Performance Enhancement of Unsteady Ejectors Investigated Using a Pulsejet Driver

Unsteady ejectors are currently under investigation for use in some pulse detonation engine (PDE) propulsion systems. This is due primarily to their potential high performance in comparison to steady ejectors of similar dimensions relative to the source or driver jet. The performance metric of interest is the thrust augmentation ϕ defined as

$$\phi = T^{Total}/T^{j}$$

where T^{Total} is the total thrust of the ejector and the driving jet combined and T^{j} is the thrust due to the driving jet alone.

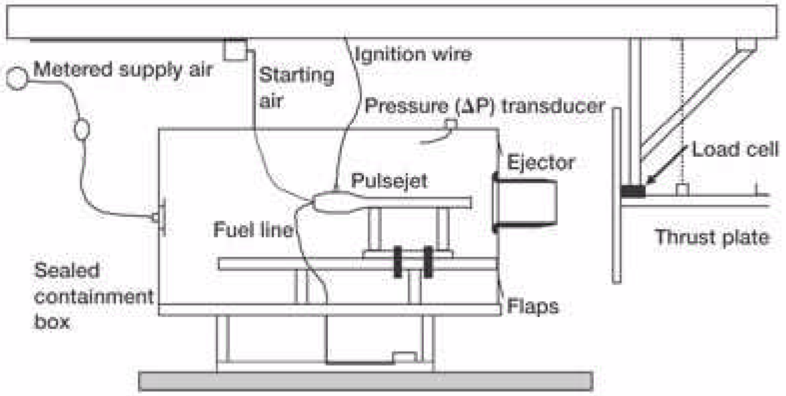
Although some experimental work has been done in the past to study thrust augmentation with unsteady ejectors, there is no proven theory by which optimal design parameters can be selected and an effective ejector constructed for a given pulsed flow. Therefore, an experimental facility was developed at the NASA Glenn Research Center to study the correlation between ejector design and performance, and to get a better understanding of the flow phenomena that result in thrust augmentation. A commercially available pulsejet was used for the unsteady driving jet. This was paired with a basic, yet flexible, ejector design that allowed parametric evaluation of the effects that length, diameter, and inlet radius have on performance.

The use of a pulsejet for such an experiment is advantageous for several reasons:

1. Pulsejets are mechanically simple and inexpensive to build and operate, particularly when compared with the target ejector application, PDEs.

2. Pulsejets resemble PDE’s, having both high enthalpy exit flow, and very large fluctuations in exit velocity.

3. Their 220-Hz operating frequency is similar to the target values of the PDEs being considered for flight.



Experimental arrangement.

Long description of figure 1 This schematic shows a drawing of the pulsejet and a typical ejector arranged as they were for the experiment. Both are mounted on a fixed test stand, in axial alignment, with a preset spacing between them. The pulsejet and a portion of the ejector are encased within a large, sealed acrylic box. Flow into the box is metered from a laboratory supply line. The exhaust portion of the ejector protrudes from the rear of the box, providing the only escape for air. This arrangement allows for the measurement of flow through the pulsejet and ejector. Immediately behind the ejector is a large suspended thrust plate. Immediately behind the thrust plate is a fixed load cell. This apparatus allows the measurement of total thrust. The thrust of the pulsejet alone, a measurement of which is necessary for the calculation of thrust augmentation, is obtained via a correlation with the mean combustion chamber pressure as measured with the average of two transducers.

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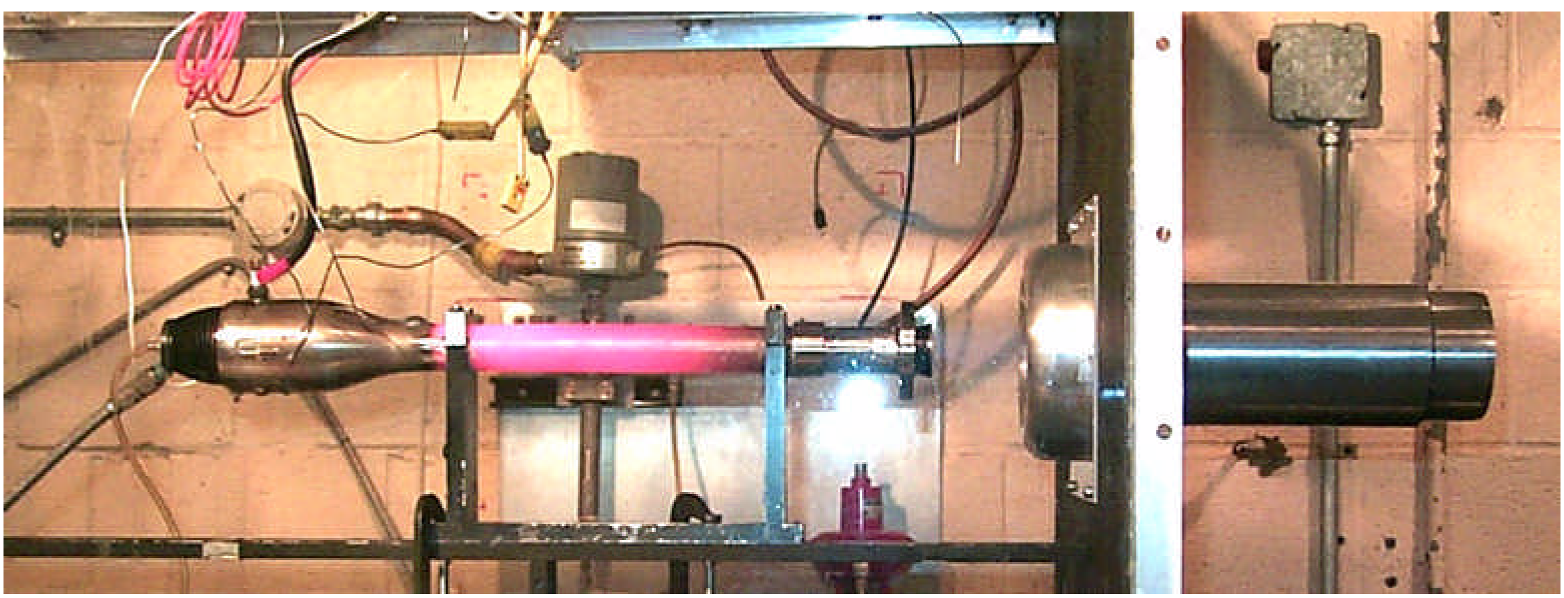
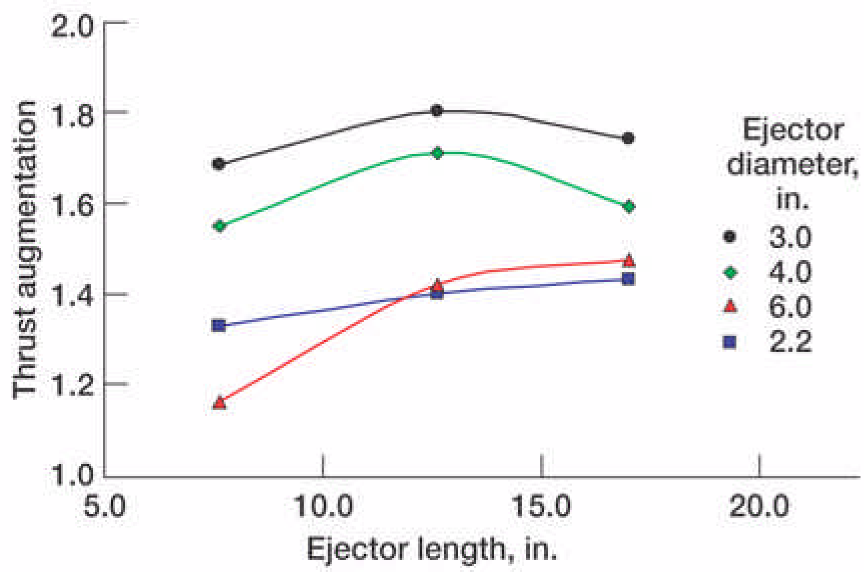
The experimental setup is shown schematically in the drawing. The containment box shown allows measurement of flow entrainment along with thrust augmentation. The pulsejet and ejector system taken during operation are shown in the following photograph.



Operational pulsejet and ejector.

Performance results from some of the ejector parameters investigated are shown in the graph. Here, thrust augmentation is plotted as a function of ejector length for several families of ejector diameter. It can be seen that large thrust augmentation values are obtained and that they are sensitive to both ejector length and diameter.



Measured thrust augmentation as a function of ejector length for different families of ejector diameter.

Long description of figure 3 Four curves are shown, corresponding to ejector diameters of 2.2, 3.0, 4.0, and 6.0 in. For each curve, there are three data points corresponding to lengths of 7.6, 12.6, and 17.0 in. The largest value of thrust augmentation is 1.81, obtained with the 12.6-in.-long, 3.0-in.-diameter ejector. All the ejectors trend toward peak performance at a particular length.

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As detailed in reference 1, it was also found that ejector performance is sensitive to the spacing between the driver and ejector and to the radius of the ejector inlet. Furthermore, there appears to be a strong correlation between thrust augmentation and the formation number associated with the starting vortex emitted from the driver. The formation number is defined here as

$$F = \frac{\sqrt{\overline{u'^2}}}{2fd_j}$$

where f is the frequency of the primary source, $\sqrt{\overline{u'^2}}$ is the root mean square of the source velocity fluctuation, and d_j is the source diameter. The presence and magnitude of a starting vortex has been determined using digital particle imaging velocimetry (DPIV) as described in reference 2. Future efforts will focus on validating the formation number correlation using other unsteady thrust sources, including an operational PDE, and on evaluating the effects of ram pressure (i.e., flight speed) on unsteady thrust augmentation.

References

1. Paxson, D.; Wilson, J.; and Dougherty, K.: Unsteady Ejector Performance: An Experimental Investigation Using a Pulsejet Driver. AIAA Paper 2002-3915, 2002.

2. John, W., et al.: Conditionally Sampled Pulse Jet Driven Ejector Flow Field Using DPIV. AIAA Paper 2002-3231, 2002.

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