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Mr. Chairman and members of the subcommittee, I thank you for inviting me here to testify today. I am Noel Hinners, an independent consultant on aerospace, working primarily with NASA and several of its contractor community. Starting in 1963, I have had the incredible privilege of participating in the Nation's human and robotic space program, first on the science associated with Apollo and subsequently as NASA's Associate Administrator for Space Science (1974 - 1979) and Director of Goddard Space Flight Center (1982 - 1987). Between those two careers, I saw firsthand the public impact of our space and aeronautics programs as Director of the Smithsonian National Air and Space Museum (1979 - 1982) and the inspirational influence on students in association with my activity at the University of Colorado's Laboratory for Atmospheric and Space Physics and its Aerospace Engineering Sciences Department. A post-NASA career with Lockheed Martin's Civil Space taught me the importance, intricacies and perspective of working with NASA's contractor community. In aggregate, these experiences molded me into an advocate of both human and robotic space exploration and provided the foundation for a belief that a synergistic collaboration between the historically two cultures is in the Nation's best interest.

I will now address the specific questions you posed in your invitation letter requesting that I testify before you today.

Management of Science in the Vision for Space Exploration

You asked that I elaborate on the management recommendations in *The Scientific Context for the Exploration of the Moon* that might optimize the scientific return of the Vision for Space Exploration (VSE) and to discuss the lessons learned from the Apollo program. Before going into the specifics, I'd like first to set the context for the recommendations.

The management recommendations are based largely upon the third report issued in the 1990's by the NRC Space Studies Board Committee on Human Exploration (CHEX), a committee that I chaired. The impetus for the CHEX study was the short-lived Space Exploration Initiative (SEI) of 1989 and although the SEI did not survive we felt that it was only a matter of time before a reincarnation would occur. We thus took advantage of the "lull" and produced our study. The recent re-look convinces me that the conclusions remain valid and do indeed apply to the VSE.

Our overall intent was to better define the role of science in human space flight and to reduce the historical friction existing between the "two cultures" of robotic and human space flight. It was our conviction that by so doing there would be improvement in the science return from and contributions to human space exploration. The management report was not initially envisioned; rather it was an outgrowth of our two earlier studies on science prerequisites for and science enabled by human exploration during which it became apparent that the quality of the science accomplished on human space flight programs was in large part a function of how it was organized and implemented. Thus we (qualitatively) assessed the science accomplished on Apollo, Apollo Soyuz Test Project (ASTP), Skylab and Shuttle/Spacelab and correlated our findings with the management structures and funding sources. The overall conclusion was that the Apollo Program, after many fits and starts in the early to mid-60's, evolved an excellent model for productively integrating science requirements and implementation into human space flight and that deviations from that model contributed to a lessening of the science quality and in the overall satisfaction of the science community.

It is instructive to elucidate some key aspects of the Apollo model to aid in assessing the applicability to the VSE. Those include the organizational elements and funding. Human space flight in Apollo was the purview of the Office of Manned Space Flight (OMSF) under Dr. George Mueller. It in turn had an experienced, technically and managerially strong Apollo Program Office at Headquarters, led through Apollo 11 by Apollo Program Director Gen. Sam Phillips and subsequently by Dr. Rocco Petrone. The Apollo Program Office included an Apollo Lunar Exploration Office which incorporated a novel management approach: the science and engineering staff of the Apollo Lunar Exploration Office reported jointly to the Office of Space Science and Applications (OSSA) and to the OMSF. Science goals, objectives, prioritization and requirements, science and scientist selection and analysis of data were the prerogative of OSSA and conformed to its established policies and procedures. Mission implementation, including engineering and operations, was the responsibility of the OMSF. This arrangement proved on balance to be congenial and cooperative. It does not mean that there were no disagreements or frustrations but there were clear paths to issue resolution with no ambiguity on decision authority: Dr. Mueller. He was advised by his Manned Space Flight Experiments Board which dealt with science, technology and engineering experiments and which included representatives from the science and technology organizations. Dr. Mueller also had a Science and Technology Advisory Committee led by Dr. Charles Townes that provided advice directly to him on science in the Apollo program. In Dr. Mueller's words: "I set up the Science and Technology Advisory Committee to be sure that we incorporated the maximum and the best possible science in the Apollo program."

Many were the vigorous discussions of what to do on the Moon, how to do it and where to go. The mission implementation was largely through the Johnson Space Center. A key success element in the view of CHEX was the establishment at JSC of a science division headed by an experienced scientist. This gave an in-house voice to science and provided expert liaison with the OSSA and the external science community. This was most effectively augmented by the establishment of the geographically adjacent Lunar Science Institute (now the Lunar and Planetary Institute). These two organizational elements provided a degree of science ownership and buy-in in an otherwise engineering dominated culture.

Returning now to the report, the first management recommendation is:

NASA should increase the potential to successfully accomplish science in the VSE by (1) developing an integrated human/robotic science strategy,(2) clearly stating where science fits in the Exploration Systems Mission Directorate's (ESMD's) goals and priorities, and (3) establishing a science office embedded in the ESMD to plan and implement science in the VSE. Following the Apollo model, such an office should report jointly to the Science Mission Directorate and the ESMD, with the science office controlling the proven end-to-end science process.

There is a process underway in NASA to develop such an integrated human/robotic science strategy. The Lunar Reconnaissance Orbiter, scheduled for launch late this year, has finally had its management approach resolved with ESMD responsible for the first year of operations and data collection needed to satisfy their requirements. LRO will then be transferred to SMD for continued use as a science mission. Among numerous collaborative efforts within NASA there is an ESMD/SMD Outpost Science and Exploration Working Group. The recently established NASA Lunar Science Institute is jointly supported by SMD and ESMD. Further, the Lunar Exploration Analysis Group brings together both internal and external scientists into ESMD/SMD planning. It is groups such as these that will help clarify the relative roles of lunar science and exploration preparation.

An office equivalent to the Apollo Lunar Exploration Office does not exist within ESMD. I recognize that we are over a decade away from implementation of the human element of lunar exploration. However, establishing the nucleus of such an office now could do much to establish the path, clarify processes and give further impetus to the integration of science into exploration. It would solidify a management structure that just might survive the all-to-frequent changes in leadership at the AA level in NASA.

Recommendation 2 addresses the need to initiate early the process of landing site selection and mission planning. This does not mean identifying now the specific sites where crews will land but should include developing criteria that can lead to optimization of the science in the context of the overall exploration goals and priorities. Such will be significantly different for sortie missions and an outpost. Sortie missions, to the degree that they occur, will be largely science-driven while an outpost will be driven as much or more so by exploration preparation. Site selection will be an ongoing process with results influenced greatly by data yet to be acquired (e.g., is there really accessible water in the polar regions and is In Situ Resource Utilization a practical objective?). It is possible that the requirements for "Exploration Preparation," a major VSE theme, can be met by one of a large number of lunar site locations and that the science optimization can play a prime role in which specific location is finally selected. The considerations for an outpost location should include the potential to serve as a servicing and laboratory node for robotic exploration.

Recommendation 3 relates to the need to identify and develop advanced technology and instrumentation. This recognizes that there does not exist an inventory of applicable technology and capability. This results from what will be, by 2019, close to a 50 year gap in human and most robotic lunar exploration. It also derives from a much changed capability from the days of Apollo and envisions a more collaborative robotic/human effort. For example, much of the Apollo lunar surface traverse time was used in going to locations selected on the basis of relatively low resolution, panchromatic photography. Today, through the use of instrumentation such as on LRO and the use of Mars Exploration Rover (MER) type rovers, one could identify in detail locations worthy of detailed follow-up by astronauts. As a thought experiment, think of the MER sites on Mars and how efficiently we could explore those sites with astronauts. Similarly, emplacement of some geophysical instrumentation can be done robotically rather than primarily by Apollo ALSEP-type deployments; indeed, that is the basis of the recent SMD announcement of initiation of two elements of a robotically emplaced geophysical network. If a pressurized crewed rover is developed, the potential to use it in a robotic mode when not crewed can greatly extend the science utility of either an outpost or sortie missions.

Our last recommendation, 4, urges a thorough review and subsequent upgrading of the capability to collect, preserve, analyze and curate lunar samples both on the Moon and upon return of the samples to Earth. This is based on the fact that the major science return from Apollo was in the immediate and ongoing analyses of the samples, an activity that continues today. The Lunar Curatorial Facility at JSC is the key to this. While it has maintained a degree of modernity through the ongoing curation of Apollo samples, meteorites, cosmic dust and solar wind, it is not prepared to handle the "next generation" of acquired lunar samples. An outpost on the Moon will add further challenge in meeting the need for conducting preliminary analyses and curation on the Moon, both to enable real-time feedback into the exploration and to "high-grade" samples for return to Earth.

I will now address the second tangible, funding. This was not an inherent part of the NRC study yet the budgetary implications of the study are enormous with major implications for the scientific success or lack thereof in the exploration program.

Funding of lunar science in conjunction with human exploration in the VSE is a major problem not yet overtly faced by NASA. It is a latent issue guaranteed to create major tensions some five or so years downstream and can negate the best of intentions. This problem did not exist in Apollo; had it, I can only believe that Apollo would not have been nearly as successful as turned out. Apollo was extremely well funded and it paid for the implementation of essentially all of the Apollo science (OSSA funded the science and Apollo site-certification robotic precursors such as the Rangers, Surveyors and Lunar Orbiters). Today ESMD is having difficulty adequately funding (on a rational development schedule) the infrastructure basics of the future lunar architecture: Ares I and V, Orion and Altair. Until those developments are largely completed, there is not much room to start development of "auxiliary" equipment, i.e., that which allows one to use the infrastructure for a purpose.

The seeds of the science related funding problem are evident in the elements of the lunar architecture. The priority is to establish a lunar outpost with the goal of learning how to live and operate for extended time on a planetary surface. It is stated that such an outpost provides needed experience as a feed-forward to eventual human exploration of Mars. Many of the presumed auxiliary equipments potentially useful for scientific exploration - rovers, advanced habitats, advanced EVA suits, lab facilities, etc. - are "open for contribution" from potential international partners. Let us hope that such contributions are offered in a timely manner. An ancillary, not insignificant, funding issue is recognizable in the discussions of "sortie" missions. Sorties are advocated by the science community to accomplish the exploration of multiple, geologically diverse lunar sites for relatively short time periods (up to seven days); this is essentially an extension of Apollo type missions. ESMD indicates that it is planning to have a capability in the Lunar Surface Access Module, (LSAM, recently named Altair), to conduct sortie missions. Consider, however, that the Administrator of NASA has noted many times that we are not returning to the Moon for science. Fair enough (although the Lunar Architecture Global Exploration Strategy lists "Science Knowledge" as one of the prime themes). At the Tempe lunar workshop in February of 2007, the Administrator (via call-in) noted that scientists are free to buy a sortie mission at some $2B per sortie which, he noted, is similar to the cost of a Science Mission Directorate flagship mission. I do not anticipate that SMD will pay for such a privilege very frequently given that the bulk of lunar science is not demonstrably competitive with the other space science <u>at that level of funding</u>. I note that one might make the case for the science value of a sortie mission to the South Pole-Aitken Basin which if done robotically might well be in the flagship category. I do not want to leave an impression that there is not good lunar science to be done. There is, as is detailed in the NRC report *The Scientific Context for the Exploration of the Moon.* and much of which can and ought to be done robotically. Indeed, the recently proposed on-going lunar robotic mission budget of ~$60M per year, in conjunction with international missions, is a reasonable start on that approach. How much lunar science is worth doing depends on its relative competitiveness with all that is on the plate in SMD. This is the basis of a recommendation in the 2005 NRC report *Science in NASA's Vision for Space Exploration*: "Science that is enabled by human exploration is properly competed directly with "decadal survey" science and then ranked and prioritized according to the same rigorous criteria."

There is no implication in the above that either the NASA Administrator or those in ESMD are anti-science. Quite the contrary: Administrator Griffin has unabashedly supported earth and space science and ESMD is working closely with SMD to understand and define a science component for exploration. It is simply a matter of facing a stark fact: NASA's budget today and in the outlook is grossly inadequate to enable NASA to properly fund the human lunar exploration to accomplish significant science. The import of that conclusion is considerable - and ironic: we are not returning to the Moon to do science yet the conduct of science is virtually the singular major activity associated with lunar exploration other than attending to the mechanics of living there (in situ resource utilization has yet to be convincingly developed as a near-term major activity either in an engineering or economic sense).

Observations on the Exploration Architecture

The second topic I have been asked to address is my perspective regarding the exploration architecture and how it relates to preparing for exploration beyond the Moon. As a starting point I take the NASA Authorization Act of 2005: "The Administrator shall establish a program to develop a sustained human presence on the Moon, including a robust precursor program to promote exploration, science, commerce and U.S. preeminence in space, and as a stepping stone to future exploration of Mars and other destinations." This indeed sets the high-level goal. I and many others assume Mars as the prime and tantalizing future destination yet also include Near Earth Objects (NEOs) and Sun-Earth libration points (with astronomical observatory servicing/construction potential) as among other feasible and desirable destinations for both science and stepping stone reasons. The Global Exploration Strategy theme of "Exploration Preparation" is supportive of this in theory yet the Exploration Systems Architecture Study of Nov. 2005 contains no mention of NEOs or Sun-Earth libration points. It thus implies a leap directly from the Moon to Mars.

How does lunar exploration serve as a stepping stone? In the lunar architecture plans (e.g., LAT2) there is an incorporation of Moon to Mars stepping-stone elements and the very selection of a focus on outposts instead of sortie missions is based on the greater contribution of outposts vis-à-vis sorties to exploration beyond the Moon. That said, I believe that we do not yet have as comprehensive an understanding as one should have. of how the Moon - or any other pre-Mars destination - can optimally contribute to getting to Mars. There does not today exist a inclusive, fully-developed, accepted long-range (e.g., 30 year) architecture for exploration, a void that hinders more efficiently structuring a lunar architecture and strategy and getting the most out of it for "Exploration Preparation." In an ideal world in which one aspires to the human exploration of Mars as the goal for which we are incrementally preparing, one would first establish the requirements for Martian human exploration and feed them back into "precursor" architectures for the Moon and other pre-Mars destinations and for preparatory "precursor" robotic exploration of Mars. Recognizing that need, last year the NASA Administrator asked that an up-dated Mars reference architecture be developed. Work was initiated and an excellent start made. It is thus unfortunate that the work on an updated Mars Design Reference Mission has been halted just when it was starting to be productive in developing requirements, assessing risks and identifying technology and precursor needs that could be used to guide precursor lunar and other architectures. It is not NASA's choice to stop: it is a direct result of language in the Appropriations Act of 2008: "Finally, bill language is included, as proposed by the House, prohibiting funding of any research, development, or demonstration activities related exclusively to the human exploration of Mars." That direction is not in the best interests of structuring an integrated human exploration program architecture that gives the nation an optimum return on its investment. I urge the Committee to reverse the restriction and let NASA conduct those studies essential to providing the best possible total, integrated human exploration program. Indeed, I would go so far as to suggest the Committee direct NASA to conduct such studies and demonstrate to the Congress that there is a logical, economically feasible, technically effective progression of human exploration endeavors that is efficient and in consonance with the Authorization of 2005.

The lack of an updated detailed Mars architecture does not prohibit top-level strategizing and planning for exploration beyond the Moon. Indeed, NASA has taken a major first step in that direction in its determination that the basic launch capability being structured for the return to the Moon must have applicability to Mars. The planned heavy-lift cargo vehicle Ares V clearly fits that requirement. There are many other things we know today that are obviously required and that have feed-back implications: long-duration human flight (up to three years) with attendant crew-related questions dealing with radiation, micro-gravity, isolation, health and safety, etc. and those treating the hardware and software systems that support the exploration. There are "operational" considerations: aerocapture vs. direct entry, the actual entry, descent and landing; the potential use of in situ resources to reduce mass (thus cost), logistics, science planning, the effects of dust, possible toxicity of Martian soil, mobility and trafficability, etc.

A lunar outpost-centric program can contribute to learning about the long-duration planetary surface operations component of "Exploration Preparation." It will not contribute to many of the key elements noted above. The lander, Altair, e.g., has virtually no applicability to landing humans on Mars. Today, budgets aside, we dare not embark on a Mars human exploration program despite some ill-founded hallucinatory calls external to NASA for so doing. We simply cannot do it. As the top example of non-readiness, consider safe and reliable long-duration space flight such as required for Mars. We simply do not have crews or crew systems that are "flight qualified" for three year sojourns. Short-duration flights to the Moon will not add to that development any more that Apollo did. Jumping right to development of a three-year Mars system, while theoretically feasible, is not reasonable. Rather, a step-wise, evolutionary development building on Orion in a "Block X" approach would be more rational. This is where a long-range, comprehensive exploration architecture development might show, for example, how using first the International Space Station as a realistic prototyping local (getting some ROI on the ~ $35B investment), thence proceeding to libration missions of ~ a month's duration followed by longer duration asteroid missions of several months leads more realistically to Mars. Such a sequence could be accomplished over a span of some 10 to 15 years. It is also consistent with an obvious conclusion that one gets the most data at lowest cost on Earth, and progressively less data more expensively as one moves to LEO, Moon, NEO or L-point and, finally, Mars. The obvious question is not so much one of can such a plan be constructed; rather it is can such a plan be implemented while conducting a lunar program that appears capable of consuming the entire available budget through at least 2030. This question is part of what lurks behind the sometimes heard phrase "stuck on the Moon." Ideally the lunar program would be constructed and implemented in a way that allows for simultaneous development of non-lunar, pre-Mars missions. Budget reality might well preclude that approach, a likelihood that also applies to the simultaneous development of a Mars capability as implied in the ESAS. All of this suggests avoiding a large build-up of lunar infrastructure. In any case, one should have a lunar program exit strategy: when will the lunar program provide the required data in support of “Exploration Preparation” and how does one disengage from the Moon? Hoped for turn-over of lunar infrastructure to commercial and/or international partners does not seem particularly realistic.

Thus far I’ve discussed mostly the human mission aspect of exploration architectures. There is a corollary aspect that begs discussion and that is the role of robotics. Noted above is the new lunar robotic program and ESMD lunar thinking considers using robotics in association with an outpost or using crewed rovers in a robotic mode when not crewed. This is all to the good and is consistent with our recommendation in *The Scientific Context for the Exploration of the Moon* for development on an integrated human/robotic program. It thus seems logical that a similar approach would apply to Mars for which today we can conduct only robotic exploration.

What is the relationship of the Mars Exploration Program (MEP) to eventual human exploration? It provides, or can provide, two critical contributions. First, science. As is the case with the Moon, science will be a major activity of human exploration of Mars as is noted in the recent report of the Human Exploration of Mars Science Working Group. The MEP of the last decade has been a remarkable demonstration of how rapidly and productively science progresses when there is a strategically guided, methodical, scientifically focused, superbly engineered program. In accord with this, the Appropriations Act of 2008 makes clear the Congressional intent that there continues to be a strong MEP with missions at every Mars opportunity. Such is apparently not to be. Testimony at the March 13, 2008 hearing of this Committee addressed the major cutting of the MEP in the President’s proposed 2009 budget and the damage that will accrue to the MEP. While adding my congratulations to Dr. Alan Stern for doing much to improve the overall status of space science, I do not believe that the cuts to the MEP are either warranted or acceptable. I come to that conclusion based on the observation that the MEP is arguably NASA’s most successful robotic exploration program in terms of continued, step-wise public-engaging exploration (I note the difference between a program and individual projects such as Hubble and Cassini). It has taken a decade of Mars missions to develop the engineering and scientific communities able to both implement and understand how to explore Mars. That capability can be lost in just a couple of years. The “case study” of the potential damage can be readily seen as NASA is now working hard and paying the price to recreate an engineering workforce capable of developing the Ares vehicles, Orion and Altair. The new NASA Lunar Science Institute was formed partly in order to help recreate a community of lunar scientists.

There is further a direct link between the MEP and the needs of the VSE. We need to keep Mars in the public eye as an ongoing indication of the import of Mars, regardless of the VSE; the public is having a difficult time understanding where the return to the Moon fits in. Mars, along with Earth, is a special planet, not one that should be subject to equipartition of attention in the solar system. In the MEP, and supported by Dr. Stern, is a Mars Sample Return (MSR) mission envisioned towards the end of the next decade. Adequate funding for that is tenuous as you heard on March 13. A sample return from Mars will have incredible science value. Moreover, it will provide absolutely essential precursor information for eventual human exploration. Specifically, we must understand the precise nature of the highly oxidizing Martian soil, will it be toxic to humans and, if so, how does one counter that? What is the nature of the dust particles in an engineering sense. Just as dust is a major concern on the Moon, it is of equal or greater concern on Mars (with active dust storms) and one must have returned sample to adequately treat the issues. One might argue that human exploration of Mars is a long way off, so what's the rush? My response is that the sooner we know and deal with what might be real impediments to human exploration of Mars, the better. Waiting to find out until 2030 or so would be irresponsible given the likelihood that a significant technology development may be required to deal with the results (note that several years ago there was active participation of ESMD in the MEP but was stopped due to budget issues). Lastly, an MSR mission will be proof-of-concept of a Mars round-trip, a not inconsequential demonstration. Many will be the "Oh my goodness" aspects that will need to be considered before we commit to the human adventure.

International Cooperation: Opportunities and Challenges

The final topic you asked me to address relates to the potential opportunities and challenges of international cooperation for human exploration beyond low Earth orbit and what things might NASA and Congress do now to enhance the potential. The opportunities are in a sense obvious: we cannot afford the exploration we'd like to implement; without significant international contributions the architecture is moot and must be scaled back or stretched out to the point of marginal value for the investment. The latter can force one into the approach of "go as you pay" which is deceptively attractive. There is, however, an ugly potential downside of "go as you pay" in that if there is not enough "pay," the largest budget increment goes to sustaining the infrastructure on Earth. The drawn-out "level-funding" development of the ISS gives some hint of that impact.

Many of the world's space faring nations have developed sufficiently in skill and desire that we should look to them as desirable partners for their own sake and not simply as a source of funding to solve our budget shortfalls after we have announced "Our Vision". Bringing potential partners in early, in the concept formulation phase where they contribute to structuring the basic approach strikes me as the right way to approach international cooperation. That is indeed the way NASA is now approaching the possible international participation in a Mars sample return mission (the recent budget cuts in the MEP do not provide confidence to potential partners that we are serious in our commitment). The Global Exploration Strategy Framework for Cooperation certainly contains a basis for building to eventual closer collaboration.

As we develop more and more collaborative programs, today's trend, it is likely that we shall have to develop a degree of trust that goes beyond what we are historically comfortable with. It is always good if collaborations are not on what is called the "critical path" in which the failure of one party to produce sinks the ship. This becomes more important the larger the program and its collaboration dependency such as in the VSE or MSR. While there are few guarantees for these ventures, having overt, consistent political support from the Congress and Administration can substantially enhance the stability and probability of success. That kind of support was a stabilizing element of the cooperation with the Soviet Union (later Russia) in the Apollo Soyuz Test Project and ISS program.

The politically motivated and largely successful historic cooperation with the Soviet Union naturally raises the question of China, a country clearly aspiring to emulate much of what we do or have done. It is worth examining and questioning whether there is a comparable role with China to what we did with the Soviet Union at the height of the Cold War - recognizing that we are absent much of the Cold War rhetoric and threats. However, there is obviously an embedded political issue regarding military implications and I leave that for others to wrestle with.

There does remain a thorn in the side of international cooperation and that is the ITAR regulations. While few of us would argue that ITAR does not serve a good purpose in preventing a damaging transfer of technology, the restrictions seem at times to be excessive and unnecessarily make it more difficult to obtain the ease of dialog necessary for effective cooperation and on occasion lead to a vocal negative response from potential partners. Congressional support for assessing and appropriately easing the restrictions would be welcome.

Mr. Chairman and subcommittee members, you have my appreciation for the opportunity to testify today. I hope that my comments are taken as an attempt to contribute to improving the long-term outlook for the NASA space programs in an extremely challenging budgetary and technical environment.