Science Tools/Instrumentation Payloads Description
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1.0 Introduction

Scientific tools and instruments have the potential to increase the science return from lunar surface missions. Our only experience of deploying advanced scientific equipment was the deployment of the Apollo Lunar Seismic Experiment Package (ALSEP) during the Apollo missions, but the astronauts did not have the ability to view data real-time or assimilate data into mission and traverse execution. This write-up summarizes broad-scale styles of scientific payload deployment and discusses operational considerations of each deployment style.

Definitions/Acronyms:
Tool – A tool is an implement used for collecting or storing scientific samples (i.e. hammer, scoop, etc.)
Instrument – An instrument is an implement capable of higher-resolution, in situ analytical measurements beyond sampling
EVA – Extravehicular Activity
MCC – Mission Control Center
ST – Science Team (supporting EVA from a science backroom in MCC)

2.0 Deployment Styles

- 2.1 Handheld Instrumentation – Instruments requiring direct interaction during data acquisition and handheld by an astronaut.
  - 2.1.1 Example: handheld cameras (visible, multispectral, etc.)
  - 2.1.2 Example: analytical geochemistry tools such as handheld laser induced breakdown spectroscopy (hLIBS), handheld x-ray fluorescence spectrometry (hXRF), etc.
- 2.2 Walking Stick Mounted Instrumentation – Instruments mounted on a walking stick carried frequently by astronauts (additional benefit of astronaut stabilization)
  - 2.2.1 Scientific benefit of data collection wherever the astronaut walks as data is generally collected continuously without initiation or direct interaction by the astronaut
  - 2.2.2 Example: LiDAR, multispectral camera sensor, etc.
- 2.3 Rover-Mounted Instrumentation – Instruments mounted on a rover (unpressurized or pressurized)
  - 2.3.1 Scientific benefit of taking data wherever the rover drives without additional crew time required
  - 2.3.2 Rover can also transport large payloads to take load off crew
  - 2.3.3 Example: Ground Penetrating Radar (GPR), gravimeter, magnetometer, etc.
- 2.4 Suit-Mounted Instrumentation – Instruments/sensors affixed to suit
  - 2.4.1 Best data coverage because everywhere the astronaut walks, data will be collected
  - 2.4.2 Example: magnetometer, etc.
- 2.5 Lander-Mounted Instrumentation – Scientific payloads attached to lander
  - 2.5.1 Heavier/bulkier payloads can be mounted on lander to characterize landing site

        2.5.1.1 Doesn't require transport away from landing site
        2.5.1.2 If left on descent stage, can provide long term characterization of landing site
    2.5.2 Example: lunar environment characterization, high-resolution panoramic imager, etc.
  2.6 Astronaut Deployable Science Experiment Packages – packages deployed in exploration zone that require long duration times
    2.6.1 Astronaut transports payload to deployment site, sets up/calibrates the instrument as necessary, confirms functionality with science team, and leaves the instrument for data collection both during and after the crewed surface mission
        2.6.1.1 Could also deploy the payload and move it on subsequent EVAs
    2.6.2 Example: Apollo Lunar Seismic Experiment Package (ALSEP), geophysical network nodes, seismic station, etc.

3.0 Operational Considerations – Address each of the following from the perspective of 2.1-2.7
  3.1 Hardware Design
    3.1.1 Handheld Instruments – must interface with gloved hand
    3.1.2 Walking Stick – must mate with walking stick design and not throw off center of gravity as crew will be using the walking stick to help with balance
    3.1.3 Rover-Mounted – need to be mounted in the optimal location to collect data during translation (i.e. right location on the rover, right distance b/w ground and instrument)
    3.1.4 Suit-Mounted – must mate with xEMU without interfering at all with suit function or ease of movement
    3.1.5 Lander-Mounted – if instrument is not stowed in deployment location, crew would have to mount it on the lander and could have to access it for maintenance/repairs so must be able to interface with EVA system
    3.1.6 Astronaut Deployable Packages – likely to be bulky so must be able to transport and interact with these payloads
  3.2 User Interface/Software Design
    3.2.1 Handheld Instruments – How much will data have to be viewed/accessed real-time; this is the type of instrument that would benefit most from real-time data access so figuring out how to do this without overloading the crewmember is critical
    3.2.2 Walking Stick – Given conops of crew collecting data wherever they go, would be challenging to view data real-time
    3.2.3 Rover-Mounted – As data collected real-time might result in changes to traverse plan (i.e. if GPR data shows interesting/unexpected results, crew could drive rover to investigate), crew needs real-time access to data (preferably while driving) or real-time comms with MCC to discuss data
    3.2.4 Suit-Mounted – Given that payloads will likely be mounted on PLSS (suit backpack), user will not be able to view data real-time; could have a 'Ready' light or calibration indicator mounted so EVA buddy can diagnose any potential

problems; if real-time data view is necessary, will need separate data viewing console

- 3.2.5 Lander-Mounted – Payloads expected for lander mounting shouldn't require data viewing real-time as they will likely be long-duration instruments that will potentially continue data collection post crew departure; however, feedback for calibration and accurate set-up is necessary
- 3.2.6 Astronaut Deployable Packages – Payloads expected for astronaut deploy shouldn't require much data viewing real-time as they will likely be long-duration instruments that will continue data collection post crew departure; however, feedback for calibration and accurate set-up is necessary, or real-time comms with MCC; some payloads might be moved several times throughout a mission so this real-time feedback is critical

3.3 Mission Control Center (MCC)/Flight Operations Integration

- 3.3.1 Handheld Instruments – Due to handheld instruments being potentially used in both sample triage and traverse execution, it's likely these instruments will be used a lot relative to other payloads and will therefore generate a lot of data; MCC/ST will be critical in helping manage these data and help crew assimilate them into traverse execution
- 3.3.2 Walking Stick – Depending on the payload, MCC/ST can track data return from the walking stick and provide guidance on when follow-up data collection and the possible corresponding adaption in traverse plan is necessary
- 3.3.3 Rover-Mounted – Depending on the payload, MCC/ST can track data return from the rover-mounted instrumentation to inform the crew when follow-up additional data might be needed
- 3.3.4 Suit-Mounted – Depending on the payload, MCC/ST can track data return from the suit-mounted instrument and provide guidance on when follow-up additional data collection might be requested
- 3.3.5 Lander-Mounted – As most of the data collection is likely to be collected without direct crew intervention, MCC/ST comms will likely happen while the payload is being set up and calibrated
- 3.3.6 Astronaut Deployable Payloads – As most of the data collection is likely to be collected without direct crew intervention, MCC/ST comms will likely happen while the payload is being set up and calibrated

3.4 Required Crew Time

- 3.4.1 Handheld Instruments – Time required to retrieve payload from stowage and stow for transport to worksites (either on tool caddy or on rover); these instruments are likely to be used at many science sites so time required will depend on technique and how much crew/science backroom are able to view, triage, and react to data real-time (could range from the time only required to collect data to a lot of time spent discussing data, both IVA and EVA)
- 3.4.2 Walking Stick – Time required to retrieve payload from stowage and affix to walking stick (if it's not transported to lunar surface already mounted to walking stick), calibrate and test; TBD amount of time (depending on payload and data return) to adapt traverse plan based on data return (could range from very

minimal time/required deltas to a lot of time required depending on data return)

3.4.3 Rover-Mounted – Time required to retrieve payload from stowage, affix it to rover, calibrate and test; TBD amount of time (dependent on selected payload) to view data and make resulting traverse changes based on data return (could range from very minimal time/required deltas to a lot of variation depending on data return)

3.4.4 Suit-Mounted – Minimal – just the time required to mount the payload (if it wasn't already) and possibly check a calibration light or communicate with MCC on functionality

3.4.5 Lander-Mounted – Time required to install, initialize, and calibrate payload

3.4.6 Astronaut Deployable Payloads – Time required to unstow from lander, transport to deployment site (via crew walking or via rover), deploy, initialize, calibrate, and, if necessary, move the payload between data collection sites

3.5 Training Implications

3.5.1 Handheld Instrument – Training required in the scientific technique and operations in a variety of environments (analog, reduced gravity, etc.); Ops training required w/ MCC/ST to evaluate how to assimilate data into sampling and traverse execution as high volumes of data are expected

3.5.2 Walking Stick – Training required in the scientific technique of each attached payload and operations in a variety of environments (analog, reduced gravity, etc.), especially as this tool will also aid in balance

3.5.3 Rover-Mounted – Training required to operate the rover in a manner ideal for scientific data collection; science operations training required to determine how to assimilate data into traverse execution and determine whether flexible adaption is needed

3.5.4 Suit-Mounted – Training required in suit operations should the instrumentation at all impact suit mobility; science operations training required depending on if data acquisition requires specialized body movements (i.e. bending over; accessing your buddy's suit, etc.)

3.5.5 Lander-Mounted – Training to unstow instruments and install in correct location to ensure proper data collection/calibration

3.5.6 Astronaut Deployable Payloads – Training required in how to deploy payloads in a variety of environments/conditions (analog, reduced gravity, etc.); training to unstow instruments and install for transport on tool caddy/rover/etc.

3.6 Sample Triage Impacts

3.6.1 Handheld Instruments – High likelihood that handheld instruments (i.e. handheld spectrometers) will impact sampling as quick, in situ data can provide resolution quickly on collecting a diverse sampling suite

3.6.2 Walking Stick – Low likelihood of walking stick mounted instruments impacting sampling, except potentially in selecting new sampling sites (depending on the payload)

3.6.3 Rover-Mounted – Medium likelihood of rover-mounted instruments impacting sampling (i.e. GPR identifying potential buried volatiles requiring core sampling)

- 3.6.4 Suit-Mounted – Low likelihood of suit-mounted instruments impacting sampling, except potentially in selecting new sampling sites (depending on the payload)
- 3.6.5 Lander-Mounted – Very low likelihood in lander-mounted payloads impacting sampling
- 3.6.6 Astronaut Deployable Payloads – Very low likelihood in astronaut deployable payloads impacting sampling

3.7 Science Traverse Flexible Execution Impacts

- 3.7.1 Handheld Instruments – High likelihood of impacting traverse flexible execution as new data will give situational awareness over geologic diversity in the area and hone geologic hypotheses
- 3.7.2 Walking Stick – High likelihood of impacting traverse execution as data return might prompt ST to request crew follows up on anomalies observed in sensor data
- 3.7.3 Rover-Mounted – High likelihood of impacting traverse execution as data return might prompt ST to request crew follows up on anomalies observed in sensor data
- 3.7.4 Suit-Mounted – High likelihood of impacting traverse execution as data return might prompt ST to request crew follows up on anomalies observed in sensor data
- 3.7.5 Lander-Mounted – Low likelihood of impacting traverse execution as instrument task will likely be only to install on the lander
- 3.7.6 Astronaut Deployable Payloads – Medium likelihood of impacting traverse execution as instrument task will likely be only to set up/calibrate instrument; only impact on traverse execution is in selecting deployment location

3.8 Communications Requirements

- 3.8.1 Handheld Instruments – Real-time data transmission is critical as instrument deployment benefits from a lot of interaction with MCC/ST (depending on instrument, required bandwidth is likely to be low)
- 3.8.2 Walking Stick – Real-time data transmission important for MCC/ST to provide guidance on data acquisition and make any requests for additional data collection and changes to the traverse plan (depending on the instrument, required bandwidth could be high)
- 3.8.3 Rover-Mounted – Real-time data transmission important for MCC/ST to provide guidance on data acquisition and make any requests for additional data collection and changes to the traverse plan (depending on the instrument, required bandwidth could be high)
- 3.8.4 Suit-Mounted – Real-time data transmission important for MCC/ST to provide guidance on data acquisition and make any requests for additional data collection and changes to the traverse plan (depending on the instrument, required bandwidth could be high)
- 3.8.5 Lander-Mounted – Data transmission to ensure successful set up and calibration would be ideal, but if most of the data collection occurs post crew departure, impact on comms bandwidth during crew operations could be low

3.8.6 Astronaut Deployable Payloads - Data transmission to ensure successful set up and calibration would be ideal, but if most of the data collection occurs post crew departure, impact on comms bandwidth during crew operations could be low

3.9 Contamination/Dust/Planetary Protection Considerations

3.9.1 Handheld Instruments – As instrument touches the sampled surface and will then touch another surface, the instrument surface that touches the sample must be cleaned between each use; dust is a concern should the instrument be brought inside the crew volume (see 3.11.1)

3.9.2 Walking Stick – As walking stick will go everywhere the crew goes, crew will need to ensure material from prior sampling site does not contaminate new sampling site

3.9.3 Rover-Mounted – No additional implications of including the rover-mounted instrument on contamination/dust beyond the risks of the rover doing so

3.9.4 Suit-Mounted – No additional implications of including the suit-mounted instrument on contamination/dust/planetary protection beyond the risks of the suit doing so

3.9.5 Lander-Mounted – Very low considering the instrument won't go beyond the lander

3.9.6 Astronaut Deployable Payloads – Low contamination risk as most of these payloads will be deployed in only one location; should the payload have to be moved between sites then decontamination steps should be taken

3.10 Tool/Instrument Transportation Constraints

3.10.1 Handheld Instruments – Must be transported between sites and will likely often be used; therefore, there should be a reliable spot for handheld payloads in whatever transport mechanism is used for sampling tools and collected samples (caddy, rover, etc.)

3.10.2 Walking Stick – Crew will likely carry the walking stick with them but should they need to stow it on a tool caddy or rover, care should be taken to protect the instrumentation mounted on the walking stick

3.10.3 Rover-Mounted – Instrumentation will be mounted on the rover but care should be taken in operating the rover as instrumentation could be mounted on the belly of the rover

3.10.4 Suit-Mounted – Instrumentation will be mounted on the suit, so no additional transportation is required except if the suit-mounted payload has a tablet/power source/etc. that goes with it

3.10.5 Lander-Mounted – Instrument would only have to be transported from wherever it's stowed during descent to its deployment location which hopefully should not require the rover

3.10.6 Astronaut Deployable Payloads – Should the deployment location be far from the lander (not easily walkable); transport might be needed depending on the size of the payload; high likelihood that rover/tool caddy allow for payload transport

3.11 Maintenance/IVA Operations Potential and Requirements

3.11.1 Handheld Instruments – Depending on the instrument and dust mitigation protocols, handheld instruments would be useful IVA to provide additional analyses on collected samples (should the curation plan allow for it or if samples that will not be returned to Earth could be brought inside to maximize IVA time); battery swap also might prompt IVA activity

3.11.2 Walking Stick – Should only be necessary if maintenance/fixes are required

3.11.3 Rover-Mounted – Should only be necessary if maintenance/fixes are required but this should be avoided as it would require uninstalling from the rover which would waste crew time

3.11.4 Suit-Mounted – Given that the suit has to come in/out with the crew, these instruments will also come in/out; crew should likely only have to interface with these instruments IVA if maintenance/fixes are required assuming data can be transmitted without hard mate to the lander

3.11.5 Lander-Mounted – Should only be necessary if maintenance/fixes are required but this should be avoided as it would require uninstalling from the lander which would waste crew time; should the payload go down in the pressurized crew volume, IVA will be required to unstow

3.11.6 Astronaut Deployable Payloads - Should only be necessary if maintenance/fixes are required (low likelihood)

4.0 Summary

The incorporation of scientific payloads into future Artemis lunar exploration missions is probable. This document summarizes the types of payloads currently in development with the scientific community and breaks these payloads down in terms of how crews will deploy them. Additionally, EVA implications of each deployment style are discussed, including hardware and software design constraints, crew time required, training required, communications requirements, and more. This is not meant to be an exhaustive list of every payload that could be included on an Artemis mission, but rather an overall summary of what the science community is working on for future Artemis deployment. The science team is ready to engage with the EVA community to provide more information and elaboration on anything contained in this document.