1st Conference on Space Science and Technology in Serbia, May 12-15, 2026, Niš, Serbia
Book of Abstracts, Eds L. Č. Popović and M. Stojanović
Astronomical Observatory, Belgrade, Special Issues No. 4

https://doi.org/10.69646/1csst26

DROPCOAL: ENGINEERING DESIGN AND ADAPTATION FOR ISS AND NYX MICROGRAVITY OPERATIONS

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ABSTRACT

This paper presents the engineering development, qualification, and deployment of DropCoal, a compact microgravity payload designed to generate, control, and image millimetre-scale droplet coalescence in space. Developed by Romanian InSpace Engineering (RISE) under an ESA contract, the DropCoal systems were conceived to enable an international scientific team to advance fundamental fluid-dynamics research in microgravity. The payload integrates a sealed dual-containment fluidic architecture, precision droplet-generation mechanisms, and a high-speed telecentric imaging chain within a 4U (ISS) or 6U (Nyx) mechanical envelope. Using coaxial needles actuated by piezoelectric linear motors, DropCoal autonomously forms droplets between 2 and 5 mm, controls approach velocities from 0.01 to 10 mm/s, and records coalescence and mixing at up to 8000 fps with a spatial resolution of ≈15 μm/pixel. Microgravity provides two major experimental advantages: droplets remain nearly perfectly spherical, and convective flows are suppressed, enabling clearer observation of capillary-driven dynamics and simplifying the interpretation of bridge formation and mixing.

A key engineering distinction lies in the platform-specific safety and mechanical environments. DropCoal-ISS was designed as a human-rated

payload, requiring strict compliance with ESA and NASA safety standards, including toxicity limits, double containment, chemical compatibility, and fault-tolerant electrical design. Engineered for long-duration operation inside the ICE Cubes Facility, the ISS model was ultimately launched as a soft stowage item aboard a SpaceX Dragon mission. This launch mode reduced mechanical loads compared to hard-mounted payloads, easing constraints on packaging and structural reinforcement while maintaining full compliance with crew-safety requirements.

In contrast, DropCoal-Nyx was developed for The Exploration Company's first Nyx capsule flight, where the payload was hard-mounted to the capsule structure and exposed to significantly higher mechanical loads during ascent and re-entry. This required a redesigned 6U enclosure, a simplified two-line fluidic system (methylene-blue water and 50% ethanol), low-volume FEP reservoirs, and a new 28 V electrical interface via a single DB15 connector. Despite these adaptations, both versions share common subsystems, piezoelectric linear motors, telecentric optics, high-speed camera, and containment strategy, ensuring subsystem reuse and cross-platform consistency.

Both payloads successfully completed full qualification campaigns, including vibration, thermal-vacuum, EMC, and chemical-compatibility testing. DropCoal-ISS demonstrated stable droplet generation and controlled coalescence during commissioning and operational phases on the International Space Station. DropCoal-Nyx was launched on a SpaceX Dragon rideshare mission and was expected to validate its adapted architecture during short-duration microgravity; however, the Nyx capsule failed during re-entry, preventing recovery of the scientific data.

Together, the two systems demonstrate a modular, space-qualified engineering solution for precision fluid-dynamics experimentation across both crewed and uncrewed microgravity platforms.