"Optimization of Mixing Efficiency in Low Reynolds Unlike Doublet Injectors by Incorporating Swirl"

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Background & Significance

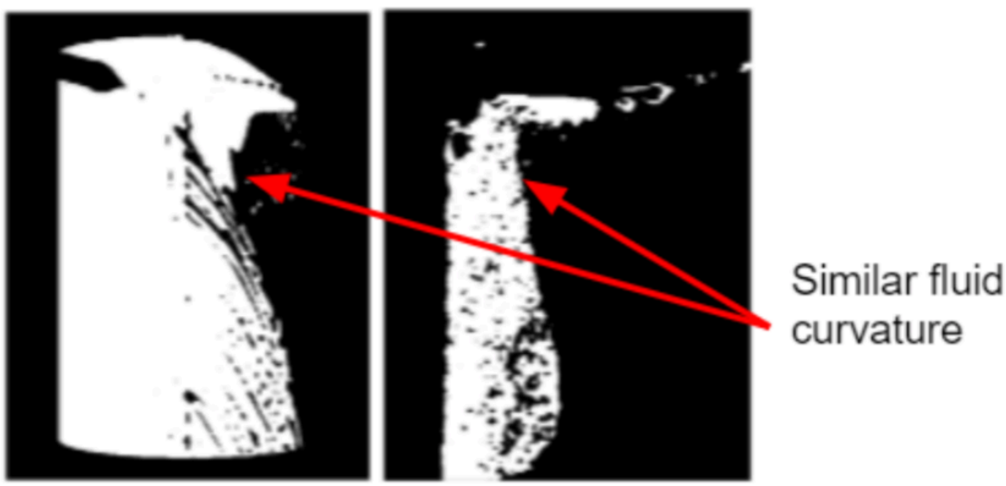
As cube satellites become a larger and larger market, emphasis on the propulsion system of the cube satellite becomes more and more important. One of the largest issues concerning industrial cube satellite manufacturing is the development of propulsion systems at extremely small scales. More specifically, liquid propulsion management. Bipropellant cube satellite propulsion systems face challenges associated with the mixing of two fluids which operate in low Reynolds number environments. Low Reynolds, or laminar, fluid flow is unique to cube satellite injection systems because of their unprecedented small scale. In large scale injector systems turbulent flow is unavoidable and helps aide the mixing of the fluids. With the absence of this implicit benefit, exterior solutions must be sought for laminar mixing. NASA benefits from this study because the advancement of cube satellite technology is in their vested interest per the NASA roadmap.

Project Goals

This work is intended to both test the validity of a proposed cube satellite injection system, and to test the accuracy of numerical method approaches to solving the problem of laminar flow mixing in such devices. The proposed injector is an unlike doublet impinging system operating in laminar conditions and incorporating swirl methods to encourage mixing. Several geometries are examined each with different angles of propellant injection to the combustion chamber. The numerical approaches are characterized by use of the VOF model. Numerical cases are first compared directly to experimental cases via image comparison. This is used as a means of proving the validity of the numerical methods as a means of examining fluid mixing in a laminar environment specific to the thruster scale. The numerical methods are then used to conduct a parametric sweep examining fluid interface size of different combustion injection geometries.

Summary of Key Findings

Results from the numerical study are compared directly to those of the experimental study to test the accuracy of the numerical study. Dyed liquid is used in image collection of the experimental case, where phase contours can be generated for the numerical. The numerical results are then used to quantify the fluid contact region, which is understood to directly correlate with higher quality bipropellant combustion. Qualitative results indicate reasonable similarity in a steady state numerical case, but differences in the transient case. This is likely the result of irregular hydrophilic behavior between polymer surfaces and liquid water present in the experimental case but not the numerical. The difference between experimental and numerical is quantified with hand calculations related to water's adhesion to a polymer surface, which has a similar order of magnitude with the results seen. The numerical methods are thus understood to hold similarity to the experimentation, and subsequently the ability to track correlation between geometries, but with the understanding that results will be of lower momentum in the experimental case. Furthermore, these differences are expected to be mitigated in the practical application, where a metal and non-adhesive bipropellants are the working materials. The ideal combustion chamber design generates axial momentum by increasing the injection angle, which in turn decreases thermal loading at the injection site. The parametric sweep indicates that fluid mixing is maximized when fluid injection angles are between 0 and 20 degrees in a gravity influenced environment. It is therefore concluded that in a gravity influenced environment, the ideal injection angle is between 10 and 15 degrees. The numerical approaches may be applied to other geometries where gravity is not an influence. Above a propellant injection angle of 30 degrees, fluid contact is lost entirely.



An annotated comparison between the numerical (left) and experimental (right) cases where similarity is visible. A mask function has been utilized on the image to reduce both the phase indicating color in the numerical case and the dyed liquid in the experimental case to a white hue. The injection angle is 15 degrees. A lower momentum flow is thought to be the cause of the different placement of the fluid leading edge.