**Policy Recommendations**

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**GUIDING PRINCIPLES:**

 - Most cost-effective approaches.

 - Near-term technologies.

 - Reasonable risk.

 - Remarkable accomplishments.

**WHAT COULD BE ACCOMPLISHED:**

 - A low-cost, sustainable, commercial cis-lunar transportation system.

 - An American-led, permanent, international lunar base also with a small sustainable habitat as humanity's first off-Earth foothold, and a clear path to transition off of government support.

 - A low-cost path to Mars exploration and settlement a bit sooner than the current path.

 - The establishment of a low-cost transportation system for cargo and crew anywhere in the inner solar system.

 - The establishment of a permanent public and private base on Mars.

 - Solidifying America's leadership in space including America taking the lead by establishing the historically-significant, first permanent off-Earth foothold for humanity.

**NASA BUDGET:**

 - In general, maintain the current budget with inflation.

 - NASA's budget is more than sufficient to accomplish great things IF the money was spent more cost-effectively. If the current large programs are continued at their current level then **Moderate Recommendation:** a 5-7% increase to accommodate a 'Lunar COTS' set of programs.

**1) LUNAR LANDER DEVELOPMENT:**

 - $20 million for the development of the Xeus Terrestrial Demonstrator.

 - **Very Strong Recommendation** - Fund the development of a terrestrial demonstration of a full-sized, cryogenic lunar lander. (Est. cost = $20 M).

 - **Very Strong Recommendation** - Fund the development of an operational, reusable, cryogenic lunar lander. (Est. cost = $200 M).

**2) RETURN TO THE MOON PROGRAM:**

 - Lunar COTS (public-private programs). A set of programs to facilitate American companies to develop transportation from LEO to the Moon for cargo and crew and to operate on the lunar surface.

 - **Very Strong Recommendation -** Right away, fund a full-size (5-7% of NASA’s budget) set of public-private programs to facilitate American companies to develop a transportation system from LEO to the Moon aiming to fuel it using lunar polar resources. (Est. = $15.2 B over 16 years 🡪 8-person permanent base).

**3) SOLAR ELECTRIC PROPULSION (SEP):**

 - **Very Strong Recommendation -** Fund the development of SEP scaled to the size that would be useful for pushing cargo large enough to be useful in support of crewed missions to the Moon and Mars. [AJ]

**4) CIS-LUNAR 'GATEWAY' STATION:**

 - **Very Strong Recommendation -** Do not develop a crewed or uncrewed, long-duration mini-station in cis-lunar space. Yes, we do need a transhab for missions to Mars and this would be appropriately tested in cis-lunar space. But it is not necessary for access to the lunar surface nor as a staging station for Mars missions. Instead, payloads launched from Earth can be simply handed off to vehicles headed to the Moon or Mars. Having a mini-station using recurring SLS launches to rotate crew would be the quickest way to consume budgets and delay progress towards the Moon or Mars. [HSC]

**5) NASA GOVERNANCE:**

 - The real problem isn't the switching of directions but rather the continuation of the very expensive, large programs which strain the budgets, jeopardize their own sustainability, and prevent much more cost-effective programs from being funded.

 - If inefficient programs are made 'sustainable' by locking them in, then real progress will be impeded for a long time.

 - **Strong Recommendation** - Do not change the NASA governance structure until cost-effective programs are adopted in place of the current, large, very expensive programs.

**6) LUNAR-DERIVED PROPELLANT:**

 - **Strong Recommendation** - Lunar propellant is for reducing the cost of accessing the lunar surface. Given the cost-efficiency of Falcon Heavy and SEP, the Moon will not be a cost-effective source of propellant for missions beyond the Earth-Moon system. [FH-SEP Calcs]

**7) LUNAR RESOURCE PROSPECTING MISSION:**

 - **Strong Recommendation** – Fund and expedite the Lunar Resource Prospecting Mission. However, do not delay the development of crewed lunar landers. We already know where to set up lunar bases (i.e. the “Peaks of Eternal Light”) and a permanent lunar base should be pursued regardless of the results of the Prospecting Mission.

**8) PROPELLANT DEPOTS:**

 - The Apollo Program didn't require propellant depots. The Constellation Program didn't envision the need for propellant depots. The Mars Design Reference Architectures didn't envision the need for propellant depots. Are propellant depots actually necessary?

 - SEP makes LEO depots unnecessary for cargo.

 - Large commercially-viable vehicles (e.g. Falcon Heavy) will be more cost-effective than smaller launchers. Docking two such vehicles at LEO is safe and achieves HLV capability.

 - The energy needed to send craft, crew, and cargo from an EML staging point to the trans-Mars trajectory is small and may not need a propellant depot for such a small kick.

 - **Moderate Recommendation** - Be skeptical about the presumed value of and need for propellant depots.

**9) MARS:**

 - **Strong Recommendation** – NASA should partner with SpaceX including the incorporation of their technology into NASA’s plans.

 - ‘Going to Mars’ could be done early with a flyby mission. The mass shielding data and Valerie Polyakov’s in-space record supports the idea that such a mission could be done sooner than later.

 - A combined Phobos-Deimos (PhD) mission could be an exciting and useful interim step without having the up-front cost and risk of a Mars surface mission. However, crew on a PhD mission should do Mars surface teleoperations not for science but to set up a large inflatable habitat in order to compel us to take the next step of a Mars surface mission.

 - Given the risk of rotating crew, consideration should be given to extending crew stay even on the first Mars mission.

**10) INTERNATIONAL LUNAR DEVELOPMENT:**

 - The decision about America’s role in lunar development should not be put off any longer.

 - The ISS is an example of how not to proceed in a cost-effective manner. This should serve as a caution for an international approach to lunar development.

 - Rather, America should invite its international partners to likewise do their own ‘Lunar COTS’ by funding their companies to add redundancy and competition to the development of a cis-lunar transportation system, ice-harvesting operations, and crewed bases.

 - **Strong Recommendation** – NASA should avoid making lunar development primarily an international venture like the ISS. Rather, it should encourage our partners to help their own companies participate in a Lunar COTS set of programs.

**11) CHINESE LUNAR AMBITIONS:**

 - First, we have no evidence that China intends to claim the best lunar property (i.e. the poles).

 - However, if we neglect leading a human return to the Moon any longer, we will find ourselves in the position to where we will not be able to respond in time in case they land a human-sized lander and give their one-year notice and pull out of the OST.

 - Without going into too much detail, it is technically possible for the Chinese to strengthen a claim to the best lunar property. [Sunlit Areas]

**12) SLS:**

 - Lunar development does not need anything greater than the Falcon Heavy (FH), Vulcan, or New Armstrong launchers. An SLS-class rocket is not needed for this.

 - An SLS-class capability is needed for Mars exploration, development, and settlement.

 - FH-class rockets combined with SEP can provide nearly SLS-class capabilities. Docking FH-class payloads provides SLS-class capabilities. America hasn't had a docking failure in over 40 years.

 - New, 'commercial' SLS-class launchers (e.g. SpaceX's 'BFR')) will likely be less costly to develop and operate than the SLS. There is a good chance that they will be partially or fully reusable.

 - **Moderate Recommendation** - Critically evaluate whether reasonable architectures using FH-SEP-like approaches can achieve savings by reducing or eliminate the number of SLS launches needed.

 - **Moderate Recommendation** - Financially support the development of the engines and rockets of 'commercial' SLS-class launchers.

**13) THE ISS AND COMMERCIAL ORBITAL STATIONS:**

 - The ISS is a large and ongoing burden on the NASA budget thereby hindering beyond LEO (BLEO) development. Therefore, its operations must be justified financially and programmatically.

 - It is unlikely that the ISS will adequately address the two major human factors necessary for BLEO operations (i.e. deep space radiation and artificial gravity).

 - There are relatively low-cost missions which could be conducted apart from the ISS which could adequately address these two issues.

 - The launches of only three Bigelow 330 modules would provide has much internal space as the entire ISS. It likely that a commercial space station could be developed for an order of magnitude less than the ISS did.

 - It is unlikely that commercial development of the ISS will ever make it profitable. It is questionable whether commercial orbital research stations will be profitable independent of sovereign clients. The exception might be orbital tourism which depends strongly upon the development of fully-reusable launchers.

 - It is not clear that the commercial development of LEO will hasten the development of BLEO destinations. E.g. The development of the commercial satellite industry didn't inevitably lead to low-cost, sustainable human spaceflight. The sustainable development of the Moon, Mars, and asteroids can be achieved using local resources, reusable transportation systems, and perhaps meeting a demand for off-Earth retirement.

 - **Moderate Recommendation** - Do not extend the ISS beyond 2024. Critically evaluate what opportunities we will lose as we spend $25 B until 2024.

 - **Moderate Recommendation** - Critically evaluate whether NASA support for the seamless transition to a commercial station will result in freeing NASA’s budget or continuing to significantly burden it.

**14) ASTEROID REDIRECT MISSION (ARM):**

 - It is true that the ARM cannot be sufficiently, logically justified by the science, planetary defense, inspiration, or asteroid mining benefits.

 - However, if there is nothing in cis-lunar space to go to, the necessary SLS / Orion missions to cis-lunar space before going to Mars with be rather uninspiring. This is the real justification for the ARM.

 - Using the SLS and Orion for a crewed, EML2 far-side telerobotics mission also cannot be justified because a much less expensive relay satellite can do just as well and the 3-second time delay is not a significant problem.

 - Using SEP for a sample return from Phobos will do nothing to help the cis-lunar missions for SLS / Orion to be inspiring.

 - SEP is a critical technology and either the ARM or the Phobos mission would be a good use of it.

 - **Moderate Recommendation** - Be honest and admit that the real purpose of ARM is primary to make the interim SLS / Orion steps more exciting. Since interim SLS / Orion missions need to be done anyhow and since SEP missions are very valuable, recommend funding and support for the ARM mission.

**15) PLANETARY (ASTEROID) DEFENSE:**

 - There is no unknown asteroid large enough to cause a K-T ("dino-killer") impact. We would be able to see essentially all of the asteroids a kilometer or greater.

 - Earth-crossing comets are so much less common than asteroids that they are not a statistical risk worth caring about.

 - Asteroids of 20m to 300m are the greatest concern because they are small enough that they can impact before being detected. This should be the focus of planetary defense.

 - **Moderate Recommendation** - We should continue to fund asteroid detection programs including systems to detect small incoming asteroids with a few days’ notice.

**REFERENCES**

[AJ] <http://www.space.com/32692-solar-electric-propulsion-asteroid-mars.html>

[HSC] Testimony of Tom Young - <https://www.youtube.com/watch?v=jscG37SuS1I&t=99m04s>

[FH-SEP Calcs] $135M = Last published price for a Falcon Heavy (FH); 54.4 tonnes = Published FH performance to LEO. 30% = Stated reduced price of F9 if first stage reused. 15% propellant mass fraction for SEP from LEO to EML1 (Isp=2,500 sec). ($135 M \* 70% / 54,400 kg) / 0.85 = $2,044/kg for cargo at EML1.

[Sunlit Areas]

<http://www.astronomy.com/news/2005/04/eternal-light-at-a-lunar-pole>

<https://en.wikipedia.org/wiki/Lunar_Roving_Vehicle>