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HUMAN EXPLORATION AND OPERATIONS COMMITTEE

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MEETING REPORT

N. Wayne Hale, Chair

Bette Siegel, Executive Secretary

Table of Contents

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Opening/Announcements

Dr. Bette Siegel, Executive Secretary of the Human Exploration and Operations Committee, called the meeting to order and made administrative announcements, detailed FACA rules, and described the ethics surrounding committee membership. She introduced HEOC Chair, Mr. Wayne Hale, who noted that the meeting marked the first time HEOC had met in more than a year, and was now in the position of advising the newly separated Human Exploration and Operations Mission Directorate (HEOMD). HEOMD has been organized as two directorates: the Space Operations Mission Directorate (SOMD), and the Exploration Systems Development Mission Directorate (ESDMD). Mr. Hale marked the passing of HEOC member, Ms. Ruth Gardner, as well as Dr. Hans Mark former Deputy Administrator. Mr. Hale welcomed new HEOC members Ms. Lynn Cline, Mr. Kwatsi Alibaruho, Dr. George Sowers, and Mr. Doug Ebersole. HEOC is expecting to have at least three meetings this year. General Lester Lyles, Chair of the NASA Advisory Council (NAC), made brief remarks, thanking everyone for their support and dedication, particularly in the area of human exploration, and added that the full NAC was planning its first formal meeting some time in February.

SOMD/ESDMD Status

ESDMD

Mr. Jim Free, newly appointed ESDMD Associate Administrator (AA), recounted the accomplishments in human spaceflight that took place in 2021. First and importantly, the Space Launch System (SLS) Green Run hotfire test at Stennis Space Center ran successfully for the full and planned test duration, which provided much data about the cutoff limits of Artemis I. Similarly, the selection of the initial Human Landing System (HLS) contract represented another big milestone for the Artemis program. NASA celebrated the launch and return of the SpaceX Crew-1 mission, a top priority for NASA and which represents great progress. In addition, Mr. Free detailed the awarding of the launch vehicle contract for the initial Gateway elements, as well as the return of ISS astronaut and researcher, Kate Rubins, the progress of vehicle stacking for the Artemis I mission, the graduation of new astronauts some of whom will be eligible for the Artemis missions, and the selection of five companies for lunar lander concept development, the latter of which will help refine requirements and buy down risk for future missions. STEM activities based on the International Space Station (ISS) reached 1.5M students in 2021. The James Webb Space Telescope launched successfully and has been smoothly meeting its deployment and activation milestones. NASA has also selected three commercial low-Earth orbit (LEO) free flyer concepts, in preparation for the decommissioning of ISS in 2030. In other commercial space achievements, private astronaut missions are becoming nearly regular events.

Reflecting on his four months as AA of ESDMD, Mr. Free took a moment to recognize and celebrate the fact that all the tremendous accomplishments he had just presented had been overseen by Ms. Kathy Lueders, in her leadership as AA of the former HEOMD, and now as AA of SOMD. Ms. Lueders chimed in briefly with remarks commending her team, and noting how NASA tends to spend one second celebrating, before jumping in to meet the next challenge, and agreed that in all ways, Mr. Free had described the accomplishments in human space flight very well. Mr. Hale added that the appointment of Fiona Turett as the 100th NASA Flight Director was another notable accomplishment for the year 2021.

Mr. Free continued the briefing with a look ahead for 2022. JWST will insert into its Earth-Sun L2 orbit in late January, with support from NASA's Space Communication and Navigation (SCaN) and Launch

Services Program (LSP) teams, signifying another tremendous achievement. The Geostationary Operational Environmental Satellite-T (GOES-T), will launch at the beginning of March. There is much activity planned from March to May of 2022; Artemis I is scheduled to launch in the latter part of March; the mission's first launch window ends on 27 March and opens again on 8 April. A number of Commercial Lunar Payload Services (CLPS) missions will provide opportunities to take advantage of Science Mission Directorate (SMD) projects. NASA's SpaceX Crew-4 mission will launch no earlier than (NET) mid-April 2022, and Boeing's second Orbital Flight Test (OFT-2) of the Starliner is scheduled for May. During the second half of 2022, SpaceX will launch Crew 5, and there will be an Artemis II Crew announcement. Boeing will fly a Starliner Crew Flight Test (CFT) in 2022, pending the outcome of OFT-2.

Mr. Free addressed the rationale of the separation and re-organization of HEOMD, in response to the increasing scope of its activities. The re-organization was intended to help focus the directorates, and facilitate the development-to-operations hand-off cycle. The re-organization is currently undergoing a number of internal and external approvals taking place at NASA Headquarters (HQ) and at the Office of Management and Budget (OMB). Early on, Mr. Free said that he and Ms. Lueders have identified and adopted management tenets that are designed to minimize duplication of effort, get mission management at the right levels, and identify the right interfaces. He said he hoped that the re-organization would soon be formally approved by all the stakeholders, especially in light of the preparation for Artemis, future plans for human exploration of Mars, and maintaining international partnerships. Ms. Lueders agreed, saying that the two directorates have been making sure that their conceptual direction has Agency buy-in, and have been working at the next level to get up and running. The directorates are already working to conduct missions according to the new structure. Ms. Lueders expressed great confidence in her teams, and noted that everyone has been rolling up their sleeves. Mr. Free added that the two directorates are retaining common functions for practical purposes, institutionally and programmatically, and have people on both sides attending to day-to-day activities, and decision-making, working together closely to resolve issues as they come up.

Mr. Free highlighted areas that ESDMD intends to prioritize as it continues preparation for the Artemis I flight, including power, propulsion, and thermal subsystems, the integration of subsystem team, and the incorporation and embedding of science across Artemis, as well as the impact of science requirements on Artemis systems. Early science payloads have already been selected for the Gateway. It will be essential to meet schedule requirements for Artemis II through V missions, and to define the lunar and Mars architectures such that human safety and science are paramount. Mr. Free displayed the current manifest for technical integration: Artemis II is scheduled for mid-2024, and will be the linkage between Artemis I and III. Artemis I is the uncrewed flight test demonstration about the moon to test the spacecraft and rocket including new heatshield design, Artemis II will be a crewed flight test around the Moon, and Artemis III will have multiple elements: a crewed demonstration of HLS, a flight system that feeds forward to future Artemis missions, and advanced spacesuits. Artemis III is scheduled for NET 2025. Artemis IV will include delivery of the International Habitation module (I-HAB) to the Gateway. Artemis V will be the first lunar surface mission that includes crew egress from the Gateway. ESDMD is talking about challenges openly along the way. Artemis IV and V dates are still under review, as there are a number of challenges associated with NASA budget processes. Dr. Sowers asked how much range time would be needed for an Artemis attempt. Mr. Free said that as much range time as possible was desirable. If a wet dress rehearsal can be achieved by 15 March, then NASA can get to the April launch window period. Ideally, it would be good to get as many attempts in as possible. Mr. Pat Condon asked if there were any issues related to COVID that were impacting Artemis I. Mr. Free said the processing of the vehicle had been affected by a large number of cases at Kennedy Space Center, which has impacted

the schedule. Ms. Lueders added that while teams are taking the necessary precautions, when someone gets sick, the whole team has to stand down. These same issues impacted the Green Run schedule. Mr. Free reviewed the checkmark chart for the Artemis KSC flow process, noting that a wet dress rehearsal will be the next big milestone.

Mr. Free reviewed the principles of the Moon to Mars effort, including relying on time on systems for validation, with an initial focus on the lunar surface, and on the Gateway to help evolve the Transit Habitat and Mars Transit. NASA will also continue to engage additional partners to meet objectives on the lunar surface, such as for the development of surface rovers, and the study of system performance in microgravity vs. partial gravity. Hardware progress continues for Artemis II and III, as well as continued work on the Core Stage for Artemis III and IV. Touching briefly on the reasons for the Gateway's Near-Rectilinear Halo orbit, Mr. Free cited access to the lunar South Pole, and advantages for power, lighting, thermal balance, communications, time on systems, incremental build-up of systems, and an aggregation point for international and commercial partners. Mr. Free concluded by noting that Artemis III now has a credible plan for HLS development and execution, as well as suit development, and Artemis IV mission elements (Mobile Launcher-2 and Block 1B) are in focus, with some challenges expected with Block 1B development.

SOMD

Ms. Lueders, SOMD AA, reviewed directorate priorities, the first of which is getting the team set up for its Exploration Operations function, so that it can execute strategies over the next decade to accommodate the increasing complexity of space operations; building Commercial LEO is going to be much tougher than building Commercial Crew. Continuing ISS through 2030 will allow NASA to continue to reap its benefits, and allow the 2020s to be a decade of results. NASA needs to focus on the transformation of the Near Earth Network support strategy to help the US reap economic benefits, while turning over LEO to commercial entities, especially as the Agency moves to human missions. NASA must also continue to ensure launch vehicle strategies so that it can have a fleet at hand. The ISS extension through 2030 will allow SOMD to enable deep space exploration, conduct research to benefit humanity, lead international collaborations, foster the commercial space industry, inspire humankind, and provide a national human spaceflight infrastructure.

SOMD is really about the linkages across generations that will create our future explorers. Commercial crew success has been heartening; the three Commercial Crew flights in 2021 accomplished a great deal. As NASA turns to its vision for an LEO economy, it must consider how it can use its missions to expand commercial capabilities. The vision includes viewing NASA as one of many customers in a robust low-Earth orbit (LEO) economy, with commercially-owned and operated transportation for cargo and crew; commercially-owned and operated LEO destinations that are safe, reliable, and cost-effective; regular production, distribution, and trade of goods and services; ongoing research and science activities including a LEO National Lab; continuation of human spaceflight exploration objectives, and sustained presence and U.S. leadership in LEO. Developing Commercial LEO will take the same ingenuity it took to build the Commercial Crew program. In this area, SCaN's goal is to continue evolve how to provide communications for all NASA missions, particularly as humans move to deep space will require higher communication needs. These improvements will also improve communications for SMD and future deep space science missions. SCaN will have to work closely with commercial and other federal agencies as well. Similarly, LSP is going through a big change, and is really reaching out and expanding relationships, working with different companies in different ways to support NASA and other federal agencies. Juno is just one mission that has benefited from improved communication bandwidth, having

just transmitted spectacular images of Jupiter. Mr. Hale noted that some of these missions are a light-day away from Earth. Ms. Lueders said that Mr. Hale's observation underscores the importance of the ScAN and Deep Space Network (DSN) communication infrastructure, and closed by stating that SOMD's goal is to become a premier directorate as it optimizes its infrastructure, and uses Lessons Learned to maximize mission capabilities.

Mr. Hale commented that HEOC has always been supportive of keeping ISS alive to enable research for long-duration missions to Mars, and other deep space ventures. Mr. Mark McDaniel noted that ISS having touched 1.5M students through STEM outreach is a tremendous accomplishment; he noted also the tremendous amount of progress that has taken place since HEOC's last meeting. That progress represents outstanding leadership. General Lyles joined Mr. McDaniel in praising NASA for its STEM efforts, and asked how contracts were being made consistent with regard to development and operations activities within program management. Mr. Free said that the first step in ESDMD was setting up requirements and considering impacts on operations; while the second step is actually selecting the contractor (operations folks have to be part of that). The third step involves executing the contract while making programmatic decisions that recognize the impact on operations and long-term mission support. If the mission directorates both work through it together and think about what the government looks like in the contract, this creates the framework that the commercial organization works within. It's an important point, and both directorates are working toward this framework.

ISS Status

Ms. Robyn Gatens, ISS Director, presented an update, beginning with 2021 station highlights. 2021 was a busy year with many accomplishments. There were 11 crew on ISS for the first time in quite a while, 5 crew launches, a number of extra-vehicular activities (EVAs), and new international participation. ISS is currently in the middle of Increment 66. There will be a Russian EVA on 19 January, and later in the week SpaceX CRS-24 will be undocked, while the crew prepares more EVAs to install more solar arrays. Astronaut Mark Vande Hei will soon break Mark Kelly's record for number of days flown on ISS. ISS is scheduled to receive three cosmonauts via Soyuz in March; four US crew have been assigned to US crew vehicles, and there will be a direct handover to make sure there is US crew on ISS. NASA is working with Roscosmos to ensure a "crew swap" to guarantee mixed crew on ISS at all times. The plan is currently being reviewed by Russia. The ISS configuration will soon include six brand new solar arrays, for augmenting power. A new Cygnus vehicle will be launching in February, carrying with it a new Russian module and a European robotic arm.

Ongoing issues at ISS include an atmosphere leak in the PRK section of the Russian Service Module. Crew have isolated one leak location and have permanently sealed it, resulting in a reduction of the original leak to about half of what it had been. The crew and ground specialists are continuing to search for additional leak locations in the PRK, which are very small and hard to find and monitor, as well as determine the root cause. There is enough gas on board, and the leak poses no danger to the crew. The PRK section can be isolated by closing a hatch. In another recent incident, Russian MLM thrusters misfired after docking, causing ISS to briefly lose attitude control; a subsequent analysis indicated that the loss of control did not exceed structural load limits. The root cause of the misfire is still under analysis; a report is expected to be released soon. In November 2021, a Russian anti-satellite test created a debris field in LEO. This was a significant event, necessitating safe havens and closing of hatches. Operations were to back to normal in 24 hours. However, this event increased background debris by two-fold, and the risk of a penetrating collision to Station is now between 1 in 25,000 to 33,000 orbits. Space Command tracks these objects, and NASA has procedures in place for monitoring them.

FY21 accomplishments include the installation of a four-bed CO2 scrubber; completion of the SAFFIRE V experiment, followed by preparations to launch (Space Craft Fire Safety) SAFFIRE VI; installation of an airborne particulate monitor and a Brine Processor Assembly; and an RFID system for helping crew to locate items. A new Universal Waste Management System (UWMS) toilet was installed. The crew is working issues with it so it is currently dormant; the new UWMS is an important technology demonstration that will feed forward to Orion. There is now a double toilet stall, with the new toilet now situated side by side with the Russian toilet. The UWMS will soon be tested with an alternate fecal container that is designed to reduce mass. Metrics for Agency Priority Goals (APGs), for advancing deep space exploration technology, were Green for 2021 and are well on their way to Green in 2022. Some 2021 utilization highlights include exciting results in fluid physics, and the demonstration of "cool flames" that have implications for better combustion processes on Earth. The Alpha Magnetic Spectrometer (AMS) has been operating on ISS for ten years, and is continuing to provide theory-challenging results. Crew has been implementing Augmented Reality techniques for upgrading instruments in the Cold Atom Lab. Crew also recently harvested chile peppers grown in the Plant Habitat experiment; growing food in space will be critical for long-duration missions. Astrobees, small robots deployed on ISS, are doing inventory, and acting as sensors to assist the crew. Crew Earth Observations are helping to record how the planet is changing over time, from human-caused changes, such as urban growth and reservoir construction, to natural dynamic events, such as hurricanes, floods, and volcanic eruptions. Research in protein crystal growth has improved in terms of higher throughput. Medical research includes the flight of Cardinal Heart, an NIH tissue chip that studies how gravity affects cardiovascular cells. STEM activities aboard ISS, from pre-K through college, include an Amateur Radio project. ISS has now had 109 countries involved in its utilization, with a total of over 3200 research investigations to date. ISS efforts in STEM education and inspiration, through social media and other means, continue to make an everyday impact on students and the general public.

Ms. Gatens now serves as the current NASA liaison to the Center for Advancement of Science in Space (CASIS) National Lab. Subsequent to an independent review, new annual performance goals have been established for CASIS, designed to be more outcome-based and to better detail the results of projects; e.g., achievement of science objectives. CASIS hosted 88 payloads in FY21; Ms. Gatens noted that many current projects are self-funded, bringing in their own research. The pinch point for National Lab used to be Crew time; now it is upmass that is constrained. As soon as a crew swap agreement is in place, Ms. Gatens felt that crew time and upmass would supply settle with 4 crew on the USOS. The CASIS team feels positive and motivated after changes implemented following the independent review, and NASA is now considering what a National Lab will look like on a commercial LEO destination, raising questions about what ISS should be doing to move in that direction, and what changes, if any, should be made to move in that direction. Now that ISS has been extended to 2030, the other ISS international partners are working with their governments' processes, timelines and budget cycles to also commit to 2030. Ms. Gatens displayed the ISS "2030" video that is now in the public domain, and encouraged HEOC members to watch it online.

The ISS is not just "hanging on" until 2030. There are mission goals that NASA is working toward to maximize the results from the ISS. Ms. Gatens has named it the "Decade of Results". Importantly, the ISS will be testing the Exploration Environmental Control and Life Support System (ECLSS) that will be needed to go to Mars, accruing time on the system to thoroughly understand it, and to burn down human health risks. ISS will also continue life-saving research and contributing to the understanding of mechanisms that affect climate. Other research areas include fiber-optics manufacturing, retinal implants, and tissue engineering. Operating ISS through 2030 will allow continuous presence in LEO, as commercial space stations prepare to be operational by 2028. In transitioning from ISS to a Commercial

LEO Destination (CLD), NASA has been doing a lot of strategic and tactical thinking, and has kicked off a Working Group to consider these things. It is also critical to keep NASA's international partners engaged throughout this transition, and to determine what does NASA and our international partners want to do in CLD: Decadal Survey-driven science, tech demos, etc. NASA has also been reaching out to other government agencies to see what they would like to do. In terms of full-scale space product manufacturing and commercial marketing and tourism, Ms. Gatens felt that such agreements would be a strictly business-to-business proposition once LEO has been transitioned to a CLD.

Top indicators of readiness to transition are: having a CLD to go to, and the health and status of ISS. The two-year overlap (2028-2030) will be helpful and is currently thought to be sufficient. The emergence of non-NASA markets for CLD services will be needed to ensure CLDs are sustainable. NASA is also watching the health of commercial crew and cargo providers, ensuring that there is continuity for them. In summary, the decade of results is under way for ISS.

Ms. Nancy Ann Budden congratulated Ms. Gatens on a great briefing, and on the extension of ISS, and asked about public sharing of ISS URLs. Ms. Gatens noted that the video on the ISS extension to 2030 is a public URL [[https://www.youtube.com/watch?v=a-flzdifn54]] and has already been tweeted out. She said she would work to get other briefing videos out to the public domain. Mr. Hale asked if there would be an independent review of what commercial entities and the government want to do in LEO. Ms. Gatens said that as the Agency attempts to forecast NASA and National Lab activities, NASA would be meeting with other government agencies, through National Academies studies, to find this out, and would also be talking with future commercial providers about the front end of connecting users with providers. Ms. Lueders added that NASA knows that the demand discussion will be important for developing the market; there will be a little dance as users adapt to change, and the CLDs will have probably have to go through a certification process in the 2025-26 timeframe; in the last half of the 2020s, NASA will be adapting what it needs to the services and vice versa. It will be a combination of government forecasting and commercial innovation. Mr. Hale said he thought activities such as station spotting were great for public relations, and noted that interesting news items on subject like growing beef on ISS would be critical to increasing public awareness of NASA's human exploration goals. Mr. Kwatsi Alibaruho asked which key Lessons Learned (LL) had informed newly modified life support system designs. Ms. Gatens noted that the principal LL was not starting all over, and trying to improve and evolve what NASA has already developed. Some things are not changing at all, it's a mixed bag. The recently installed four-bed CO2 scrubber is just a reengineered version of the previous CDRA (for example, square beds replaced with round for easier sealing). The urine processor has newly designed distillation assembly to resolve known life limiting issues. Ms. Gatens noted that ISS management had been very forward leaning in its approach, pushing through the issues to locate the next problem. Reliability is the big key, followed by time on systems. Ms. Lueders added that she hoped HEOC appreciated how ISS is helping exploration in so many ways; Augmented Reality (AR), Astrobee monitoring, and Crew time are "gold" on ISS, but will be "diamond" on Gateway and on the lunar surface. Food and telemedicine, among other parameters, are all key to operating in space for the long term. Dr. Sowers said he was very encouraged to see transition plans and that NASA is thinking about demand models. Companies are going to view NASA as an anchor tenant; they are going to want to see real numbers as soon as possible, as these numbers will make or break their business cases. The Commercial Crew Program did this well. Ms. Gatens agreed, saying that she understood that companies will need certainty. Mr. James Voss thanked Ms. Gatens for her briefing and asked about specific problems with the new UWMS. Ms. Gatens said there had been an issue with a fan separator, where it looks as if fluid got in where it should not have. Crew is also troubleshooting a conductivity sensor, to sense the treated vs. pre-treated status of urine. It is hoped that the UWMS will be able to resume

operations soon. There were also some minor software issues, the usual problems encountered when flying something for the first time.

Discussion

Mr. Hale asked "around the table" to hear topics for discussion and recommendations. Mr. Doug Ebersole raised the issue of requirements stability, and tracking requirements between the development and operation phases, and then once product is in use, how requirements are closed out between the two AAs. Dr. Sowers said he was concerned about the readiness process for Artemis I; it's a first-of-a-kind mission and terrifying, and he wanted to know how NASA is getting comfortable about pushing the button. As for the LEO transition to CLD and future Artemis missions: who owns the integrating elements? The earlier the NASA demand for LEO can be articulated, the better. Mr. Alibaruho suggested HEOC present a recommendation to closely examine the overall program and project management approach to material procurement plans, especially with regard to items in the master program schedule, given current COVID pandemic constraints and global supply chain issues. Ms. Lynn Cline felt that the two directorates have overflowing plates, and wanted to hear more about the transformation of launch vehicles. Dr. Pat Condon said there seemed to be confusion about the exact responsibilities between the two mission directorates, and the interfaces. While this is being figured out, NASA has a major mission to launch and execute. It is like trying to change four tires on a race car at 220 mph, a big challenge. His other comment referenced the recent report of the Aviation Safety Advisory Panel (ASAP) and how NASA plans to address ASAP recommendations. Mr. Mark McDaniel commented on the importance of STEM, and the many students that are reached per year via ISS, and how important ISS is to human exploration. The public needs to know how important this work is to the future of the nation. The entire nation is touched by the excellent work being done at NASA. Mr. Hale ensured that Mr. McDaniel's comment would get to the STEM Committee. Mr. Voss asked if HEOC could hear more about Commercial Lessons Learned. Ms. Budden said it had been exciting to see the progress that has been made and the incredible momentum. She agreed that STEM outreach has been excellent. She cautioned that NASA has often been impacted by changes in administrations and has often gotten dead-ended: how do we encourage NASA HQ to maintain and sustain this momentum, beyond the political perspective? NASA needs to communicate with the funders. Dr. Patricia Sanders, Chair of the ASAP, said it was interesting to hear HEOC perspectives on the ASAP report, and echoed Ms. Budden's comments on the "constancy of purpose" needed for human exploration; she added that she would soon be testifying on Capitol Hill to that effect Ms. Sanders was struck by HEOC's thirst for understanding. General Lyles said that he resonated with all the comments, and also with the concern over the challenge of the split directorate issue. He recounted discussion with the NASA Administrator and his team, noting that Administrator Nelson is pushing to close out old NAC recommendations, to get to fresh ideas. Thus far from what he had heard, General Lyles felt confident that he would hear fresh ideas. Mr. Hale commented that there seemed to be three potential recommendations: an intense focus on Systems Integration, first and foremost. It is impossible to overstate the importance of Systems Integration, given the importance of executing a successful first flight of Artemis. Secondly, Mr. Hale aired a real concern for NASA to be able to be flexible in its planning as new launch vehicles come along in LSP, as these decisions can greatly affect the plans for long-term exploration. Third, there is a current lack of transparency about what the Agency is doing; NASA must be forthcoming about problems and schedules. It appeared to him that there has been a marked change in the amount of information that is coming out of NASA.

Dr. Siegel adjourned the meeting for the day.

January 19, 2022

Dr. Siegel re-opened the meeting and made administrative announcements. Mr. Hale made brief remarks and asked HEOC members to forward any initial drafts to Dr. Siegel. Mr. Hale announced that he would recuse himself for the first two presentations of the day, given his ties to commercial space. Mr. McDaniel acted as Chair for the interim.

Mr. Phil McAlister, Director of the Commercial Spaceflight Division (CSD), gave a status, beginning with the Suborbital Crew project at Kennedy Space Center (KSC). In 2021, the directorship of the ISS National Lab was transferred back to Ms. Gatens, after responding to six actions by the IRT; the actions were largely finished before the transfer. All commercial programs in CSD have a competitive aspect, even after contracts are awarded. While much information about those programs is proprietary, Mr. McAlister hoped to present enough detail about them. The year 2021 was great for Commercial Crew. NASA continues to take it very incrementally on assessing both Dragon and Falcon 9 vehicles. He noted that Crew 2, before it returned to Earth, was able to fly around ISS and take high-resolution images of Station. CSD plans to conduct fly-arounds in the future, as needed, prior to the entry burn. There have been many firsts in the program, which have been inspiring for the workforce, and launches have gone smoothly and safely. Many people have now flown on commercial vehicles, starting with Demo 2 in May 2020, and which have also included Inspiration4, and Soyuz flights. Later this year, the Axiom I mission will be conducted using the Dragon vehicle to bring private astronauts to ISS. Answering Mr. Voss's question on why ISS did a Dragon relocation maneuver, Mr. McAlister clarified that the Crew 2 fly-around and port relocation were separate activities. The port occupied by Dragon was needed by another visiting vehicle and so SpaceX had to relocate the Dragon vehicle to another available port. Ms. Lueders added that it was also a logistical challenge for the external payload, which needed access to the robotic arm. CSD's Suborbital Crew program intends to increase flight times for microgravity projects, and fill the gap between the capabilities of ISS and parabolic flights. Via suborbital flight, it is possible to attain several minutes of microgravity at a fairly low cost. Two challenges for the next year will be, first, safety, as NASA needs to understand the risk posture of the vehicles. Secondly, CSD must determine the demand at NASA for these missions: e.g., how many seats; is there a need for cargo positioning, etc.? Mr. McAlister made it clear that Suborbital Crew is designed to enable NASA employees to utilize these suborbital capabilities. Current commercial suborbital capabilities, provided by Blue Origin and Virgin Galactic, are completely privately developed. Mr. McAlister thought these two companies would consider NASA as a customer, although not as an "anchor" customer. These flights are flown under informed consent for private citizens. CSD will need to recognize commercial suborbital flight history while considering the risk posture for NASA, which involves distinguishing system qualifications from traditional human rating. NASA is currently in discussion with the providers to reveal how they determined safety for their current vehicles. Mr. McAlister reported having attended Blue Origin launch, and touring the site and facilities. NASA is also leveraging the Armstrong Flight Research Center and Kennedy Space Center expertise for its review. In 2022, CSD will continue refining the system qualification process, identifying, characterizing and quantifying NASA demand. There will also be coordination with other government agencies, especially the Departments of Defense, to idenfity their demand. CSD will need to work with CASIS to identify possible collaborations, and with the Flight Opportunities Program within the Space Technology Mission Directorate (STMD), for the next round of contracts that are coming up in early to mid-2023.

In terms of commercial LEO, the intent is to strategically phase down ISS operations in 2028, while phasing in commercial LEO destinations, to be completed by 2030. ISS deorbit is planned for January 2031. Before that time, NASA must ensure that there will be sustainable, reliable, cost-effective LEO

destinations. This effort will employ the same goals that were used for Commercial Cargo and Crew, a strategy that worked very well. The Axiom port is being designed as a commercial port on ISS, that is planned to transition to a free flyer in 2028.

It is now US policy to provide continuous human access to space. NASA also wants to continue LEO science, maintain international partnerships and cultivate strong bonds, and perhaps expand partnerships to other countries. Crucially, it will be important to free up ISS personnel in order to transition to the Artemis program. It is estimated that retiring ISS will save the Agency about $1.5B, while also boosting the Artemis program. Ultimately, the aim is to revolutionize space flight in LEO, and open up what is possible to do in LEO, a very motivating and exciting goal. Ms. Sanders asked if the cost of transport to ISS/LEO was taken into account when calculating the $1.5B savings figure. Mr. McAlister confirmed that it was and that the NASA Chief Financial Officer concurred on the estimate, adding that the number was estimated to be start around $1.3 right after the transition from ISS and expand to $1.8B in savings after the transition is complete. ISS costs NASA about 3.5B a year, and NASA estimates it will need about $1B per year to purchase services from CLDs, after ISS retires.

Mr. McAlister presented a slide that detailed the rationale behind the savings calculation. Overall, NASA will be saving on maintenance and workforce (NASA and contractor) costs. Soyuz rides cost $80M per seat, while CCP is about $58M. A large part of that cost savings was based on the efficiencies of private sector development models, coupled with NASA's 50 years of safety assurance, a very powerful combination. The Commercial Destination free-flyer (FF) contracts are worth between $125-150M. The Nanoracks Starlab is aiming to achieve a critical design review (CDR) level of maturity by 2025, which Mr. McAlister felt was aggressive but achievable. The Northrup Grumman/Dynetics FF concept is trying to achieve Preliminary Design Review (PDR) maturity by 2025. The Blue Origin/Sierra Space FF is also seeking a CDR level of maturity by the mid-part of the decade. Mr. McAlister said he would be attending the initial milestone activities for each of these projects the following week. He said he was very pleased by industry response; NASA received 11 proposals from industry, all of which were reasonable, and a very good indication of commercial interest in LEO.

The commercial destination on ISS, in development by Axiom Space, completed its System Requirements Review and PDR last year, and has purchased long-lead items in September 2021. It is expected that the first module will launch to ISS in late 2024. It is a very aggressive schedule, which may also spur competition with other companies. The first launch for an Axiom Private Astronaut Mission (PAM) was targeted for late February, but it had to be slipped a month. This will be a 10-day mission, and it will not be certified by NASA. NASA's sole responsibility in this instance is to protect the ISS and ISS Crew, and to provide limited services to enable the PAM. The plan is to enable up to two short PAMs to ISS per year. While onboard ISS, PAM crew members are bound to the NASA code of conduct. Another PAM is scheduled for early 2023. NASA did not make a selection for a PAM-3 as expected because NASA did not receive any proposals that were satisfactory. Dr. Condon said that it appears that Axiom is buying transportation service from SpaceX. Mr. McAlister confirmed that this was the case, and added that Axiom has almost the entire responsibility for its crew safety and mission success. NASA will however assure the safety of ISS and ISS crew. In addition, while Axiom defines the PAM commercial activities that its crew plan to engage in, these activities are approved by NASA.

Mr. McAlister brought forth a specific request to the HEOC and the NAC, given that NASA has been given specific direction, through the Space Act, to enable the fullest commercial use of space possible. Since 2005, for each of these missions in the commercial arena, there has been some level of NASA support. A fully commercial human spaceflight industry, however, must be capable of being completely independent of NASA support. Commercial human spaceflight is happening, but NASA is not the right

agency to be monitoring or overseeing it. The US government as a whole must enable a seamless transition to fully commercial LEO spaceflight. Therefore, NASA is requesting that the NAC support the engagement of the national space policy community to lead an interagency effort to address the roadblocks to fully commercial human spaceflight.

HEOC discussed which agencies might be involved in specific functions: the Federal Aviation Administration, Departments of Defense and Commerce. Asked to identify specific roadblocks, Mr. McAlister referred the HEOC to backup slides in his briefing package. Just one example is the matter of orbit regulatory responsibility. There are also the matters of export controls, proprietary data release, and human safety requirements. Dr. Sowers asked if NASA has identified funding with which to buy services from future CLDs. Mr. McAlister said that as the need is anticipated until 2028, the funding is not yet part of the budget runout exercises. Dr. Sowers reiterated that it will be important to have a long-term commitment from NASA in order for these businesses to be viable. Mr. McAlister concurred, and said that the message to industry is that NASA believes that it will need a continuously crewed LEO destination beyond ISS for the foreseeable future. Mr. McDaniel thanked Mr. McAlister for an outstanding presentation and for the CSD team's hard work.

Commercial Crew Program Status

Mr. Steve Stich, Program Manager for Commercial Crew, gave a status of the program. He thought Commercial Crew had benefited greatly from the NASA workforce, which has carried with it long experience from the Shuttle era, and with ISS operations. NASA's Commercial Crew has partnered with Boeing and SpaceX to provide safe, reliable, cost-effective transportation to and from LEO, and to date, Boeing and SpaceX have been tremendous partners, deploying a super-talented team across the NASA space centers. The SpaceX Dragon led the effort, beginning with the successful launch of the first crewed Dragon vehicle, and has subsequently helped to maximize the use of ISS. SpaceX completed its contractual milestones and became fully certified in 2020. Boeing is on track to complete OFT-2 and CFT this year and is expected to move toward certification in 2022. Commercial Crew has awarded 12 post-certification missions (PCMs), and is pursuing three additional PCMs from SpaceX. NASA is also celebrating 21 years of human presence on ISS.

Mr. Stich cited major achievements: the Crew 1 mission, launched in November 2020, returned to Earth in May 2020. Crew 1 stayed docked for 167 days, and carried out a port re-locate to facilitate payload unloading. Several Lessons Learned were obtained from this Crew Dragon flight, with its full complement of crew; port re-location; direct crew handover; nighttime recovery off Panama City, FL (with enhanced public protection); and operational experience. Weather was a primary factor for landing. It was also necessary to work with the Coast Guard to clear private vessels from landing area. The Crew-2 mission was implemented from April through November 2021; Lessons Learned included inspections and operational workarounds due to a waste management system leakage, and observation of a single main parachute that lagged during inflation prior to landing. As part of the standard practice for every flight, NASA and SpaceX jointly review the imagery data and perform physical inspection of the parachutes.Prior to Crew-3 launch, it was concluded that the chute performance experienced during Crew-2 landing was within the system design margin at splashdown.

Boeing is using the Starliner Avionics and Software Integration Lab (ASIL), a facility that is similar to what was used for Shuttle, to prepare for OFT-2. The Lab enables an end-to-end mission dress rehearsal; Boeing completed the first five-day, end-to-end check out of software in April 2021. Crew was part of simulation, as well as the flight control team. The dress rehearsal overcame the challenges of a major winter storm in Houston, and during COVID. Boeing will do an ASIL dress rehearsal before every

flight, and is currently preparing one for the Crew Flight Test (CFT). In the Spring, Boeing closed out its completion of all IRT software actions that stemmed from OFT-1.

The NASA-Boeing joint IRT looked at the causes of OFT-1's flight software problems and made numerous findings and recommendations, e.g., strengthening Boeing software and Mission Data Load processes, and strengthening Boeing systems engineering and systems integration. Since the IRT, NASA has seen improved software and oversight teams, and feels that all actions combined should significantly reduce risks of the OFT-2 mission. Numerous upgrades were made to the communications system, which will also be tested on OFT-2.

The SpaceX Crew-3 vehicle, *Endurance*, was launched in November and is currently docked at ISS. Crew-3 re-used a Crew Dragon nose cone and other components, and carried out an indirect handover of Crew-2 to Crew-3. Due to weather conditions in November, Crew-2 was brought back safely two days before launching Crew-3. Mark Vande Hei handled the US segment during the handover, and the program learned more about weather, and post-flight turnaround conditions. The Crew-3 vehicle has enhanced software for directing re-entry, which will be exercised when vehicle returns to Atlantic Ocean recovery site after it completes a 180-day mission.

2022 will be a full year, with a Crew-4 launch planned for NET 15 April, also intended to complete 180 days on orbit. Crew-4 will launch on the first flight using a Falcon 9 booster that has flown three previous times (the goal is to re-use the booster five times). For Dragon, SpaceX is adding more re-usable composite components (re-use of the heat shield in this case). SpaceX is continuing comprehensive post-flight analyses, and the build has been going very well. The un-crewed Boeing OFT-2 test will launch on an Atlas V, and is currently scheduled for May 2022. NASA has been working closely with Boeing to determine the cause of an oxidizer isolation valve anomaly on the vehicle's service module; the investigation has not been concluded but it is thought that the most probable cause is oxidizer and moisture interaction. Boeing continues to prepare for its Crewed Flight Test with the vehicle Calypso, and Service Module 5. Mr. Stich thought it would take 6 months, post OFT-2, to get to the Crew Flight Test. The biggest schedule driver will be Service Module 5 production. Thus far, Boeing has hot-fired thrusters and abort engines, and upgraded the parachute systems. The SpaceX Crew-5 launch will take place NET Fall 2022, and will feature the first female commander, Nicole Mann. Plans are to include a Russian cosmonaut on this vehicle.

For Suborbital Crew, CCP is in the process of developing an approach to safety risk assessment for flying NASA personnel, along with an acquisition strategy, using its existing resources. Mr. Stich closed the briefing with the principal Lessons Learned from the experience of the CCP: safety, reliability and cost effectiveness of the crew transportation system are key to developing a commercial capability; and NASA and industry have demonstrated that the public/private approach is viable. Mr. McDaniel thanked Mr. Stich for an outstanding presentation, and ceded the Chair back to Mr. Hale.

<u>Systems Engineering and Integration</u>
Dr. Gregory Chavers, Acting Deputy AA for HEO Systems Engineering and Integration (SE&I), presented a status of SE&I in the context of HEOMD's reorganization, focusing on the relevant components of Space Policy while looking at the SE&I functions, refining the Moon to Mars architecture, coordinating science and utilization goals, identifying and closing gaps in the architecture for future needs, and documenting requiremetns in HEO-level products.

Some of the products at the HEO level include Crewed Deep Space Systems Human Rating, (003, 004, 006, and 007 documents), which flow down to Advanced Exploration Systems (AES), Exploration

Systems Development (ESD), and SCaN. The implementing organization for the Crewed Deep Space Systems Human Rating is AES. Within the SE&I architecture, major hardware concepts in formulation include a Pressurized Rover, Surface Habitat, and Transit Habitat, which will eventually be turned over to Operations. In response to a question, Dr. Chavers noted that the leading consideration for a lunar Surface Habitat site is the lunar South Pole, per agency direction to set up a base camp for two crew at the South Pole. He noted that one of ESDMD's goals is to add clarity to the lunar architecture this year, and refine it. It is not too late to revisit the question of sites, as the requirements are not yet set. The HEOMD Strategic Campaign Operations Plan for Exploration (HEO-007), released in late September 2021, provides a strategy forward, describing campaign and campaign segments through roughly Artemis 10. There are many constraints and elements for each mission, and SE&I is trying to stay flexible to develop missions that are able to progressively meet more and more requirements throughout Artemis. The HEO-007 strategy presupposes continuous human presence in LEO, human lunar visits and returns with increasingly longer crew expeditions aboard the Gateway and on the lunar surface, followed by sustained lunar presence, followed by human missions to Mars. The buildup of capability to attain sustained lunar presence (pressurized rovers, habitats, ISRU) all have relevance to Mars.

The Strategic Analysis Cycle of FY21 (SAC 21) has helped to align analysis teams, and set ground rules and assumptions in each fiscal year, as the budget ultimately "turns the knobs" on schedule. The completed SAC 21 gives key takeaway messages on affordability and risk analyses. Key trades will be coming up in FY22; the Pressurized Rover is identified as an initial base camp element, followed by Surface Habitat. SE&I is looking at how to deliver large surface elements, how to integrate logistic delivery, and how to plan rover traverses alongside with SMD, to take advantage of maximum sun time. For Mars, SE&I is looking at interim mission options (orbital, others), and assessing transportation capabilities for cruise to Mars, and development timelines. Propulsion systems under consideration include Nuclear Electric Power (NEP) hybrid, Solar Electric Power (SEP) hybrid, nuclear thermal, and "all chemical."

NASA SE&I is also looking at opportunities for international partnerships, and is in a study phase with JAXA at present, and is also talking with the Canadian Space Agency (CSA), Italian Space Agency (ASI), the European Space Agency (ESA) for participation in Artemis missions. Recognizing that SMD science is dependent on upmass, downmass, and crew time, SE&I relies on a Utilization Plan (HEO-006) jointly with SMD and STMD, to ensure that science and technology inputs are integrated into architecture formulation activities. There are a few "shall" statements in the plan, which are not mission requirements and not systems requirements that require engineering verification (which are in HEO-004). The Utilization Plan currently includes goals and objectives, and will soon have use cases for major utilization capabilities added. Mr. Hale requested copies of the Utilization Plan, and others associated with the briefing. Dr. Chavers agreed to provide them to the Committee.

For tracking of capabilities integration, SE&I keeps a gap list, and has been prioritizing "top 10" gaps. Many gaps that have been identified are actually funded, which is helping to optimize return on the architecture. Some gaps are tied to roadmaps (ECLSS roadmap, e.g.). Technical Integration collaborates with Division level SE&I functions in order to maintain insight throughout the directorate on Configuration Management and Data Management, Risk Management Requirements Development, ensuring that top-level requirements are being maintained as capabilities move forward. Crewed Deep Space Systems Human Rating Certification Requirements (HEO-003) are focused on lunar requirements. Human Exploration Requirements cover SLS and Orion. One example of Technical Integration to Maximize Objectives While Balancing Risk is an atmospheric risk item associated with improving EVA times on the lunar surface by minimizing pre-breathe times. Mr. Hale noted that one

medical issue of interest is the human response to microgravity, and that he had not seen have much information in the briefing on the lunar gravity environment. Dr. Chavers assured HEOC that the decision to minimize pre-breathe times, as well as other decisions impacting human physiology, was made with the aid of human health experts. Mr. Hale said he was also struck by the assumption of all-chemical propulsion, because the best way to mitigate radiation is to minimize transit time, which points more to nuclear propulsion (for transit to Mars). Dr. Chavers said SE&I had been analyzing all propulsion techniques in order to determine "bookends," and to understand the value of all-chemical propulsion in terms of different trajectories, or refueling in space. Mr. Hale asked how the Artemis campaign was structured beyond Artemis missions III and IV. Dr. Chavers referred the question to Mr. Mark Kirasich for further details.

Dr. Sowers commented on the general functions of SE&I for Artemis, noting that the recent ASAP report had raised concerns about systems integration across elements of Artemis. While it sounds like SE& I has good front-end plans, who owns the ICDs between the elements of Artemis? Dr. Chavers said this would be another good topic for Mr. Kirasich to address; the ICD level is more at the implementation phase and between the programs. Ms. Sanders clarified that ASAP was a bit concerned with the title of the organization (SE&I), but not the function. Dr. Chavers said that many SE&I functions are distributed throughout higher level and lower levels. For Orion, Dr. Chavers noted that most functions were heritage, but that Artemis III and beyond are under Mr. Kirasich's purview. Mr. Hale wanted to know more about how ICDs connect Orion, Gateway, Artemis, etc. Mr. Voss said he was reassured by what he was hearing today about SE&I far future plans, mentioning that his previous concern was more about studies that had been repeated. Ms. Budden asked if there had been a conversation on how science missions would be accommodated by the architecture (data, power, surface, science module, habitat), so that it is not left out toward the end. Dr. Chavers said that yes, the discussion has begun, and allocated upmass and downmass had already been allocated. He said he recognized that SMD would need more quantification of crew time, etc., and felt there was a healthy tension about SE&I and SMD were documenting requirements. There are nearly daily discussions on the subject. Each mission is increasingly complex, and will have different requirements. There will be pre-screening samples, for instance and subsequently, optimization of robotics for that purpose. Science will not be an afterthought. Dr. Julie Robinson added that there is a Utilization Coordination Integration Group (UCIG) that is coordinating utilization requirements and long-term capabilities, and its output is presented to a four-Directorate Program Management Council (DPMC); the general approach going forward for the integration of exploration and science will be formal and deliberative. The UCIG considers such issues as sampling from shadowed regions, temperatures, etc., and addresses the top-level mission objectives. The UCIG has representatives from every involved program and division, including commercial. Mr. Hale commented that the SMD CLPS missions will help some development for Artemis; these are higher-risk missions, and their knowledge output is not in the critical path. Dr. Chavers, adding that CLPS missions will include sensors to help understand interaction with regolith. SE&I also has 25-kg allocations on some CLPS that may provide data that can help with the architecture.

Exploration Systems Development

Mr. Amit Kshatriya, Assistant DAA for Exploration Systems Development (ESD), gave an update on Artemis I, noting that in his 200 days with the program, he had witnessed a growing wave of progress in Artemis. The first test flight of SLS and Orion is eagerly awaited. Among a number of mission priorities, demonstration of the heat shield is paramount. The goal is to observe the shield achieve at least 11km/s on a skip re-entry trajectory. The heat shield has undergone significant subscale testing in

an arc jet facility, but the test flight will be the most critical test to determine thermal and structural stresses. The next priority is the performance of the Orion vehicle itself in the deep space environment/cis-lunar space. Getting as much flight time on Orion as possible will also test ground-based and mission support capabilities. The final major priority is the recovery of the spacecraft's crew module for post-flight analysis, recovering all flight instruments, and exercising all recovery systems. The flight test will also exercise redundant capabilities, and will involve deployment of secondary payloads as well. Mr. Kshatriya noted that the Navy personnel involved in recovery operations have been very enthusiastic participants. Artemis 1 will launch from pad 39B at KSC. Many cubesats will study the cis-lunar environment following the spacecraft separation from the upper stage. The Artemis I mission will use a lunar gravity assist and insert Orion in a distant retrograde orbit (DRO), a circular, stable orbit 38,000 miles from Moon, remain in orbit from 6-23 days, before a splashdown off the coast of California. Dr. Condon asked what was driving the establishment of the launch date. Mr. Kshatriya said the first constraint is the performance of the launch vehicle itself, the second is how long Orion can dwell in eclipse, and third, a lit landing; this establishes the two week on/off cadence.

Recent Artemis I accomplishments over the last three months include integration of the final components of the stack, followed by integrated testing to verify that the stacked vehicle can communicate and cleanly separate from the mobile launch tower umbilicals at lift-off; structural modal tests; dynamic response; electrical continuity; integrated vehicle communication systems test with network elements; and verify flight software in conjunction with ground software. The entire stack is then retested under cryogenic loading conditions at the upcoming Wet Dress Rehearsal (WDR) test.

The Umbilical Release & Retract Test (URRT) is complete; Mr. Kshatriya noted that it had taken ten years to refine the choreography of this test. The Integrated Modal Test (IMT) was also successfully completed; the stack was slightly stiffer than expected, which was a good indication for a stack of this size; the IMT retired much risk. The Integrated Vehicle Interface Verification Test (IVT) was completed and performed post-mate of the SLS and Orion vehicles. An End-to-End Communications Test (E-T-E Comm Test) was recently completed, during which the mission carried out communications with required facilities and NASA Centers via SCaN's Near Earth Network (NEN) and DSN. There was an issue with the Engine Controller around late November, after some failures in power-up attempts. The team made sure to build a rigorous fault tree, and did thorough testing at the Cape to verify that there was connector conductivity. New cables had to be fabricated and installed for diagnostic purposes. It was concluded that the fault was probably in the controller itself. The eventual recommendation was to remove and replace the Engine Controller, while hot-fire tests provided enough confidence in to keep the engine in place. In December, the Engine Controller was swapped out and Core Stage was completed. The Engine Controller (EC) has been taken to the OEM, which reproduced the failure on the bench. Work is still in progress, in hopes of completion within 3-4 weeks. Mr. Hale commented that this was a very familiar story, and offered kudos to the team. Asked if the IMT results were used to modify the models, Mr. Kshatriya said that the observed stiffness was within the model's limits, but added he would take an action to confirm this statement.

The Countdown Sequence Test (CST), Part 1, was completed on 20 December. The CST was stopped at T-33 seconds; another CST run will be carried out before the Wet Dress Rehearsal. The CST captured a couple dozen issues, which were documented and followed up with actions, the second part of the CST is planned for 24 January, followed by Wet Dress Rehearsal scheduled for 15 February. WDR will run the countdown to T-10 seconds, just prior to the main engine start of the R-25, followed by de-tanking, and inerting the tanks. Mr. Hale commended Mr. Kshatriya for his thorough presentation; he asked if the Agency had a backup plan in the case of Artemis I failing to achieve one or more important objectives.

Mr. Kshatriya said that some orbit-shaping techniques had been identified, and that ESD is absolutely thinking about that, as well as keeping the hardware moving and getting as much data as possible. Dr. Sowers asked about the status of requirements verification. Mr. Kshatriya said that ESD was very close to final completion of several thousand Artemis I requirements, at about 97-98% completion, with many clean reviews from the PMs. Dr. Sowers asked if there had been independent audits of those closures. Mr. Kshatriya said he knew that each individual program has done this, and offered to provide more detailed answers after consultation. ESD has also deliberately participated in Boeing's Starliner reviews and incorporated their Lessons Learned.

With Artemis II, risk tolerance will change significantly with crew on board. The mission will employ an apogee raise burn to achieve a high Earth orbit, during which time ESD will learn as much as possible during a demonstration of Orion proximity operations: getting a baseline of Orion vehicle behavior, and allowing the crew to take Orion for a spin and 24-hour shakedown. The spacecraft has been supplied with ISS-heritage and enhanced technology, including waste disposal and life support systems. A docking system will not be flown on Artemis II, however, NASA expects to get more data on docking systems from Starliner flights and from ISS. To measure the radiation environment, Artemis I will have a mannequin outfitted with radiation sensors, so that the Artemis II crew can be shielded more effectively. Artemis II preparations thus far include completion of a heatshield thermal test, and installation of ECLSS bay components. Mr. Kshatriya commended Artemis II's efficient teamwork. The Core Stage for Artemis II is also making progress, but the schedule is being impacted by post-hurricane, pandemic, and global supply chain issues. The path to Artemis III and beyond is making good progress, with work going on across the country. Mr. Hale and Mr.Voss thanked Mr. Kshatriya for the detailed briefing.

Advanced Exploration Systems

Mr. Mark Kirasich, DAA for Advanced Exploration Systems (AES) gave an overview of the scope of the current program: the Human Landing System (HLS), Gateway, Exploration suits, Lunar Terrain Vehicle, future Surface Mobility program; planning and execution of Artemis III+ missions; and development of advanced technology for long-duration exploration missions. Mr. Kirasich reviewed the organization of the HLS Program Office at Marshall Space Flight Center (MSFC). Ms. Lisa Watson-Morgan is the HLS PM, and has recently established program governance. NASA now has a contract with SpaceX (Appendix H, Option A) for the initial Human Landing System. Initially, SpaceX worked to NASA's reduced requirements established to meet the 2024 landing target. Current requirements are for two crew; sustained requirements will be for four crew. After having dealt with two different contract protests, as of November the Marshall team has been fully engaged in working with SpaceX. SpaceX did make progress during the protests, and has completed five milestones. Every time a milestone is completed, it is followed by a full HLS Program review. Mr. Alibaruho asked whether the protests were a standard play, or if there were opportunities for improvement. Mr. Kirasich said that while AES may discover in the future whether or not protests will be standard practice, it is always possible to learn from these experiences. After the seven-month stay and subsequent engagement with SpaceX, AES targeted Summer 2025 for landing, and is just starting to look at the integrated master schedule. The SpaceX lander is called the Starship; each variant launches on a super-heavy booster. There is a version called the Depot, followed by a series of launchers carrying oxygen and methane. The Starship is designed to fuel up in Earth orbit. There will be an orbital flight test within months.

Because the Artemis plan includes recurring human landings on an annual basis, and since it will be necessary to land large cargo such as the pressurized rover and surface habitats on the lunar surface, AES has made additional HLS procurement actions. NASA has bought one crew landing, and has

awarded as of September 2021 Appendix N, a "bridge" Broad Area Announcement (BAA) that will prepare industry for the transportation competition. Initial awards have been made to five companies: Blue Origin, Dynetics, Lockheed Martin, Northrup Grumman, and SpaceX. In addition, AES is now in the middle of procurement planning through the HLS Lunar Exploration Transportation Services (LETS), and hopes to have a draft Request for Proposals (RFP) out in Spring 2022. Mr. Hale said it was good to hear ground truth about these items, the process, and where AES is going. He asked: Artemis IV doesn't have a lander, is that because of the LETS process? Mr. Kirasich affirmed that this was so. He added that Artemis IV will be the first flight of the Enhanced Upper Stage (EUS), and will carry a 10-metric ton ESA habitat. Mr. Voss asked if there were a budget line for Appendix N. Mr. Kirasich said that the budget line was in the President's Budget Request (PBR), so NASA will have to wait to see the actual appropriations, but it is in the budget plan. Lisa Watson-Morgan, the HLS Program Manager, said that Mr. Kirasich had done a great job with the budget items, and that they had just received an integrated master schedule and were going through a realism assessment, maintaining very good communication with SpaceX. Starship is a large program for SpaceX, but they have been good at keeping NASA apprised on HLS as they proceed with their commercial activities.

Mr. Kirasich reviewed the organization of the Gateway Program Office, emphasizing that this a multi-Center program, just like HLS Program Office. NASA has memoranda of understanding (MOUs) with ESA, JAXA, and CSA for their elements of Gateway, and has contracts for all components except the airlock. The initial components of Gateway include the Power Propulsion Element (PPE), a solar-electric system being built by Maxar; and HALO, a derivative of the Cygnus module being developed by Northrop Grumman. The next are ESA components: the International Habitat (I-HAB) and the ESPRIT-refueler. CSA will provide the Gateway External Robotic System (GERS). SpaceX has been contracted for a Logistic Module. The PPE and HALO will be integrated and tested at KSC before it is launched on a Falcon Heavy. Mr. Dan Hartman said that JAXA, CSA, and ESA also have additional contributions to the first PPE/HALO launch, and a couple of payloads from Goddard Space Flight Center and ESA on this launch. Asked how challenging it has been managing across players and components, Mr. Hartman said that it has been important to think about the end-to-end architecture, and think about faults and propagations, much like the ISS assembly process. It will be necessary to think about the effects of plumes, and the thermal effects of each incoming vehicle on the Gateway appendages, such as solar arrays and antennae dishes.

In terms of Gateway accomplishments, Calendar Year 2021 (CY21) included a 6 kW solar electric propulsion (SEP) subsystem test of the PPE, and a HALO PDR close-out. Upcoming major events include a PPE Maxar Systems and Integrated CDR; HALO Systems and Integrated CDR, and Falcon Heavy Extended Fairing CDR. Dr. Condon commented that it seems, given the large number of partnerships, that interface configuration management would be a challenge. Is this challenged ameliorated by ISS experience? Mr. Hartman said that coming from ISS experience, AES does have many interfaces defined, and with earlier elements, the program is at ICD level. For some future elements like the airlock, there are specifications, but the Gateway Program hasn't had detailed discussions. However, there are weekly discussions with partners. JAXA and ESA have formed a good relationship at I-HAB, because JAXA provides many components for the interior of ESA's I-HALO. Mr. Hale asked if the discussion of Gateway as a proving ground for Mars was still being considered. Mr. Hartman said that nothing prevents long-duration missions at Gateway except a robust logistics train. ~~save supplies~~ (oxygen, food, water, research projects). Mr. Hale said he thought of Gateway as serving three purposes: a place for the lander to meet Orion (transfer point); a point for logistics operations; and a proving ground for testing long-duration systems to prepare to go to Mars. Mr. Hartman added that he thought Gateway would also support the human system risk buy down for Mars.

AES just received approval for a new program at JSC to focus expressly on suits, and has initiatedan xEVA Services procurement to provide suits for ISS, Gateway, and the lunar surface. Requirements are for much more mobility, accommodation of a wider range of sizes, and for reduced pre-breathe capabilities and increased reliability. Proposals were received in December 2021 and the team is now evaluating them, in a blackout period. AES is now undertaking a design verification testing (DVT) process of the pressure garment subsystem (PGS) and the portable life support subsystem (PLSS). Test data reports will be added to the EVA Technical Library for commercial proposers to access. In August 2022, there will be a tailored internal review of CDR-level design products. Asked if the procurement strategy had changed, Mr. Kirasich said that in September 2020, AES looked at the procurement landscape and wanted to get production going, which was supported by the successful government risk reduction activities, and NASA did make an adjustment in the strategy. Dr. Condon asked if AES had consulted with astronauts that had experience on the lunar surface, with regard to issues that arose gloves and dust. Ms. Lara Kearney noted that AES had consulted with Apollo astronauts quite a lot over the last decade, documenting Lessons Learned with a series of workshops, the outcomes of which have driven requirements and design decisions. The IRT has 4 or 5 "graybeards" that have influenced the design process. Ms. Budden said she had been part of similar processes in the DoD and cited many issues around ease of tool use, pressure in gloves, etc., and hoped that NASA would be looking at new tools, and more digital techniques. Similar to Navy Seal requirements, the suits need flexibility to allow efficient and easy use of instruments, scientific and exploration tools, and vehicles. Ms. Kearney said the team talks a lot about informatics and heads-up displays; the beauty of the new program is that it can integrate across aspects of the whole mobility architecture. Ms. Budden endorsed the use of virtual reality (VR), such that others can experience the sortie through an astronaut's heads-up display, which also serves as an opportunity for education; the "back rooms" can be there with the explorer. Ms. Kearney said there had been much improvement of suit flexibility, mostly in the joints, and improvements also in the shoulder range. Mr. Hale said that in a future meeting, HEOC would like to hear how the suits play forward to Mars.

The Human Surface Mobility (HSM) project released a second Lunar Terrain Vehicle (LTV) RFI in September 2021, and received 21 responses. The intent is to have a 10-year operational lifetime for the LTV; AES is getting smarter about the South Pole every day in terms of battery life, time in sun, etc. In addition NASA is having discussions with JAXA on system requirements and concepts of operations for a pressurized rover.

The Exploration ECLSS/Human Habitability Needs project is focused on a Lunar Surface Habitat, and Mars Transit Habitat, both of which will require better recycling and highly reliable systems. Currently there are two different CO2 removal systems being tested on ISS, and additional systems on the ground. One goal is to increase the efficiency of the water recycling using the Brine Processing Assembly to 98%; the Assembly is now in its fourth or fifth cycle on ISS. On the ground, efforts are under way further human habitat needs: the Crew Health and Performance Exploration Analog (CHAPEA) is a simulated one-year Mars mission that will take place in a 3D-printed habitat. There are over 4000 applicants for this study.

Top AES integration accomplishments since September 2021 are the completion of an Artemis in-space communications architecture trade that takes into account line-of-sight methods, and better understanding of the lighting at the lunar South Pole; much end-to-end analysis is ongoing. A working manifest for technical integration is now in planning for Artemis III, IV, and V. AES is not currently planning for Artemis III to have access to Gateway since the Gateway will not be on station until the Artemis IV timeframe;. NASA is working to acceleratelogistics module plans into the Artemis IV

timeframe to improve mission robustness. Mr. Voss asked how Starship factored into planning. Mr. Kirasich said that SpaceX is only under contract for the Artemis III mission. The LETS procurement must be complete in order to determine what company could support a mission in the Artemis IV timeframe. In interfacing with STMD for sustainability planning, AES is working hard to coordinate technology development efforts, reducing overlap and gaps, and ensure the government gets the most for its technology dollars. AES works directly with STMD leadershipand utilizes HEO SE&Is gap list, to drive the coordination with STMD.

Public comment period

Mr. Steven Wolfe (BEI) asked if the LTV and habitat modules would be developed under a private/public arrangement with commercial partners. Mr. Kirasich said this is one of the options being considered during the procurement strategy process. Mr. Wolfe asked how Artemis could stimulate commercial development as NASA turns its attention to Mars in the 2030s. Mr. Kirasich said that this was in fact one of the (stated) purposes of the Artemis program and NASA is focusing on scientific and technology utilization. Mr. Dave Huntsman asked where in-situ resource utilization was being developed. Mr. Kirasich said ISRU is led at STMD and SMD, and will be incorporated into the Artemis program when matured. Mr. Huntsman asked when Lunar Surface Modules (LSMs) would be deployed. Mr. Kirasich said this would likely occur at the end of this decade, or early next decade.

Discussion and Recommendations

HEOC began deliberations on findings and recommendations, and reviewed Dr. Sowers' written recommendation on NASA's financial commitment to Commercial LEO Destinations (CLDs). The HEOC unanimously accepted the wording, and characterized it as a recommendation to both Ms. Lueders and Mr. Free. Mr. Alibaruho submitted a recommendation to reevaluate elements of the program schedule and manifest due to pandemic supplier performance, to de-risk the schedule appropriately. Mr. Hale and HEOC unanimously agreed with the recommendation to both ESDMD and SOMD. Mr. Sowers thought the recommendation was applicable to anyone procuring hardware, i.e. the entirety of NASA (NAC). Mr. Alibaruho rewrote the recommendation to reflect this.

Mr. Hale went around the table for final comments. Mr. Ebersole suggested that how the two AAs are managing the "seam" between ESDMD and SOMD could be a topic for future discussion: How do they know how well they are doing? Mr. Hale said that he appreciated the fresh set of eyes brought by Mr. Ebersole. Dr. Sowers commented that it is not obvious how SE&I is being accomplished in both directorates. Given that SE&I has critical functions all the way to the end of each mission, maybe the subject should be elevated and clarified. Mr. Hale agreed, and requested that Ms. Erika Alvarez present at the next meeting to brief the HEOC on details of Systems Integration. Ms. Sanders said she thought that Ms. Alvarez had brought SE&I a step forward, and encouraged HEOC to look at how she is managing a bottom-up integration effort, adjudicating as things come up. It's good work, but it's a complex program, thus Ms. Sanders encouraged more scrutiny. Mr. Hale agreed that this could be a special topic for the next meeting. Dr. Sowers said that that some level of independent review should have been carried out for Artemis I readiness, and that independent reviews should be embedded throughout the mission arc. Mr. Hale thought that the NASA Technical Authority functioned effectively as an independent review arm, but agreed it could be a future discussion topic. Mr. Alibaruho said that other than his submitted recommendation, he thought the meeting had been great, and was impressed to have seen so much progress take place. Ms. Cline commented that Mr. McAlister had not addressed how NASA is talking to partners about their commercial plans for LEO; she was concerned about the potential conflicts in acquisition strategies that might impair the ability to do joint selections and solicitations. Secondly, the major transformation in launch vehicles invites a different risk level

acceptance. Lastly, Ms. Cline emphasized the importance of Mr. McAlister's specific request to HEOC to broadcast the need for other agencies to step up their role in monitoring LEO. Dr. Sowers thought the National Space Council would be the proper venue for that request. Ms. Cline agreed. Mr. Hale took an action to speak to General Lyles and get the topic onto the Council's agenda.

Dr. Condon expressed his appreciation for Mr. Hale's leadership, and the detailed update on Artemis. He echoed Mr. Ebersole's comments on the organizational realignment, which is especially challenging when NASA is just months away from launching an important mission. It is critically important that Artemis I be a success. He expressed keen interest in what NASA's response to the ASAP report would be. Mr. McDaniel thanked Mr. Hale for his leadership at HEOC, and at NASA for decades, and said he was impressed with all the progress that had been made since last meeting; he agreed that the most important thing for HEOC to look at is systems integration. He also felt that NASA must be more flexible in its planning. Most importantly, he noted that there was a real thirst for what NASA is doing. The US is a nation of pioneers, and they want their children to be successful in STEM-related endeavors. Pointing out that James Cameron once sat on the NAC, he felt NASA must employ more creative solutions to get its story out to public. NASA must also must be forthright about its problems and challenges. Mr. McDaniel echoed Ms. Budden's comments on NASA carrying a vision that transcends administrations, but thought that NASA was on a good path for the Moon to Mars journey.

Mr. Voss agreed with general HEOC sentiments about the division of HEOMD, but worried that the seam is more like a crack that things might fall through: Who has the responsibility for all the different pieces? NASA will need robust processes in place for super-good handovers. Mr. Voss said he would like to learn about what measures have been put in place to prevent oversights, and how the reorganization is being implemented. He felt that the same issue applied to the Artemis program, which could use an Integration Manager. HEOC should stay tuned to NASA's response to ASAP recommendations. Mr. Hale noted that HEOC has recommended that there should be an overall systems integration group that oversees all the parts. Most accidents happen at the interfaces; Mr. Hale felt that both Ms. Lueders and Mr. McAlister are very cognizant of this issue. However, NASA is not the captain of its own fate; these re-organizations have to be approved by OMB and Capitol Hill. That said, Mr. Hale suggested that HEOC hear a detailed presentation and discussion about this issue at its next meeting. How it all flows down to the working level is another, tougher question. Ms. Budden thought the HEOC could help with the reorganization questions by proposing a model like that used in the Shuttle program. Ms. Budden further recommended that the HEOC receive a briefing from the Science Committee, from whoever is constructing the science program for Artemis. It would be good to hear a list of what components are involved: disciplines, contributions from Centers, transit science, orbital science, surface science, plans for in-situ testing, upmass/downmass requirements, etc. She added that she had sponsored a study (Eppler, *et al.*) on science that can be accomplished during the lunar night, with Earthshine. Mr. Hale supported holding a joint meeting with the Science Committee, and Dr. Siegel took an action to follow up. Dr. Sanders noted the value of meeting in person and hoped to have the HEOC do so soon. She commented on the potential "chasm" between two organizations, which still have integration challenges especially with regard to LV transitions. Starliner will be launched on a vehicle that will be obsolete in the near future, which will mean new certifications for new vehicles, another challenge. In terms of HLS, there may be a real danger of developing a vehicle that has requirements for only that demonstration, and of questionable resources for that second vehicle. Dr. Sanders added that with regard to the discussion re: regulatory responsibilities for commercial vehicles, ASAP has pushed on this issue, specifically on space traffic management. The government needs to agree on who does what. ASAP also raised the issue on standards for commercial mishaps, noting that private space customers should be mindful that they are taking calculated risks.

Mr. Hale offered final thoughts, observing that this is a time of great changes in the space industry, which can change the way NASA does business. The Agency needs to consider how the SpaceX super heavy LV, Starship, and Blue Origin New Glenn launch vehicle will fit into NASA's plans. An environmental impact statement at the SpaceX site could turn out to be a showstopper. NASA needs to maintain flexibility and be willing to bring in new systems as they are proven out. Mr. Hale also expressed concern about transparency at the Agency, commenting that when he was a Flight Director for Shuttle, the program had to brief out every 8 hours, and had to talk to the press about challenges. At present, NASA Public Affairs issues mostly happy words. There needs to be an honest discussion about the complexity of NASA's work, and how good a job NASA is doing in making these systems fly. NASA should be more open about talking about the very real and enormous difficulties. He thought that the recent outreach effort on JWST had been very successful. Mr. McDaniel mentioned the success of a Risk Symposium that was hosted by Keith Cowing and stood up by former NASA Administrator, Sean O'Keeffe. The symposium made clear that launches are extremely dangerous; it is a fact that needs to be stressed in the public arena. Ms. Cline seconded the thought, adding that one of her tasks under HEOMD AA William Gerstenmaier was to give a heads up to the Office of Science and Technology Policy (OSTP) any time NASA was proposing an activity that would be questioned. She noted that such efforts go a long way to prevent over-reaction.

Mr. Hale wrapped up the meeting. Dr. Siegel expressed her appreciation to all participants and adjourned the meeting at 4:09pm.

Recommendations:

For NAC Recommendations (actionable):

Short Title of Recommendation: Financial Commitment to the Commercial LEO Destinations (CLD)

Recommendation: NASA should determine its demand for LEO services as soon as practical, but well in advance of ISS retirement. This demand should be translated into a contractual commitment as soon as practical. NASA should begin transitioning its needs to the commercial providers well before the ISS is retired.

Major Reasons for the Recommendation: Business viability of the CLDs is as important as technical viability. The CLD contractors will regard NASA as an anchor tenant. A firm commitment by NASA will be essential in enabling the CLDs to attract additional customers and close the business case.

Consequences of No Action on the Recommendation: Long term availability of commercial LEO services depends on the business viability of the service providers. A lack of firm NASA commitment as a customer will dramatically reduce the business viability of the providers.

Short Title of Recommendation: All Mission Directorates Re-evaluate Program Schedules & Manifest Due to Pandemic Supplier Performance

Recommendation: Please be sure to assess those elements of the launch manifesst and program development schedules for which material procurement is in the critical path and be sure that we have incorporate sufficient planning buffer to address the mid-pandemic supply base performance.

Major Reasons for the Recommendation: Due to the COVID-19 global pandemic and the impact on the global labor market, microchip availability, and general industry impairment, typical delivery lead times for material procurements are running between 2x – 5x of what is normal.

Consequences of No Action on the Recommendation: NASA's various projects with near and intermediate term material procurements may miss schedule commitments due to unforeseen and unmitigated delivery schedule and quality risks from key suppliers. Given the scale of the programs, significant schedule slips due to material procurements will have significant downstream cost impacts to the affected programs.

Appendix A

Attendees

Wayne Hale, *Chair*, Ret. NASA
Kwatsi Alibaruho, EATON Corporation
Nancy Ann Budden, Director for Special Operations Technology, OSD
Lynn Cline, Former NASA Deputy Associate Administrator, HEOMD
Stephen "Pat" Condon, Aerospace Consultant
C. Douglas Ebersole, Ret. Air Force Research Laboratory
Mark McDaniel, McDaniel and McDaniel Attorneys, LLC
Patricia Sanders, Chair, Aviation Safety Advisory Panel, *ex officio*
George Sowers, Colorado School of Mines
James Voss, University of Colorado, Boulder
Bette Siegel, *Executive Secretary*, NASA

Webex attendees

Robin Gjelstrup
Robert Medina
Todd Rutovich
Ron Hartke
Cloud Morrison
Alex Garner
Marlena Cervantes
Esther Veras
Kathy Coats
Bailey Spencer
George Freeman
Jeffery Horne
Pat Benson
Joyce McDowell
Peter Miller
Scott Gray
Kevin Hoover
Tim Burzette
Iqbal Amiri
Dave Hardik
Nia Ogletree
Renee Watson
Mary Griffith
John Burns
Francisco Mejia
Kay Doane
Mary Russell
Kara Vernon
RavanasamudramVenkatachalam
Sean Corrigan
Patricia Arauz
Mark Anthony Garrett
Giovanna Marcantonio
Robert Watts
Mike Johnson
Ron Marinzel
Loay Elbasyouni
Kevin Pollard
Kimberly Bell
Matt Resler
Jeremiah Quarles
CW Bennett
Leon Baptiste
Kelly Boos
Jose Gonzalez
Matt Charmbury
Amar Patel
Camila Saunier
Kim Patz
Thomas Chappell
Matthew Russell
Patricia Walden
Steven Tsvetkoff
Ella Daya
Jamila Hashil
Tumarrow Romain
Karen Pardy
Heather Herod
Karen Kensok
Debbie Newberry
Gladys Roberson
Jared Ross
David Ross
David Petricone
Taneshia Jones
Bill Davis
Bert Purcell
Christina Hercek
David Larson
Dave Parsonage
Julie-Anne Rose
Paul Albertson
Frank Rea
Tony Wredt
Jim Bailey
Papillon Wu
Nellie Chappell-White
Liza Pierce
Brittany Quade
Dale Haupt
Allen Nejah
John Madhu
Zhiqing Cheng
Thomas Georgantis
Stephanie Owen
Debbie Batson
Flora Wu
Carmen Journey
William Sola
Michael Whitby
Jacqueline Rodriguez-Valdes
John Buckley
Tony Rubio
Shayla Coles
Kiara Moore
Jake Kordana
Enrique Kinsey
Eric Freer
Truphelia Parker
Yardia Spencer
Jim Elliott
Patrick Fitzgerald
Mackenzie Crosswell
Karen Jones
Leo Rshtuni
Michelle Chaudry
Hannah Powell
Joey Hutchins
Sandy Davis-Schiermeyer
Jennifer Ross
Ben Lawless
Ken Rojas
Henry Breems
Paul Gupta

Nic League
Zakir Mahmood
David Eldredge
Mark Swantko
Hamed Maysami
Ashlie Crawford
Kimberly Andriotakis-Hoskinson
Kelly Jones
Stacy Lloyd
Justin von Mizener
Tizoc Loza
Christine Munroe
Jon Myers
Garrett McQueen
Rhonda Sutton
Lourdes Kessler
William Cordero
Jennifer Bobbitt
Linda Andrews
David Wallace
Constance Ashford
Lisa Harvey
Damien Lawson
Lawrence Adkins
Sherman Davis
Dena Sandy
Miguel Rodriguez
Regina Garson
Doug Stewart
Morgan Moses-Allen
Ralph Kennedy
Prashanthi Reddy
Scott Thurston
Ronney Revis
Ron Patrick Castro
Naeemah Lee
Tina Balthazar
Larry Ellis
Dean Rosales
Michael Minor
Annie Soh
Christopher Borlas
Andrew Hair
Troy Miller
Tej Kanitkar
Marcus Drummond
Elizabeth Schaub
Alexandra Laureano
David Light
Richard Hamilton
Jerri-Mae Ross
Robert Duffett
Tracy Wacker
Bob James
Lisa Brown
Lorena Shaw
Jeremy Sandoval
Ron Ellman
Brandon Blair
Trace Culp
Nelson Mendez
Matt Mills
Michael Ansley
Michael Cheek
Suzanne Larson
Leanne Marshall
Becky Behan
Christopher Brehier
William Hamblin
Rani Bartlett
Susan McGrath
Stephanie Andre
Praveen Yalamanchi
Teri Twigg
John Jordan
Alexander Weixel
Robert Harris
Joe Fredricks
Chantal Elizabeth
Jorge Bustillos
Jon Brown
Melanie Hedgepeth
Portia Evans
Mary Fox
Shannan Starling
Alexander Hayes
Alan Riendeau
Patrick Chery
David Delancy
Delia Gallucci
Bill Boggs
Bruce Fox
Eric Blythe
Anna Reyes-Potts
Joseph Scheer
Patricia Hamilton
Dan Bittner
Helena Van der Merwe
Debbie Kropp
Biju Kurian
Paul Johnson
Anastasia Vasilyeva
Ricky Ricardo
Alexander Craig
Kathy Swanson
Christopher Poulos
Krishna Annambhotla
Wendace Riley
Claudia Herrera
Afzal Khan
Kris Garner
Jerrod Young
Frank Louis-Jeune
Jill Koehler
Edwin Martinez
Cornelis Bruyns
Adam Karides
Karen Riffice
Oliver Little
Annette Colbert-Black
Scott Smith
Andrey Miroshnichenko
Laurie Boehm
Eunice Adams-Sipp
Susan Thibodeaux
Richard Price
George Hauer
Michael Reeves
Jason Conley
Anthony Stephens
Michelle Ramirez
Michael Egge
Rick Head
Timothy O'Brien
Danielle Shears
Antonio Gonzalez
Edward Ellegood
Andrew Horn
M Brodrick
Monica Coburn
Briana Lynn
Ashley Patterson
Matt DeLao
Jesus Lugo
Jim Miles
Jose Abril
Randall Manning
Monica Craft
Toni Hall
May Costa
Andres Garcia
Robert Betts
Michael Tolfree
Sean Wesley
Eamon DiMilano
Elizabeth Jensen
Fin Johnson
Ryan Lamos
Nicole Banville
Mark Bruneman
Bryan Banks
Don Smith
Barbara Scudder
Matt Gierman
Clarence Moultrie
B. Reed
Kirsten Armstrong
Mark Rerko
Jeanne Chun
Kristy Wallace
Dorette Nysewander
Lydia Plummer-Alleyne
Kathy Saufl
Jonathan Reed

Donna Hagedorn
Dwayne Washington
Stephen Berge
Jenifer Scoffield
Angela Czupta
Marcus Orr
Rayricus Matthews
Warren Youngclaus
Natalie Colvin
Shawna Neumann
Gale Armel
Joe Tulskie
M Grasel
Monique Myers
Kristin Thomas
Gil Duran
Christopher Crossley
Elizabeth Huy
Jason Tangi
Todd Haines
Mark Walker
Blair Stultz
Vaughn Turner
Alaa Negeda
Tiffany Simmons
Angela Lee
Khari Heru
JonathanTaylor
Philip Corrado
Josh Huntley
Melanie Snow
Cadence Smith
Eric Boyle
Tim Middendorf
Marco Sabatini
Marlon Fonrose
Peggy Hughes
Patrick Moran
Jessica Nelms
Daphne Martinez
Pamela Cook
Carmine Bailey
Eddie Rivera
Steven Bledsoe
Jeffrey Smith
Karrie Brazaski
Paul Verdile
Gwen Waldron
Arvind Lal
Tameisha Singfield
Daniel Burgess
Raymundo Carreon
Greg Quinones
Todd Gross
Larry Snyder
Cassie Contreras
Steve Meriweather
Sue Nathan

Duleep Amarasinghe
Jeremy Iglesias
Gabrielle Cavalier
Nadia Ali
Al Alegre
Carl McManus
Raynor McKinnon
Nick Chauhan
Chuck Petrilla
Marilyn Westropp
Kevin Kurian
Mikayla Holland
Julie Martz
Heather Bushart
Janice Kugelmann
Laura Rochester
Bob Varney
William Bayer
Keaton Senti
Allison Thurman
YC Lawson
Kevin Perrigo
Misha Ford
Sonya Hopson
Shawn Bowman
Rusty Coleman
Gracie Orr
Kim Whitson
Brack Clemons
Ricardo Castano
Mark Burkowski
Avi Morales Sanchez
Shirley Rivas-Beck
Doug Jackson
Lori D. Coombs
Robyn Gatens
Ned Penley
Renee Pullen
Badri Younes
Tom Whitmeyer
Kathryn Luеders
Benjy Neumann
Ken Bowersox
Rita Willcoxon
Tonya McNair
Brian Dewhurst
Alotta Taylor
EraceniaKennedy
Mark Kirasich
Dennis McSweeney
Ashley Strickland
Derek Garza
Kota Umeda
Makusu Tsuizaki
Ruth Siboni
David Millman
Greg Mann
Janet Karika

Walter Eilers
Eric Berger
Patrick Lynch
Doug Cameron
Liam Kennedy
Nick Johnston
Brian Harvey
Liz Warren
Jennifer Scott Williams
Lester Lyles
Maritta Gostanian
Steven Wolfe
Angeliki Kapoglou
Jamil Castillo
Charles Mudd
Masami Onoda
Karin Sturm
Patrick Chai
Dave Huntsman
Michael Lapidus
Joe Levy
Andrew Ellsberry
Rose Jones
Etienne Dauvergne
Katelyn Kuhl
Diane Butterfield
Natalie Logan
Mayu Manawadu
Nick Cummings
James Zimmerman
Marcus Miller
Jim Azbell
Lewis Groswald
Jackie Jester
Linda Karanian
Mark Carreau
Erin Mahoney
Gary A Morrison
Maggie Landers
Ryan Mills
Danny Lentz
Robert Zimmerman
Kirill Veprikov
Taylor Rine
M Rucker
Tom Hammond
Lisa Watson-Morgan
Miles Doran
Kerry Funston
Maria Chaplygina
Chris Gilbert
Kelly O'Rourke
Stephanie Schierholz
Loren Grush
Alessandro Meloni
Irene Klotz
Patrick Forrester
Sean Fuller

James Lochner
Barbara Zelon
Joe Vermette
Andy Hoskins
Diane Rausch
Chris Davenport
Ann Zulkosky
Alicia McPhail
Michael DeKlotz
Joy Kim
Saki Hirama
Darcy Elburn
Brian Powers
Barret Hoffstetter
Christopher Flaherty
Daniel Murray
Tim Finkel
Meghan Bartels
Mike Theriault
Robert Pearlman
Karim Rachid
Khoa Vo
Kevin Foley
Michele O'Connell
Julie Robinson
Deborah Circelli
Matt Guibert
Stefanie Payne
Stephan Gerard
Kristina Gibbs
Eddie Semones
William Harwood
Mario Pereira
Lucas Souza
Jem Palo
Cullen Balinski
Monica Witt
Daniel Boston
Will Robinson-Smith
John McManamen
Ron Ticker
Stratis Catacalos
Dee Russell
Stephen Clark
Michael Chandler
Jacob Keaton
Dmitriy Zaytsev
Chris Moore
Cathirame Lee
Jessica Landa
Leonardo Barreda
David Gaba
Gale Allen
Martin Frederick
Aaron Weaver
Andrea Warmbier
Lakiesha Hawkins
Chris Strickland
Michael Sheetz
Nick Benardini
Erin Kennedy
Marcia Dunn
Zudayyah Taylor-Dunn
Frank Slazer
Karl Becker
Jorge Piquero
Kathryn Hambleton
Beverly Perry
Rosemary Baize
Sylvie Espinasse
Rick Irving
Jamie Favors
Lisa Allen
Jeanine Esperne
Richard McKinney
Lindsay Aitchison
Daniel Dumbacher
Andrey Ochepovskiy
Aimee Crane
Marcia Smith
Barry Jenekuns
Joan Zimmermann
James Green
Aleksi Ylonen
Atif Qureshi
Jon Smith
C. Koerner
Sharon Jefferies
Sam Scimemi
Christine Joseph
Barbara Cohen
Lars Kefka
Marco Tantardini
Christopher Aguilar
Andres Martinez
John Guidi
Dillon MacInnis
Mary Lynne Dittmar
Laurie Chappell
Laura Means
Gabe Merrill
Jeff Foust
Caitlin Smith
Valerie Chabot
Mike French
Artem Rukavov
Lauren Seabrook
Barbara Adde
Lisa Haber
Lauren Holt
Azita Valinia
Michael Greshko
Nantel Suzuki
Ashlee Wilkins
Thomas Schlotterer
Gina Anderson
Nikolay Vlasov
Nathan Price
Dan Hartman
Alex MacDonald
Alicia Baturoni
Sabrena Yedo
Anthony Colangelo
Amanda Mitskevich
Antanas Mitrikas
Ryan Whitley
Jim Broyan
Mark Tobias
Alejandro Alcantarilla
Richard Rogers
Tremayne Days
Gene Mikulka
Paul Brinkmann
Chris Nie
Mark Lucas
Kate Maliga
Brian Night
Dani Gibbs
Nicole Figueroa
Grant Tremblay
Allison Wolff
Tonya Woodbury
John Bebel
Rick Mastracchio

Appendix B
Membership

N. Wayne Hale, *Chair*
Former Flight Director
NASA Space Shuttle Program

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

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

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

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

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

Lynn Cline
Former NASA Deputy Associate Administrator for Human Exploration and Operations

Kwatsi Alibaruho
Vice President, Program Management
Industrial Sector Eaton

George Sowers
Professor, Colorado School of Mines

C. Douglas Ebersole
Former Executive Director
Air Force Research Laboratory

Appendix C
Agenda

HEO FACA Agenda

Tuesday, January 18, 2022

NAC HEO Committee Public Meeting

10:00 - 10:05am	Opening	Dr. Bette Siegel/Mr. Wayne Hale
10:05 - 11:00am	SOMD/ESDMD Status	Ms. Kathryn Lueders/Mr. Jim Free
11:00 - 12:00pm	ISS Status	Ms. Robyn Gatens
12:00 - 12:30pm	Discussion/Recommendations	
12:30pm	Adjourn	

Wednesday, January 19, 2022

HEO Committee Public Meeting

8:30 - 8:35am	Opening	Dr. Bette Siegel/Mr. Wayne Hale
8:35 - 9:30am	Commercial Spaceflight Division Status	Mr. Phil McAlister
9:30 - 10:30am	Commercial Crew Program Status	Mr. Steve Stich
10:30 - 11:30am	Systems Engineering and Integration	Dr. Gregory Chavers
11:30 - 12:30pm	Lunch	
12:30 - 1:30pm	Exploration Systems Development	Mr. Amit Kshatriya
1:30 - 2:30pm	Advanced Exploration Systems	Mr. Mark Kirasich
2:30 - 2:35pm	Public comments	
2:35 - 4:30pm	Discussion and Recommendations	
4:30pm	Adjourn	

Appendix D
Presentations

1. SOMD and ESDMD Status Report; *Kathryn Lueders, Jim Free*
2. International Space Station Status; *Robyn Gatens*
3. Commercial Spaceflight Division Status; *Phil McAlister*
4. Commercial Crew Program Status; *J. Steve Stich*
5. Systems Engineering and Integration Status; *Greg Chavers*
6. Exploration Systems Development Status; *Amit Kshatriya*
7. Advanced Exploration Systems Status; *Mark Kirasich*