NASA ADVISORY COUNCIL

HUMAN EXPLORATION AND OPERATIONS COMMITTEE

Virtual Meeting

May 13-14, 2020

MEETING REPORT

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N. Wayne Hale, Chair

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Bette Siegel, Executive Secretary

Table of Contents

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May 13, 2020

Call to order and welcome

Dr. Bette Siegel, Executive Secretary of the Human Exploration and Operations Committee (HEOC), called the meeting to order, made administrative announcements, and reviewed items concerning Federal Advisory Committee Act (FACA) governance. Mr. Wayne Hale, Chair of the HEOC, offered introductory remarks and welcomed committee members. Mr. Hale noted that the meeting had been delayed due to a number of circumstances, and sought to recognize three HEOC members who were preparing to rotate out of Committee membership: Dr. Leroy Chiao; Mr. Robert Sieck; and Mr. Tommy Holloway. He thanked the three members for their outstanding service.

NASA HEOMD Overview

Mr. Douglas Loverro, Associate Administrator (AA) of the Human Exploration and Operations Mission Directorate (HEOMD), provided an update, first displaying a new logo for HEOMD that was designed to reflect plans to travel to the Moon and Mars.

Mr. Loverro first presented findings from a Program Status Assessment of the Artemis Program. The Assessment ran from January to February 2020, with the participation of members internal to NASA, as well as with that of representatives from the Department of Defense (DOD), civil space, industry, and other government entities. The Assessment evaluated the proposed timeline for a Moon landing in 2024, including Systems Engineering (SE) structures, program organization, and schedule, and issued a number of findings. Among major findings, with regard to SE, the Assessment found that NASA lacked a Concept of Operations (ConOps) for the Artemis III mission, that the mission's SE structures were not designed for the necessary decision velocity, and that the mission lacked an integrated verification and validation (V&V) plan. Second, the Assessment found that there is no single formal Artemis Program Organization, which was deemed to be necessary to support the two phases of Artemis. In response, NASA proposed specific HEO organizational changes, which are under evaluation in Congress at present. Third, the Assessment concluded that the Artemis mission schedule is at risk, with the Human Landing System (HLS) being the most critical element of the overall architecture. A number of actions are needed to address the schedule shortcomings, including the provision of appropriate management reserve for HLS. Mr. Loverro recounted, in light of an historically based Schedule Risk Analysis for the Apollo Lunar Exploration Module (LEM), that the LEM had experienced a fairly normal schedule up to the Preliminary Design Review (PDR) milestone, which was then followed by a two-year slip due to drastically altered requirements. The implications for Artemis mean that NASA must focus on requirements from the outset to ensure schedule adherence; must limit new technology development to the maximum extent; and that the program must further evolve as it moves forward to sustainability.

International Space Station

The latest crew for the International Space Station (ISS) is Expedition 63, which launched in April. There are two Russian and one American astronauts on board; this is the first time in a long time that NASA is down to a single astronaut on Station. HEO is very much looking forward to the first crewed Dragon launch by SpaceX. In the meantime, NASA has awarded one more Soyuz seat in October to ensure that the ISS program maintains cadence, while simultaneously anticipating the success of the first human-rated Dragon launch in the Commercial Crew Program (CCP). The two-person Dragon crew is being prepared, taking into account all the necessary Covid-19 precautions. Another CCP vehicle in development, the Boeing Starliner, is still recovering from its December 2019 Orbital Flight Test (OFT) failure, and continues to fix issues. Boeing will repeat the OFT later this year, and is expected to enter into crewed service shortly afterward.

LEO Commercial Service

ISS continues to use commercial resupply service companies. In addition, there are already 17 commercial facilities operating on ISS, which appears to represent the early years of a growing commercial LEO economy development. Biomedical and material science experiments are producing much data. NASA would like to go beyond hosting facilities on government platforms. To this end, Axiom Space has been selected by NASA to provide an ISS commercial port offering "commercial destinations in space." This commercial element is designed to be a free-flyer after ISS itself is decommissioned. Other companies are interested in developing free-flyers, thus NASA foresees a time where the Agency is just one of many users for commercial platforms in LEO.

Artemis Updates

The Space Launch System (SLS) Core Stage is currently at the B-2 test stand at the Stennis Space Center, where it has come through a series of tests to prepare for a full-powered Green Run test firing. SSC and other centers have had to shut down temporarily due to the Covid-19 pandemic. However, Mr. Loverro noted that SLS had been ten days ahead of schedule when the work interruption occurred; SLS had been scheduled to ship to Kennedy Space Center (KSC) in October/November of this year. NASA is beginning to go back to reopen, with restricted operations, and hopes to not be too delayed. Meanwhile, the program staff has been actively writing software and completing the necessary paperwork, to prepare for a smooth resumption of normal operations. The facilities will probably not go back to full operational status until late Spring or early Summer of this year. The Orion capsule has been returned to KSC, having recently returned from the Plum Brook testing facility, where it performed nearly flawlessly. Mr. Loverro expressed high confidence that SLS will enjoy a successful test flight. The Mobile Launcher at KSC is ready to go, and there is a large ground network in place to support the Artemis missions. Mr. Loverro also had extremely high confidence that these ground operations will perform well for Orion.

NASA selected three partners in April— Dynetics, Blue Origin (National Team), and SpaceXto propose three very different designs for human-rated lunar landers (Human Landing System; HLS). Gateway is also moving forward and doing exceptionally well. HEO will now integrate the Power Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO) on the same manifest for a single launch, in order to diminish technical and operations risks, lower costs, and better ensure mission objectives for Gateway. To solidify its 2024 lunar landing plans, HEOMD is also working on changes to the architecture. To buy down risk for future Orion docking capabilities, HEO plans to add a Rendezvous and Proximity Operations (RPO) demonstration to the Artemis II mission. Gateway is not intended to be used for Artemis III, but it will be available for subsequent missions. HEOMD is also doing multiple requirements trades for HLS to ensure that it remains on schedule.

The Artemis Program aims to create a sustainable presence on the Moon to prepare for long-term operations at Mars. NASA recently published a Lunar Surface Plan detailing these preparations. Plans are now in place to completely commercialize NASA's Space Network (SN). The goal is to have a completely commercial source for space-based communication relay services by 2030; Direct-to-Earth service will be maximized, but some user requirements will only be met with relay capability at that time. NASA will no longer build or deploy Tracking and Data Relay Satellites (TDRS); rather, the Agency will capitalize on using the services of the growing commercial space communications industry. In the interim, NASA's Space Communication and Navigation (SCaN) has continued to perform as the unsung hero of space travel. The SCaN network continues to run well despite Covid-19, and is logging a 99.9% success rate on all of its contacts, even with a hugely reduced staff, Mr. Loverro offered kudos to SCaN for its professionalism.

At this time, 70% of NASA's Near Earth Network (NEN) services are commercial; by 2023, NASA plans to move this to 100%, and has an aggressive plan to move forward to take advantage of a healthy and growing market. Mr. Loverro answered a question about how NASA plans to ensure it has access to space

communications, noting that DOD and the intelligence community depend on commercial networks for communication; this is true even for the most important national security entities. These networks all have back-ups. Mr. Loverro firmly believed the same type of services can be used for space networks, while recognizing that there may be technical issues to be resolved along the way. Cellphones, for example, are now able to host many different protocols. NASA will just need to build the right receivers and devices to create similar access in space.

Discussion

Mr. Hale opened the meeting to discussion, noting that many members had been eager to get updates on HEO. Dr. Siegel took an action to post presentations on the HEOC website to enable wider access to information. HEOC member Mr. Thomas Holloway commented that the presentation had been outstanding and thought that if done well, the Commercial Crew Program (CCP) will be successful. He was surprised, however, that the commercial approach was being used to build lunar landers. Mr. Loverro noted that the word "commercial" is not always an accurate depiction of what HEO is doing for HLS, but acknowledged that Mr. Holloway had well-founded concerns. He said that NASA has learned many lessons from the Commercial Orbital Transportation Services (COTS) period, and the adaptation to Commercial Crew Program (CCP) and CRS (Cargo Resupply Services). As a result, NASA now has a host of standards, and is using close-to-traditional contract mechanisms, but recognizes that there will be a multi-step process as both NASA and the private sector "re-learn" how to fly. There is already a large complement of folks across NASA that will be involved in HLS, and which can move more quickly as commercial comes along. A better description for the HLS process is "collaboration," with commercial bearing some of the financial risk, while NASA continually gains insight as the phases move forward. Mr. Holloway asked: who is accountable and ultimately responsible? Mr. Loverro said that NASA is absolutely accountable for human lives and the success of the mission, and will carry out all the necessary certification and testing. He recognized that the Boeing OFT provided a number of lessons, and that he was making sure NASA has more insight going forward. Dr. Pat Condon asked when Gateway would be ready to be used for a lunar landing mission, given that there are no plans to use Gateway for the crewed Artemis III lunar mission. Mr. Loverro said that while the baseline for Gateway is still a Near-Rectilinear Halo Orbit (NRHO), HEO is looking at other orbits within the present architecture to reduce mission risk; there may be alternative orbits to ensure the right balance of risk and benefit. Mr. Micheal Lopez-Allegria asked if the purchased Soyuz seat was a hedge against CCP performance. Mr. Loverro said that the buy was not intended as a hedge, but as a means of better managing the flow of certification for the Dragon vehicle. Ms. Ruth Gardner echoed Mr. Holloway's concerns about commercial HLS efforts, and asked if NASA were using firm fixed-price contracts for HLS; she was concerned that there might be hidden cost drivers in HLS. Mr. Loverro said that the HLS contract is for the first ten months of the effort, which precedes a downselect; NASA is looking for companies to privately invest in their efforts. When NASA does its proposal updates before the downselect, it will make sure there is a clear agreement on what is being built and delivered. NASA reserves the right to change the strategy, and expects PDR-level maturity by the time of the downselect.

Advanced Exploration Systems

Mr. Marshall Smith, Advanced Exploration Systems (AES) Program Director, updated the HEOC, first addressing Artemis mission trades on flights I through III. Currently, AES is considering orbit trades (NRHO vs. lunar polar); balancing risks (e.g., abort options); and options to demonstrate Rendezvous and Proximity Operations (RPO) on Artemis II to reduce risks associated with first-time RPO prior to the lunar landing during Artemis III.

Artemis I will launch from Cape Canaveral, do a burn with the Interim Cryogenic Propulsion Stage (ICPS), and travel to a distant retrograde orbit (DRO). This mission will be a good test for the vehicle, providing a cold soak and a number of engine start/stop maneuvers before it returns to Earth via

splashdown in the Pacific Ocean off the coast of California. AES has left the mission "as-is" as the mission is making good progress. Artemis II will be somewhat different; AES wants to make sure that the crew environmental systems work properly. Artemis II is being planned as a 42-hour High Earth Orbit (HEO) mission, with a lunar fly-by and subsequent return to splashdown off the coast of California. Artemis III follows the same ConOps as Artemis I; however, it will enter into the NRHO elliptical orbit, perform a 6.5-day orbit, land on the lunar surface via the HLS vehicle, support extravehicular activity (EVA), rendezvous with Orion, and then return to Earth. For Artemis III, an AES analysis team is still looking at orbit trades to reduce risk to crew and mission. NASA conducted these final mission analysis trades as part of the Program Status Assessment to ensure safety and mission success.

The HLS Broad Agency Announcement (BAA) stated that contractors may or may not use Gateway for the initial demonstration missions and may dock directly with Orion. For Artemis II, the addition of RPO is seen as a high-benefit choice which will yield a better understanding of how Orion moves and behaves in space, if NASA decides to direct the initial landing demonstration(s) to dock with Orion instead of the Gateway. Each of the three companies that NASA selected to begin development of Human Landing Systems (HLS) has different approaches and architectures for the HLS, and each company must provide an explicit certification approach

AES is considering the pros and cons of an Elliptical Coplanar Posigrade (ECP) orbit; it gives shorter mission durations, allows more opportunities to abort, as well as better access to the lunar poles. Compared to NRHO, an ECP mission risks communication losses during occultation, and requires a number of critical maneuvers to achieve. Its biggest risk is a 17-day delay for a missed return. In addition, eclipse periods need to be kept under 90 minutes to ensure continuing power for Orion. In this orbit, Orion also drifts away from the landing site during the surface mission.

Mr. Hale asked why AES was assessing all the various options again. Mr. Smith described the effort as one last check to see if there is anything else that can be done to improve mission success criteria before finalizing mission requirements. He said he also wanted HEOC to understand how detailed the considerations are. As a result of the most recent mission trades, AES will probably recommend adding a Rendezvous-Proximity Operations (RPO) maneuver the Artemis II mission. The ICPS or a co-manifested satellite might be useful as an RPO target for Orion. As for orbits, AES has not found an orbit, including the discussed co-planar orbits, that offer a lot of advantages over NRHO. Mr. Jim Voss asked if there were a timeframe for the modifications in order to lock in requirements. Mr. Smith said that for current contracts, modifications must be opted for within weeks. Any other mission design changes are three months out; he didn't anticipate any major changes overall. Mr. Loverro added that AES was also looking to lock down requirements for mass brought to the surface, which is also driving trades.

Technology Development

NASA has just signed several contracts to move forward with Bigelow Aerospace, Lockheed Martin, and Sierra Nevada Corporation for Phase 3 of the NextSTEP A Habitation Systems development effort. Phase 3 is focused on Gateway and Foundation Surface Habitat capabilities.

The Bigelow Exploration Activity Module (BEAM) on ISS has been performing well, and has elevated human-rated expandable habitation capabilities from a technology readiness level of 7 (TRL-7) to TRL-9. Expandables have a good mass advantage and the two-year BEAM demonstration has exhibited better radiation protection than some of the typical rigid structures. The module is being used as a storage unit on ISS while it continues to provide data on thermal, radiation, air and surface samples and resiliency to micrometeoroid and orbital debris impacts.

Life Support Systems must be reliable, regenerative systems, and will be critical to life beyond LEO and on Mars. AES has been looking at what will be needed for the evolution of life support systems beyond ISS, e.g., environmental monitoring, microbial controls, oxygen generation, carbon dioxide removal, and water purification. In atmosphere management, AES is looking at four different carbon dioxide scrubbers, three of which will fly to ISS in 2021, and one of which is on the space station now. The scrubbers must be tested for long periods of time before they can be downselected, to yield enough data to demonstrate that they can be deployed on long-duration missions. Radiation management in terms of detection, shielding, and monitoring have been studied on ISS for a decade; there are now miniature sensors for monitoring and detection; and a better understanding of shielding. The fourth Spacecraft Fire Safety Experiment (Saffire IV) was remotely activated inside the Cygnus cargo vehicle after it departed the space station on 11 May. Throughout several remote-ignitions, Saffire-IV will burn multiple samples of materials to determine how the flame spreads across different materials in microgravity at pressures and oxygen concentrations that are varied from previous Saffire experiments.

AES is developing technologies that reduce mass, volume, and crew time devoted to logistics management. Projects include 3D printing with lunar regolith simulant, and the use of RFID tags for logistics tracking and inventory location. The Universal Waste Management System (UWMS) toilet has been delivered to Orion, for use on the Artemis II mission, and a duplicate will be delivered to the space station for testing later this year. Trash compaction and processing systems under consideration convert some trash to gas, performs trash compaction, and removes or recycles water and gas from waste. A new Tank Health monitoring technology called the modal propellant gauge allows an accurate picture of what is left in the tank during gravitational transitions without penetrating it (lowers risk of leaks). Artemis I will launch with 13 secondary CubeSats, three of which AES is developing: BioSentinel, a space radiation exposure experiment using yeasts; Near Earth Asteroid (NEA) Scout to image an asteroid during a slow fly-by maneuver; and Lunar IceCUBE, a student-led orbiter to prospect for lunar ice using an infrared spectrometer. The AES launch and payload schedule includes three instruments that will launch on the Mars 2020 Perseverance Rover in July 2020: Mars Entry, Descent, and Landing Instrumentation-2 (MEDLI-2), Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE), and Mars Environmental Dynamics Analyzer (MEDA). In September 2020, a fifth Spacecraft Fire Safety Experiment (Saffire V) will take place.

FY2021 President's Budget Request

Mr. Brian Dewhurst presented details of the HEOMD Fiscal Year 2021 (FY21) President's Budget Request, with the caveat that the budget numbers do not yet reflect the impact of the Covid-19 pandemic. The NASA budget continues to follow the guidance of four strategic principles: continuity of human spaceflight and scientific exploration; global collaboration and leadership; advancement of commercial partnerships; and continue to inspire the next generation, through four strategic themes. The themes are to land at the lunar south pole by 2024, establish lunar surface sustainability, support the maturation of a commercial LEO economy, and develop a sustainable lunar operating platform (Gateway). FY2021 provides a total of $12.9B for HEO, with $8.7B for the Moon-to-Mars effort. Lunar surface sustainability will require developing a sustainable surface landing system, the continuation of surface suit development for long-duration missions, reducing risks to human health and performance through basic, applied and operational research, and leveraging the work of the Science Mission Directorate and Space Technology Mission Directorate. To create a sustainable lunar operating platform, HEO will deploy initial functional elements of Gateway, HALO and PPE, and initiate other Deep Space Exploration tasks, enable a commercial LEO economy, and provide support systems for operating in all locations of space.

FY2021 planned activities are to launch Artemis I in 2021 and to continue Artemis II preparations. Exploration Ground Systems (EGS) will begin making modifications to infrastructure to accommodate crewed flight missions, starting with Artemis II; and the HLS program will make a downselection. Plans to support lunar surface sustainability include studies in Advanced Cis-lunar and Surface Capabilities

(ACSC) to support components for surface habitation, mobile habitat and power systems, and activities to support Environmental Control and Life Support (ECLSS) evolution (with an ISS flight demonstration by 2025). In order to create a sustainable lunar operating platform, HEO will implement a Gateway strategy focusing on a minimal configuration that enables human lunar missions starting in 2024, conduct a Gateway Phase 1-focused PDR, conduct a HALO PDR, demonstrate xEVA space suit life support sub-systems on ISS for use on lunar landing missions, and complete the PPE System Integration Review (SIR). To enable a commercial LEO economy, the budget will support development and demonstration of commercial destinations in LEO, and demonstrate promising new markets through the ISS National Laboratory and activities funded by the ISS and Commercial LEO Development programs. The FY21 budget also supports five Commercial Resupply Services (CRS)-2 launches and two commercial crew launches. Lastly, the budget will support systems for operating in all locations of space, new ISS long-duration missions to address health risks associated with lunar missions, continue to operate ISS and support critical research and technology demonstrations; provide critical communication coverage; award demonstrations of commercially provided communications services; enable propulsion test infrastructure for NASA programs, commercial partners and DOD, and maintain a prioritized core capability of skilled test and engineering crews and test stand facilities, acquire commercial launch services, including certification of new launch providers, provide trained astronauts for all NASA human space flight efforts, and maintain crew health and safety.

In the overall program, beginning with the $12.9B requested for 2021, HEOMD will see further budget growth in 2022-2024. Mr. Dewhurst noted that the budget reflects only the initial proposal; some funds for HLS have been updated in the Operating Plan that will be sent to Congress. Mr. Dewhurst further explained that after the FY20 budget was released, it was amended in early Summer 2020. A continuing resolution (CR) was passed shortly thereafter, after which NASA received some additional resources, but not everything it asked for. In the meantime, Congress continues to consider the 2021 budget. Mr. Lopez-Allegria asked if another CR would present any funding problems for contract structures, particularly for HLS. Mr. Dewhurst said that NASA does possess some flexibility under a CR in terms of where funds can be applied in the HEO portfolio. That would be foremost in mind should NASA be compelled to operate under a CR.

Deep Space Gateway and Concept Status

Mr. Dan Hartman presented an update on the Gateway. Gateway will be a 24/7 operation around the Moon, designed for a 15-year lifetime and with an initial crew mission duration of 30 days, that is eventually extensible to 60-90 days. The Power and Propulsion Element (PPE) is being developed by Maxar Technologies; and Habitation and Logistics Outpost (HALO) by Northrop Grumman. NASA now plans to integrate the PPE and the HALO on the ground and launch as an integrated spacecraft inside a large fairing rocket. ~~An initial plan is under way for integrating PPE and HALO into a single payload on a large fairing rocket.~~ There are several benefits to an integrated launch: HEO can optimize systems by on-ground integration by eliminating one launch vehicle, one service module, and an on-orbit assembly scheme via an RPO demonstration. Launch is targeted for November 2023, after which the integrated payload spirals out to NRHO via PPE and chemical propellant over 270 days. This will enhance mission assurance ~~success~~ by reducing on-orbit integration complexities. Ms. Gardner asked if there were a qualified LV~~,~~ that can carry both the PPE and HALO. Mr. Hartman said that NASA had put out a draft request for proposals (RFP) via the Launch Services Program (LSP) on 5 May, and has confirmed that there is at least one provider. The contract is expected to be awarded in November, there may be multiple options available.

Early Gateway utilization will be important for the Science Mission Directorate (SMD), the Space Technology Mission Directorate (STMD), and international partners. Gateway will fly a European Space Agency (ESA) radiation package, with resulting data to be shared across all entities. SMD will contribute a space weather instrument suite. HEO will use Canadian robotic adaptors to install these payloads, and to

change out payloads across the life of Gateway. SpaceX was recently selected as the initial provider to fly cargo to Gateway (Gateway Logistics System; GLS), with an eye to multiple supply missions in which the cargo spacecraft will stay at the Gateway for six to 12 months at a time, deliver up to 5 metric tons (5MT) of cargo capability, provide power to internal and external payloads, remove trash, and use automated RPO. GLS currently has agreements in place with Space X for two missions on a fixed-price, indefinite delivery, indefinite quantity (IDIQ) basis. The total maximum GLS contract value across SpaceX and all other potential providers over the life of the Gateway is $7 billion. NASA is iterating on Memoranda of understanding (MOUs) with international partners for additional Gateway capabilities. The Canadian Space Agency plans to provide external robotics, tentatively targeted for delivery to the Gateway in 2026. ESA will also plans to provide the IHAB (international habitat) module with support from the Japan Aerospace Exploration Agency (JAXA), and a refueler to allow transfer of xenon. International partners are embedded within the Gateway team, with membership on Gateway Boards and technical integration embedded at all levels. NASA has also embedded all the international partners in its control boards. Discussions are ongoing with Roscosmos, but only in the preliminary stages, for a possible airlock contribution.

Planning is under way for the first two space suits to be fabricated in-house for 2024, to be followed by industry provision of suits. The current pair of suits is almost at delta-PDR; preparations have been impacted by the Covid-19 situation, but the program is looking to resume soon. NASA held an Industry Day on 12 May, with 100 participants, and is looking for feedback on a statement of work (SOW). Good progress is being made on the new suit that will be worn on Artemis missions, called the Exploration Extravehicular Mobility Unit, or xEMU. NASA is currently doing mass reduction exercises for xEMU. A suit vendor will be on board by the end of this calendar year. The draft solicitation will ask for feedback on desired contract mechanisms, after which NASA will come up with a strategy for contract vehicles. The funding line for xEMU lives in the Gateway Program, and will be funding suit production through 2028, with commercial provisioning of the suits starting in 2024. Mr. Hale asked how these suits are expected to function in lunar polar regions. Mr. Hartman said that cold will be challenging in long-duration missions, and that the suit will require operational constraints to long term cold exposure. Thermal protection is part of the suit design. Mr. Hale noted that the technology effort must ensure crews are protected, and cited a case of frostbite in an astronaut that was conducting a thermal vacuum test. Mr. Hartman agreed that thermal protection was concern, but that it was not a driver for the 2024 mission. There is a long history of EMU experience at ISS, thus the program is applying these Lessons Learned to the xEMU, and is also looking at some modularity to address mass issues. The program is looking at pressure garments, and is also looking at ways to simplify panels, and to standardize vehicle interfaces and flight support equipment for multiple providers, as well as to create a simplified, lightweight standard set of tools. Ms. Nancy Ann Budden asked if there had been any upgrades in EVA tools to accommodate sample storage and curation, such as voice activation. She noted that EVAs were very time-intense during Apollo. Mr. Hartman said some Lessons Learned from Apollo had been applied to the development of the upgraded toolkit. Ms. Budden requested a point of contact from Mr. Hartman, to obtain further information.

Mr. Hale asked: if we don't need Gateway for the first lunar landing, why do we need it at all? Mr. Hartman noted that Gateway addresses the sustainability question, provides multiple uses, and allows significantly longer mission times. With the right ECLS system, a crew's mission duration can be doubled to 60 days. Gateway also allows additional hardware positioning and logistics support. There is also the "intangible effect" of international partnerships to be considered; i.e. nations coming together in the peaceful exploration of space. Ms. Gardner asked if there were a requirement for the landers to be reusable. Dr. Lisa Watson-Morgan answered, saying that reusable landers would be required for future missions, but not for 2024.

Human Landing System Program

Dr. Lisa Watson-Morgan, Program Manager for the Human Landing System (HLS), presented a status of the Program, which awarded three contracts in April. Complete lander systems were proposed, including launch vehicles (LVs), to provide an end-to-end solution to place humans on the Moon in 2024, and for sustaining missions. Base period awards were made to three contractors, that are to run from May 2020 to February 2021. The National Team led by Blue Origin includes Draper, Lockheed Martin, and Northrop Grumman. Blue Origin proposed a three-stage landing system (ascent, descent, transfer) launching on the New Glenn or the United Launch Alliance (ULA) Vulcan. Key attributes of this design are the existence of significant, proven space flight heritage, and compatibility with Orion and Gateway. The National Team three-stage design is similar the Government Reference Design, and will include a test flight of the descent element. Blue Origin was awarded $579 million for the base period activities.

Ms. Gardner asked what the status of the contracts would be at the end of the base period. Dr. Watson-Morgan said that most test demonstrations will be scheduled after February 2021, and that downselection would then be followed by major testing. Only minor testing would be done during base period. She added that no designs include certified launch vehicles at present. Any certified vehicles would require three successful launches before they could be considered for HLS.

Dynetics (a Leidos company) proposed a combination-stage design providing both ascent and descent capabilities, with "mass produced" multiple modular propellant vehicles (MPVs) launched separately to fuel the tanks at different stages of the mission. The Dynetics design employs a large subcontractor team with many partners, and would fly on a ULA Vulcan. The crew cabin sits low to the surface in this design. The lander has a double androgynous docking system, and is Orion- and Gateway-compatible. Dynetics was awarded $253 million for the base period activities.

SpaceX proposed a "Starship" integrated lander, with a fully reusable launch and landing system. The Starship has an elevator, two airlocks, a capability of delivering 2000kg to the lunar surface, and the ability to fuel in LEO with Starship Storage and Starship Tanker variants. The proposed launch vehicle is the SpaceX Super Heavy. SpaceX was awarded $135 million for the base period activities. Dr. Watson-Morgan observed that SpaceX has made a good amount of progress, and that she had been very impressed over the last five years with what Commercial Crew has been able to try and achieve.

There are four base-period contract line item numbers (CLINs); the first (CLIN 001) supports 2024, period. CLIN 004 includes special studies, in areas of high-risk in general, with respect to future lunar exploration. NASA is asking the contractors to do trade studies, so that the Agency can make data-driven decisions. There are recognized challenges and risks: LV maturity is a big risk across the board. Refueling is complex, as are integrated propulsion systems; crew egress-ingress height is an issue with one of the designs. These are all areas to watch, and areas for which NASA might ask for further study. Today the program has 375 staff; there has been a slight lag in ramping up personnel. The program is projecting 565 staff by September of this year. The target is 660. The plan is to nail down standards as quickly and clearly as possible. This will also help NASA to set up planning for certification of flight readiness (CoFR) as soon as possible.

There are a number potential trades for a 2024 HLS. The program is assessing the TRLs of systems; inter-element mechanisms for mating and in-space aggregation of the HLS; an extravehicular mobility suit mass reduction effort; and an orbit best suited for fast abort and optimal mission duration. There may be more or less than the presented list. Types of work are: insight, or traditional government review of contractor products leading to CoFR; joint flight operations, including mission planning with a blended team; collaboration, with government experts working alongside the contractor developing products; and advanced development and risk reduction, whereby the government team works in parallel activities to aid in quick turnaround, and to provide risk mitigation, informing the program and the contractor for

decision-making. Dr. Watson-Morgan emphasized that NASA will have sole responsibility, however, when the 2024 mission flies with crew.

Mr. Hale asked how the schedule would be laid out: would contractors be at a PDR stage at the time of selection? Dr. Watson-Morgan said there would be a "continuation review" at the end of the base period, which is a procurement activity. The continuation review will assess the data, assess gaps, and determine what more is needed. If there are gaps in the data, the IDIQ vehicle can be used to fill the gaps. Dr. Watson-Morgan added that all the contractors have been continuing necessary work during the COVID-19 shutdown. At the end of the base period, instead of putting out another RFP or BAA, NASA will start to evaluate which HLS contractor(s) are eligible for option A (initial landing demonstrations), and continue after February 2021. The base period will be used to evaluate each contractor's design, and their ability to stay on schedule. Mr. Loverro commented that the evaluation begins at seven months, and the downselect occurs at 10 months. Mr. Voss said there seem to be a number of low-TRL items and asked: how can these be resolved by 2024? Dr. Watson-Morgan commented that there is no guarantee. Decisions on HLS will be based on design,.

Discussion

Mr. Hale asked HEOC members for initial thoughts. Mr. Voss felt that NASA was spinning its wheels a bit, still doing trade studies. He quoted a maxim: "there are a thousand ways to do something, and most of them are right." He did not feel great confidence that NASA was truly moving forward. Mr. Sieck agreed with Mr. Voss, adding that the complexity of some of the HLS proposals seemed challenging, and that given more time, engineers can make things overly complex. NASA needs to stick with requirements—if the Agency asks for complexity, it will get it, along with schedule and cost complexity. Mr. Lopez-Allegria echoed the commentary, and more broadly, regarding Artemis, felt that there are greater forces at work. He thought HEO should worry more about tactical stuff, and to think about a potential budgetary continuing resolution and its possibly deleterious effects on funding. Mr. Holloway concurred, saying that it sounds like people are still planning for 2028. HLS is too complex, there is no consideration of flight operations, and there appears to be no way to get to the Moon by 2024. One might say the same thing about the orbits; better is the enemy of good enough. Mr. Holloway conceded that the integration of PPE and HALO was a good example, however, of improving the schedule. Ms. Gardner felt that making the 2024 date, using new landers on unproven LVs, seems unlikely, and that it might be better for NASA to focus on one or two concepts for HLS. It seems that NASA gets enamored with fixed price contracts, which does not seem the best vehicle for collaborative activities. Gateway activities also seem to be a distraction for 2024. Mr. Mark McDaniel offered kudos to Dr. Watson-Morgan and to Mr. Loverro, adding that NASA is doing commercial work in a much better way. Gateway will also enable NASA activities to transcend administrations, and provide sustainability, like ISS. Mr. McDaniel also commended NASA's Science, Technology, Engineering and Mathematics (STEM) activities, and NASA in general, for inspiring the next generation. Ms. Budden commented that she was worried about the HLS schedule for all the previously aired reasons, and worried particularly that the effort is politically driven, rather than risk-driven. Regarding trade studies, she noted that many technologies have greatly advanced over the years, thus the trade studies are really essential, but that she was starting to really worry about integration. There are many contributors, commercial and international, which pose a risk to integration; Gateway is starting to look like an afterthought, despite the obvious progress that has been made. Dr. Patricia Sanders, Chair of the Aviation Safety Advisory Panel (ASAP), noted that the Panel had been actively studying the issues of late. She felt that one of the things that is different is that the program is looking at risk all across the first three Artemis missions, which is good. Dr. Sanders noted that ASAP does echo Ms. Budden's concern about integrating all the pieces, but that Mr. Loverro's reorganization proposals are a good first step. ASAP has the sense that HEO is currently trying to decouple Gateway from Artemis I, while still deeming Gateway necessary for sustainability. It may be that future briefings will be needed to better articulate the purpose of Gateway in this context. Dr. Pat Condon said he

appreciated all the well-done briefings, but did concur with many of the concerns expressed. He pointed out that in the Mercury/Gemini/Apollo days, there was much rehearsal, and in all of those programs, things went substantially wrong. Artemis is not getting much rehearsal time, and there is still a high degree of risk to get to Artemis III. Mr. Condon also raised concerns about achieving human presence on Mars in the 2030s: who is the Program Manager for a Mars human exploration mission? Who is integrating the robotic missions that will lead to human exploration capabilities? Who is developing the ConOps?

Mr. Hale applauded Mr. Loverro's organizational planning, noting that HEOC has said for some time that the project needs better integration. He felt reorganization would help to rectify technical risks, and offered to begin drafting a finding on program integration and management. Mr. Holloway cautioned that NASA would have to watch how a re-organization is implemented. Mr. Hale agreed, and added that he was a little leery of more studies, and that NASA needs to pick a path. He asked Mr. Voss to write up a finding about spending less time on trade studies. Mr. Hale commented, in terms of schedule, that he was very worried about safety. He noted that the two Shuttle accidents were caused by schedule accelerations. Mr. Hale requested more insight into a back-to-back integrated program schedule that shows what needs to happen starting today, particularly with regard to HLS, to get to a lunar landing in 2024. Dr. Condon and Ms. Budden began drafting a finding on schedule, simplification, and risk reduction.

Mr. Hale commented on the future of Gateway, and asked Mr. McDaniel to draft a finding on Gateway's role for sustainability, although HEOC has made a similar recommendation in the past. Mr. McDaniel also felt there was a need to underline the inherently dangerous nature of the exploration enterprise. Ms. Gardner commented that Gateway funds are in danger of being raided in the current scenario. Mr. Holloway felt that Mr. Condon's points on flight rehearsal were very important, and reiterated that the HLS plan as proposed is complicated.

May 14, 2020

Call to order
Dr. Siegel re-opened the meeting and introduced Chairman Hale.

Exploration Systems Development
Mr. Tom Whitmeyer presented an update on Exploration Systems Development (ESD), beginning with mission details of . Artemis I, its challenges and opportunities. Artemis I is planned as 22-26 day mission overall, during which the capsule will travel 1.3 million miles. It is a challenging mission, and the first full-up demonstration of SLS. There has been much detailed mission planning and analysis. It's been a long time since the Apollo mission, and NASA will also doing maneuvers it has not done before.

Hardware is pretty much all manufactured; right now the focus is on Core Stage of SLS, which is now in the B2 test stand at Stennis Space Center. After it completes a full-duration, Green Run hot fire test, ESD will start to stack and integrate the vehicle. All motor segments are ready to transport by rail to KSC by mid-June. Orion is nearly complete and in temporary storage awaiting integration.

In November 2019, the Orion capsule was transported to Glenn Research Center, while the integration of the Core Stage was being completed and prepared for testing. In January, the Core Stage was sent to SSC. It took 10 days to get the Core Stage into the test stand due to weather obstacles. Until March, crew worked on connections of feed lines and pressure lines. Mr. Whitmeyer noted that the development of the Core Stage had other ramifications for NASA, in that it contributed to manufacturing process improvements. On 16 March, Stennis was forced to halted operations due to Covid-19, and stood down for 6-7 weeks, with a handful of staff attending the Core Stage. Ancillary work continued in order to prepare for resumption of operations; the staff completed a lot of paperwork and improved some

processes and procedures, thus the downtime was time well spent. There will be a press release about current status of operations at Stennis, which has resumed limited operations. It is expected that the Center will work up to a full complement by the Summer in order to carry out integrated testing. SSC is beginning to get technicians back on board, following Centers for Disease Control (CDC) and Federal guidelines.

SSC will begin phase I testing of Core Stage as soon as the full complement of staff returns. The plan is to operate avionics, check out the communication links between computers on Core Stage and control centers, etc. The Green Run was originally scheduled for August, but will likely be pushed to the November timeframe, so that the Core Stage can be delivered to the Cape in early 2021, while also being mindful of the risk of weather (hurricane season) impacting the schedule.

In February 2020, ESD got some work accomplished in mission-critical software for the Orion vehicle. In March, Orion completed its final thermal and vacuum testing. Mr. Whitmeyer praised Glenn Research Center, contractors, and the European cohort, for their hard work, which successfully guided Orion through all test conditions. Orion performed very well. The staff also practiced water recovery of Orion with a vehicle facsimile. Overall, Mr. Whitmeyer was very pleased with results, and commended the SuperGuppy crew that transported the Orion vehicle. In March 2020, Orion was moved to the Final Assembly and Systems test cell at KSC, where it awaits integration Core Stage. Two forward assemblies are ready to go too.

Major milestones remaining before the Artemis I launch include final assembly items and remaining testing. For Artemis II planning and beyond, the Artemis II pressure vessel is complete, and technicians are now doing work inside and outside of the capsule, working on plumbing and welding. All the engines and motors have been completed and are ready to go well in advance of need. The Artemis II intertank completed a thermal protection application, and the build-up of a new liquid hydrogen tank is under way at KSC. Essentially, ESD is a third of the way through on Artemis II physical construction. In April 2020, the launch abort system for Artemis II was completed. For Artemis III, R-25 engines have been prepared and are now in storage; the payload adaptor is in work. The Artemis III crew module barrel is being machined, while the Artemis III European Space Module is being assembled in Turin, Italy. The liquid hydrogen tank for the third SLS Core Stage is in production at NASA's Michoud Assembly Facility (MAF). Mr. Whitmeyer noted that much of this work is going on at sub-tier facilities with highly skilled personnel, which will require some vigilance. Mr. Hale inquired about the status of a 27 August hot fire test; Mr. Whitmeyer said he would send advance notice of the test to Mr. Hale. Mr. Whitmeyer concluded the briefing with a progress video.

Mr. Hale asked if there were any work going on beyond Artemis III, aimed toward sustainability. Mr. Whitmeyer said that as ESD looks forward, it is doing what it can to be available for future ConOps decisions and large-scale manufacturing efforts, and is ready to share its team and be part of the overall effort, ready to partner and ready to respond to new ideas, or to the continuation of traditional ideas. It will take all the expertise and capabilities NASA can get to pull off challenging missions. On 21 May, there will be more announcements in planning for the path forward, given the Covid-19 situation. Beyond Artemis III, ESD has a person who is watching all the production activities, so that the cores and boosters can be prepared and be made ready for future missions. ESD also has a Systems Engineering lead for a fully integrated schedule. Mr. Loverro noted that the team has made incredible progress, and if not for Covid-19, the program would be on or ahead of schedule. Mr. Hale asked for a more detailed briefing on long-lead items. Mr. Whitmeyer said he would make a point to share more details on long-lead items at the next meeting.

Mr. Sieck asked if all the control rooms would be tied in for the static fire test. Mr. Whitmeyer said that Huntsville, the Cape, and Houston would be tied in, and that there will also be experienced people from

the Cape in attendance, to oversee the test. ESD fully acknowledges the importance of the expertise to be garnered from experienced KSC staff, and will also be taking advantage of the experience of other Centers that are further along in resumption of operations. Ms. Gardner- impressive progress, is critical path still thru Core Stage? Whitmeyer, once Core Stage is at Cape, critical path will switch to integration.

International Space Station

Mr. Kirk Shireman, Program Manager for ISS, presented a status of Station. Today there are three astronauts on board. Increment 63 launched in early April and will stay thru 21 October. There will be a crew of three until SpaceX Demo 2 launches on 27 May. ISS is looking forward to having a permanent crew of seven, eventually. The flight plan for Increment 63 includes numerous activities, including up to four battery EVAs in June/July, the arrival of the JAXA HII Transfer Vehicle (on track to launch 20 May 20 and to arrive at Station on 25 May). The SpaceX Demo-2 launch and docking is still on schedule. In July, the Progress vehicle is due to dock. The next cargo resupply will be provided by a Northrop Grumman CRS-14 launch. In October, one US crew member will take the Soyuz back home.

Exploration technology and development capability gaps

Today, there are a number of exploration technology gaps that can be tested on the ground, while some need to be tested at LEO, and some can only be tested out beyond the van Allen belts, or on the lunar surface. The strategy for filling these gaps is to mature the technologies at the most cost-effective location. ISS is actively implementing gap-filling tasks. One critical technology needed for long-duration space flight is a highly reliable carbon dioxide removal system, with performance goal of 2mm Hg ppCO2. The effect of carbon dioxide on physiology is not a linear one; small increases in carbon dioxide can adversely affect human performance in major ways. ISS had been testing a thermal amine scrubber (TAS) until it had a blower failure that paused operation. The same blower is on Orion and one of the Commercial Crew vehicles; the knowledge gained from the failure has been beneficial to the program.

Human Research Program

The Station crew effectively comprises the test subjects in the Human Research Program (HRP), which is working to buy down the risks to support humans as they spend longer periods away from Earth. ISS tested a Space X Space Linear Acceleration Mass Measurement Device (SLAMMD), a device that aims to improve predictions of mass, which provided some positive initial results. ISS is also used as a deep-space analog, simulating mission durations, isolation and confinement, autonomy, and events such as communications delays. HRP is studying elements of similarity of ISS with a Mars transit vehicle, matched with gravity. There are however, significant differences in the radiation environment that will be encountered in deep space transits, as well as the nature of the closed environments, between ISS and a theoretical Mars transport. ISS is too large and too active to be a true analog for a Mars transit vehicle, and its distance from Earth is too close and connected. Crew have carried out one-year missions on ISS, and 11- and 9-month stints, which has provided some useful data for duration. HRP is currently doing analogs for a medical event, with autonomy from the ground, trying to understand the components needed for effective response. HRP is also studying the effects of gravity transitions and operational capabilities; currently, it has crew performing tasks, such as navigating an obstacle course, while they are still de-conditioned from ISS flight, to simulate the first one to three days of a Mars landing. HRP is also looking to test conditions such as communications delays and blackouts for one day to two weeks. HRP is planning more one-year missions with NASA astronauts in order to collect adequate data; Russian crew has declined participation in these longer missions.

Utilization of crew time

Increments 61-62, in general, have had a much smaller crew and therefore somewhat less activity. Research activities are going well, especially with just one US astronaut on board. To date, there have been 204 NASA/US-led investigations on Station. Mr. Shireman noted that 108 countries have been involved on ISS in a variety of ways (Principal Investigator on board, experiments, education events). ISS

touches the world as a global endeavor, and is adding countries all the time. The Increment 63 research plan includes experiments on bone and muscle physiology, radiation impacts on humans, combustion and materials science, Earth and space science investigations, and educational and cultural activities, and continuation of commercial presence on Station (NanoRacks, e.g). In the case of JAXA, "cultural" also sometimes means commercial activities. In Technology Development and Demonstration, there will be continued testing of EVA systems, and fire suppression experiments. The latest Saffire-IV test has been operating since early May, in a module that has departed the ISS. Some featured investigations include JAXA's Mouse Habitat Unit, which is analyzing changes in gene expression.

Mr. Alexander MacDonald, NASA Chief Economist, provided an ISS National Laboratory update, which was recently part of an assessment by an Independent Review Team (IRT), whose final report was delivered to NASA in February. ISS National Laboratory is currently following the guidance from findings, and is committed to transforming operations to respond to criticism. Among other actions, the IRT recommended identifying an ISS National Laboratory Program Executive (currently Mr. MacDonald) to help manage ISS as a single point-of-contact liaison with the Center for the Advancement of Science in Space (CASIS). The IRT also recommended seating a new Executive Director for CASIS, and seating a new board with a new board chair, all of which should happen within a month or so. A CASIS advisory committee, with appropriate representation, is also being established, with a first meeting expected to take place in late Summer. Another key criticism from the report was lack of transparency, so the program is also working on this issue, and is rewriting the Cooperative Agreement. The program is also exploring new avenues for hosting low-mass, high-value payloads, to ensure that it is developing cutting-edge technology with other federal partners, such as the National Institutes of Health (NIH). The ISS National Laboratory 2019 Annual Report is now online, showing a lot of good use, and with 64% of investigations being done by new-to-space users. ISS set a record for total hours of crew time used over a year (967 hours). Crew time has also increased, and with the arrival of the SpaceX Demo-2 crew in late May, having more crew time will mean more research.

Mr. Shireman continued the briefing, addressing ISS operational status. The Alpha Magnetic Spectrometer (AMS) was repaired via a set of four spacewalks. This activity took years to prepare, because the device was not meant to be serviced. The repair required complex execution, which was carried out phenomenally well. The repairs to the AMS cooling system worked very well. In January, two EVAs were carried out to begin the process of replacing NiH batteries on the solar arrays with lithium ion batteries. There are four planned spacewalks to replace the batteries on the S6 truss segment. If it can't be done in Summer, the EVAs will be pushed to Fall. Mr. Holloway expressed amazement at how well NASA has kept ISS running, given its logistics, handling of huge batteries, and the number of EVAs (227). Mr. Shireman commented that the people who preceded him had set up ISS for success.

Total consumables on ISS are in good shape. All of the crew resupply missions have been successful, and have facilitated much off-loading of trash. The crew also operates some payloads when these visiting modules are docked. The CRS-20 mission was the last of the first re-supply contract. The NG CRS-13 module is currently docked, and is expected to dispose of 2.5MT of trash on the way down. The HTV9 mission will also bring 2.6MT of waste down; it has proven to be a great vehicle for stuffing full of trash.

Future of ISS

ISS continues to work to buy down risk for humans in space, in terms of both health and operations, and is trying to support LEO commercialization. ISS now has commercial cargo visits on a regular basis, and hopes to soon have commercial crew flying on a regular basis. Mr. Voss asked about plans for hosting private astronaut missions. Mr. Shireham said that Axiom Space has been selected as a commercial destination provider, and is working on modules. ISS is also anticipating demand scenarios involving transportation providers and destinations. NASA is providing seed money to enable companies to mature concepts and stimulate demand for future LEO markets. On 2 November 2020, NASA will mark 20 years

of continuous human presence in space thanks to ISS. Mr. Shireman said he was proud to be part of this accomplishment, and expressed gratitude for NASA support. Mr. McDaniel commended NASA and ISS for their education and outreach activities.

Commercial Crew Program

Mr. Phil McAlister presented an update on the Commercial Crew Program (CCP). CCP has made significant progress since the last NAC meeting—both providers have completed uncrewed flight tests and abort tests. The SpaceX Demo-2 crew is under quarantine for 14 days due to Covid, and launch is still a go for 27 May. The next Boeing Orbital Flight Test (OFT-2) is still under review. Contract milestones for remaining Boeing flights are also under review. The Boeing Pad Abort test was completed on 4 November and experienced an anomaly in parachute deployment (1 of 3 parachutes did not deploy). A full investigation revealed that the failure was due to insecure rigging, and a subsequent test was completely nominal. The next Orbital Flight Test will be the same as the first: two seats with no crew members. NASA and Boeing stood up an Investigation Review Team (IRT) to review Boeing OFT-1 anomalies, looking primarily at two software coding errors on the upflight, and another coding error on the downflight. OFT-1 experienced an unexpected loss of communications and intermittent outages. The IRT is preparing to conclude after three months of essentially full-time activity, and after having identified more than 60 corrective actions. NASA also did an extensive Lessons Learned assessment of OFT-1, and will also perform an Organizational Safety Assessment of the workplace culture of Boeing's CCP team. NASA has designated OFT-1 a High Visibility Close Call. Mr. Holloway asked if NASA had established a list of firm requirements for the next Boeing flight test. Mr. McAlister said he would provide a detailed list to HEOC, noting also that NASA has implemented process fixes, and that it will be NASA's responsibility to hold Boeing accountable for carrying out the IRT actions.

Demo-2

The SpaceX In-Flight Abort Test, a prerequisite for Demo-2, performed very well. It was a very challenging test, and resulted in nominal performance of the SuperDraco engines and parachutes. Post-splashdown, DOD rescue forces carried out a simulated crew rescue prior to capsule recovery, to prepare for the case of an anomaly. The Demo-2 mission will be the first human launch from the US since STS-135, and the first human water landing since Apollo-Soyuz. The flight plan is from 30 days to up to 119 days, based on a complicated set of criteria. Flight test objectives include manual pilot tests; emergency safe-haven configurations; emergency hardware storage evaluations; assessments of Dragon habitability (i.e. how four crew members will fit); crew life support functionality; waste management system; post-landing rescue equipment demonstration; and water recovery operations. There are a number of risks to the 27 May date, but there is overall optimism that the schedule will hold.

For the Boeing crewed vehicle, Boeing has decided that the best approach was to fly a second uncrewed mission to ISS, to include a docking demonstration with ISS. NASA will track the flight and ensure that Boeing carries out all actions developed by the IRT. A date will be announced soon, after initial planning is complete. Mr. McAlister commended Boeing for their focus on crew safety, not schedule.

Mr. McAlister provided a view of CCP program cost performance. Based on the Augustine report, it was expected that the Ares 1 and Orion (Block 1) would cost $34.5B. NASA had estimated the cost at $24.5B. In reality, actual expenditures for developing Boeing and SpaceX crew transportation systems were $5B, representing a substantial savings that has enabled NASA to use funds to bring SLS and Orion further along, for NASA's deep-space ambitions. While the CCP commercial model works, it is recognized that it is not appropriate for everything in NASA exploration, especially SLS and Orion. Mr. McAlister applauded the HLS program, which incorporated some of the CCP model into its development processes in order to achieve similar cost savings. Mr. Sieck commented that in the early years of CCP, NASA was only appropriated half or two-thirds of what it was requesting for CCP; this is another data point to consider. Mr. McAlister added that one must also recognize that the CCP represented a big change for the

way NASA does business. NASA now enjoys full funding requests from Congress, which has been critical to CCP success.

CCP contract performance is still within 5 percent of contract values for both companies. Mr. McAlister thought that this statistic was notable. In terms of schedule, Space X experienced a 37-month slip (from April 2017 to May 2020). The Boeing slip is yet to be determined. The schedule demonstrates that NASA and its industry partners are driven by safety, not schedule. Mr. Holloway said that conventional wisdom implies that there's an optimal profile; was stretching out the schedule a source of cost savings, or was the schedule too aggressive to begin with? Figuring that out might be useful in the future. Mr. McAlister noted that NASA awarded integrated systems about eight years before flight, commenting that this was a reasonable length of time for developing two human space transportation systems. NASA does, however, own the 37-month slip by SpaceX.

Space Adventures announced in February that it has entered into an agreement with SpaceX to fly a dedicated Crew Dragon mission that would send four space tourists on a five-day mission to a relatively high Earth orbit as early as 2021. In addition, Axiom Space announced on 5 March that it has an agreement with SpaceX to launch a team of three private astronauts and an Axiom-trained mission commander to the ISS for a 10-day mission as early as 2021. These space tourism activities are very new, but they appear to bode well for future US market leadership in private space travel. Historically, comparisons with "planes, trains and automobiles" show that private space tourism costs might decrease anywhere from 50 to 75 percent over time. Mr. Sieck asked if there would be any difference in roles and responsibilities between the Demo-2 and Crew-1 missions. Mr. McAlister said that the integration of operations teams would be the same; the Demo-2 flight is not licensed by the Federal Aviation Administration (FAA), but the Crew-1 missions and beyond will be. Everything else is expected to stay the same. For Crew-1, the final milestone is the certification milestone; NASA will ensure that SpaceX meets it. Mr. Voss said he was interested in hearing about how NASA will handle safety during the private astronaut missions, and was concerned about putting Station and its crew at risk. Mr. McAlister said that these details are still to be worked out, and that he would brief HEOC with further details when they are finalized.

Commercialization of Low Earth Orbit

Mr. McAlister briefed HEOC on the progress of LEO commercialization. NASA is trying to bring LEO into the economic sphere to benefit the US and the world, with the view that NASA would be just one of many participants in space. There are indications that there is much potential there.

The NASA National Performance Plan, in item 2.1, lays the foundation for America to maintain a constant human presence in LEO, and deems this objective to be just as important as the other strategic objectives— it is now a high priority for HEO and NASA at large. Part of NASA's strategy is to create a dedicated organization and management structure to look at the effort in a more holistic manner, expanding enabling policies and examining potential prohibitions, better engaging with industry to help and not hamper the commercialization effort, reshaping CASIS, adopting a more business-focused decision process, and working toward early demonstrations of success. Before 2005, NASA had a monopoly on LEO and did not see a lot of commercial potential. Seven and eight years later, SpaceX and Orbital launched their Dragon and Cygnus capsules to successful capture at ISS. Since these early successes, NASA has added a new cargo provider, Sierra Nevada. There are now 21 commercial facilities on ISS, a number that is increasing every year. The Bigelow Aerospace expandable module (BEAM) and a 3-D printer are also on board. Today, NASA is transitioning from a NASA-centric LEO economy to a multi-user LEO economy. Transportation to LEO today is now almost completely commercial. NASA has also developed an interim pricing policy for providing things such as upmass, stowage, data downlink, and power for commercial users. NASA is also making an effort to stimulate sustainable demand; projects recently announced include a semiconductor chip facility, a stem cell

production unit for personalized medicine, among others. By 2030, the vision is to have a variety of private sector entities in LEO. The "big buckets" to focus on are private astronauts; commercial free flyers; service providers; and international and commercial transportation.

NASA's Plan for Sustained Lunar Exploration and Development

Mr. Tom Cremins provided a briefing on NASA's sustained lunar plan, which was recently presented to the National Space Council. The lunar plan is a result of a six-month activity with HEO, SMD and STMD. The effort ties into a whole-NASA, whole-government strategy, bringing together capabilities and partnerships in a "juggernaut" to build budgets over time. This strategy covers the present through a mid- to late-2030s first human Mars mission, with Level Zero goals and resiliency built in (i.e. an "accordion"). "Accordion" is a reference to the development of a "living strategy" that can respond to changes. Mr. Condon asked for examples of Level Zero goals. Mr. Cremins said that these would be Agency-level goals such as reaching the Moon by 2024, or having a sustained presence in and around the Moon.

The Artemis program is using the Moon to prepare for Mars. Mobility on the Moon is a key part of preparing for Mars; among the critical capabilities needed are the ability to venture further than 2 km from landing sites, and a mobile habitability platform, which will be demonstrated in the mid- to late-2020s. ISRU and surface power capabilities must also be demonstrated. These elements on the Moon are called the Artemis Base Camp, which will allow access to lunar poles for decades to come. Cis-lunar space is also a component of the strategy of establishing a strategic high ground that will allow the US to deal with geopolitical competition at cis-lunar space and on the lunar surface. Achieving a sustained lunar presence is planned to take place after 2024 and into the 2030s.

The lunar strategy will be based on commonality and interoperability in areas of mobility, suits, ascent systems, propulsion, habitation systems, and deep space aggregation. Behavior and physical health will be critical areas to address in terms of burning down risk; the lunar experience can really help in this area. Scientific exploration of a planetary surface will also be part of the program, to bring us from drilling on Moon to drilling on Mars, to examine the Solar System history locked in the regolith. There are many linkages that will feed forward to Mars, as well as opportunities unique to the Moon itself.

Elements for the first human Mars mission include studies of lunar surface analog systems, Mars Sample Return, Evolved Gateway Habitation, deep space aggregation, Mars Ice Mapper, EDL, nuclear propulsion, and crew science at Mars. A long-term focus is essential to bringing these components forward in an integrated manner with government entities, as well with as industry and international partners. Mr. Cremins noted that ISRU is key to long-term space exploration, which has led to the establishment of a pilot plan in the mid- to late-2020s. Mr. Condon asked: who has the overall responsibility for human missions to Mars? Who is identifying the activities on the Moon to support Mars missions? Who is integrating robotic science missions on Moon and Mars? Scenarios? Hardware? Preparatory work? In answer, Mr. Cremins described himself as the "orchestra leader" responsible for the strategy, with the mission directorates responsible for their respective tasks. He added that the strategy continues to evolve because it is becoming more real. However, he felt that the A suite should not be doing any detailed analyses or the programmatics. Mr. Condon felt that there ought to be an architecture for Mars missions, as well as an entity that integrates the actions of the directorates and divisions. Mr. Cremins noted that he serves as more of a team function with the mission directorates, helping to direct long-term investments, determining how to leverage the robotic functions, and then synchronizing them with the existing architecture.

Public comments

Mr. Neil Wolf commented, as a long-term fan of the space program, that it had been an absolute privilege to sit in on the meeting, and asked for HEOC's views on the Artemis Accords and how the accords take account of commercial and international partners.
Mr. Keith Cowing commented that HEOC might want to start looking at something simpler than Webex for its virtual meetings, such as YouTube or cell phones.
Mr. Bob Zimmerman, directing a question to Mr. Cremins, said he had heard nothing about surface habitats in terms of how they evolve to Mars; he asked if there were any concerns about the orbital mechanics getting in and out of the polar regions, as lunar injections do not have not a lot of commonality with Mars EDL.
Dr. Clive Neal, in another question for Mr. Cremins, said he had not heard anything about sustainability on the lunar surface, beyond government-funded efforts.
Ms. Wendy (?), a graduate student, asked if there were any long-term plans to incorporate graduate level scientists into the exploration program, to future inspire scientists.
A commenter remarked that Mr. McAlister had underscored the importance of having two commercial crew providers, and thought it would be important to have similar redundancy in other areas, such as HLS.

Discussion of findings and recommendations
HEOC discussed and finalized findings and recommendations.

The committee discussed factors that may be contributing to slow progress toward a 2024 lunar landing; e.g., trade studies are delaying progress. Mr. Voss felt that the main point would be to encourage early decisions to allow more progress to take place more quickly; make a decision to move on. Mr. Sieck agreed with Mr. Voss, save for some contradictions with a potential finding on the HLS schedule. Dr. Condon felt that the HEOC concerns expressed in the finding could be addressed by a recommendation regarding improvements for HLS safety.

Dr. Condon commented that there are an awful lot of things to be done before Artemis III, and there does not appear to be enough time to get it done. Many other activities need to take place as well. Mr. Holloway thought that the HLS schedule was a pipe dream. Dr. Condon said that thought was reinforced by Mr. McAlister's reference to the eight years of development for the CCP (uncrewed to date). Is NASA proposing to develop a crewed mission in half the time it took to develop CCP? Mr. Hale asked: are we saying the Agency shouldn't do it? Mr. Holloway felt the HEOC should state that NASA must take extraordinary measures to make the date. Dr. Condon agreed, likening the issue to the main "elephant in the room." The direction for a human landing in 2024, is top-down, and it puts NASA in an awkward position. The likelihood of making 2024 is remote, but Dr. Condon didn't know what the Administrator could do about such a finding. Mr. Hale commented that the policy decision to baseline a 2024 landing was outside the perview of the HEOC and that the committee needed to address recommendations that would enhance the chances of success to the goals the agency had been given.

Mr. McDaniel thought HEOC might do well to issue a finding that acknowledges the substantial challenges and significant risks on the path to 2024, but that it applauds NASA's efforts to go forward. He thought that the goal in itself remained an inspiration. The goal, after all, is the stepping stone for getting to Mars. HEOC should not throw cold water on the aspiration. Mr. Lopez-Allegria echoed Dr. Condon and Mr. Holloway's concerns, and thought the Committee had identified something it must talk about, which is the lack of appropriate testing for HLS. A potential finding can state that the pressure applied by the compressed path is something HEOC finds fault with. Dr. Sanders reminded HEOC that the HLS competitors may have proprietary test plans that cannot seen in a public forum; it doesn't mean that these testing plans don't exist. Mr. Holloway supported a finding that explicitly deals with the schedule issue. Mr. Hale asked if Mr. Holloway thought NASA needed an Apollo 10-type mission (before 2024). Mr. Holloway said he felt HEOC should be direct about what the problem is, and suggest

that NASA find a way to achieve 2024 and do it right. Mr. McDaniel supported raising the issue of "time constraints."

HEOC discussed a finding on Gateway. Mr. McDaniel felt that Gateway was a good way to transcend administrations. If it's there, it can be used like the ISS. NASA should take advantage of the enthusiasm for the lunar shot to get Gateway done, and leverage Gateway's presence to underscore the Agency's unique abilities. NASA is the only agency in the world that can get to Mars. Mr. Holloway did not agree that Gateway is necessary for a Mars mission—NASA can go to Mars without going to the Moon, with or without Gateway. Mr. McDaniel commented that many say NASA should put all its efforts in getting to Mars; that's where a discussion of risk buydown is valuable. The Moon can't be the goal- we've been there. Mr. Voss agreed with Mr. McDaniel about endorsing Gateway. NASA needs a proven habitat to eventually get to Mars, and Gateway is the best analog opportunity for demonstrating a deep space habitat.

HEOC discussed issuing an "attaboy" on the HEOMD reorganization. Mr. Holloway felt the need for reorganization was less important in a scenario where launch is 10-15 years out. Dr. Condon felt that NASA organization in general was awkward, as there is a degree of program management at the Headquarters level, but there is also program management and execution being done at the field level. This sometimes leads to an intermingling and confusion between policy and strategy, and actual program management. Mr. Holloway agreed with Mr. Condon's assessment. Mr. Lopez-Allegria thought it was encouraging to hear about HEO's organizational changes, and that HEOC should just stick to commending them.

Mr. Hale asked HEOC members for any remaining thoughts. Mr. Holloway felt that HEOC had not received a good understanding about commercial implementation on HLS. Has HLS figured out how to make procurement work while maintaining safety? They should consider an independent review. Mr. Hale said he would request a more detailed briefing on how Lessons Learned are being applied to HLS, and that it would be good to have the discussion before HLS gets to the end of its procurement activity. Mr. Holloway said he was also curious about the ground rules for Axiom- is NASA subsidizing them? How will it work when three commercial astronauts go up- who is accountable and responsible for safety? Mr. Hale put these issues onto the agenda for the next meeting.

Mr. Hale asked departing members for parting remarks:
Mr. Sieck said his departure felt like retirement again, noting that one of the last people he spoke to upon retirement twenty years prior, was Tom Holloway, his boss. He said that his tenure at HEOC never felt like work, and that he would miss it. He added that he would be happy to continue as a spectator, and thanked NASA for allowing him to be part of history.
(Dr. Leroy Chiao was not online at the time of the wrap-up.)
Mr. Holloway commented that he had thoroughly enjoyed his tenure, and intended to stay in touch, adding that he had given 40 years to NASA, and it had been hard to retire. His advice to HEOC was to continue to tell it like is. Dr. Condon added his comments, thanking the three departing members. He thanked Messrs. Holloway and Sieck for all they had done for the country. NASA and the nation have benefited from their experience and mentorship, and he wished them all the best. Mr. McDaniel said it had been an honor and privilege to serve with two legends, the "Michael Jordans" of NASA. Mr. Holloway and Mr. Sieck are great men and great Americans; their deeds will live on forever as an inspiration to young scientists.

Mr. Kenneth Bowersox added final comments, saying he had appreciated the discussion, and giving thanks to the departing HEOC members. He asked Mr. Voss which assessments he had been concerned about. Mr. Voss felt that the orbital trade studies seemed to be a rehashing of old work, and that with 2024 looming, NASA should make decisions and move on. Mr. Bowersox said the work being done on

the orbits constituted taking the understanding to the next level of detail. As far as TRLs are concerned, HEO is assessing where it stands and seeing if it can make things better; however, he said that he understood the message behind the finding.

Mr. Hale deferred planning for the next meeting, and thanked everyone for their participation.
Dr. Siegel thanked the participants, and adjourned the meeting at 3:30 pm.

Findings and recommendations (final)

1. Finding regarding trade studies
Short Title of Finding: Contributors that are slowing progress toward 2024 lunar landing.
Finding: Current Artemis programmatic work such as trade studies, TRL assessments, and technology development projects do not seem to support rapidly moving forward in support of a lunar landing by 2024. The key decisions needed for hardware developers to move forward appear to be delayed by this activity. The result is slow progress that may not support a lunar landing by 2024.

2. Finding regarding Gateway
Short Title of Finding: Endorsement of Gateway
Finding: We will not put an astronaut on Mars during this administration, but we can inspire the nation to take that journey. To say to the nation, we are going back to the moon is great, but it will not inspire the nation like a Mars mission. America has been to the moon. While NASA knows how difficult a moon mission is, many people take it for granted. The nation (and Congress) should recognize the fact that a successful Mars mission will have a much better chance of success if we first establish a permanent presence on the moon. Such a presence could mine the moon for resources which will enable a Mars mission as well as study physiological effects on the astronauts. Gateway is a way to facilitate these activities. Number One: Gateway will help maintain a sustainable continuous presence on the moon. Number Two: Gateway will provide a test bed for technical improvements which will greatly improve the success of future Mars missions. Number Three: Once Gateway is in place it will be in continuous use and provide sustainability. One or two moon missions a year will not transcend administrations. With Gateway, there is a much greater chance that long term programs will continue.

3. Finding regarding HEO Organization
Short Title of Finding: HEO Organization
Finding: The organization required to meet a lunar landing goal of 2024 and subsequent sustainable cis-lunar operations and development of human Mars missions needs to include clearly defined roles and responsibilities, strong integration functions, a single program manager function, and a separation of the roles of management into policy and planning, finance, and execution. The HEO committee has been concerned for some time that the exploration program has not been well organized for rapid and effective development and operations. The HEO committee is pleased that the new Associate Administrator is taking steps to address these critical organizational requirements. We encourage further that master schedules with appropriate resource planning be baselined by the program leader for all elements to work together. Strong systems engineering and integration function is critical to successful program execution. Decision making must be made at the appropriate level. The committee sees that organizational changes in these directions are underway and we encourage their completion.

4. Recommendation regarding Artemis execution (actionable):
Short Title of Recommendation: Improvements for Artemis execution
Recommendation:

a. NASA Management at all levels but especially in the HLS program should always emphasize safety over schedule.

b. Uncrewed and other precursor flight missions should be performed to demonstrate the readiness of the systems before committing to high risk human missions.
c. Mission abort and potential crew rescue operations should be included in the HLS planning.
d. Timeliness of decision making can lead to improved safety by avoiding later schedule compression.

Major Reasons for the Recommendation: The goal of landing humans on the moon is an inspiration to the nation and a worthy goal for NASA. We applaud the efforts of NASA to achieve this goal to date. However, the current schedule is extremely compressed toward a human lunar landing by the end of CY 2024. The HEO Committee is concerned that the current schedule being considered for Human Landing Systems is not realistic. Historically these complex systems require long-term design, trade study, proof-of-concept, prototyping, multiple operational demonstrations, and rehearsals along the way. NASA has always employed a 'crawl, walk, run' approach to human missions. With the compressed schedule, involving multiple sophisticated components being built and tested, many of these steps appear to be abbreviated or perhaps not included at all. During the 1960's NASA took the approach of flight demonstrations prior to committing to high risk operations: Apollo 9 and 10 are examples but there are many others. Currently there is no allowance for flight demonstrations of critical equipment in the published schedule for HLS. We observe that time pressure was a major contributor in each of the three accidents that NASA has incurred in human space flight. The HEO Committee applauds NASA's efforts in reducing overall program risk but feels that more needs to be done, including development of a more robust HLS development and demonstration phase, to assure mission success.
Consequences of No Action on the Recommendation: Mission failure either in development or flight. Potential loss of crew increased.

Appendix A
Attendees

Human Exploration and Operations Committee

N. Wayne Hale, **Chair**, Retired NASA
Nancy Ann Budden, Office of the Secretary of Defense
Leroy Chiao, Retired NASA
Stephen "Pat" Condon, Aerospace Consultant
Ruth Gardner, NASA Kennedy Space Center
Tommy Holloway, Former Space Shuttle and International Space Station Program Manager
Michael Lopez-Alegria, Former NASA astronaut
Patricia Sanders, **Chair,** Aviation Safety Advisory Panel
Robert Sieck, Former Space Shuttle Launch Director
James Voss, Former NASA astronaut
Mark McDaniel, Partner at McDaniel and McDaniel Attorneys, LLC.
Bette Siegel, NASA, Executive Secretary

Virtual Attendees

Martin Anderson
Eric R Berger
Sharmila Bhattacharya
Nathan Brady
Cindy Martin-Brennan
Edward Chandler
Jacqueline Cortese
Jeffrey Fesler
James C Gatenby
Irene Klotz
Dillon MacInnis
Carlo Mirra
Dmitry Samoilov
James Watkins
Michael Deklotz
Robert Smith
Marco Tantardini
Steve Siceloff
Hanneke Weitering
Aarti Matthews
Neil G. Wolf
Timothy Tawney
Joe Searle
Gene Mikulka
Linda Karanian
David Madden
William Vincent
Charlie Stegemoeller
Michael Sheetz
Kevin Metrocavage
Gregory Mann
Erin Kennedy
Sam Schmidt
James Favors
Wilbert A Ruperto
DeAnn Reilly
Jim Zimmerman
Bradley Smith
Emma Lehnhardt
Andrea Leinfelder
Matthew Guibert
Daniel Mazanek
Chris Gilbert
Gina Anderson
John Moore
Joshua Barrett
Barbara Adde
Neal Newman
Jacob Bleacher
Richard Irving
Samantha Fonder
John Rummel
Christopher Moore
Ramon Osorio
James Holt
Barbara Zelon
Patricia Moore
Eracenia Kennedy
Jeanie Hall
Becca Browder
Nantel Suzuki
Tim Fernholz
Lisa Watson-Morgan
Tariq Malik
Stefan Will
Edward Semones
Chris Esser
Marc Timm
Karin Sturm
Christopher Ayers
David Millman
Marcia Lindstrom
Hugh Cate
Kate Kronmiller
Richard Fischer
Laurie Chappell
Kevin Sato
Jim Way
Deepthi Srinidhi
Sam Gunderson
Richard Rogers
James Lochner
Douglas Loverro
Patricia Rausch
Timothy Finkel
Chris Brand
Benjamin Ashman
Danielle Gibbs
Ryan Whitley
Theodore Kronmiller
Tremayne Days
Pierre-Alexis Joumel
Erin Welshans
Tim Cichan
Alyssa Sieffert
Scott Stagliano
Michael Lapidus
Tony Reichhardt
Bill Mackey
Marcos Pena
Cassandra Nagy
Jiří Hošek
Juan Castilleja
Richard DalBello
Kathleen Boggs
Dimitra Tsamis
Lynn Bowman
Douglas Messier
Tracy McMahan-Mayhan
Russ Dill
William Stanton
Andy Rechenberg
Rene Balanga
Kenneth Bowersox
Angelina Ermakov
B Harvey
Cheryl Reed
Kristina Gibbs
Kermit Pagel
Brian Dewhurst
Joan Zimmermann
Layi Oshinowo
Tommy Sanford
Homer Hickam
Meenakshi Wadhwa
Kacey Templin
Marguerite Broadwell
Donna Rogers
Ryan Schaefer
Jeff Foust
Christian Lange
Suzanne Liebert
Thomas Plumb
Kandyce Goodliff
Francesco Bordi
Eileen Collins
Marc Julian Zuther
Haley Fauntleroy
Renee Pullen
Michael Barrett
Bradley Carpenter
Frederick Hubbard
Sam Grey
Tim Alexander

Pamela Workings
Rebecca Zia
Anthony Tsougranis
Panita Van Besien
Sarah Ruiz
Mark Kinnersley
A.C.
Caitlyn Torres
Kathy Nado
Cat Hofacker
Sirisha Bandla
Leslie Swartman
Darrell Branscome
Ibrahim Al Shidhani
Mary Lynne Dittmar
Altonell Mumford
Luc Dube
Miriam Kramer
Stefanie Payne
Chris Sanders
JM Stout
Marc Seibert
Al Tadros
Abdiel Santos Galindo
Robert Cicconetti
Maribeth Davis
Stephan Gerard
Kelly O'Rourke
Christy Hansen
Tom Martin
Robert Curbeam
John Mitchell
David Eisenman
Paul Wooster
Alexandra Cross
Deborah Circelli
Jeffrey Markowitz
James Norman
David Gaba
Jessica Landa
Ken Shields
Don Hassler
Kristin Van Wychen
Ruth Siboni
Sylvie Espinasse
Erin Mahoney
Brandon Burroughs
Dennis Stone
John Warren
Mark Lucas
Magdiel Santana
Keith L Cowing
Gale Allen
Lauren Wright
Frank Slazer
Jim Rice
Heather Smith
Azita Valinia
Stephen Davison
Francisco Moreno
Desiree Seaward
Kathryn Hambleton
Cory Simon
Laura Pope
Elaine Denning
Loren Grush
Stephen Clark
Patrick Besha
Markus Wey
Refaat Rashad
Meghan Bartels
David Jones
Andrew Rowe
Lawana Bryson
Rick Kendust
J Pappalardo
Twyman Clement
Ashley Edwards Wilson
Chelsea Gohd
Dave Mosher
Jeffrey Cullen
Jonathan Munetz
Thomas Whitmeyer
Caray McKenzie
Josh Brost
Aaron Oesterle
Michele O'Connell
Anica Silimon-Hill
Meredith Blasingame
Samuel Scimemi
B Ehren
Alexander Macdonald
Lex Berezhny
Tom Gardner
Christie Cox
Robert Zimmerman
Kevin Foley
David Adams
Mary Chevalier
Alan Feinberg
Joey Roulette
Amy Chabot
Lisa Allen
Taylor Duffin
Daniel Evans
Darcy Elburn
Philip McAlister
Kim Veris
Sandra Graham
Martin McLaughlin
Shandy Mcmillian
Lynne Loewy
Marcia Joseph
Sean Fuller
Julie Robinson
Steven Ramm
Alessandro Lovesio
James Gleeson
Samuel Lawrence
Daniel Hartman
James Crockford
Bill Peterson
William Harwood
Marcia Smith
David Wolf
William Hitt
Zac Hall
Michael Roberts
Michele Gates
Aravind Reddy
Zudayyah Taylor-Dunn
Kirk Shireman
Wendy Yang
Denise Varga
Victor Schneider
Ethan Pogliano
Chris Davenport
Bill Beckman
Stephanie Schierholz
Laura Forczyk
Laurent Sibille
Meg Abraham
Justin Lazear
Kota Umeda
Thomas Morris
Robyn Gatens
Alan DeLuna
Warren Ruemmele
Jamiel Charlton
Rachel McNeal
Sven Eenmaa
Clive R. Neal
Narasimha Prasad
John Kross
Carrie Arnold
Joan Higginbotham
Meredith McKay
Jana Stoudemire
Joe Cassady
Jay Hollenbeck
Scott Stover
Matthew Cunningham
James Miller
Michael Sarafin
F. Joshua Krage
Clifford Ledford

Appendix B
HEOC Membership

N. Wayne Hale, Chair
Former Space Shuttle Program Director

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

Leroy Chiao
Former NASA astronaut and International Space Station Commander

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

Ruth G. Caserta Gardner
Technical Deputy Director for the Engineering and Technology Directorate at NASA's Kennedy Space Center

Tommy Holloway
Former Space Shuttle and International Space Station Program Manager

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

Robert Sieck
Former Space Shuttle Launch Director

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

Mark McDaniel, Partner at McDaniel and McDaniel Attorneys, LLC.

Patricia Sanders
Chair, Aviation Safety Advisory Panel

Appendix C

Presentations

1. Human Exploration and Operations Mission Directorate Overview; *Doug Loverro*
2. International Space Station Status and Transition; *Kirk Shireman*
3. Low-Earth Orbit Commercialization Status; *Phil McAlister*
4. Commercial Crew Program Status; *Phil McAlister*
5. Deep Space Gateway and Concept Status; *Dan Hartman*
6. Exploration Systems Development Status; *Mr. Tom Whitmeyer*
7. Advanced Exploration Systems Status; *Marshall Smith*
8. Fiscal Year 2021 Program Review Update; *Brian Dewhurst*
9. Human Landing Systems Update; *Lisa Watson-Morgan, Greg Chavers*
10. Sustained Lunar Exploration and Development Plan; *Tom Cremins*

APPENDIX D
AGENDA

Agenda

May 13, 2020

NAC HEO Committee Public Meeting

10:00 - 10:05	Call to order	Dr. Bette Siegel / Mr. Wayne Hale
10:05 - 11:00	HEOMD Update	Mr. Doug Loverro
11:00 - 11:30	Budget	Mr. Brian Dewhurst
11:30 - 12:30	Advanced Exploration Systems	Mr. Marshall Smith
12:30 - 1:00	Lunch	
1:00 - 1:30	Gateway	Mr. Dan Hartman
1:30 - 2:00	Human Landing System	Dr. Lisa Watson-Morgan
2:00 - 3:00	Discussion	
3:00	Adjourn	

May 14, 2020

NAC HEO Committee Public Meeting

10:00 - 10:05	Call to order	Dr. Bette Siegel / Mr. Wayne Hale
10:05 - 10:50	Exploration Systems Development	Mr. Tom Whitmeyer
10:50 - 11:35	International Space Station	Mr. Kirk Shireman
11:35 - 11:45	Break	
11:45 - 12:30	Commercial Crew	Mr. Phil McAlister
12:30 - 1:00	Commercialization of Low Earth Orbit	Mr. Phil McAlister
1:00 - 1:30	Lunch	
1:30 - 2:00	NASA's Plan for Sustained Lunar Exploration and Development	Mr. Tom Cremins
2:00 - 2:05	Public comments	
2:05 - 3:30	Discussion and recommendations	
3:30	Adjourn	