CAPTEM FINDINGS WITH ARCM EVA RESPONSE

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Asteroid Retrieval Mission EVA sample-collection operations study

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CAPTEM Findings: Situational Awareness

- CAPTEM Finding 1: **Assessment of textural and mineralogical heterogeneity of the sampled body will be critically important for site and sample selection.** If such an assessment will not already have been done as part of the robotic retrieval or in an earlier rendezvous mission, it will be required prior to EVAs. **A spacecraft-mounted high-resolution camera and a spacecraft-mounted spectrometer spanning near-IR to UV will be required.**

- CAPTEM Finding 2: **As with the Apollo missions, active participation of a ground-based Science Team is critically important.** This team would interact with the EVA team in sample selection and drilling target sites to ensure maximum scientific return.

- CAPTEM Finding 3: **Hand-held high-resolution cameras and supporting analytical instruments will be valuable for sample selection during EVAs.** Cameras will be vitally important for photo-documentation of the sampling site, before and after collection, and for photo-documentation of the samples in their containers. Hand-held instruments (e.g., X-ray Fluorescence spectrometers) that can assess bulk composition and mineralogy, and document compositional heterogeneity, could be valuable in the selection of specific samples during EVAs.

ARCM Response: Situational Awareness

- First three findings sum to situational awareness for science planning, EVA and sample capture.
- Capture mechanism assessment:
  - Communication with ground unaffected by capture mechanism
  - Reference mission
    - Imaging of asteroid post-capture is very limited
    - Bag could modify the state and position of selected asteroid sampling sites
    - During EVA, situational awareness of sample capture is limited by bag openings.
    - Refinement of sample selection during the EVA will be very limited because bag openings will be small and overhead of abandoning first area in favor of selecting a new one will be prohibitive
  - Alternative mission
    - Asteroid can be imaged post-capture to record any modification of selected sampling site
    - Capture arm may partially cover selected site thereby limiting situational awareness, and prompting alternative sampling site
    - Provides significant contextual information about sample origin

CAPTEM Finding: Contamination Control

- CAPTEM Finding 4: **Contamination Control is vitally important.** There are several aspects of contamination control. Because in practice it is impossible to eliminate contamination entirely, it is important to use materials for tools and containers that are readily recognized in the laboratory after recovery by, for example, deliberately introducing cosmochemically rare elements at minor to trace levels. It is also important to use witness materials to serve as blanks, and to develop and curate a complete list of materials to which the asteroidal samples might be exposed. Storage containers should be sealable in space. The sample containers should be purged with high purity nitrogen if a vacuum-tight seal cannot be ensured. We highly recommend the Catalog of Apollo Lunar Surface Geological Sampling Tools and Containers (JSC-23454, LESC-26676, attached) compiled by Judy Allton as a reference. Finally, the sampling sites should not be disturbed by or contaminated by spacecraft operations (e.g.., maneuvering engine plumes).

ARCM Response: Contamination Control

- Contamination control is a similar challenge for both capture mechanisms; similar mitigations would be used for either.

- Sample purity may be compromised by such activities as capture bag contact

- Greater potential for dust contamination from the reference mission design due to bag contact and opening
  - *Reference mission asteroid type may have less cohesion, thus allowing break-up inside bag. Bag may impart localized stress concentration during de-spin.*
  - *Alternate mission must be more cohesive boulder by definition. Free dust can be liberated during transit to DRO.*

CAPTEM Findings: Sample Capture

- CAPTEM Finding 5: **We recommend the collection of at least 1000 g of material from two sites that sample the apparent diversity of the body.** The selection of photodocumented materials should be made in real time in consultation with the ground-based Science Team. The samples should be stored in containers with dividers to separate the samples from each other. Samples that are analyzed in situ should be stored separately from pristine samples collected from the same location, if possible. We recommend the use of storage containers with at least 1000 cm3 capacity, with 5000 cm3 containers desirable.

- CAPTEM Finding 6: **We recommend the collection of at least one 5-cm diameter core sample of regolith from each of the two sites.** These cores should be at least 4 cm in depth, but 100 cm depth is desirable. The coring method and the core storage containers should maintain the integrity of the stratigraphy. The Apollo Lunar Tool and Container Catalog gives detailed descriptions of core sampling tools that may be suitable with some modification.

- CAPTEM Finding 7: **Preservation of volatiles is desirable, particularly if the sampled asteroid is of type C, P, or D.** We recommend that the storage containers include an integrated valve so that outgassed volatiles can be sampled without breaking the integrity of the main seals. Such containers were used during Apollo, and are described in the Apollo 2 Lunar Tool and Container Catalog. We also recommend that the core samples be returned in refrigerated (< -20C) storage.

ARCM Response: Sample Capture

- Early crewed mission planning is bookkeeping 100 kg for sample return in Orion
- No technical showstoppers for ambient sample capture, core drilling, and stowage of samples
  - Alternate mission may have capability to use robotic manipulators to acquire core drill samples
- Orion vehicle cannot support environmentally controlled sample return on first crewed mission

CAPTEM Findings: Other Science

- CAPTEM Finding 8: **A measurement of the porosity and internal structure of the body, while not of highest priority, is desirable.** This would require the placement of geophones at several locations on the body, and the use of an instrumented hammer during the EVAs to provide an acoustic signal. We have identified an existing, certified, Al-faced, low outgassing, EVA-, ISS-rated hammer that may be suitable.

- CAPTEM Finding 9: **If there is a possibility of deformation of the body during either phase of the mission, placement of appropriate surveying tools (e.g.., retroreflectors) on the surface could enable accurate assessment of deformation of the body.**

- CAPTEM Finding 10: **Optical albedo measurements and measurements of the Yarkovsky effect are not of high priority.** Consultation with outside experts led to the conclusion that a study of the Yarkovsky effect using a combination of albedo measurements and a permanently-deployed retroreflector were unlikely to be scientifically compelling for the specific target asteroids currently being considered for this mission, because earlier missions, such as OSIRIS-Rex and Hayabusa 2, will already have made the appropriate measurements.

ARCM Response: Other Science

- These findings sum to <u>multi-site surveying and tool placement</u> during EVA.

- ARCM Ops Con timeline will need to be analyzed for effect of multi-site surveying; placement of sensors at multiple remote worksites will come with significant overhead

- Reference mission:
  - Creating multiple bag openings and precisely measuring the placed tool would be a challenge

EVA RFIs

- EVA RFIs were used in the consideration between the reference and alternative capture mechanisms

- At this time, the RFI responses do not add a distinguishing factor between the capture mechanisms
  - The EVA tool and translation RFI responses can be used on either capture mechanism

Backup

Finding 1: Textural and mineralogical heterogeneity

- CAPTEM Finding 1: Assessment of textural and mineralogical heterogeneity of the sampled body will be critically important for site and sample selection. If such an assessment will not already have been done as part of the robotic retrieval or in an earlier rendezvous mission, it will be required prior to EVAs. A spacecraft-mounted high-resolution camera and a spacecraft-mounted spectrometer spanning near-IR to UV will be required.
- EVA comments:
  - Tools:
    - The Finding recommends space-craft mounted instruments which will ease EVA Crew workloads and shift costs from EVA Tools to Spacecraft (may or may not be a savings). If mission requirements change, there are known feasible technical solutions (hand-held spectrometers, IR and UV cameras) for EVA Tools that could be used for individual worksites and samples. Note that these tools when used by EVA are likely inadequate to survey the entire body due to limited timeline/mobility of EVA Crew.
  - Ops cons / timelines:
    - N/A. Assume spacecraft will have appropriate cameras to acquire this imagery prior to asteroid capture.

Finding 2: Active participation of a ground-based Science Team

- CAPTEM Finding 2: As with the Apollo missions, active participation of a ground-based Science Team is critically important. This team would interact with the EVA team in sample selection and drilling target sites to ensure maximum scientific return.
- EVA comments
  - Tools:
    - The EVA Tools development team will utilize Science Team inputs to define Sample Tools requirements and evaluate design concepts and solutions for sampling hardware.
    - Science Team and Principle Investigator (PI) inputs should be readily available during flight/EVA and will aid in ensuring the context of the samples taken as well as the manner in which they are obtained and in-flight curated is accurately understood and recorded.
  - Ops cons / timelines:
    - Sampling sites should be identified and selected based on ARV imagery during capture to allow ARCM crew opportunity to train accordingly.
    - Real-time coordination during the first ARCM mission with two 4-hr EVAs will be difficult. The short EVA duration drives a highly pre-planned EVA timeline. Best opportunity for EVA timeline modification is between EVA1&2, already planned into the ops con.

Finding 3: High-resolution cameras and analytical instruments

- CAPTEM Finding 3: Hand-held high-resolution cameras and supporting analytical instruments will be valuable for sample selection during EVAs. Cameras will be vitally important for photo-documentation of the sampling site, before and after collection, and for photo-documentation of the samples in their containers. Hand-held instruments (e.g., X-ray Fluorescence spectrometers) that can assess bulk composition and mineralogy, and document compositional heterogeneity, could be valuable in the selection of specific samples during EVAs.
- EVA comments:
  - Tools
    - There are known feasible technical solutions (hand-held spectrometers, IR and UV cameras) for EVA Tools that could be used for individual worksites and samples, no technical show-stopper for Tools Development in this Finding.
    - Will likely want to limit handheld imagers and use helmet cameras, but intent is same.
  - Ops cons / timelines
    - Assume spacecraft will have appropriate cameras to acquire this imagery prior to asteroid capture.
    - EVA imagery is already planned into the ops con.
    - For JPL capture bag concept, refinement of sample selection during the EVA will be very limited because bag openings will be small and overhead of abandoning first area in favor of selecting a new one will be prohibitive.

Finding 4: Contamination Control

- CAPTEM Finding 4: Contamination Control is vitally important. There are several aspects of contamination control. Because in practice it is impossible to eliminate contamination entirely, it is important to use materials for tools and containers that are readily recognized in the laboratory after recovery by, for example, deliberately introducing cosmochemically rare elements at minor to trace levels. It is also important to use witness materials to serve as blanks, and to develop and curate a complete list of materials to which the asteroidal samples might be exposed. Storage containers should be sealable in space. The sample containers should be purged with high purity nitrogen if a vacuum-tight seal cannot be ensured. We highly recommend the Catalog of Apollo Lunar Surface Geological Sampling Tools and Containers (JSC-23454, LESC-26676, attached) compiled by Judy Allton as a reference. Finally, the sampling sites should not be disturbed by or contaminated by spacecraft operations (e.g.., maneuvering engine plumes)..
- EVA comments
  - Tools
    - Concur with the Finding: Lessons Learned from the Apollo Program indicate EVA Tools development should utilize a "Contamination Control Board" that includes representatives from the Science Team and the Tools Engineering team. The Board will define, manage and implement an agreed-upon process for Materials & Process selection, witness material curation techniques, and other matters in the end-to-end string of hardware that will contact the samples.
    - Beyond the Contamination Control Board, the EVA Tools development team will utilize Science Team inputs to define Sample Tools requirements and evaluate design concepts and solutions for sampling hardware. This is expected to include consideration of both in-flight EVA Crew operability as well as design features for ground-based curation & experimentation upon sample return.
  - Ops cons / timelines
    - Dust mitigation protocols will be needed such as glove swap, etc. between sites
    - Sample purity may be compromised by such activities as capture bag contact, ion beam deflection.
    - Storage containers that are sealable in space are in ops con.

Finding 5: Collection of 1000 g from two sites

- CAPTEM Finding 5: We recommend the collection of at least 1000 g of material from two sites that sample the apparent diversity of the body. The selection of photodocumented materials should be made in real time in consultation with the ground-based Science Team. The samples should be stored in containers with dividers to separate the samples from each other. Samples that are analyzed in situ should be stored separately from pristine samples collected from the same location, if possible. We recommend the use of storage containers with at least 1000 cm3 capacity, with 5000 cm3 containers desirable.
- EVA comments
  - Tools:
    - The EVA Tools development team will utilize Science Team inputs to define Sample Tools requirements and evaluate design concepts and solutions for sampling hardware
    - The specific recommendations of this Finding do not appear to present any technical show-stoppers from a Tools Design perspective but must be validated with spacecraft mass and volume allocations for sample return.
    - Assuming stowage mass/volume allows: Tools team to design sample containers with dividers and sized with 1000-5000 cm^3 capacity. See Tools response in Finding #3 for in situ sample analysis tools.
  - Ops cons / timelines
    - Sample collection is already accommodated in mission ops con; amount now provided.

Finding 6: Core Samples

- CAPTEM Finding 6: We recommend the collection of at least one 5-cm diameter core sample of regolith from each of the two sites. These cores should be at least 4 cm in depth, but 100 cm depth is desirable. The coring method and the core storage containers should maintain the integrity of the stratigraphy. The Apollo Lunar Tool and Container Catalog gives detailed descriptions of core sampling tools that may be suitable with some modification.
- EVA comments
  - Tools:
    - There is significant technical challenge for EVA Tools development in this Finding- the unknown nature of the specific body combined with the micro-gravity environment present a wide spectrum of possibilities for body consolidation and the corresponding power required to core drill.
    - Proven methods to "maintain stratigraphy" of core under vibration of drilling but no gravitation load are beyond experience base of terrestrial and lunar core drilling examples.
    - Ground reaction force and attachment/anchoring methods needed to obtain cores are in early development stages and present promising options. Note that the solutions are heavily dependent upon the nature of the capture vehicle- "Bag" vs. Hard Structure significantly changes solutions/options.
    - As expected, this challenge increases significantly with depth.
    - Recommend a concept development effort with demonstrations to reduce risk and increase science and engineering confidence.
  - Ops cons / timelines
    - Sample collection is already accommodated in mission ops con; details now provided.

Finding 7: Preservation of Volatiles

- CAPTEM Finding 7: Preservation of volatiles is desirable, particularly if the sampled asteroid is of type C, P, or D. We recommend that the storage containers include an integrated valve so that outgassed volatiles can be sampled without breaking the integrity of the main seals. Such containers were used during Apollo, and are described in the Apollo 2 Lunar Tool and Container Catalog. We also recommend that the core samples be returned in refrigerated (< -20C) storage.
- EVA comments
  - Tools
    - Known design solutions for EVA sealable containers that will maintain a high quality vacuum seal exist and are proven in spaceflight. Integrated sampling ports are also known and have been successfully used in spaceflight; no significant design challenges on these requirements.
    - Existing proven cold stowage equipment is currently flown on ISS for Science Samples, so cold stowage design solutions are known and proven in spaceflight.
    - Readily conceived of solutions for integrating sealed volatile containers for refrigerated storage exist; however the question of spacecraft mass/volume/power for consistent cold stowage of the sample from acquisition through ground return must be determined at spacecraft level.
  - Ops cons / timelines
    - Manage collected samples per system capabilities (e.g. if refrigerator is available, EVA will fill it up)
    - Does this drive EVA to perform EVA out of the sunlit area? Present ops con has vehicle move stack to allow sunlight on the area many hours before EVA. EVA performed entirely in sunlight for visualization and thermal management reasons
    - Cold storage is not included in ops con.
    - Additional steps may be necessary to preserve volatiles, adding complexity to timeline.

Finding 8: Porosity and Internal Structure

- CAPTEM Finding 8: A measurement of the porosity and internal structure of the body, while not of highest priority, is desirable. This would require the placement of geophones at several locations on the body, and the use of an instrumented hammer during the EVAs to provide an acoustic signal. We have identified an existing, certified, Al-faced, low outgassing, EVA-, ISS-rated hammer that may be suitable.
- EVA comments
  - Tools
    - Analysis must be conducted to verify current ISS-certified EVA tools are acceptable for use in the environment experienced during the proposed mission, though no technical show-stoppers are currently known.
    - Coordination between the EVA Tools and Science Team will be necessary to define/evaluate attachment solutions for all "Anchored Instruments", including the proposed geophones (determination of stiffness of attachment, depth of attachment feature, etc).
    - Designing for precision placement of multiple Anchored Instruments relative to each other will be challenging and should be avoided if possible (recommend documenting as-installed placement with photographs and backing out relevant measurements afterwards).
  - Ops cons / timelines:
    - Timeline will need to be analyzed for effect of acoustic study, but placement of sensors at multiple remote worksite will come with significant overhead, especially for JPL capture bag concept.

Finding 9: Survey tools

- CAPTEM Finding 9: If there is a possibility of deformation of the body during either phase of the mission, placement of appropriate surveying tools (e.g.., retroreflectors) on the surface could enable accurate assessment of deformation of the body.
- EVA comments
  - Tools
    - Coordination between the EVA Tools and Science Team will be necessary to define/evaluate attachment solutions for all "Anchored Instruments", including the proposed retroreflectors (determination of stiffness of attachment, depth of attachment feature, etc).
    - Designing for precision placement of multiple Anchored Instruments relative to each other will be challenging and should be avoided if possible (recommend documenting as-installed placement with photographs and backing out relevant measurements afterwards).
  - Ops cons / timelines
    - Timeline will need to be analyzed for effect of survey.

Finding 10: Optical albedo and Yarkovsky effect

- CAPTEM Finding 10: Optical albedo measurements and measurements of the Yarkovsky effect are not of high priority. Consultation with outside experts led to the conclusion that a study of the Yarkovsky effect using a combination of albedo measurements and a permanently-deployed retroreflector were unlikely to be scientifically compelling for the specific target asteroids currently being considered for this mission, because earlier missions, such as OSIRIS-Rex and Hayabusa 2, will already have made the appropriate measurements.
- EVA comments
  - Tools:
    - No impact; will not design for these tasks.
  - Ops cons / timelines
    - N/A