Constellation Lessons Learned Overview for AAS

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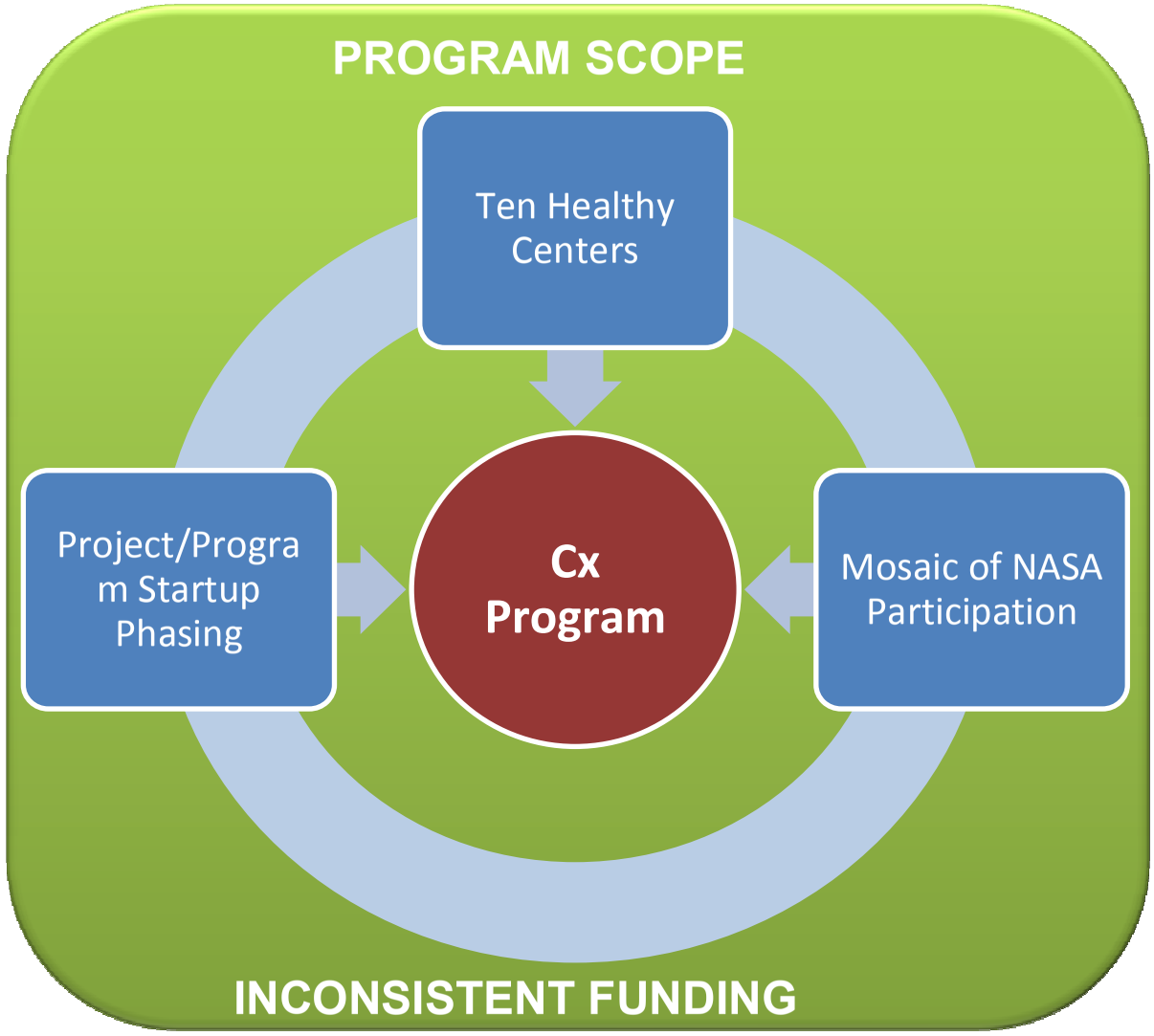
Introduction

- This package represents the key lessons learned synthesized from hundreds of inputs across the Constellation Program
  - Constellation “Challenge”
  - Individual Program Office activities
  - Project lessons learned activities
  - Ares I-X test flight lessons learned
- Overview focuses on factors which influenced the Constellation Program to provide context for the lessons learned
- Is simply the tip of the iceberg
  - Full reports have been written or are planned, detailing multiple aspects of the program and its accomplishments

Key Lessons Learned

- **Robust vs. optimal planning – the only certainty is that the funding will not match the plan**
- **Schedule creep & the fixed base – the law of diminishing returns**
- **In-house tasks – sustaining the NASA institutional base vs. affordably supporting the Programs – getting from "or" to "and"**
- **Flight Tests – learning by doing**
- **Communications among a far-flung team – interpersonal networks and IT applications can improve bandwidth**
- **Tailoring of D&C Standards – drinking from a fire hose**
- **Tailoring process simplification – the law of unexpected consequences**
- **Risk-Informed Design – risk as a commodity**
- **Roles, responsibility, & authority – a non-thermodynamic application of entropy**
- **Decision making – is only as efficient as RRAs are clear & understood**
- **Organization is organic – you'll never get it right, but you can make it better**

LL Context – Factors influencing Cx



These factors, individually & jointly, influenced the Cx Program in ways both beneficial and detrimental. This provides the context for Cx Lessons Learned.

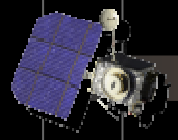
NASA's Exploration Roadmap Circa 2006

What Was Our Timeline?

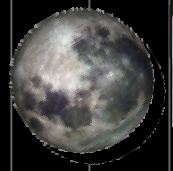
05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

Initial Capability

Lunar Capability

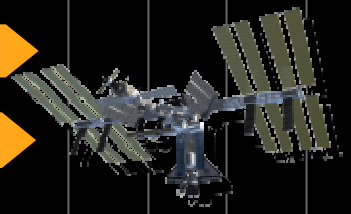


Exploration and Science Lunar Robotics Missions

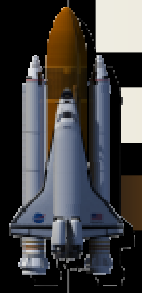


Lunar Outpost Buildup

Research and Technology Development on ISS



Commercial Orbital Transportation Services for ISS



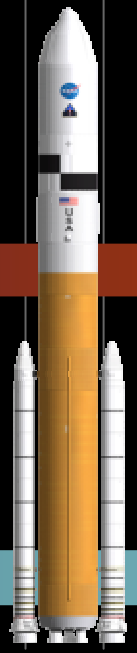
Space Shuttle Operations

Space Shuttle Program
Transition and Retirement

Ares I and Orion Development

Operations Capability Development
(EVA Systems, Ground Operations, Mission Operations)

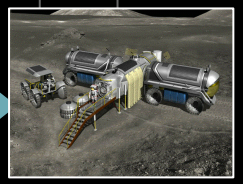
Orion and Ares I Production and Operation



Altair Lunar Lander Development

Ares V and Earth Departure Stage

Surface Systems Development



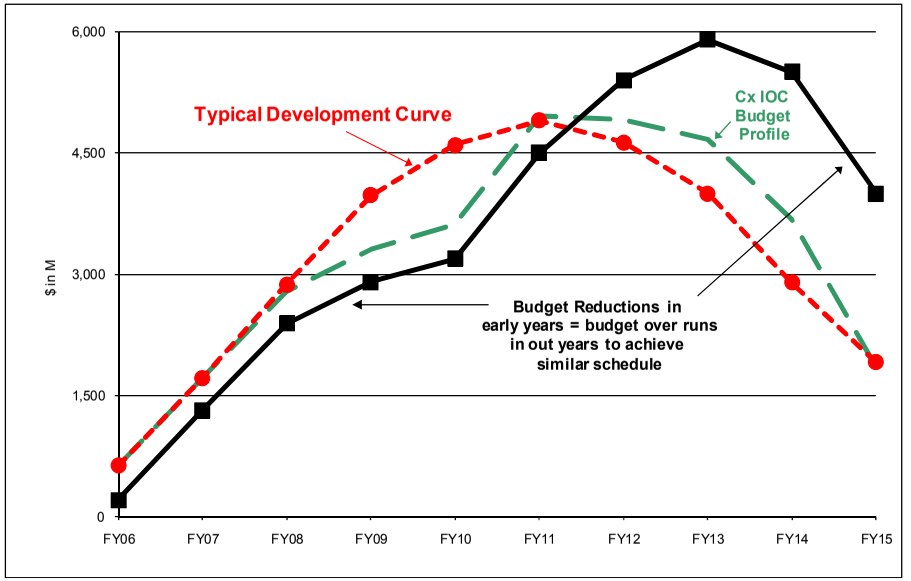
Program Scope – Constellation as a multi-decadal undertaking

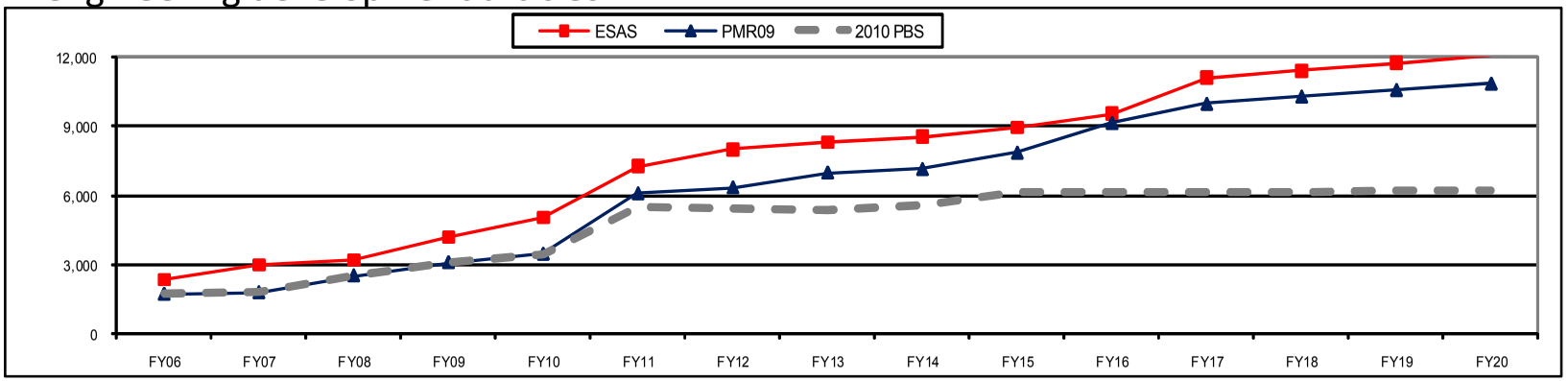
- Program focus on getting beyond LEO drove technical and programmatic decisions that were sub-optimal when viewed from a near-term (e.g. Phase I IOC only) perspective
  - Ares Upper Stage common bulkhead incorporated to provide ascent margin for the block 2 Orion's increased propellant load, and increased near-term risk
  - ESAS configuration to LEO included an Ares I First Stage derived from a four segment booster and SSME Upper Stage Engine
    - Configuration change to five segment First Stage and J-2X engine driven by desire to begin development of components for the heavy lifter (Ares V) needed for beyond-LEO missions

- Long-term, strategic view influenced other Program decisions on organization, application of Agency technical standards (e.g. CEQATR), units of measure (SI), data architecture, etc. that were perplexing when viewed only from an IOC perspective

Inconsistent Funding: Plans vs. Reality

- Through FY10, **10% in real budget cuts**
  - $3.9B worth of content transferred out of Program budget of $17B
  - $1.3B of true budget reductions
- Funding "notch" in FY10 departure from typical development profile
  - Smaller "notch" encountered each year as the FY tended to start with a CR
  - Impaired ability to buy down risks, invest in engineering development articles



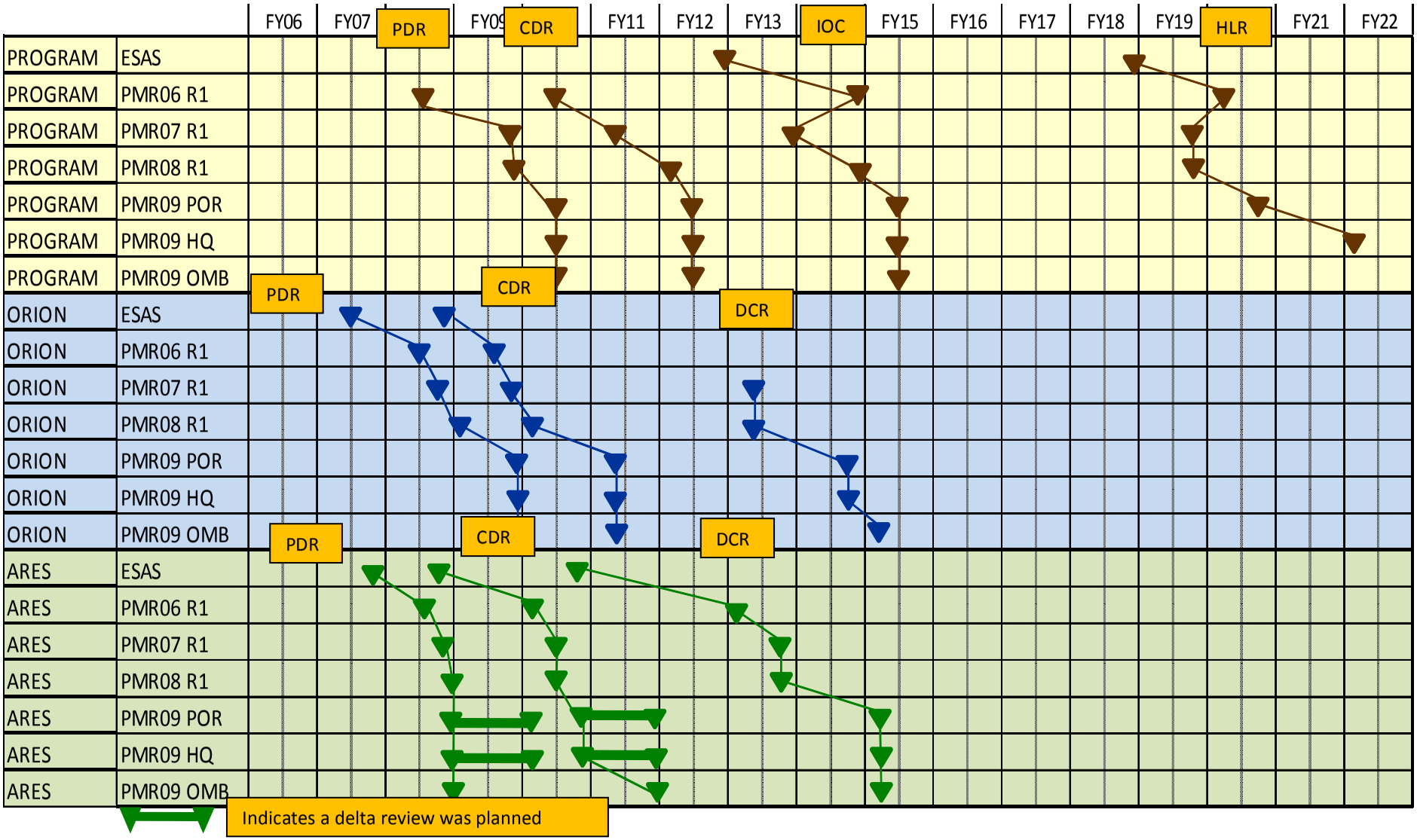


RY$ In M	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	Total
ESAS	2,333	2,976	3,195	4,202	5,034	7,273	7,994	8,324	8,558	8,948	9,547	11,107	11,422	11,744	12,073	114730
PMR09	1707	1779	2514	3085	3454	6085	6346	6991	7145	7856	9145	9983	10294	10582	10854	97820
2010 PBS	1707	1779	2514	3085	3454	5524	5444	5376	5570	6153	6161	6170	6178	6186	6195	71496
PMR09 vs. ESAS Delta	(626)	(1197)	(681)	(1117)	(1580)	(1188)	(1648)	(1333)	(1413)	(1092)	(402)	(1124)	(1128)	(1162)	(1219)	(16910)
Passback vs. ESAS Delta	(626)	(1197)	(681)	(1117)	(1580)	(1749)	(2550)	(2948)	(2988)	(2795)	(3386)	(4937)	(5244)	(5558)	(5878)	(43234)

Inconsistent Funding: The Over-riding Context

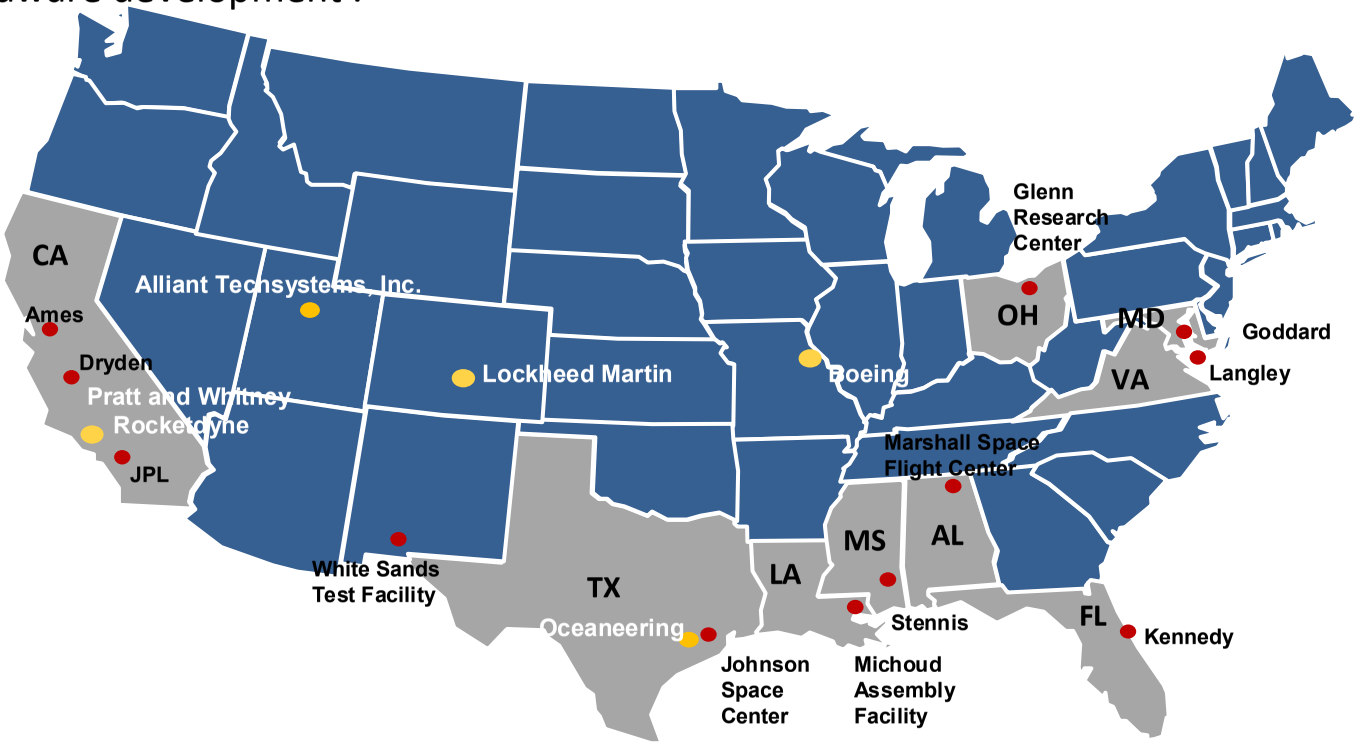
- Budget pressure influenced everything – exacerbated all the other factors
  - Efforts to hold schedule without sacrificing content despite funding cuts depleted Cx reserves
- The Contractor's fixed base ramps up proportionately with the contract value, but cuts tend to be absorbed primarily in the variable content – deferring hardware buys, etc.
  - Schedule risk grows as more activities creep onto the critical path
  - Risk mitigation is deferred
- Inadequate reserves or spending flexibility
  - Inability to fund risk mitigations
  - Inability to respond to cash flow disruptions resulting from annual CRs at the beginning of each FY

Funding below Plan: the Consequences



10 Healthy Centers
Cx as an Agency-wide Flagship Program

- **Beneficial Effects**
  - Engagement of non-traditional human spaceflight Centers in Cx allowed Cx to tap into key skills and unique facilities across the Agency.
  - Various Center teams contributed to Cx Program successes in tangible ways – engineering analysis, program integration, & flight hardware development .
- **Detrimental Effects**
  - Different ways of doing business among Centers & contractors at times led to confused RRA across the Cx Program & convoluted the decision making process.
  - Large team size can mask needed changes to clarify RRA over time



Summary – Key Lessons Learned

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Challenges for the Future

- Most significant issue in Human Space Flight is the “fixed cost” of the enterprise – the ‘fundamental conundrum’
- Technology investment strategy should address “cost” and “mission risk” as a key figures of merit
- Must continue to press for lean, flat teams
- Must continue to press for a more incremental flight test approach to evolve exploration capabilities
- Must continue to listen to industry and embrace ‘best of the best’ to reduce “fixed cost”
- Most effective government/industry split to maximize progress
- Must continue to attend to lifecycle cost even under highly constrained development budgets

“All that is gold does not glitter,
Not all those who wander are lost”

J.R.R. Tolkien, Fellowship of the Ring

Bonus Material

Historical Exploration - Learning Lessons from the Past to Inform the Future (Bedford, Quigley, Revie and Walls)

- **"Unknown unknowns" can be converted to "known unknowns" by experience, but we can use information gathering to buy down uncertainty on known unknowns (All)**
  - This arises in all the cases. For example Columbus studied the currents around different Atlantic islands in order to reduce uncertainty about departure and return directions. He had to encounter land before he found out that the Americas existed.
- **Some unknown unknowns remain and can be mitigated by goal change (All)**
  - Columbus remained publicly convinced that he had found a route to Asia, but mitigated this uncertainty by concentrating on exploiting the lands he had discovered.
- **Goal changes are natural and can be opportunistic (Columbus, Raleigh, Shackleton).**
  - For Columbus, the Spanish monarch shifted their goals from identifying a trade route to the Far East to exploitation of America.
  - Raleigh shifted his goals between privateering and colonization.
  - However in both cases, the strategic goal of prosperity and increased security remained – it was only the program goals that changed.
  - In the case of Shackleton, the strategic goal was abandoned and the program goal became survival.

Historical Exploration - Learning Lessons from the Past to Inform the Future (Bedford, Quigley, Revie and Walls)

- **History judges by hindsight (Columbus, Shackleton, Apollo 13)**
  - With hindsight many judge the successful return of Apollo 13 to be as great an achievement as the landing on the moon – certainly, it has remained as high in public consciousness.
  - In the case of Shackleton, history remembers the name of the Shackleton party but the successful Ross Sea party is largely unknown.
  - Columbus is considered a visionary and very successful explorer when in actual fact he was an excellent mariner but not necessarily an excellent explorer.
- **Need to be wary of decisions that restrict future goal changes (Raleigh, Darien)**
  - Both Raleigh and Darien made initial choices of location that greatly restricted their ability to continue the missions. Raleigh attempted to move location at great cost and was ultimately unsuccessful.
- **Technology heavily influences goal setting and political agenda (Franklin, Apollo)**
  - Franklin"s goals were set because the organizers believed that technology had increased to the point where they could overcome the environmental conditions previously encountered.
  - The Apollo goals were set based on the political and technical assessment of US capability relative to the USSR. The International Geophysical Year pushed the US and USSR governments into competition in space.

Historical Exploration - Learning Lessons from the Past to Inform the Future (Bedford, Quigley, Revie and Walls)

- **Historically, internal risks are not causes of strategic failure (All)**
  - Internal risks are problems at mission and sometimes at program level, but not at strategic level.
- **Competition is a principal driver for exploration (All)**
- **Exploration success can be accelerated by competition (Columbus, Apollo)**
  - Columbus was forced to identify a trade route to the Far East by sea due to the collapse of the Silk Road. In addition he had to choose a route that avoided the Horn of Africa because of posts set-up by the Portuguese.
  - For Apollo, because the Soviet Union was able to achieve significant advances in the space race prior to the US, the US focused substantial resources on their strategic goal.
- **Lack of alignment in stakeholder and actor priorities is a contributor to strategic failure in colonization (Columbus, Raleigh, Darien)**
  - In all three cases, what the crew had expected to be accomplished during the mission was not met. This was because the goals of the leaders and the crew were not aligned with one another. Actors, both leaders and crews, were acting in their own self interest and not meeting the strategic or program goal.

Historical Exploration - Learning Lessons from the Past to Inform the Future (Bedford, Quigley, Revie and Walls)

- **A potential downside of any form of collaboration is the self interest of actors**
  - More opportunities for problems during colonization than exploration. However incentives provide means of aligning priorities but must be robust to future events (Columbus, Raleigh)
- **Natural and generated in situ resources can provide substantial competitive advantage, e.g. choice of point of departure (Columbus, Apollo)**
  - Columbus was able to leave from the Canary Isles due to the fact that the Spanish monarch had previously acquired the island.
  - The US had an advantage over the Soviet Union as they were able to depart from a site much close to the equator.
- **Failures can open up new opportunities and chances to learn (Columbus, Apollo)**
  - In the case of Columbus, the loss of a ship on his first sortie meant that he had to accelerate plans for colonization.
  - The fire of Apollo I meant that stricter procedures were put in place for future missions.

- **Safe havens and alternative modes offer the chance to mitigate against program failure when mission failure occurs (Columbus, Shackleton, Apollo 13 as opposed to Darien)**
  - Columbus was fortunate that there were abundant natural resources and good weather at his destination.
  - Similarly, whilst the environmental conditions were difficult, Shackleton was able to find safe havens so he could break up his party and have greater chance of success.
  - For Apollo 13, the Lunar Module acted as a safe haven for the crew when their primary ship, the Command and Service Module could no longer support them. If this failure had occurred, during the Apollo 8 mission where the Lunar Module was unavailable, the crew would not have been able to return to Earth.
- **Tangible outputs keep stakeholders happy and give credibility (Columbus as opposed to Cabot, Raleigh)**
  - **Skill of the crew to be flexible to failures and opportunities is important for crew survival and mission success (Shackleton, Apollo as opposed to Raleigh, Franklin)**
  - The crew, in the case of both Shackleton and Apollo, were able to adapt to the difficulties they were facing