

Considerations for a “Minimum Path” Architecture

The Second Affording Mars Community Workshop

October 14 – 16, 2014

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The opinions and recommendations provided in this presentation
are my own and do not represent an official NASA position

What Constitutes Affordable?



A strategy that enables success within a budget and timeframe justified by the importance of mission goals - Affording Mars I, 2013

- **This definition resembles early 1990's NASA Administrator Dan Goldin's mantra of *Faster, Better, Cheaper***
- **Given that success is a must¹, there is natural tension which remains between the three other key elements of this definition**
 - Budget
 - Timeframe
 - Mission Goals
- **Expecting success when each of these three factors are defined independently usually results in a null set**
- **The challenge is to find a reasonable balance of all three - Simultaneously**
 - Budget: *What level of modest budget increase is acceptable?*
 - Timeline: *What is a reasonable Mars date with demonstrable achievements along the way to the end goal? (Avoid the impression of quicksand – e.g. the Moon)*
 - Mission Goals: *Which goals make the endeavor worthwhile (not a low cost stunt)*

¹ This assumes that a reasonable level of risk is achieved. No formal risk level has yet been established for human missions to Mars. Perceived risks are not viewed the same today as in the past. "Historically, or even today in underdeveloped countries, loss of life was an unfortunate, but commonplace, occurrence within families and all other types of social units What has changed is the public expectation for success and the shock when risk and danger show themselves as injury and loss of life." Dick, S.J., Cowing, K.L., *Risk and Exploration*, NASA, 2004.

The Key Principles of Mars Affordability in a Budget Constrained Environment



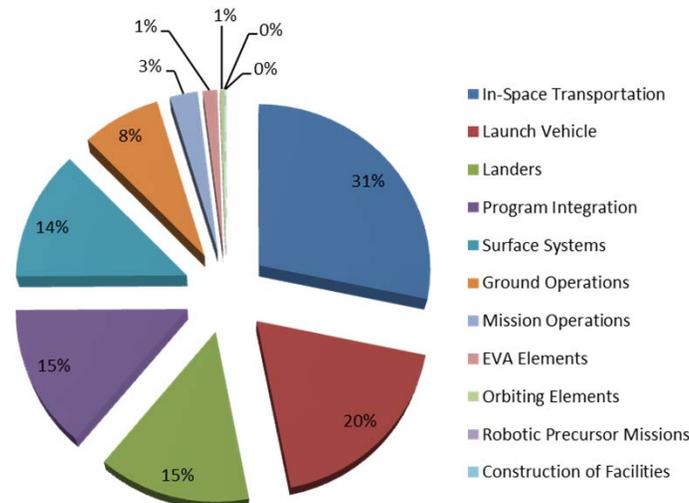
- ✓ Lower the mission mass and number of launches
- ✓ Minimize the number of unique developments
- ✓ Leverage early developments and system extensibility – sneak up on the problem
- ✓ Implement efficient management practices – Lean, Skunk Works, etc.
- ✓ Focus technology insertion
- ✓ Pay proper attention to the proper risks
- ✓ Establish a reasonable mission cadence

Mission Mass and Number of Launches

Typical Cost Distribution

- **Architecture mass has traditionally been used as the first order measure of cost**
 - Cost models are mass based (dry mass)
 - Total mass (including propellant) drives number of launches
 - Number of launches required for each vehicle stack drives operational complexity and vehicle integration costs
- **Mars architectural costs driven predominantly by space transportation and associated infrastructure costs**
 - Long-term cost (recurring and non-recurring) of NASA as Commercial customer - TBD
 - Government systems are major components of cost

Example Only. Although this is legacy data and thus old and outdated, it provides a good example of the cost drivers for typical architectures.



Mission Mass and Number of Launches

Total Delta-v as a Function of Mission Duration

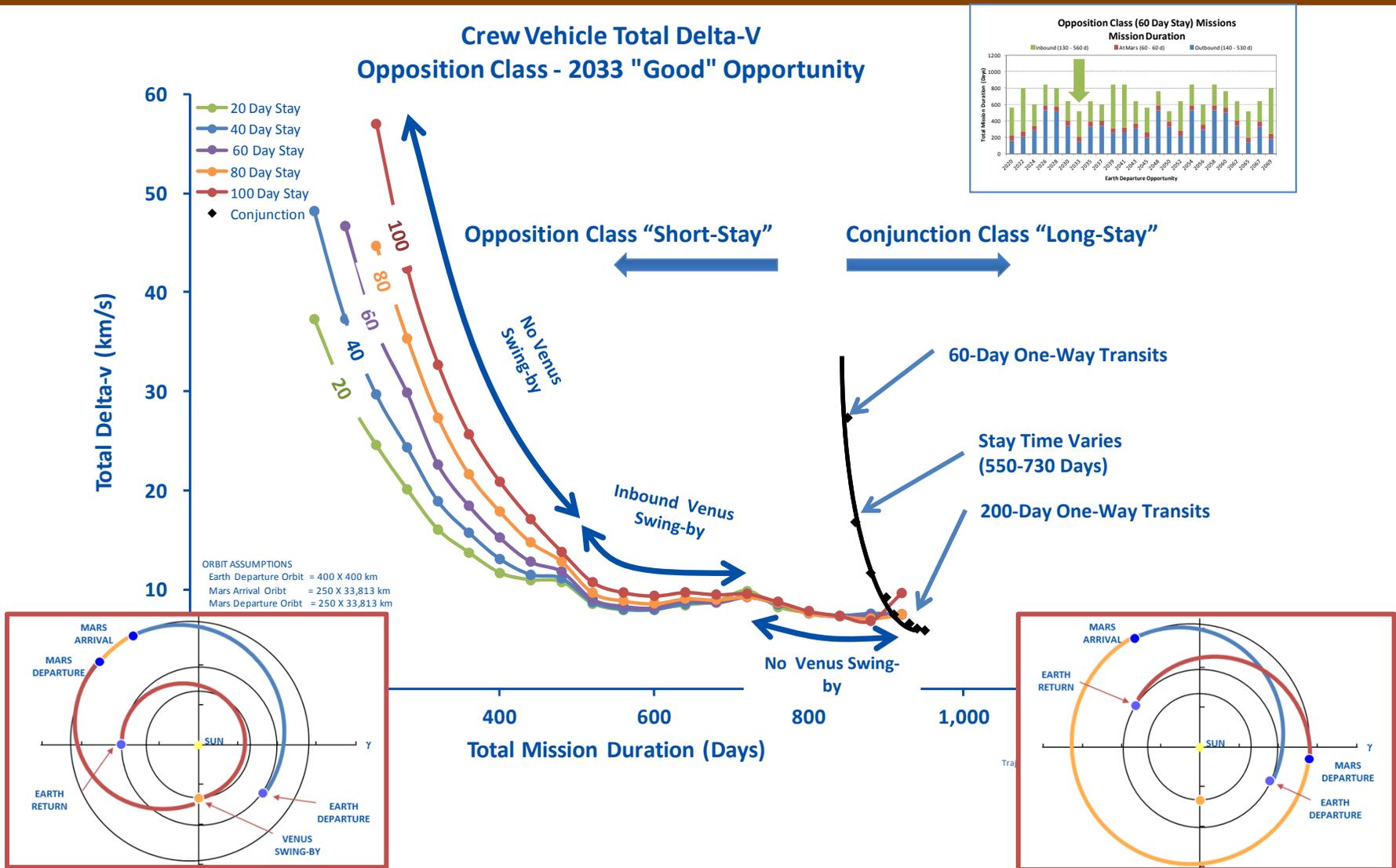


Image derived from: Drake, Bret G., et al, "Alternative Strategies for exploring Mars and the Moons of Mars", Global Space Exploration Conference, Washington, D.C., GLEX-2012.08.2.2x12575, May 2012.

How to Reduce Mission Mass

Mission Mode

- **Choice of Mission Mode**

- Provides the greatest leverage on total mission mass as well as system inert mass

- ✓ **Minimum Energy (Conjunction Class) missions for the crew**

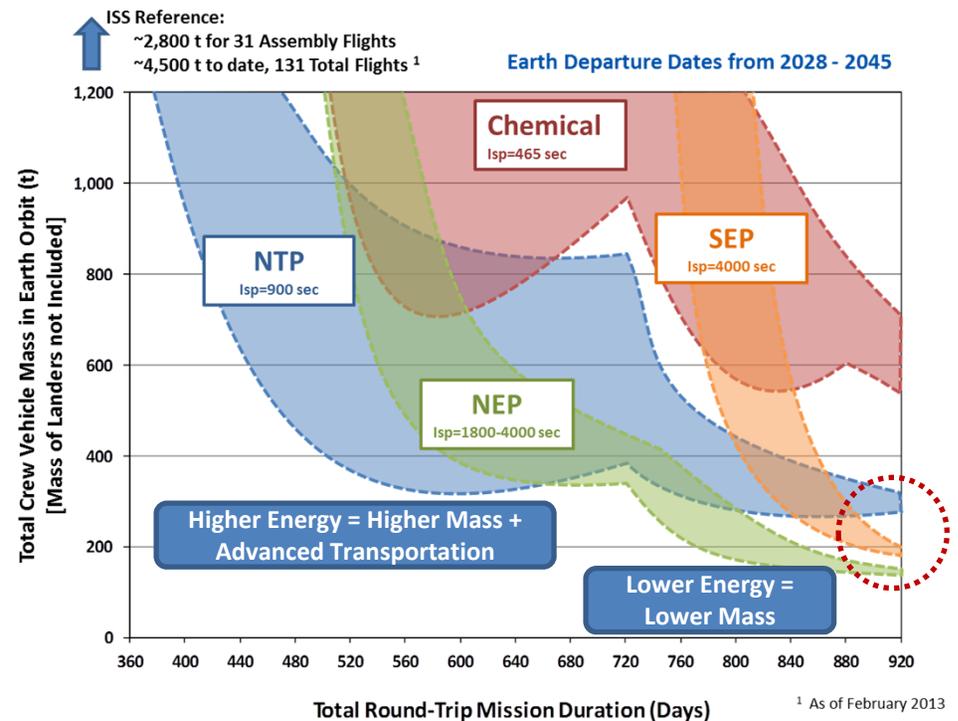
- **Split mission approach**

- Sending cargo on minimum energy transfers reduces mission mass and size/complexity of crew vehicle stack

- ✓ **Pre-deploy mission assets to Mars ahead of the crew**

- **Note**

- Pre-deploy strategies introduce greater system reliability requirements (two years or more depending on propulsion technology and mission strategy)
- Conjunction class orbital (Phobos or Deimos) missions can be especially demanding from a human health perspective (conducted entirely in deep-space)



Courtesy NASA: Drake, Bret G., "Footprints on Mars", 12 June, 2013



Capability Developments Required



- Total architecture cost driven by the number of new developments and number of systems to be maintained for long-term use
- Significant, but not unreasonable, capability and technology advancements are required to get to the surface of Mars

ISS and ARM Provides First Steps to Mars

	Mission Sequence	Current ISS Mission	Asteroid Redirect Mission	Long Stay In Deep Space	Mars Orbit	Mars Surface, Short Stay	Mars Surface, Long Stay
Mars Destination Capabilities	In Situ Resource Utilization & Surface Power						X
	Surface Habitat						X
	Entry Descent Landing, Human Lander					X	X
	Advanced Cryogenic Upper Stage				X	X	X
Initial Exploration Capabilities	Deep Space Habitat			X	X	X	X
	Exploration EVA		X	X	X	X	X
	Solar Electric Propulsion for Cargo		X	X	X	X	X
	Deep Space Guidance Navigation and Control/Automated Rendezvous		X	X	X	X	X
	Crew Operations Beyond LEO – High Speed Entry (Orion)		X	X	X	X	X
	Heavy Lift Beyond LEO (SLS)		X	X	X	X	X
ISS Derived Capabilities	Deep Space Habitat	* →		X	X	X	X
	High Reliability Life Support	* →		X	X	X	X
	Autonomous Assembly	* →		X	X	X	X ¹¹

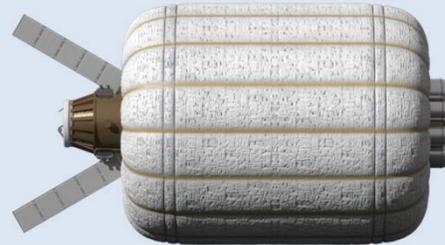
Courtesy NASA: Stich, Steve, "Asteroid Redirect Mission Building Human Space Flight Exploration Capabilities", March 6, 2014

Six Fundamental Needs

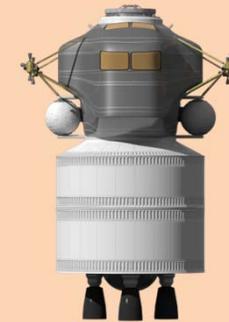
For Any Mars Surface Mission – Typically the largest cost items



Orion



Transit Habitat

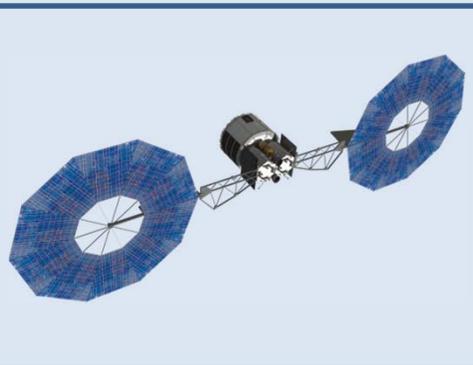


Mars Ascent Vehicle



Space Launch System

To/From Cis-Lunar staging...



In-Space Propulsion

... to/from Mars orbit



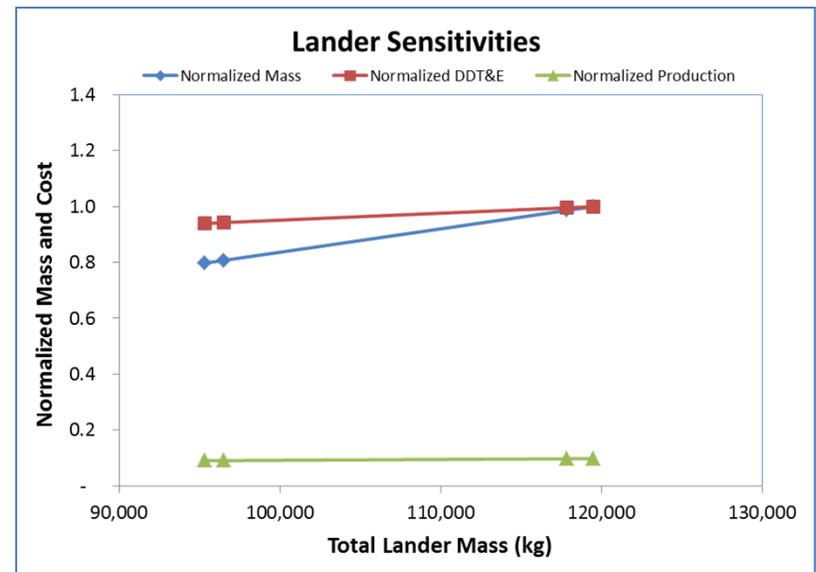
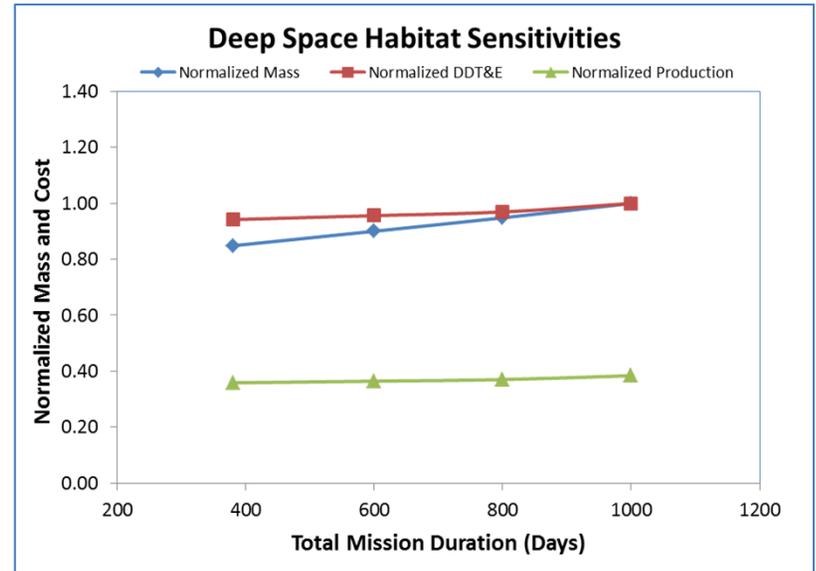
Mars Lander

... to/from Mars surface

Image derived from: Raftery, Michael, et al, "An Affordable Mission to Mars", 64th International Astronautical Congress, Beijing, China, 2013. Additional annotation with permission

Does Size Really Matter?

- **From an element cost perspective – Not really!**
 - The Design, Development, Test, and Evaluation (DDT&E) is the predominate driver of cost
 - That is, introducing a new element drives the architecture cost more than the size of the element itself
 - ✓ **Minimize the number of unique elements in the architecture or drive as much heritage between elements as possible**
- **But size is IMPORTANT**
 - Where an element is introduced into the architecture does matter
 - “The gear ratio paradigm”: A slightly heavier ascent stage will have a much greater impact on the architecture than a slightly heavier transit habitat
 - It also matters when that increased mass requires a jump in capability (e.g. adds another launch)



Affordability - Most Significant Challenge Moving Forward

Human Exploration Formulation Team (HEFT) II (January 2011)

Affordability - Most Significant Challenge Moving Forward



- ◆ **Affordability: The ability of NASA to safely execute missions within the available funding constraints (long term and short term).**
 - Program/Project Management, Risk Management Culture, Systems Engineering, Workforce/Infrastructure, Acquisition Approaches
- ◆ **Opportunities to address affordability in program/project formulation and planning**
 - Levy lean development approaches and “design-to-cost” targets on implementing programs
 - Identify and negotiate international partner contributions
 - Identify and pursue domestic partnerships
- ◆ **Traditional development**
 - Balance large traditional contracting practices with fixed-price or cost challenges coupled with in-house development
 - Use the existing workforce, infrastructure, and contracts where possible; address insight/oversight, fixed-costs, cost analysis and cost estimation
- ◆ **Adopt alternative development approaches**
 - Leverage civil servant workforce to do leading-edge development work
 - Attempt to minimize use of NASA-unique infrastructure, seeking instead to share infrastructure costs where feasible.
 - Specifically, take advantage of existing resources to initiate the development and help reduce upfront costs on the following elements: Multi-Mission Space Exploration Vehicle, Solar Electric Propulsion Freighter, Cryo Propulsion Stage, Deep Space Habitat

In order to close on affordability and shorten the development cycle, NASA must change its traditional approach to human space systems acquisition and development.

For Public Release

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Industry Input on Affordability – Major Themes

Human Exploration Formulation Team (HEFT) II (January 2011)

Industry Input – Major Themes



◆ Key tenets and recurring themes identified in industry submissions:

- Systems engineering is more than requirements tracking and documents
- Model, test and fly early and often
- Use small lean projects with highly competent empowered personnel
- Push decision authority to the lowest level. Trust them to implement and don't second guess (over-manage)
- Maintain aggressive schedules
- Manage cost and schedule as well as technical performance (maybe even more so)
- Keep it simple
- Dramatically minimize fixed costs (the key driver of mission cost)
- Oversight/Insight model has to change

**Focused, Realistic and Stable Requirements + Capable, Connected and Incentivized
Lean Teams + Short Schedules = Low cost**

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Disruptive Approaches & Advanced Technology

Pioneering Space

- Countless studies have examined revolutionary approaches of human exploration in search of the single “game changing technology”
 - Few have shown promise, especially for the near-term horizon (next 20 years)
 - Some key technologies continue to form the heart of future exploration strategies
 - Highly reliable and maintainable life support
 - Advanced propulsion (SEP)
 - Advanced EDL technologies
 - ISRU (O₂ from Mars atmosphere)
 - Nuclear surface power
- ✓ Examination of breakthrough approaches should continue, but the majority of technology investments should be applied to the core exploration technology set

Space Elevators



Power Beaming



Life Support



Advanced Launch



Virtual Research



Advanced Transportation



In-Situ Resources



Self Assembly



Nano-Structures



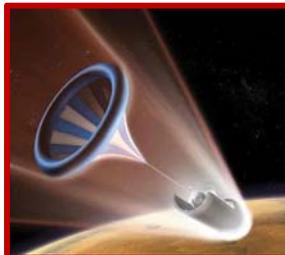
Nuclear Power



Space Farming



Entry and Landing



He3 Fusion



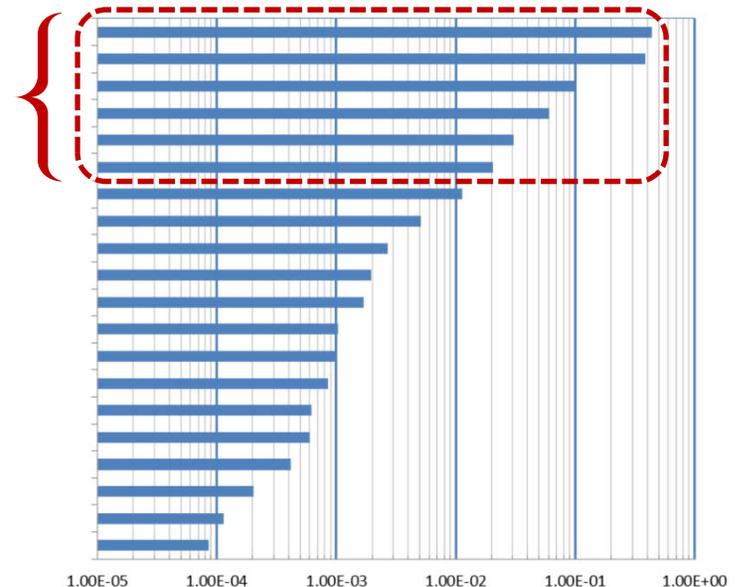
Advanced Information



Risk and Cost



- The public is not risk averse. In fact, minimizing risk may mean minimizing public interest.
- Acceptance of risk changes with time and culture. We need to be an active voice in changing the culture to accept the risks of pushing the boundaries of human exploration.
- ✓ **Not all risks are equal and resources should continually be focused on the risks that matter**
- **In this example the top few risks constitute 97% of the total risk)**
 - Habitat life support reliability
 - Entry, descent and landing
 - Transportation system reliability
 - Human health and performance risks
 - Mars ascent
 - Surface system reliability



Risk Posture in the Modern Era



The Man in the Arena - Theodore Roosevelt

"It is not the critic who counts; not the man who points out how the strong man stumbles, or where the doer of deeds could have done them better. The credit belongs to the man who is actually in the arena, whose face is marred by dust and sweat and blood; who strives valiantly; who errs, who comes short again and again, because there is no effort without error and shortcoming; but who does actually strive to do the deeds; who knows great enthusiasms, the great devotions; who spends himself in a worthy cause; who at the best knows in the end the triumph of high achievement, and who at the worst, if he fails, at least fails while daring greatly, so that his place shall never be with those cold and timid souls who neither know victory nor defeat." †

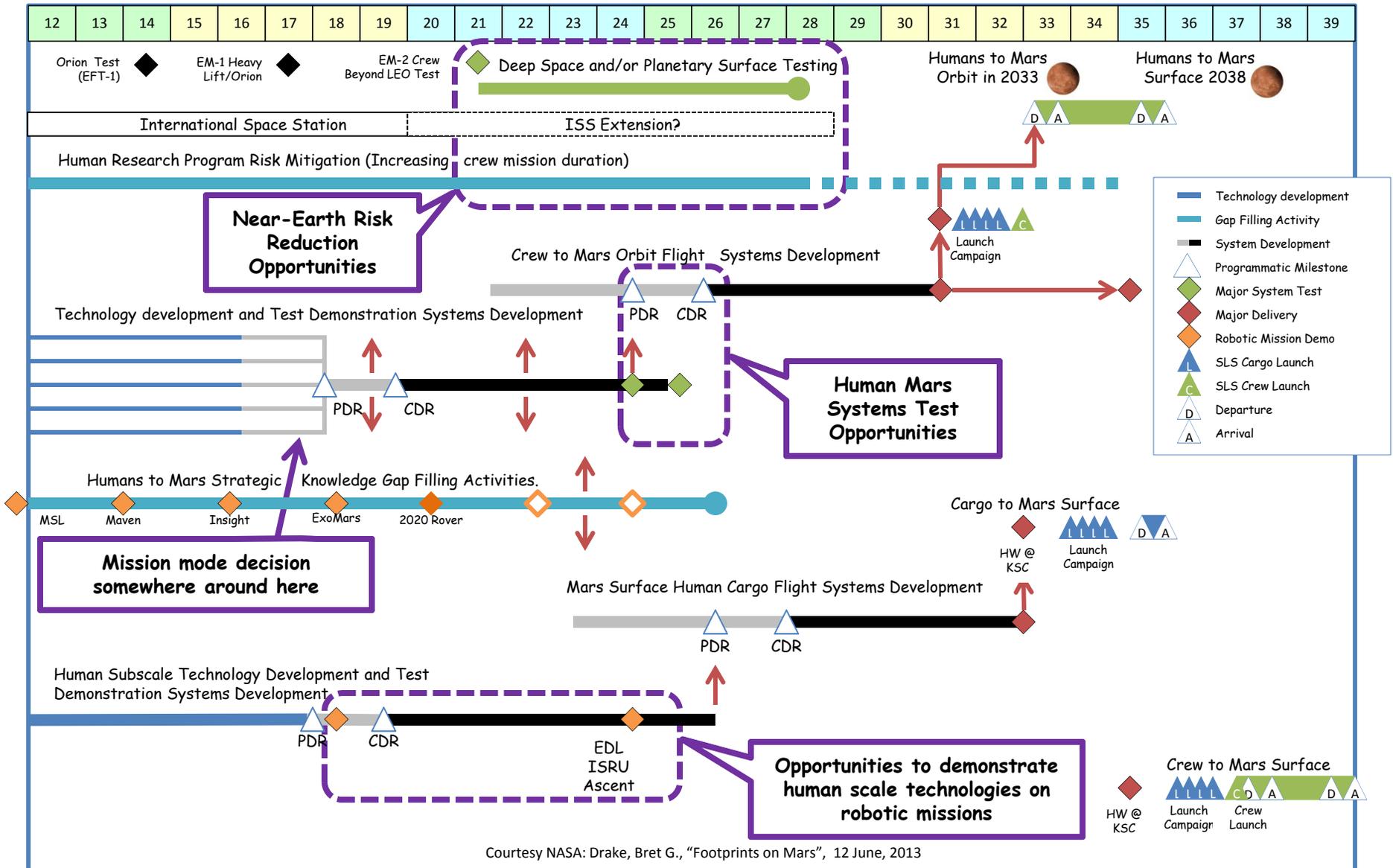
† Excerpt from the speech "Citizenship In A Republic" delivered at the Sorbonne, in Paris, France on 23 April, 1910

Titanic and Other Reflections - James Cameron

" It is absolutely important to use all of our accumulated knowledge to be as safe as possible. However, safety is not the most important thing. I know this sounds like heresy, but it is a truth that must be embraced in order to do exploration. The most important thing is to actually go. Because if safety were the most important criterion, we would not go to Mars for 10,000 years, because only then could we assure absolute, 100 percent success. Historically the success of cultures and nations has been the result of their ability to balance risk and reward—to put it another way, caution and boldness." *

* Dick, S.J., Cowing, K.L., *Risk and Exploration*, NASA, 2004.

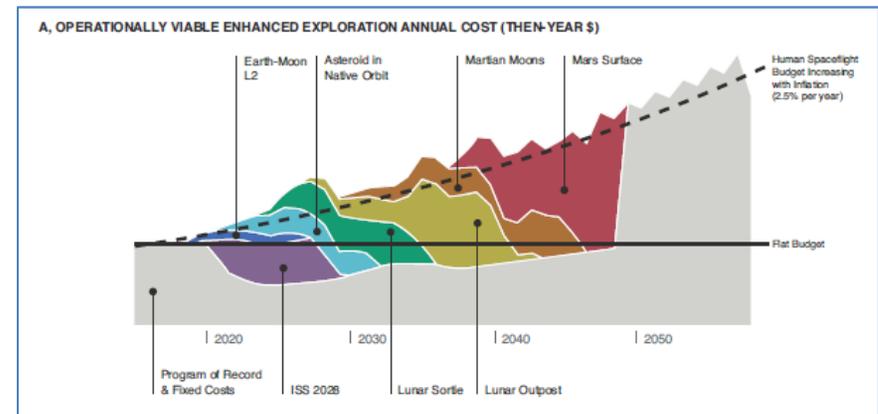
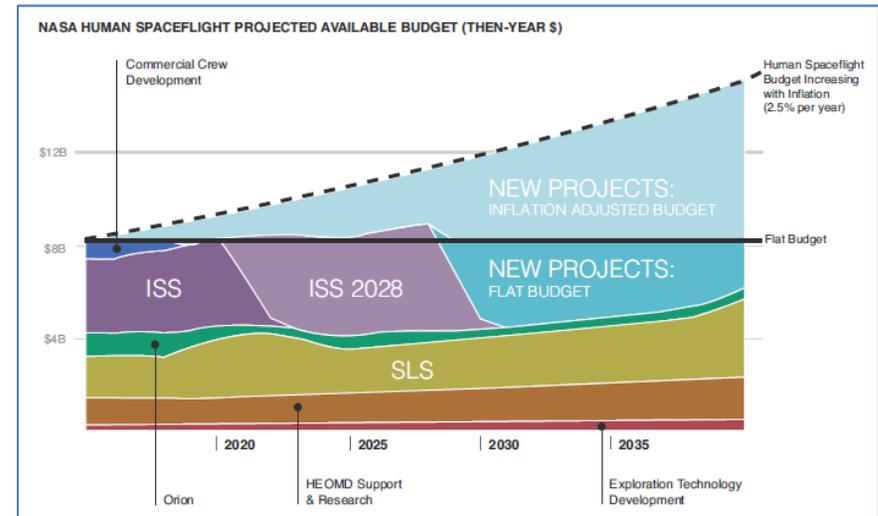
If Humans to Mars Orbit by 2033 and to the Surface Two Opportunities Later, then...



Courtesy NASA: Drake, Bret G., "Footprints on Mars", 12 June, 2013

The Cost Profile Component of Affordability

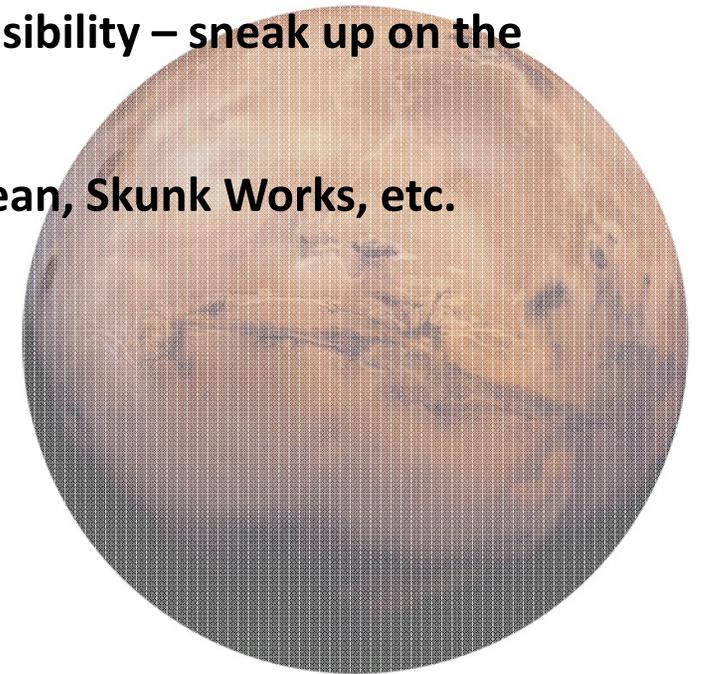
- **Affordability challenges**
 - Continual erosion of future exploration budget wedge
 - Early development of SLS and Orion help buy down initial investments
 - But near-parallel development of other large systems remain (habitation, transportation, lander, ascent stage)
 - Combined with optimal cost profiles, this can result in large peak funding
- **Careful examination of the budget implications of architecture and mission design is critical**
 - ✓ **Maximize extensibility of early developments (ISS demonstrations, transportation {ARM} and habitation {EAM}) while minimizing requalification**
 - ✓ **Stagger and phase large developments if possible to help reduce peak funding required**
 - ✓ **Target mission opportunities to coincide with budget availability (may need to skip opportunities)**
 - ✓ **Minimize infrastructure sustaining costs**



* National Research Council, "Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration", The National Academies Press, 2014

So what constitutes a “minimal path” Mars architecture in a budget constrained environment?

- **Lower the mission mass and number of launches**
 - ✓ Split-Missions (pre-deploy mission hardware ahead of the crew)
 - ✓ Utilized minimum energy conjunction class missions
- **Minimize the number of unique developments**
 - ✓ E.g.: Exploration Augmentation Module = Mars Transit Habitat = Surface Habitat
- **Leverage early developments and system extensibility – sneak up on the problem**
 - ✓ E.g.: ARM SEP = Mars SEP
- **Implement efficient management practices – Lean, Skunk Works, etc.**
- **Focus technology insertion**
 - ✓ Highly reliable closed life support
 - ✓ Advanced propulsion (SEP)
 - ✓ Advanced EDL technologies
 - ✓ ISRU (O₂ from Mars atmosphere)
 - ✓ Nuclear surface power
- **Pay proper attention to the proper risks**
- **Establish a reasonable mission cadence**
 - ✓ Cis-Lunar Demonstrations => Mars Orbit => Mars Surface (if human health protocols ok)
 - ✓ Cis-Lunar => Mars Surface Long Stay (if human health protocols not acceptable)



The Key Principles of Mars Affordability



Discussion