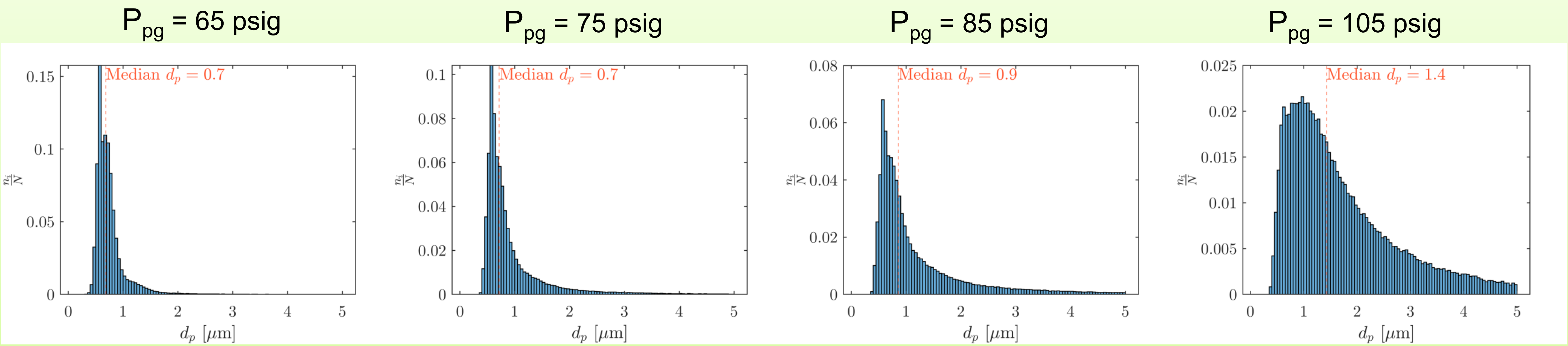
Table 1 Test conditions – seeder optimization.

M_0	P_{t0} [psia]	T_{t0} [°R]	P_{pg} [psig]	P_{tp} [psig]	Δt [μs]
2.47	50	517 ± 2	65–105	50–70	2.5
3.46	55	531 ± 2	55–85	55–70	1.8

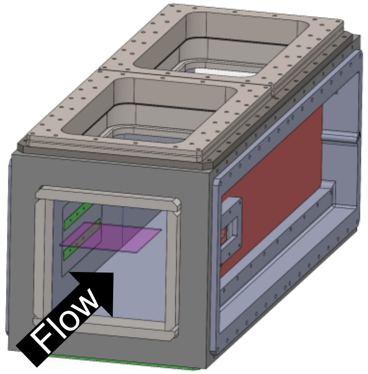
Particle Size Assessment

- Maximum purge flow rate available was used for all results shown
- Operating at minimum N_2 pressure (need ΔP above tunnel pressure) yielded smallest median particle size
- Small secondary peak is likely from combined pairs of droplets, $d_2 = \sqrt[3]{2} d_1$
- Same result at M3.5

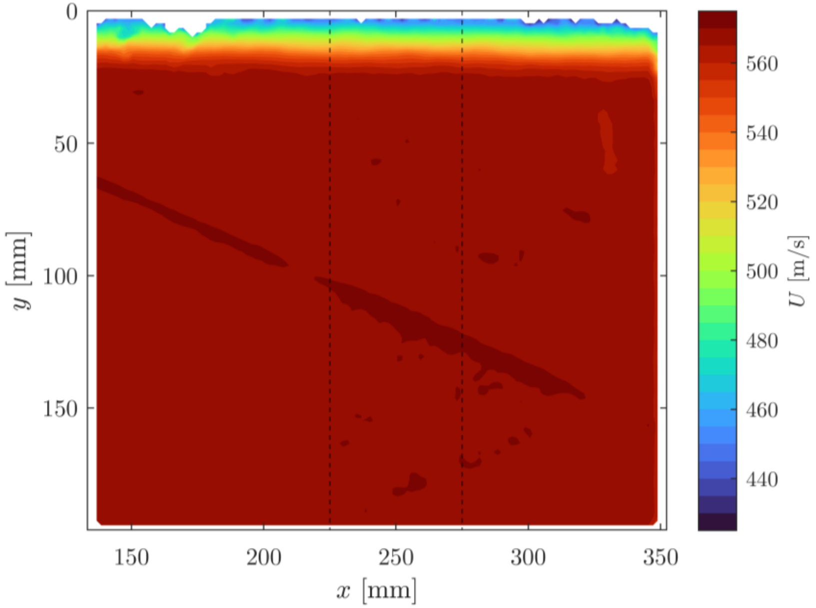
Increasing particle generator supply pressure →



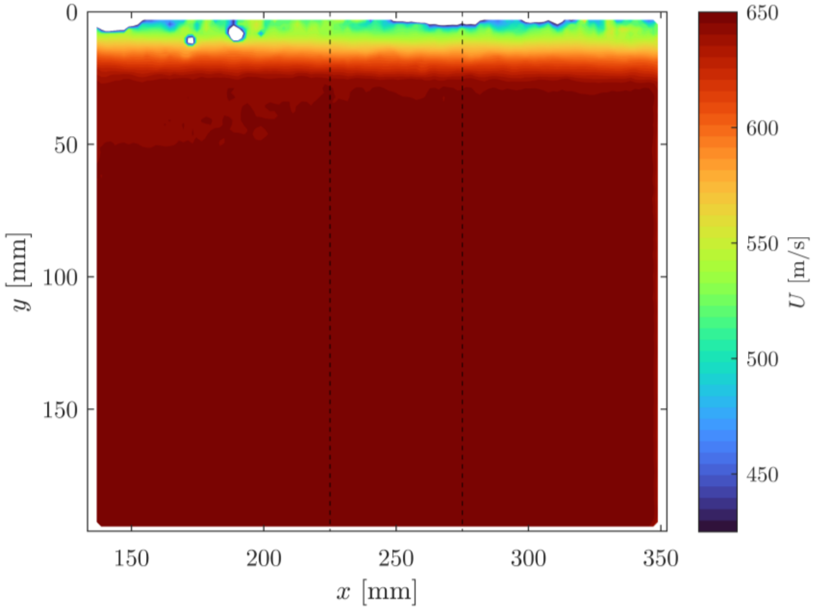
Sidewall Boundary Layer Characterization

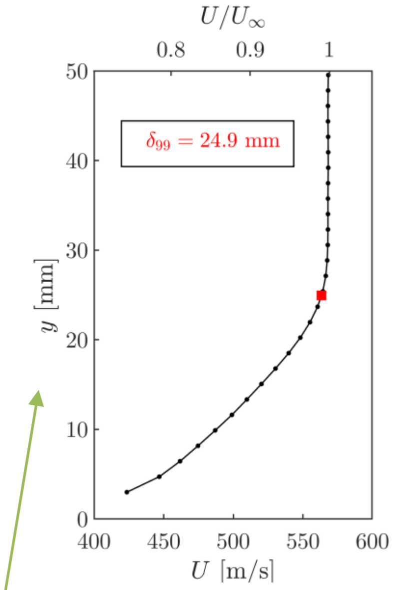


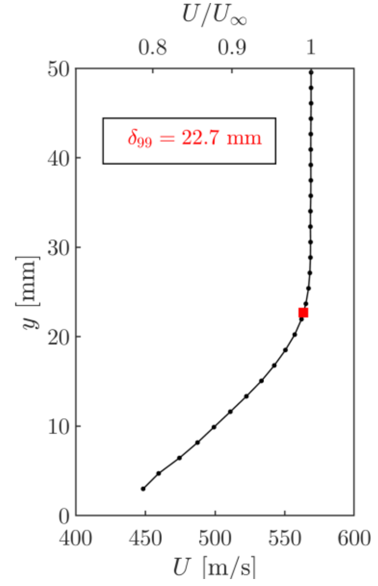
Mach 2.5, P_{t0} = 50 psia



Mach 3.5, P_{t0} = 55 psia







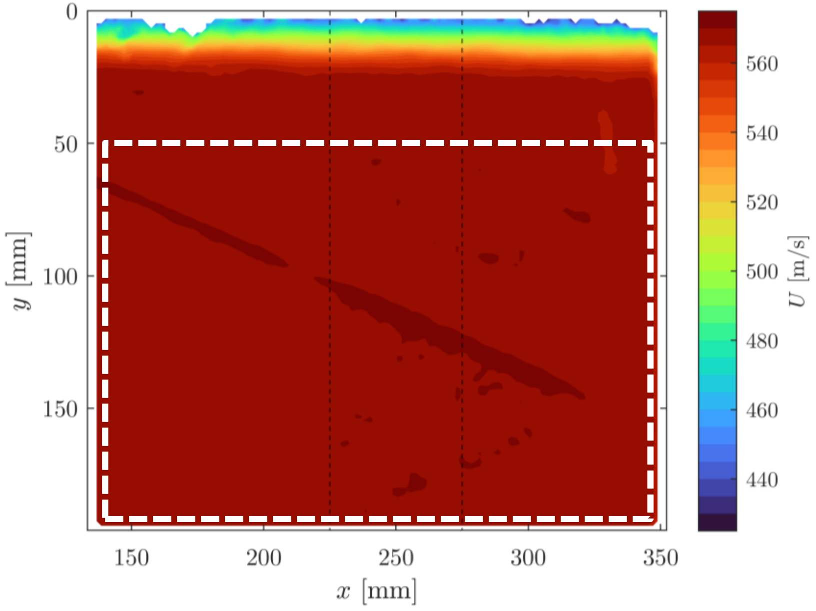
- **2 nozzle blocks: M2.5 and M3.5**
- **Goal was δ_{99} measurement at maximum Re using 40 psig supply air**

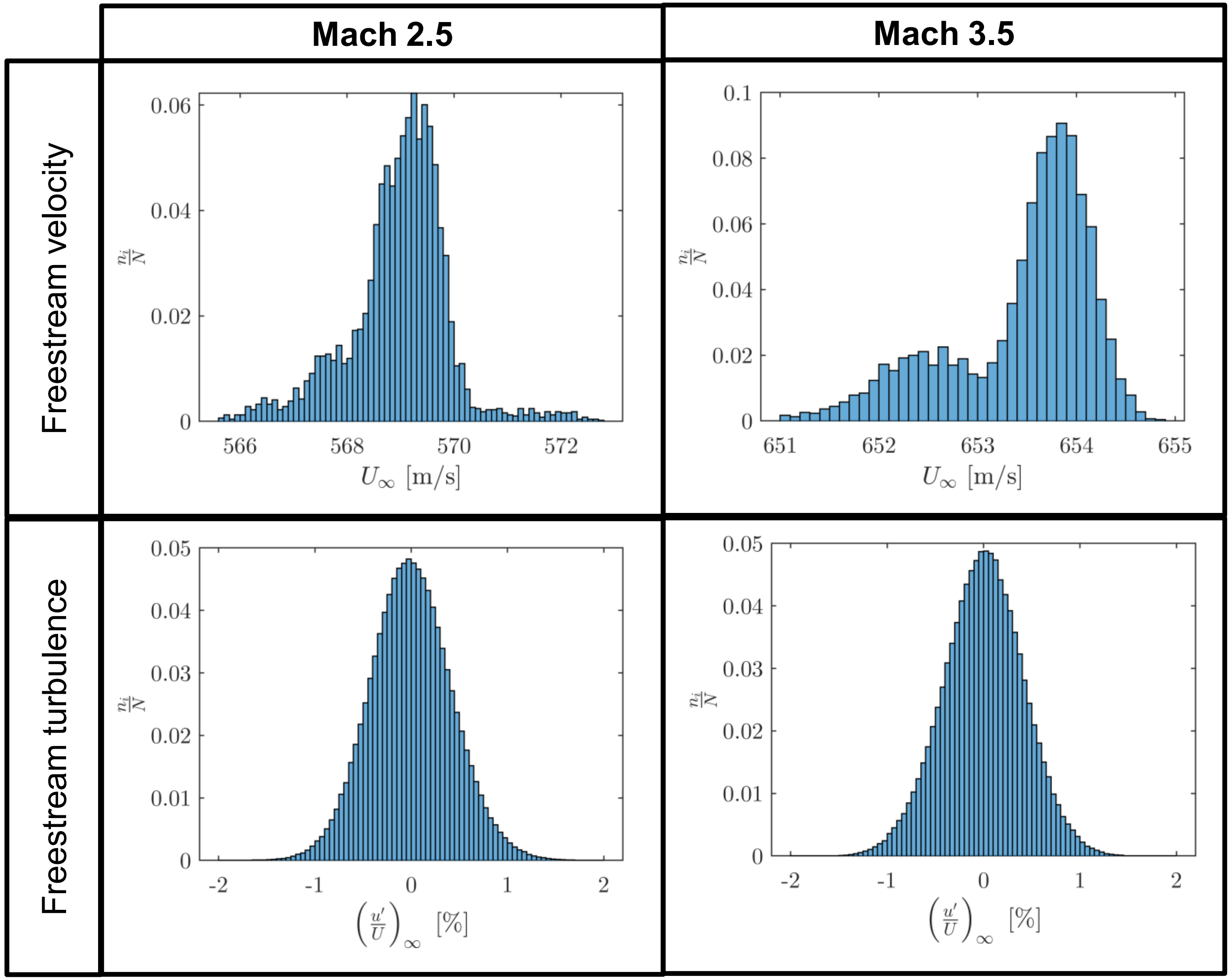
Table 2 Sidewall boundary layer height measurement summary.

M_0	P_{t0} [psia]	T_{t0} [°R]	P_{pg} [psig]	Re [ft^{-1}]	$\delta_{99}(x = 25$ cm) [mm]	$\widehat{\delta_{99}}(x = 0)$ [mm]
2.47	20	535 ± 2	65	4.45×10^6	24.9	19.1
2.47	30	535 ± 2	65	6.46×10^6	23.9	19.0
2.47	40	535 ± 2	65	8.45×10^6	23.1	18.7
2.47	50	535 ± 2	65	10.7×10^6	22.7	18.1
3.46	55	535 ± 2	65	6.99×10^6	26.6	24.7

Test Section Freestream Characterization

hypersonic technology project

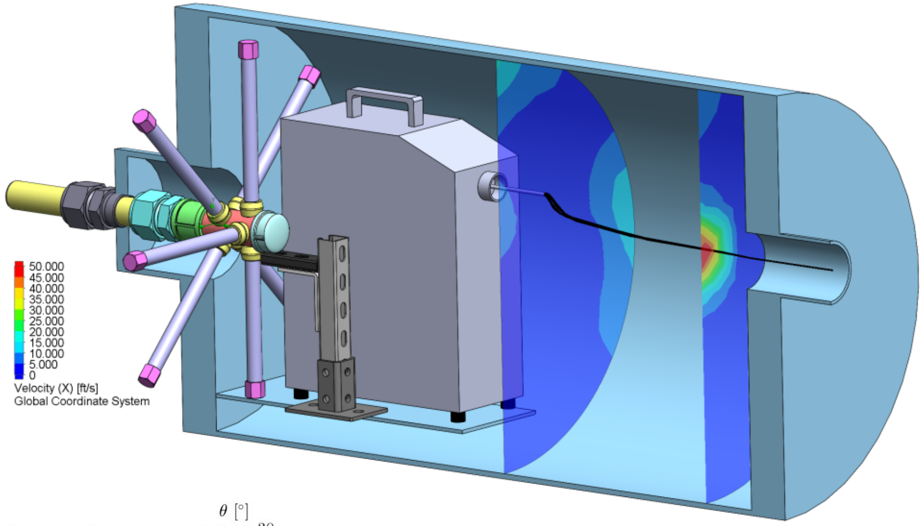


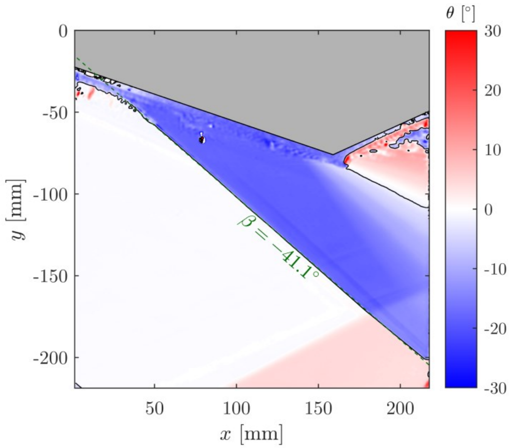


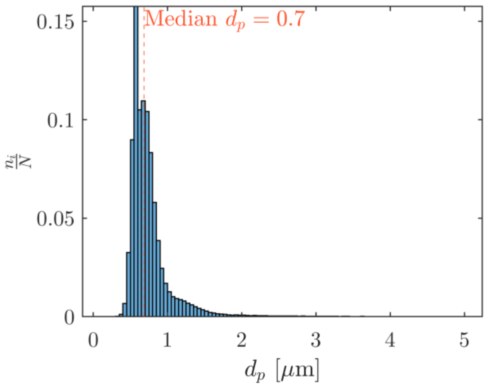
- Velocity data for $y > 2\delta$ compiled
- Good spatial uniformity
- Turbulence intensity of 0.4% for both cases

Conclusions

- **Improved particle seeder performance**
  - New air distribution device in seeder tank to thoroughly expel particles into facility supply line
  - Verified reduction in seed particle size through PIV measurements across oblique shock
    - Median particle size as low as ~0.7 μm
    - Consistent performance across range of facility conditions
  - Identified optimal seeder operating condition for M2.5 and M3.5
- **Characterized baseline flowfield near starboard sidewall**
  - Used PIV measurements to quantify δ_{99} for M2.5 and M3.5 nozzles







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