



## SpaceWorks Engineering, Inc. (SEI)

---

# The Trillion Dollar Question: Anatomy of the Vision for Space Exploration Cost

AIAA-2005-6637

AIAA Space 2005  
30 Aug - 1 Sep 2005  
Long Beach Convention Center  
Long Beach, California



**Mr. A.C. Charania**  
Senior Futurist  
SpaceWorks Engineering, Inc. (SEI)



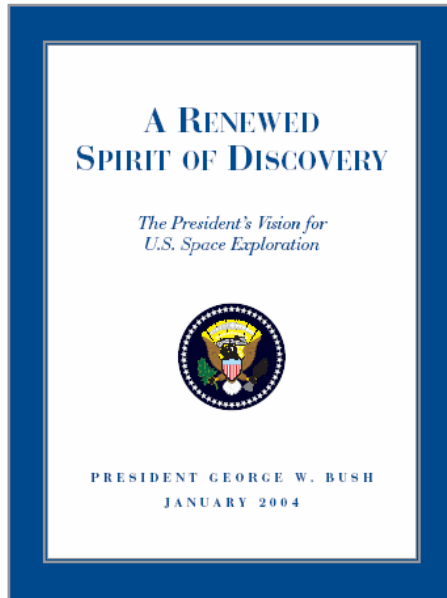
# Introduction





## National Vision for Space Exploration (VSE)

**THE FUNDAMENTAL GOAL OF THIS VISION IS TO ADVANCE U.S. SCIENTIFIC, SECURITY, AND ECONOMIC INTEREST THROUGH A ROBUST SPACE EXPLORATION PROGRAM**



Implement a sustained and affordable human and robotic program to explore the solar system and beyond

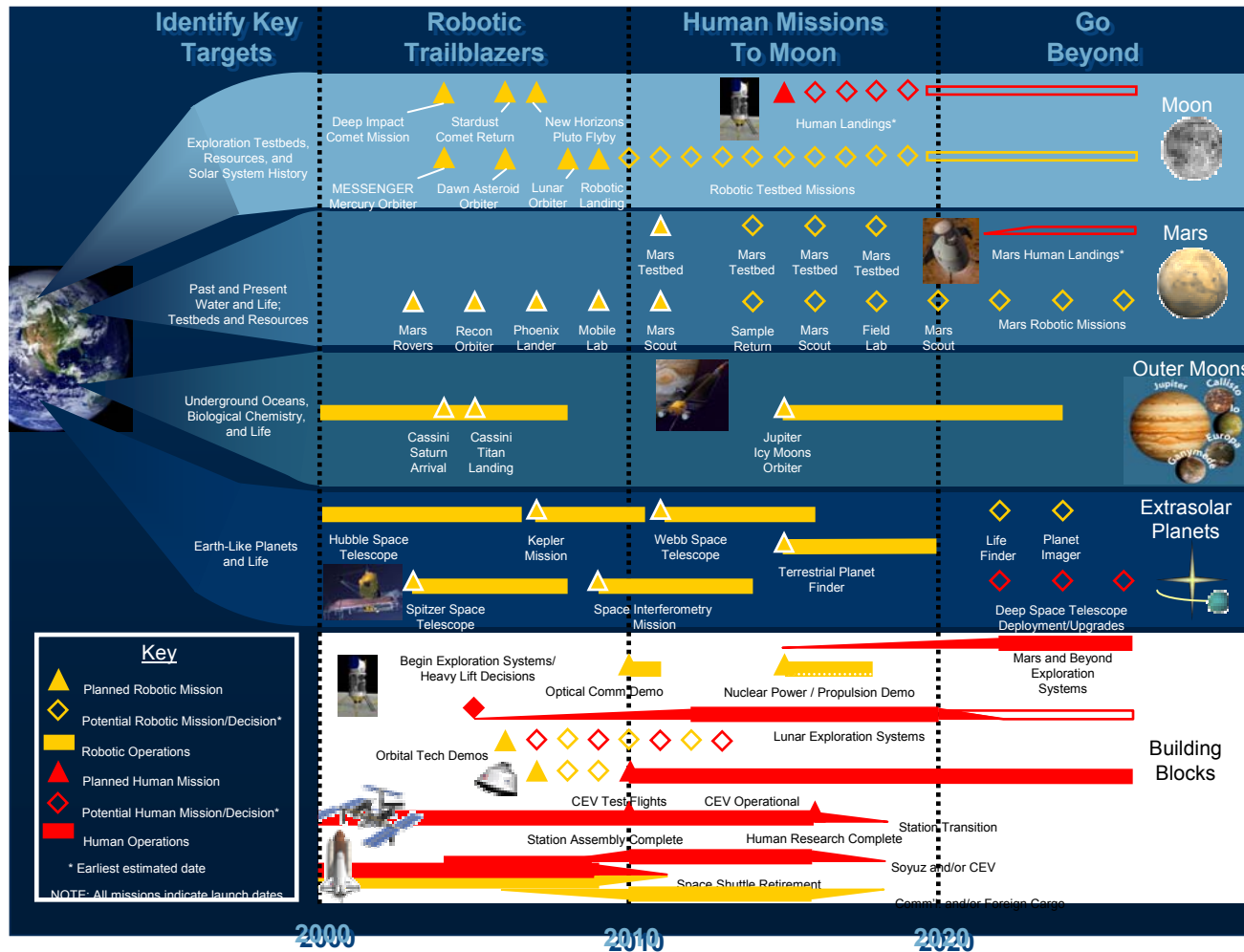
Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;

Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and

Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

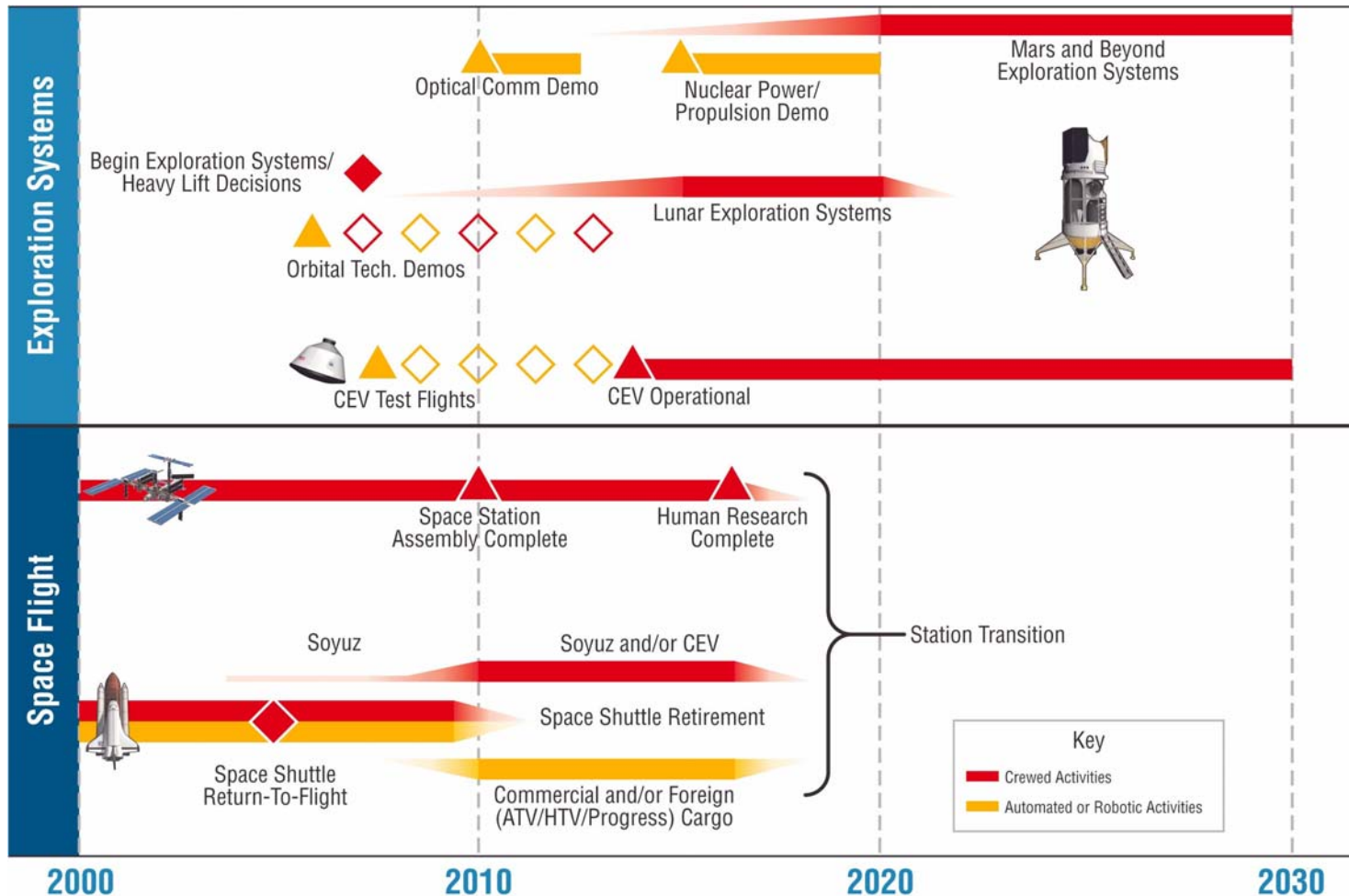


# Outline of Nation's Vision for Space Exploration (VSE) (Subject to Revision)





# Building Blocks of the Vision (Subject to Revision)





## The Revision: NASA HQ Exploration Systems Architecture Study (ESAS)

- ▶ The ESAS is a 90-day study that is examining many of the larger questions associated with the Vision for Space Exploration (VSE)
  - From NASA HQ's Office of Program Analysis and Evaluation
  - Will provide the analytical support for a number of key near-term decisions for NASA, the White House, and Congress
  
- ▶ Some of the topics the ESAS is reviewing include the requirements for returning to the Moon and extending human exploration to Mars, as well as possibilities for accelerating the development of the Crew Exploration Vehicle (CEV)
  
- ▶ This team is expected to complete its work in July and to start presenting findings
  
- ▶ Focus areas
  - Complete assessment of the top-level Crew Exploration Vehicle (CEV) requirements and plans to enable the CEV to provide crew transport to the ISS and to accelerate the development of the CEV and crew launch system to reduce the gap between Shuttle retirement and CEV IOC.
  - Definition of top-level requirements and configurations for crew and cargo launch systems to support the lunar and Mars exploration programs.
  - **Development of a reference lunar exploration architecture concept to support sustained human and robotic lunar exploration operations.**
  - Identification of key technologies required to enable and significantly enhance these reference exploration systems and reprioritization of near-term and far-term technology investments.





# Process Overview





- Objectives** For this examination, a top level cost estimate is provided of the Vision for Space Exploration in order to better understand the true nature of this project and the validity of the oft-quoted trillion dollar estimate.
  
- Methods** This estimate is developed using historical analogies, external cost estimates, and specific Cost Estimating Relationships (CERs) from NAFCOM 2004. The estimate includes the cost of robotic precursors, hardware development/acquisition, launch development, operations costs (launch and mission operations), ISS support, Space Shuttle support, and Mars-related technology development. The cost estimate is presented up to and including fiscal year 2025.
  
- Limits** The cost estimate here only extends to the development of a lunar outpost and initial development of Mars technologies. The publicly available information for the ESAS is used as the starting point of this lunar exploration architecture.
  
- Architecture** The specific architecture chosen for this analysis is an all-chemical propulsion solution using Space Shuttle derived ETO launch vehicles. Earth orbit rendezvous is required on the outbound leg of the mission since the crew is launched to Low Earth Orbit (LEO) separately from most of the other in-space elements. Also, this architecture assumes lunar orbit rendezvous both before and after surface exploration because the crew's Earth return vehicle remains in Low Lunar Orbit (LLO). Specific lunar surface activities were not modeled as a part of this effort.

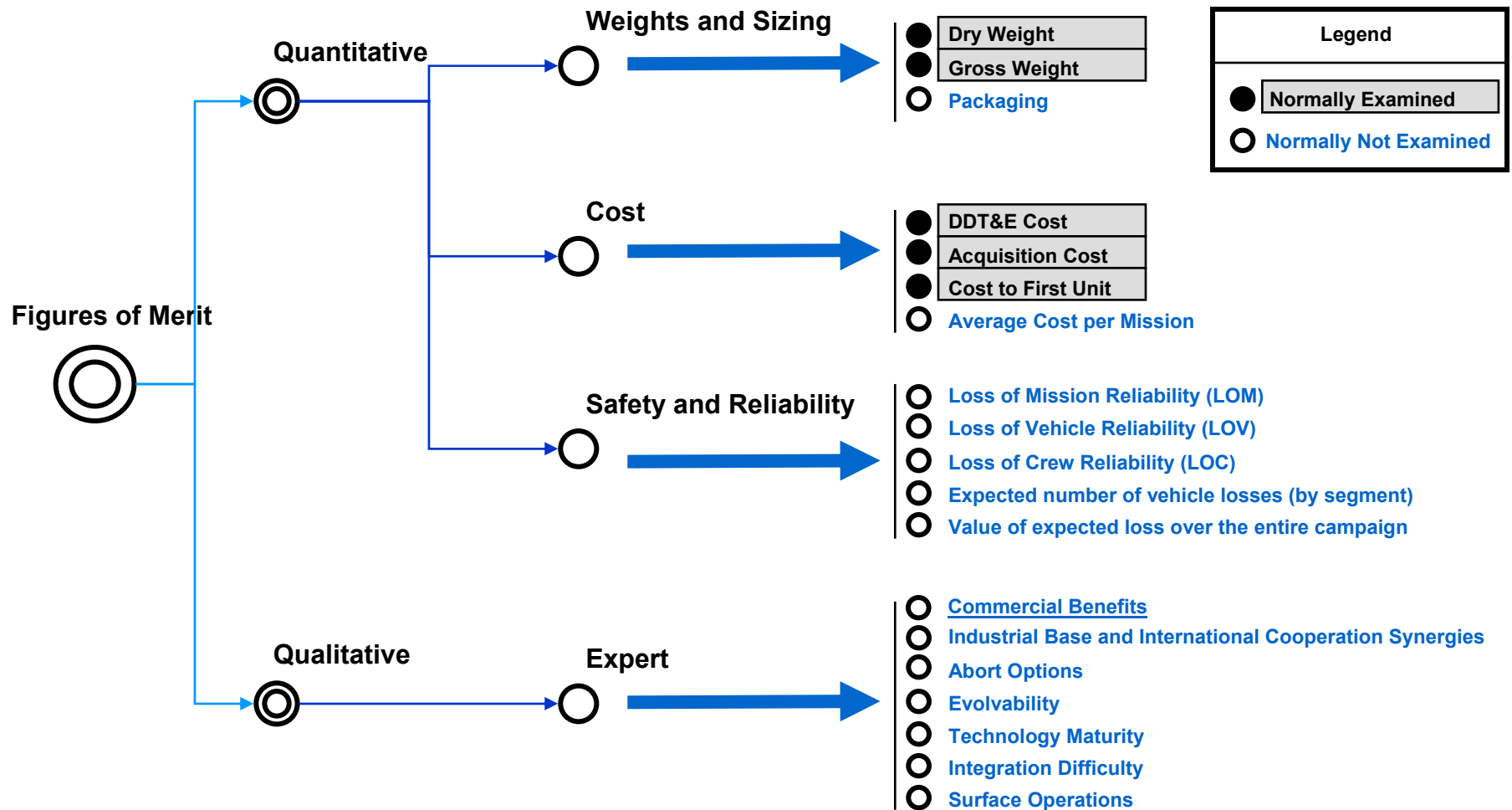


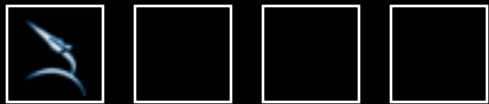
## Overview





# What Defines Value? Sample NASA Figures of Merit (FOMs)





# The Appearance of the Trillion Dollar Estimate





The \$1 trillion cost estimate is wrong. It is based upon a completely inaccurate reading of historical data and deeply flawed mathematics. But the problems are worse than this. Not only was an inaccurate number repeated endlessly by the media without confirmation, but the flawed calculations were repeated again and again by various people with their own agendas. Reporters also appear to have ignored or evaded obvious weaknesses with the original source of the information, preferring to repeat an inaccurate number that they saw repeated endlessly rather than seek out better information. The story of the \$1 trillion cost estimate raises some troubling questions about how modern journalism is conducted... Another unfortunate lesson here is that although NASA has little credibility when it comes to cost estimates, neither does the press. There is certainly tremendous irony in the fact that reporters who are so skeptical of NASA cost estimates are themselves prone to wild exaggeration and inability to apply simple inflation adjustments.

Source: Day, D. A., "Whispers in the echo chamber: Why the media says the space plan costs a trillion dollars," SpaceReview.com [online article], 22 March 2004, URL: <http://www.thespacereview.com/article/119/1> [cited 8 August 2005].



## Origins of a Number





# Developing a New Estimate



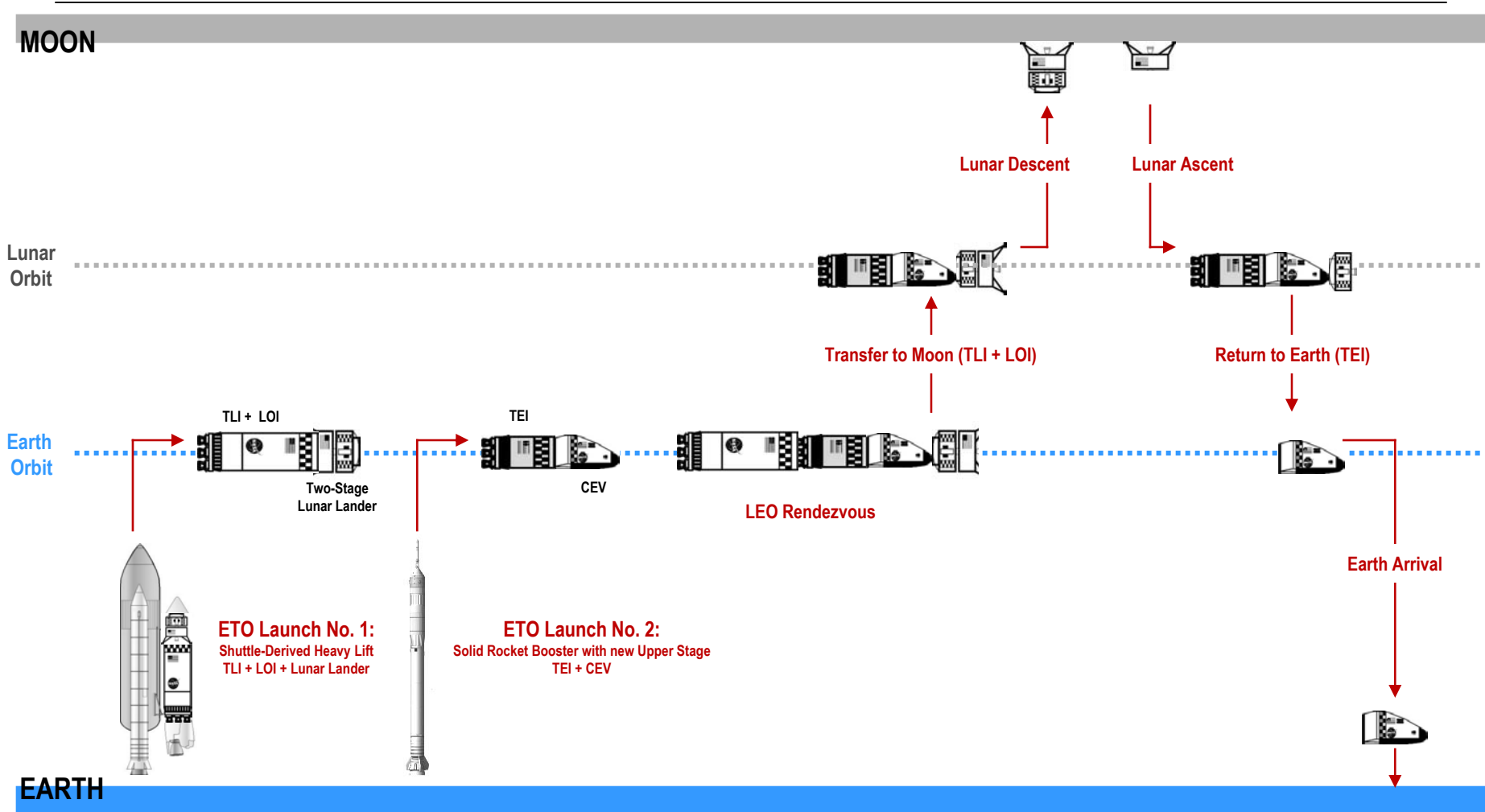


# Exploration Architecture





# Human Lunar Conceptual Mission Architecture



Note: Notional representation of lunar exploration architecture. Architecture elements may not be in scale.





# Deterministic Life Cycle Costs





## Cost Modeling Assumptions

- ▶ Given the uncertainty inherent in the early stages of such a program, a **probabilistic cost estimate** is developed for the various components of a lunar exploration architecture consistent with the Vision for Space Exploration
- ▶ Various cost methodologies were used to arrive at the estimate presented here. For some portions of the architecture, the NASA/Air-Force Cost Model (NAFCOM) 2004 was used to estimate the Design, Development, Testing, and Evaluation (DDT&E) and Theoretical First Unit (TFU) costs. Results from the Mission Scenario Analysis Tool (MSAT) physical sizing process were input into NAFCOM for the Earth Departure Stage (EDS), lunar lander, and Earth Return Stage (ERS). Other costs for other program elements such as the CEV, ETO launch vehicles, Space Shuttle support, ISS support, surface system, facilities, and operations (launch and mission) are developed from reference reports and historical experience/expert judgment.
- ▶ Mars development costs are set at a pre-determined amount for technology/systems development and do not include actual architecture development.
- ▶ These costs are inflated to then year dollars in the final Life Cycle Cost (LCC) calculation. A learning curve is applied for any multiple units acquired or for any additional learning on list the assumptions related to the costs of various elements in the architecture. A just-in-time production process is assumed for the CEV, EDS, lunar lander, and ERS.
- ▶ Triangular uncertainty distributions were placed on baseline costs and a Monte Carlo simulation was performed for twenty-five thousand runs.





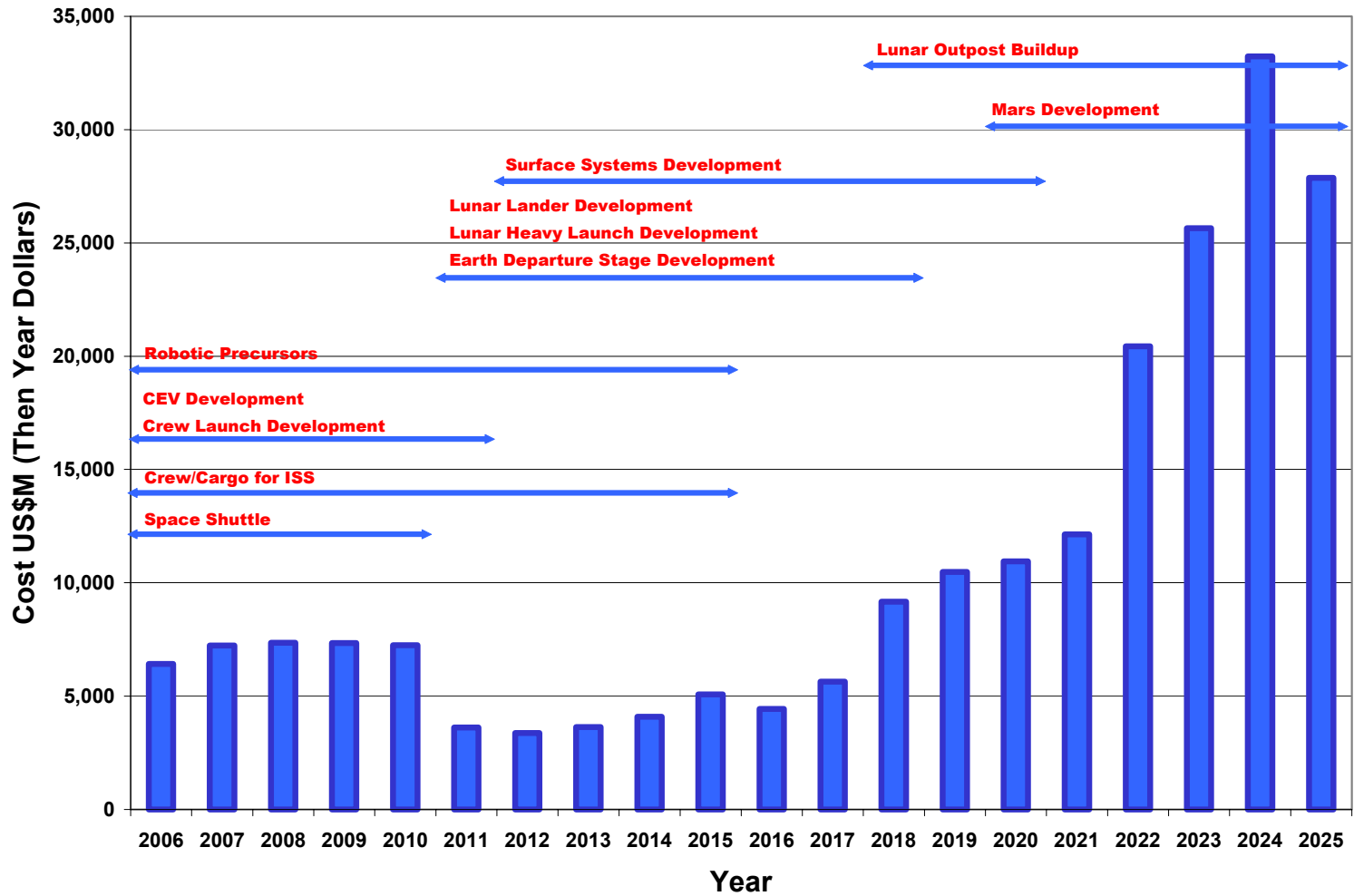
## Elements of VSE-Based Exploration Architecture Cost Estimate

Element	Start Year	End Year	Note (Most Likely Costs)
<b>Mission</b>	<b>Start Year</b>	<b>End Year</b>	US\$300M per mission, one mission per year, based upon Discovery-class mission cost
Robotic Precursors	2006	2015	US\$250M additional return to flight cost after STS 114
Space Shuttle	2006	2010	US\$3.5B for annual operational cost for 4 mission per year
International Space Station (ISS) Support	2006	2015	US\$1.4B per year ISS support costs, based upon GAO Estimate
Crew Exploration Vehicle (CEV)	2006	2011	US\$5.0B DDT&E cost, US\$1.5B TFU cost, 85% learning curve
Crew Launch	2006	2011	US\$2.5B DDT&E cost, US\$280M7 TFU cost, 97% learning curve
Lunar Lander	2011	2018	US\$3.6B DDT&E cost*, US\$334.5M TFU cost*, 85% learning curve
Lunar Heavy Launch	2011	2018	US\$6.0B DDT&E cost, US\$540M7 TFU cost, 97% learning curve
Earth Departure Stage (EDS)	2011	2018	US\$2.0B DDT&E cost*, US\$170.4M TFU cost*, 85% learning curve
Earth Return Stage (ERS)	2011	2018	US\$1.5B DDT&E cost*, US\$110M TFU cost*, 85% learning curve
Surface Systems	2011	2020	US\$5.0B DDT&E cost, US\$400M TFU cost, 85% learning curve 2019-2021: 1 surface package per year, 2022-2023: 2 surface packages per year 2024-2025: 3 surface packages per year
Lunar Outpost Buildup	2018	2025	2018: 1 mission per year, 2019-2021: 2 missions per year 2022-2023: 3 missions per year, 2024-2025: 4 missions per year
Launch Operation Facilities for CEV Launch	2007	2011 (Dev. Ends), 2025	US\$500M DDT&E cost, US\$25M per CEV launch
Launch Operations Facilities for Lunar Heavy Launch	2012	2018 (Dev. Ends), 2025	US\$3.0B DDT&E cost, US\$20M per Lunar Heavy launch
Mission Operations Facilities: Development and Operations	2010	2018 (Dev. Ends), 2025	US\$250M DDT&E cost US\$417M per each mission per year (30% of ISS annual operations costs) US\$125M per each surface package per year (10% of ISS annual operations costs)
Mars Development	2020	2025	US\$39.4B, based upon previous NASA MSFC cost estimate for Mars development comparing Mars Direct and Apollo

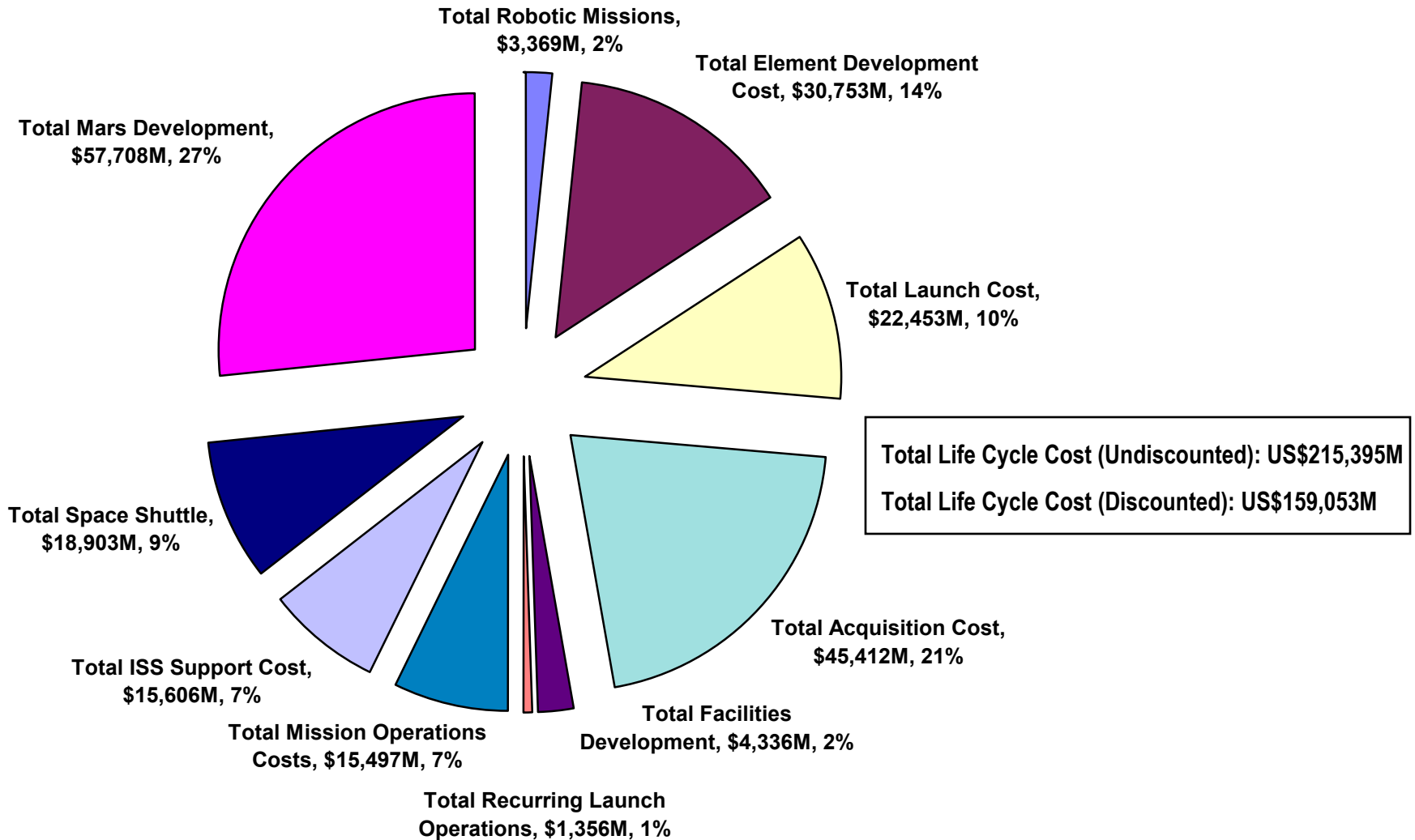
Note: Note: Unless otherwise stated, costs as in US\$FY2005, \*NAFCOM 2004 based cost estimate



# Deterministic Annual Costs for Selected VSE-Based Exploration Architecture (2006-2025)



# Deterministic Life Cycle Cost Breakout for VSE-Based Exploration Architecture (2006-2025)





# Probabilistic Life Cycle Costs

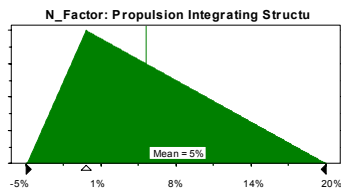




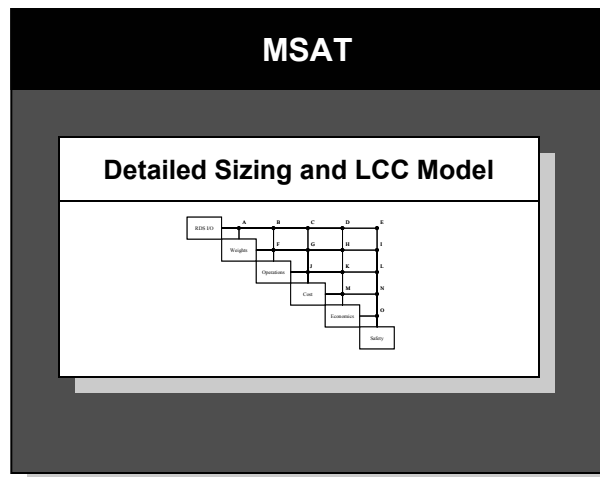
# Monte Carlo Implementation

- “Risk” is not the same as “reliability” or “safety“. Risk can be seen in payload variation, mission capture rate, LCC variation, weight variation, and even safety variation. Immature technologies and incomplete knowledge of the conceptual design are sources of uncertainty leading to program risk.

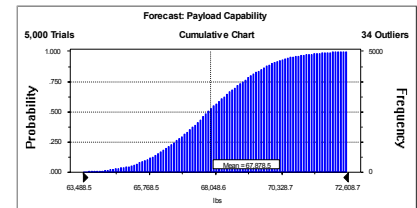
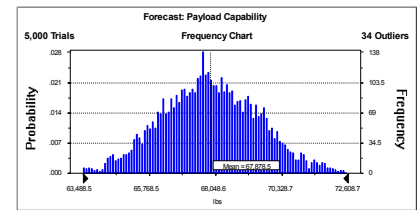
Triangular distributions placed on qualitatively and quantitatively derived costs



25,000 Monte Carlo Simulations  
Through Pi Blue Software Inc. ProbWorks®



Frequency and Cumulative Distributions of Output Metrics

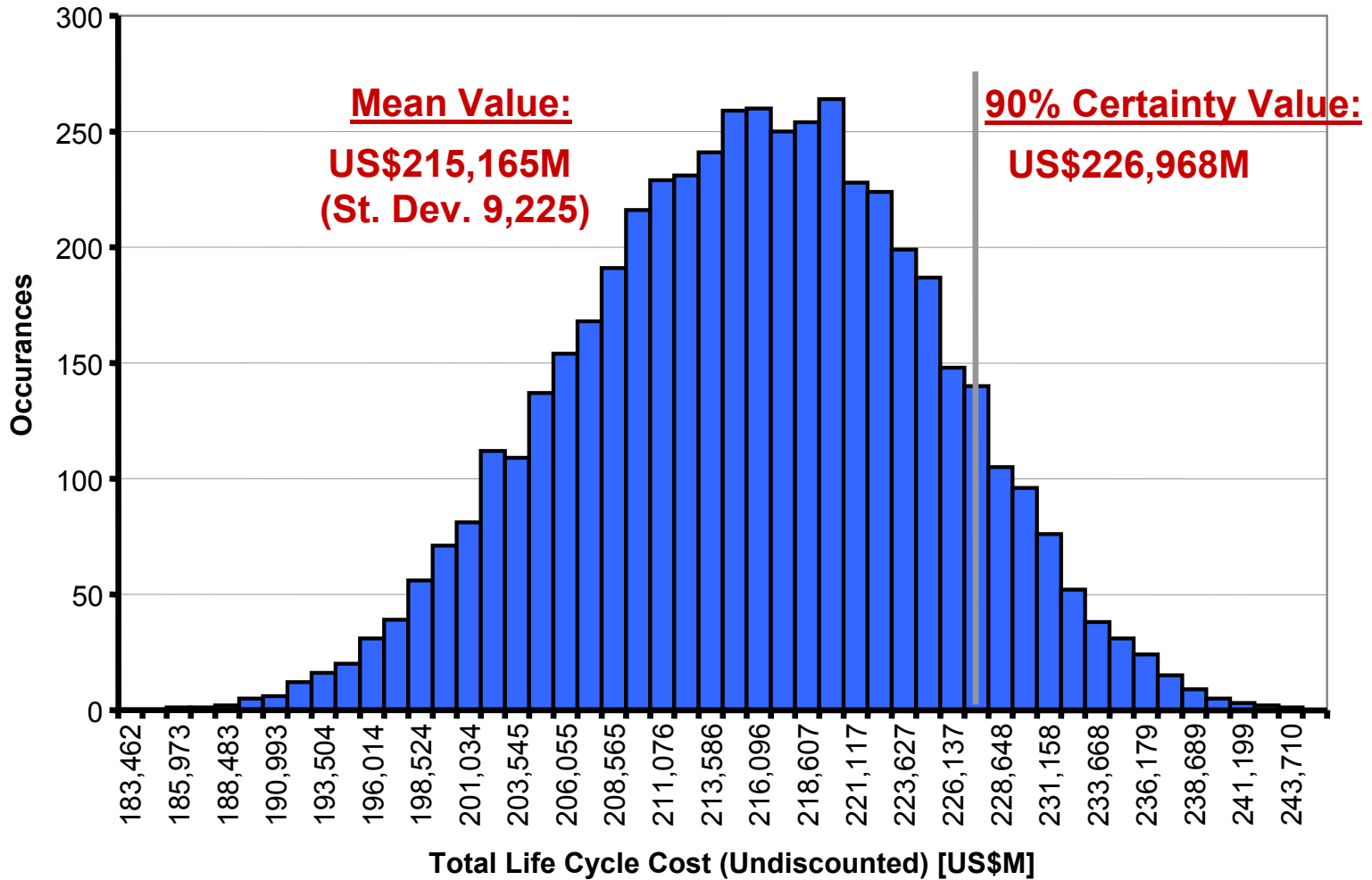


## Input Cost Uncertainty Distributions

Factor	Parameter	Minimum	Most Likely	Maximum
Robotic Precursors	Average Cost per Mission	\$300M	\$300M	\$400M
Crew Exploration Vehicle (CEV)	DDT&E	\$4.5B	\$5.0B	\$6.5B
	TFU	\$1.0B	\$1.5B	\$2.0B
Crew Launch	DDT&E	\$1.5B	\$2.5B	\$3.0B
	TFU/Initial Recurring Cost	\$280M	\$280M	\$350M
Lunar Lander	DDT&E	\$3.5B	\$3.6B	\$5.0B
	TFU	\$300M	\$334.5M	\$500M
Lunar Heavy Launch	DDT&E	\$4.5B	\$6.0B	\$6.5B
	TFU/Initial Recurring Cost	\$500M	\$540M	\$650M
Earth Departure Stage (EDS)	DDT&E	\$1.5B	\$2.0B	\$2.5B
	TFU	\$500M	\$170.4M	\$200M
Earth Return Stage (ERS)	DDT&E	\$1.2B	\$1.5B	\$2.0B
	TFU	\$100M	\$110M	\$150M
Surface Systems	DDT&E	\$3.0BB	\$5.0B	\$8.0B
	TFU	\$100M	\$400M	\$600M
Launch Operation Facilities for CEV Launch	DDT&E	\$400M	\$500M	\$800M
	Initial Recurring Cost	\$20M	\$25M	\$40M
Launch Operations Facilities for Lunar Heavy Launch	DDT&E	\$2.0B	\$3.0B	\$5.0B
	Initial Recurring Cost	\$20M	\$20M	\$30M
Mission Operations Facilities: Development and Operations	DDT&E	\$200M	\$250M	\$400M
	Mission Ops Cost – Main (% of ISS)	10%	30%	35%
	Mission Ops Cost – Surface (% of ISS)	5%	10%	15%
Mars Development	Total	\$25.0B	\$39.4B	\$50.0B



## Output Distribution for Undiscounted Total Life Cycle Cost (2006-2025)





# Conclusions



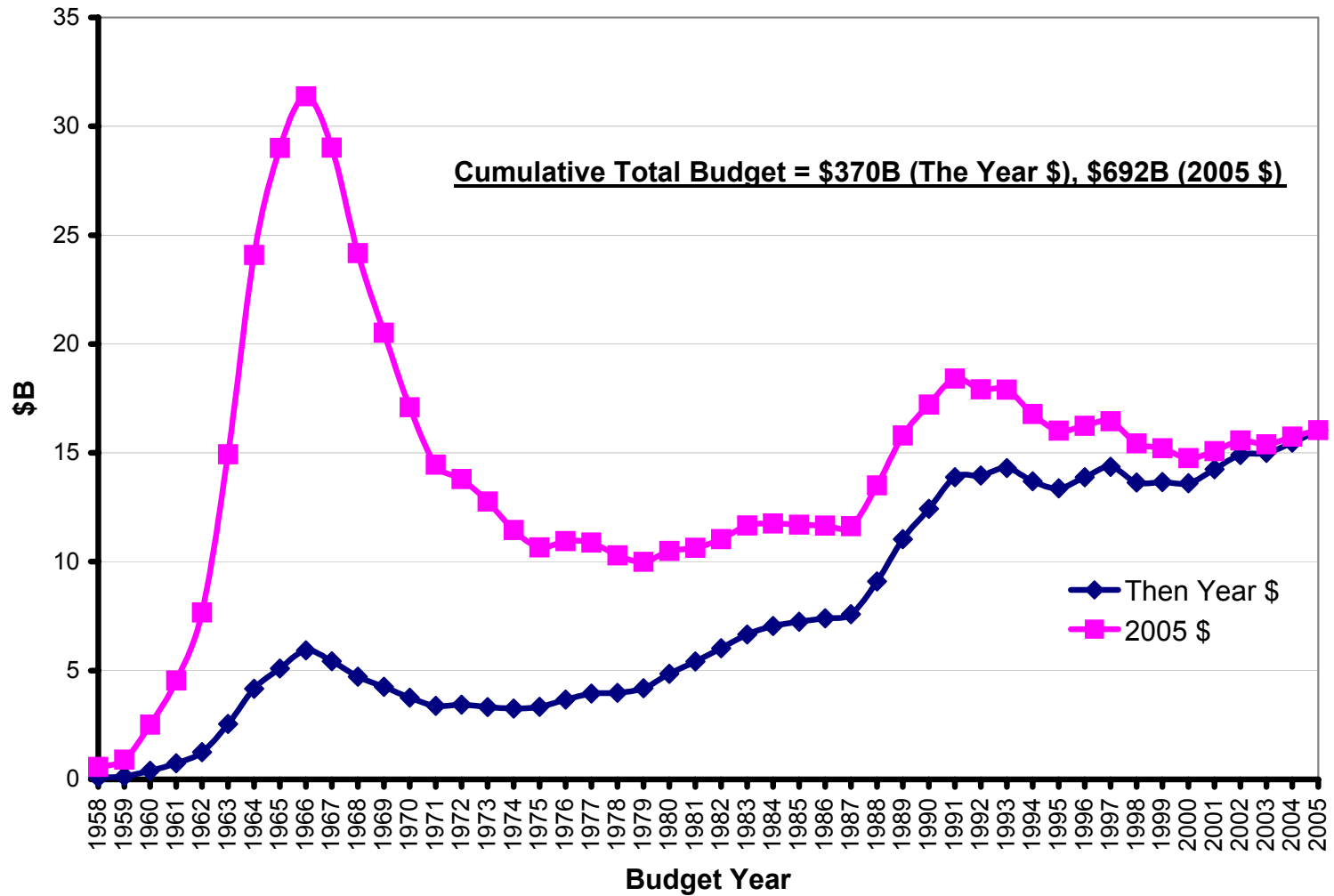


## Observations

- ▶ About one-fifth of the cost is related to vehicle acquisition
- ▶ For these assumptions, just over 10% of the total LCC is associated with CEV crew and Shuttle-derived heavy cargo launch.
- ▶ A large investment is required during the initial years in the program for development of the CEV and crew launch system
- ▶ Taking a more thorough estimation approach one can arrive at a life cycle cost of around **US\$215B (90% certainty US\$227B)** for the program years of 2006 through 2025. This is for a converged lunar architecture with Shuttle-derived heavy lift launch vehicles, lunar landers, in-space stages, Crew Exploration Vehicle, and initial cost for Mars development.
- ▶ Even with some assumptions of the uncertain future costs of individual architecture elements, the probabilistic LCC is only approximately five percent higher than the deterministic value given in the previous section
- ▶ Total development for Mars is over 25% of the total LCC
- ▶ **The effect of the large investment in Mars-related technologies in the post 2020 timeframe may be obscuring the costs for the direct lunar related exploration elements**



# NASA Annual Budget





## Conclusions

- ▶ The **one trillion dollar estimate** for implementing the Vision for Space Exploration, as provided by multiple sources, **is not a credible estimate**.
- ▶ Previous estimates have used rough analogies of historical cost estimates of previous programs and then doubled the resultant amount to arrive at estimates such as one trillion dollars.
  - As a simple counterpoint to these large estimates, consider NASA's total life cycle budget as a government entity from 1958-2005
  - This amount, if added together and inflated to fiscal year 2005, would approach \$700B
  - **Thus the projected estimates of a trillion dollars for the VSE would be more than the cumulative NASA budget**
- ▶ The estimate presented here is not meant to be a complete and final judgment on the cost of the VSE. That will require a more detailed analysis using the actual architecture scenario resulting from the ESAS activity.
- ▶ But, a rational first approach was used in this examination to elevate the debate and provide clarity through a more rigorous cost estimate of lunar exploration, **from cost guessing to cost estimation**.



## References

---

- ▶ 1. "The Vision for Space Exploration," National Aeronautics and Space Administration, June 2004.
- ▶ 2. Foust, J., "A Vision for Commercialization," SpaceReview.com [online article], July 2005, URL: <http://www.thespacereview.com/article/418/1> [cited 8 August 2005].
- ▶ 3. Day, D. A., "Whispers in the echo chamber: Why the media says the space plan costs a trillion dollars," SpaceReview.com [online article], 22 March 2004, URL: <http://www.thespacereview.com/article/119/1> [cited 8 August 2005].
- ▶ 4. Mealling, M., "Innovative Programs Announcement," RocketForge.org [online posting], July 2005, URL: <http://www.rocketforge.org/modules.php?op=modload&name=News&file=article&sid=385&mode=thread&order=0&thold=0> [cited 8 August 2005].
- ▶ 5. St. Germain, B., Charania, A., Olds, J. R., "A Stochastic Process for Prioritizing Lunar Exploration Technologies," AIAA-2005-6607, Space 2005 Conference and Exhibit, Long Beach, California, August 30 - September 1, 2005.
- ▶ 6. "Space Station: Cost to Operate After Assembly Is Uncertain," GAO/NSIAD-99-177, August 6, 1999.
- ▶ 7. Cabbageunt, M., "NASA outlines plans for moon and Mars," orlandosentinel.com [online posting], 2005, URL: <http://www.orlandosentinel.com/news/custom/space/orl-asec-moon073105,0,3136666.htmlstory?coll=orl-home-promo> [cited 8 August 2005].
- ▶ 8. Hunt, C., Van Let, M. O., "Comparing NASA and ESA Cost Estimating Methods for Human Missions to Mars," marssociety.org [online posting], 2004, URL: [www.marssociety.org/docs/MDCost.pdf](http://www.marssociety.org/docs/MDCost.pdf) [cited 8 August 2005].





## SpaceWorks Engineering, Inc. (SEI)

---

### Contact Information

**Business Address:**

SpaceWorks Engineering, Inc. (SEI)  
1200 Ashwood Parkway  
Suite 506  
Atlanta, GA 30338 U.S.A.

**Phone:** 770-379-8000

**Fax:** 770-379-8001

**Internet:**

WWW: [www.sei.aero](http://www.sei.aero)

E-mail: [info@sei.aero](mailto:info@sei.aero)

