Effects of Orifice Configuration on Pintle Spray Cones

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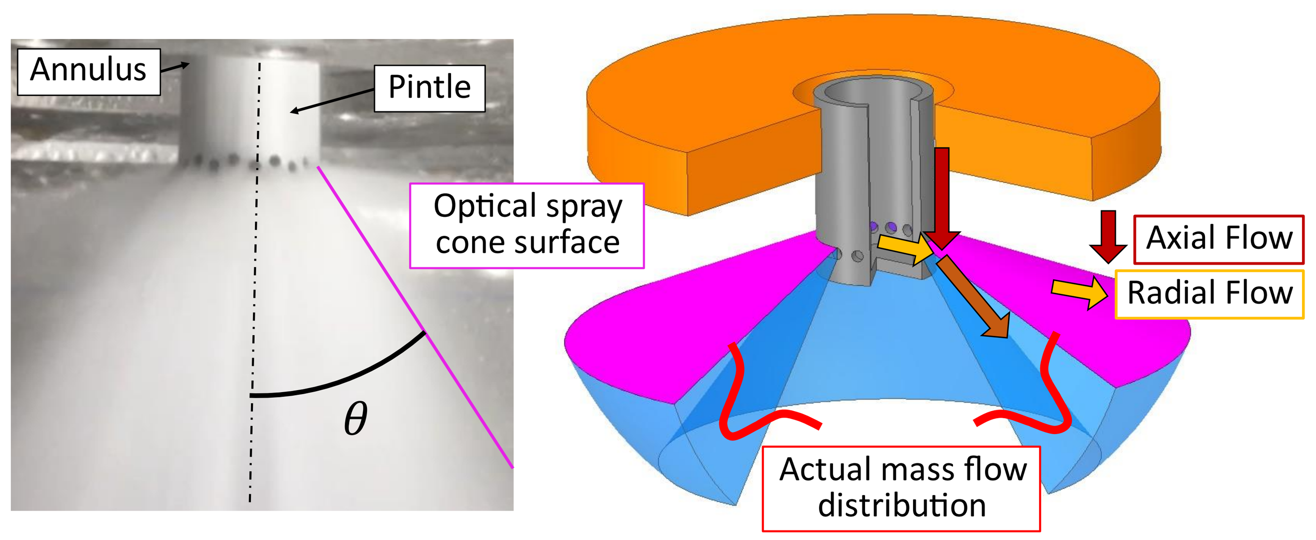
Motivation

- **Injectors** are used in bipropellant liquid rocket engines to atomize and mix propellants for combustion.
- **Pintle** injectors impinge flows via one radial flow through orifices and one axial flow through an annulus. This creates a **sheet** with a corresponding **spray cone angle** and **mass flow distribution**



- A sheet can be characterized nondimensionally using its **total momentum ratio:**

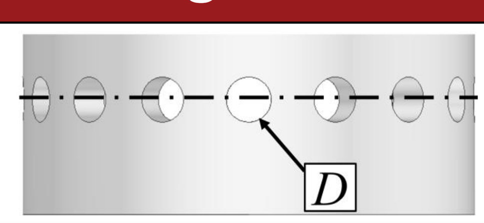
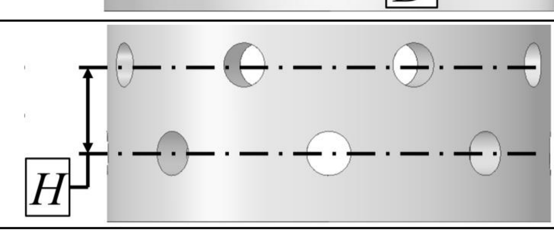
$$\boldsymbol{TMR} = \frac{\text{radial momentum}}{\text{axial momentum}} = \frac{m_r v_r}{m_a v_a}$$

- The behavior of the mixed sheet can be predicted from TMR, assuming an inelastic collision, using

$$\theta = \tan^{-1}(TMR)$$

or through empirical relations found in literature.
- Neither approach considers the effects of the pintle's **orifice configuration**.

Orifice Configuration Defining Parameter H/D

$H/D = 0$	
$H/D = 2$	

- Increasing H/D allows for a greater mass flow rate and resulting thrust from a given engine size.

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Testing Videos

Experimental Design

This project used the USC Liquid Propulsion Lab's Water Flow Test Stand to control flow and collect data.

- Single-flow: determine pintle and annulus discharge coefficients (C_d).

$$C_d = \frac{\dot{m}}{A\sqrt{2\rho\Delta P}}$$

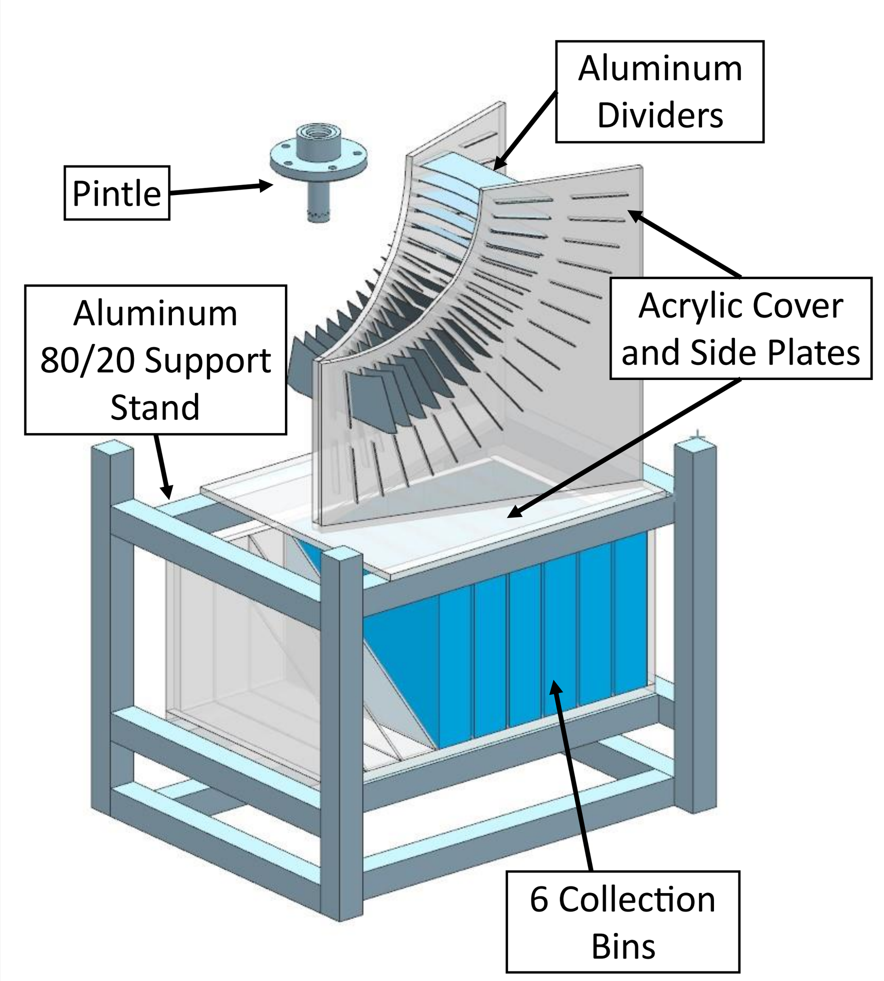
Flow	C_d
Pintle	0.60
Annulus	0.57

- Dual flow:
  - Calculate TMR from injector pressure drop and C_d.
  - Mass flow distribution (see right)
  - Optical θ from video footage.

The TMR range follows previous experiments and features the greatest rate of change of θ. This allows comparison of mass flow distribution to optical spray cone with H/D.

Test Ranges			
H/D	0.0	TMR	0.35
	0.5		0.47
	1.0		0.6
	1.5		0.8
	2.0		1.1

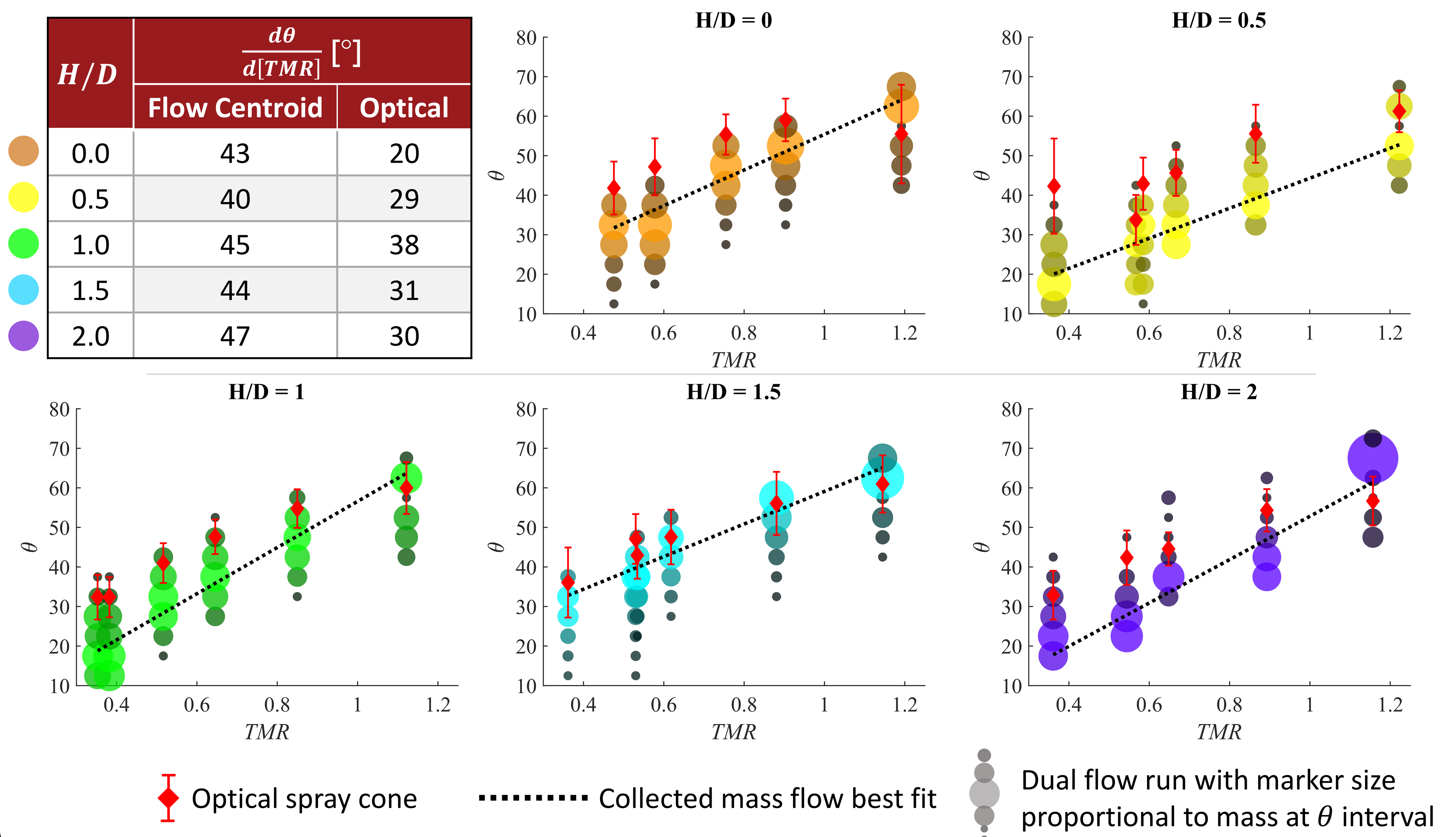
Mass Flow Collection Apparatus



Water from the spray cone is collected at 5° increments of θ. Collection bins are removed and massed after each test.

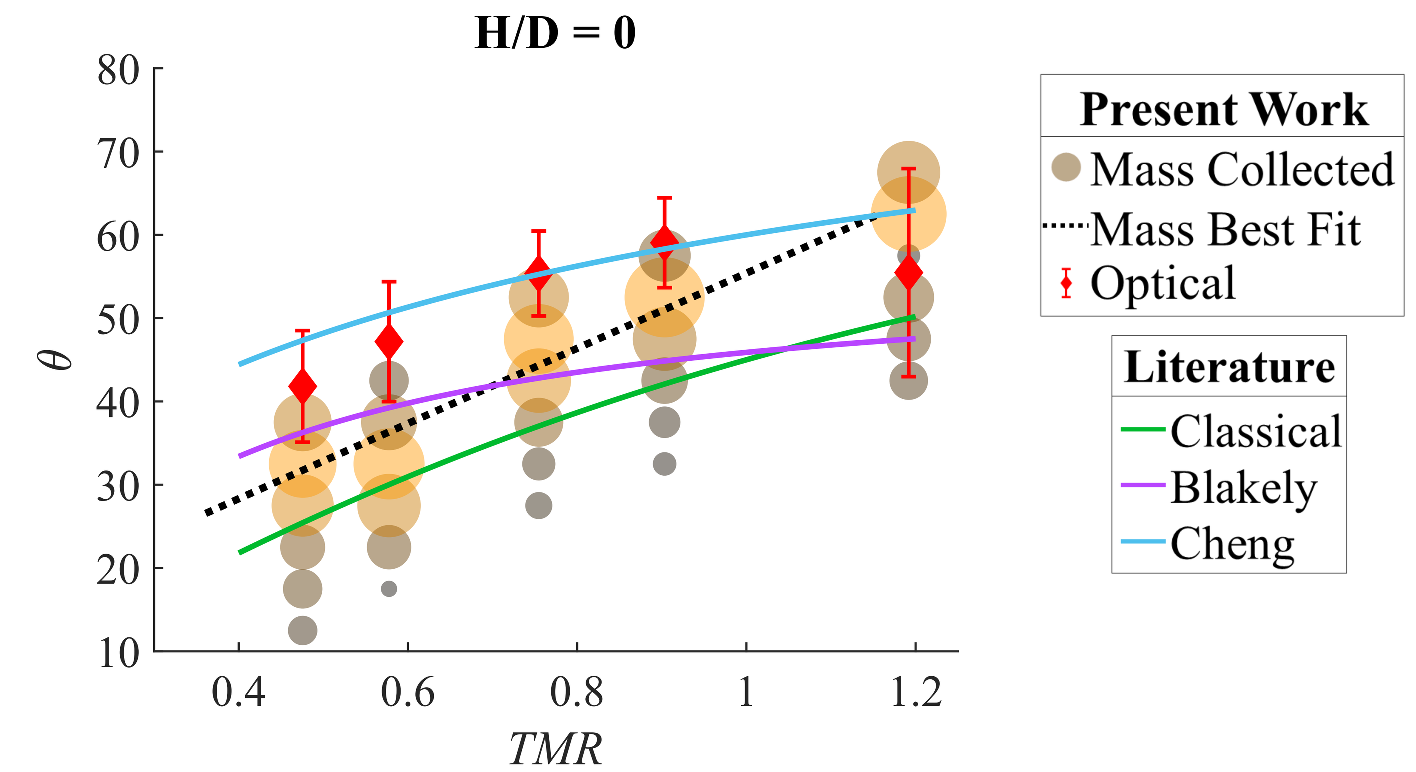
Results

	H/D	$\frac{d\theta}{d[TMR]}$ [°] Flow Centroid	Optical
(orange)	0.0	43	20
(yellow)	0.5	40	29
(green)	1.0	45	38
(cyan)	1.5	44	31
(purple)	2.0	47	30



Conclusions

- Spray cone behavior is constant with respect to H/D. Therefore, two rows of orifices can be employed without affecting chamber flow conditions.
- Optical spray cone measurements overpredict the angle of mass flow distribution at low TMR because the upper spray cone surface disproportionately reflects radial momentum. Comparing to previous results with one row of orifices:



Optical and mass flow spray cone descriptions converge at higher TMR where radial momentum dominates.

- On $TMR \in [0.4, 0.8]$, θ measured by mass flow distribution is approximately linear with TMR.
- A "double spray cone" with two distinct regions of higher mass flow shows radial momentum breaking through the annular sheet at distinct points as TMR increases.

Future Work

- Historical studies based on optical spray cone measurements at $TMR < 1$ should be reevaluated to account for actual mass flow distribution under the spray cone.
- A wider range of measured θ at finer increments could characterize a TMR at which a double spray cone emerges, expected on $TMR \in [0.8, 1.2]$
- Collection of spray cone with one stream labeled with a dye or marker would enable assessment of mixing performance.