

Modeling Spacecraft Demise Using the KATS Multi-Physics Framework

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Abstract

Accurate prediction of spacecraft demise during atmospheric re-entry requires tightly coupled modeling of aerothermal loading, material response, and structural failure. This work presents the capability of the Kentucky Aerothermal and Thermal-response Solver framework (KATS) to address this challenge through an integrated, multi-physics approach. The methodology combines KATS-FD for flowfield reconstruction, KATS-MR for detailed material response, and KATS-SM for structural mechanics, enabling a unified simulation of degradation and breakup processes under hypersonic conditions.

KATS-FD provides the external aerothermal environment, capturing high-enthalpy flow effects and surface heat flux distributions along the trajectory. These loads are directly coupled to KATS-MR, which resolves in-depth material behavior including pyrolysis, oxidation, and ablation for a range of thermal protection and structural materials. The resulting thermochemical state and recession rates are then passed to KATS-SM, a structural module that incorporates a crack formation and propagation algorithm to model progressive weakening and fragmentation of the structure.

A key feature of the framework is its ability to predict the onset and evolution of structural failure as a function of both thermal degradation and mechanical loading. The crack formation model in KATS-SM enables simulation of fracture initiation driven by thermal gradients, internal pressure, and material property evolution, providing a physics-based pathway from intact structure to fragment generation. This approach allows for more realistic prediction of breakup altitude, fragment size distribution, and release conditions compared to traditional uncoupled or empirically driven methods.

The integrated KATS framework therefore offers a powerful tool for design-for-demise studies, enabling improved assessment of spacecraft survivability and debris risk. By bridging flow physics, material response, and structural failure within a single modeling environment, the approach supports the development of more reliable predictive capabilities for controlled and uncontrolled re-entry scenarios.