Prediction of Particle Impact Conditions via CFD Process Modeling

ARL Cold Spray Modeling Program

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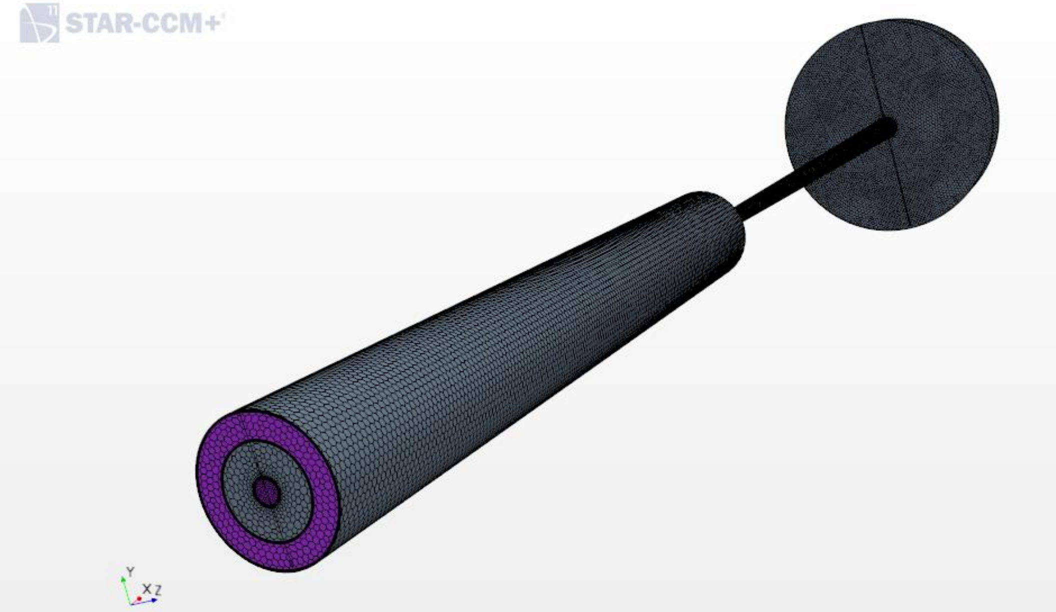
06/22/2016

Approved for Public Release

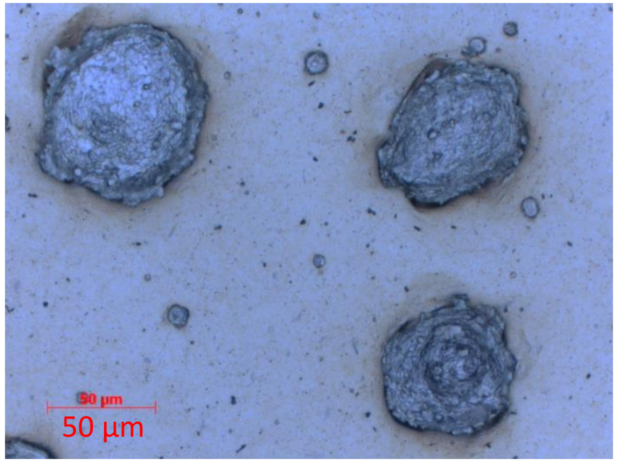
Program Objective

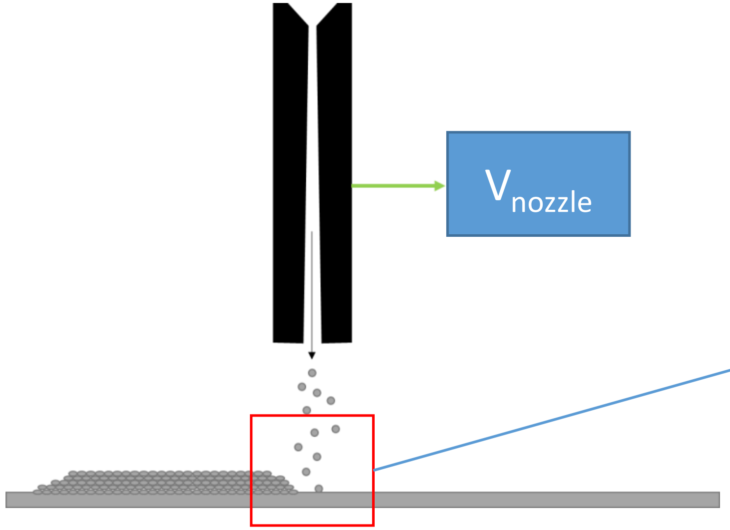
To generate a model or a series of models to predict the resulting mechanical properties of a deposit sprayed from a new material, based on the process parameters used produce the deposit.



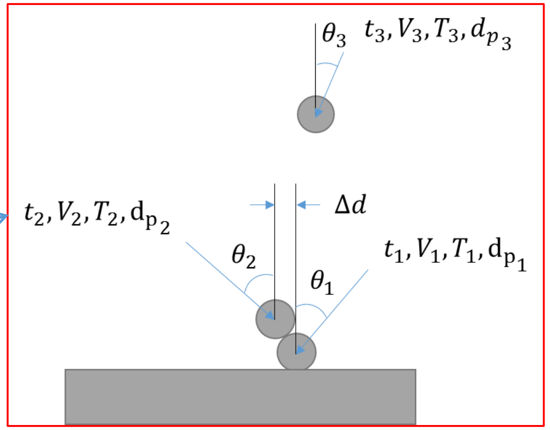
Outline of Work at SDSM&T

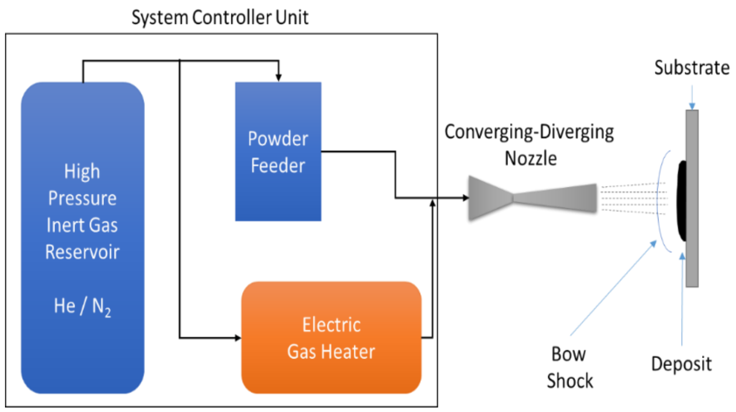
- Estimation of effects of He/N_2 mixing through 1D model
- Produce particle splat samples and model process
- Accurate estimation of particle impact conditions through CFD
- Effects of particle injection imperfections through CFD
- Provide accurate input for solid mechanics models





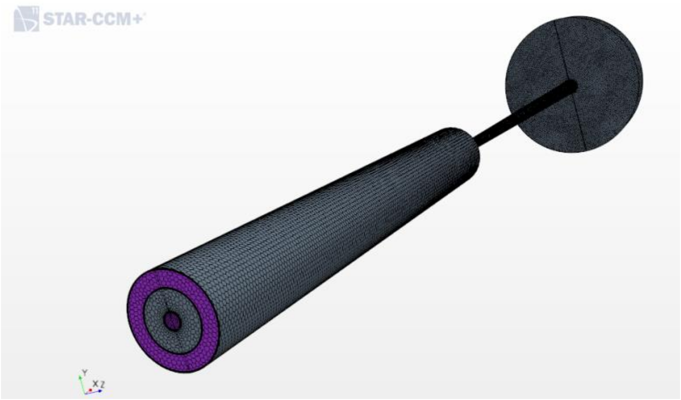
Estimate coating formation sequence in 3D

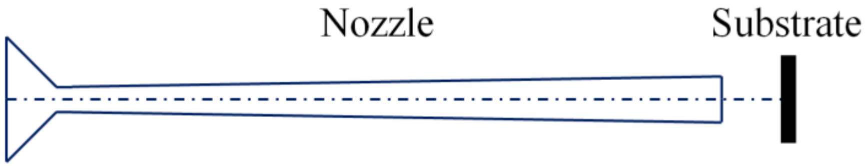




Today's Outline

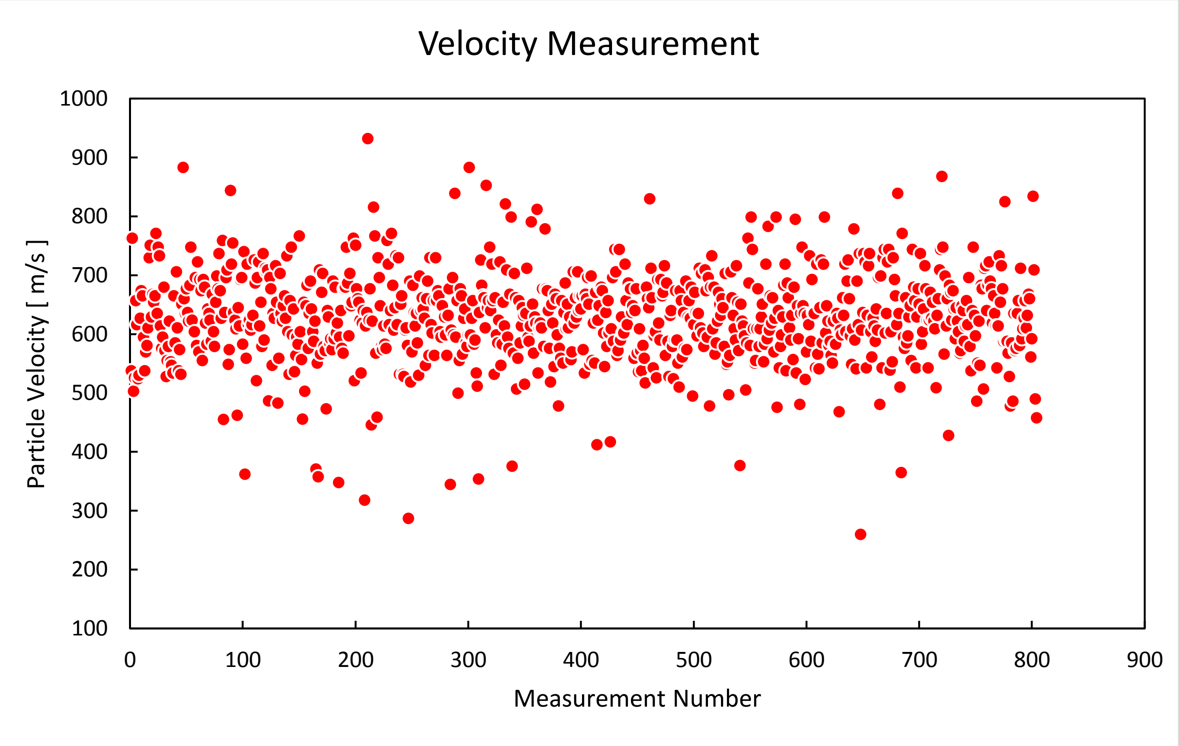
- 3D case study: Powder feeder line misalignment
- Controlling particle impact velocity & temperature





Effects of Powder Feeder Line Misalignment

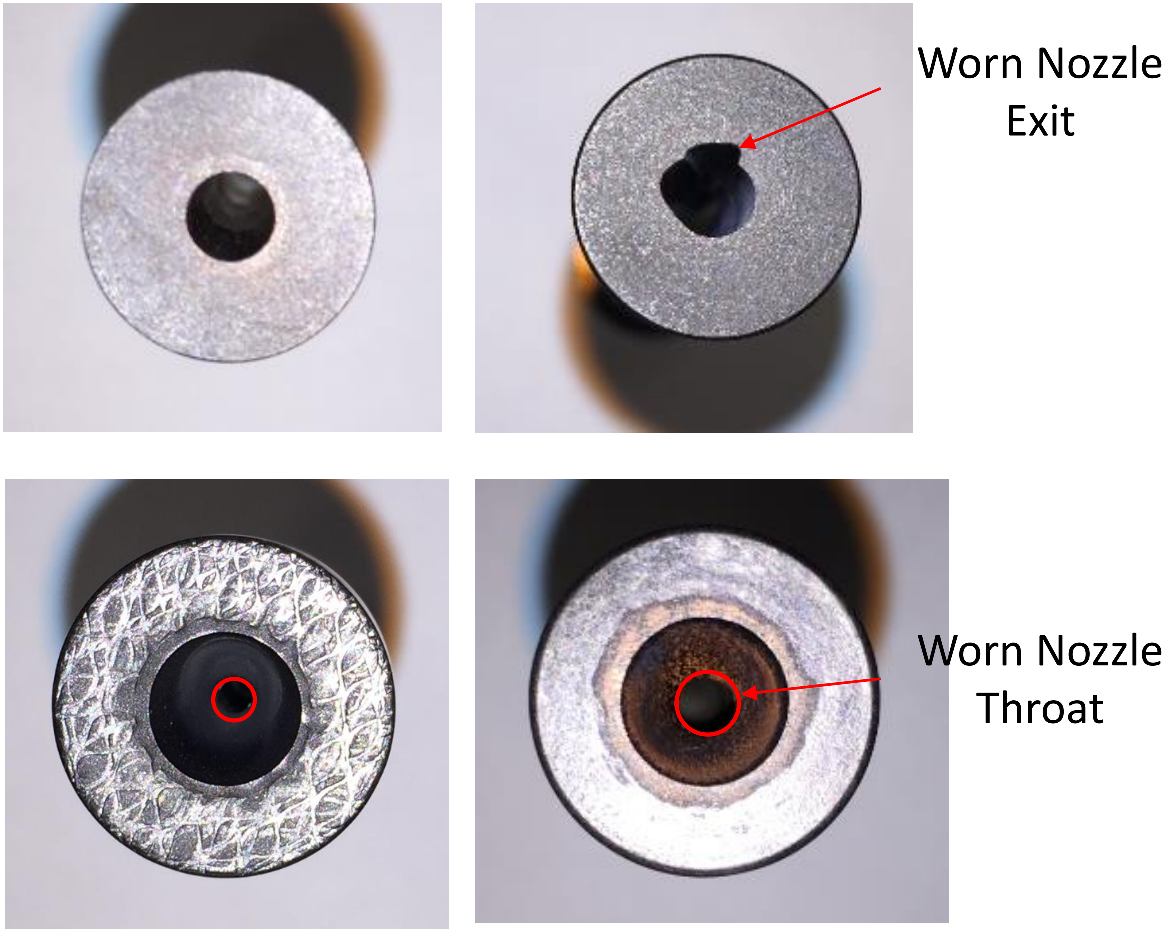
- Experimental velocity measurements reveal lower velocity particles than expected…
- Imperfections?
  - Hose assembly
  - Nozzle assembly
  - Feeder tube assembly
  - Powder feeder assembly
- Introduce imperfections to evaluate process sensitivity
  - Starting with feeder tube alignment



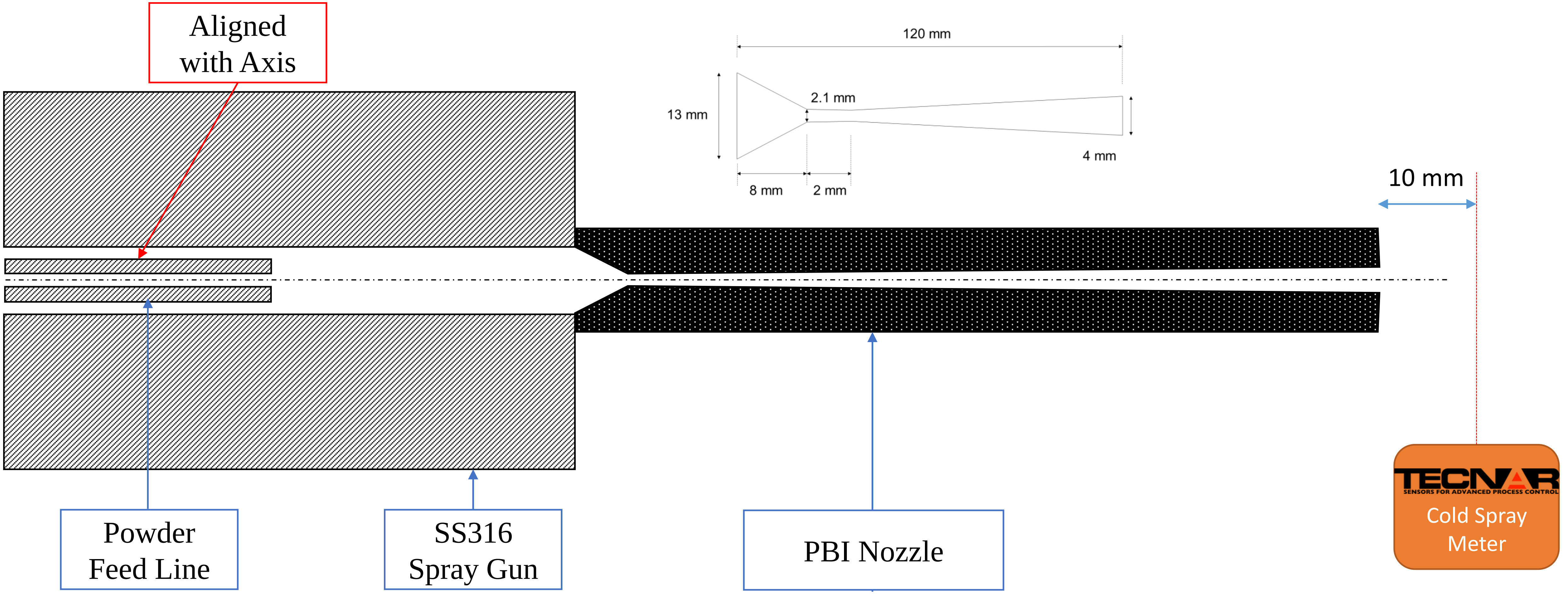
Can we simulate like real particle exit velocities by introducing imperfections?

Signs of Misalignment

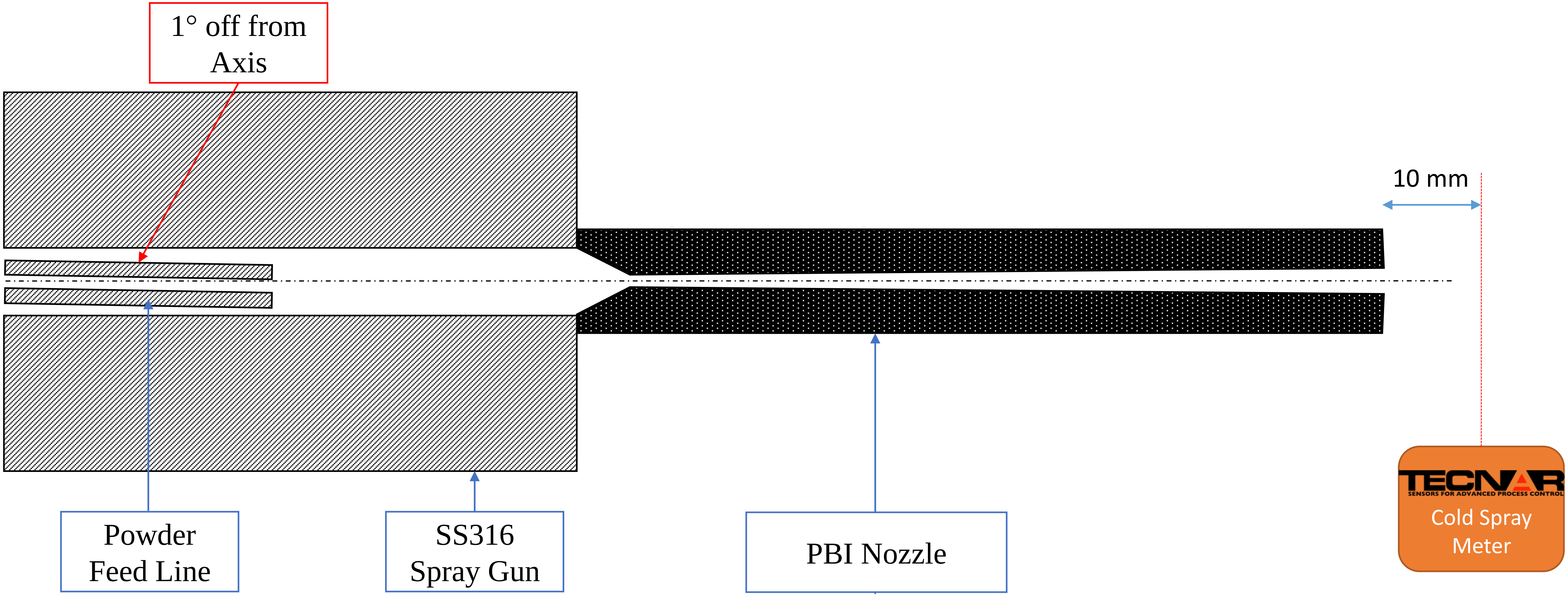
- Accelerated wear in the nozzle
- Reduction in particle velocity
- Increase in velocity variation



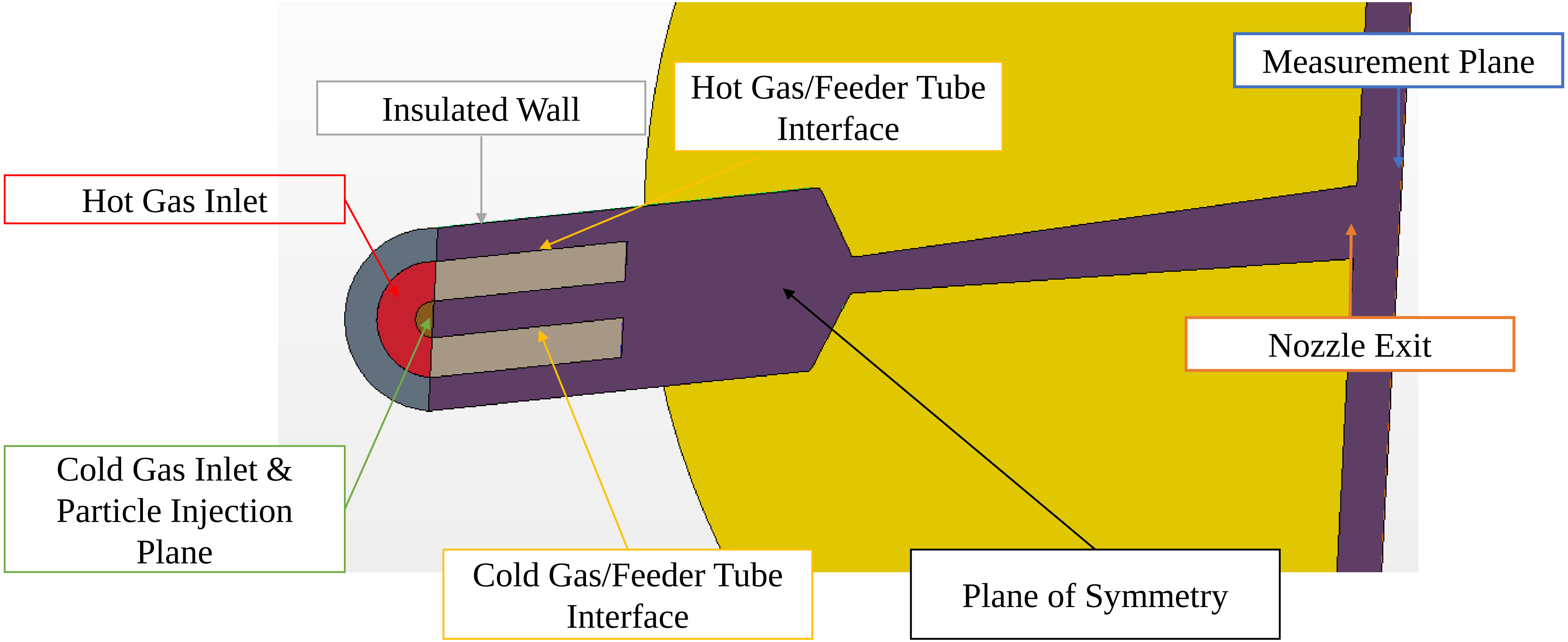
Aligned Powder Feeder Tube



Misaligned Powder Feeder Tube



Model Setup



Measurement Plane
Hot Gas/Feeder Tube Interface
Insulated Wall
Hot Gas Inlet
Nozzle Exit
Cold Gas Inlet & Particle Injection Plane
Cold Gas/Feeder Tube Interface
Plane of Symmetry

Physical Model

Gas Model

- Nitrogen (ideal gas)
- Energy equations
- k-ϵ turbulence model
- Hot gas input
  - 3.85 MPa & 360 °C
- Cold gas input
  - 3.85 MPa & 50 °C
- Outlet
  - Atmospheric conditions
  - 0.101 MPa & 20 °C
- Gas flow rate
  - 1150 g/min

Particle Injection

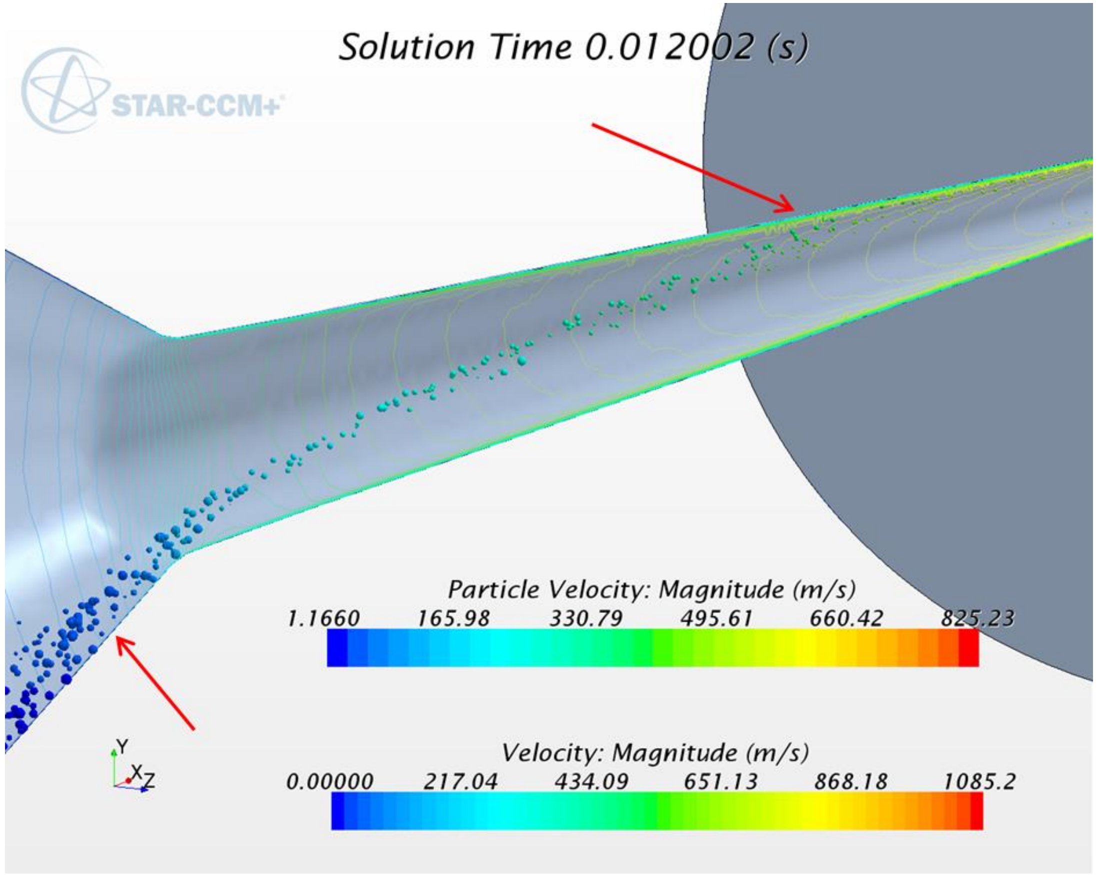
- Lagrangian particles (DEM optional)
- Input Microtrac data for d_p
  - Real particle size distribution
- Drag forces
- Lift forces
- Two-way coupled flow (Gas/Particle)
  - Momentum & Energy
- Particle injection rate: 12.4 g/min

Accounting for Losses from Particle/Nozzle Interactions

- Nozzle wall impact angles assumed*

  $< 30°$

- Coefficient of friction*
  - *Coulomb's law of dry friction (0.33)*
- Tangential coefficient of restitution*
  - $e_t = 0.7$
- Normal coefficient of restitution*
  - $e_n = 0.8$



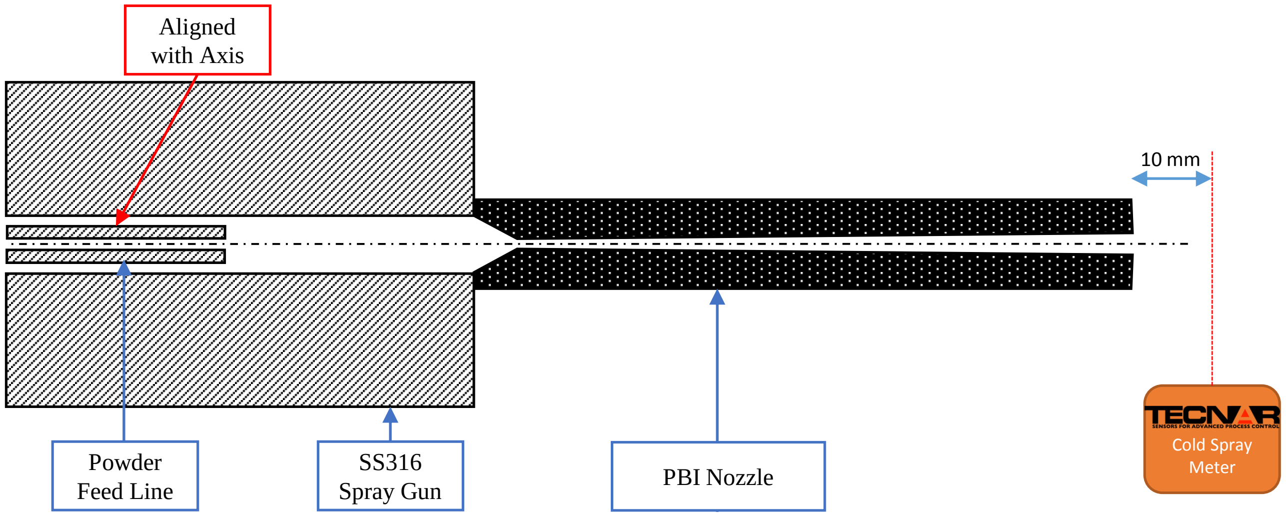
*Wu, C.Y., Thornton, C., Li, L.Y. Rebound Behavior of Spheres During Elastic-Plastic Oblique Impacts. International Journal of Modern Physics B. 22 (**9, 10, 11**). 2008. *pp. 1095-1102.*

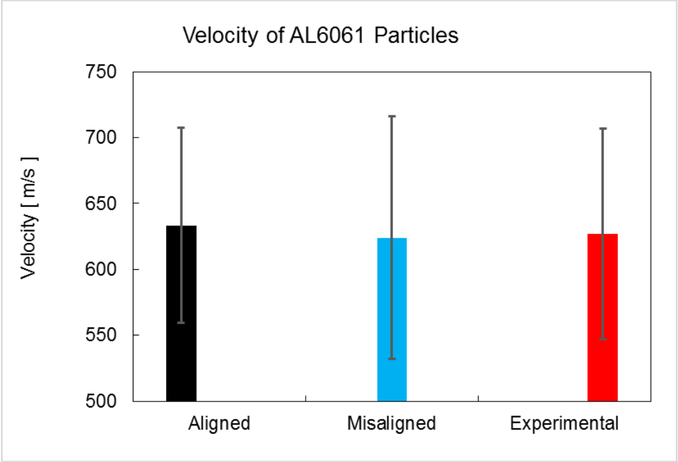
Simulation

Aligned Powder Feeder Tube Case

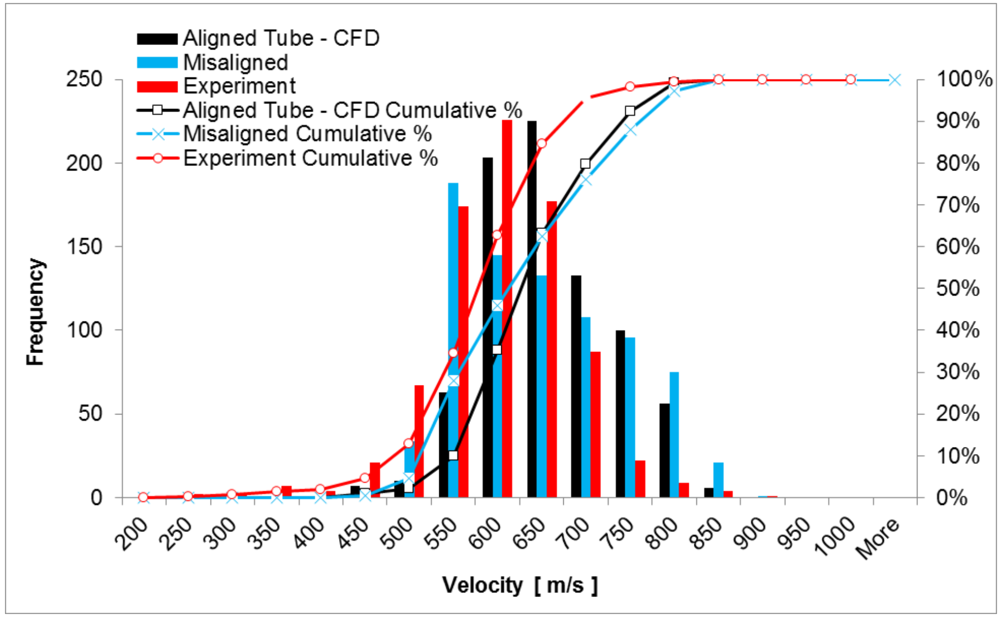
Misaligned Powder Feeder Tube Case

Model Validation

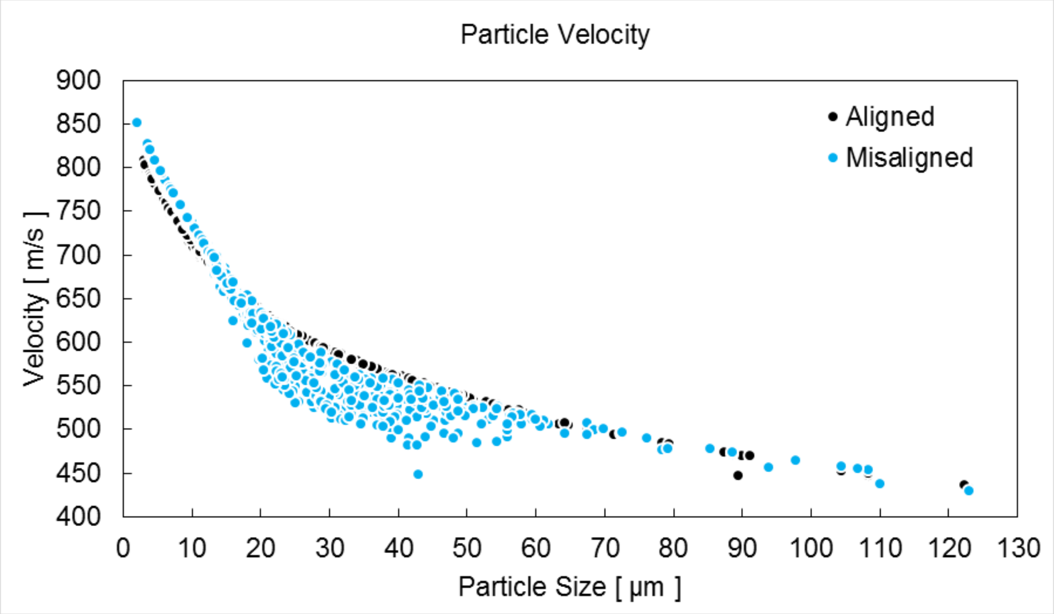


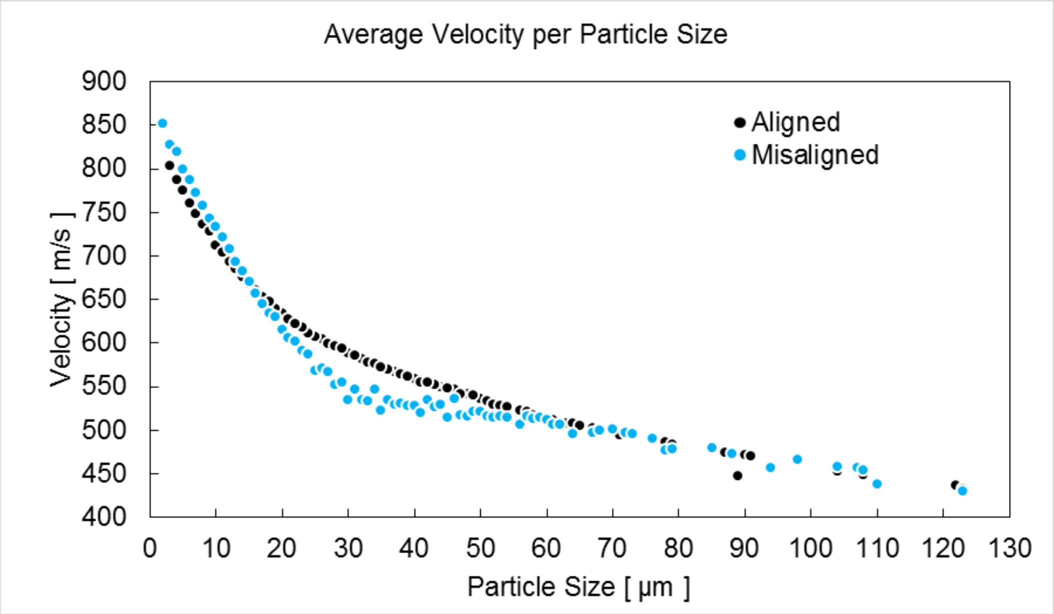


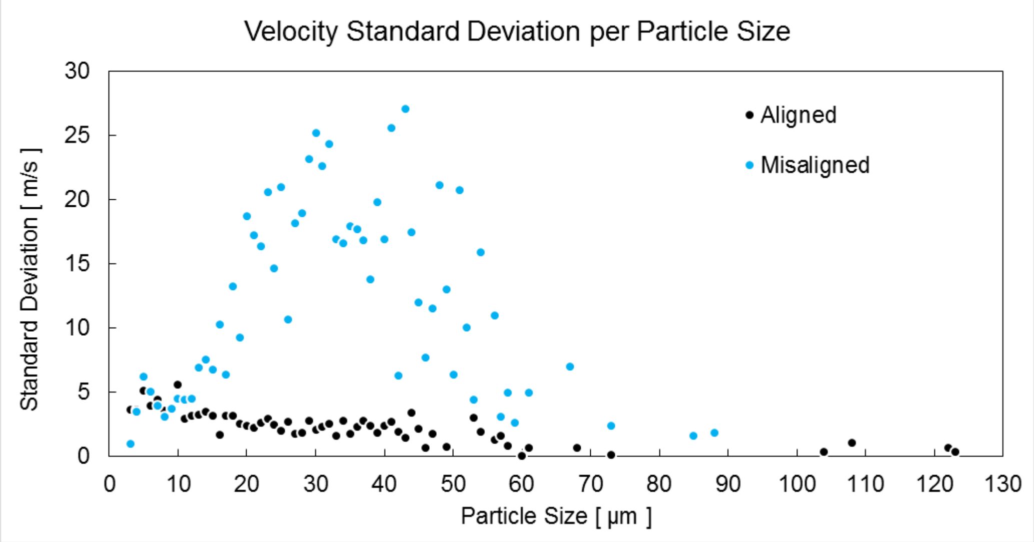
	Mean [m/s]	Std. Dev. [m/s]	Variance [%]	Min [m/s]	Max [m/s]
Aligned Tube Simulation	633	74	12%	432	809
Misaligned Tube Simulation	623	92	15%	430	852
TECNAR Measurement	627	80	13%	260	932

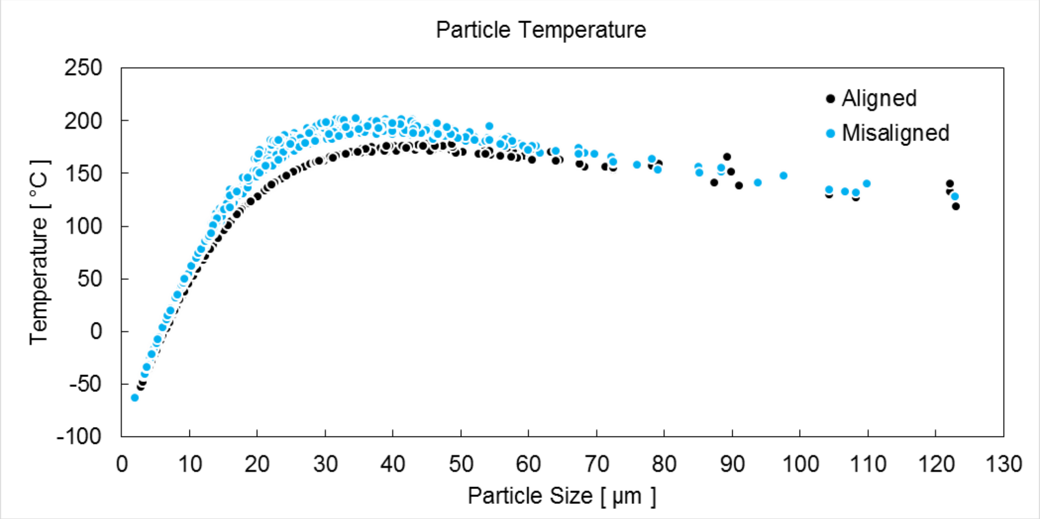


Effects of Misalignment on Particle Impact









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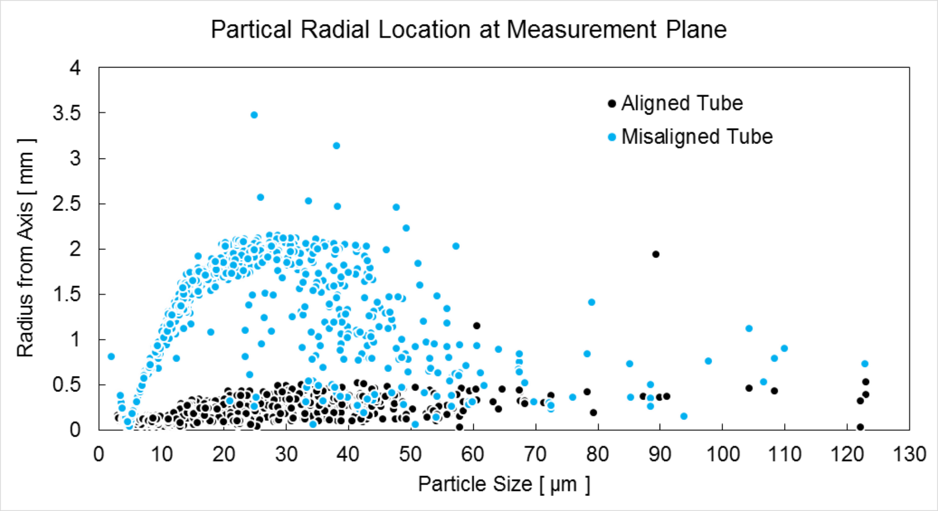
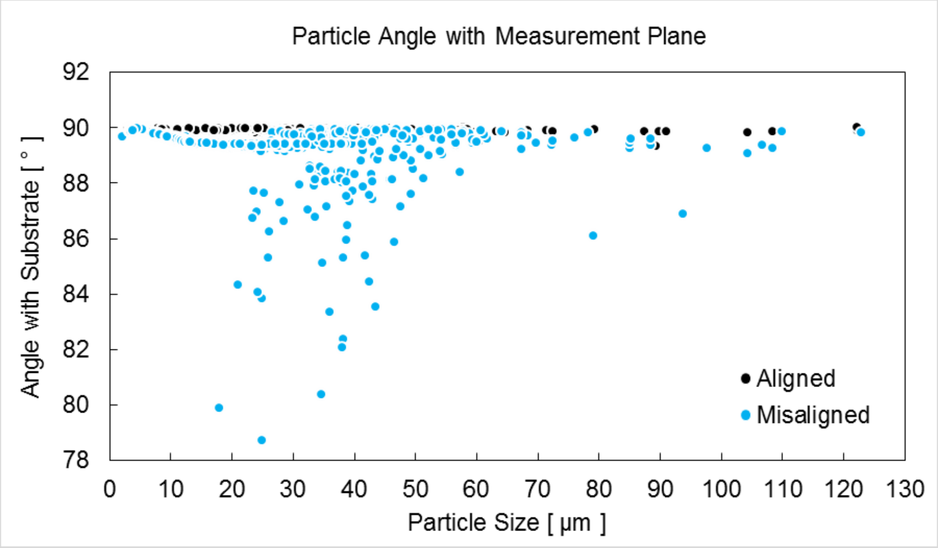
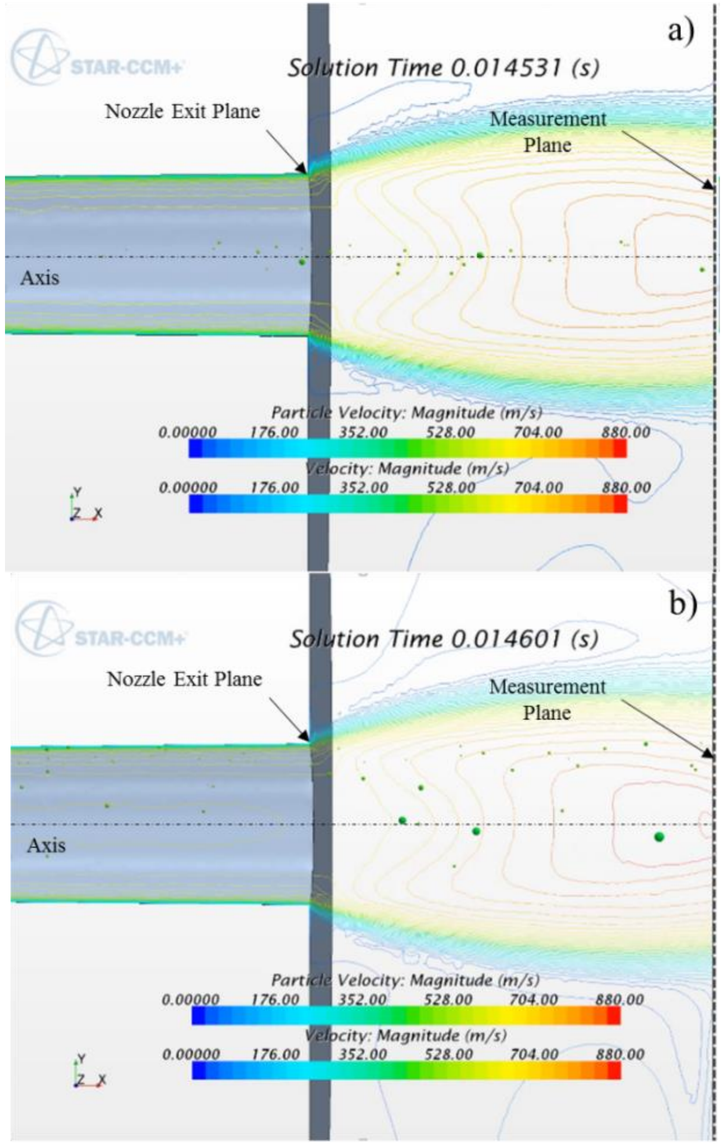
Spray Radius & Particle Angle with Measurement Plane





Aligned Case

Misaligned Case



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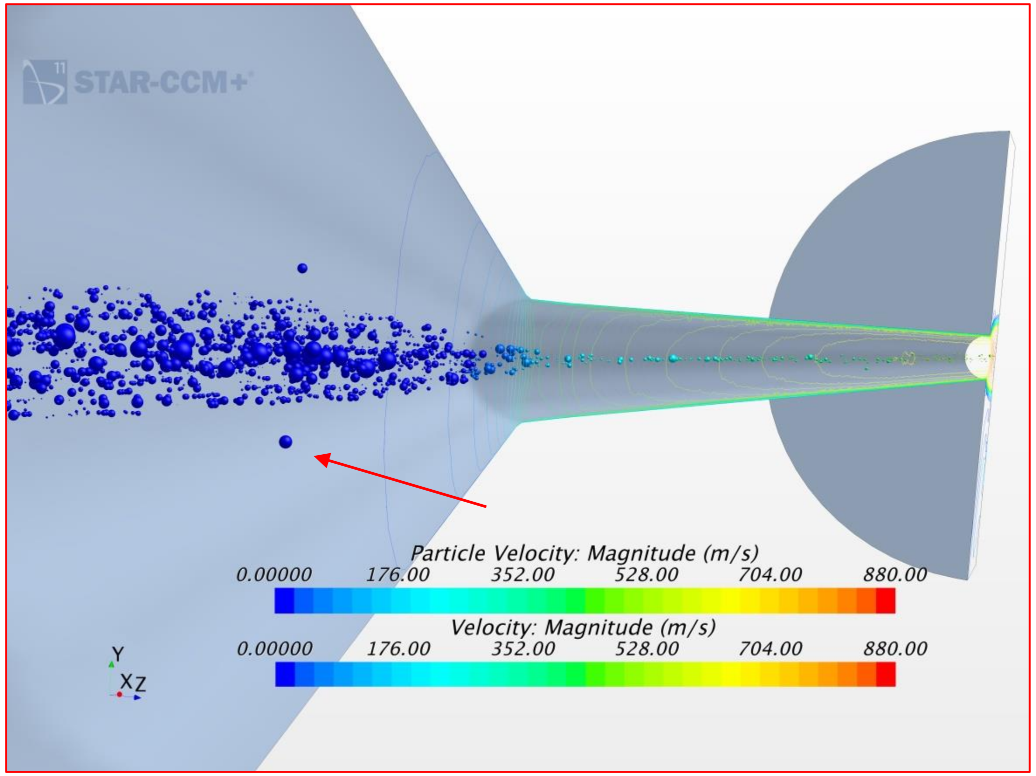
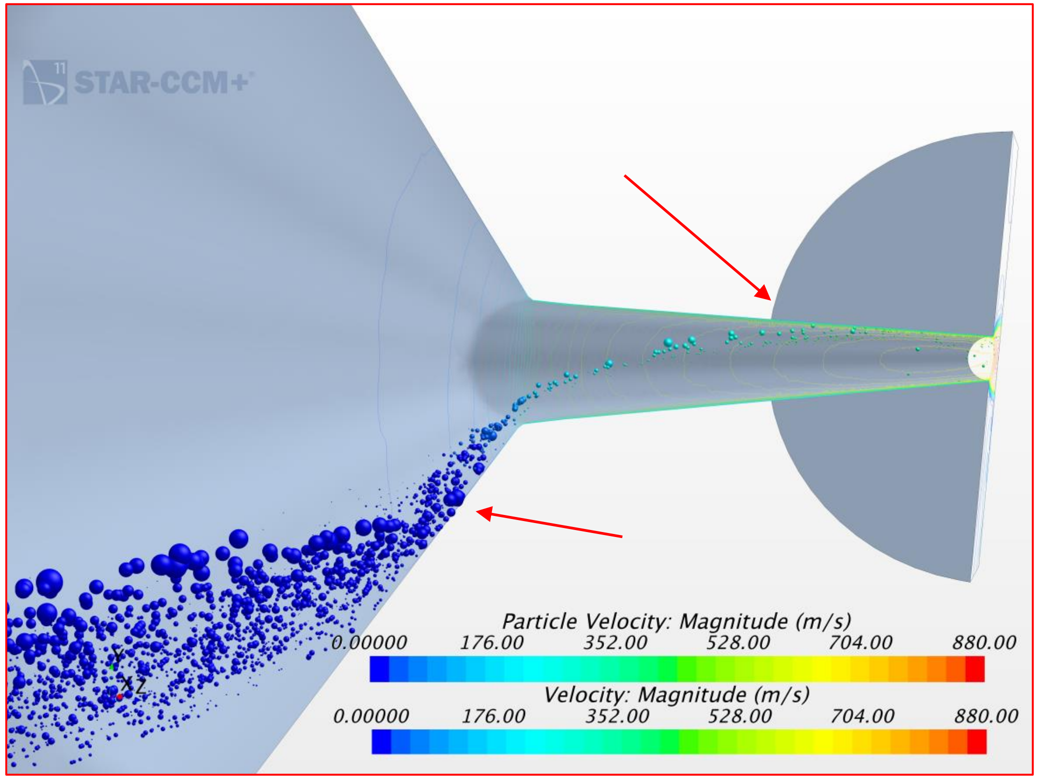
Particle Nozzle Interactions

Aligned Feeder Tube Scenario



Misaligned Feeder Tube Scenario



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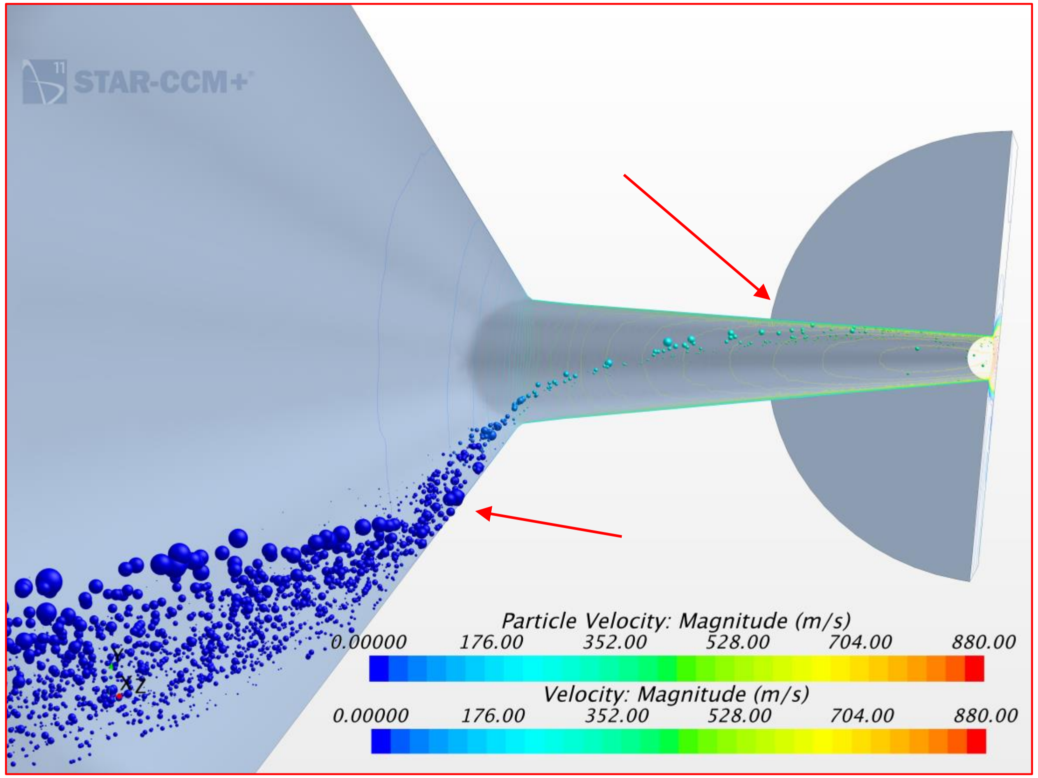
Effects of Misalignment on Nozzle Wear

- Reduction in nozzle expansion ratio
  - Nozzle throat wear
  - Drop in particle velocity
  - Reduction in the amount of
  - Inefficient increase in gas consumption
- Increase in nozzle expansion ratio
  - Wear in diverging section
  - Colder particles
  - Particles possibly impacting too substrate too fast
  - Causing erosion



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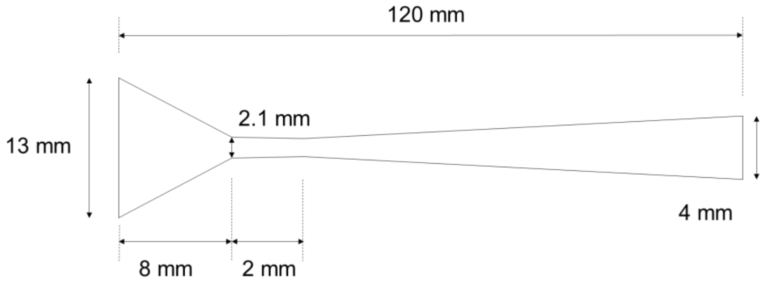
Controlling Particle Impact Conditions

- Control impact velocity for an average size particle (22 µm)
- Help control particle bonding mode on substrate
- Use Al6061
- Use 1-D *He*-N_2 mixing model



Al 6061 Properties	
Density (kg/m^3)	2700
Ultimate Tensile Strength (MPa)	310
Melting Temperature ($°C$)	650
Thermal Conductivity ($W/m\ °K$)	170
Specific Heat ($J/kg\ °K$)	900

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22 µm Particle Impact Velocity

Impact Velocity Ranges

Particle Impact Velocity Contour [m/s]

600	825	1050	1275	1500

0% He — 595 – 700 m/s

T [C] \\ P (MPa)	2.38	2.94	3.51	4.07	4.64	5.21	5.77
250	595	603	609	613	617	620	623
300	620	628	634	639	643	647	650
350	644	652	659	664	669	672	676
400	666	675	682	688	693	697	700

50% He — 741 – 885 m/s

T [C] \\ P (MPa)	2.38	2.94	3.51	4.07	4.64	5.21	5.77
250	741	754	765	773	780	785	790
300	770	785	796	805	813	819	824
350	798	813	825	835	843	849	855
400	824	841	854	864	872	879	885

75% He — 876 – 1065 m/s

T [C] \\ P (MPa)	2.38	2.94	3.51	4.07	4.64	5.21	5.77
250	876	898	914	928	939	948	956
300	909	932	950	964	976	986	995
350	939	964	982	998	1011	1022	1031
400	968	994	1014	1030	1044	1056	1065

100% He — 1156 – 1457 m/s

T [C] \\ P (MPa)	2.38	2.94	3.51	4.07	4.64	5.21	5.77
250	1156	1198	1233	1261	1286	1307	1326
300	1193	1237	1273	1304	1330	1353	1373
350	1228	1274	1312	1344	1371	1395	1416
400	1261	1309	1348	1381	1410	1435	1457

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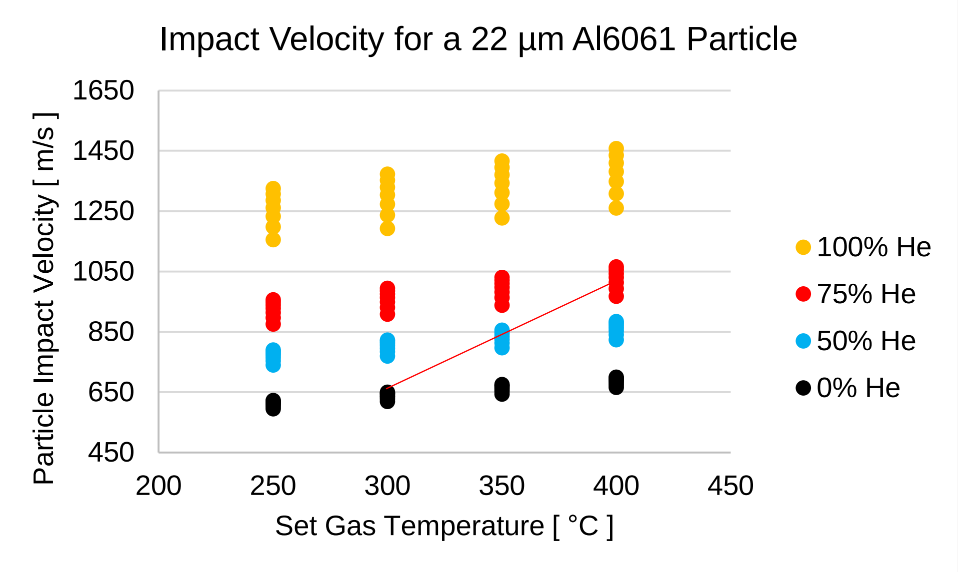
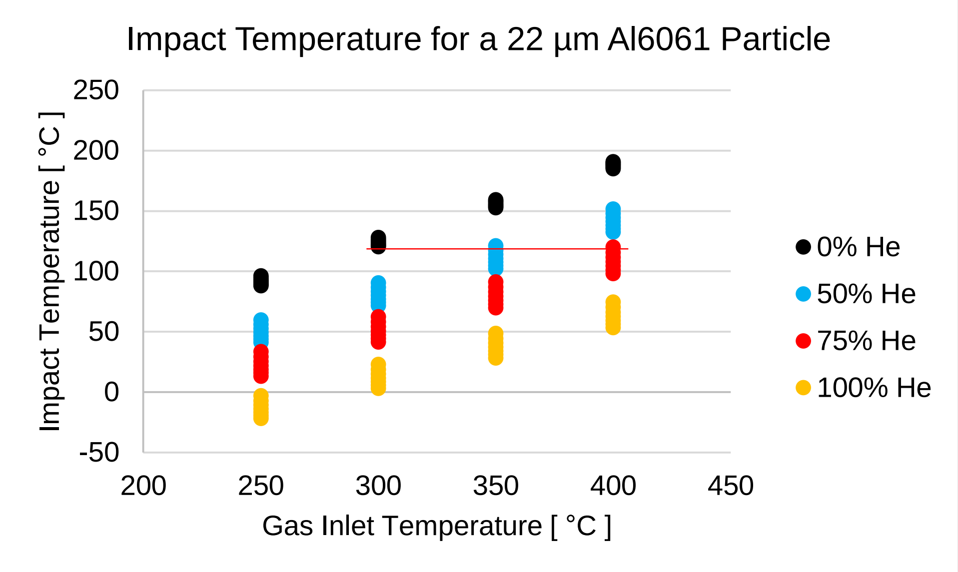
Correlation of Al Particle Impact Conditions with Spray Parameters

1. Capability of adjusting helium & nitrogen
2. 1D modeling of mixed gas spray conditions
3. Controlling particle impact conditions

Assumptions
1. Constant nozzle geometry
2. Constant standoff distance
3. Pressure is high enough to maintain supersonic flow exiting the nozzle

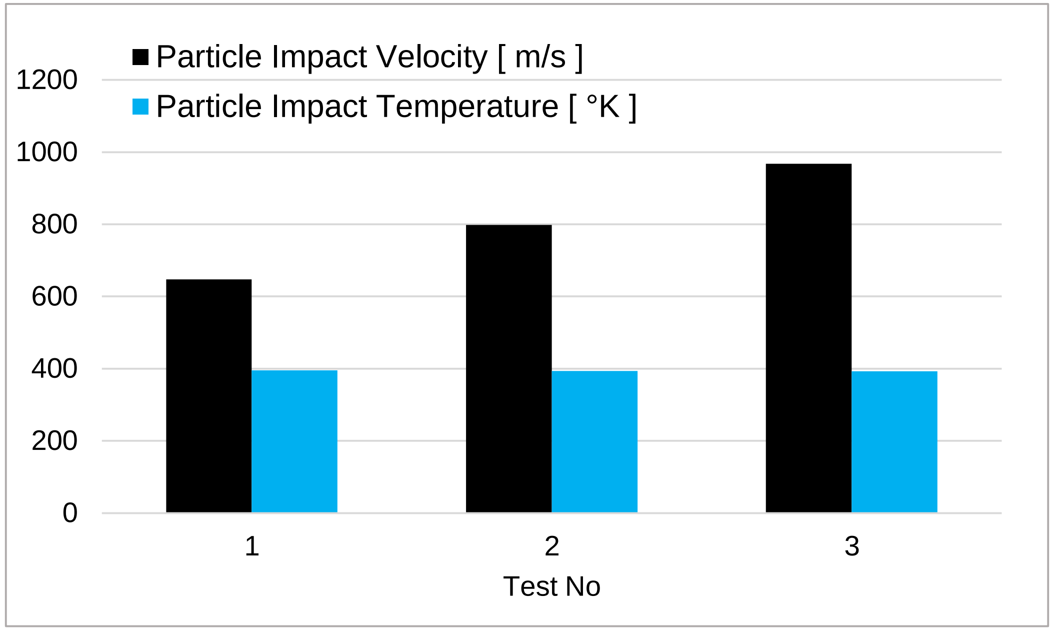




Sample Impact Velocity Variance Study Setup

- The desired particle velocity variance can be achieved by adjusting gas mixing ratio
- Recommended experimental setup:
  - Change impact velocity holding impact temperature constant
  - Varying pressure, temperature, gas mixing ratio for control

INPUTS				OUTPUTS		
Test No	He Mix [%]	Gun Pres. [MPa]	Gun Temp. [°C]	η V_{im} / V_{cr}	Impact Vel. [m/s]	Impact Temp. [°C]
1	0	5.21	300	0.91	647	122
2	50	2.38	350	1.12	798	121
3	75	2.38	400	1.36	968	120



Expected velocity measurements ~10% lower
70-100 m/s standard deviation

Questions

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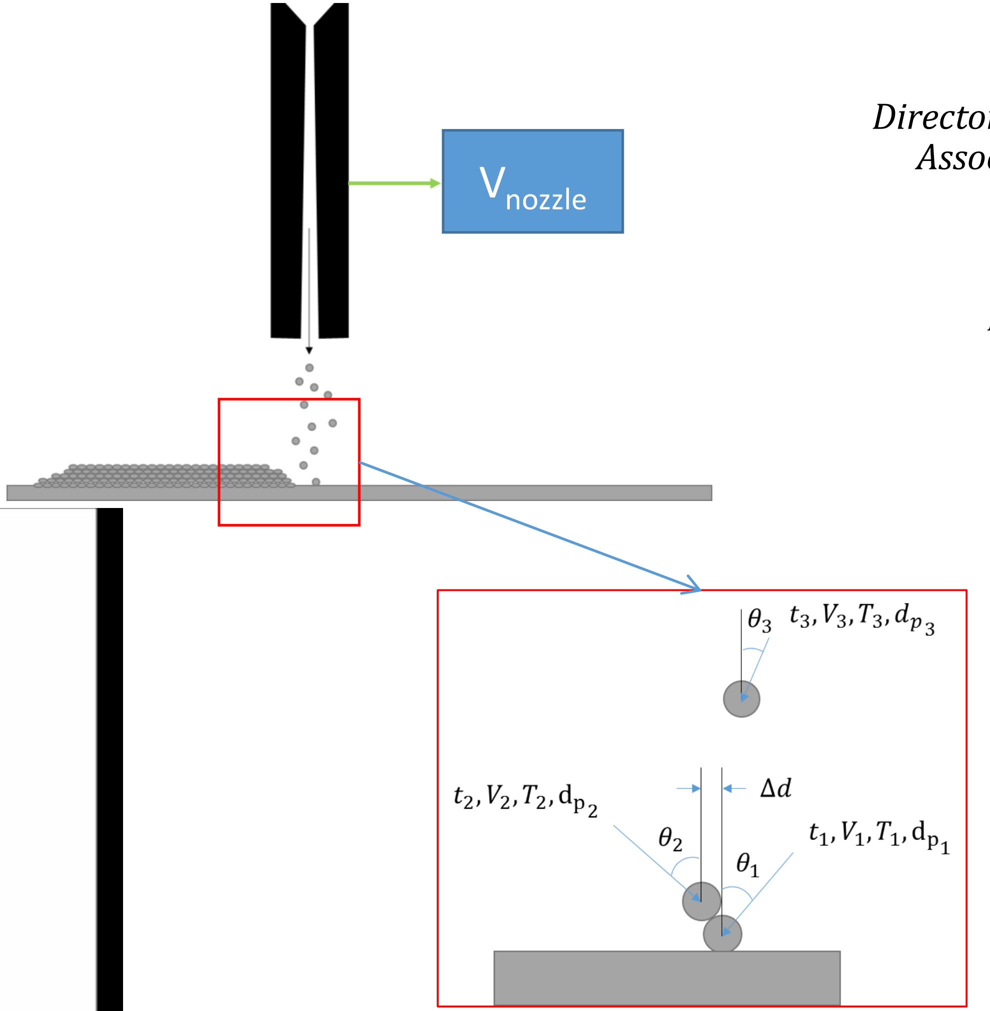

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