AEROSPACE PROPULSION LABORATORY

AE 345

Atomizers for Propulsion Devices

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August 13, 2024

Injectors

Application

There are many practical instances where injectors are frequently used in which two initially segregated streams mix and forms a uniform mixture. A significant example is the case of liquid rocket propellant engines (Gas turbine, Liquid rocket engine, ramjet, scram-jet propulsion etc.) because the length of the combustion chamber is limited by the ability of the injecting devices to fragment and mix the reactants down to a sufficient level of homogeneity for evaporation and combustion to completion at the desired distance from the injector outlet.

For technological constraints one of the reactants is usually available in the liquid state and the other in the gas phase; for historical reasons the coaxial geometry is commonly used to merge the two streams. The relative flow rates of the reactants must be adjusted so that the global stoichiometry is maintained, so that the gas phase is in excess for all of the liquid to vaporize and burn. This emphasizes that the gas stream is usually much more rapid than the liquid stream at the injector outlet. It is the situation encountered rocket in H_2/O_2 engines, where a slow, dense liquid oxygen (LOX) stream in the central jet of the coaxial injector is surrounded by a fast, light, gaseous hydrogen annular stream.

Theory

In Liquid Rocket Engine systems, propellant injectors and feed manifolds are used to feed the propellants into the combustion chamber. The injectors atomize the propellants as much as possible and spray them into the combustion chamber in a pattern that helps the propellant to mix and burn. Here, Two type of injectors or atomizer are briefly discussed here:

1. Air-blast injector

2. Gas centered swirl coaxial injector

Air-blast atomizer

The liquid is formed into a sheet by a nozzle, and air is then directed against the sheet to promote atomization. The momentum flux of the gas stream is of the same order, or exceeds that of the liquid jet, the breakup and atomization is caused by the kinetic energy transfer from the gas to the liquid. This type of atomization is generally referred to as air-blast atomization. The addition of the external air stream past the sheet produces smaller droplets than without the air. Though the exact mechanism for this enhanced performance is not completely understood, it is thought that the assisting air may accelerate the sheet instability. The air may also help disperse the droplets,

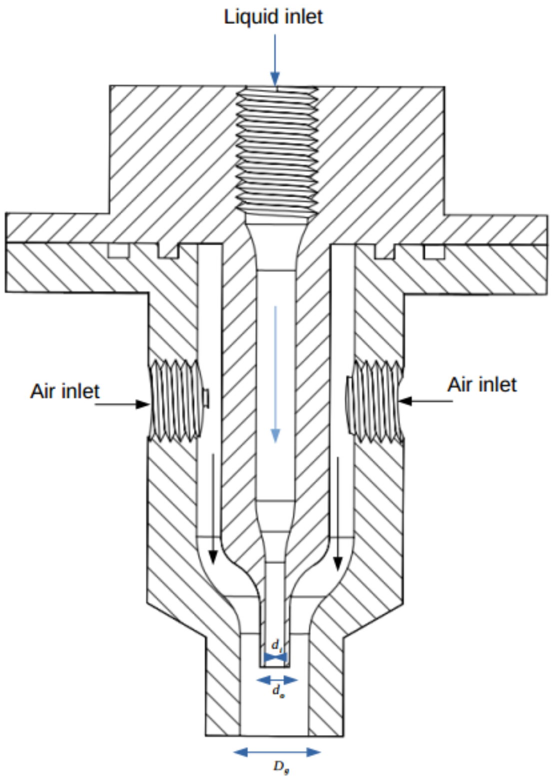


Figure 1: Coaxial air-blast configuration

preventing collisions between them. Air-assisted atomization is used in many of the same applications as pressure-swirl atomization, where especially fine atomization is required. The coaxial air-blast atomizer geometry is shown schematically in Fig.(1), consisting of the geometrically simple case of a round liquid jet surrounded by a co-flowing annular air stream.

Dimensions for air-blast (mm)		
d_i (liquid)	d_o (liquid)	D_a (air)
2	3	7

Gas centered swirl coaxial injector (GCSC)

A typical coaxial atomizer consists of flow passages for both the propellants (fuel and oxidizer) arranged concentrically.n a gas-centered swirl coaxial atomizer, the interaction between the high-speed gas jet issuing from the central orifice and the swirling liquid sheet coming out from a concentric annular region leads to the formation of spray as shown in Fig. (2a) . A swirl injector can generally achieve good atomization quality and high mixing efficiency. As shown in Fig.(2), the circumferential velocity component is first

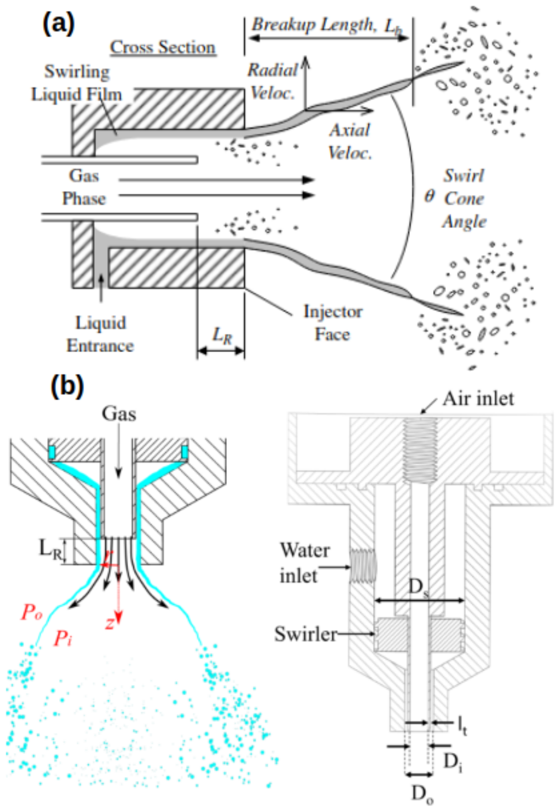


Figure 2: (a) Breakup mechanism of GCSC injector (b) Injector used in present experiment

generated as the propellant enters through helical or tangential inlets producing a thin, swirling liquid sheet. A gas- filled hollow core is then formed along the center-line inside the injector due to centrifugal force of the liquid sheet. In a swirl injector, the spray cone angle is controlled by the ratio of the circumferential velocity to the axial velocity. The breakup process of the swirling liquid includes thinning and perforation of the liquid sheet, ligaments, and droplets. The spray breakup of these injectors is largely controlled by the interaction between the liquid and the gas, and it will be discussed in terms of the axial Reynolds number Re_l and the momentum flux ratio ($MFR = \frac{\rho_g u_g^2}{\rho_l u_l^2}$).

Dimension for GCSC (mm)			
D_i (gas)	D_o (liquid)	t_s (sheet thickens)	D_s (swirl chamber)
3	5	0.5	22

Where, D_i diameter of orifice for gas flow, mm
D_o diameter of orifice for liquid flow, mm
t_s liquid sheet thickness,mm
From Fig. (2), $D_o = 2t_l + 2t_s + D_i$
Where t_l is lip thickness. Area for gas flow $=\frac{\pi D_i^2}{4}$
Annular area for liquid flow $=\frac{\pi[D_o^2-(D_i+2t_l)^2]}{4}$

Regimes of sheet breakup in GCSC injector

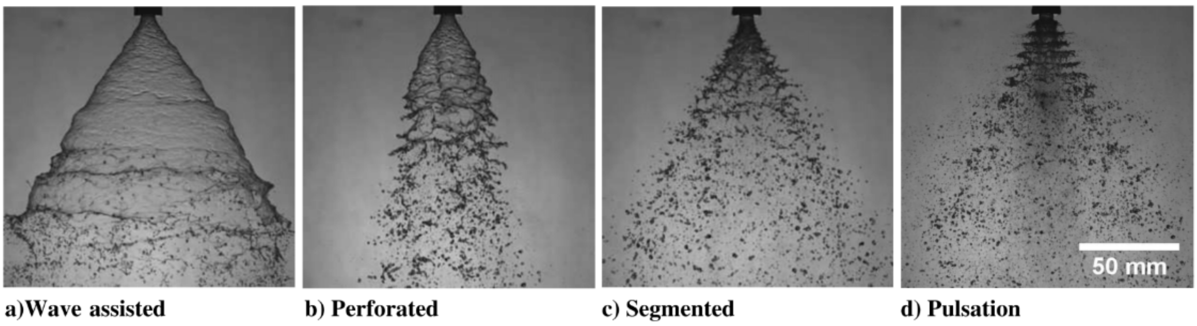


Figure 3: Various regimes of sheet break up with increase in the gas flow rate [1]

For more information on the mechanism and dynamics of these regimes, you are encouraged to read the work by Sivakumar *et al.*[2].

Experimental Procedure

1. **Spray Generation**: The spray is produced using a spray generation unit connected to a high-pressure air tank and a pressurized water tank.

2. **Flow Control**: Pressurized fluids are directed to the inlet of a rotameter, which is connected to the outlets of the water tank and air stream. The rotameter controls the liquid flow rates, allowing for precise adjustments as needed.

3. **Flow Rate Adjustment**: Adjust the liquid flow rates using the rotameter. Ensure the readings are stable before proceeding to capture the breakup events.

4. **Image Capture**: Once the desired flow rate is stable, use a DSLR camera mounted on a stand to capture the breakup events.

5. **Image Processing**: Process the recorded images using **IMAGEJ**[1] software. You can download the software from the link provided in the footnote, and refer to the user manual or YouTube tutorials for guidance on its usage.

Important parameters

1. **Momentum flux ratio (MFR):** It id defined as the ratio of gas momentum flux to liquid momentum flux at the exit of the injector.

$$\boxed{MFR = \frac{\rho_g U_g^2}{\rho_l U_l^2}}$$

2. For a given liquid and gas volumetric rate, velocities can be calculated using mass conservation.

$$\dot{V} = AU$$

Tip of Spray: Sauter Mean Diameter (SMD)

The Sauter Mean Diameter (SMD) is a key metric used to characterize the average particle size within a spray. It represents the diameter of a sphere that has the same volume-to-surface area ratio as the particle of interest. Mathematically, the SMD is expressed as:

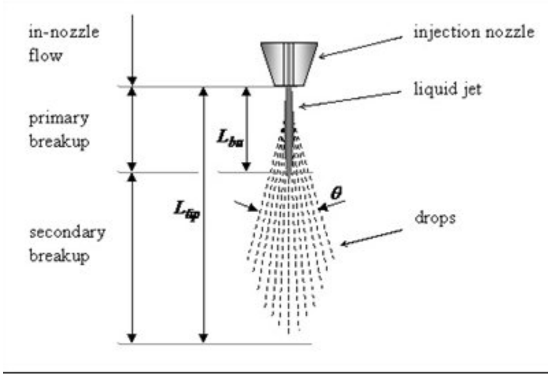
$$D_{32} = \frac{d_v^3}{d_s^2}$$

where d_v and d_s are the volume and surface diameters, respectively, defined as:

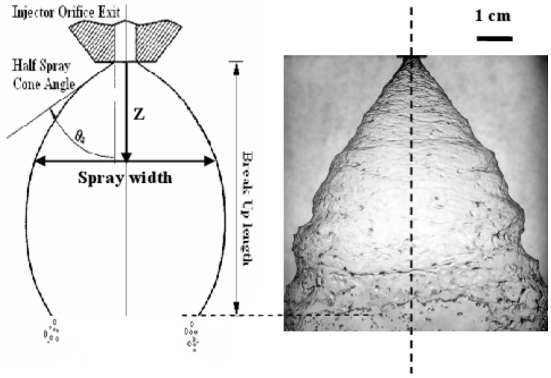
$$d_v = \left(\frac{6V_p}{\pi}\right)^{1/3}, \quad d_s = \left(\frac{A_p}{\pi}\right)^{1/2}$$

In these equations, V_p and A_p denote the volume and surface area of the particle, respectively.
To ensure statistical significance, the SMD is typically calculated as the mean of multiple measurements. The SMD is widely used in both industrial and academic settings to assess and quantify spray quality.

[1] https://imagej.net/ij/



(a) Schematic representation for breakup length



(b) Actual Spray observed in GCSC injector

Figure 4: Key parameters in spray performance

Instructions

Report should contain the following:

- The theory of injectors, schematic of experimental setup for both the injectors i.e., Air-blast and GCSC
- Your report must contain the breakup length for each cases for both the injectors i.e., Air-blast and GCSC. The breakup length of liquid sheet L_b is measured as the distance from the exit of injector to where the liquid sheet breaks up along the spray axis as show in Fig. (4).
- Images should be processed to find the cone angle for GCSC injector. Cone angle should be averaged out for each cases and plotted against the MFR meaning for one liquid flow rate, MFR vs cone cone angle (θ).
- Include representative images from the experiments to visually identify the operating regime for different MFRs. Refer to a classification Fig. (3) to categorize the operating regimes observed in the experiments.
- Observations and explanations: Summarize key observations from the experimental data and image analysis. Provide explanations for observed trends, including any anomalies or unexpected results.
- Conclusions: Discuss the practical implications of the results and suggest potential reason for errors if trends are not observed as expected.

References

[1] Santanu Kumar Sahoo and Hrishikesh Gadgil. "Dynamics of Self-Pulsation in Gas-Centered Swirl Coaxial Injector: An Experimental Study". In: *Journal of Propulsion and Power* 37.3 (2021), pp. 450–462.

[2] D Sivakumar and V Kulkarni. "Regimes of spray formation in gas-centered swirl coaxial atomizers". In: *Experiments in fluids* 51.3 (2011), pp. 587–596.