National Aeronautics and Space Administration

Supporting Exploration Missions by Enabling Exploration Mission System Software

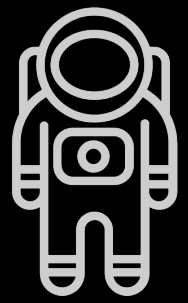
ICES 2023 Conference; Track 506: Human Exploration Beyond Low Earth Orbit: Missions and Technologies

Presenter: Matthew Miller, Ph.D.

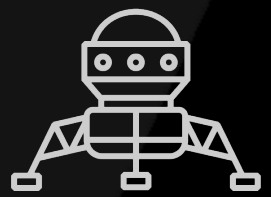
Co-Authors: David Charney, Ben Feist, Cameron Pittman, David Rynearson, Jackie Vu, James Montalvo, Katie Heinemann, Trey Davis, Stephen Lin, Omar Baig

Artemis missions face an unprecedented data management challenge

LunaNET[5,6]



xEVAS[3]

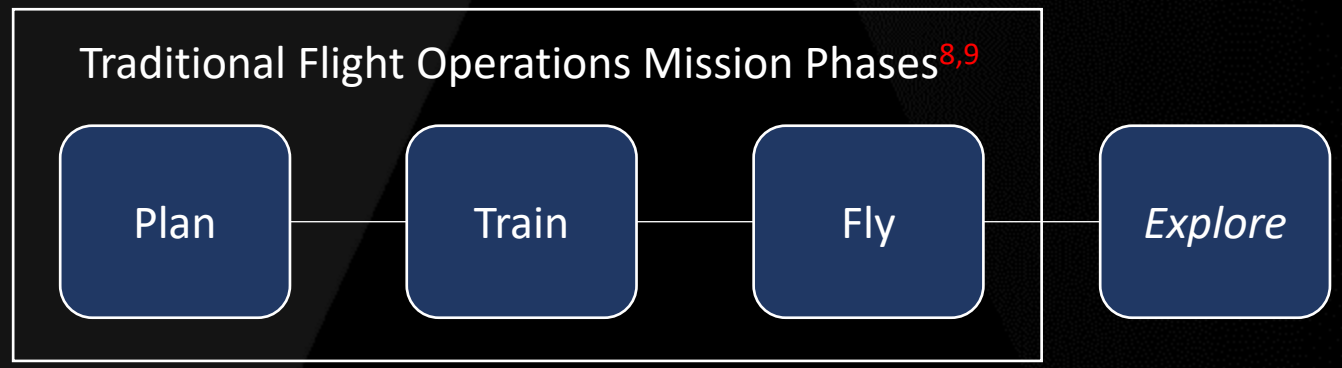


HLS[2]

- At present, there is a noticeable absence of contractual mechanisms in place to ensure seamless interoperability of data sets from a myriad of mission assets with the purpose of supporting mission operations personnel.
- We assert in this paper that mission data are at risk for becoming siloed, being in inconsistent and incompatible formats, and requiring custom tooling to manipulate.
- These risks result in limiting *mission data utility* and *delaying the acquisition of actionable information within mission operations workforce* unless there is a deliberate effort to create **temporally** and **spatially** integrated data management systems

Icons can be found at: https://www.flaticon.com/

Artemis missions should design software solutions that align with mission operations work needs



Explore examples include:

- Continued scientific learning from Apollo.[10,11]
- Mishap reporting such as ISS EVA Suit Water Intrusion Mishap Report[12]

This paper describes a specific set of tools, known collectively as the Extravehicular Activity (EVA) Mission System Software (EMSS), to transform the EVA *plan, train, fly, explore* work processes.

EVA Mission Software System (EMSS) Initiative Overview

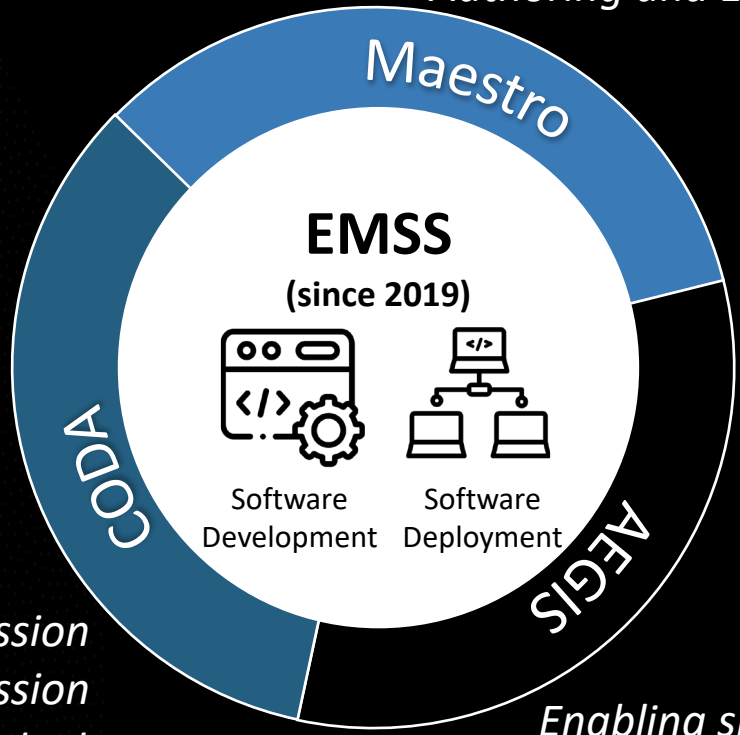
In 2013, Montalvo began working Maestro, an EVA procedure execution and authoring tool to reimagine ISS EVA.[8,13]

In 2013, Miller and Pittman apply cognitive systems engineering methods to the EVA work domain to design and develop novel decision support systems for EVA operations.[15]

In 2015, Feist launched Apollo 17 in Real-time and later Charney joined to support the launch of Apollo 11 and 13 in Real Time.[14]

In 2018, crew health and performance personnel joined the first integrated effort known as EVA Operations System.[19]

Digitizing EVA Procedure Authoring and Execution



Putting Mission Data into Mission Context

Enabling spatiotemporal awareness for EVA Procedure Authoring and Execution

EMSS Development Methods

- The EMSS suite of applications leverage a common architecture.
  - *React.js* is used as the front-end framework for creating dynamic user interfaces.
  - The back-end consists of Node applications that communicate with data sources and provide data to the front-end.
  - The applications are deployed into the Flight Operations Directorate's secure server environment using Docker containers, which are like lightweight and portable virtual machines that isolate the application from the host environment.
  - The suite also leverages continuous integration and continuous delivery (CI/CD) tools to automate the testing, building, and deployment of code changes.
  - This enables ongoing rapid development and deployment of new features and ensures that the systems are always up-to-date.

Collectively, these software development and deployment efforts bring modern software capabilities to allow EMSS team to support EVA plan, train, fly, explore for both ISS and future Artemis missions.

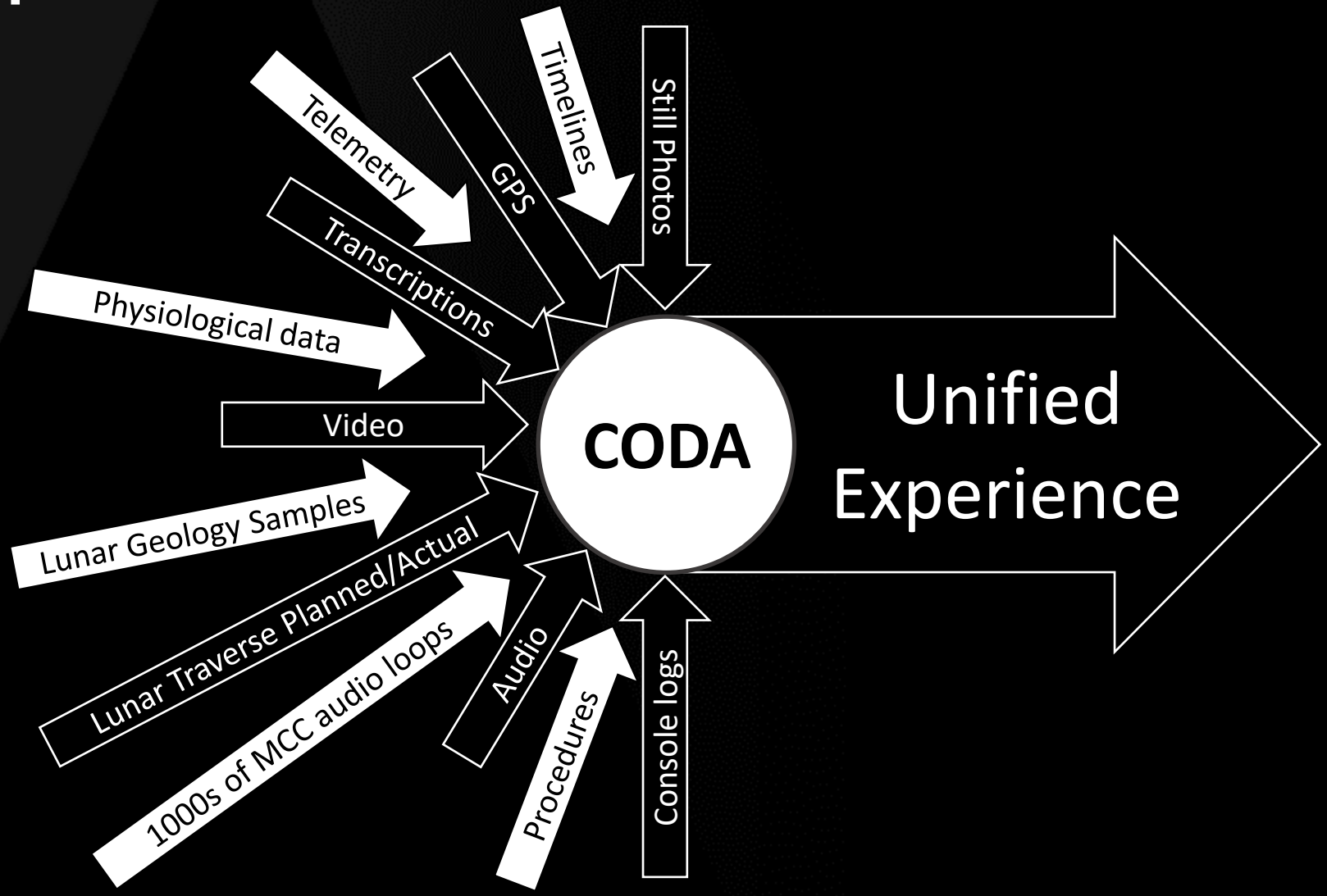
ISS Operations

Artemis Operations

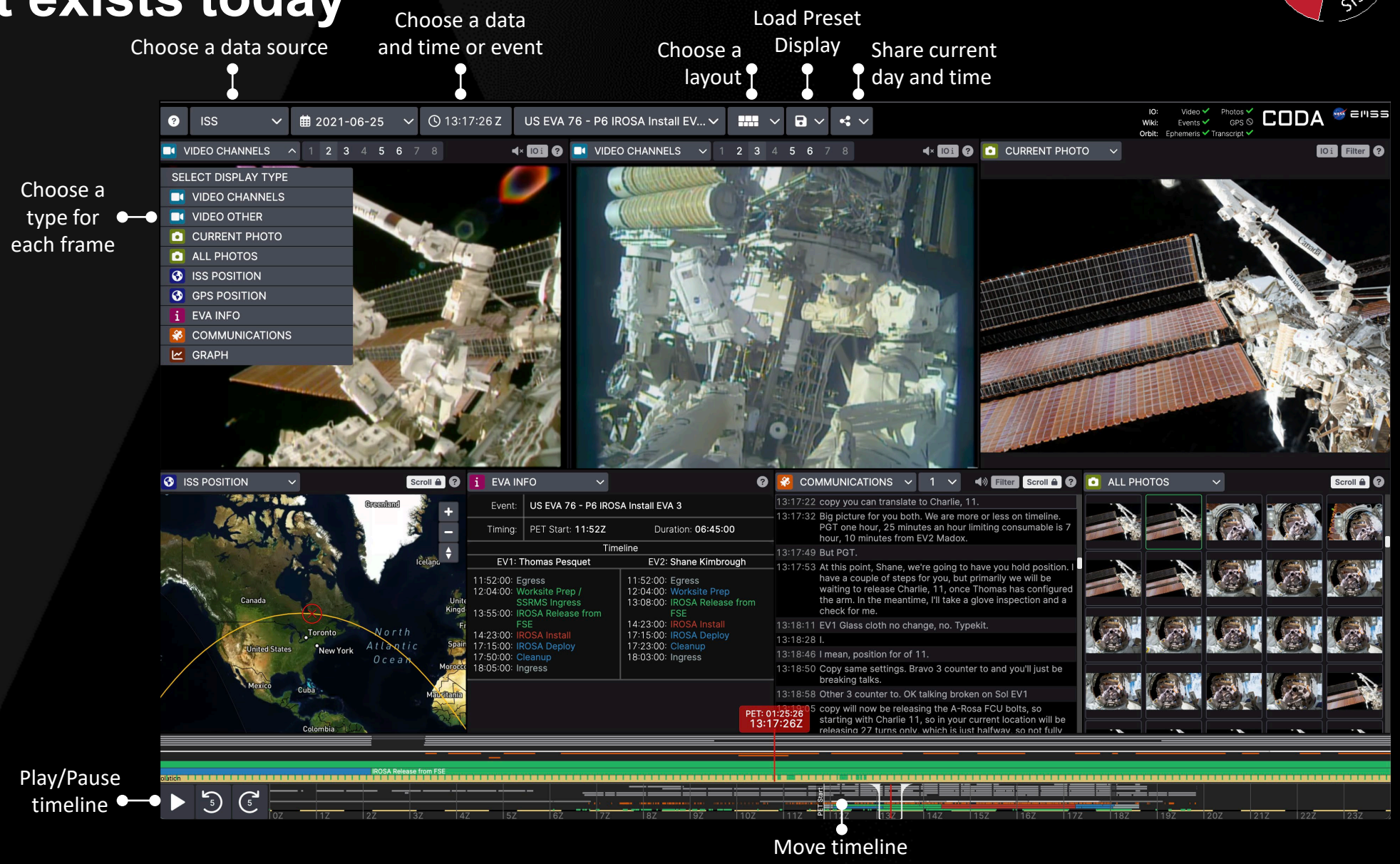
Integrated Testing

Crew and Flight Controller Training Flow

Collaborative Operations Data Activation (CODA) as a concept



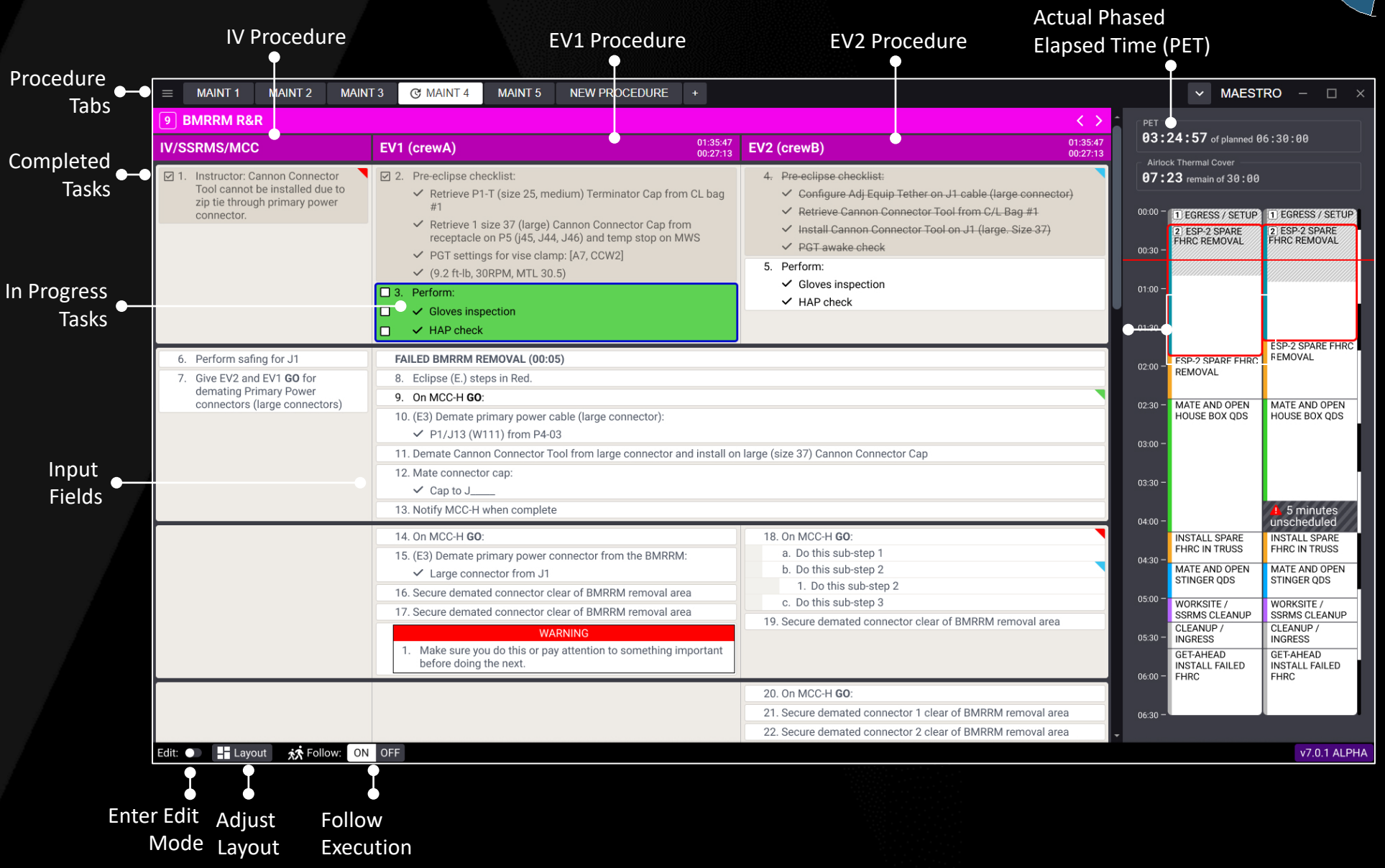
Collaborative Operations Data Activation (CODA) as it exists today



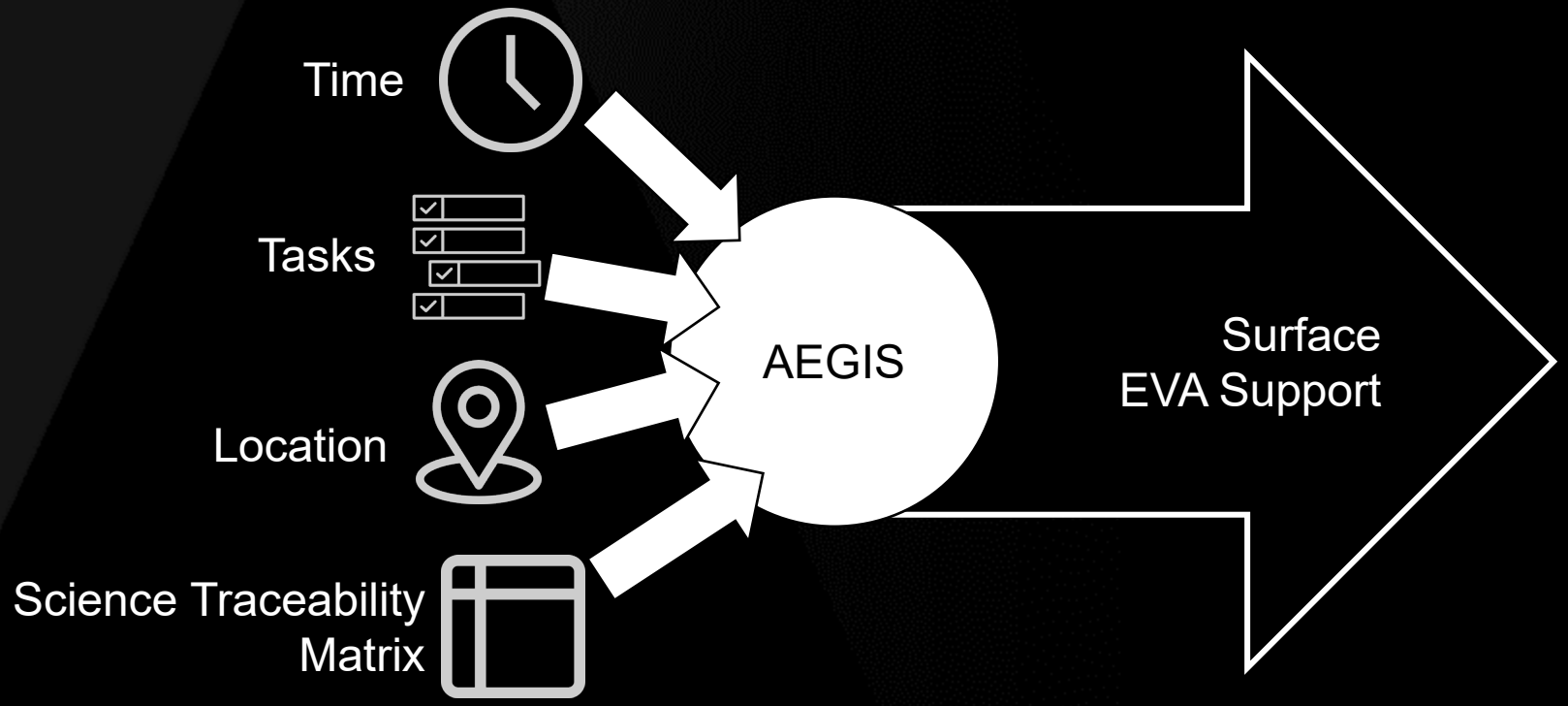
Maestro as a concept

- The Purpose of Maestro:
  - consolidate the authoring and execution process within a dedicated tool that can handle the interconnected and unique constraints of EVA procedures.
- Note: Maestro enables custom capabilities that are different from existing ISS planning and execution tools such as Optimis[21,22] and PRIDE.[23,24]
- What Motivates Maestro Development?
  - EVA requires the choreography of at least two EVA crew members and support personnel, therefore necessitating the need to handle in parallel the sequence of events for two or more agents at a granular level of detail.
  - Crew work both in tandem and independently, depending on the needs of the EVA tasks.
  - Crew procedures must be inherently associated and tracked to ensure overall EVA objectives are effectively managed and achieved.
  - In addition to simultaneously handling the planning of at least two agents, EVA procedures for ISS are highly proceduralized, demarcating minute details that must be accomplished at specific moments.
  - Maestro enables users to coordinate activities with minute precision while also fully describing the necessary actions with dependencies to be accomplished for two crew members who need to perform hours of work

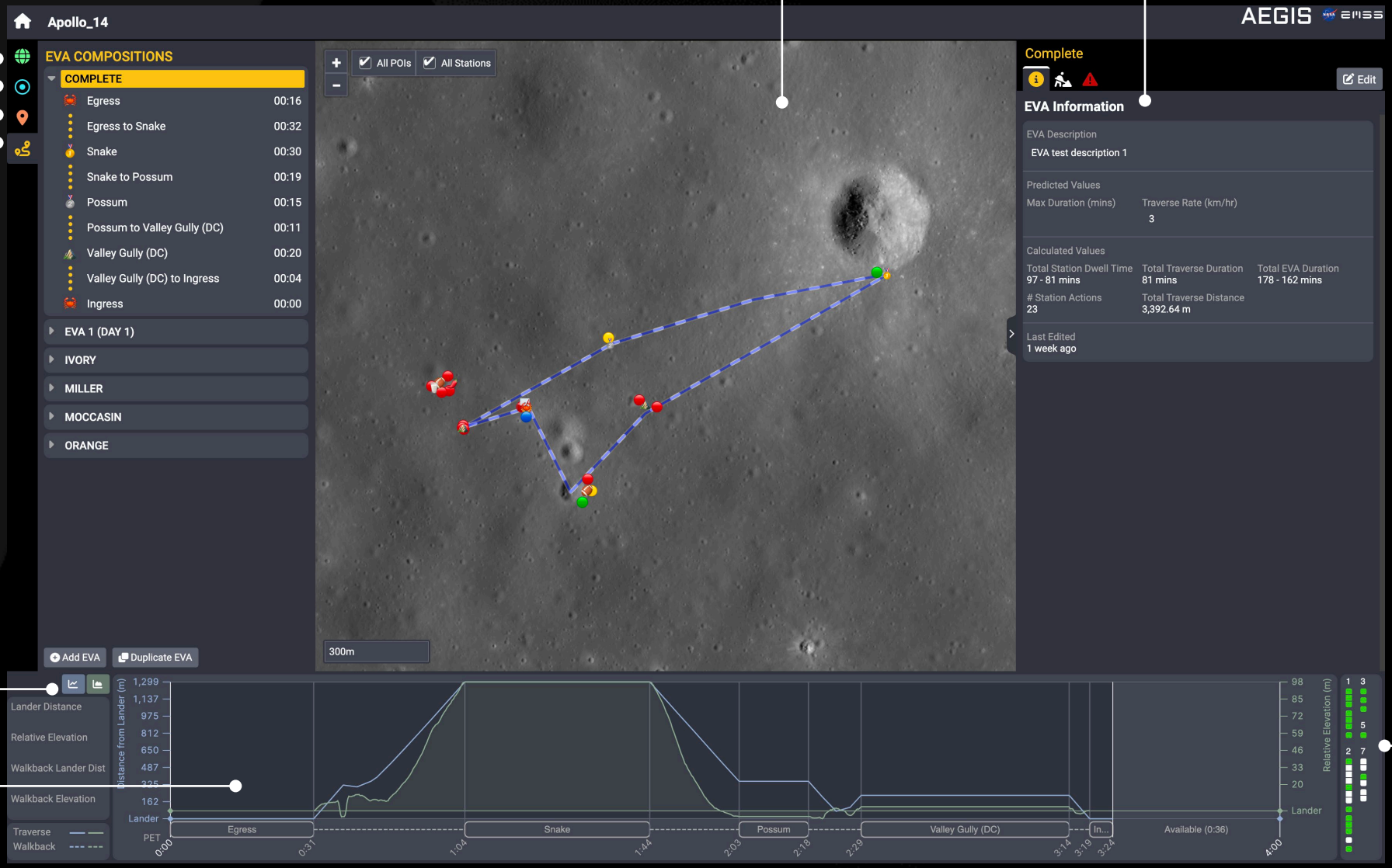
Maestro as it exists today



Artemis EVA Geographic Information System (AEGIS) as a concept



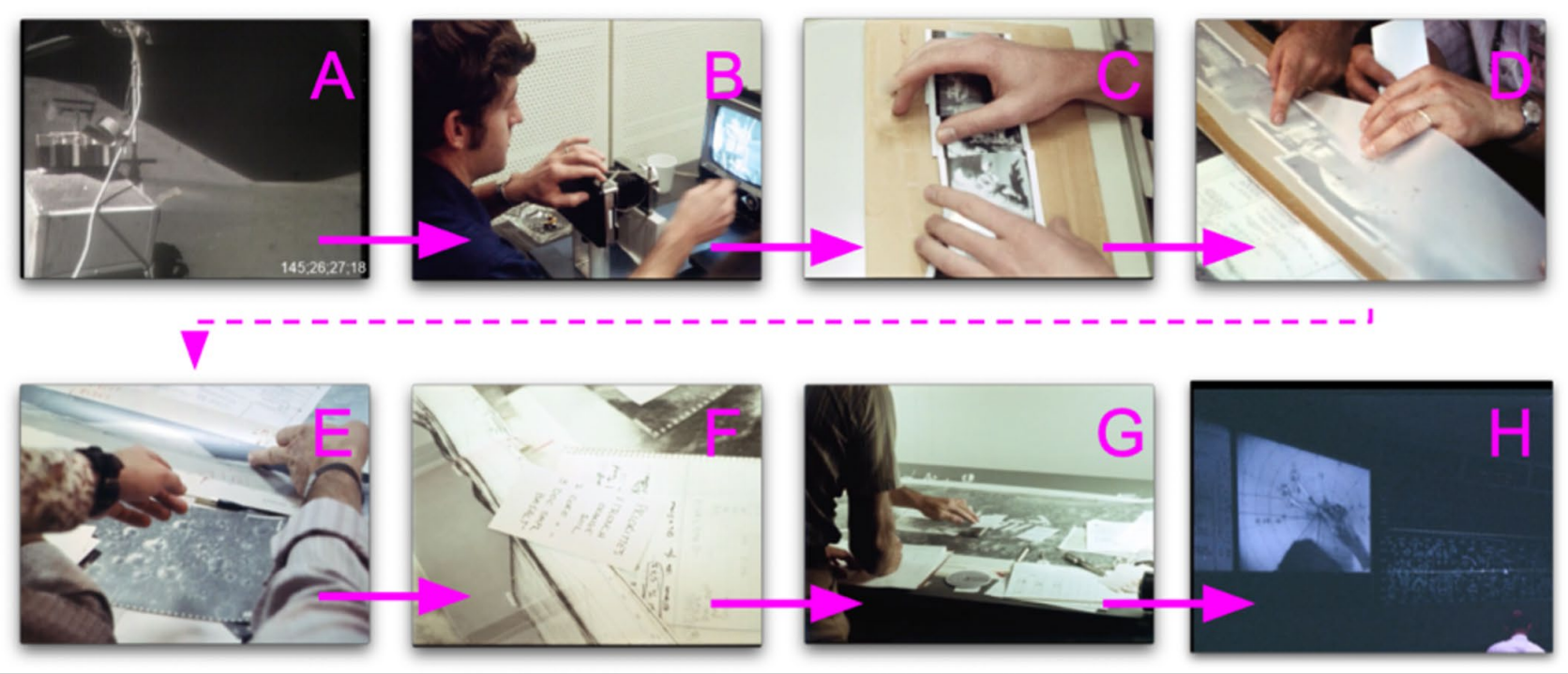
Artemis EVA Geographic Information System (AEGIS) as it exists today



Areas of Integration between EMSS and Mission Operations Work Efforts

- Actively supporting ISS operations and NBL training:
  - Maestro has successfully been deployed in 6+ ISS EVAs to-date and is now actively used in the support of planning and training activities at the NBL.
  - CODA is routinely used in support of anomaly reporting for on-going ISS operations and there is active development underway to align NBL data streams to bring similar CODA capabilities to review all NBL EVA training activities.
- Integrated into Artemis development:
  - Dr. Miller has been named the NASA Science Mission Directorate - Artemis Internal Science Team Software Systems Lead
  - Integrated component of the NASA EVA and Human Surface Mobility Program (EHP)[30] and leverages NASA Joint EVA Test Team (JETT) events to inform Artemis functionality across the EMSS tools.
  - Supported the JETT3 field test in October 2022, that included the most complete Artemis flight team surface EVA planning and execution activities performed to-date.[28,31]
  - Close engagement with with the Artemis Geospatial Data Team[32] so that EMSS tools can leverage the most relevant lunar surface map data for EVA FOD utilization.
  - Active support is ongoing for JETT5.
- EMSS Awards include:
  - CODA was awarded the JSC Software Excellence Award and subsequently received the NASA agency-wide Major Space Act Award in 2022.
  - Maestro has received numerous acknowledgements within the FOD for helping pave a modern way of enabling the flight team to conduct EVA and has also been awarded the 2023 JSC Software Excellence Award and the 2023 EVA and Human Surface Mobility Program Recognition of Excellence Award

Conclusion: Supporting human spaceflight operations requires the seamless integration of temporal and spatial data to enable mission operations personnel to make timely and accurate decisions



Snapshots taken from 16mm film shot during Apollo 17 EVA. Video feed from the lunar surface (A) was transferred to Polaroid still photography (B) and collated into panoramas (C) that were overlaid with precursor imagery to estimate crew location and facilitate scientific interpretation (D). These images were compared with other map products (E) to synthesize and articulate real-time science priorities that were passed along the chain of command to impact crew behavior (F). Additionally, estimates of crew location were indicated using icons moved manually on a map alongside operations relevant data such as clock time and event markers (G), which were all shared among the flight team via overhead projector (H).

Questions and Contact Information

Presenter: Matthew J Miller, Ph.D.
Email: matthew.j.miller1@nasa.gov

References

1. NASA. Artemis Accords [Internet]. NASA. 2017. Available from: https://www.nasa.gov/specials/artemis-accords/index.html
2. Mahoney E. NextSTEP Appendix P: Human Landing System Sustaining Lunar Development. NASA. 2021. Available from:http://www.nasa.gov/nextstep/humanlander4
3. NASA. Exploration Extravehicular Activity Services (xEVAS). 2021. Available from:https://sam.gov/opp/cbf17a8bb3954f33a0e70a6dc2b7754c/view
4. Daines G. Commercial Lunar Payload Services. NASA. 2019. Available from: http://www.nasa.gov/content/commerciallunar-payload-services
5. Baird D. LunaNet: Empowering Artemis with Comm and Nav Interoperability. NASA. 2021. Available from:http://www.nasa.gov/feature/goddard/2021/lunanet-empowering-artemis-with-communications-and-navigation-interoperability
6. Esper J. Draft LunaNet Interoperability Specification. 2022. Available from: https://ntrs.nasa.gov/citations/20220004317
7. O'Neill J. Plan, Train, and Fly: Mission Operations From Apollo To Shuttle. Ask Magazine. 2009;(34):13–6.
8. Bell E, Coan D, Oswald D. A Discussion on the Making of an EVA: What it Really Takes to Walk in Space. In: SpaceOps2006 Conference. American Institute of Aeronautics and Astronautics; 2006. (SpaceOps Conferences). Available from:https://arc.aiaa.org/doi/10.2514/6.2006-5570
9. Miller MJ, McGuire KM, Feigh KM. Decision Support System Requirements Definition for Human Extravehicular ActivityBased on Cognitive Work Analysis. Journal of Cognitive Engineering and Decision Making. 2017 Jun 1;11(2):136–65.
10. Apollo Next Generation Sample Analysis Program (ANGSA). Apollo Next Generation Sample Analysis Program (ANGSA)..Available from: https://www.lpi.usra.edu/ANGSA
11. Pernet-Fisher JF, McDonald FE, Zeigler RA, Joy KH. 50 years on: legacies of the Apollo programme. Astronomy & Geophysics. 2019 Aug 1;60(4):4.22-4.28.
12. International Space Station (ISS) EVA Suit Water Intrusion - High Visibility Close Call. NASA; Available from:https://www.nasa.gov/sites/default/files/files/Suit_Water_Intrusion_Mishap_Investigation_Report.pdf
13. Miller MJ, McGuire KM, Feigh KM. Information flow model of human extravehicular activity operations. In: 2015 IEEE Aerospace Conference. 2015. p. 1–15.
14. Apollo in Real Time [Internet]. Apollo in Real Time. Available from: https://apolloinrealtime.org/
15. Hall L. Decision Support Tool Development for Human Extraterrestrial Extravehicular Activity. NASA. 2013. Available from: http://www.nasa.gov/spacetech/strg/2013_nstrf_miller.html
16. Miller MJ. Decision support system development for human extravehicular activity. Georgia Institute of Technology; 2017. Available from: https://smartech.gatech.edu/handle/1853/59210
17. Miller MJ, Feigh KM. Addressing the envisioned world problem: a case study in human spaceflight operations. Des Sci. 2019;5:e3.
18. Miller MJ, Feigh KM. Assessment of Decision Support Systems for Envisioned Human Extravehicular Activity Operations: From Requirements to Validation and Verification. Journal of Cognitive Engineering and Decision Making. 2020 Mar 1;14(1):54–74.
19. Abercromby AFJ, Alpert BK, Cupples JS, Dillon EL, Garbino A, Hernandez Y, et al. Integrated Extravehicular Activity Human Research & Testing Plan: 2019. 2019. Available from: https://www.nasa.gov/sites/default/files/atoms/files/nasa-tp-2019-220232.pdf
20. Gebhardt C. Pesquet & Kimbrough complete new solar array installation on ISS. NASASpaceFlight.com. 2021. Available from: https://www.nasaspaceflight.com/2021/06/usa-eva-76/
21. Smith EE, Korsmeyer DJ, Hall V. Exploration Technologies for Operations. In: SpaceOps 2014 Conference. Pasadena, CA: American Institute of Aeronautics and Astronautics; 2014. Available from: https://arc.aiaa.org/doi/10.2514/6.2014-1619
22. Marquez JJ, Hillenius S, Healy M, Silva-Martinez J. Lessons Learned from International Space Station Crew Autonomous Scheduling Test. In 2019. Available from: https://ntrs.nasa.gov/citations/20190027148
23. PRIDE. TRACLabs. Available from: https://traclabs.com/projects/pride/
24. Hudson M, Molin A, Kortenkamp D. Electronic Procedures for Medical Operations in Space. In: AIAA SPACE 2011 Conference & Exposition. Long Beach, California: American Institute of Aeronautics and Astronautics; 2011. Available from:https://arc.aiaa.org/doi/10.2514/6.2011-7175
25. Cohen TE, Lees DS, Deans MC, Lim DSS, Lee YJG. Integrating time-synchronized video with other geospatial and temporal data for remote science operations. In: 2018 IEEE Aerospace Conference. 2018. p. 1–10.
26. Marquez JJ, Miller MJ, Cohen T, Deliz I, Lees DS, Zheng J, et al. Future Needs for Science-Driven Geospatial and Temporal Extravehicular Activity Planning and Execution. Astrobiology. 2019 Mar;19(3):440–61.
27. Miller MJ, Coan DA, Abercromby AF, Feigh KM. Design and Development of Support Systems for Future Human Extravehicular Activity. In: 55th AIAA Aerospace Sciences Meeting. American Institute of Aeronautics and Astronautics; 2017. (AIAA SciTech Forum). Available from: https://arc.aiaa.org/doi/10.2514/6.2017-1444
28. Caswell E, Young KE, Coan D, Graff TG, Lindsey T, Tejral Z, et al. JETT3: A Holistic, Integrated Analog For Artemis Lunar Surface Exploration. LPSC. 2023;(2700). Available from: https://www.hou.usra.edu/meetings/lpsc2023/pdf/2700.pdf
29. Artemis III Science Definition Report. Report No.: NASA/SP-20205009602. Available from: https://www.nasa.gov/sites/default/files/atoms/files/artemis-iii-science-definition-report-12042020c.pdf
30. Mahoney E. Exploration Systems Development Mission Directorate. NASA. 2019. Available from: http://www.nasa.gov/directorates/exploration-systems-development
31. Young KE, Britton AW, Cohen BA, Edgar LA, Fagan AL, Garry WB, et al. The Integration Of Science Into Artemis Surface Mission Planning: Lessons. LPSC. 2023;(2179). Available from: https://www.hou.usra.edu/meetings/lpsc2023/pdf/2179.pdf
32. Miller MJ, Lawrence SJ, Petro NE. Artemis Internal Science Team Update: Data And Software Development. LPSC. 2023;(1362). Available from: https://www.hou.usra.edu/meetings/lpsc2023/pdf/1362.pdf