

Summary of Results of a NASA-funded Study on:

An Evolvable Lunar Architecture Leveraging Commercial Partnerships

**An economically affordable path to a permanent
return to the Moon that enables more affordable
NASA missions to Mars**

Charles Miller

President, NexGen Space LLC

spacepolicy@me.com

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If America can put a Man on the Moon, ... Why can't we put a Man on the Moon?

- NASA has made 3 major attempts in the last 45 years to recreate the magic of Apollo
 - Each of the attempts has failed because of affordability
 - Every previous attempt cost hundreds of billions
- RESEARCH QUESTIONS:
 - Could we leverage commercial partnerships (like COTS) for a human return to the Moon?
 - Is it technically feasible?
 - What would it cost?

Charles Miller (Principal Investigator, Business & Economic)

- Nearly 30 experience in space industry
- Former NASA Senior Advisor for Commercial Space
- Co-founder Nanoracks LLC, and former President and CEO of Constellation Services International, Inc.

Dr. Alan Wilhite (Co-Principal Investigator, Technical)

- 40 years of systems engineering at NASA and Georgia Tech
- More than 60 published articles and several book chapters on space systems engineering.
- Former Director of the NASA's Independent Program Assessment Office

Edgar Zapata, KSC (Life Cycle Cost Analysis)

- Has worked with NASA at KSC since 1988 with responsibility for Space Shuttle cryogenic propellant loading systems, and related flight and ground propulsion systems.
- For last 20 years has translated real-life human spaceflight operational experience and lessons learned into improvements in flight and ground systems design, technology, processes and practices. He has participated in most major agency-level human exploration studies.

David Chevront (Risk, Safety & Mission Assurance)

- David Chevront has 37 years of aerospace experience, including 19 years at NASA JSC. At Rockwell International, Chevront solved key maintenance challenges in the preliminary design of the Space Station *Freedom*, and was hired by NASA JSC to solve problems in reliability and maintainability in human spaceflight.

Robert Kelso (Lunar Robotics & ISRU)

- 37 years at NASA-Johnson Space Center, including serving as a Shuttle Flight Director in JSC's Mission Control Center. Kelso led NASA's efforts to leverage commercial lunar robotics developments for several years.

American University (AU) School of Public Affairs & Dr. Howard McCurdy

- Dr. McCurdy is an AU Professor of Public Policy and has authored seven books on the American space program, including *Faster-Better-Cheaper: Low-Cost Innovation in the U.S. Space Program*, *Inside NASA: High Technology and Organizational Change*, and *Space and the American Imagination*.

- Independent Review conducted on March 11, 2015
 - Full day briefing, followed by detailed feedback from 21-page report.
- ◆ Joe Rothenberg (Chairman)
- ◆ Jim Ball
- ◆ Hoyt Davidson (Econ. lead)
- ◆ Frank DiBello
- ◆ Jeff Greason
- ◆ Gene Grush (Technical lead)
- ◆ Alexandra Hall (Benefits lead)
- ◆ Jeffrey Hoffman (S&MA lead)
- ◆ Ed Horowitz
- ◆ Steve Isakowitz
- ◆ Christopher Kraft
- ◆ David Leestma (Cost Est. lead)
- ◆ Michael Lopez-Alegria
- ◆ Thomas Moser
- ◆ James Muncy
- ◆ Gary Payton
- ◆ Eric Sterner
- ◆ Will Trafton
- ◆ James Vedda
- ◆ Robert Walker
- ◆ Gordon Woodcock

- Three Phases to the Evolvable Lunar Architecture
 - Phase 1: Human Sorties to Equator / Robotic Prospecting Poles
 - Key transition point to Phase 2 – When LEO on-orbit propellant storage and transfer is available (LOX-H2 or LOX-Kero)
 - Phase 2: Sorties to Poles & ISRU Capability Development
 - Key transition point to Phase 3 – When Lunar ISRU, storage and transfer (LOX-H2) & a reusable lunar lander (LOX-H2) is available
 - Phase 3: Permanent Lunar Base transporting propellant to L2
 - Assume transport for 200+ MT of propellant to L2 every year for Mars EDS
- Earth orbit rendezvous, and later propellant transfer
- Incrementally develop and insert reusable elements
 - SpaceX Dragon V2.1, Boeing CST-200, Sierra Nevada Dream Chaser
 - Partially-reusable and reusable LVs as they are developed
 - E.g., SpaceX's Falcon 9R, United Launch Alliance "Vulcan", and Blue Origin LV

- Technically feasible to return humans to the surface of the Moon within a period of 5-7 years from authority to proceed
 - Assumes COTS/CRS and Commercial Crew style partnerships
- Could be accomplished by end of 2nd term of next President
- Estimated cost is \$10 Billion (+/- 30%) for two independent commercial providers, or about \$5 Billion for each provider
 - Did not estimate cost for a single provider with no competition
 - No hard empirical data available
- Cost of Duplicating Apollo (6 sortie missions)
 - \$12 Billion (+/- 30%), FY15\$
 - Cost of Apollo was ~\$140 Billion (FY15)

Summary of Study Conclusions

Implications Permanent Human Base on Moon

- Phase 3: Permanent lunar base possible in 2031-35
 - Providing ...
 - 2 human missions (6 month visits) per year
 - 4 humans permanently on surface of Moon
 - 4 cargo delivery missions/year to surface of Moon
 - 200+ MT propellant/year delivered to lunar orbital depot
 - All within a \$2.8 Billion (FY15) budget
 - **Achievable within NASA's existing deep space human spaceflight budget**
 - Total estimated cost to initial permanent ops
 - **\$40 Billion, (+/- 30%), FY15\$, spread over 12-18 years**
 - Assumes a new partnership — like an International Lunar Authority — is set up to mitigate long-term business risks

Summary of Study Conclusions

Implications for NASA Missions to Mars

- A commercial lunar base makes Mars more affordable
 - Propellant is 80% of mass launched for Mars missions
 - 200MT/year of Propellant in L2 will cost NASA ~\$3B/yr (FY15)
 - Which could be worth >\$10 Billion per year to NASA
 - Based on costs avoided from launching all that mass from Earth
 - Reduces SLS launches required per human mission to Mars
 - From as many as 12 to 3 SLS launches total
 - Mars becomes more technically, economically & operationally viable
- A permanent commercially-operated lunar base can:
 - **Substantially pay for itself by exporting propellant to NASA for Mars**

Summary of Study Conclusions

Implications for Private & Other Govt Space Travel

- Assuming a private operational lunar base
 - With an anchor tenant customer covering fixed costs
- Many nations, and many private citizens, can afford to purchase a commercial trip to surface of the Moon
 - Phase 1/2: ~\$600-700M (FY15) per round-trip ticket
 - Small lunar lander with Earth-based propellant
 - 1 passenger, 1 pilot
 - Phase 3: ~\$150-200M (FY15) per round-trip ticket (polar base)
 - Large reusable lunar lander with Lunar-based propellant
 - 3 passengers, 1 pilot

Summary of Study Conclusions

Public Benefits

- **Economic Growth:** Commercial partnership will significantly increase economic growth opportunities
- **National Security:** Will create long-term American dominance in key strategic sectors (launch, robotics, orbital operations)
- **Diplomatic/Leadership:** An American-led lunar base, founded on free people and free enterprise, will be the “ultimate shining city on the hill” for the world to see
 - Only allow democratic/free enterprise nations join partnership?
 - Significant soft power messaging
- **Innovation/Technology:** Will drive advances in robotics, additive manufacturing, environmental tech, ISRU, etc.
- **STEM/Inspiration:** Many opportunities for directly involving next generation. Private citizens operating, and landing, on Moon is very inspirational
 - As is realistic and affordable travel to Mars

Summary of Study Conclusions

Top Strategic Risk

- We know there is water at lunar poles, but ...
 - How deep and plentiful is the water?
 - How economical is it to recover?
 - Where are the best sites for water?
 - Location, location, location
- **RECOMMENDATION:**
 - Near-term commercial-service purchase by USG of robotic lunar landing(s) at lunar poles

Summary of Study Conclusions

Independent Review Team

- ***"On behalf of the Independent Review Team, I commend you and your Team for the impressive Study. Although a lot of work remains to bring the Architecture, Cost and Schedule to the next level of definition, the work of your Team provides an excellent foundation for the next Phase of the Evolvable Lunar Architecture development."***
 - Joseph Rothenberg
 - NASA Associate Administrator for Human Spaceflight, 1998-2001
 - Chairman of Independent Review Team

<https://www.researchgate.net/publication/280099331> Economic Assessment and Systems Analysis of an Evolvable Lunar Architecture that Leverages Commercial Space Capabilities and Public-Private-Partnerships