The CAESAR New Frontiers Mission: Comet Surface Sample Acquisition and Preservation

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1. Introduction

NASA recently selected the Comet Astrobiology Exploration Sample Return (CAESAR) mission for Phase A study in the New Frontiers Program. This mission will acquire and return to Earth for laboratory analysis at least 80 g of surface material from the nucleus of comet 67P/Churyumov-Gerasimenko (hereafter 67P). CAESAR will characterize the surface region sampled, preserve the sample in a pristine state, and return evolved volatiles by capturing them in a separate gas reservoir. The system protects both volatile and non-volatile components from contamination or alteration that would hamper their scientific analysis [1]. Laboratory analyses of comet samples provide unparalleled knowledge about the presolar history through the initial stages of planet formation to the origin of life.

2. Sample Acquisition and Sample Containment Systems

The Sample Acquisition System (SAS) developed by Honeybee Robotics has been explicitly designed to collect a sample of the smooth terrain on comet 67P, as observed by the Rosetta mission. The SAS is mounted on a robotic arm and contacts the comet surface during a brief touch-and-go maneuver. A pneumatic system attached to the robotic arm provides high-purity nitrogen gas to a series of pneumatic nozzles within the SAS sampling cone. During contact with the surface, the nitrogen gas jets act to funnel cometary particles and ices through flexible Kapton flaps into a centralized 1.5 L sample container. We demonstrated the performance of the SAS in both vacuum and zero gravity at the NASA Glenn Zero Gravity Research Facility, routinely collecting over 300 g of autoclaved aerated concrete "Aircrete" which has a density similar to the bulk density of comet 67P [2].

Direct imaging of the sample container interior verifies sample acquisition, and a load cell on the end of the forearm measures the mass of the collected sample via artificial gravity. After sample verification is complete, the SAS sample cone jettisons (Fig. 1), exposing the cold sample container, which is then inserted into the Sample Containment System (SCS) mounted inside the Sample Return Capsule (SRC) and decoupled from the robotic arm. The SCS lid is closed and sealed with a knife-edge and copper ring that has been shown via test to substantially exceed leak rate requirements after sealing under a range of cold and dirty conditions. The SCS interfaces directly to the Gas Containment System (GCS), a gas reservoir for volatiles separation and isolation.

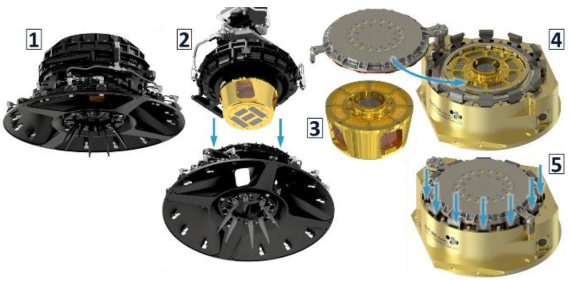

Figure 1: SAS (1), Jettison Sample Cone (2), Gold-Plated Sample Container (3), SCS Open (4), SCS Preloaded and Sealed (5).

3. Gas Containment System

Comet solids must be kept cold and dry to avoid aqueous-solid and gas-solid reactions. Even brief exposure to liquid water or brines would confound attempts to determine if aqueous activity ever occurred on 67P. CAESAR preserves much of the science of a cryogenic sample return by retaining volatiles in a dedicated reservoir securely separated from the solid sample. After sealing, the SCS slowly warms the collected material from the cold temperatures of the collection to 67P surface temperatures experienced near perihelion. As gases evolve from the sample, they are passively cryo-pumped into a separate radiator-cooled GCS gas reservoir developed by the NASA Goddard Space Flight Center (Fig. 2). Once H_2O ice transfer from the SCS to the GCS is complete, the GCS is sealed to capture the volatiles it contains, and the SCS is vented to space to maintain the solid sample under vacuum. The SCS vent is closed before Earth entry to prevent atmospheric contamination of the sample. The system records sample temperature and pressure from sealing at the comet until opening on Earth. The interiors of the SCS, GCS, and associated plumbing are coated with an inert material to minimize surface reactivity and catalysis.

Brassboard H_2O ice transfer experiments conducted inside a thermal vacuum chamber have shown that >99.99% of sublimated H_2O can be captured inside a GCS cooled to less than -60°C while maintaining water pressure well below its triple point (4.58 Torr), preventing liquid formation. Other known comet species such as CH_3OH and H_2CO have similar volatilities to water and should also condense as ice in the GCS. More volatile species (*e.g.*, noble gases, CO_2, CO, O_2, HCN, NH_3, CH_4) will not solidify in the SCS or GCS. The GCS gas reservoir is sized to maximize its volume (5 L) relative to the SCS headspace (~1 L), to trap the largest possible fraction (83%) of the non-condensable species. Preflight calibration of the SCS-to-GCS volume ratio enables recovery of the original portion of gas abundances.

The SCS temperature during gas transfer is controlled to enable H_2O ice sublimation from the sample and prevent aqueous alteration of the most reactive amorphous silicate minerals (based on measured amorphous Mg-silicate powder gas-solid hydration rates [3], a sample temperature of -30°C requires completion of H_2O transfer in ≤ 100 days. We are currently conducting a series of gas transfer experiments using a SCS-GCS breadboard at NASA Goddard to determine the optimal gas transfer conditions and to establish the conditions under which comet analog materials will not alter during exposure to water vapor. During the transfer experiments, the partial pressure of H_2O and CO_2 vapor is measured directly in a gas cell between the SCS and GCS using two redundant thermopile detectors with 2.7 µm and 6.5 µm H_2O and 4.2 µm CO_2 spectral band absorption filters, each paired with IR sources. Laboratory breadboard experiments have shown that the gas sensor can measure water pressure down to ≤ 10 mTorr, the expected vapor pressure of water when gas transfer to the GCS is complete.

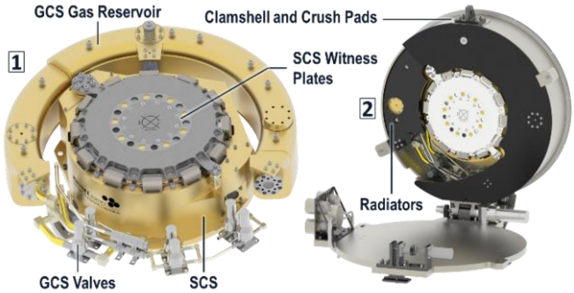

Figure 2: SCS and GCS (1), SCS and GCS mounted in a clamshell mechanism (2).

4. Sample Return Capsule

The Japanese Aerospace Exploration Agency (JAXA) provides the CAESAR SRC. Its design is based on the SRC flown on the Hayabusa and Hayabusa2 missions [4]. Before Earth re-entry, the GCS lid shuts, and the SRC closes by driving the backshell/payload into the front heatshield with a linear actuator. The spacecraft, built by Orbital ATK, releases the SRC using a spin-separation mechanism. The SRC uses a two-stage subsonic parachute system and drops its heat shield during parachute descent, greatly simplifying thermal control of the comet sample. The SRC lands at the Utah Test and Training (UTTR) range and the recovery team expeditiously places it into cold storage. The system maintains the SCS and GCS below 0°C throughout entry, descent, landing, and recovery. Phase change material sealed in aluminum housings mounted on the GCS ensures that no melting of H_2O ice will occur even if SRC recovery is delayed for several hours.

References

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