Plume Impingement Software Module for Real-Time Proximity Operations

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Successfully executing proximity operations in space, such as docking or in-orbit servicing, requires sophisticated spacecraft design that accounts for induced environments. As a chaser vehicle's attitude control thrusters fire, they create rarefied plumes that can impact the target vehicle, with the potential to overload components, exceed thermal limits, and spin the target vehicle out of control. High-fidelity simulations of the thruster plume impingement environment require the direct simulation Monte Carlo (DSMC) method, but DSMC is too computationally expensive to simulate proximity operations that involve thousands of thruster firings. For this analysis to be tractable, engineering models of the plume flowfield and impingement events are used to simulate these trajectories [1]. Currently, on-orbit plume impingement environments are modeled through an inefficient open-loop analysis cycle where the vehicle's flight controller and plume impingement teams iterate on the trajectories until they pass the target vehicle's plume requirements.

As complex on-orbit missions evolve and become more frequent, lengthy design cycles will become operational bottlenecks. To address this gap, this work develops an advanced plume impingement module capable of operating at real-time scale that can be integrated with existing mission planning tools and onboard flight systems. The plume module leverages state-of-the-art plume simulation techniques [2] to deliver fast, physics-based impingement predictions in a software architecture that can be tailored to diverse proximity operations scenarios. A prototype of this plume impingement module is built to demonstrate the feasibility of real-time performance. This prototype completes plume impingement calculations in microseconds per target geometry mesh point. The software serves as a foundational capability for plume-aware trajectory design, operational risk assessment, and future autonomous decision-making systems.

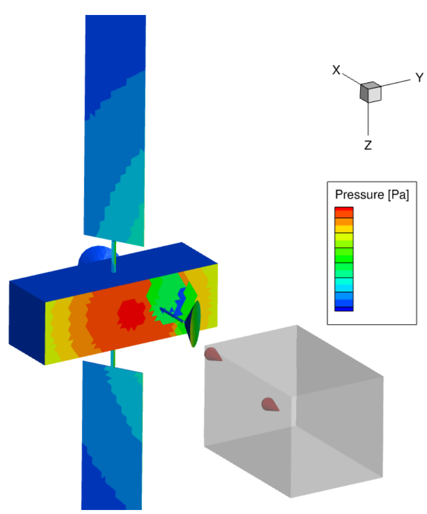

Fig. 1. Plume Impingement Pressure for a Demo Dual-Jet Firing.

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REFERENCES

[1] K. J. Higdon, F. E. Lumpkin, "On-Orbit Plume Impingement Overview," NASA NTRS 20240013965, 2025.
[2] G. A. Simons, "Effect of nozzle boundary layers on rocket exhaust plumes." *AIAA Journal*, Vol. 10, No. 11, 1972.