Investigation of Water Droplet Flow Behavior in a Vertical Nozzle Chamber

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OBJECTIVES

The solid rocket motor (SRM) nozzle erosion is a challenge which should be overcome to enhance the solid rocket motor performance and to facilitate the development of the aerospace research. Due to the nature of the combustion process inside the SRM chamber (high pressure and temperature), the aluminum is oxidized into aluminum oxide which agglomerate into small droplets and impinge on the exit nozzle walls causing a severe erosion and compromising the rocket performance. Thus, identifying the factors, which facilitate the agglomerates' break-up, became a persistent need. So in this project, experimental and numerical simulations are conducted to study the liquid break up phenomena to determine the best solution for the SRM nozzle erosion problem.

APPROACH

Experimental
- Run the experimental set-up and collect data using high speed camera (PHOTRON MINI UX50 with 2000 fps for 1.09 sec) for Three different air velocities 20, 30, 40 m/s and water flow rate of 0.019 m3/min.

Numerical
- Build, run three numerical model with the same experimental conditions using Star CCM+.

Data Analysis
- Experimental and numerical Images' processing using MATLAB.
- Data acquisition and analyzing.
- Compare between experimental and numerical results (Validation).

Numerical
- Build new models to study different liquid properties (three cases with 50 % reduction in the water surface tension) and different configuration (future).

Results
- Collect data and analyze them.
- Discuss the results and find the conclusion.

METHODOLOGY

Experimental set-up components and configuration

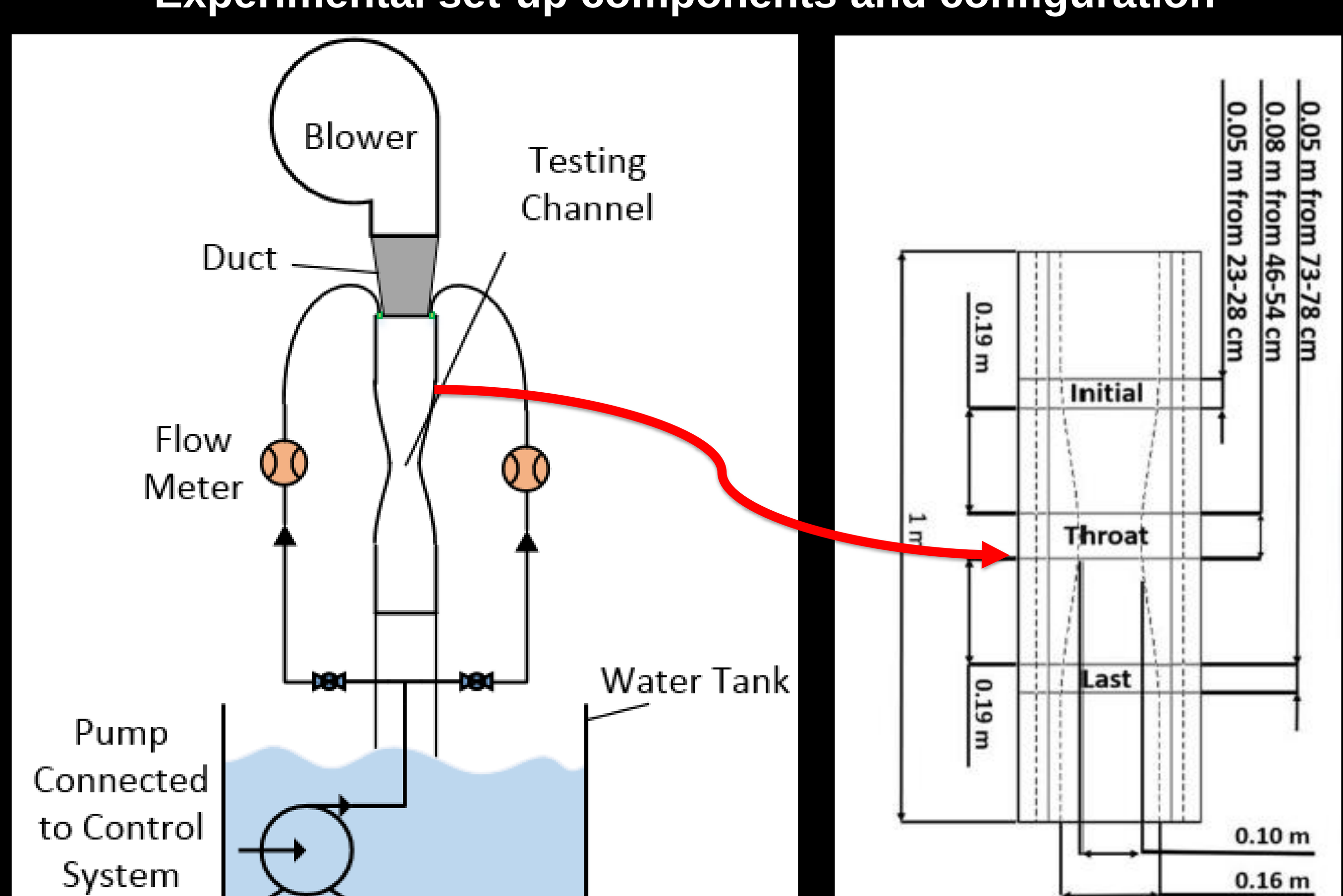

Figure 1: Experimental Setup Schematic

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IMAGE PROCESSING

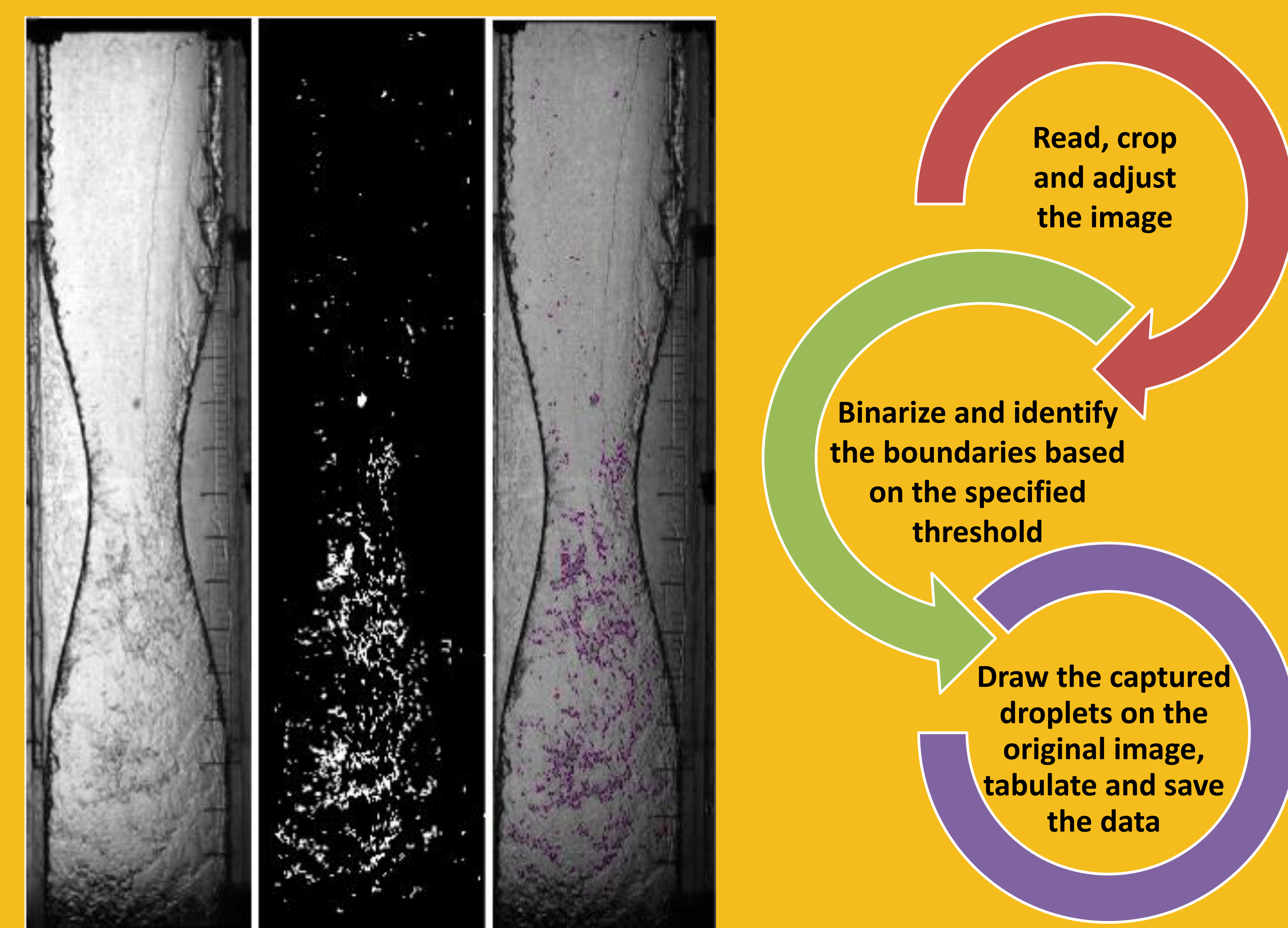

Figure 2: Image processing sample results

RESULTS

Figure 3 provides visual images of the break-up shape pattern at an air velocity of 30 m/s; experimentally, numerically for normal water surface tension (NWST), and numerically for 50% reduced water surface tension (RWST) which indicate a good agreement between the experimental and the numerical results.

Two different analysis schemes were used, the first one is comparing the droplet's average diameter, number and volume per frame with the different air velocities for the total volume of the C-D nozzle (frame), while the other one is comparing the same parameters but for different sections (initial, throat and last) inside the C-D nozzle.

Using the first approach, it is found that increasing the air velocity causes a higher number of separated droplets. On the other hand, the average diameter of droplets decreases. . A plausible reason is when the air velocity increases, the liquid body's surface is speeding up, causing more break-up of major separated liquid bodies—these liquid bodies break-up into smaller droplets with high air velocities as shown in figure 4.

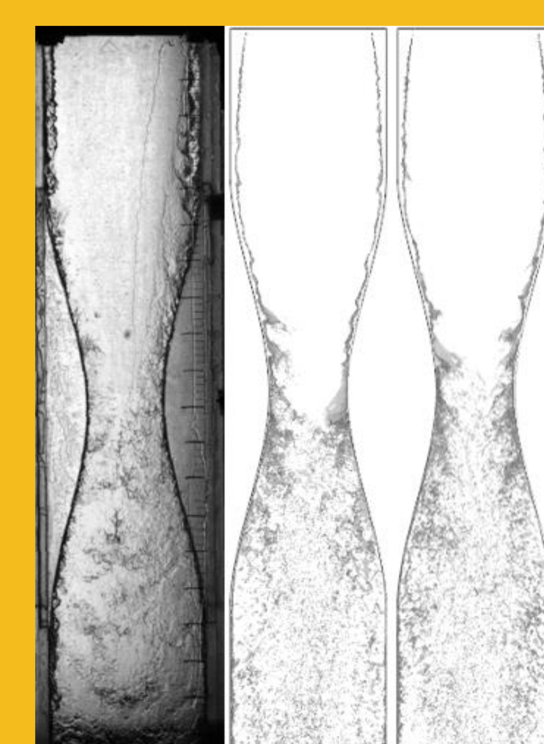

Figure 3: The breakup shape pattern at air velocity of 30 m/s

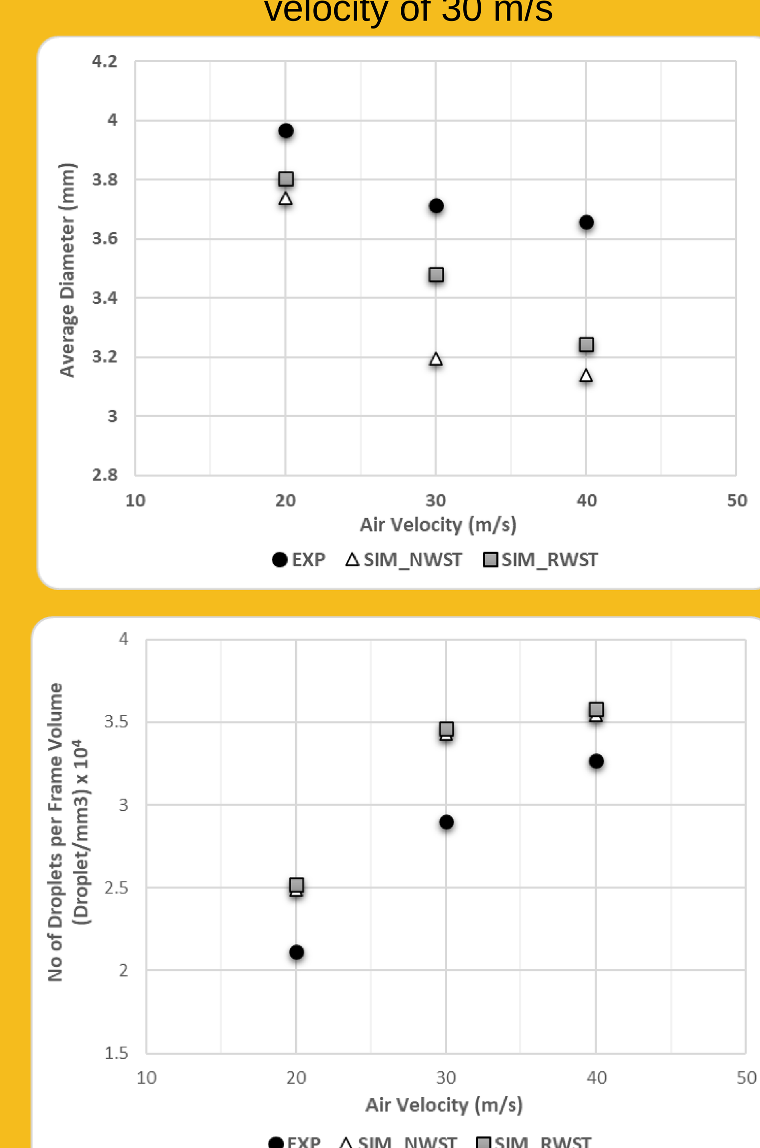

Figure 4: Droplets characteristics at different air velocities for the total volume of the C-D nozzle

The error, between the experimental and numerical results, in the average diameters and the droplets' numbers through the different C-D nozzle sections, is from 6% to 18%. Accordingly, this numerical model is used in further cases to study the effect of reducing water surface tension on the break-up process.

Comparing the NWST and RWST cases, It can be observed from the break-up shape patterns in figure 3 that the RWST cases have higher droplet volume distribution per the C-D nozzle volume. The post-processed data from the algorithms obtained the same results as shown in figures 5 & 6.

Decreasing the surface tension means reducing the cohesive forces between water surface molecules, facilitating the break-up process. The increase in the average diameter ranges from 0.5% to 17% and from 4 to 100% for the droplets' number for each section volume.

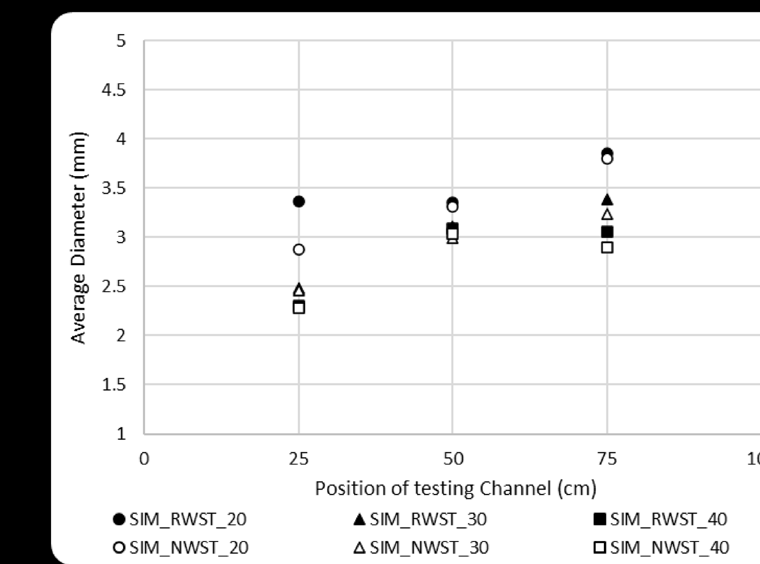

Figure 5: Average droplet diameter at different sections of the testing channel, different air velocities and different water surface tension

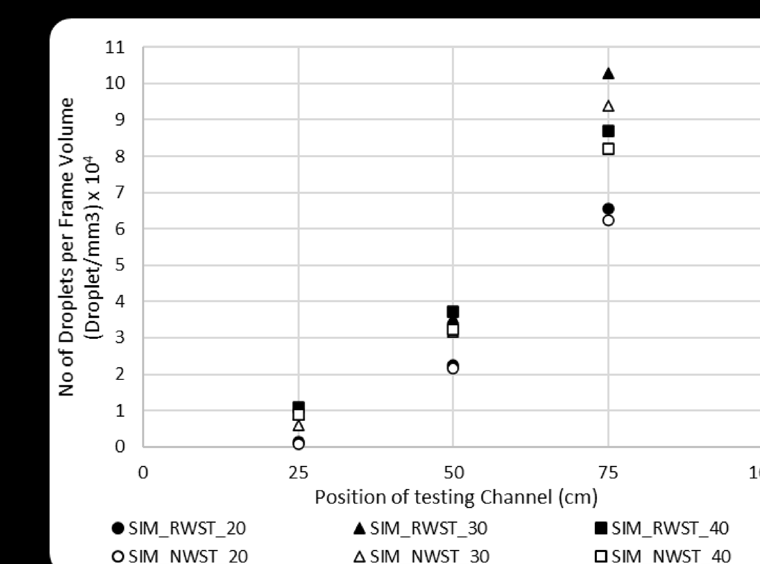

Figure 6: Number of droplets at different sections of the testing channel, different air velocities and different water surface tension

CONCLUSION

- The numerical model results showed an acceptable agreement with available experimental data (6-18% difference in results) to be reliable in predicting the break-up phenomena.
- Decreasing the water surface tension does not affect the general behavior (trend) of the break-up process through the nozzle's different sections. However, it weakens the cohesive forces between water surface molecules, which facilitates the separation of voluminous water bodies from the interface surface. So larger droplets' average diameter (0.5% to 17% increase) and higher droplets' number (4 to 100% increase) occurs in the RWST case.

In conclusion, reducing the aluminum alloy surface tension by adding strontium and magnesium can be very effective in enhancing the break-up process, which will facilitate the droplets' entrainment by the exhaust gases momentum; thus, avoid impinging the nozzle walls and of course reducing the erosion.

FUTURE WORK

- Complete the different air flow acceleration cases to study its effect on the erosion process
- Complete the new experimental submerged nozzle set-up and examine the effect of the cavity behind the nozzle wall on the break-up process.
- Conduct a numerical study for the effect of supersonic air flow on the break-up process and use the lagrangian approach to determine the agglomerates trajectory and the possibilities of either its break-up or coalescing.

REFERENCES

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