Summary of Results of a NASA-funded Study on:

An Evolvable Lunar Architecture Leveraging Commercial Partnerships

Lunar Exploration Analysis Group
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NASA-funded Study by NexGen Space
Background & Purpose

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:
  - What if we leverage commercial partnerships (like COTS) for a human mission to deep space?
  - Is it technically feasible?
  - What would it cost?

NexGen Study Team

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 Cheuvront (Risk, Safety & Mission Assurance)

- David Cheuvront has 37 years of aerospace experience, including 19 years at NASA JSC. At Rockwell International, Cheuvront 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*.

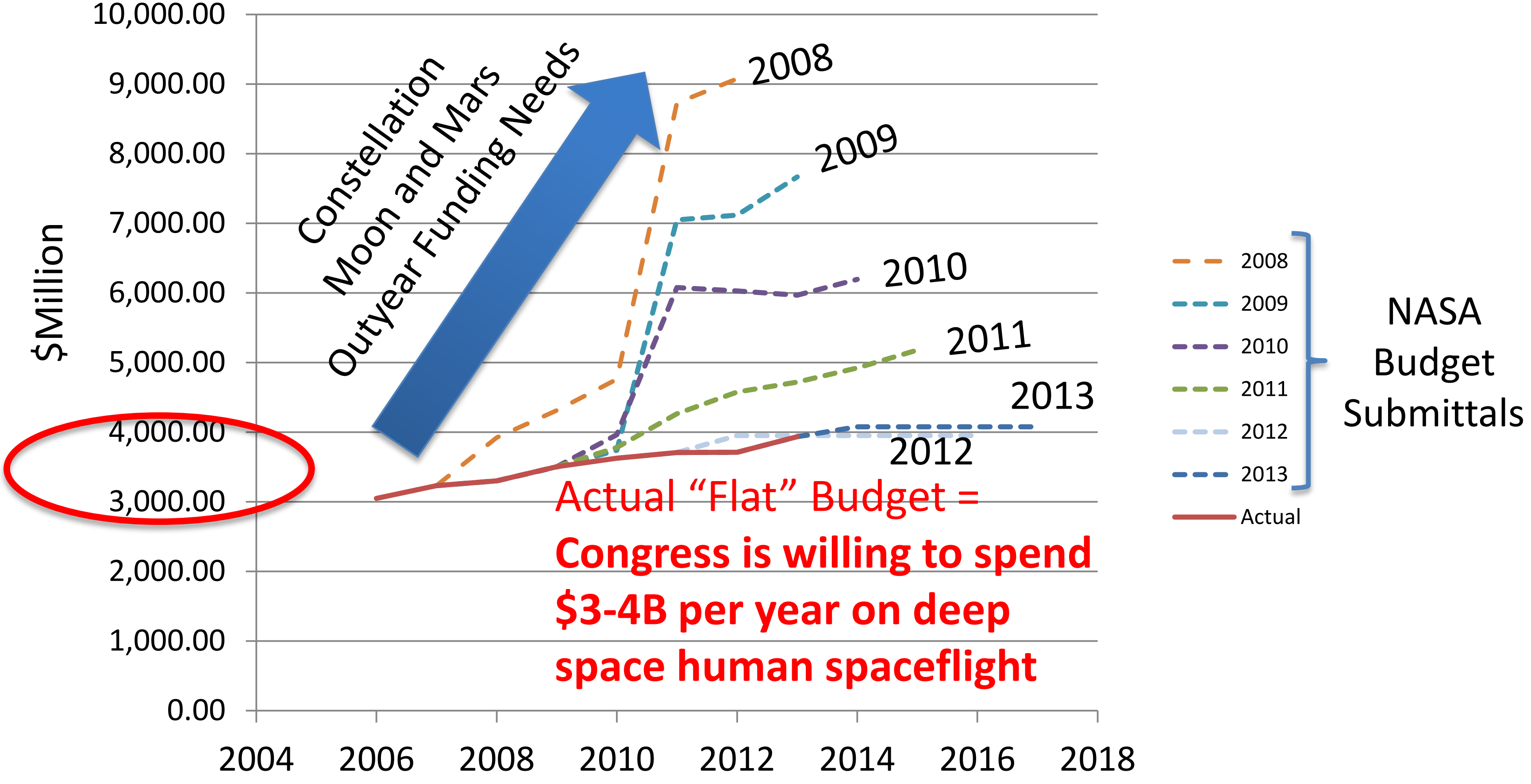
Independent Review Team

- 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

NASA's Deep Space Human Exploration program
Key Assumption — Stay in existing budget

NexGen
Space LLC



Actual "Flat" Budget =

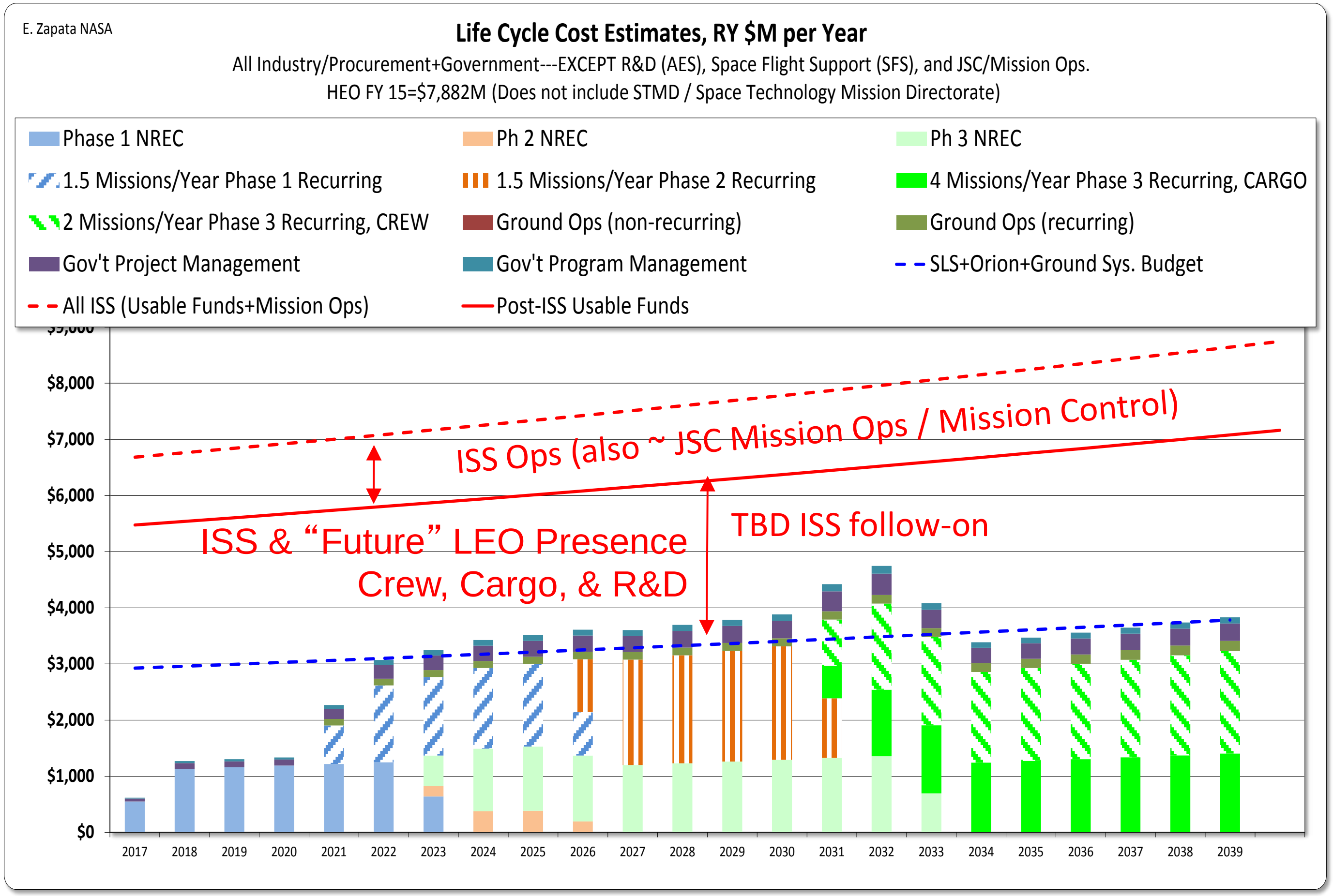
Congress is willing to spend $3-4B per year on deep space human spaceflight

What Is the Evolvable Lunar Architecture?

- 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
- Assessed 2 specific tech approaches (SpaceX & ULA)

Life Cycle Costs – ELA Scenario (Variant)

Variant: 1.5 Missions per year (Phase 1 and 2)



E. Zapata NASA

Life Cycle Cost Estimates, RY $M per Year

All Industry/Procurement+Government---EXCEPT R&D (AES), Space Flight Support (SFS), and JSC/Mission Ops.
HEO FY 15=$7,882M (Does not include STMD / Space Technology Mission Directorate)

ISS Ops (also ~ JSC Mission Ops / Mission Control)

ISS & “Future” LEO Presence
Crew, Cargo, & R&D

TBD ISS follow-on

- Reduce operational missions in Phases 1 & 2 to fit within budget constraints
- We don’t assume any efficiency in a continuing NASA LEO presence (pre and post-ISS), which could cover the ELA life cycle cost profile slightly overshooting a ~$3B a year cap

Summary of Study Conclusions

Implications Near-term Human Return Moon

- 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 <u>two independent commercial providers</u>, or about $5 Billion for each provider
    - Constellation cost of “first boots on the Moon” = $120 Billion
  - Did not estimate cost for a single provider with no competition
    - No hard empirical data available
- ELA 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 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

Implications for NASA Missions to Mars (1)

- A commercial lunar base can reduce costs of Mars
  - 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

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

Study Final Report

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