

From Molecular Beam Studies to Aerodynamics: Development of a Gas-Surface Scattering Model for LEO/VLEO

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Abstract

Spacecraft end-of-life mitigation strategies are increasingly important to tackle the space debris problem. Among these, drag-driven de-orbiting solutions such as deployable drag sails rely on increasing aerodynamic drag to accelerate orbital decay. Alternatively, operating satellites in very low Earth orbit (VLEO) offer a passive de-orbiting approach, where the denser atmosphere rapidly leads unpowered spacecraft to re-entry at end of life. However, the dense atmosphere produces significant drag during normal satellite operations, requiring novel surface materials/coatings which promote gas-surface scattering consistent with low platform drag. In both drag sail de-orbiting and VLEO operations, predicting spacecraft orbital decay requires accurate aerodynamic models.

In these rarefied environments, aerodynamic coefficients can be calculated using direct simulation Monte Carlo or similar numerical methods. The aerodynamic coefficients calculated with these methods fundamentally depend on the gas-surface scattering models used to describe the scattering dynamics of atmospheric particles impinging on the spacecraft. However, commonly used gas-surface scattering models are not sufficiently detailed to capture material-specific surface properties, leading to uncertainties in the calculation of aerodynamic coefficients.

This presentation provides an overview of a new gas-surface scattering model, detailing how it can be parametrized using molecular beam experiments, and subsequently used to estimate aerodynamic coefficients. The gas-surface scattering model uses a stochastic representation of the surface and includes surface corrugation as an input parameter. The model parameters are fitted using molecular beam-surface scattering experiments, which measured the scattering dynamics of hyperthermal atomic beams of argon and oxygen on satellite surfaces with different roughnesses. We observe that the fitted roughness parameters correlated positively with the surfaces topographical parameters measured by atomic force microscopy. While the fitted corrugation parameters are not identical to the AFM-measured roughness, the positive correlation between them supports the model's physical basis. These scattering measurements are then linked to macroscopic aerodynamic forces: the surface-specific fitted parameters are used in the gas-surface scattering model to estimate the aerodynamic coefficients of flat plates, coated with the tested surfaces, at different angles of attack. The resulting values illustrate how different materials and surface morphologies alter aerodynamic behavior under orbital conditions.