Does divergence angle affect shock standoff distance in SRP??

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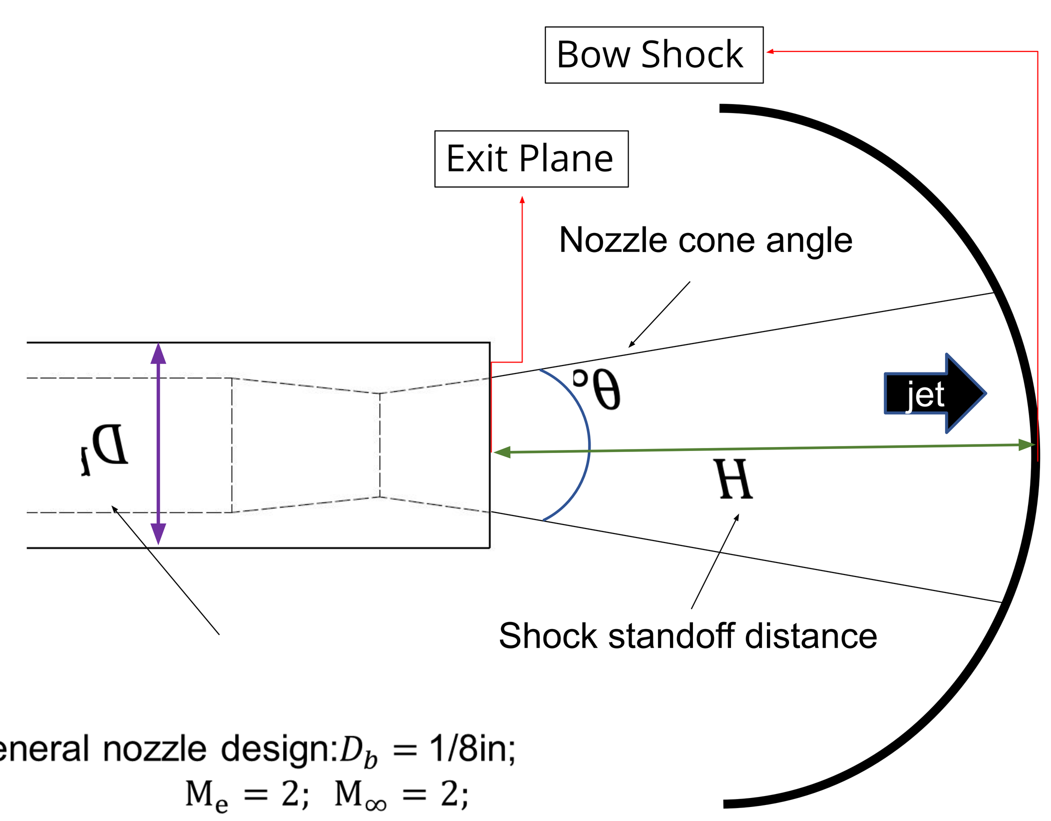
Introduction [1]

Supersonic Retro-propulsion(SRP) is a technique used by Entry Descent Landing (EDL) vehicles to decelerate in the high energy phase during entry into a planet's atmosphere. Scaling SRP experiments from to lab setup can expand our understanding in the domain and is extremely efficient and sustainable as compared full-scale experiments. They can also be used to validate CFD results [1] under the right conditions. A previous student identified the correct scaling parameters for thrust and gas temperature and molecular weight [2]. But the role of conical nozzle angle is unknown

This study explores the dependence of conical nozzle divergence angle on bow shock standoff distance, a parameter arising from a phenomenon occurring in SRP flows.

Geometry and setup [2]



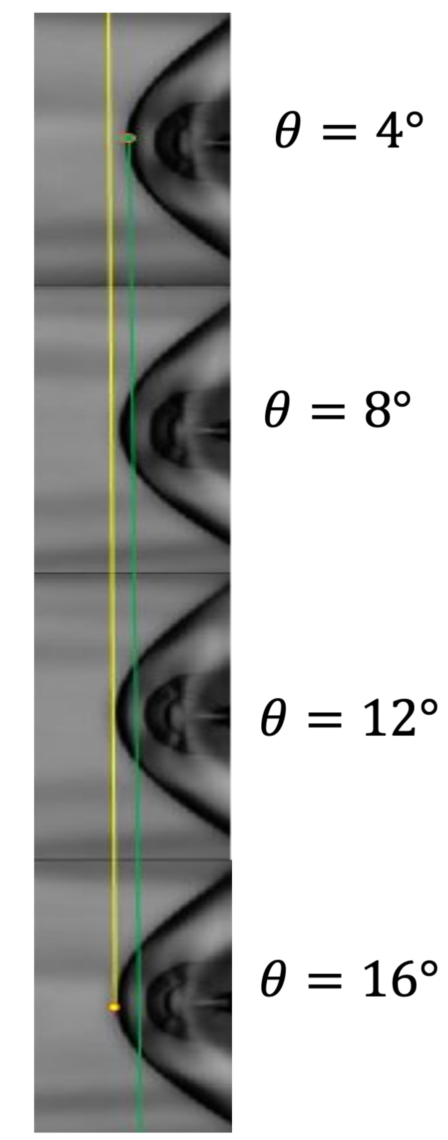
General nozzle design: D_b = 1/8in;
$M_e = 2$; $M_\infty = 2$;
$Retrojet(j) = N_2$; $Freestream(\infty) = CO_2$

Flow field viewed with high-speed schlieren photography (single mirror, double pass configuration).

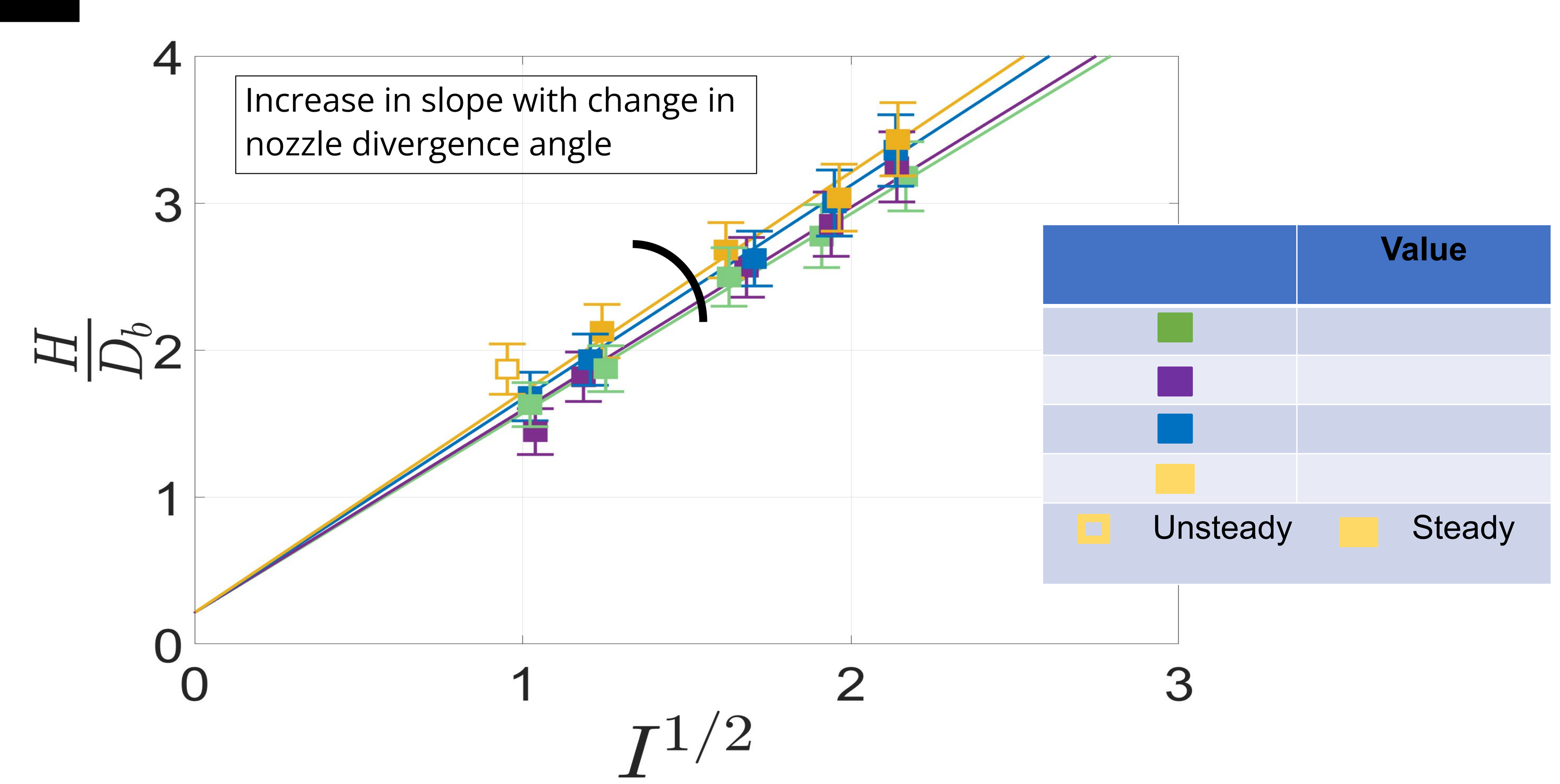
Schlieren systems utilize the density change occurring in compressible flows to refract light differently. This creates an image dark regions indicating shock structures.

Motivation [3]

- No previous experiments have systematically explored the influence of nozzle divergence angle on shock standoff distance.
- The flow divergence angle as it leaves a nozzle plays an important role in the matching of pressures between jet and freesream. As a result, it is thought likely to determine the area of the bow shock surface region covered by the retrojet.
- Figure in the right shows the standoff distance difference between 4° (green) and 16°(yellow) cases for a pressure ratio of $\frac{P_e}{P_{02}} = 1.7$, where P_e is the pressure at exit of the jet and P_{02} is the calculated ambient pressure.
- The difference in Shock standoff distance of the 16° case was found to be 8.1% greater than that of the 4° case.



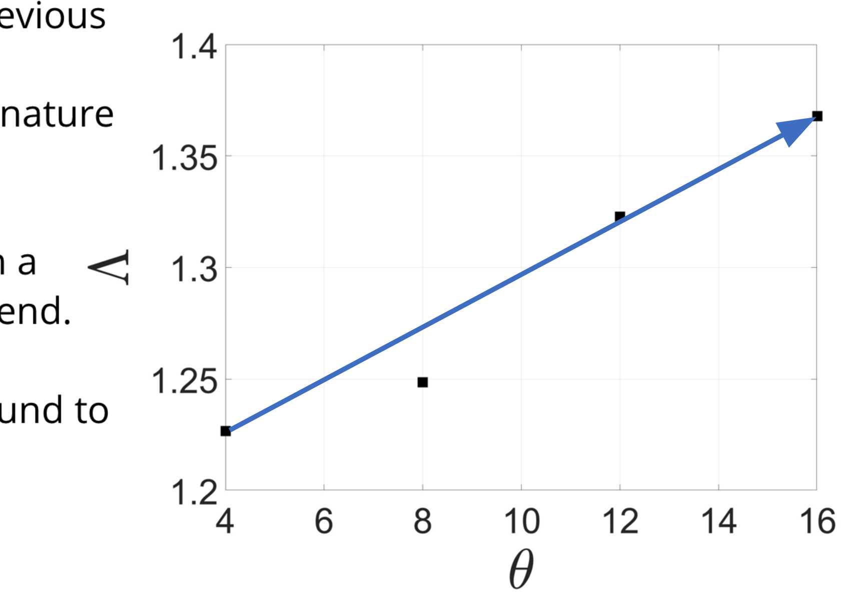
Shock Standoff distance(H/D_b) - Momentum Ratio(I) [4]



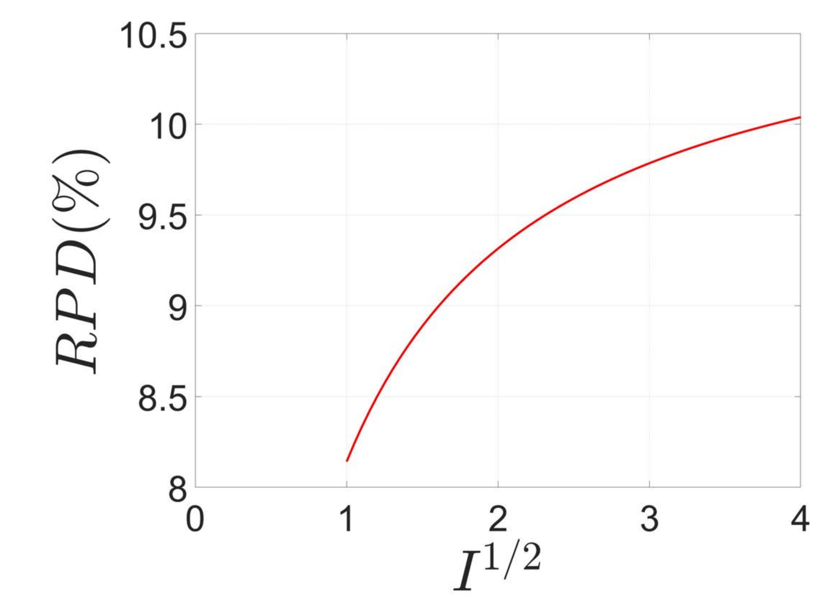
- For each angle 5 different pressure ratio cases ranging between of $P_e/P_{02} = 0.37$ to $P_e/P_{02} = 1.7$ were tested.
- Lowest pressure – highest angle case was omitted from the fit due to instability thought to be caused by nozzle flow separation.
- The momentum ratio I is the ratio between the momentum of the gas ejecting from the retrojet and the freestream.

Slope(λ) vs nozzle angle(θ) [5]

- Slopes of the fitted lines from previous segment are plotted against the divergence angle to observe the nature of the trend.
- The slopes(λ) of each angle lie on a straight line indicating a linear trend.
- The variation in the slope was found to be 11.48%
- $(\lambda_{16} - \lambda_4)/(\lambda_4) * 100 = 11.48\%$



- The amount of variation that is expected due to changes in the exit angle of the nozzle can be determined by calculating the Relative Percentage Difference(RPD(%)).
- $RPD\% = \frac{H - L}{\frac{H+L}{2}} * 100 =$ 10.84% at $I_{\frac{1}{2}} > 50$
- After a certain threshold it was found that variation in performance due to change in angle was constant.



Conclusions, Future Work and References [7]

Conclusion:

- For the highest-pressure case difference in H/D_b of the 16° case was found to be 8.1% greater than that of the 4° case.
- The slope values followed a linear trend with 11.48% variation between lowest and highest angles
- RPD plot shows nonlinear rise for small values and becomes constant at high values of $\sqrt{I}$.

Future work:

- CFD models can be simulated to study and verify this relationship of nozzle divergence angles with shock standoff distance.
- The numerical value of slope was seen to increase linearly for small angles, but this linear relationship might not be true as we go higher. Finding the threshold of this relationship and finding methods to identify and prove the cause of this behavior could be motivation for future work.

References:

1. Korzun, A. M. and Cassel, L. A., "Scaling and similitude in single nozzle supersonic retropropulsion aerodynamics interference," AIAA SciTech 2020 Forum, 2020, p. 0039.
2. Jennis, E., Thermodynamic Scaling of Supersonic Retropropulsion Flowfeilds, Ph.D. thesis, University of Washington, 2022.

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