NASA AEROSPACE SAFETY ADVISORY PANEL
National Aeronautics and Space Administration
Washington, DC 20546
Dr. Patricia Sanders, Chair

March 23, 2018

Mr. Robert M. Lightfoot, Jr.
Acting Administrator
National Aeronautics and Space Administration
Washington, DC 20546

Dear Mr. Lightfoot:

The Aerospace Safety Advisory Panel held its 2018 First Quarterly Meeting at the Marshall Space Flight Center, Huntsville, Alabama, on March 1, 2018. We greatly appreciate the participation and support that was received from the subject matter experts and support staff.

The Panel submits the enclosed Minutes resulting from the public meeting for your consideration.

Sincerely,

Patricia Sanders

Patricia Sanders
Chair

Enclosure

AEROSPACE SAFETY ADVISORY PANEL
Public Meeting
March 1, 2018
Marshall Space Flight Center, Huntsville, AL

2018 First Quarterly Meeting Report

Aerospace Safety Advisory Panel (ASAP) Attendees
Dr. Patricia Sanders, Chair
CAPT (Ret.) Christopher Saindon
CAPT (Ret.) Brent Jett (telecon)
Lt Gen (Ret.) Susan Helms (telecon)
Dr. Donald McErlean
Dr. Sandra Magnus
Mr. David West
Dr. George Nield
Dr. James Bagian (telecon)

ASAP Staff and Support Personnel Attendees
Ms. Carol Hamilton, NASA ASAP Executive Director
Ms. Paula Burnett Frankel, Writer/Editor
Ms. Evette Whatley, Administrative Officer

NASA Attendees:
Jennifer Stanfield

Other Attendees:

Martin Burkey	ASRC Federal
Ann Yelle	ASRC Federal

Telecon Attendees – see Attachment 1

Opening Remarks
Ms. Carol Hamilton, ASAP Executive Director, called the meeting to order at 9:45 a.m. CST and welcomed everyone to the ASAP's first quarterly meeting of 2018. Because of some difficulty with dial-in connections, she provided alternate information for telecon attendees. She indicated that the public had an opportunity before the meeting to request to make verbal statements or to file written statements on the subject of NASA safety. A written statement was submitted by Dr. Harry Stanley Morehead, Jr., which Ms. Hamilton read it into the record. [Dr. Morehead's input is included as Attachment 2 to these minutes.]

After reading Dr. Morehead's statement, Ms. Hamilton turned the meeting over to the ASAP Chair, Dr. Patricia Sanders, who thanked Dr. Morehead for his input and indicated that his letter and paper would be forwarded to NASA's Office of the Chief Health and Medical Officer (OCHMO) for disposition.

Dr. Sanders thanked Mr. Todd May, Marshall Space Flight Center (MSFC or Marshall) Director; Ms. Jodie Singer, MSFC Deputy Director; and the MSFC personnel for their excellent hospitality in hosting the Panel's first quarterly meeting of 2018. She also thanked Mr. Jonathan Pettus, MSFC Associate Director, for bringing the Panel up to date on Center activities since the last visit. Marshall is at the center of the Space Launch System (SLS) development and test with impressive hardware testing currently underway. However, the SLS is by no means the only NASA program supported by MSFC. Among the many innovative efforts at Marshall is the next astrophysics mission, the Imaging X-Ray Polarimetry Explorer.

Dr. Sanders noted that the Panel has said farewell to Mr. John Frost, who has served the ASAP's safety mission ably for twelve years. On behalf of the Panel, she welcomed the newest member, Mr. David West, a career safety professional who will be an asset to the Panel's work. Dr. Sanders also applauded the dedication of Panel members CAPT Brent Jett and Lt Gen Susan Helms, who participated in all of the Panel deliberations by WebEx, despite being assaulted by the influenza virus.

Commercial Crew Program

Dr. George Nield reported that the Panel had a very good interaction with the CCP staff, led by Ms. Kathy Lueders, Program Manager of the CCP, with commentary from Mr. Ed Burns, Manager of the CCP Systems Engineering and Integration (SE&I) Office. There has been significant progress over the past quarter. Mission planning and preparations are underway for eight CCP missions, four by Boeing and four by SpaceX. Boeing has an uncrewed orbital flight test to the International Space Station (ISS or Station) scheduled for August 2018, with a crewed flight test in November 2018. Two post-certification missions are also in the flow. SpaceX has Demo Mission 1 to the ISS (without crew) scheduled for August 2018, with Demo Mission 2 (crewed) scheduled for December 2018. SpaceX also has two post-certification missions in flow.

Dr. Nield observed that there is a considerable amount of space hardware in manufacturing, testing, and qualification, as well as progress in the key certification products. He noted that the ASAP's assessment of the schedule is that it will be very challenging to make the reported launch dates. However, the Panel has not seen any sign of schedule pressure negatively impacting the decisions being made. The ASAP will continue to monitor the Program to ensure that continues.

The Panel reviewed the CCP's top programmatic risks: an inability to meet the loss of crew (LOC) target and the Department of Defense's (DoD's) search-and-rescue training schedule. With regard to LOC, Dr. Nield noted that it is a complex issue, and the LOC target is very challenging. NASA is using Probabilistic Risk Assessment (PRA), which is not intended to be a prediction of the actual safety of the vehicles, but it is an excellent tool to assess different options for system design. The providers are putting finishing touches on both hardware and operations, and the CCP is getting close to having a final assessment on LOC capability.

With regard to the CCP top safety risks, three were highlighted: inability to meet LOC target, the possibility of an abort into a sea state with unsafe rescue conditions (which could factor into launch commit criteria), and crew entry accelerations and spaceflight-associated neuro-ocular syndrome and acerbations, which could have potential impacts on visual acuity and eyeball health under some conditions during re-entry and landing. The Panel noted that the top two NASA-assessed safety risks are the same for both providers: spacecraft tolerance to the micrometeoroid and orbital debris (MMOD) environment and parachute system testing. These challenging issues dominate the predicted LOC probabilities.

Dr. Nield mentioned that the ASAP is continuing to watch both providers in terms of application of systems engineering and process discipline. The Panel has seen some signs of progress, but the jury is still out on whether the providers will be able to demonstrate that they have been able to embrace and internalize those processes in time to support certification. As a closing observation, Dr. Nield noted that the CCP has shown the Panel that in spite of very challenging circumstances, the Program is doing an excellent job making decisions, weighing inputs and data, and carefully watching the progress being made. A number of other organizations, including the Air Force and the Launch Services Program, are assessing these companies. In some cases, they have different viewpoints, but the CCP itself seems to be proceeding in a very thorough, objective, and professional manner toward developing and certifying a commercial crew transportation capability.

Dr. Sanders agreed that there has been lot of progress; however, as noted, a great deal of work has yet to be done, and there are some technical challenges before certification. The CCP and the providers have good schedule awareness, and so far, the Panel has not seen shortcuts being taken in response to schedule pressure. The ASAP encouraged the Program to continue in that manner.

International Space Station

Dr. Sandra Magnus discussed the fact-finding and discussions on the ISS. She thanked Mr. Kirk Shireman and his team for a very thorough presentation. The ISS Program continues its success and progress related to science and research on board, recently having set a new record (109.3 hours) of crew time in one week devoted to the science program. The Station remains a very busy place. The crew recently completed a series of extravehicular activities (EVAs) targeted at replacing a failed latching end effector on the CanadaArm. The arm is now in a healthy configuration to interact with commercial cargo vehicles as well as commercial crew vehicles, which are scheduled to arrive at the ISS later this year. CCP transition to the operational phase will be an important, long sought milestone for the ISS program and theoretically will add flexibility to operational planning. Until that time, however, the Panel urged NASA to closely monitor the ongoing evolution of the CCP, consider scenarios, and lay plans to ensure that the appropriate skill sets are available on board to adequately maintain and sustain the U.S. Orbiting Segment.

In response to a request, the Panel received some insight into the strategy and plan related to the maintenance and management of the extravehicular mobility units (EMUs) and other EVA hardware for the remaining life of the ISS. The Johnson Space Center (JSC) EVA office shared its approach, and Dr. Magnus reported that the Panel was pleased to see the level of detail and thoroughness with which both the systems and components of the equipment were tracked and examined for either retirement, replacement, or refurbishment. One of the major adjustments the technical community had to make with the retirement of the Space Shuttle was the displacement of regular, planned maintenance from ground facilities to on-orbit. She indicated that the plan appears to be thorough, and the Panel will be looking into aspects related to operational implementation. As far as the recently announced policy regarding cessation of ISS activities in 2025, the Panel will be interested in understanding how the implementation and execution of this directive may affect operations in the future. Currently, there is not enough information for the Panel to make an assessment.

Dr. Sanders noted that it was interesting to hear Dr. Magnus's comments, since she herself spent time on the ISS. As noted, the Panel believes that it is prudent for NASA to consider contingency plans for continuity of operations on the ISS, given the schedule risk still inherent in the CCP. There are considerable safety issues involved should the Station be unmanned or undermanned for any period. But it is also undesirable from a human space flight safety perspective to rush the certification of commercial vehicles for transport to the Station.

Exploration System Development (ESD)

Dr. Donald McErlean reported on the Panel's discussions with ESD management. ESD is a program that is now and into early 2019 diverging in a number of directions with many large and complex tasks. ESD involves several NASA Field Centers in addition to Marshall. Test articles that are the size of small buildings are being moved around the country into testing. Dr. McErlean noted that at times, just the transportation of those articles themselves can be a huge technical and technology issue. The Panel's review started with a program summary from Mr. Jonathan Pettus, MSFC Associate Director. As noted earlier, the ESD program at Marshall is a major program for the Center, which is very proud of its accomplishments. Mr. Pettus emphasized that the workforce understands that they are accountable for results and are building toward several significant milestones. The principal milestone for MSFC is the delivery of the core stage to Stennis Space Center (SSC) for "green run" operations late this year. While that is a schedule challenge, there does not appear to be anything at this time that would delay that milestone. The green run hot fire takes place at SSC in mid-2019, and everyone is building toward the Exploration Mission (EM)-1 launch window in late-2019 to mid-2020. The core stage, which is principally Marshall's responsibility, is on the critical path to EM-1.

Earlier problems with the friction stir welding operation have been overcome and welding has now been completed on all EM-1 components, including the liquid hydrogen (LH_2) qualification tank. The proof test on that tank is complete. Dr. McErlean commented on the structural testing, which is one of the principal activities in which the Program is involved today. The Panel had a lengthy discussion with Mr. Tom Whitmeyer, Assistant

Deputy Associate Administrator for ESD. Dr. McErlean explained the two approaches to structural validation: analysis and test. While analysis is often quicker and less expensive, it often does not provide the type of valid data that a physical test provides. The Program decided to use the more expensive and longer path—physical testing of the components in flight configuration with real loads on actual test stands. The large ESD components require the building and operation of some very significant test facilities as well as fabrication of flight-sized components called structural test articles (STAs). Testing at full scale provides much higher fidelity data. Since the SLS is to be NASA's deep space transportation system for perhaps decades to come, building the data that allows NASA to create very detailed models of structural components pays off in dividends whenever small modifications for new payloads are required in the future. The models will enable detailed assessments of structural loadings.

NASA reported that all the test stands are ready and the STAs are complete. The largest ones—the intertank, the LH_2 and the liquid oxygen stands—will begin testing late this year/early next year. The engine section testing was completed this year. One of the engines was run to 113 percent power. All of software for the engine control units has been qualified and tested. Software itself remains on the critical path. Flight control software and application software are scheduled for various releasees late this year. The Exploration Ground System (EGS) software and the spacecraft command and control software Release 4 is out; Release 5 will occur in December. The ground flight applications software initial testing is at the Systems Integration Laboratory. Software is working according to plan, but as always, software remains the "long pole in the tent." At this point, the Panel is pleased to report that progress appears to be satisfactory and is on schedule.

With respect to ground system facilities, the launch equipment test facility recently completed Orion umbilical testing. The core stage intertank umbilical test was completed late last summer, and the crew access arm was delivered and has been installed. Dr. McErlean noted that there were various descriptions on the internet about the tower having an angular "lean." He noted that was expected; the huge load placed on the tower was allowed for, anticipated, and is not a concern. With regard to the launch pad itself, the work for EM-1 will be completed in late FY18; design for changes to the pad to support EM-2 is very near completion. The European Service Module (ESM) is the third item on the critical path. Delivery is expected sometimes between May and June 2018. It will move to mate with the crew module adaptor in July, have power-up and functional testing through most of the fall of 2018, and mate to Orion in late December. The integrated stack goes to Plum Brook for testing in the first half of 2019 and will be delivered to the Cape in the latter half of that year. Orion has undergone structural qualification. The launch abort system load test was completed late last year. The flight system for EM-1 should be completed late this summer and is on track. The combined stack testing is currently underway. For EM-1, the Orion build up is underway; testing is partially complete and is expected to be finished by August 2018. It will mate with the service model in December 2018.

The Panel spoke with several people in Cross-program System Integration (CSI). Many of the assembly and test issues are currently moving from component build to integrated test. The role of CSI is growing; 14 separate teams are looking at integration issues. Dr. McErlean mentioned two that are especially important: (1) the management of fracture-critical parts and testing, and (2) enterprise validation and verification. EM-2 will be the first use of the Environmental Control and Life Support System (ECLSS). The Panel was very pleased to see that components are being fabricated and moving forward for testing, which is underway on the ISS. The new astronaut suit for Orion has been in work for a number of years; components are now under test. The Program has recently completed some "human system" testing to ensure safe egress from the Orion capsule to the ground.

With regard to EM-2 mission planning, the plan is for two low-Earth orbits, primarily for immediate system checkout, keeping Orion close to the Earth so that it could be returned in a matter of hours should there be any difficulties. Orion will then shift to high-Earth orbit, which includes an apogee burn; however, for a considerable portion of the orbit, Orion will still be close to Earth, allowing for system checkout and rapid return if a problem should develop. Subsequently, the plan is for a trans-lunar injection burn and a four-day transit around the Moon. This transit will include passage about 5000 miles beyond the dark side of Moon—farther into space than any human has ever traveled before.

In summary, all integrated avionics and software are now moving from build to integrated test, validation and verification of STA testing is underway at many locations, and the launch equipment test facility is making progress with the umbilicals. The EGS software remains on the critical path and is a watch item. Orion is making excellent progress. The ESM is a critical path item. The delivery date is mid-2018 and is currently holding. On the core stage, the welding is done. The green run delivery to SSC is on the critical path and is currently doing well. EM-2 ECLSS testing is underway, and the mission is planned. With regard to the budget, the Fiscal Year (FY)17-FY19 budgets were consistent with NASA's plans, although the out-year funding does remain a watch item.

Dr. Sanders noted that while the focus of the presentations was on EM-1 progress, the Panel's discussions with the Program did include progress and preparations for EM-2. The ASAP continues to urge NASA to look for prudent and safe ways to shorten the timeframe between flight operations to mitigate the erosion of launch operations experience.

Dr. Magnus made an observation and a note of caution: the Panel has heard from both the CCP and the ESD programs, which collectively represent three different vehicle systems that will attempt to launch in a close timeframe. Before that, there will be a "wall" of verification and qualification processes where a finite number of NASA people will be involved. She encouraged the NASA and contractor community to be aware of this potential "bottleneck" and contemplate how to accomplish the work in a productive, thoughtful way to ensure the proper verification of all three vehicles. Across those programs, there will be a considerable amount of pressure on the system to expedite the work to meet the schedules. The ASAP will watch this very carefully.

Dr. Sanders agreed with Dr. Magnus's point. She noted that it is normal for validation and verification to come toward the end of a program, but this needs to be metered and addressed with some thought.

Lunar Orbiting Platform – Gateway

Dr. Magnus continued with a report on the Panel's engagement with Mr. Mark Geyer (Deputy Associate Administrator for Technical, Human Exploration and Operations Mission Directorate at NASA Headquarters) on the Lunar Orbiting Platform (LOP)-Gateway. She noted that the Panel had been briefed previously on a conceptual formulation of the Deep Space Gateway as a concept. The Gateway, now renamed the LOP-Gateway, has been formally incorporated into a larger, comprehensive exploration strategy with the release of the President's FY19 budget. The Panel was pleased to see some continuity from previous plans with respect to the continued development of the power propulsion module as the proposed first piece of LOP-Gateway infrastructure to be deployed in 2022. Since this capability was under development as part of the now-cancelled Asteroid Redirect Mission (ARM) Program, the 2022 date was felt to be a realistic estimate. Other elements being proposed for deployment include a habitation module and an airlock, which will follow in subsequent years. The Orion vehicle will act as a tug for the various elements, simplifying operations by negating the requirement for rendezvous and docking capabilities. The exploration strategy NASA is now pursuing puts more emphasis on the Moon, including expeditions, both robotic and eventually human, to the lunar surface as well as activities in cislunar space. The strategy also emphasizes the importance of merging science, exploration, human, and robotic activities into an integrated approach; plans are currently under development to do just that. As the cadence of missions and objectives take shape, the Panel will be interested in understanding what objectives will be identified for execution, either on the Moon or in cislunar space, that will mitigate risk associated with the horizon goal of going to Mars. The Panel will also be interested in understanding how the roles and responsibilities associated with private companies and international partners will integrate to create a safe, reliable, and comprehensive exploration system in cislunar space. Dr. Magnus indicated that this particular strategy has not matured enough to allow the Panel to make an assessment at this time; however, it will be on the Panel's radar as plans develop and mature.

Enterprise Protection Program (EPP) and Cyber Security

CAPT Christopher Saindon reviewed the Panel's discussions with Mr. Raynor Taylor, Principal Advisor of the NASA EPP, and Mr. Mike Witt, Associate Chief Information Officer (CIO) for Information Technology Security, both at NASA Headquarters. The discussion with Mr. Taylor focused on three key areas: (1) progress on the formal charter of the EPP, including the Principal Advisor role for enterprise protection and the EPP in the NASA Procedural Requirement (NPR) Organizational Document (NPR 1000.3); (2) overall progress towards establishing a more well defined framework for enterprise protection governance within the Agency; and (3) some recent examples of enterprise protection efforts and a couple of "good news stories" that resulted from collaborative efforts across the Agency.

CAPT Saindon indicated that the Panel believes that Mr. Taylor has started down the right path with regard to identifying more clarity in the EPP process but is having some trouble understanding exactly how that process, as it is defined, will actually function. For example, how will it have the capability to bring "risk problems" to key decision makers? It is also not clear how mitigation solutions will flow "back into the field" in a manner that reduces enterprise risk in a proactive manner. Enterprise governance—specifically, how the designated risk management decision authorities across NASA work in concert to manage integrated protection problems, responsibility, and accountability—is one of several areas the Panel feels needs more clarification and structure.

Mr. Taylor shared a recent example of a success story within the enterprise protection arena, which highlighted the potential promise of the EPP. That success story involved timely detection of a low-level threat that kick-started a subsequent effort to develop an effective risk-mitigation policy for the Agency. Although this was a relatively simple issue to address, this "good news story" served as an example that demonstrated the value of an integrated enterprise protection approach. The Panel will watch with interest how this particular policy is developed and approved and how the various NASA entities implement that policy to reduce risk.

Mr. Mike Witt provided an update on cyber security, a huge subset of enterprise protection. The cyber team admittedly owns a large piece of the enterprise protection area of responsibility: the traditional computer network infrastructure areas that naturally come to mind when one considers enterprise protection. They are clearly examining the enterprise threat through the lens of the CIO and are working in response to the direction of the recent Executive Order (EO) and required Office of Management and Budget (OMB) follow-up actions in the information technology (IT) realm. Their scope of responsibility involves identifying and mitigating risk not only in the traditional institutional/corporate IT systems, but also in the physical (plant and industrial control systems) and mission system networks. As the Panel learned and discussed at previous meetings, they have essentially divided their trade space into three distinct security layers—physical, corporate, and mission—and have been doing well addressing threats in these three areas with what they describe as an "Identify-Protect-Detect-Respond-Recover" strategy, which is used in the DoD. The Cyber Security Tiger Team, established as a result of the EO and OMB assessments, appears to be proceeding quite well. The Panel has seen excellent progress in this area and feels that the cyber security piece of enterprise protection is on a solid, positive vector.

CAPT Saindon returned to the overall enterprise protection discussion. In accordance with the draft charter, the Enterprise Protection Board (EPB) is intended to provide cross-agency communication, coordination, and decision-making on national security, cyber security, space and aeronautical system protection, ground system protection, technology protection, and institutional and infrastructure protection. Additionally, the EPP Office is charged with scheduling meetings, driving agendas/administrative work for the Agency-wide Board, creating NASA-wide NPR/NASA Interim Directive documentation, following operational intelligence, making recommendations for threat mitigation, driving integrated assessments between members of the EPB, and representing NASA with the DoD space community. However, the EPP has only two full-time people assigned to do what is clearly a monumental task. CAPT Saindon noted that after seeing the draft charter for the EPB, the Panel believes that the EPP is under-resourced. If there is any expectation for the EPP to advance, the Agency will need to find a way to allocate more resources to achieve the desired effect.

With the basic framework of the EPP and the EPB established, the Panel will look for indications that the EPP continues to work to flesh out greater granularity on enterprise protection governance—to include policy development, leverage of existing boards, practices, and integration of risk management decision makers spread across the Agency. The Panel is interested in the details of the enterprise protection governance process that drives processes from threat detection, to assessment, to decision making, down to execution of protective measures once threats are detected.

Technical Authority (TA)

CAPT Saindon continued his report on the TA topic. Mr. Ralph Roe, NASA Chief Engineer, led an excellent review and discussion on the TA process. TA was created to establish a more robust system of checks and balances and to provide independent oversight of programs in support of safety and mission success. It balances against traditional Program Authority and is funded independently of the program it supports. TA is delegated downward from the Administrator.

The genesis of the TA process stems from the Columbia Accident Investigation Board's (CAIB's) recommendation that NASA should establish two separate Agency authorities to support this "check and balance system." It is designed to enable sound risk decision making, provide a "healthy tension," and an independent view of program and project activities.

There have been some minor changes since the CAIB recommendation. Programmatic Authority remains with the traditional Mission Directorate/Program/Project chain of command, which remains responsible for the overall safe conduct and successful outcome of the project in conformance with all governing NASA requirements. Institutional Technical Authority includes oversight roles in three specific areas in a given program: Chief Safety and Mission Assurance TA, Chief Engineer TA, and Chief Health and Medical Officer TA. Individuals in these TA positions serve as members of various working groups within the program and function side-by side with the program. They assist the program with making informed risk decisions and ensuring that any requests for deviations or waiver requests are submitted to the appropriate level of TA for adjudication.

The Panel was interested in how the TA process has been working since inception and minor changes in 2014. Mr. Roe provided specific recent examples of the dissenting opinion process and gave the Panel more insight into the timelines to fully adjudicate those. Mr. Roe and the Panel spent some time discussing the "velocity of decision making" in this regard.

Until now, the Agency has been primarily focused on the Design, Development, Test and Evaluation (DDT&E) part of the system life-cycle in its major flight programs that are underway. In this part of a program's life-cycle, the velocity of decision making can be less of a driver than it may need to be in the future as NASA returns to manned flight. There is naturally greater decision space in the DDT&E phase. In some cases that were examined, dissenting opinions took longer than desired to adjudicate.

Another aspect that is directly related to the velocity of decision making during the dissenting opinion process is determining the proper decision-making level. In other words, how far up the chain does the dissenting opinion need to go before risk is accepted? For example, does every dissenting opinion need to go to the highest levels of the Agency for adjudication? The Panel believes that this aspect of the process, i.e., how far up the chain a dissenting opinion truly needs to go, should be carefully considered. Adjudication should occur at the appropriate TA level, perhaps within the program itself where appropriate.

Mr. Roe and the Panel also discussed the difference between "individual" dissenting opinions and "organizational" dissenting opinions. For example, organizational dissenting opinion would be a disagreement on a risk decision between program engineering and program management. In that case, it would clearly be appropriate to elevate that decision to higher TA for adjudication. Currently, it appears that both individual and organizational dissenting opinions are treated in a similar manner, with some individual dissenting opinions being elevated to very senior NASA leadership for adjudication. The Panel believes that in most cases, individual dissenting opinions could and should be addressed more effectively and efficiently at the program TA level. Every dissenting opinion does not require final adjudication by the Chief Engineer, Chief Safety Officer, or NASA Administrator.

One final point CAPT Saindon made is that the policy on final decision documentation should be clear regarding who is making the risk decision. The final risk decision should be documented and accepted by a specific individual rather than a panel or committee. In the past, the Panel had seen evidence that decisions were being accepted by consensus panel or board rather than a designated decision maker or TA. The Panel believes this issue has been addressed and will continue to seek to validate that during its future fact-finding and insight visits.

As the Agency moves closer to flying human-rated hardware, both in the CCP and the SLS, there will be a great deal of work to accomplish (such as validation and verification, hazard closures, risk acceptance, etc.). This will naturally be coupled with additional schedule pressure. The Panel will be paying particularly close attention to how the TA process continues to function as NASA approaches return to manned flight.

Dr. Nield added that some of those issues are very important, and the ASAP believes they deserve attention; specifically, TA and the appropriate levels and how dissent is being handled. The Panel heard a number of examples about how long it has been taking to resolve issues dealing with dissenting opinions. In the design process, a little more extra time can be afforded. As NASA gets closer to operations, it will be important for the Agency to have a more appropriate decision velocity. The Panel would like to see NASA senior leadership address this in a more proactive way—look at the metrics and consider possible mitigating steps that could be taken to ensure an understanding by the entire workforce in terms of what the culture needs to be: full and open communications and processes to have dissenting opinions voiced, but a process to get to a final decision in a reasonable length of time. NASA has done a good job of trying to document how things should work, but now leadership needs to ensure those processes are followed in an appropriate way.

Dr. Magnus agreed with Dr. Nield. She commented that there is a fine line—NASA needs to have a culture that is comfortable voicing dissenting opinions but needs to have processes to deal with them so that everything doesn't grind to a halt. This is the leadership challenge.

Office of Safety and Mission Assurance (OSMA) Update

Mr. David West reported on the discussions with Mr. Terry Wilcutt, Chief, OSMA. He noted that in a previous year, the Panel had visited the NASA Safety Center (NSC) and inquired about audits – how often they were done and what kinds of subjects and areas they covered. During that previous visit, the Panel learned that audits were done once every four years, and they didn't cover system safety at all. Following that visit, the ASAP made a recommendation regarding audits and system safety; in response to that recommendation, the OSMA at NASA Headquarters agreed to perform a System Safety Capability Assessment. Dr. Homayoon Dezfouli, a NASA System Safety Technical Fellow in the OSMA, shared with the Panel the current status of the assessment. The System Safety Capability Assessment included a clear articulation of the purpose for doing the assessment and the value to be gained. The OSMA developed a survey questionnaire and distributed it to three targeted audiences: the practitioners of system safety, the Program Managers who benefit from it, and the Technical Authorities who assist with it. The Panel learned that the plan forward includes collation and analysis of survey results, more in-depth investigations, and focused audits at selected centers. Based on what is learned, further recommendations will be made to improve the practice of system safety across NASA. At this point, with the information provided, the Panel is not sure that this survey approach will get to the heart of the issue. The Panel is also concerned about what appears to be a very small sample size. OSMA is considering extending the deadline and obtaining more survey responses. The Panel will look at this issue more closely at its next meeting when it will know more about the actual survey questions and the results obtained. The Panel also plans to continue to follow up and inquire about the practice of system safety during future visits to Centers.

Dr. Sanders offered an opportunity to the public to make any comments. Dr. Morehead expressed appreciation for the reading of his letter and indicated that he has an interest in the VIIP that comes with microgravity exposure. He noted that the Russians have a negative pressure machine on the ISS and inquired whether the ASAP could provide any specifics on the machine or its use, e.g., Scott Kelly was supposed to have used it on his mission. Dr. Sanders responded that the Panel did not have any information at this time; however, Dr. Magnus suggested contacting the JSC Flight Clinic. She indicated that there is an engaged, rigorous community trying to study this problem, and they could probably direct Dr. Morehead to the appropriate people who could inform him on the current status or the research.

There were no other comments, and Dr. Sanders adjourned the meeting at 10:50 am CST.

Telecon Attendees:

Ali Sanford	Commercial Space Flight Federation
Alison Sheridan	Boeing
Bill Hill	NASA Headquarters
Dan Beck	Boeing
Daniel Wentz	[not affiliated]
Diane Rausch	NASA Headquarters
Eva Behrend	SpaceX
Harry Morehead	[citizen]
James Dean	Florida Today
Jeff Foust	Space News
Joe Miller	NO
Kristin Van Wychen	US GAO
Linda Karanian	supporting Aerojet Rocket
Lyn Loewy	NASA Headquarters
Marcia Smith	Space Policy Online.com
Maribeth Davis	Boeing
Michelle Green	Commercial Crew Program
Michelle Parker	NASA
Pasolum	[not affiliated]
Phil Pudder	NASA
Rebecca Regan	Boeing
Shawn Pitt	SpaceX
Stephen Clark	Space Flight Now
Tabitha Thompson	NASA
William Readdy	Stafford Task Force International Space Station

March 1, 2018 Harry S. Morehead Jr., M.D.

Dear Ladies and Gentlemen of the Panel;

Thank you for the opportunity to present this letter. A longer paper with additional references and figures accompanies it for your convenience.

I have two reasons for this presentation. One concerns a particular microgravity (MG) illness outlined below. The second is to urge NASA to consider continuous artificial gravity (AG) for missions beyond Earth orbit as the *only* means of avoiding all MG related illnesses.

I became interested in MG disorders after my retirement in 2015. The disorder that caught my interest is referred to as "Visual impairment/ intracranial pressure risk" or "Visual Impairment and Intracranial Pressure" syndrome (VIIP). It has been studied thoroughly since its discovery, and as you are aware, is thought to be primarily secondary to abnormal fluid dynamics in the head associated with MG.

The connection has also been made between this MG disorder and a terrestrial illness that I have treated in my neurology practice, termed Idiopathic Intracranial Hypertension (IIH), or Pseudotumor Cerebri Syndrome. Clinically and radiographically, VIIP and IIH appear to be virtually the same illness[1]. Obesity is definitely a risk factor for IIH, and oral contraceptives and certain antibiotics have a strong association. Many other agents have been suspected as being causative; in at least one textbook MG has already been added to that list[2].

Treatment of IIH involves medication, repeat lumbar punctures, and rarely surgical shunting[2]. The main risk to leaving the disorder untreated is impairment of vision *that may become permanent*.

VIIP along with bone mineral loss and perhaps other MG related illnesses do not always resolve on return to Earth. One survey of 300 astronauts experiencing three to six months of MG noted a high percentage of visual complaints, some lasting years after the mission ended[3]. In another study one astronaut underwent a lumbar puncture from clinical concerns and was demonstrated to have elevated CSF pressure 453 days after returning to Earth[1].

Some of the methods being considered to thwart VIIP and other MG related disorders include intermittent short arm centrifugation, lower body negative pressure, and bicycling inside a spacecraft fuselage. But would such devices prevent other known complications of MG such as immune system changes, increased virulence of certain organisms, or pooling of CO_2? And ironically the bungee exercises designed to protect the musculoskeletal and cardiovascular systems during prolonged spaceflight not only have *not* been entirely successful, but may be an additional risk factor for VIIP.

The one solution that solves all the problems is to live, work, eat and sleep in AG.

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Utilizing AG would almost certainly entail revolving some portion of the spacecraft around a central axis. Concerns have been raised regarding such a system, mostly regarding *tolerance* and *cost*.

Living and work pods on retractable arms is one possible design. The human labyrinthine system has been proven to be quite adaptable, and I think could tolerate this feature. This is discussed in more detail in the accompanying paper.

If more of the world's nations would contribute money and resources, cost might be less of a restriction. In addition there are at least two companies that are determined to mine asteroids for water and minerals in order to build components of spacecraft in orbit. This would provide fuel and avoid some heavy lifting from the Earth's surface that is so expensive.

In summary, I am urging NASA to consider full-time AG at near 1g for missions to Mars and beyond as the only reliable prevention for all the MG related disorders. Our present experience is limited to a three to six month exposure to MG primarily, with only a few flying longer missions. I fear that a multiple year exposure in MG would result in unexpected morbidity or worse.

More immediately: in regard to VIIP, I strongly recommend that NASA demand crew members that continue to have visual disturbances or headaches one month after completion of a mission be evaluated for IIH, if this is not already protocol. The presence of papilledema at the end of a mission would demand immediate evaluation. If obesity is not present (must be rare in the astronaut program) an elevation of CSF pressure *over 200mm of* H_2O should be treated as IIH.

Thank you very much.

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To: NASA Aerospace Safety Advisory Panel Harry S. Morehead Jr., M.D.
March 1, 2018 Meeting

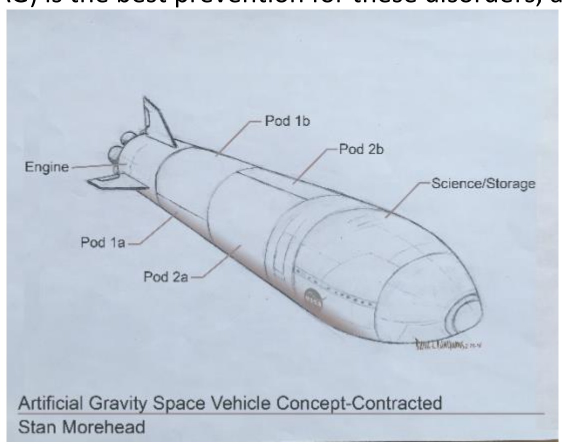
Dear Ladies and Gentlemen of the Panel;

I am grateful to be able to pass along some thoughts about astronaut safety communicated in the short letter to be read today. This paper supplies more detail and references as needed.

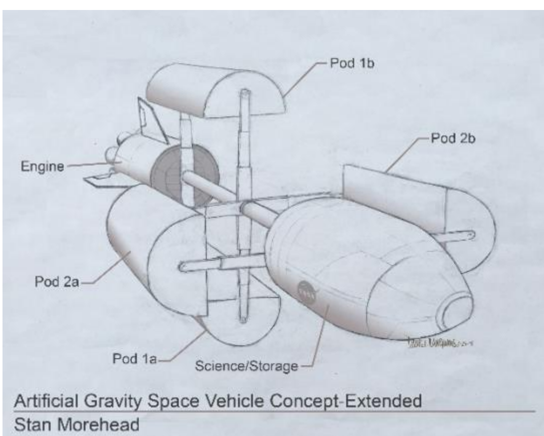
My points are two. The first is that some microgravity related illnesses may become chronic after returning to Earth. The second is to urge NASA to consider continuous artificial gravity for missions beyond Earth orbit as the *only* means of avoiding all microgravity related illnesses.

In this paper we will review a few of the more serious microgravity (MG) related illnesses, including one that is strikingly similar to a terrestrial illness I have treated in my neurology practice.

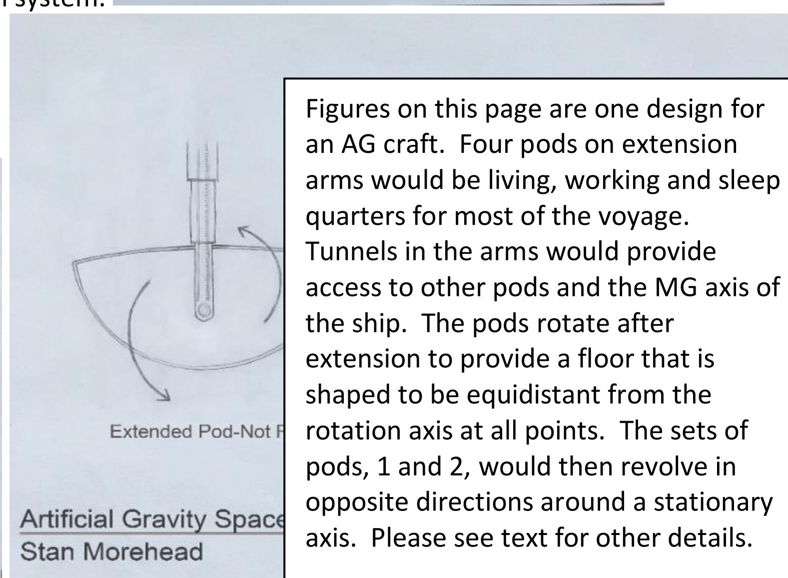
We will then try to demonstrate *why* artificial gravity (AG) is the best prevention for these disorders, and is a necessity for missions beyond the Earth-Moon system.



Artificial Gravity Space Vehicle Concept-Contracted
Stan Morehead



Artificial Gravity Space Vehicle Concept-Extended
Stan Morehead



Artificial Gravity Space
Stan Morehead

Figures on this page are one design for an AG craft. Four pods on extension arms would be living, working and sleep quarters for most of the voyage. Tunnels in the arms would provide access to other pods and the MG axis of the ship. The pods rotate after extension to provide a floor that is shaped to be equidistant from the rotation axis at all points. The sets of pods, 1 and 2, would then revolve in opposite directions around a stationary axis. Please see text for other details.

While reviewing NASA and other websites with science fiction writing
“Visual impairment/ intracranial pressure risk”, also called “Visual Imp
syndrome” (VIIP). This disorder can be manifest in astronauts exposed to MG for three months or longer, with symptoms of visual impairment and headaches[1]. VIIP has been identified as virtually identical to a terrestrial illness, Idiopathic Intracranial Hypertension (IIH), also called Pseudotumor Cerebri syndrome, in its clinical and radiographic features of the orbits and brain[2]. Detailed (3Tesla) MRI studies of astronauts spending three to six

months in MG show kinking and other abnormalities of the optic nerves postulated as secondary to increased intracranial pressure and responsible for at least some of the visual complaints[2].

The IIH adult population differs from VIIP in that females>males are affected. Obesity is definitely a risk factor for IIH, and oral contraceptives and certain antibiotics have a strong association. Many other agents have been suspected as being causative; in at least one textbook MG has already been added to that list[3]. Treatment of IIH involves medication, repeat lumbar punctures, and rarely surgical shunting[3]. As noted in the letter, permanent visual loss is a complication of untreated IIH.

VIIP symptoms may not resolve on completion of exposure to MG. Visual symptoms that last years are a well-documented complication, and a select group of astronauts will have optic disc edema and elevated spinal fluid pressure months after the mission[1]. In this same study a questionnaire was given to 300 other astronauts exposed to MG for 3 to 6 months but not examined as part of the paper. A significant number indicated that they suffered visual complaints during the MG environment, with 60 percent of those in space for six months recording difficulty. Some crew members reported residual visual changes still present years after returning from space[1]. As noted in the letter, one astronaut in the MRI study had clinical findings and an elevated CSF pressure 453 days after completion of the mission[2].

Other factors on a space mission are possible suspects as a cause of eye changes and pressure on the brain, such as a high sodium diet, resistive exercises and higher than normal ambient CO_2 levels[4]. Earth-bound research, however, provides supporting evidence that the findings considered here are related to MG[5].

MG is associated with changes in the heart, thought to be secondary to reduced work load. Loss of muscle bulk and a drop in stroke volume and diastolic blood pressure are associated findings[6]. Thus far this has not been life threatening, but it is possible that a multi-year trip in MG could leave the heart dangerously weak.

Loss of bone mineralization in MG varies remarkably from individual to individual, and can be significant. An early study on astronauts spending 4 to 6 months in the ISS found that while

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some crew members suffered only minor changes, others “incurred losses equivalent to one-half the bone mineral they would lose in a lifetime of normal aging.”[7]

Some of the calcium lost from bone can collect as renal stones, a painful and potentially hazardous complication that would be difficult to deal with on an extended space mission.

The bungee work does not appear to be entirely effective in preventing loss of bone strength. Scott Kelly remarked about knowing two astronauts who developed hip fractures after participating in long term space missions[8]. Recovery of bone mineral density consistently takes longer than the duration of the mission, and some crew members may have permanent deficits despite the daily in-flight hours of regular exercise[9].

There are at least three other health considerations influenced by microgravity that do not get as much publicity as others, but which may have serious consequences on an extended space mission. The first two I will describe are not intuitive.

Extensive research on the effects of MG on microorganisms finds that some pathogens gain virulence in microgravity conditions. Forms of bacterial growth called biofilms, which contribute to a number of chronic diseases, develop more easily[10]. Predictably, there has been documented transfer of pathogenic organisms between crew members during a space flight [11, 12].

The second concern is the observed impairment of the human immune system during space flights. Multiple factors are probably involved, including stress, nutrition, and radiation, but research has shown that MG plays a part[13].

Finally, gravity pulls dust and other particulate matter to the floor. In microgravity those particles float around producing a possible risk to the lungs and mucous membranes until filtered out by the ventilation system. In one famous case, the particulate matter was feces that escaped the zero g toilet. (It was eventually re-captured after a couple of weeks.)

Numerous therapies for the individual problems have been suggested. Osteoporosis medication to prevent bone loss is one example; short arm centrifugation and centrifugation by cycling have been proposed[14]. Lower body

negative pressure (LBNP) has been considered for the brain and eye complications of MG, and has been tested by the Russians on the ISS but I could not find how effective it has been. I suspect that the duration and frequency of treatment required for these modalities to be effective in preventing the MG illness of focus has not been worked out yet, and not all have been tested in space.
I believe the key to dealing with all the MG related ailments is simple; prevention with full time AG. It is the only modality that will impact *all* of them, and is thoroughly time tested.

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There is now increased interest in artificial gravity, but actual trials in space have been few and most proposals are for intermittent and/or partial gravity, such as the Nautilus X system.
Our understanding of the science of gravity limits our ability to generate AG in space to moving portions of the spacecraft. The easiest to visualize is some type of compartment that rotates around a central axis to generate an apparent acceleration perceived as gravity on the "floor" of the living or work space.
The main objections to utilization of a rotating spacecraft to produce AG are three as I understand them;

1. It hasn't been proven to prevent MG related disorders.
2. Effects on the labyrinthine system will be intolerable in this closed rotating system.
3. It will be too expensive, especially considering the heavy lifting required to get all the parts into orbit.

In regards to the first objection, Einstein would probably agree that proof of effectiveness is unnecessary. Earth gravity at sea level is simply an acceleration of approximately 9.81 meters/sec^2 and the human body would be unable to differentiate the source of such acceleration; whether gravitational pull, an elevator attached to a rocket, or a centripetal/centrifugal system as in a rotating spacecraft. I rest my case here; the source of this acceleration should make no difference.
In regard to effects on the labyrinthine system, we know that the human labyrinth and brain connections have been shown to be very adaptable. Developing "sea legs" is an example.
The "comfort zone" for short radius centrifuges was once thought to be 4-6 rpm, and it was tolerated best if the head was held still. Higher rotation speeds on earth bound systems produced disorienting sensations of movement and motion sickness especially if the head were turned back and forth, leading to the conclusion that the use of rotating systems to produce AG would be limited.
However, as far back as 2002, more vigorous AG studies have found remarkable adaptability up to 23 rpm in a short-radius centrifuge, with a daily, gradual attenuation of symptoms evoked by head turning as tolerance developed[15].
Certainly in a rotating system with a radius of ten meters, an astronaut's head would be moving more slowly than his feet on the "floor" of the system, but that is similar to the movement one will experience on a playground swing. And most of those have a chain length much shorter than ten meters.

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Ground based centrifuge systems are presently used in astronaut training. The astronaut may experience the centrifuge as merely an accelerating machine rather than a spinning one, as attested to by astronaut Tim Peake[16]. In this same publication Mr. Peake describes being immune to labyrinthine dysfunction after adapting to the ISS, including experimenting with head turning while being spun briskly.
The author has had a centrifuge experience on a carnival ride, called the Round-Up. In this centrifuge-type ride, a spinning cylinder holds riders to the wall against gravity. Noted was how difficult it was to lift one's head off the support at the maximum rotation velocity, without labyrinthine symptoms.
Concerns have been voiced that an astronaut's movement opposite the direction of rotation would lessen the AG effect, leading to disorientation effects on the labyrinthine system. If the centrifuge system of a ship has a ten meter radius, it would generate 1g at the floor level if rotating at about 9.5 rpm. The speed of the "floor" would be over twenty miles an hour, faster than most people can run. I would propose that the reduction of the AG effect due to moving against the rotation direction would be minor, and adaptation should take place easily.

An Earth-bound test of tolerance to this type of system might be possible in a low speed centrifuge with 7 to 9 meter arms. Subjects could be tested in the sitting or standing position, and could bend over or turn the head, movements that are predicted to be symptomatic. This type of centrifuge might also help with acclimatization. And good news about the cost of a spacecraft with such an AG system! A portion of the ship is already in space! There are at least two companies with serious intentions of mining near Earth asteroids[17, 18]. Plans include printing spacecraft parts in orbit, thus avoiding the expense of heavy lifting from the Earth. Water-containing asteroids could also supply oxygen and hydrogen fuel.

Additionally, at present there are at least 15 countries contributing money and effort to the ISS, and astronauts from 18 have visited the station[19]. New partners should be encouraged to come on board to share the cost of missions beyond Earth orbit.

I have placed figures on the first page as one proposal of what a long duration mission craft could resemble. The pod arms are retractable in emergencies or when aerobraking, and would need micrometeorite protection especially on the leading surfaces. Tunnels through the arms connect to the "axis" of the ship which would contain the engine in the stern and forward compartments for storage, instrumentation, and MG science studies.

Waking and sleeping hours would be expected to be near Earth gravity, lessening the time needed for daily bungee exercises. The level of 1g above the "floor" of the pod could be adjusted by changing the speed of pod rotation. For instance, for daytime activities 1g could be at the

chest level. At night, the rotation could be slowed slightly to bring 1g down to bed level. The "floor" would need a shallow curve to be equidistant from the axis of rotation at all points so that the apparent vector of "gravity" is everywhere perpendicular to this floor. Moving into the storage area or to other pods through the tunnels would probably evoke some labyrinthine symptoms, which would be expected to be brief.

In summary, prolonged exposure to a MG environment has been proven to have a negative impact on astronaut health ranging from minor problems to those potentially severe and permanent. Our experience with humans in MG only covers what would develop in a year or less, and at least two of the disorders identified can become chronic in some individuals. A multi-year journey could bring to light greatly increased and even new, hitherto unexpected complications.

I believe AG can be safely utilized despite the increased cost, and that it *must* be an important part of multi-year missions as the only reliable prevention of microgravity disease.

Thank you.

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