National Aeronautics and Space Administration
Washington, DC

NASA ADVISORY COUNCIL
Human Exploration and Operations Committee

October 31, 2022-November 1, 2022
NASA Headquarters
Virtual Meeting

MEETING MINUTES

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Bette Siegel, Executive Secretary	**N. Wayne Hale, Chair**

Public Meeting Minutes
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Meeting Report prepared by
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October 31, 2022

Call to Order/Announcements

Dr. Bette Siegel called the meeting of the Human Exploration and Operations Committee (HEOC) to order, and detailed the Federal Advisory Committee Act (FACA) rules that govern the NASA Advisory Council (NAC) Committees. She introduced the Chair of the HEOC, Mr. N. Wayne Hale. Mr. Hale spoke briefly, explaining the hasty decision to meet virtually before the NASA Advisory Council was to meet in November. That meeting has been postponed to mid-January, and HEOC is now planning to meet in person in early January 2023, location yet to be determined. Mr. Hale noted that HEOC member, Mr. Mark McDaniel, would be rotating off the committee, and thanked him for his long service, most notably in his efforts to keep the committee focused on STEM and public sector issues. There are now some vacancies on HEOC, and a list of nominees is currently being circulated and considered at NASA Headquarters. Because the NAC meeting had been postponed, HEOC is scheduling some fact-finding sessions that had been previously delayed, on subjects such as the longer-term Artemis plan, and organizational items. General Lester Lyles, Chair of the NAC interjected briefly, thanking Mr. Hale and HEOC for their complete dedication to human exploration and space operations. He explained that the NAC had been working closely with the NASA Administrator's challenging schedule in the midst of a very busy time for the Agency, necessitating a delay for the full NAC meeting. Mr. Hale said he had briefed the National Academies on NASA's Artemis plans, an event which had been well covered by the media.

Status of SOMD/ESDMD

SOMD

Ms. Kathryn Lueders gave a status of the Space Operations Mission Directorate (SOMD), beginning with a summary of Expedition 68 highlights on the International Space Station (ISS). The current Expedition is looking at a number of extravehicular activities (EVAs) from November through January, which will include upgrades to the station's solar arrays. The manifest is packed full with other activities, now that ISS is at the stage of having to orchestrate vehicles coming to and leaving station on a regular basis, including Soyuz vehicles, Northrop Grumman and SpaceX commercial cargo deliveries, SpaceX crew flights, and the upcoming Boeing Starliner Crew Flight Test (CFT). The Human Research Program (HRP), a small but mighty program, has been quite busy as well, because additional crew, including commercial astronauts, have participated, offering blood and saliva samples for the continued assessment of protocols for long-term spaceflight. HRP has done many studies on nutrition as well, all of which will be very applicable for lengthy Mars cruises as well as terrestrial health. ISS has had to figure out how to work with different populations on long-term missions; Ms. Lueders pointed out that in addition to work on ISS, valuable HRP data comes also from terrestrial labs, parabolic flights, the NASA Space Radiation Laboratory, and analogue sites such as those in Antarctica, all of which are helping SOMD prepare for the next phase of space exploration. Both Soyuz and Commercial Crew astronauts go through strenuous activities once they have completed missions; data from these post-flight workouts have shown that exercise does indeed help the human body recover from lengthy periods spent in microgravity. This information will help inform future crew health regimens when astronauts will have to deal with recovery from long mission cruise times.

SOMD and the Space Communications and Navigation (SCaN) Program are working together to plan for the post-Tracking and Data Relay Satellites (TDRS) era, and SCaN is developing a commercial communication services project located at Glenn Research Center. A Near Space Network procurement is also underway, as SOMD starts to match up missions with providers as those services are being demonstrated; this has been a huge activity. NASA is also continuing to upgrade the Deep Space Network (DSN), adding antennas on the ground, and also offloading DSN network systems in order to support science mission communications; the Agency is looking at international and commercial partners to supply commercial lunar communication services around the moon, and is signing agreements with the

European Space Agency (ESA). This represents a major transformational phase for near-Earth, lunar, and deep space communications.

The Launch Services Program (LSP) is preparing for a launch at Vandenburg Air Force Base, which will be marking its 100th mission. LSP is a successful small program that supports the Science Mission Directorate (SMD), SOMD, the Exploration Systems Development Mission Directorate (ESDMD) and the Space Technology Mission Directorate (STMD). The launch vehicle (LV) market is also in flux, as emerging vehicles and new launch providers are brought on board via new NASA Launch Services (NLS) contracts to fly more and more high-value payloads. The Gateway Power Propulsion Element (PPE) and Habitation and Logistics Outpost (HALO) will be launched on an LSP mission, thus high reliability of such missions must be assured. LSP is also working with SMD on developing more high-risk payloads within the new VADR procurement system; this is proving to be a good way to allow smaller emerging providers to start building up their services. LSP statistics over the last 25 years include a 98% success rate. There are critical missions coming up soon, with the Northrop Grumman Cygnus capsule, the Joint Polar Satellite System-2 (JPSS-2) launch, SpaceX 26, and the SMD mission, Surface Water and Ocean Topography (SWOT) launch on 5 December.

Mr. Kwatsi Alibaruho applauded the extraordinary activity at SOMD. Dr. Pat Condon noted that Ms. Lueders had done a great job showing how much more traffic there is in low Earth orbit (LEO) today, compared to 50 years ago, and asked who was responsible for monitoring return trajectories for missions such as Artemis. Ms. Cathy Koerner and Ms. Lueders said that the Flight Operations Directorate (FOD) tracks all known objects in LEO; they work every launch and reentry. Ms. Koerner said that FOD also interfaces with Strategic Command (StratComm), by way of planning trajectories around objects that are in the catalogue. Mr. Hale noted that 31 October marked the 22nd anniversary of the Expedition 1 launch to ISS.

ESDMD

Mr. Jim Free gave a status of ESDMD, including a status of Artemis I. Rollout of the Space Launch System (SLS) rocket and the Orion vehicle is scheduled for 4 November. Much work has been accomplished in the Vehicle Assembly Building (VAB) since the rocket had been rolled back in response to hurricane conditions. The rocket is in better shape, having undergone some repair to foam. The next attempt will be made on the evening of 14 November, with other opportunities on the 16th and 19th. Everyone has reviewed the parameters of a night launch, and feels comfortable. For Artemis II and beyond, the teams have been busy working hardware; progress on the crew module is going along well. Artemis III recently took delivery of its heat shield. Core Stage work for both Artemis II and III is going well, while the team will be anticipating Lessons Learned from Artemis I, to apply to Artemis II and beyond. ESDMD continues work on option A contract work for the SpaceX Human Landing System (HLS). Option B negotiations also continue with SpaceX.

Two Exploration Extravehicular Activity Services contracts have been awarded, one to Axiom Space and one to Collins Aerospace, allowing the companies to compete for task orders for space station and Artemis missions. Axiom was selected for the first task order, to develop the surface exploration suits for Artemis III. A draft Request for Proposal (RFP) is out for the the Lunar Terrain Vehicle (LTV), intended for use by both exploration and science. Mr. Hale asked if international participation was involved with LTV. Mr. Free indicated that NASA continues to work with the Japan Aerospace Exploration Agency (JAXA) on a pressurized rover, but intends to develop the LTV with American companies. For the LTV, NASA had been talking to Canada about contributing a robotic arm, but the schedule became too complex to include the Canadian contribution in that particular procurement. Asked about the procurement mechanisms in use, Mr. Free said that for HLS, options A and B, are under the NextSTEP Appendix H Broad Agency Annoucement (BAA) contract award. NextSTEP Appendix P is an on-ramp

for additional American companies to demonstrate HLS capabilities. Beyond these BAAs, NASA intends to pursue sustainable HLS services contracts.

In the Moon to Mars effort, the program is in the process of carrying out the 63 Moon to Mars Objectives that NASA Deputy Administrator Pam Melroy initiated late last year. The objectives were put out to the global community for comment and the agency hosted two workshops for additional engagement to refine the objectives. The directorate will hold an architecture concept review at the end of January to present the baseline architecture, which will be followed by an annual review for defining new capabilities, to take place each November to align with the budget planning process. The Agency will set up a Moon to Mars Program Office, to be aligned with authorization language that will incorporate findings from the Aerospace Safety Advisory Panel (ASAP) and the NAC about single-mission ownership and responsibility. Mr. Hale said the National Academies had expressed great interest in the Moon to Mars program; many don't understand that it is not yet cast in concrete, and that NASA is still figuring it out. Mr. Free agreed that yes, from a transportation perspective, STMD is still working on propulsion, and is still on the front end of development. Mars is still in a very early, formative phase. ESDMD is still working on detail definition for the Artemis VI-IX missions. Going too fast will mean that the program will grow too expensive and will run the risk of being poorly understood.

Mr. Michael Lopez-Alegria asked what Artemis III and IV will look like, from architecture standpoint. Mr. Free said that the most change has been occurring in the Artemis IV mission; the Agency has been evaluating a lunar landing decision for Artemis IV. Through Appendix P and Option B, it seems like a landing on Artemis IV is possible, however anything beyond Artemis III is incredibly complex given the number of launches that are planned for Gateway. The program is also still quite challenged by budget constraints in Appendix P and Option B for hardware, to get to services down the road. Mr. Hale asked what kind of advice ESDMD could use from HEOC. Mr. Free requested that HEOC point out blind spots; e.g: what is the next element to pursue, what do we do between Artemis I and II? For the Moon to Mars program: what is the right organizational structure for handling risk, accountability, and keeping missions flowing? What is a reasonable pace? Ms. Lueders echoed Mr. Free's remarks, noting the many things going on, current geopolitical positions, and the great deal of interdependence between programs and frameworks: maintenance of cargo and crew services to ISS, getting ready for the ISS extension, planning for what comes after ISS in terms of commercial capabilities in LEO. How do we do things around and on the Moon? Mr. Free added that NASA has to get used to doing multiple complex missions, such as pushing the I-HAB out to Gateway during Artemis missions— these are all going to be difficult things to do.

Artemis I - IV

Mr. Mark Kirasich provided a mission overview of the Artemis program, missions I through IV, first presenting the planning manifest from 2022-2031, split into SMD-led, ESDMD-led, and STMD-led elements. Focusing on ESDMD, the manifest shows that Artemis II will fly in 2024, followed by Artemis III in 2025, which will include the SpaceX Starship lander. Artemis IV is scheduled for 2027, which will include the I-HAB delivery to Gateway. The Lunar Reconnaissance Orbiter (LRO), an SMD mission, is providing imagery for ESDMD, SMD, and STMD to plan landing sites on the lunar surface. The CAPSTONE CubeSat is also on the way to the Moon, where it will perform navigation and control maneuvers in the near-rectilinear halo orbit (NRHO) and validate the utility of the NRHO attitude for Artemis missions.

Mr. Amit Kshatriya continued the briefing, covering the major milestones for Artemis I. He paused to applaud the Artemis team, comprising thousands of people who have contributed to this vehicle through manufacturing, component-level testing, and assembly, all over the country. These American workers and

engineers, who are also moms and dads, understand that the sacrifice is worth something, in addition to their own technical duties. Technical progress has continued over the last few months at Kennedy Space Center (KSC). At the last wet dress rehearsal (WD4), the team demonstrated full cryogenic loading, and validated software and communications systems. The last test objective is the all-up test in space. The first launch attempt was pretty decent, but there were some issues with signatures from Engine 3, so the attempt was called off. It was a good test of moving from the testing mindset to the operational mindset. During the second attempt, there was a fairly large liquid hydrogen leak in the tail mast umbilical interface. Since that time a pad servicing technique was developed for performing a full-up cryogenic test. Another attempt on 27 September was prevented by Hurricane Ian, the eye of which crossed over KSC. The teams have rallied, and are not tracking any major issues before the next attempt. Dr. George Sowers asked how confident the team is about hydrogen issues. Mr. Kshatriya said he thought they had done the right engineering analysis, while they still don't have the full proximal cause of the leak; the fault tree is still open and is continuing to be worked as the team prepares for the next attempt. There are operational and engineering mitigations in place for all the open branches and leaves on the fault tree, however. Dr. Sowers noted that this represented some residual risk. Mr. Kshatriya concurred. Mr. Alibaruho asked if there were any type of system-level testing that had been done in the past (Shuttle, or similar rocket system) that wasn't done this time. Mr. Kshatriya said that the program has probably done more than it has been doing in other hardware programs, including component-level testing that had been performed to a level of rigor that the Agency has adhered to in the last 15-20 years. Mr. Hale felt it had been very analogous to what was done during the Shuttle era, very rigorous and complete. Mr. Kshatriya noted that as the program transitions from development to operations, he would say they'd be going in the other direction in order to keep moving. However, operations will have been preceded by maximum rigor before reaching this point. Mr. Kshatriya briefly reviewed the mission map: launch, initial orbit, insertion into an orbit between Lagrange points 1 and 2, return transit, and retrieval off the Pacific coast.

Artemis II, the crewed flight test, is progressing well. Engine section components are due to be joined shortly. Mr. Hale asked, assuming a successful Artemis I, how likely Artemis II would be to launch in 2024. Mr. Kshatriya felt the date was pretty solid, but there would need to be some component availability post-Artemis I. In terms of the LV, the launch is ready to go. About 70% of all the Crew Module hardware has been installed, the Service Module initial power-up has been completed, and functional testing is under way. Artemis II Core Stage progress at Michoud Assembly Facility also continues apace. Artemis II is being designed as a free-return mission, and risk is constrained by the Loss of Crew requirement; NASA will not commit to the Moon until it really understands the vehicle. Mr. Lopez-Alegria asked for details about the Artemis II mission. Mr. Kshatriya said that the vehicle will stay in high-Earth orbit for 24 hours, travelling four days out from and four days back to Earth. Mr. Voss asked what the biggest concerns were for staying on schedule for Artemis II. Mr. Kshatriya cited assembly flow out of KSC for the Crew Service Module (CSM), and also ongoing struggles with craft labor availability; this is true for spacecraft in general. Spacecraft workforce specialists are in high demand. Dr. Sowers asked if there were adequate schedule margin to allow Lessons Learned to be absorbed from Artemis I, in time for the launch of Artemis II. Mr. Kshatriya noted design is finalized but Artemis I launch lessons learned will be incorporated. The main issue will be the heat shield and the time needed to deal with any changes that might need to be made between mission launches. Asked about vibration, environment, and loads, Mr. Hale said there was extensive development flight instrumentation (DFI) on the spacecraft. Mr. Kshatriya felt there would be enough time built in to make the necessary updates. Mr. Hale added that there were a handful of avionics components from Artemis I that will be re-used.

Mr. Kirasich described details of the Artemis III mission, noting that it will require the integration and cooperation of six programs. The Artemis III baseline is an Orion-to-HLS direct mission; delivery to an NRHO, with four crew to lunar orbit, and two crew to surface. The new elements will be Starship and exploration spacesuits. Orion will perform a full-up rendezvous with HLS. Common elements will be the

Crewed Orion on Block 1 SLS with Interim Cryogenic Propulsion Stage, enhanced ESA Service Module, and Mobile Launcher 1. Artemis III will enter an NRHO orbit, 69,000 km at its highest point, 1600 km at its closest. NRHO provides a stable orbit, and will be a good position for Gateway. As the Moon rotates around the Earth, the plane of the NRHO always faces Earth, providing a direct view to Earth for communications; the thermal and solar situation is also fairly constant. Before Orion launches, the HLS Starship will launch; this is a large spacecraft that will carry much up- and down-mass. Its size will require fueling from a fuel depot in Earth orbit, and it will require a multilaunch scheme. An orbital powered maneuver (OPM) will be required to get Starship into NRHO; Orion will then dock to Starship, move supplies and crew, and a few days later, two crew will use HLS to descend to the lunar surface while two crew remain aboard Orion. Crew will spend about six days on the lunar surface; walk on the surface and collect samples, then ascend to Orion and re-dock. There will be a two-critical-maneuver sequence to return to Earth. There is still discussion about how many EVAs to do on the mission. Asked why Starship will need to refuel in space, Mr. Kirasich said that it is a large spacecraft that requires a lot of propellant. The amount of fuel can be modulated depending on the mission. The Starship is not launched with a full allotment of fuel; it needs tankers and depots to deploy. Asked if anything had recently changed in Artemis III mission planning, Mr. Kirasich said the basics have been constant: details, particularly related to contingency planning and surface operations are in work.

One accomplishment over the last six months is that the agency has downselected to from 30 to 13 candidate landing regions at the South Pole for Artemis III,. These regions are mostly of interest to *in-situ* resource utilization (ISRU) community, but also to science. Key site features include continuous sunlight, gentle slope, and an Earth view. Another downselection will take place in Summer 2023. Asked if the program were considering the activity of CLPS missions such as the Volatiles Investigating Polar Exploration Rover (VIPER; launching in 2024), Mr. Kirasich affirmed that this was the case, and that the program expects to learn a lot from the early missions, and will be paying attention to plume surface interactions and lighting. The programs are staying in close contact, talk to each other regularly, and this will help inform the downselect process. Asked if there would be any chance of interference with the CLPS missions, Mr. Kirasich said the missions will stay informed of both commercial and international players. Mr. Hale noted that the Chinese have announced a similar set of target exploration sites at the South pole. Dr. Condon asked if there would be primary, secondary, and tertiary sites, with some flexibility to change sites during the descent stage. Mr. Kirasich said that planning will include some amount of flexibility to maneuver the spacecraft; that is still in work.

Mr. Kirasich reviewed major ACD milestones for Artemis III, as the production makes good progress around the world, at sites including Germany. The crew module pressure vessel proof test and motor segments have been completed, and engines are ready for delivery to the Michoud Assembly Facility. Manufacturing has started for the existing three elements. There is a detailed master schedule in place; the critical path for this flight is currently Orion. The Program is coming up to speed on Starship, which will launch on the first flight of the SpaceX Super Heavy Booster. Axiom Space was just selected to develop the lunar exploration suits. For the initial Human Landing System, the appendix H option A was awarded to SpaceX, which includes two test flights to the lunar surface, one uncrewed and one crewed (Artemis III). Starship will fly more than what is on contract for NASA. SpaceX has done very well in completing the Option A contractual milestones for HLS in calendar year 2022, and has made a lot of progress on engines, and on Raptor in particular, which is a new engine. The original goal was to produce seven engines per week, and SpaceX has met this milestone. The company also demonstrates very appropriate levels of insight dealing with issues that have arisen from this rapid production rate. Cryofluid management, in-space propellant transfer, and long-duration flight tests are on the top of the risk list. There will be extensive testing on multiple tankers and on Starship refueling in low Earth orbit. Dr. Sowers asked about plans for long-duration storage for cryogens in space. Mr. Kirasich indicated that SpaceX intends to use these fuel depots to demonstrate their utility for other missions, and there seems to be a plan in place to keep the depot “filled up.” Asked about the risk assessment for micrometeoroid

orbital debris (MMOD) damage, Mr. Kirasich acknowledged the point, but did not have the most recent analysis at hand; he said he would add it to the list. Mr. Hale asked about timeline details such as: When is the uncrewed demonstration? How many tankers does it take to build up the depot? Mr. Kirasich said there is an integrated master schedule which is tracking four major Starship flights, which also includes the first flight in early December, the first flight of the Super Heavy booster, and Starship-to-Starship propellant transfer. Asked to describe the HLS to Orion docking procedure, Mr. Kirasich said that Orion, on the outbound flight, is the chaser vehicle. It meets with HLS at about 4 o'clock on the NRHO orbit, with a 12-hour window, a relatively linear process. The Orion nose docks to the Starship nose. For ascent from the lunar surface, the mission is still working out those details. All the vehicles meet common docking standards. In terms of rendezvous and proximity operations (prox ops) sensors, Orion has a lidar sensor and docking camera, and an out-the-window view. There will also be relative navigation capability. The lidar will require some sort of retroreflector. Asked if the first time docking will take place in NRHO, Mr. Sarafin said that this will be demonstrated first, and there will be prox ops testing in other orbital environments. Asked how the crew accesses the lunar surface, Mr. Kirasich said that SpaceX has developed an elevator, with an independent back up system, with a similar system for cargo. The bottom 2/3 of the Starship holds fuel, while the "garage" is slightly above the surface. Mr. Alibaruho asked, with respect to the known human response to space environment, whether such data had been taken into account. Mr. Kirasich said that yes, everything from decisions about food and exercise devices, to pre-breathing protocols, have been based on data collected over the decades. Cabin conditions have been refined to reflect this as well. The mission duration will range from 25-34 days on this particular flight, thus the crew will need to do more focused exercise to offset physical impacts. Mr. Voss requested a detailed briefing on the HLS; Mr. Hale put the briefing on the agenda for HEOC's January meeting.

. Mr. Kirasich described the plan to put another landing on contract in the near future, through Appendix P, which is open to all industry except for SpaceX and will contain commensurate requirements to the work SpaceX will perform under Option B, an option included in their initial lander contract under Appendix H. At present, the Agency is conducting Sustaining HLS studies; the ultimate goal is to have two companies on board to provide support. The program is getting close to having Option B on contract, which would support an Artemis IV mission. Mr. Hale described the "Sustaining Lunar" concept as increasing from two crew on the lunar surface to four, a longer duration on the surface (up to 30 days), and a larger amount of mass. Mr. Lopez-Alegria asked what happens to Starship once the crew transfers to Orion. Mr. Kirasich said that for the first mission, the plan is likely to dispose the Starship into a heliocentric orbit. For future missions, there may be plans to reuse. Mr. Kirasich described the steps remaining for the first Starship Orbital Flight Test/Super Heavy Booster, including a Federal Aviation Administration (FAA) license before launch in early December. Starship will descend and land off the coast of Hawaii. Asked if the booster would be recovered after the first flight, Mr. Kirasich thought not.

The Artemis III EVA system will include use of updated suits that will be suitable for lunar surface exploration. The system will have advanced life support across the board, and improved thermal control. The suits will accommodate a larger range of body types, and will also use updated tools for collecting samples and doing other work. The exploration EVA Services (xEVAS) contract was awarded to Axiom Space and Collins Aerospace, allowing both the companies to compete for task orders within the contract. ISS task orders (TOs), and Exploration task orders. Each company has its own suit design. The TO for Artemis development and demonstration on Artemis III has been awarded to Axiom. Award of the TO for ISS development and demonstration is planned for the near future. NASA developed a government reference design to validate requirements and reduce development risks; an experiment to test the thermal system of this design was completed and flown on ISS for two years, completing 25 simulated EVAs. Testing is now being done in analogs, such as terrain in the Iceland highlands, Desert RATS, and other field studies, to practice navigating under a variety of lighting and surface conditions.

Artemis IV will have a new set of first flights; the biggest change will be Gateway initial capability, including the placement of the Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO). These two elements will launch together approximately one year before Artemis IV. During Artemis IV, Orion will bring the International Habitat (I-HAB) to the Gateway. Two other elements will also be part of this mission: a human landing system, and the first flight of the larger upper stage of SLS, SLS Block 1B with Exploration Upper Stage (EUS). Orion will dock at Gateway and crew will transfer there via a far more complex series of maneuvers. The descent to the Moon and the ascent will likely be similar to the Artemis III mission. The EUS is a larger, higher-performing upper stage, which will enable missions to bring larger co-manifested payloads to NRHO. Launch opportunities will be constrained by the co-manifested payloads; the I-HAB is estimated at 10 metric tons. The I-HAB CDR will take place on November 3, on schedule to support Artemis IV. The larger rocket will need a bigger Mobile Launcher (ML, or ML-2), taller and heavier, with modified access arms, and additional interfaces for co-manifested payloads. Right now, ML-2 is driving the Artemis IV schedule and is affected by steel supply chain issues. The team is working the challenges to get it back on track.

Gateway will provide an orbiting platform where astronauts can live and work in lunar orbit PPE will provide power to Gateway. High-power solar electric propulsion (SEP) will be used to transfer PPE/HALO, launched on a SpaceX Falcon Heavy, on a 10-month cruise to its NRHO orbit. Gateway initial capability (PPE/HALO) failed a PDR Sync Review in May, due to some thermal issues, which led to some changes. A PDR-informed Sync Review technical closeout is now scheduled for December. Manufacturing has begun for both HALO and PPE. Testing is ongoing at Glenn Research Center and elsewhere. The I-HAB will be provided by ESA, and logistics will be provided by SpaceX; SpaceX was recently selected under the Gateway Logistics Services contract to deliver cargo, experiments, and supplies. Mr. Hale commented on the many moving parts involved, and the impressive amount of work that had been accomplished. Asked who the contractor is for SEP, Mr. Kirasich said Aerojet was providing the smaller component and Busek the larger. Ms. Nancy Ann Budden asked if any improvements had been made in glove design to address known issues such as hand exhaustion and flexibility. Mr. Kirasich said that advances had been made in both suit and glove performance, including hand motion, and that he would follow up with specific data. Asked about any major schedule concerns, Mr. Kirasich identified ML-2; otherwise the Gateway schedule is pretty set. A larger integrated master schedule is to come. With Gateway, changes in the PPE contract need to be finalized and integrated into the schedule, and some issues with the Aerojet thruster need to be worked out. There are a lot of moving parts, with components at varying levels of maturity.

International Space Station Update

Ms. Robyn Gatens gave an update on ISS. Station is currently in the Decade of Results: enabling deep space exploration, fostering commercial space industry, inspiring humankind, providing national human space flight infrastructure, enabling international collaboration, and conducting research to benefit humanity, as the transition is made to commercial LEO. ISS just completed Increment 67, and enabled the Axiom-1 mission in Spring 2022. Since that time there has been a SpaceX Crew-4 rotation, two Russian EVAs, Boeing OFT-2 launching/docking, SpaceX CRS-25, the end of one Soyuz crew rotation, and the first integrated crew flight with Russia. ISS is now in Increment 68, and will soon be receiving a Cygnus delivery, and SpaceX CRS-26 with second set of rollout-solar arrays (ROSAs).

NASA signed an integrated crew agreement in July with Roscosmos for astronauts to fly on both US Crew Vehicles and Soyuz, which is important because it ensures that Russian and NASA crew expeditions fly together. US and Russian crew are not trained to operate each other's side fully. The agreement provides much better risk postures, and provides one crew swap per year, until Boeing comes online in addition to SpaceX. NASA is still assessing options for Fall 2023. The current configuration includes a Crew-5 Dragon on the forward port. Station is always busy with vehicles coming and going. EVAs are coming up in November and mid-January to prepare the next site for the next ROSAs; crew will be installing mod kits and routing cables. Russian crew also have EVAs scheduled in November and December to do more work on the European

robotic arm. Ms. Gatens noted an EVA anomaly that had taken place in March of this year. Upon completion of this EVA, crew noticed a thin layer of moisture inside the helmet after re-pressurization, obviously a concern. The event was identified as a close call, ISS stopped all EVAs pending investigation, and the suit was returned for inspection. No hardware failures were identified. The moisture was most likely caused by integrated system performance. ISS added a helmet absorption band in addition to the existing absorptive material. A special FRR was called, with no disruption in schedule.

Ms. Gatens provided an update on an atmosphere leak identified in 2019, in the Russian Service Module. Crew located and permanently sealed two very small cracks (grain of salt size), and sealed a third; Russian crew taped up some sections as well with Kapton tape. The leak has been knocked down to about a pound a day. Strain gauges were installed. Right now, there is no immediate concern. ISS is isolating the compartment as much as possible, and can permanently seal it in the future if necessary. Mr. Voss said the leak volume sounded high. Ms. Gatens said that while it exceeded specifications, it is not as high as it had been. A meeting participant clarified that the actual specification/day is actually 1.5 pounds.

Other significant items of interest include End-of Life (EOL) deorbit planning. Under baseline planning, the original thought was to use 3 Progress vehicles. Russia was reluctant to do this and asked NASA to look to U.S. solutions. NASA released an RFI to industry in August of this year for a US deorbit vehicle, and received good responses. Forward work is in planning, and an RFP is expected early in 2023. US-Russia relations and Station operations continue to run smoothly and professionally. The first integrated crew rotation is successfully under way. Science demand has been increasing for both internal and external ISS space, and crew time; it is a good problem to have. The bad news is that demand is so high that creative planning is needed to accommodate everyone. NASA is taking a look, at the Agency level, at what to do to maximize the use of ISS and to revisit the science prioritization processes.

In terms of utilization, there remain some capability gaps that need more time on LEO to close out. These areas include the Environmental Control and Life Support System (ECLSS), food, and exercise equipment. These data are being used to inform requirements for LEO contractors. It is a busy time for technology demonstrations. ISS successfully initiated technology demonstrations: a hydrogen sensor for oxygen generation assembly; a radiation monitoring BioSentinel, a control experiment for Orion on Artemis I; RFID Enabled Autonomous Logistics Management (REALM); and XROOTS, a food and nutrition experiment. ISS is currently working through issues with the Universal Waste Management System and hoping to get it operational soon. At present, ISS is using an alternate fecal container, and a collapsible contingency urinal. Other Exploration Capabilities Development Technology Demonstrations for FY23 include projects in life support, environmental monitoring, fire safety, and exploration medical systems. There are 8 technology demonstrations planned for FY23.

In research highlights on ISS, the Earth Surface Mineral Dust Source Investigation (EMIT) recently reached its "first light" milestone. EMIT measures spectra, looking at minerals and the composition of dust in various areas on Earth. The data are collected in 60 square kilometer "scenes," wherein each slice is a wavelength. EMIT can also detect methane, a potent greenhouse gas. In the area of biological research, UC San Diego has donated $150M to set up a laboratory on ISS for in-space production of stem cells. There is also a project devoted to manufacturing a protein-based artificial retina, designed as treatment for retinal degenerative diseases. The experiment successfully manufactured a 200-layer film on ISS, found to be more uniform than control retinas created on Earth. The project has the potential to create better retinal implants than can be manufactured under terrestrial conditions. Research has begun to commercial LEO providers; Sierra Space recently signed a memorandum of understanding (MOU) for this purpose.

ISS research statistics to date include almost 3500 investigations carried out through Increment 68, representing 109 countries, soon to be 111. Station also continues to provide STEM education opportunities and inspiration; over two million students have engaged in over 800 experiments launched to the ISS, reaching from pre-kindergarten to high school to the university-level population. Public engagement is also very important, as millions follow "Spot the Station" on social media; many other are participating in Mission

Equity Campaign Initiatives. Following the outcome of an independent review, the ISS National Laboratory, or Center for the Advancement of Science in Space (CASIS), has completed all IRT actions, overhauled its annual performance goals measuring the progress of CASIS and used to measure throughput, and is now measuring outcomes from work. The Office of Science and Technology Policy (OSTP) has kicked off a microgravity research interagency working group, which Ms. Gatens is co-chairing with a National Science Foundation representative; NASA is now looking at how an entirely interagency space station would work.

With regard to the extension of ISS lifetime, NASA has been working with all international partners as they extend operations from the original 2024 EOL, now extended through 2030. The new Director General of Roscosmos has publicly announced that Russian would like to continue working with NASA until their own station is up by the end of the decade. A structural life assessment is now under way, which will actually assess the health of ISS through 2032. Next steps will be to examine how international partnerships will work on commercial platforms; NASA is working to define partnership goals, and is looking at platform-agnostic applications and investigations. Mr. Hale said he hated to hear the word "deorbit," considering the many accomplishments of ISS. Dr. Condon asked if NASA was considering what sorts of things it would like to salvage from ISS. Ms. Gatens said there are things on Station that could be salvaged for historical purposes, as well as for re-use (of ground spares, e.g.), that could be brought down on cargo vehicles. The Agency is already talking to the Smithsonian Institution. It will not be possible to retrieve whole modules. Dr. Sowers asked if there had been any talk of boosting ISS to a long-term stable orbit. Ms. Gatens said that NASA had concluded that such a scheme would be impractical, as it would take great deal of energy to boost, followed by continuing attention to maintain the orbit.

Commercial Crew

Mr. Phil McAlister gave a briefing on the Commercial Crew Program (CCP), which has enabled 30 space travelers to visit ISS since its inception two and half years ago. Almost a third of market has come from private astronaut side thus far. NASA is pleased to see that the public purpose part of CCP is coming to fruition. The CCP vision for 2022/23 is to safely execute the mission manifest, and sustain a productive healthy safety-focused programmatic culture. CCP has approved a five-time re-use of the Dragon capsule and the program is working to get the Boeing Starliner certified. CCP wants to ensure crewed access to space for the long term, and has purchased additional missions to take it through the bulk of the ISS lifetime. NASA is going to need certified crew transportation even after ISS retires, thus a primary goal for CCP is to ensure a competitive landscape for commercial human space transport.

SpaceX completed Crew-4 in October, with 170 days on orbit, having overlapped with a number of missions. Crew-4 was the fourth rotational mission with SpaceX, launching four crew members, in the fourth month of the year, on a fourth flight booster; a first for Commercial Crew and a huge accomplishment for the team and industry. CCP continues to take an incremental approach to more and more re-use of flight subsystems. Crew-5, launched on 5 October, will return in February, and is giving daily newsbriefs. Operations are nominal so far. Crew-5 marked the second flight of Endurance; it was a smooth uphill flight, launched on the first attempt two days after Hurricane Ian passed through. Crew-6 is scheduled for February. The crew has been named, and the Endurance vehicle will be used.

The Boeing Orbital Flight Test-2 (OFT-2) was launched in May on an Atlas V rocket, and marked the first time both CCP crews were docked to ISS at the same time. Starliner met all its orbital flight test objectives, although there were several flight anomalies that will need to be assessed and closed before Crew Flight Test (CFT). Overall OFT-2 was a very good mission. The CFT launch date is still under review. It will be an approximately two-week mission; the vehicle will be Spacecraft-3, Calypso, with a new expendable service module. A Centaur, booster, and LV adapter are in storage at the Cape and awaiting final integration while NASA and Boeing continue to evaluate hardware. To date, both CCP providers have operated safe flights to ISS in 2022. Going forward, the program will focus more on flight cadence, while continuing to be smart and safe. It is not a time for complacency, despite how smoothly things have been running.

Mr. Lopez-Alegria asked where CCP was on certifying five flights on the Dragon, in terms of boosters and spacecraft. Ms. Lueders indicated that CCP was up to five on the spacecraft side, but might not be up to five re-uses yet on boosters. Mr. McAlister said that once Boeing is certified, CCP hopes to alternate providers regularly, every other flight. As to direct handovers vs. indirect, Mr. McAlister said that the preference is to always do direct handovers, but there may have to be some indirect handovers depending on conditions. Asked if Starliner was a new expendable service module, and whether there is a difference between the reusable and "new" expendable models, Ms. Lueders said that the Boeing service module has never been reusable. Mr. Voss asked if there were any major unresolved issues from Boeing OFT-2. Mr. McAlister said he knew of no major issues, but that CCP was still working on parachutes, software, and thruster issues, and has gotten over the hump.

Just within the last year, the program has spent much more time on Lessons Learned than it has in the past. The other programs have also been responsive to the CCP experience since it has been breaking new ground. The lessons are obviously not portable to every program, but CCP has been pleased at the receptivity. That said, the public-private paradigm is not right for every mission. Fixed price contracts can create their own challenges: for instance, such contracts can't push the state of the art, technologically. It is important that the industry partners really understand the job and it is important to maintain competition as much as possible.

Ms. Lueders commented that Boeing has made tremendous progress through OFT-2, while they are continuing to go through the list, and it will be important to have multiple providers. Mr. Hale agreed, and asked what sort of lead time can be anticipated for establishing multiple providers for commercial LEO. Mr. McAlister noted that CCP started, practically speaking, in 2015, and its goal was to be operational by 2017. However, this was not an Agency baseline commitment. SpaceX was certified in the March 2020. Mr. McAlister felt that outcome showed that NASA was performing as it said it would: safety first, not schedule-driven, but obviously not as fast as NASA had hoped. Plan B had been to purchase more Soyuz rides. Mr. McAlister felt that NASA is using a similar strategy with commercial LEO destinations. The current hope is to have commercial LEO destinations by 2028, as the Agency is focused on having "no gap" between ISS EOL and commercial LEO platform availability. He said he hoped the US government would recognize that space transportation is shaping up to be much like maritime, highway, and air transportation, and would take steps to relieve some of the burden from NASA. Without a push, everyone will think "NASA's taking care of it." Ms. Lueders noted that with fixed price contracts, initial worries had been that companies would take short cuts, but that Boeing had taken it upon themselves to invest in the second orbital test flight. SpaceX had to redesign its whole propulsion system as well. These actions are a credit to both companies in that they have continued to press on with human safety and test flights.

Asked if there were enough Atlas rockets available for Boeing launches, Mr. McAlister said that the Agency is having that conversation now, and would like to have at least two independent LV providers. There are other companies that are interested in getting certified for Commercial Crew transport. Sierra Nevada and Blue Origin are still under consideration. Mr. Hale commented that everybody thought after Shuttle that capsules were easy, and since that time we have certainly found this belief to be untrue, especially with regard to parachutes. He added that once the learning period expires, the FAA will be allowed to impose a much more extensive set of regulations for commercial crew transport; this could be eye-watering. Mr. McAlister said that CCP talks with FAA regularly, and that NASA must truly partner with other government agencies and share its 50 years of experience.

<u>Public Comments</u>
Chris Gilbert:
In the Artemis III presentation, the Starship landing legs as shown in the graphic seem to be under-dimensioned considering the height of the vehicle and the possible height of the center of mass. I am sure

the Starship can maintain a vertical attitude during the final landing phase, but there is no guarantee that the lunar surface will provide uniform load-bearing properties, or that one or more landing feet end up higher or lower than the others.
Does the Committee consider the Starship configuration to represent an undue stability risk?

Emily Braswell:
Is the Mars Transportation Architecture Study (referenced in previous meetings) completed, and if so, when will it be publicly released?

Robert Zimmerman:
During the July NAC-HEO meeting, there was considerable discussion of two topics where follow-up information would be helpful: 1.) The need for a unitary Program Manager for Artemis at HQ. Further discussion or resolution of this? 2.) Lunar sustainability appears to have been dropped from the briefing charts - 'returning to the Moon to stay. "Where does this stand?

Heather D. Smith:
Good afternoon, will the slides be published for the public to see/use?

Chris Gilbert:
Will Starship lunar descent and landing maneuvers be fully automated or will the crew be able to take over manual control, as they did in the Apollo missions?
If manual control is envisaged, would the Committee expect SpaceX or NASA to provide a flying simulator vehicle to enable astronauts to practice manual control of the Starship during the landing phase?

Angeliki:
Is there any thinking within NASA to explore if it is feasible for a landed Starship HLS to be turned into a first basecamp for extended surface operation?

John Tylko:
In order to evaluate the reality of the Artemis schedules, have any efforts been made to compare to Apollo? For example, the Apollo LM contract was awarded in November 1962 and the first unmanned flight was in January 1968 and the first manned flight in March 1969, six years and five months later. It seems like Artemis is underfunded relative to Apollo with an expectation that it can achieve vastly better schedules with fewer resources. An unintended consequence of NASA's public-private partnerships is a lack of detailed insight into many of the programs and a lack of responsiveness to media queries. Perhaps going forward NASA's service contracts and agreements should address this issue more directly. Thank you.

William Harwood:
Wayne, you asked at one point how many Starship tanker flights would be required before an HLS can head for the moon. I don't think there was an answer to that part of your question. Does anyone know?

Mr. Hale noted that there appears to be a great deal of (pubic) interest in more details, and said he would carry these questions will go forward to the next HEOC meeting. Dr. Siegel announced that slides would be made available on the HEOC website shortly after the conclusion of the meeting.

<u>Discussion and Recommendations</u>
Mr. Doug Ebersole asked if the hydrogen leak on SLS had been identified in any of the risk management plans. If it was identified, there could be more confidence in the rest of the system. Mr. Hale said would think it had been identified, but he was not certain at what level, or how it was categorized. Dr. Ebersole asked whether it was known to be a design failure, or manufacturing process failure (i.e. what was the

root cause of the failure?). Dr. Sowers said he didn't think they knew if it was seal design, or process implementation, but that they did freely admit that they hadn't closed out the root cause analysis. Dr. Ebersole asked if any changes had been made in the pre-launch checklist. Dr. Sowers asked if they had a design change in mind that would preclude procedural workarounds. Dr. Ebersole asked: is there some process that triggers a thought process on mitigating a risk in other systems, such as on the lunar surface? He added that the number of concurrent contracting activities going on brings up concerns about supporting specifications and keeping them aligned: what kind of governance of "shall" statements is in place? How do they maintain discipline and diligence in keeping the "shalls" aligned? Mr. Hale said these were questions for Erica Alvarez. Dr. Patricia Sanders thought that HEOC would be pleased by what the ASAP has uncovered in terms of findings, with respect to these questions. Mr. Hale asked if HEOC had any recommendations to render on the ISS leak in the Russian service module. Mr. Voss said he would be interested to hear what NASA has done to allay concerns. Mr. Lopez-Alegria agreed that the HEOC should request a deeper briefing, to determine what the likely failure mode would be were the leak to propagate quickly. Mr. Alibaruho concurred. Ms. Lynn Cline said there used to be a joint Stafford Committee that would consider these issues on a periodic basis. Mr. Hale said they still exist and meet, and that he would contact them. He added that he was pretty sure that ASAP is on top of this problem and didn't want to overload NASA with quasi-independent groups. Dr. Sanders confirmed there is a lot of work going on between Russia and the US to understand the ISS situation. Ms. Budden suggested obtaining more information from the ASAP.

Ms. Cline suggested HEOC say something about the value of competition and having more than one provider (re: Commercial Crew and Commercial LEO), and encouraging the Agency to continue with its efforts; she offered to write some language for a recommendation. Dr. Sowers said he was struck by how dependent Artemis is on HLS/Starship, including using propellant tankers and space depots; he was a little worried about program risk, as it is the one case where NASA doesn't have the benefit of competition. Mr. Hale shared the concern, adding that the Lunar lander had been the pacing item for Apollo. There is also the matter of dependence on new launch vehicles. Dr. Sowers noted that propellant depots are not trivial to implement; the other part of the concern here is that two of three components are not under NASA control. Dr. Condon thought that this was an important point. Dr. Condon and Mr. Hale suggested either a more detailed presentation or a fact-finding meeting. Dr. Sowers said it sounds like there is a quasi-competition for Starship, and asked if there were some way to pull the competition forward, or to have a plan B in a timely fashion. Ms. Cline said such an approach might be very budget-constrained. Dr. Sanders said it was a two-edged sword, as the leverage on HLS is that they have to meet requirements, but NASA does not control the design, and SpaceX also has to meet other mission needs. The plus side is that it will cost NASA less in the long run. However, it is a delicate balance that does introduce more risk. Mr. Hale said that as the RFP has already gone out for HLS, it is technically in the embargoed competition period, thus he was not sure how much HEOC can press on that. Ms. Cline noted that early in the commercial space transportation effort, NASA also had Space Act agreements with no exchange of funds such that commercial providers could tap into NASA expertise; she thought that some of that experience is already baked into Commercial Crew, which might alleviate some HEOC concerns. Dr. Ellen Stofan complimented Ms. Gatens on her ISS briefing, adding that it was good to hear the inclusion of science in lunar missions, as there are so many other priorities to juggle at an aging space laboratory. She said she hoped that artifacts from ISS would be a priority going forward. Ms. Budden re-addressed the exploration glove issue, as it affects the ability to meet science objectives on the lunar surface: citing Navy Seals experiences, she pointed out that gloves don't always work with human/machine interface in terms of dexterity and specificity, and expressed interest in hearing about how the glove designers are talking with scientists. Dr. Sowers said it would be helpful to understand how science is being incorporated into the many CLPS missions on the manifest. Dr. Siegel took an action to clarify the CLPS mission relationships to SMD.

Ms. Budden noted that with regard to humans taking samples from the lunar surface, the big issue will be temperature and light. Some permanently shadowed regions (PSRs) on the lunar surface are far too cold for human operations, and some tools will not work at all in such extreme environments. Mr. Hale cited this as a topic for a future briefing. He added that HEOC may also want to comment on workforce availability; there is a limited workforce for these tasks, and companies have been raiding NASA for the expertise. Ms. Budden requested a briefing between the suit designers and the science plan. Mr. Hale concluded the discussion, suggesting that HEOC may want to make a formal comment on how well Ms. Lueders and Mr. Free are managing a complex program.

November 1, 2022

Opening

Dr. Siegel re-opened the meeting. Mr. Hale reviewed the previous day's events and introduced the day's first presentation.

Commercial LEO Development/Commercial Space Stations

Ms. Angela Hart provided an update Commercial LEO development at NASA, beginning with a discussion of acquisition strategy for procuring services post-ISS, to allow NASA's continuous use of LEO. The strategy is based on targeting a potential two-year overlap between implementation of commercial platforms and ISS EOL. Phase 1 is early design maturation, allowing industry to develop at their own pace and with their own vision; this approach differs greatly from that used to develop Commercial Resupply Services (CRS) and CCP. The key difference is that at the end, NASA wants to be one of many customers. NASA envisions bringing prices down with competition and allowing industry to develop the economy in different non-NASA ways, while also encouraging these companies to have a business case, with NASA as an anchor customer (not more than 50%). Currently there are contracts in place with four partners: Axiom, which got started a bit earlier than the other three, which have funded SA agreements with Blue Origin, Northrop Grumman, and Sierra Space Orbital Reef. Maturation is ongoing, and early mitigations will be proposed. As part of Phase 1, NASA is maturing its formal requirements, because it is important for industry to understand what NASA requirements are for achieving a human rating. The Agency started putting RFIs out this year, and will for the next few years work toward Phase 2, while acquiring information about the safety strategies offered by the different companies.

The first RFI went out in May 2022. NASA received 292 comments. Workshops are now being developed for Overall Safety Approach and Requirements, and a Commercial LEO Destination (CLD) Certification Strategy and Approach. The effort is still at a very high level of concepts-of- operations (ConOps) for a jointly operated LEO destination. The Agency and industry are "in the same building and city, but not in the same room yet." NASA put out a paper in 2018/19 describing what it wants to do post-ISS, and will follow up with another white paper updating minimal capabilities. This will be an iterative process, as the NASA wants to hear industry thoughts on both core and unique capabilities, and how those stack up against industry/LEO market interests. Mid-2023, the Agency is planning to put out Level 2 requirements, working closely with the Commercial Crew Program. The plan is to have an end-to end-contract that incorporates transportation and integrates thoughts, using a common language for clarity and consistency. NASA wants to extend the success of CCP, which means the Agency and commercial entities really need to think about what this means for human rating, safety, and responsibility. NASA is pressing hard to put out early information that may not be fully vetted, as it really wants to get early feedback to move the iterative process forward. The current plan is to release the minimal capabilities document via RFI, while also trying to find a better way to release such information. RFIs tend to be time-consuming for industry, and workshops seem to be the preferred conduit. A library concept is being considered as well.

Dr. Ebersole asked about the size of the team executing the plan. Ms. Hart said there were about 30 Civil Servants, and a larger contract workforce, and that the team was also matrixed into other expertise. A much larger team is executing; for example, for Axiom, there are hundreds of people working on CDRs and PDRs. As the plan moves to different deliverables, the team will be expanded, and will also move to more traditional Program Offices as Phase 2 (Mission Ops, spacecraft technical offices, etc.) is reached. Dr. Ebersole said that it the work plan sounds well-resourced. Ms. Hart confirmed that sufficient funding has been provided to ensure success. Ms. Budden asked about how many companies the team is reaching out to, and how they are being identified. Ms. Hart said that participation in RFIs have been good; there are about 8-10 other companies that are seriously interested in being involved as sub- or prime contractors. The team will also reach out to those NASA has worked with in the past. NASA is trying to figure out how to advertise better and more widely, and is using press releases as well. Ms. Cline asked Ms. Hart to provide an example of how ConOps might differ in Commercial LEO. Ms. Hart said that providers generally follow NASA models in terms of astronaut selection, and maintenance; a very government-like approach. The differences can be seen in levels of responsibility and where NASA is involved and not involved. NASA is pushing more responsibility toward the commercial world. Some providers will come in and ask NASA astronauts to do some tasks, and others will bring in their own astronauts. The challenge is to come up with an architecture that supports both of these things. Commercial LEO will need both redundancy, and the positive pressure of competition. Commercial LEO is looking at entertainment modules, for instance, but they are also looking to attract commercial research interests. Blue Origin is planning to have the biggest windows ever seen in space, a "desirement" that is driven by market research and business cases. Dr. Sowers commented that in terms of the human rating requirements, there is a concern that getting to the path of requirements may have a stifling effect on innovation; NASA doesn't want to end up getting four copies of the ISS. Ms. Hart said that this is definitely a concern, because people are going to naturally look to high-TRL items in order to make the schedule. NASA is watching this, and it is why the Agency is having the certification discussion early. NASA wants to hear from industry ideas on safety requirements, and what their unique certification processes are for getting to a human rating. It is also a reason that Commercial LEO slowed down the path to Level 2 requirements, in order to take in Lessons Learned from CCP, with proper areas of exceptions and understanding. In the end, human rating must be achieved. It is definitely a work in progress. NASA has lived the pain of certification of CCP with both vendors, so there is a good understanding of how to get to the sweet spot for data and safety.

Ms. Hart discussed the status of various Commercial Destination Free Flyer projects. In September of this year, Nanoracks completed the first in a series of Starlab Research Workshops for their George Washington Carver Science Lab; they do have a good plan to move forward and get to their original CDR. They have also held numerous workshops for industry, one of which NASA participated in. They are working toward a December SRR for the George Washington Carver terrestrial lab, and are attracting an increasingly diverse customer base. Northrop Grumman completed their third milestone, a CDFF ConOps review, in July 2022, and are in the middle of their SRR. They are completing SRRs and SDRs to their own requirement set, with Research Infrastructure Development (RID) closures due by November. They have increased their marketing presence, and are talking publicly about their station to develop business case. Blue Origin has completed three major reviews, and has made many resource requests of NASA. Upcoming- amendment to modify Creep Test. Axiom has a fifth Task Order (TO-5) in place to support Axiom Hab 1 and Hab 2 activities; they will bring their first module to ISS in 2025. NASA must do a lot of work to get a port ready for them. Axiom is progressing well, they have a lot of hardware in build for the two Hab modules. Axiom is also moving forward with the AX-2 Private Astronaut Mission (PAM) on ISS, which is expected to launch in May 2023. AX-2 will have four crew, including Peggy Whitson and John Shoffner, and it will have objectives that are similar to AX-1. As part of that contract, NASA will receive a number of services, such as return of components. The next big milestone on AX-2 will be vehicle integration reviews. A solicitation is out for the next two PAMs. As a result of Lessons Learned, some changes have been made to requirements: stricter workday requirements;

and changed adaptation and setup/teardown times for Private Astronauts; and a formal requirement that a formerly flown NASA government astronaut serve as PAM commander. Axiom has submitted 12 commercial activity requests for AX-2. Only one new commercial activity request outside of PAMs has been submitted since the last DPMC; this request is now in process with the Commercial LEO panel. CLDP is currently evaluating potential updates required for NID 8600-121, and programs in place to enable commercial activities on ISS.

The Commercial Space Capabilities (CSC) program had four unfunded Space Act Agreements (SAAs), including one with Northrop Grumman, Final Frontier, and SpaceX. These are expiring in 2022. NASA is putting out a CSC-2 competition in November; the only difference from CSC-1, NASA will require proposals to show a link to commercial LEO. CSC is also adding other people to come in under unfunded SAAs for transportation, while continuing an umbrella RSAA with SpaceX to support commercial flights. Ms. Hart requested HEOC's continued advocacy for the development of Commercial LEO, especially as the government extends the regulatory framework. Budgets will be very important for continuing human presence in LEO, in the post-ISS era.

Discussion

Mr. Voss asked Ms. Hart if Commercial LEO had reached out to organizations such as other government agencies, internationals, academia, or research organizations. Ms. Hart said the program had not yet included them in the workshops, but that there are a number of teams in the process of reaching out to them. Right now CLD is developing a proposal for what international participation will look like in a public/private scheme. There has definitely have interest from international partners that are already on ISS; CLD is trying to understand what their needs are. NASA is also working with the National Academies to understand what the Department of Defense and other federal agencies want to do in LEO. The presence of multiple capabilities and platforms will support future success. At the Agency level discussions are ongoing in order to support continuation of the National Lab framework, supported by fund allocation; there is a team at Headquarters looking at this. Ms. Lueders said it would be important to keep continuity in the LEO science community, as NASA helps them transfer over to the new paradigm. She reiterated that Ms. Gatens is co-chairing the interagency working group on microgravity research, because maintenance of continuity is a big deal. NASA will have to ensure that ISS science can be continued at multiple locations. The Headquarters team led by Ms. Gatens is also working with other providers to develop a strategy as NASA moves to new platforms in LEO. She is also leading the framework activity.

Dr. Condon commented that NASA has many different roles here, as coordinator, traffic cop, etc. He said he would like to see a definition of roles and responsibilities of the agencies involved. Ms. Hart said the organization is evolving. Ms. Lueders said that NASA will remain a user; ideally when LEO is a fully commercial item, however, NASA will not be a certifier. The National Space Council is working to define and streamline these relationships, oversight, and framework. In 15 years, if NASA is doing NASA work on a commercial station, Ms. Lueders hoped by that time that NASA would be out of the certification role for LEO. She offered to create a simple table and discuss roles and responsibilities at a future briefing, bearing in mind that it is still a work in progress. Mr. Hale said he had been paying attention to high-level policy discussions. Under the articles of the Outer Space Treaty, countries are responsible for their commercial transportation activities. In the US, FAA may be much more involved as a regulatory authority after the learning period ends. Ms. Lueders commented that the discussion is demonstrating that NASA is hitting this maturation period, and will have to start working out details. Dr. Condon cautioned against duplication, and against allowing things to fall through the cracks. Mr. Hale noted that service contracts include launch and landing. Ms. Hart felt that as a program, they were not duplicative; CCP will continue to do its work in human rating; they support missions as the technical experts for transportation. As CLD develops the contracts for commercial LEO, the program will be thinking about those things, and will be tightly aligned with CCP to prevent confusion or concern about

duplication. Mr. Lopez-Alegria said that the NID policy on commercial use doesn't allow for charitable activities, and wondered if HEOC could help with language to bolster that movement. Ms. Hart said that the program was working on it, as many areas are not very clear. Gaps have been found; charitable activities on a government facility is an area that has elicited many questions. These issues will flow into what NASA can and cannot do on commercial destinations, which will be important for PAMs. It's a gray area for now. Ms. Lueders noted that these activities need to retain the fundamental intent of NASA budget appropriations; NASA lawyers are looking at it too. These discussions help and give NASA clarity on what its stakeholders want. NASA is here to serve the public interest.

Findings and Recommendations Discussion:
The HEOC discussed a recommendation on the value of multiple providers to the Artemis program. Ms. Cline discussed the rationale behind the recommendation, and suggested broadening the language beyond Moon and Mars to capture the broader portfolio. Mr. Hale and HEOC agreed that a broadened recommendation would benefit all HEO-related programs. Dr. Sanders said the recommendation should support strategic application and resourcing, which seems to be the long pole. At present, HLS is on a shoestring. Mr. Hale noted that resourcing is beyond the purview of HEOC, but agreed with the sentiment. Dr. Sanders said that ASAP can comment in this area, because it advises Congress as well as NASA. Mr. Hale welcomed ASAP support on the resource issue. Dr. Condon suggested expanding the recommendation to beyond the Directorate AAs to the Administrator, either formally or informally. Ms. Cline noted that final approval of acquisition strategy is beyond the AAs. Mr. Hale said that the sense of the Committee is that this is a recommendation to the Administrator, and that he would carry it forward as such.

Ms. Cline presented a finding entitled Organizational Stability and Focus, explaining that complicated programs can be undermined by a fast pace of operational activity. Mr. Hale and HEOC approved the language.

Mr. Voss offered a thought on the participation of other government agencies and research organizations, and wondered if HEOC should suggest the inclusion of a broader group in the CSC RFI and workshop invitation process, beyond industry. There was not a lot of concurrence with this idea from HEOC. Mr. Hale said he felt that Ms. Hart had absorbed the discussion. Dr. Condon suggested putting the idea in the parking lot and request an update on progress in 6 months to a year. Mr. Lopez-Alegria said that it was really is incumbent on industry to go out and pursue those partners; Axiom is certainly doing that. Mr. Hale thought that commercial development of LEO is of great importance, and deserving of a budget commensurate with the activity. Ms. Cline said that another way to think about it is to tie it to the EOL of ISS, to avoid a gap of human presence in LEO. Mr. Hale noted that HEOC is on the record for having made a similar recommendation in the past.

Findings and Recommendatins:

Short Title of Finding: Organizational Stability and Focus

Finding:

The Committee notes that the volume and pace of programs under ESDMD and SOMD are intense and complex. It is important for the Agency to promote and maintain an organization that is robust and to ensure executing organizations and personnel are insulated from organizational and external turbulence to the maximum extent possible.

For NAC Recommendations (actionable):

Short Title of Recommendation: The Value of Multiple Providers to Administrator

Recommendation: In going forward with the Artemis Program and other HEO programs, NASA should continue to strategically apply its approach of procurement through competition and selection of multiple providers of key products and services, as they have for Commercial Crew and the Human Landing System.

Major Reasons for the Recommendation: The Committee notes that competition for key products and services reduces the cost to the government and selecting more than one commercial provider provides flexibility and potentially safety. Past programs have demonstrated that delays or disruptions to an overall program can occur if there is only one option on a critical path, such as a vehicle to launch crew. The Artemis Program requires many new developments. Given that, it is important to structure acquisitions to provide multiple paths to success.

Consequences of No Action on the Recommendation: Reducing competition and limiting providers puts the program at greater risk of delays and disruptions.

Mr. Hale wrapped up the meeting, and looked to arranging an in-person HEOC meeting for early January 2023.

Dr. Siegel adjourned the meeting at 11:19 am.

Appendix A
Agenda

8:20 – 8:30am	Opening	Dr. Bette Siegel/Mr. Wayne Hale
8:30 – 9:30	Status of SOMD/ESDMD	Ms. Kathy Lueders/Mr. Jim Free
9:30 – 11:30	Artemis I - IV	Mr. Amit Kshatriya/Mr. Mark Kirasich
11:30 – 12:30pm	Lunch	
12:30 – 1:30	International Space Station Update	Ms. Robyn Gatens
1:30 – 2:30	Commercial Crew	Mr. Phil McAlister
2:30 – 2:35	Public Comments	
2:35 – 3:35	Discussion and Recommendations	
3:35pm	Adjourn	

Tuesday, November 1, 2022
NAC HEO Committee Public Meeting

9:30 – 9:35am	Opening	Dr. Bette Siegel/Mr. Wayne Hale
9:35 – 10:30	Commercial LEO development/Commercial Space Stations	Ms. Angela Hart
10:30 – 11:30	Discussion and recommendations	
11:30am	Adjourn	

Appendix B
HEOC Membership

Mr. Wayne Hale, Chair

Ms. Nancy Ann Budden
Director for Special Operations Technology
Office of the Secretary of Defense

Dr. Stephen "Pat" Condon
Aerospace Consultant, former Commander of the Ogden Air Logistics Center,
the Arnold Engineering Development Center
Air Force Armament Laboratory

Mr. Michael Lopez-Alegria
Former NASA astronaut and retired U.S. Navy Captain
President of the Commercial Spaceflight Federation

Mr. James Voss
Former NASA astronaut and retired U.S. Army Colonel
Department of Aerospace Engineering Sciences,
University of Colorado, Boulder

Ms. Lynn Cline
Former NASA Deputy Associate Administrator
Human Exploration and Operations

Mr. Kwatsi Alibaruho
Vice President, Program Management
Industrial Sector Eaton

Dr. George Sowers
Colorado School of Mines

C. Douglas Ebersole,
Former Executive Director
Air Force Research Laboratory

Dr. Ellen Stofan,
Under Secretary for Science and Research
Smithsonian Institution

Appendix C
Attendees

Human Exploration Operations Committee
N. Wayne Hale, Jr., *Chair*, NASA, ret.
Kwatsi Alibaruho, Industrial Sector Eaton
Nancy Ann Budden, Special Operations Technology, DoD
Lynn Cline, NASA HEOMD, ret.
Douglas Ebersole, former AFRL
Pat Condon, Aerospace Consultant
Michael Lopez-Alegria, Commercial Spaceflight Federation
James Voss, University of Colorado, Boulder
George Sowers, Colorado School of Mines
Ellen Stofan, Smithsonian Institution
Bette Siegel, Executive Secretary, NASA

Attendees
Patricia Sanders, *Chair,* Aerospace Safety Advisory Panel
Jeremy Fehrenbacher
David Kerley
Etienne Dauvergne
Renee Pullen
Chris Gilbert
Angela Hart
Mark Carreau
Rick Irving
Kailey Melton
Cullen Balinski
Jeff Foust
Lewis Groswald
Michael Smith
Theodore Kronmiller
Robert Zimmerman
Stephan Gerard
Kevin Foley
Lisa Terrell
Mary Lynne Dittmar
Denise Varga
Joel Graham
Cathy Sham
Barbara Zelon
Catherine Sham
Erin Mahoney
Sylvie Espinasse
Noreen Dahl
Gregory Heckler
Barbara Adde
Laura Forczyk

Joshua Finch
Christy Hansen
James Miller
Kathryn Lueders
B Harvey
Karin Sturm
Robyn Gatens
Jacob Bleacher
Ken Bowersox
Kenneth Chang
Heather D. Smith
Kailey Melton
Rose Jones
Patrick Forrester
Misty Snopkowski
Barry Jenakuns
Stephen Lichten
Angela Hodge
Rose Jones
Lisa Terrell
Margaret Roberts
Dmitriy Zaytsev
Allison G Hannah
Eracenia Kennedy
Joan Zimmermann

Appendix D
Presentation Material

1. Exploration Systems Development Mission Directorate/Space Operations Mission Directorate Status Report; *James Free, Kathryn Lueders*
2. Artemis I-IV Mission Overview; *Mark Kisarich, Amit Kshatriya*
3. International Space Station Status; *Robyn Gatens*
4. Commercial Spaceflight Development Division Status; *Phil McAlister*
5. Commercial LEO Development/Commercial Space Stations Status; *Angela Hart*

Appendix E
Chat

B. Harvey
I didn't notice any lunar base discussion.
from Chris Gilbert (Ext) to Everyone: 2:16 PM
In the Artemis III presentation, the Starship landing legs as shown in the graphic seem to be under-dimensioned considering the height of the vehicle and the possible height of the center of mass. I am sure the Starship can maintain a vertical attitude during the final landing phase, but there is no guarantee that the lunar surface will provide uniform load-bearing properties, or that one or more landing feet end up higher or lower than the others.
Does the Committee consider the Starship configuration to represent an undue stability risk?
from Emily Braswell (Ext) to Everyone: 2:20 PM
Is the Mars Transportation Architecture Study (referenced in previous meetings) completed, and if so, when will it be publicly released?
from Robert Zimmerman (Ext) to Bette Siegel (Ext) (privately): 2:30 PM
During the July NAC-HEO meeting, there was considerable discussion of two topics where follow-up information would be helpful: 1.) The need for a unitary Program Manager for Artemis at HQ. Further discussion or resolution of this? 2.) Lunar sustainability appears to have been dropped from the briefing charts - 'returning to the Moon to stay",,Where does this stand?
from Heather D. Smith (Ext) to Everyone: 2:30 PM
Good afternoon, will the slides be published for the public to see/use?
from Chris Gilbert (Ext) to Everyone: 2:31 PM
Will Starship lunar descent and landing maneuvers be fully automated or will the crew be able to take over manual control, as they did in the Apollo missions?
If manual control is envisaged, would the Committee expect SpaceX or NASA to provide a flying simulator vehicle to enable astronauts to practice manual control of the Starship during the landing phase?
from angeliki (Ext) to Everyone: 2:33 PM
Is there any thinking within NASA to explore if it is feasible for a landed Starship HLS to be turned into a first basecamp for extended surface operation?
from John Tylko (Ext) to Everyone: 2:36 PM
In order to evaluate the reality of the Artemis schedules, have any efforts been made to compare to Apollo? For example, the Apollo LM contract was awarded in November 1962 and the first unmanned flight was in January 1968 and the first manned flight in March 1969, six years and five months later. It seems like Artemis is underfunded relative to Apollo with an expectation that it can achieve vastly better schedules with fewer resources.
An unintended consequence of NASA's public-private partnerships is a lack of detailed insight into many of the programs and a lack of responsiveness to media queries. Perhaps going forward NASA's service contracts and agreements should address this issue more directly. Thank you
from William Harwood (Ext) to Everyone: 2:38 PM
Wayne, you asked at one point how many Starship tanker flights would be required before an HLS can head for the moon. I don't think there was an answer to that part of your question. Does anyone know?

rom Chris Gilbert (Ext) to Everyone: 2:43 PM

Thanks for providing this channel for asking questions
from angeliki (Ext) to Everyone: 2:44 PM
likewise, thank you for the public questions opportunity. Very useful discussions today
rom Emily Braswell (Ext) to Everyone: 2:50 PM
What types of ISS components are being considered for return to earth at the station's end of life?
from John Tylko (Ext) to Everyone: 2:56 PM
What efforts are being made to identify mitigation steps to remedy "brittle" aspects of the Artemis lunar architecture, for example the significant limitations of the service module propulsion system which drives many orbital considerations including reliance on HLS for almost all lunar orbit maneuvers, without the redundancy of an adequate propulsion system on Orion. This is another major difference with Apollo that creates significant additional risk for the Artemis lunar missions.