NASA ADVISORY COUNCIL

HUMAN EXPLORATION AND OPERATIONS COMMITTEE

Kennedy Space Center

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MEETING REPORT

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N. Wayne Hale, Chair

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Bette Siegel, Executive Secretary

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Call to Order and Welcome

Dr. Bette Siegel, Executive Secretary of the Human Exploration and Operations Committee (HEOC) opened the meeting and made administrative announcements. Mr. Wayne Hale, Chair of the HEOC, called the meeting to order and welcomed HEOC members, and introductions were made around the room. The last meeting of the HEOC took place May 2019, and the present meeting is the third and final of this year. The next HEOC meeting will likely place at NASA Headquarters, after the 2020 Presidential Budget Request is released in the Spring. The Committee Chair attended the Aviation Safety Advisory Panel's (ASAP) quarterly meeting in September, as assigned by the NAC Chair, General Lester Lyles, and also undertook an additional fact finding tour at the Michoud Assembly Facility (MAF) and Stennis Space Center (SSC), where it viewed the Space Launch System (SLS) Core Stage 1, which is nearing completion; the Orion structural facility; the B-2 test stand; and the Green Run facilities. The Committee also received briefings from Orion and SLS Program Managers (PMs), Exploration Systems Development, and the new Program Manager (PM) for Human Landing Systems (HLS), Dr. Lisa Watson-Morgan. Exploration is in the midst of a procurement that is currently in blackout, but the intent is to have Dr. Watson-Morgan brief at the next HEOC meeting, as well as other PMs. The new nominee for NASA Associate Administrator, Mr. Douglas Loverro, has an impressive resume, and HEOC anticipates his arrival.

NASA HEOMD Overview

Mr. Kenneth Bowersox, Acting Associate Administrator (AA) for the Human Exploration and Operations Mission Directorate (HEOMD, or *HEO*), reported on the program status. Much work is going on in Commercial Crew, SLS, Orion, and the International Space Station (ISS, or *Station*), with great progress being made. Mr. Bowersox focused his presentation on the Artemis program and how it fits into the Exploration framework. The accelerated pace has been very exciting, and is helping HEO to move more quickly on critical procurements. Space Policy Directive 1 (SPD-1) is about much more than the Moon; it will help pave the way for what's next.

Current Mars transport ideas are based on 50-plus years of study. For human exploration, there will need to be some sort of vehicle pre-emplaced on the surface. Mars exploration will require multiple launches and a high orbit around Mars that will allow low-energy trajectories. In early missions, given the current and planned state of in-space transportation technology likely to be available over the next 15-20 years, HEO is looking at Mars missions lasting 2-3 years, with either short (approximately 30 day) or long (up to hundreds of days) stays on the Martian surface. Some of the crew may stay in orbit while others are on the Mars surface. Solar Electric Propulsion (SEP) makes sense for Mars as the most economic and reliable means of transport for cargo, which is why it is will be used at Gateway. Hazards to the human crew include radiation, isolation and confinement, the long-term effects of a microgravity environment, and the ramifications of being a long distance from Earth. Mission needs will ultimately drive design and will affect technology development. To get to Mars, NASA needs to further enhance and develop fire detection suppression systems and cleanup, life support systems, etc. At Gateway, HEO will advance technologies in autonomous rendezvous and docking (ARD), communications systems, and propulsion. For operation on the Mars surface, progress must be made in developing technologies for in-situ resource utilization (ISRU); cryogenic fluid management; Entry, Descent and Landing (EDL); and sustainable power sources, as well as advanced heat shield development for eventual Mars usage. HEO has already sent Environmental Control and Life Support System (ECLSS) demonstrations to ISS. NASA has also released international interoperability standards for avionics, space power, rendezvous, communications, ECLSS, and external robotics, to encourage the participation of commercial and international partners.

Continuous and ongoing cargo and crew operations aboard Station, along with international partnerships, are allowing human exploration to go forward sustainably. The ideal would be to see increased commercial activity in low-Earth orbit (LEO), to allow NASA to spend time farther out in space.

Artemis Phase I will be providing the path to the lunar surface, being the first un-crewed flight of the Orion vehicle, the schedule for which is managing to the end of 2020. Artemis I test priorities will be to fly the spacecraft and then retrieve it to assess how the heat shield, propulsion, and avionics systems perform. Artemis II will be the first flight with crew, and will perform one lunar orbit before returning to Earth. Artemis III will be launched to a Near-Rectilinear Halo Orbit (NRHO) before landing on the Moon in 2024, using a much different orbital sequence than used previously for rendezvous and transfers. There are two paths to 2024, one involving crew, SLS, and Orion. The second path deals with cargo, based on commercial launches taking payloads to Gateway. The cargo vehicles will be designed to have small pressurized areas for crew. By end of year, HEO will have had the SLS Core Stage shipped to Stennis, with a little schedule uncertainty, and test firing at Stennis planned for Spring 2020. Artemis II core stage work is going a little more smoothly, and will not require a Green Run, as the Artemis I testing is deemed sufficient. For the third flight and beyond, five RL-10 rocket engines have been completed, and a letter contract is in place to buy long-lead items that will follow. Artemis I's crew and service module is stacked, ready to be shipped to the Plum Brook facility soon for testing.

There is strong international support for Artemis. We have started the process to negotiate agreements to cooperate on Gateway with Canada, Europe, Japan and Russia. The European Space Agency will provide the service modules that will propel Orion to the Moon and discussions are underway to cooperate with Japan on lunar exploration.

Initial Gateway planning focuses on the minimum systems needed to support a 2024 human lander, while also supporting future planning for Gateway. Initially, Gateway will function principally as a command center and aggregation point to support a 2024 human landing on the Moon, and establishing a strategic presence around the Moon, with the U.S. in a leadership role. The goal is to be able to carry extra cargo up to the lunar lander, and to be able to refuel around the Moon. Gateway gives room to move things around in cis-lunar space and is designed to provide three docking ports, science capability, and maneuvering and station keeping with the Power Propulsion Element (PPE). Over time, there are plans to expand Gateway capabilities to provide three docking ports and opportunities for science investigation. Potential science opportunities at Gateway include biological studies in microgravity and radiation environments, as well as lunar surface experiments. NASA's international partners are proposing additional capabilities for the Gateway to provide more room for utilization, such as an international habitation module (after 2024), and Canada has committed to contributing a robotic arm. Eventually, Gateway will have more life support capability to enable 30-90 day orbital and surface missions.

The Human Landing Systems solicitation is open, and awards are contingent on FY 2020 appropriations. Sustained surface activities will require modernizing space suits; the suits for 2024 will be built in-house. Mr. Robert Sieck asked how HEO intended to address the physical and biological hazards of human traverse to, and surface exploration of, Mars. Mr. Bowersox said that these issues would be worked out in LEO and at ISS, although it is recognized that a higher radiation environment will be encountered than at LEO. Gateway can provide some of this latter condition; but the duration experiments will be done mostly at ISS. Mr. Hale said he often got questions about Gateway, and how it provides a rally point for Orion to get to the Moon and back. The need for Gateway is really dictated by orbital mechanics, and because lunar exploration really needs more propulsive capability than Orion possesses, the Gateway solves the propulsion problem. Mr. Bowersox commented that part of exceeding the reach of the Apollo program means that more mass is necessary; even if HEO used the same size service module as Apollo did, there would be less maneuvering capability. Mr. Bowersox added that Gateway provides re-use of componentry, and the ability to re-fuel elements also helps to accumulate the propulsion data needed for eventual transport to Mars. A NASA architecture study has been helping to cost out what it takes to develop a human landing system, based on three elements. However, proposers could come back with concepts that use a different number of elements. HEO expects to see some creative solutions from the

private sector, ideas that NASA has not thought of previously. The Decision Authority for the Artemis Program will be at the Associate Administrator level at HEO, but this is still under discussion.

Mr. Bowersox emphasized that there are carefully analyzed quantitative studies that dictate these decisions. Artemis is a NASA-wide plan, undertaken in close partnership with the Science Mission Directorate (SMD) and the Space Technology Mission Directorate (STMD). Ms. Ruth Gardner asked about period of performance for 2024. Mr. Bowersox said that NASA is considering two providers to provide assurance for the 2024 flight, with the second provider supporting a flight in 2025, followed by an annual cadence of flights. Landers may be re-used. One idea has two landers with separate crews on the Moon simultaneously, or one lander could serve as a rescue vehicle. Mr. Hale asked if there were enough staff to support Artemis. Mr. Bowersox indicated the next step would be to bring more people in. Mr. Bowersox acknowledged the challenge of integrating all the elements across programs, and that it would be important to have a centralized managing function; this is also under discussion. Ms. Nancy Ann Budden asked which showstoppers seemed to rise to the top. Mr. Bowersox said that radiation protection, human performance, and microgravity are the top risks, but that the obstacles to a 2024 lunar landing are different from long-duration risks. The risk of longer-duration spaceflight is a big one. One surprise has been the effect of increased intracranial pressure on vision; NASA is still learning about this, and expects more surprises. There are some drugs can counteract the pressure issue. Risks like radiation will likely be treated as either part of a risk trade, or NASA may decide to reduce risk by speeding up traverses. On the technical side, all the work that needs to be done is up against time constraints for developing the landers. There are some hardware problems for long-lead items. HEO is seeing cracks in some aluminum materials from the Shuttle era, an unexpected effect of aging. Dr. Leroy Chiao noted that if ISS is de-orbited, NASA will no longer have a human research laboratory. Mr. Bowersox said that it is clear HEO needs time in LEO for the foreseeable future, whether it's on ISS or another platform. NASA should use ISS as long as it can, knowing that ISS partners are not ready to ditch in 2024. They will be launching new modules soon, and there is still much discussion going on. Mr. Sam Scimemi, Director of the ISS program, noted that part of the policy being submitted for Artemis is that NASA will be in LEO indefinitely.

International Space Station

Mr. Sam Scimemi presented an update of activities on the ISS, which began Increment 61 on 3 October, and has just released the latest HII Transfer Vehicle (HTV-8). During this Increment, the crew performed a series of extravehicular activities (EVAs) to undertake an extensive battery exchange. A battery failure that stopped ISS midstream was mitigated by an all-female EVA repair, and ISS is now back up to regular power status. Coming up, there will be a Cygnus launch from Wallops Island that contains all the hardware for repairing the Alpha Magnetic Spectrometer (AMS); and a Boeing Orbital Flight Test (OFT) launch. Increment 61 will end in February 2020 with a Soyuz 59S undock. Mr. Scimemi presented Exploration Research and Technology progress on filling technology gaps for Mars, and suggest that the NAC hear a briefing on the subject. A total of 270 technology gaps have been identified. There are development gaps wherein no new knowledge is needed, but effort is required to fill them. Results are the fed forward into the development of future systems, and integrated into the budget process. About 50 technology gaps, such as dealing with microbial growth in spacecraft, will also be fed forward, as will be the gaps in architecture and knowledge. Thirty percent of the total number of gaps are being addressed at ISS (70% of gaps are for life support at ISS).

The Spacecraft Atmosphere Monitor (SAM-2) will launch to ISS next year, where it will measure trace gases on Station, representing a big advance for human space flight in terms of crew safety. The Spacesuit Evaporation Rejection Flight Experiment (SERFE), a next-generation thermal control loop demonstration, with a carbon dioxide scrubber system, will be flown to ISS in March 2020. The Human Research Program (HRP) continues on the risk reduction path, and includes a rodent research project on circadian

rhythm, investigating how microgravity interrupts the body clock. During Increments 59 and 60 crew utilization time hit over 100 hours per week during some weeks. During the last Increment, over 300 investigations were carried out. There have been close to 2900 investigations on ISS to date, with107 participating countries. National Laboratories use about 50% of the resources on Station; highlights include a Biofabrication Facility operated by Techshot, which is growing human tissue, such as retinas and stem cells, without collapsing them. The Goodyear Tire Company is doing research on silica fibers for automotive tires, producing these fibers in space to see if they can improve tires. NASA recently instituted an independent review of the strategic direction of the Center for the Advancement of Science in Space (CASIS), to be chaired by Betsy Cantwell

Mr. Scimemi reviewed the operational status of ISS. ISS is reevaluating some EVAs to prepare for AMS repairs, and is waiting to see if the Northrop Grumman launch, which has the hardware, goes as planned. The thermal system for the AMS is failing and is down to one pump. Repairs are needed to replace the pump package and requires cutting into the cooling system, which has never been done on Station. The repair will require five EVAs as well as some unique tools. Mr. Bowersox noted that such repairs will have to be perfected for Mars exploration. Dr. Chiao commented that the AMS repair could drive a re-design that could help NASA down the road. Mr. Sieck asked how much crew time is spent on trouble-shooting. Mr. Scimemi said the requirement for utilization is 35 hours per week and does not affect ISS productive work. Mr. James Voss commented that he found it difficult to justify five EVAs to repair the AMS; it is a big investment. Mr. Bowersox and Mr. Scimemi noted that the AMS is providing some groundbreaking data, and that NASA has weighed the risks and costs of the repair against the value of the fundamental physics.

Total consumables on ISS are well stocked. SpaceX Commercial Resupply Service missions CRS-17 and CR-18 went smoothly. Northrop Grumman's CRS-11, the first of its kind, will spend six months as a free-flyer to demonstrate other capabilities as a science platform. Upmass and downmass have been increased considerably, and disposal capacity has gone up by 1000 kg. HTV-8 will unberth this week after having performed a flawless mission, transferring water tanks, etc. SpaceX CRS-19 is scheduled for early December. ISS is in the midst of updating a 2018 Transition Report, and is planning to deliver it to Congress in December of this year.

Mr. Mike Lopez-Alegria posed a question to Mr. Bowersox about budget: what if NASA doesn't get the $1.6B augmentation; how might this affect procurements? It also obviously increases the risk to the 2024 date. Mr. Bowersox said that the shortfall is mostly in funding of 2024 landing system. Mr. Hale noted that this is not a trivial task, particularly in light of an accelerated schedule, and asked if there would be a test flight of the HLS, adding that Apollo had two test flights before it landed. Mr. Bowersox said there is potential for plenty of run time. Mr. Mark McDaniel commented that NASA and HEO are doing what they should be doing to inspire the next generation, at a time when the nation is falling behind in science and mathematics; politicians understand this point about NASA's role in inspiring the future workforce. Mr. Tom Holloway noted that he wouldn't have finished college without help from the government.

Mr. Hale asked a question about burning down risk in the Human Research Program (HRP) and in what venues this can be accomplished. Mr. Scimemi said that a new HRP risk reduction pathway chart, which includes Gateway, would be released in 2020. The goal is to buy some of these risks down at the Gateway and on the lunar surface. If Station goes to 2030, most of the red risks will be retired. NASA is committed to not having a gap in LEO. Mr. Hale noted that much is not known about the neuro-optical issue experienced by astronauts. Dr. Patricia Sanders added that blood clots in the carotid artery are also being seen. These issues are being monitored by carotid ultrasound, and mediated by the use of blood thinners. Mr. Scimemi noted that ISS is also finding that the current food system would be inadequate for Mars. Right now, NASA is studying these risks vertically, and once the risks are integrated, it is likely that other problems will crop up. Mr. Hale observed that it all goes back to asking how long ISS needs to be in orbit

to observe the effects of long-term space habitation; Gateway will be only intermittently inhabited and not suited to the task of sustained testing of humans in space.

LEO Commercialization

Mr. Douglas Comstock presented a briefing on LEO commercialization. Pursuant to the Transition Authorization Act of 2017, containing Congressionally defined goals, NASA has developed a plan to achieve its vision for LEO commercialization. The idea is that NASA will eventually be just one of many customers for commercially owned and operated LEO destinations. Another key theme is the maintenance of continuous human presence in LEO. NASA's vision for the near term is that ISS will be essential for developing new commercial activities in LEO, for continuing collaboration with internationals, and for supporting the LEO needs of NASA for Research and Development (R&D) and the ongoing research conducted through the ISS National Laboratory. Eventually, the goal is to have the private sector own and operate LEO destinations, and to have industry activities including manufacturing, marketing, and entertainment thrive in LEO. ISS assets would be transitioned prior to the end of its life, and NASA would continue to purchase Research and Development services from commercial providers, at lower cost than continued operation of ISS. This would enable NASA and its international partners to shift their focus and resources towards exploration. Mr. Holloway asked: is the long-term vision shared by international partners? Mr. Comstock said he believed so, and that Japan in particular has picked up on this strategy. Mr. Scimemi added that different partners have different perspectives on long-term goals, but in the near-term, internationals are right on board with NASA.

Historically, commercial LEO has its roots in 2005, when Commercial Orbital Transportation Services (COTS) competitions were first released and NASA began to partner with industry for development of capabilities, then competitively purchase services. The COTS philosophy has also been applied to the Commercial Crew Program. Two LEO procurements are out right now to partner with industry to develop commercial destinations in LEO; the intent is for NASA to purchase services from these commercial destinations beginning during a transition period from ISS. There is already an "ecosystem" on ISS for commercially owned facilities and users, and the commercial development approach builds on these activities. Private astronaut missions and other demand-stimulating activities are also in work. NASA examined 12 industry studies in 2018 to see what commercialized LEO might look like, and used the studies to inform the strategy NASA rolled out in June. The idea is to move from cost plus contracts for systems that NASA owns, towards a model where NASA purchases of services on a firm, fixed-price basis, where government is one of many customers, akin to buying bandwidth "by the yard" from commercial satellites. Mr. Holloway said that at best, this seems to be an emerging activity, and it seems that government will have to spend a lot of money in the transition phase. Is there commercial money on the table for this plan? Mr. Comstock said that there are only nascent markets at present, but these markets can leverage the effort off the capabilities of the ISS. Industry needs to build the market, while NASA can set the table. Ms. Budden asked: how do you wean industry off the government? Mr. Hale felt that NASA would need to find some business case that makes enough money to overcome the transportation costs. How will NASA help commercial entities find a business case? Just making a port on the station will not solve the problem. Mr. Comstock admitted that the program has not yet had a home run, but if the 3-D printing experiment or other promising R&D works well, production of items such as artificial retinas could be very profitable. Uncertainty about getting crew and cargo back and forth to ISS is also improving. However, NASA recognizes that innovation has no guarantees, and is simply trying to create the environment to help the innovation happen. The bottom line is that NASA wants to help develop a robust LEO economy from which NASA can purchase services as one of many customers.

The NASA Plan for Commercial LEO Development was released in June 2019, and delineates a five-point plan. The Commercial LEO development rollout was held in New York City, where NASDAQ provided a lot of good coverage and awareness.

The five elements of the plan are:

1. *ISS Commercial Use and Pricing Policy*
   A new Commercial use and pricing has been extablished as a NASA Interim Directive (NID) process, which is seen as a flexible approach that will enable adjustments as needed. Under the new directive, US entities can pursue manufacturing in LEO, and private astronauts can do such things as filming an advertisement (Civil Service astronauts roles would be limited). NASA will set aside 5% of the US allocation to ISS for this effort, commercial activities being 2.5% of US total, in effect. In response to a question, Mr. Comstock said that in the last seversal years, over half of the research projects going to Station through the ISS National Laboratory have been commercial. NASA has an interim pricing policy for these projects, and prices may be adjusted as the market responds.

2. *Private Astronaut Missions*
   Russia has sold eight private seats on the Soyuz, and NASA is now planning to enable private astronaut missions to the ISS that would use commercial crew vehicles being developed by SpaceX and Boeing, the goal being commercial charter flights. These would be additional commercial missions to ISS, beyond commercial crew flights that NASA is purchasing for crew rotation. NASA is encouraging international partners interested in purchasing seats as part of these missions to work through US companies. An initial private astronaut mission could be accommodated by the ISS as early as October 2020 if a mission is ready. Mr. Holloway asked if a commercial entity could put a piece of hardware on ISS. Mr. Comstock said this depends on what is proposed and ultimately negotiated. NASA could accommodate up to two "sortie" flights per year to ISS. Benefits of private astronaut missions include helping industry gain insight into markets for private astronauts and gain experience in commercial operations. Dr. Sanders asked if NASA would be able to gather physiological data from private astronauts. Mr. Comstock thought this could possibly be negotiated.

3. *Commercial Destination LEO Solicitations*
   Apply what NASA has learned from commercial cargo and crew to partner with industry to develop commercial destinations in LEO. The approach was laid out in a notional LEO destinations roadmap, which includes a two-pronged approach. The first would allocate use of the ISS node 2 forward port to accommodate a commercial module attached to the ISS then evolving to a free-flying destination. The second would be for concepts that would begin directly as free flyers. NASA would then conduct competitive services acquisition from these commercial destinations. Decisions on how to allocate ISS resources among competing concepts will have to be made carefully, and NASA will assess the portfolio of concepts to ensure that NASA needs are met in the process.

4. *Stimulate Sustainable Demand*
   The ISS National Laboratory is already accommodating many industry R&D projects. Two new thrust areas introduced as part of the ISS utilization NRA are in-space manufacturing and regenerative medicine/bioengineering, as well as other concepts. There is an abundance of commercial hardware on ISS, being used to conduct research aboard the ISS by companies such as NanoRacks, Lilly, Milliken, and Visidyne.

5. *NASA's Long-Term LEO Forecast*
   NASA recently updated a white paper that provided quantification of NASA's long-term forecast for human research, technology demonstrations, crew accommodation and training, science, physical and biological research in LEO.

A Request for Information (RFI) on the overall plan was released 7 June 2019, and RFI inputs were received on 9 July. Comments are under assessment. NextSTEP-2 Broad Agency Announcement appendices have been prepared or have been released on port solicitations, free flyers, and demand stimulation. The ISS utilization NRA has new focus areas targeting manufacturing, Lab in Space activities, and interest in private astronaut missions, and they are in varying stages of progress.

Mr. Hale asked how NASA planned to stimulate demand for commercial LEO operations. Mr. Comstock said that by partnering with nascent commercial entities to help them demonstrate, develop and prove technologies during the R&D phase, NASA could help new products through the business "Valley of Death." These research projects tend to be long-term. Dr. Sanders asked if there had been an adverse effect of the perception that Station will be ending in 2024. Mr. Comstock acknowledged that this was the case. Dr. Sanders felt that this chicken-and-egg situation posed a credibility problem for NASA at the very moment it is trying to attract commercial interest. Mr. Lopez-Alegria asked what the plan was for extending the lifetime of ISS, given that a perception of a curtailed ISS could be a problem for participating commercial activities. Mr. Bowersox said that NASA could extend current contracts for ISS operations. Mr. Comstock said that the biggest challenges for development of the LEO economy are developing the markets and reducing the transportation costs, which will not happen without a government/industry partnership. NASA has begun conversations with the Department of Commerce (DOC) on reducing barriers to LEO commercialization. Mr. Holloway applauded the effort, but said he did not understand why the government wants to launch private entities on a commercial vehicle to allow companies to make money. Mr. Bowersox pointed out that part of the NASA charter explicitly states that the Agency supports the US economy. Mr. Holloway thought NASA might be preventing companies like Bigelow from building inflatable hotels on the Moon. Mr. Hale noted that SpaceX was once funded through the COTS program, a sterling example of how commercialization partnerships have brought companies into space. He conceded that the biggest problem, however, is lowering the cost of transport to and in LEO. Small satellites have become successful through ride-sharing. Mr. Holloway said he was impressed at how much competition has been fostered in the commercial space sector, but he didn't feel NASA should worry about space tourism. Mr. Bowersox commented that NASA is trying not to be a barrier to space travel.

Public Comments

Dr. Stephen Long, a consulting senior scientist with background in the military, space and intelligence, and presented two topics for the NAC to consider with respect to the Artemis program. First, he noted that he could not find open source data describing NASA's plans to move payload mass from the Earth to the Moon, and expressed concern about the fact that Artemis launches a series of elements, particularly autonomous systems, into deep space. An NRHO configuration is very cold: cis-lunar space is colder than liquid helium. The components for Gateway will be in space for 18 months, at very cold temperatures. Dr. Long felt that this system needs further review, and had developed some alternative thoughts about shortening the time required to deliver the payloads of Artemis to LEO. His second concern area was policy, i.e. how NASA makes program decisions. He believed that how NASA makes technical and engineering decisions need to be more transparent. The Freedom of Information Act (FOIA) office resisted release of the details he sought on NASA payload plans. Noting that NASA only releases final decisional results, he felt that this practice obscures the rationale behind the Agency's decision-making process, and prevents alternative views from being shared and considered. He further felt that the system lacks the literal data checks and balances that are common to scientific and engineering practices.

Mr. Voss thanked Dr. Long for his comments and assumed that NASA would look into the temperature issues. As to the transparency of NASA's decision-making process, Mr. Voss agreed that it is very difficult to find answers. As part of NASA's role in educating the public, he agreed the process should be

more transparent. Mr. Hale noted that legal constraints make it difficult to disperse this information during procurement processes. Mr. Voss said that trade studies should contain enough technical details that allow an engineer to understand what has been studied.

Mr. McDaniel gave appreciation for Dr. Long's remarks and his distributed presentation. Mr. Hale commented that he had seen the Orion capsule with reflective material on it, suggesting that Orion could get too warm. He remembered that the Apollo capsule had to be rotated to maintain thermal equilibrium.

Discussion

Mr. Hale Opened the floor for recommendations. Ms. Budden asked if it were appropriate for HEOC to provide advocacy for the $1.6B augmentation. Ms.Gardner added that a lack of augmentation would make it extremely challenging to meet the 2024 date. Ms. Budden also raised a concern about future planning around ISS, and asked what happens if Station stops: should HEOC recommend extending ISS to 2028? ISS is still in the critical path for many NASA plans. Mr. Holloway cautioned against getting in the way of people who are really going to commercialize LEO. Mr. McDaniel recommended that NASA get the lawyers and accountants out of the way so the NASA can get some real work done. Dr. Siegel suggested having Mr. Mike Gold, Chair of the Regulation and Policy Committee (RPC) brief the HEOC, as RPC's goal is to reduce regulatory obstacles. RPC's actions have already led to a revision of Planetary Protection policy at NASA. Mr. Hale was concerned about the lack of planning for test flights, while conceding that they may be included in some of the commercial proposals for crewed landers. He was personally concerned that NASA is trying to pull off a 2024 lunar landing too rapidly. Dr. Sanders noted that ASAP has already made firm recommendations about requiring test flights for the elements of Artemis, while recognizing it will make the 2024 landing harder. Mr. Chiao said that NASA should not allow the 2024 date to affect crew safety. Mr. Bowersox said that each provider has to provide an implementation plan that will be reviewed by the appropriate technical authority. Mr. Voss recommended getting a complete briefing from HLS at the next meeting. Mr. McDaniel commented that space flight is an extremely difficult and dangerous business, and that the public needs to be very aware of this.

Mr. Hale considered a HEOC endorsement of the budget augmentation, pointing out that this could become a *de facto* endorsement of the Artemis plan and the 2024 date. HEOC should think about this carefully. Are we all on board for 2024? Mr. Holloway stated: if NASA wants to get to 2024, the augmentation must be provided. Mr. Pat Condon felt that there was a risk of targeting 2024 to the detriment to the rest of the plan—why is 2024 so important and what does it contribute to the long-term plan and architecture? Mr. Voss thought that the date acceleration had successfully shown that NASA's bureaucratic issues can be more streamlined. Mr. Hale conceded that the date is probably a policy issue, and that HEOC might simply state that NASA must have the resources to make 2024, period. Mr. Bowersox noted that the actual performance requirements for Artemis are written into the requests for proposals (RFPs), which can be easily obtained on-line.

Mr. Hale said that HEOC is on record as stating that ISS must be around as long as it is needed, and added that a Boeing lead estimated that ISS could make it to 2045. Ms. Budden suggested ISS longevity be a topic for a future meeting. Mr. Bowersox felt that it was clear that NASA needs to communicate what HEO is doing more effectively and credibly, but that there are excessive limitations on what NASA can say, both in terms of national security and intellectual property. Mr. Holloway noted that NASA has been studying the human problem for 30 years, and while progress is slow, one of these days NASA must decide to go. And when ISS runs out of structure, there will be no choice but to de-orbit. Mr. Holloway understood that date to be 2028. There may be easier ways of testing human response to space other than on a space station. Mr. Bowersox said that sixty percent of ISS cost is transportation.

Mr. Hale said he hadn't heard anyone say that the current approach to Artemis needs to be revised. Ms. Budden asked if there existed a one-page fact sheet on the value of getting to the Moon by 2024. Mr.

Bowersox said that HEO has a coordinated communication strategy and that all the information is public. The fact sheets include the relative values of NRHO compared to low lunar orbit, and the key role that delta-v plays in the architecture. The Artemis plan is also driven by the hardware that is already in development. Dr. Condon asked if there was a dialogue about what five or six things need to go right for 2024, so that HEO can address the naysayers right up front. Mr. Bowersox felt the main issue for 2024 was the need for resources, but he agreed that it wouldn't hurt to include the must-dos in the public outreach materials. Mr. Holloway commented that missing 2024 was not a big deal. Mr. Bowersox noted that while it can be good to have an aggressive goal, the big picture must be kept in mind. Mr. McDaniel said he did sense public excitement for the Artemis mission. Mr. Holloway felt the real risk is that any mistake made in an aggressive schedule would lead to a long period of inaction, citing the Apollo launchpad fire as an example.

Mr. Hale queried members for their opinions on HEOC's visit to Stennis. Dr. Condon noted that they all said they need money if they want to make 2024. Mr. Hale cited five possible findings or recommendations: budget augmentation, ISS longevity, staying out of commercial's way, more testing and resilience for the Human Landing System; and legal obstacles. Writing assignments were distributed.

October 30, 2019

Call to Order

Dr. Siegel opened the meeting and introduced Mr. Hale. Mr. Hale offered apologies for the audio being cut off during the previous day's discussion session, and briefly summarized the discussion for any members of the public that might have missed the period.

Commercial Crew Program

Ms. Kathy Lueders, Program Manager, presented a status of the Commercial Crew Program (CCP), noting that the program has begun creating and distributing crew banners. The Boeing Orbital Flight Test (un-crewed demonstration; OFT) is on manifest to launch in December of this year. Dates for the SpaceX Demo Mission 2 (crewed vehicle) and the Boeing Crewed Flight Test are to be determined. This is a busy time, with much certification work being carried out, including qualification of designs and determination of risk levels. Getting through the last check marks is very difficult.

The Boeing's Pad Abort Test vehicle is now up on the stand for a 4 November test. This is a huge milestone for CCP, as it is very important to understand how the separation and parachute systems work. The un-crewed Boeing vehicle does not have an abort system, however this test will be important for the eventual crewed flight. The Boeing OFT spacecraft is being readied to hand over to United Launch Alliance (ULA) in advance of a December launch. CCP is working through all the integrated testing and did a final crew walkdown on 30 October. The Boeing Crew Flight Test (CFT) vehicle is currently mated; CCP is working through interface testing and suited crew training. The booster has also been completed for the Atlas V rocket, which is expected to be done by the end of first quarter of 2020. The Boeing Operations division has been planning and training with the rescue crews and is preparing for a wet dress rehearsal for OFT just prior to launch. The OFT will be a short duration flight, while CFT is planned to be of a longer duration that is still to be determined. The goal is to use the crew vehicle for up to six months.

SpaceX is getting ready to do another static fire test on its In-Flight Abort Vehicle, after having experienced an anomaly during the static fire testing of the SuperDraco propulsion system. NASA and SpaceX have gone through the post-anomaly analysis, and SpaceX has made several changes. There will be a new static fire test next week, after which SpaceX will be planning toward an early December flight-abort test. The issue behind the anomaly was design, and SpaceX is now using new pressure abort systems. The good thing is that these are integrated systems, which gives the vehicle more capability. The

accident occurred as SpaceX went from low-flow to high-flow systems, creating a pressure wave on exposed titanium, which broke a valve. There is now a compatibility matrix for the pressures that the system will undergo, and there is now an understanding of how the high-pressure systems behave. An oxygen compatibility matrix has been built, as well, for exposed titanium components. The team has carefully worked through the issue with repeated, integrated testing.

The SpaceX In-Flight Abort Vehicle had a phenomenal turnaround after the anomaly. The goal now is to get through the next static fire test, change out the burst discs, and then get ready for an early December test flight. There was much debate about 88 vs. 106 seconds duration for test purposes, but the goal is to get a real sense of overall vehicle integration, with an 88-second test considered to be just stressing enough. The test data can then be extrapolated to worst case via Monte Carlo simulations. It's really about making sure the whole system is working the way it should. The other issue is that this is a different operation. CCP is taking a launch team that usually does expendable launches is now switching to crewed, so it is important to walk through the whole crew timeline with joint teams. The teams will be doing dry runs with both the static fire and in-flight abort tests. SpaceX is treating the static fire test like a flight, and is bringing in the whole team.

The SpaceX Demo-2 Vehicle status is currently trending to a first quarter 2020 launch readiness date (LRD). Spacesuit production of primary suits is nearly complete, and backup suit production is also in work. Different parachute tests (up to 12 tests in one week) have been performed and the team is analyzing final test results. SpaceX Operations is carrying out simulations, exercises and training, and joint SpaceX and NASA demonstrations on the GoSearcher spacecraft recovery vessel, including full-scale medical triage exercises. The whole vehicle will be lifted onto the boat during recovery in a major choreographic effort. Shipboard exercises are also being done with NASA, DOD, and SpaceX. CCP is planning for retrieving a de-conditioned crew, and is also assessing an option for a longer-duration mission, to see if it's a capability NASA wants. Mr. Lopez-Alegria asked if CCP had looked at the number of landing opportunities. Ms. Lueders said it would be a full-time job to determine the right conditions for landing, weather-wise, and also to consider an unplanned departure from ISS. The trade is the risk of staying on orbit vs. the risks associated with landing site. CCP anticipates many weather discussions. Asked who makes the decision from a weather perspective, Ms. Lueders said the process could conceivably go all the way to the Administrator. Steve Stich is expected to be the decision-maker in the short term, and Mike Hess for future missions. In short, the Management Mission Team (MMT) Chair makes the decision. The decisions will be made using the Certification of Flight Readiness (COFR) process. For the un-crewed missions, the focus will be on what the crew safety aspect is on Station. Obviously un-crewed vs. crewed is a different risk level, but the process for both is the same. Mr. Holloway commented that a good ground rule is that Operations makes the real-time decision, in concert with the Program Manager, recognizing that at times the decision should go up to the Administrator, but not as a rule. Asked who does the simulations, Ms. Lueders said that each contractor has a simulator, but there are flight directors that support both the stand-alone and joint simulations. NASA wants Boeing and SpaceX to do what they need to do, and to ensure everyone understands who is responsible. It's been helpful to have experienced flight directors on both sides. NASA and SpaceX will go through the whole checkout process for the static fire test. Both Boeing and SpaceX teams are doing dry runs and critical practice sessions to ensure there is enough margin in the schedule. The wet dress rehearsal will be a big deal.

CCP is also working to enable commercial spaceflight, executing mission requirements through interagency agreements and collaboration; working through air traffic management (ATM) with the FAA and the Department of Commerce, the Department of Defense (DOD), the National Oceanic and Atmospheric Administration (NOAA), licensure through the Federal Communications Commission (FCC) for crew communications, the National Telecommunications and Information Administration, certifying mishap plans through the National Transportation Safety Board (NTSB), and environmental

assessments. The process is taking a lot of work and coordination, and CCP has greatly appreciated HEOC's support as the process has moved forward.

NASA and Blue Origin are getting ready for a biannual meeting in November, where both sides will be exchanging data on parachutes, structures, and mission operations. The two teams are having many technical exchanges, which in turn gives team members a chance to look at many different concepts. Sierra Nevada is working through Commercial Resupply (CRS-2), with a goal to fly crew with their Dreamchaser vehicle at some point.

Mr. Hale asked: what's the long-term outlook for your office? Ms. Lueders said CCP was focused on providing safe reliable flights to ISS and providing consistent vehicle flows. This will take some time. Six missions doesn't mean the process is done. Getting through the development effort has been a good lesson in using a small program structure to deliver consistent services in a sustained effort. Dr. Condon asked: what will it take for Blue Origin and Sierra Nevada to achieve a crewed capability? Ms. Lueders could not provide an estimate; for now, NASA is just trying to help them. There is private investment for both Blue Origin and Sierra Nevada, but if there's anything NASA can contribute from a knowledge base perspective, it will do so. There is a capability written into the contract to on-ramp Dreamchaser for crew. NASA would work a certification for a crewed vehicle like it would work any other. All the requirements are out there for these companies to work to. Asked about the long poles, Ms. Lueders said that Boeing has gone through all their structural and environmental tests, and NASA certification is in for most aspects of OFT. It's manageable. Obviously, getting through the abort test is critical, but everything else surrounding the Boeing effort is going well.

Launch Services Program

Ms. Amanda Mitskevich, the PM for the Launch Services Program (LSP), provided an overview of the program. Deputy PM Chuck Duvall is a very experienced manager in expendable launch vehicles (ELV), James Witt is the engineer, and Jenny Lyons, who has Shuttle experience as NASA vehicle manager, heads fleet management, and is currently detailed to Gateway. Denise Pham rounds out the team; she is an electrical engineer with Shuttle experience. LSP is in the midst of a transition from NASA and DOD in using commercial launch vehicles, in lieu of government-owned vehicles, a process that started in the 1980s. Each NASA spacecraft is unique. There are very few duplicated satellites, thus the mission-unique interfaces and aspects of the launch vehicle is most important for NASA. As the Shuttle era came to a close and NASA brought on Commercial Cargo, launch vehicles for these programs were new at the time. Commercial Crew is the latest addition to LSP.

The LSP mission is predicated on uniting customers, capabilities and culture to explore space through unparalleled launch services. The LSP vision focuses on enabling science and discovery through unlimited access to the universe. LSP has brought together a number of different cultures and capabilities, and consolidated them at KSC. The culture is based on being inquisitive and diverse. The four of LSP are to maximize mission success; assure long-term launch services; promote the evolution of a US commercial space launch market; and continually enhance LSP's Core Capabilities. People in the current LSP management team generally have extensive experience in the government, and LSP recognizes it needs to continue working hard to ensure that LSP brings in new, capable people. LSP advises its partners and is expanding to include commercial resupply to station, Goddard, Artemis, and the United States Geological Service (USGS). LSP sits within HEO, and works with a flight planning board that makes flight decisions. LSP interfaces with the Centers that host robotic missions, and at Headquarters for relevant missions and projects. The people of LSP boasts a low turnover rate, although it does strive to get a lot of fresh faces into the program. The experience level in LSP averages at about 17 years; 45% have advanced degrees. LSP now possesses commercial acquisition expertise, and participates in a formalized government collaboration to prioritize launches on the manifest. LSP also works with Venture-class missions, that generally have a higher risk tolerance.

Traditional LSP roles and responsibilities are to acquire launch services, carry out verification and validation (V&V) engineering analyses; manage launch vehicles through to spacecraft integration; certify launch systems for NASA use; and to provide insight and approval of production, integration, testing and processing. The process of certifying begins with mission approval, and LSP considers mission-unique aspects as it works with the launch vehicle (LV) provider. The program uses best-value procurement practices, and has the ability to adapt to the risk posture associated with each mission; LSP also tries to promote competition amongst providers. Asked to provide a real-world example, Ms. Mitskevich cited the Mars 2020 mission, scheduled to launch in Summer 2020. LSP started working with them in 2012 to determine the LV configuration, and at about 30 months out was able to compete the LV. After ULA won the contract, LSP started integration meetings with both ULA and the spacecraft organization, testing requirements for the spacecraft and getting deliverables for the LV; in that process, it is typical to uncover certain issues. ULA is in the midst of changing their solid configuration, so LSP asked them not to change their configuration for the launch, to eliminate the risk of using a new configuration. Typical lead time for missions is 3-5 years, based on Announcement of Opportunity (AO) schedules. Funding for mission LVs comes from SMD, while HEO provides funding for LSP salaries. Another function of LSP is to provide missions facilities to do their last processing steps and final integration. LSP provides clean rooms and also has planetary protection facilities at KSC. LSP keeps resident offices (ROs) at Vandenburg Air Force Base, where 40% of launches occur, and uses Astrotech and Harris processing facilities. Currently LSP does not have an RO at the Wallops Island facility. LSP gets involved with range safety, but the launch provider is ultimately responsible.

The US Manifest coordination is done through the Current Launch Schedule Review Board (CLSRB), with the National Reconnaissance Office (NRO), FAA, USAF, and NASA Launch Director at the table, ensuring that NASA missions get manifested where they must be manifested. The participants are always trading launch dates in a well-oiled process that Ms. Mitskevich likened to a Texas Hold'Em poker game. Artemis flights will be licensed by FAA. LSP represents SLS, but only provides status, because SLS has a dedicated pad. The other providers are competing for launch pads. LSP fleets include Northrop Grumman's Pegasus, ULA's Delta IV Heavy, the SpaceX Falcon 9 and Falcon Heavy, Venture Class Launch Services' Launcher One and Electron. Emerging LVs include Firefly's Terran 1, New Glenn, OmegA, and Vulcan. There are also opportunities for emerging providers to on-ramp with LSP for robotic services. In addition to Vandenberg, LSP has ROs in Denver, CO (ULA); Decatur, AL (ULA); Hawthorne, CA (SpaceX); and Chandler, AZ (NGIS). LSP has launched many primary missions for NASA. Currently, LSP is advising the James Webb Space Telescope (JWST) mission and providing insight on mission integration, and is also advising Commercial Crew. LSP assisted, upon request, the latest Geostationary Operational Environmental Satellite (GOES) as it got close to launch; the Gravity Recovery and Climate Experiment follow-on (GRACE-FO) mission; India's synthetic aperture radar satellite, NISAR; the Lunar Atmosphere and Dust Environment Explorer (LADEE); and Cargo Resupply to Station.

LSP has a new focus area, maximizing rideshare and Venture Class Launch Services (VCLS) opportunities. Many cubesats have been launched on rideshare opportunities, but now cubesat developers are looking at launching these on their own LVs. LSP is looking at lower-price opportunities and emerging providers to provide lowest price/technically acceptable contracts. LSP just had its first government launch with Rocket Lab's Electron. The next launch will be with Virgin. LSP has also done a number of Educational Launch of Nanosatellites projects. Dr. Condon asked if LSP had any involvement in purely commercial launches. Ms. Mitskevich said that occasionally commercial launchers request the use of LSP hangars, and sometimes make agreements to use LSP facilities. From a fleet insight perspective, LSP gets data from these commercial launches, however LSP is not involved directly with these launches, and does not provide mission assurance for them. Anyone, commercial or government, who launches from the Eastern or Western range must come to the "card table" (CLSRB). There are new

challenges here, such as when boosters are reused. Reusable hardware is making things a bit more complicated. Defense launches do not necessarily trump every other launch. Once a commercial mission is on the manifest, neither NASA nor DOD can trump it. If a government launch is imperative, the government pays the commercial entity the cost of the impact.

Mr. McDaniel complimented Ms. Mitskevich for giving an outstanding presentation. Mr. Hale commented that LSP had started a revolution in how government interacts with contractors, and was a leader inside NASA. Mr. Holloway, speaking from his Apollo experience, said that it seems that NASA as a whole could use LSP's highly efficient integration system.

STEM presentation

Mr. Mike Kincaid, AA for the Office of Science, Technology, Engineering and Mathematics (STEM) Engagement, provided an update on NASA's STEM activities. The NAC STEM Engagement Committee has just completed one year of its official charter, having transitioned from former Administrator Charles Bolden's Ad Hoc Task Force, and has been actively advising NASA's STEM effort. Mr. Kincaid asked for HEOC assistance in helping STEM to fine-tune its efforts, in light of the very significant STEM challenges in US education, particularly since NASA and US technology in general will require a tech-savvy work force in the future. The Office of STEM Engagement is attempting to reach students by creating unique opportunities for students to contribute to NASA's work, with an eye to building a diverse future STEM work force by engaging students in authentic learning experiences, and strengthening understanding of STEM by enabling powerful connections to NASA's mission and work. Ms. Janet Karika commented that NASA has attracted great interest from international partners, looking to use NASA's STEM metrics and methods.

NASA STEM engagement portfolio includes many types of activities: internships, challenges, competitions, pre-college or K-12 STEM experiences, and virtual learning opportunities. FY2020 STEM Engagement Sphere 1 activities were approved by the NASA Strategic Management Council in October 2019. These include Artemis student challenges; ISS 20th Anniversary activities; Commercial Crew; Mars 2020; and Earth Day. Artemis college student challenges include a Lunabiotics competition, Student Launch, a 2020 Big Idea Challenge, Human Exploration Rover Challenge, Micro-G NExT, S.U.I.T.S., and First Nations Launch. Recently the STEM Office livestreamed an Artemis watch party on NASA TV on 23 October with more than a 1000 college students across the country.

The STEM Engagement program is largely mission-driven. Congress has provided funding for NextGen STEM activities, Minority University Research and Education Project (MUREP), Space Grant, and Established Program to Stimulate Competitive Research (EPSCoR). NASA's Museum Alliance involves content that NASA gives to museums, which can be accessed by anyone with an museum or science center affiliation. Dr. Condon noted that there is an Air Force museum in Utah that touches about 40,000 school-age children per year. Mr. Kincaid said that the 950+ members of the Museum Alliance regularly receive NASA's calendar of activities, and took an action to get Dr. Condon connected with the Alliance. Mr. Hale asked how the effectiveness of the programs were being measured. Mr. Kincaid said that for 2019 and 2020, the Office is looking at the number of students and institutions reached and the diversity of groups. Mr. Kincaid noted that when he had started in this effort 30 months before, the Office of Management and Budget (OMB) was unhappy with NASA's Education performance; this year, however, NASA has been asked to present its approach, as an exemplar, to other agencies. Mr. Holloway and Mr. McDaniel urged Mr. Kincaid to reach out to the underserved population, particularly at the elementary school level.

Exploration Systems Development

Mr. Tom Whitmeyer, Acting Deputy Associate Administrator (DAA) for Exploration Systems Development (ESD), briefed the HEOC on progress in building to Artemis I, emphasizing that hardware is ready to go and that ESD is now preparing to transition to green run test and launch integration operations. He displayed images of the completed Orion Crew Vehicle for Artemis I flight. The Launch Abort System (LAS) assembly and integration is complete, the Ascent Abort -2 system has assessed by an Engineering Review Board (ERB), and preliminary assessments of the Flight Test Objectives (FTOs) are positive. The Ascent Abort (AA-2) flight test results will be finalized on 20 November. The testing was managed well and remained on schedule. Artemis I and the Crew Service Module (CSM) were mated in July 2019. CSM will be received at the Plum Brook facility in November for environmental, thermal vacuum and other testing, and then will be transported back to KSC in March 2020. The final assembly of CSM will then be turned over to Exploration Ground Systems (EGS) in May 2020. Flight software reached a major milestone in reconfiguring ITL to support both Artemis I and II testing, and is due to be complete in November.

The build-up to the completion of the Artemis II Crew Module (CM) is making good progress in avionics. The hardware is flowing much more efficiently, building on prior experience with Artemis I. The Artemis II Crew Module Adapter (CMA) is in the KSC Operations and Checkout (O&C) building, ready to mate with European module in May 2020. ESD is very pleased with Orion thus far. Two of four RS-25 engines have been attached to the Core Stage of the SLS rocket. Mr. Whitmeyer highly recommended the Pathfinder testing scheme for building future rockets. The liquid oxygen tank structural test article has been placed into the test stand at Marshall Space Flight Center (MSFC), which is where liquid hydrogen tanks will also be tested, simultaneously. Artemis I stages are in the final integration stages, and are scheduled to ship for a Green Run in December 2019. The schedule is generally running well. The Artemis Green Run will be carried out at Stennis; it is a series of activities and checkouts, including a wet dress rehearsal, loading operations rehearsals, hot-fire testing, and post-hot-fire refurbishment. After the Green Run, the Core Stage will ship back to KSC for integration.

All booster separation motors are cast and finalized for Artemis I; segments are ready to ship. Artemis I and II engines are being installed. The Software Test Lab at MSFC is completing phase 4 (final avionics verification), due to be done in November. All segment casting is complete for Artemis II SLS; segments are being stored in Utah. The Artemis II Liquid Hydrogen (LH2) tank is complete and at the MAF. Exploration Ground Systems has completed the Rotation Processing and Surge Facility, and is conducting flow tests of Ignition Overpressure Protection and Sound Suppression. The Mobile Launcher is sitting at the launch pad, undergoing V&V.

Vehicle Assembly Building (VAB) activities at KSC include the ongoing completion and refurbishment of Pad 39B. An Operational Readiness Review is scheduled for December 2019. Spaceport Command and Control System (SCCS) and Ground Flight Application Software are also in work and making progress. Mr. Hale observed that there had been challenges with the Core Stage control software, which could be a topic for future Lessons Learned activities. Mr. Sieck asked if a flight readiness firing would be omitted. Mr. Whitmeyer confirmed this, saying that TCCs would be validated instead.

Mr. Wayne Jermstad described progress in Systems Engineering and Integration (SE&I) activities for the current quarter, including the development of an internal planning manifest that covers Artemis I through IX, and also the baselining of documentation for the configurations for each mission. Some limited mission objectives have been identified: delivering a to be determined (TBD) lunar cargo payload, and flying to NRHO. An Artemis II Sync Point #1 meeting was held in September, and plans for another one in September 2020 are under way. The Sync Point milestone is equivalent to a Critical Design Review (CDR) at the Enterprise level.

Mr. Jermstad has been meeting with schedule assessment teams every two weeks over the past 18-20 months, looking over the critical paths to understand the drivers and challenges in areas such as Core Stage assembly integration and testing, and Green Run testing. SE&I Issue Resolution Teams have been stood up on Range Safety, Pad Access/Con Ops, Ignition Overpressure Protection and Sound Suppression (IOPSS) water flow rate, IT security, Block 1B acoustics and loads, and imagery (managing camera placement and setups). SE&I is also preparing for a Flight Readiness Review (FRR)-ISMC Dry Run #1, having spent three very successful days at MSFC and uncovering some small issues with losing sensors as the process goes through the flow. A person has been assigned to this issue. The team also talked about impacts of potential nonconformances to the system, and is holding "Day in the Life" meetings to develop nonconformance processes and figure out how to run daily engineering boards.

Mr. Hale said that HEOC would like to see an integration team that works through the whole program (Orion, SLS, etc.). Mr. Jermstad noted that SE&I has an integration control board that looks at the whole program. Mr. Whitmeyer said that ESD is doing what it did for the Shuttle program, and that the only real difference now is in some vehicle configurations, and more ability to communicate virtually. Dr. Sanders commented that Artemis and Gateway is a whole other system that must be considered. Mr. Jermstad said he was actually discussing this now, working closely with MSFC in a good partnership.

Advanced Exploration Systems (Deep Space Exploration)

Mr. Marshall Smith, Director of Human Lunar Exploration Programs, presented an overview of the program, first reviewing SPD-1 goals for both the Moon, and then Mars. He emphasized that this is a continuous program, just the beginning of exploration further out. The goal is to prove technologies on the Moon that will enable us to go further out. He noted that the number of career PhDs increased by a factor of 3 after the Apollo 11 mission, and predicted that in a similar fashion, public engagement in the Artemis Program would change the way people work and think. Ms. Budden commended the succinct and articulate nature of the one-chart rationale for going to the Moon. Mr. Holloway felt that the message on science could be transmitted more clearly. Mr. Voss agreed, saying the charts were still missing the lunar science rationales. Ms. Budden suggested including a statement that emphasizes Exploration's importance for understanding humanity's place in the Solar System.

Mr. Hale said he had been hearing a lot of talk about ISRU, and asked if Advanced Exploration Systems is actually doing the work needed to obtain water on the lunar surface to convert it to fuel. Mr. Smith said that the program will start doing early experiments. While there will be an ISRU experiment on board the Mars 2020 rover, NASA must still directly sample lunar regolith to determine what it can be used for. Mr. Smith said his program was working with SMD and STMD to take the next steps on ISRU. Mr. Hale emphasized that ISRU planning must start now. Mr. Smith said that these teams are in place, and Mr. Kelvin Manning welcomed HEOC to visit the laboratories during its next visit. Dr. Condon asked if remediation efforts were in work, and Mr. Smith affirmed this.

Artemis Phase I is designed to take humans to the lunar surface by 2024. The SEP-powered PPE system will be delivered to orbit in 2022, providing the capability for moving around large elements in space. The first pressurized module and the HLS will be delivered to Gateway before the crew is delivered. At the same time, SMD will be sending science instruments, and components of ISRU experiments, to the Moon. In 2023, NASA is considering a larger-scale cargo lander that will be able to carry a large payload, or a rover. PPE and HALO delivery is now proceeding as part of their respective contracts; NASA will not take over these elements until they are on orbit. The minimum systems required to support a 2024 human lunar landing include the habitat and SEP propulsion systems, while Gateway itself will serve as a command center and aggregation point for the 2024 crew. Gateway is supported by an open architecture, and NASA already has a number of agreements in place with industrial and international partners, based on "plug-and-play" interoperability standards.

Mr. Smith discussed the reasoning behind the NRHO orbit selected for Gateway orbit. A Low Lunar Orbit (LLO) orbit deteriorates quickly and requires frequent boosting. A direct retrograde orbit (DRO) is easy to reach and stable, but it is far from the lunar surface and requires a large delta-v. NRHO orbits are fuel-efficient, always within communications capability, easy to access from Earth, and they give a good science vantage point for Earth and deep space observations.

Artemis Phase 2 will focus on building capabilities for Mars missions, and will include returning to the Moon every year, testing systems and surface habitats, and increasing the crew from two to four; NASA is also looking to international partners to contribute to this effort.

Since 1985, NASA has done more than 1000 studies on lunar exploration architectures; the studies depend on different assumptions. The current architecture is based on physics, available technologies, and weighted figures of merit. Years ago, former astronaut Buzz Aldrin proposed a "Mars Cycler" (or the Aldrin cycler, which makes a single, eccentric loop around the Sun.) The cycler concept is vaguely similar to what Gateway will do in NRHO. NextSTEP activities for Gateway include a Broad Area Announcement (BAA) activity to solicit ideas for short-duration habitats, interoperability standards, ground-based human-in-loop (HIL) testing, and larger habitats. Lunar architecture choices are based on a variety of factors and are largely physics-driven. NRHO is considered an ideal combination of delta-v, movement of total mass, distance from Earth, communications, etc. A direct-to-Moon (DTM) delta v is slightly lower than for NRHO, but it requires more mass to get to the Moon. With Gateway, more mass (cargo) can be traversed in a more leisurely fashion. Mr. Hale paraphrased the rationale as saving mass with the addition of some complexity, but with the added complexity conferring more sustainability, along the same lines of the Apollo configuration (orbiting command module, low-mass lander down to surface and back up). Mr. Voss asked: when do you break even? Mr. Smith said that depends on what happens in the future.

By 2024, lunar science, via the use of polar landers and rovers, will provide direct measurements of polar volatiles, and deepened understanding of the geology of Aitken basin. Nonpolar landers and rovers will investigate terrains not visited by Apollo to study magnetic swirls and lunar volcanic regions. Lunar orbiters will map the mineralogy and elemental distribution of the Moon. At present, SMD is putting together a lunar science strategy.

The Power and Propulsion Element (PPE), is one element of reaching the Moon and Mars faster with NASA technology. The PPE is being developed by Maxar Technologies, while the HALO habitat is the subject of an RFP issued to Northrop Grumman. Through Gateway Logistics Services, US industry will begin delivering cargo, experiments, and supplies. A BAA for the HLS was released in September, with proposals due 1 November. In-house efforts have been ramped up for space suits: a full suit demonstration is scheduled for late 2022/early 2023. NextSTEP Habitat Prototype testing is in progress; astronauts have been performing "Day in the Life" in the various test habitats. ISS deep space interoperability standards have been established. In the past 6 months, Exploration has done what it ordinarily takes two years to do.

Dr. Condon asked how much of a threat Micrometeoroid and Orbital Debris (MMOD) posed to Gateway and Artemis. Mr. Smith said that NASA is tracking impacts. MMOD is not a large concern, but it must be taken into consideration. In LEO, debris may be a bigger issue than micrometeoroids. Mr. Sieck asked: what is the biggest challenge in terms of Technology Readiness Level (TRL)? Mr. Smith said he believed that the technology for 2024 largely exists. Some technologies are at TRL 7-8 but mostly, existing systems are in use. Ms. Budden asked if NASA had a requirement for using TRL-9. Mr. Smith said the approach is to assess proposals and see if they can do the job. Mr. Scimemi added that systems are also being tested on ISS to bring TRLs up to support 2024. ARD has been proven at ISS, e.g. Mr. McDaniel

commented that NASA has the best team in the world; if they get the augmentation funding, they can get to 2024. Mr. Smith agreed, adding that NASA has all the necessary contracts in place. Hale- the political challenge appears to be the much bigger challenge. Budden- could use this fact as the basis of a recommendation.

Discussion and Recommendations

Mr. Hale led a discussion of prior HEOC recommendations, beginning with a recommendation on supporting the continuation of existing lunar planning; he felt there was no need to revisit this recommendation, as the NAC had accepted the recommendation, although NAC has not yet had a response from the Administrator. Similarly, recommendations on STEM Engagement and streamlining commercial spaceflight also need not be revisited. Other recommendations were on Intellectual Property reform (from the RPC); a unified approach to orbital debris mitigation; streamlining decision making; and reviewing and revising governance models. A recommendation from the RPC on ensuring commercial entities access to the necessary hardware on ISS, relating to the private industry that has invested in ISS, was also not accepted by NAC. Mr. Hale briefly ticked off other findings and recommendations: a Science Committee recommendation on facilitating safe and diverse environments; a finding from the Technology, Innovation and Engineering Committee (TI&E) on satellite servicing, digital transformation, and NASA-developed nuclear thermal propulsion to speed human travel to Mars; a finding from the Aeronautics Committee on the airspace vision beyond Nextgen, and applauding NASA for its University Leadership Initiative; and Science Committee findings on science goals for Moon, HRP/microgravity, Science Plan edits, and organizational issues.

The HEOC discussed a finding or recommendation on advocacy for the $1.6B proposed budget augmentation to support the Artemis program, a finding that was made in May and was not accepted by the NAC. Dr. Siegel noted that any recommendation must be actionable by NASA. Ms. Budden and Mr. Chiao wrote up new language for this recommendation to enumerate the challenges of carrying out an aggressive schedule on a limited budget. HEOC applauded the fact that NASA had not raided other budget lines, and the general sense is that NASA has done a credible job of estimating cost for the first year of Artemis. However, it appears that without an augmentation, the probability of success is greatly diminished, and will be accompanied by unacceptable risk. Dr. Gardner said that it was important to state that NASA also needed the $1.6B by a certain deadline, and that Continuing Resolutions (CRs) can undermine this process. Mr. Holloway asked why NASA was doing Commercial Lunar Payload Services (CLPS), feeling that it was more than what was necessary for 2024? Mr. Smith replied that NASA wants to make sure that the crewed mission is a useful as possible, therefore the robotic precursors are money well spent.

HEOC discussed a second recommendation on the lifetime of ISS, which will be needed beyond 2028. HEOC felt NASA should do an engineering analysis to understand the remaining life of ISS, with an emphasis on the Station structure and on critical systems that can't be replaced on orbit. Mr. Scimemi said this would require a multi-year analysis, and supported the recommendation. HEOC reached a quorum on the recommendation.

HEOC discussed a finding on reassessing the pricing of ISS resources for LEO commercialization. Mr. Lopez-Alegria noted that industry needs to pay the full price for what is necessary to support humans in space, pointing out that NASA also uses flight opportunities as an instrument of foreign policy; those countries are the very customers that LEO companies are trying to get. He thought there was already language to this effect in the authorization act, and agreed to write up the final language.

HEOC concurred on a recommendation to carry out an extensive flight testing scheme for the HLS, and removed a recommendation on streamlining, as it had been treated by the RPC in the prior NAC deliberations.

Mr. Holloway suggested a HEOC observation on harnessing and maintaining NASA's can-do attitude and allowing it to be less bureaucratic, as NASA has demonstrated over the last decade. Dr. Siegel suggested adding some concrete examples to the observation. Mr. Holloway also suggested an observation on the value of Artemis adopting the principles of LSP, as some believe that Artemis has an integration problem. LSP is an integrator and help them get to the pad on time. Artemis should take a look at how they operate.

Mr. Holloway commented that there too much NASA outreach oriented to people who are already interested in STEM fields; NASA needs to reach out to underserved populations and people who can't afford formal educations. Mr. Hale asked to hold that thought until HEOC holds further discussion with the STEM office.

HEOC finalized language on findings and set a tentative March 2020 date for its next meeting, possibly in a joint session with the Science Committee. Mr. Hale adjourned the meeting at 4:12pm.

HEO Committee Proposed NAC Recommendation (actionable):

Short Title of Recommendation: Human Lunar Lander Development for Safety

Recommendation:

NASA should review, with an acceptable team, the requirement for in flight testing of the HLS. Serious consideration should be given to demonstrating through flight test the ability to deorbit, land on, and ascend from the lunar surface under the expected physical and environmental conditions.

Major Reasons for the Recommendation:

A critical step in the development of the Human Landing System is the plan for human flight certification and its execution.

While there may not be a single correct or acceptable approach, systems developed for human space flight in the past have found that uncrewed end-to-end flight tests have been extremely valuable. Partial or ground testing may be options but the HEO committee strongly recommend flight testing.

Consequences of No Action on the Recommendation:

Inadequate design may not be uncovered prior to human use.

HEO Committee Proposed NAC Recommendation (actionable):

Short Title of Recommendation: Longevity of the International Space Station

Recommendation:

Perform an analysis of the safe and useful life of the ISS past 2028 with emphasis on the structure and other critical systems that cannot be replaced on orbit.

Major Reasons for the Recommendation:

An engineering analysis has been performed that shows the ISS can operate safely until 2028. The HEO committee believes a LEO platform to continue research for deep space, long duration missions will be needed past 2028. Enabling commercial LEO platforms and services should remain NASA's goal, but the Agency should understand the safe remaining life of the ISS in case the commercial platforms and services are not available by 2028.

Consequences of No Action on the Recommendation:

NASA will not have critical information necessary to making an informed decision about ISS life extension

HEO Committee Proposed NAC Finding (not actionable):

Short Title of Finding: Supporting $1.6B proposed budget for 2020

Finding:

The HEO Committee believes NASA has done a credible job estimating the 2020 funding total for Artemis to meet its goals for 2024. $1.6B is considered a reasonable estimate of the first-year costs toward the 2024 landing.
The HEO Committee acknowledges that even with the full 2020 funding request of $1.6B, accomplishing planned activities by 2024 will be aggressive, challenging, and difficult. The HEO Committee applauds NASA not raiding other Directorate budgets to fund the Artemis program.
An aggressive drive toward the 2024 deadline has prompted a sense of urgency within NASA to meet its goal. Programs, hardware and deliverables are proceeding at a rate unprecedented since Apollo, on or ahead of schedule. Related technology advances are proceeding rapidly.
We believe proceeding without this funding level in 2020 will result in significant risk to schedule. Additionally, funding should be provided in a timely manner in order to avoid schedule slip and to maintain the current impressive momentum within the program.
The committee therefore endorses the 2020 and follow-on budget request and recognizes it to be the top priority and threat to the success if the Artemis program.

HEO Committee proposed NAC Finding (not actionable):

Short Title of Finding:

NASA should be mindful of competing with industry in LEO commercialization.

Finding:

NASA has unparalleled brand value and significant resources with which nascent industry entities in the commercial LEO market are unable to compete for the same potential customers.

NASA's recent initiatives to stimulate demand for a LEO market for which it will be one of many customers are laudable. But care must be taken to prevent unintentional consequences. For example: highly subsidized rates for accommodations aboard the ISS for Private Astronaut Missions may stimulate demand in the short term, but the ability to simply "purchase" these accommodations from NASA will not facilitate acquisition of the knowledge necessary for longer term operation in LEO by non-NASA platform providers. If NASA provides a heavily subsidized fee-for-service option leading up to the transition from a government to commercial platform, the operating entity will not have gained the necessary knowledge and experience to independently keep astronauts safe and well during their stay.

HEO Committee Finding on Schedule
The setting of a near term schedule goal (landing on the moon by 2024) has led to a change in the culture and streamlined decision-making, new acquisition methods. NASA should document best practices.

HEO Committee Finding on LSP
The service attitude and culture of the LSP are commendable to build a team that collaborates with multiple parties to achieve a launch goal. We believe that the Artemis Program (all the elements such as SLS, Orion, HLS, Gateway, et. al.) should study the way LSP operates and use the applicable processes and attitude and culture as much as is practical.

Appendix A
Attendees

Human Exploration and Operations Committee Members
Mr. Wayne Hale, **HEOC Chair**
Ms. Nancy Ann Budden, Director for Special Operations Technology, Office of the Secretary of Defense
Dr. Leroy Chiao, Former NASA astronaut and International Space Station Commander
Dr. Stephen "Pat" Condon, Aerospace Consultant
Mrs. Ruth G. Caserta Gardner, Technical Deputy Director for the Engineering and Technology Directorate
Mr. Tommy Holloway, Former Space Shuttle and International Space Station Program Manager
Mr. Michael Lopez-Alegria, Former NASA astronaut and retired U.S. Navy Captain
Mr. Robert Sieck, Former Space Shuttle Launch Director
Mr. James Voss, Former NASA astronaut and retired U.S. Army Colonel
Mr. Mark McDaniel, Partner at McDaniel and McDaniel Attorneys, LLC
Dr. Bette Siegel, **Executive Secretary**, NASA Headquarters

NASA Attendees
Mary Ann Chevalier, NASA CCP
Chuck Dovale, NASA LSP
Amanda Griffin, NASA
Wayne Jermstad, NASA
Janet Karika, NASA HQ
Jarel Lawrence, NASA LSP
Marie Lewis, NASA
Leejay Lockhart, NASA PAO
Jenny Lyons, NASA LSP
Mary Maclaughlin, NASA
Kelvin Manning, NASA KSC
Emily McLeod, Apache Logical, NASA PX
Amanda Mitskevich, NASA LSP
Johnny Nguyen, NASA
Jim Norman, NASA HEOMD
Janet Petro, NASA HQ
Renee Pullen, NASA HQ
P. Diane Rausch, NAC Executive Director

Yonathan Reches, NASA HEOMD
David Rann, NASA HEOMD
Sam Scimemi, NASA HQ
Carlos Shurick, NASA Docent
Marshall Smith, NASA HQ
Mark Wiese, NASA
James Wood, NASA LSP

Non-NASA Attendees
Chris Gebhardt, Public
Charlie Stegemueller, SAIC
Stephen Long, Private Citizen
Dr. Meenakshi Wadhwa, Chair, NAC Science Committee
Joan Zimmermann, Zantech, Inc.

Webex Attendees
Lindsay Aitchison, NASA
Cina Anderson, NASA
Katy Bassian, GAO
Eric Berger, ARS Technica
John Bersha, South Science Space Tech
Blair Bigelow, Bigelow Areospace
Marguerite Broadwell, NASA HQ
Alisha Brown, Internet Commerce Committee
Ann Bulkosky, Lockheed Martin
Davin Bryant, NASA
Rob Campbell, Private Attorney
Latasha Carson NASA HQ
Deborah Circelli, Boeing Communications
Stephen Clark, Space Flight Now
Keith Crooker, Bigelow Areospace
Randy Cruz, NASA HQ
Chris Davenport, Washington Post
Mary-Lynne Dittmar, DDST
Miles Doran, CBS News
Bret Drake, Aerospace
William Emanualson, The Aerospace Corporation
Joshua Finch, NASA
Kevin Foley, Boeing
Jeff Foust, Space News
Robyn Gatens, NASA HQ
Chris Gilbert, BE Consult
Kathryn Hamilton, NASA
Brian Harvey, B&A Associates
Bill Harwood, CBS News
Derek Hoggins, Northrop Grumman
Rick Irving, NASA
Robert Kampen, Private Attorney
Linda Karanian,Karanian Aerospace Consulting
Colm Kelleher, Bigelow Aerospace
Erin Kennedy, GAO

Joy Kim, GAO
Theodore Kronmiller, Law Office
Jamie Lentz
Brian Lester, Yale
Lynne Loewy, NASA HQ
Stephen Long, Citizen
Dillon Macinnis, SpaceX
Tariq Malik, Space.com
Jean Masterson, Bigelow Areospace
Laura Means, NASA Marshall
Shannon Messner, NASA
Gene Mikulka, Talking Space
Amanda Mitskevich, NASA
Eleanor Morgan, Bigelow Areospace
Brian Norton, Launch Services (LSP)
Gary O'Neil, NASA
Kelly O'Rourke, NASA
Kenna Pell, Kennedy Space Center
Bill Peterson, Independent
Nick Powell, Houston Chronicle
Steven Ramm, Lockheed Martin Space
Tony Reichhardt, Air & Space Magazine
Deann Reilly, The Boeing Company
Joey Roulette, Reuters
John Rummel, SETI
Magdiel Santana, NASA
Mark Schloesflin, NASA
Mark Seibert, ASRC Federal Technical Services NASA HQ
Marcia Smith, Space Policy
Jared Smith, Private Citizen
Mark Schloesflin, NASA
Samuel Schmidt, Hobbyist
Enzo Vito, Bigelow Aerospace
R Watson, Northrop Grumman
Kiersten Whit, NASA HQ
Steven Young, Space Flight Now

Appendix B
HEOC Membership

Mr. Wayne Hale, HEOC Chair
Retired NASA
Former Flight Director, Space Shuttle Program

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

Dr. Leroy Chiao
Former NASA astronaut and International Space Station Commander

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

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

Mr. Tommy Holloway
Former Space Shuttle and International Space Station Program Manager

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

Mr. Bob Sieck
Former Space Shuttle Launch Director

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.

Dr. Bette Siegel
HEOC Executive Secretary
NASA Headquarters

Appendix C
Agenda

Tuesday, October 29, 2019
All times are Eastern Daylight Time

NAC HEO Committee Public Meeting

12:30 – 12:35	Call to order and Welcome	Mr. Wayne Hale/ Dr. Bette Siegel
12:35 – 1:30	NASA Human Exploration and Operations Overview	Mr. Ken Bowersox
1:30 – 2:30	ISS	Mr.Sam Scimemi
2:30 – 2:45	Break	
2:45 - 3:45	Low Earth Orbit Commercialization	Mr. Doug Comstock
3:45 – 4:00	Break	
4:00– 4:10	Public Comments	
4:10– 5:30	Discussion and recommendations	
5:30	Adjourn	

Wednesday, October 30, 2019

NAC HEO Committee Public Meeting

9:30 – 9:35	Call to order	Mr. Wayne Hale/ Dr. Bette Siegel
9:35 – 10:30	Commercial Crew	Ms. Kathy Lueders
10:30 – 11:30	Launch Services Program	Ms. Amanda Miskkevich
11:30 – 12:30	Lunch-	
12:30– 1:30	Exploration Systems Development	Mr. Tom Whitmeyer
1:30 – 2:45	Advanced Exploration Systems (Deep Space Exploration)	Mr. Marshall Smith
2:45 – 4:30	Discussion and Recommendations	

4:30 Adjourn

Dial-In and WebEx Information

For entire meeting October 29 – 30, 2010

Dial-In (audio): Dial the USA toll free number **1-888-324-9238** or toll number **1-517-308-9132** and then enter the numeric participant passcode: **3403297**. You must use a touch-tone phone to participate in this meeting.

WebEx (view presentations online): The web link is; https://nasaenterprise.webex.com/nasa the meeting number is 909 467 766, and the password is Exploration@2019 (case sensitive).

**** All times are Eastern Time ****