



Risk Profile for NASA's Crew Exploration Vehicle (CEV) System (aka ORION)

Presented to:

INCOSE Chesapeake Chapter

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Overview

- **Task: Risk identification for CEV**
- **Background:**
 - Vision for space exploration
 - NASA initiative
 - **Crew exploration vehicle (CEV) system**
 - **CEV servicing ISS, then to Moon and Mars**
 - Schedule and cost of exploration system
- **What we did:**
 - Applied Delphi technique
 - Developed a CEV risk profile
 - Drew some conclusions
- **Q&A**



CEV on top of
Crew Launch Vehicle
(Ares I)

Task: Risk Identification for CEV

- Office of Chief Engineer of NASA initiated a task to identify the risks faced by CEV and its crew in the new Exploration Vision
 - Period of performance: Nov 2004 through Jan 2005 (90 days)
 - Budget: under \$100K
 - Resources: NASA and industry experts (about 12)
- A plan to execute the task was submitted and approved by NASA
- NASA appointed a Project Manager, Bobbie Jenkins
- The Risk assessment team got a jump start

Background:

Vision for Space Exploration (VSE)

- US President announced a new vision for space exploration on Jan 14, 2004
 - Extend humanity's presence across solar system, starting with a return to Moon by 2020, followed by journeys to Mars and beyond
- Goals for VSE
 - Complete ISS by 2010
 - **Develop and test new crew exploration vehicle (CEV) by 2008**
 - Return to the Moon by 2020
 - Follow up with human missions to Mars and beyond



US President meets Astronauts at NASA HQ,
Jan 14, 2004

Background: US Space Exploration Policy – Commission Report

- President's Commission on Implementation of US Space Exploration Policy issued a Report on June 4, 2004 (Aldridge Report)
 - Vision for space exploration must be managed as a national priority
 - Need to develop enabling technologies to reach objectives within reasonable schedule and affordable costs
 - International participation is welcome and it will add significant value to meet mission goals



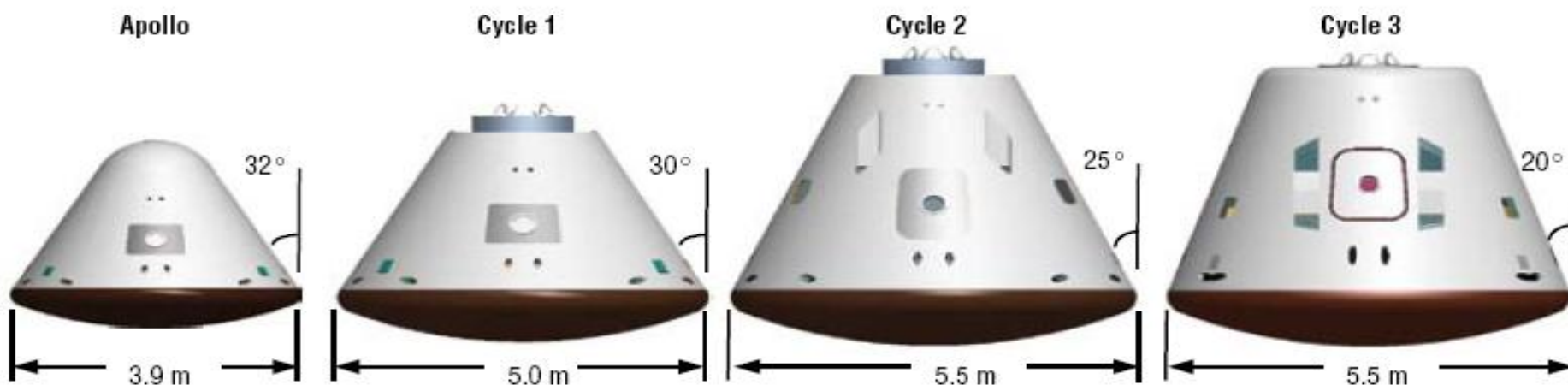
Artist's Concept of Mars Exploration

New NASA Initiative: Exploration System

- Exploration System is a system of systems, and it consists of a dozen of very complex systems, including CEV. It is the focal point of all explorations.
 - Crew Launch Vehicle (CLV or Ares I)
 - Cargo Launch Vehicle (CaLV or Ares V)
 - **Crew Exploration Vehicle (CEV)**
 - Lunar Surface Access Module (LSAM)
 - Earth Departure Stage (EDS)
 - Mars Transfer Vehicle (MTV)
 - Service Module (SM)
 - Nuclear Thermal Propulsion (NTP)
 - Cargo Delivery Vehicle (CDV)
 - International Space Station (ISS)
 - Lunar Outpost
 - Mars Surface Habitat

Approach to CEV Development

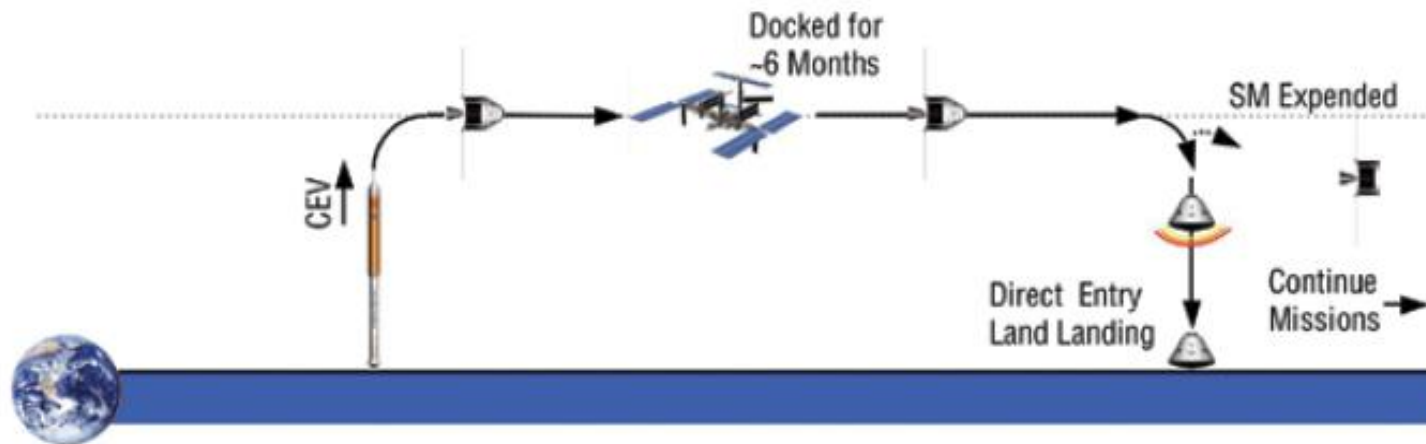
- Evolutionary development of CEV is planned by NASA
 - Cycle 1: Servicing ISS (2005-2011)
 - Cycle 2: Journey to Moon (2012-2020)
 - Cycle 3: Journey to Mars (2021 and beyond)



Configuration	Diameter (m)	Sidewall Angle (deg)	OML Volume (m ³)	Pressurized Volume (m ³)
Apollo	3.9	32.5	15.8	10.4
Cycle 1 (EIRA)	5.0	30.0	36.5	22.3
Cycle 2	5.5	25.0	56.7	39.0
Cycle 3	5.5	20.0	63.6	39.5
Cycle 4	5.5	32.5	45.9	30.6

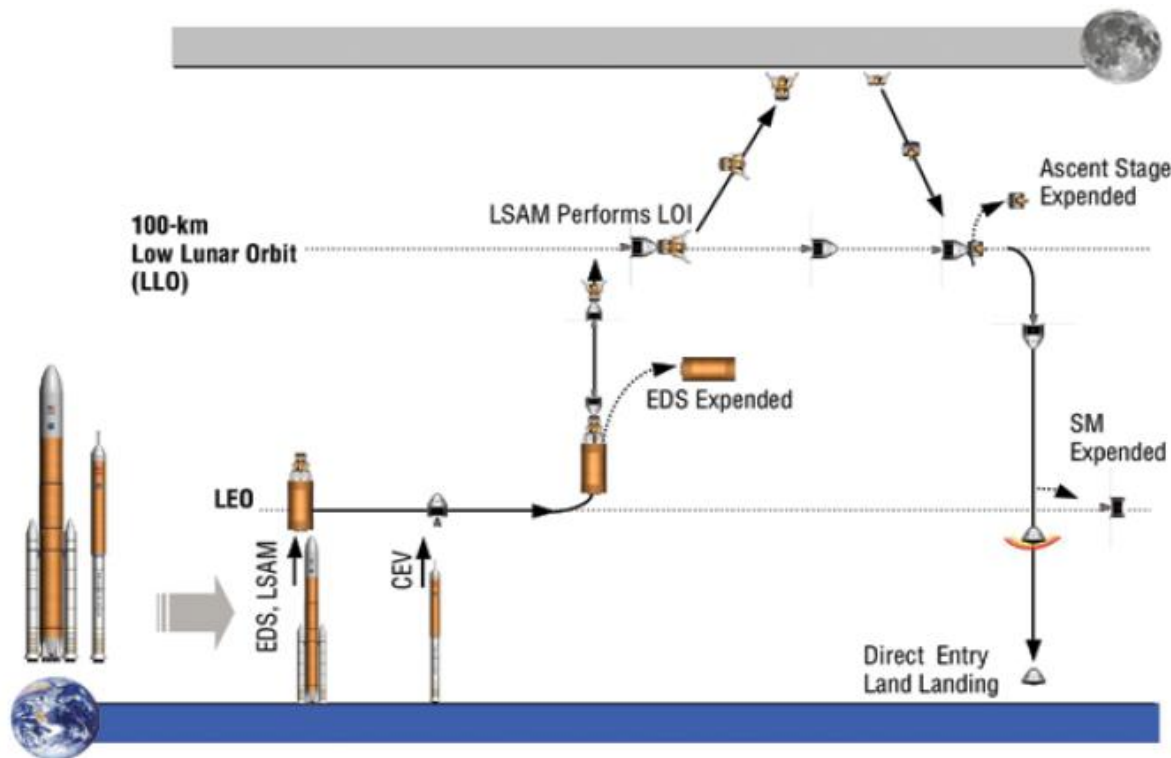
CEV Operation: Cycle 1 - ISS Servicing by CEV

- CEV deployment for servicing International Space Station (ISS)
 - CEV launch using Ares I vehicle
 - CEV docking with ISS
 - CEV landing on Earth using parachutes (like Apollo)



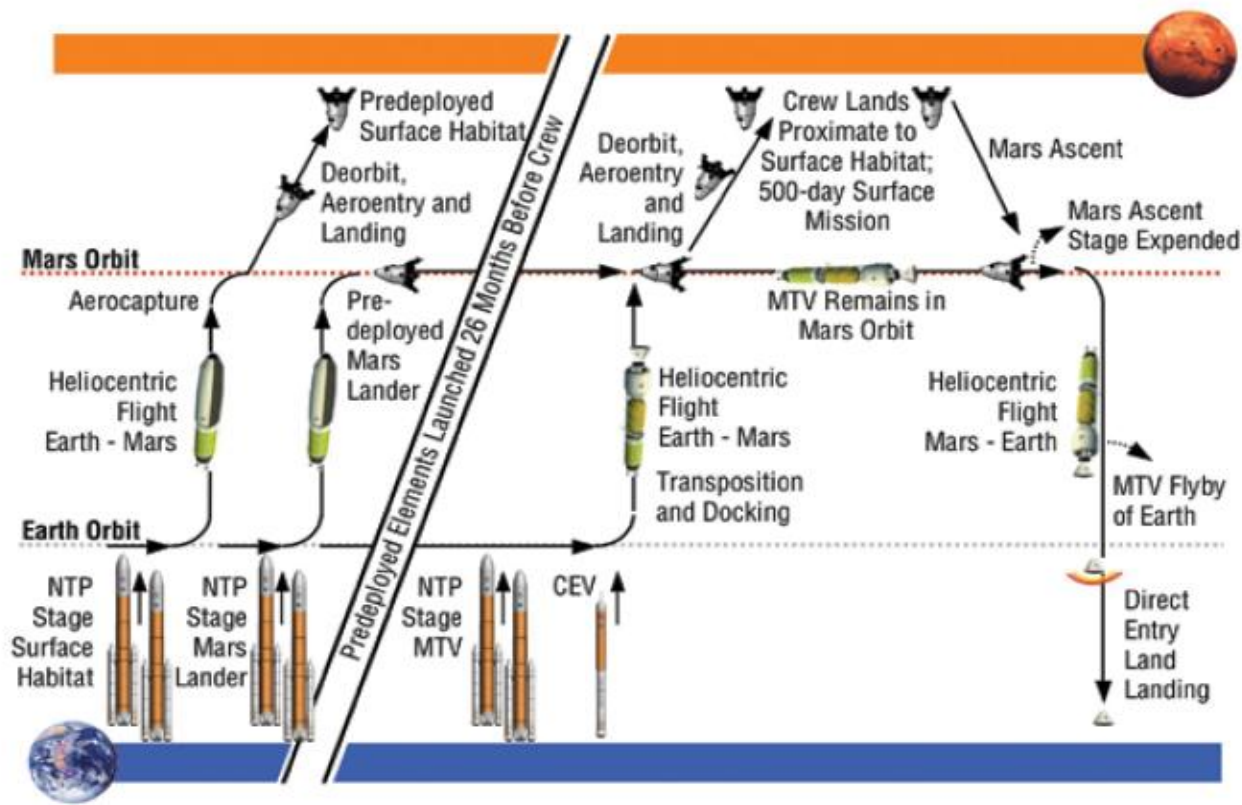
CEV Operation: Cycle 2 - Moon Mission Using CEV

- CEV journey to Moon and back
 - Earth departure stage (EDS) and Lunar Surface Access Module (LSAM) are launched separately by Ares V vehicle
 - CEV docks with EDS and LSAM to start the journey to Moon
 - Crew lands using Lunar module, CEV returns to Earth with crew



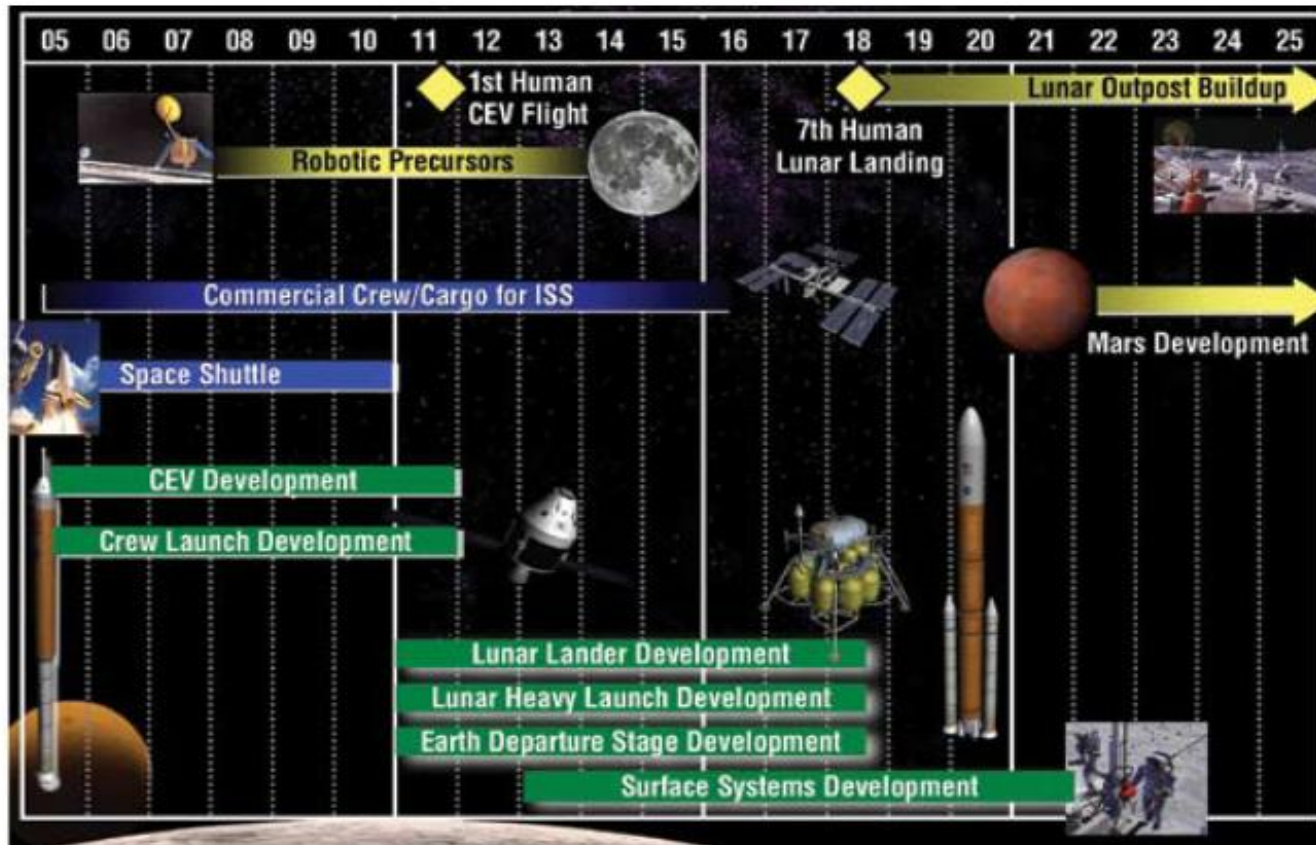
CEV Operation: Cycle 3 - Mars Mission Using CEV

- CEV journey to Mars and back. A complex operation
 - 7 Sequential launches using Ares I for CEV, Ares V for cargo
 - Complex dockings on Earth orbit and undockings on Mars orbit
 - 500-day surface mission on Mars and return to earth



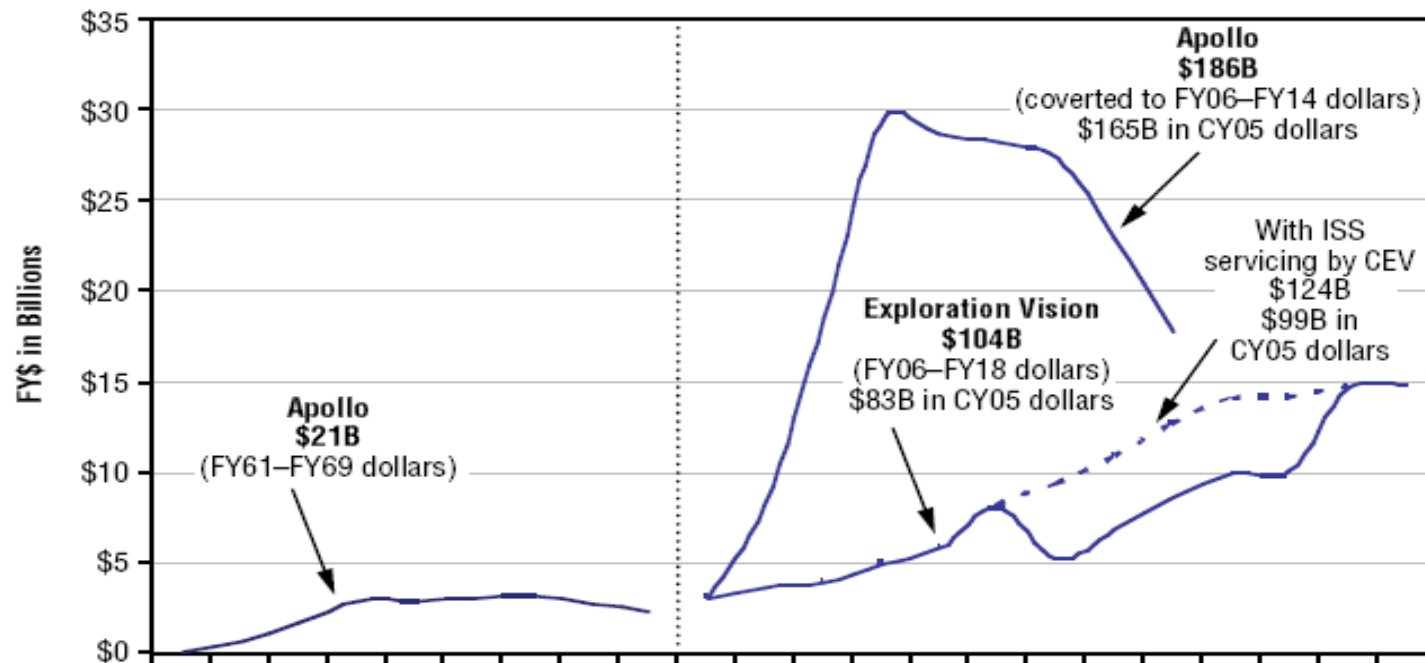
NASA's Integrated Master Schedule for CEV and Exploration Vision

- Exploration System between 2005 and 2020
 - CEV and Crew launch vehicle are first systems to be developed



NASA's Estimated Cost for CEV and Exploration Vision

- Cost estimate of Exploration Vision is \$83B, which is half of the Apollo program (in CY05 dollars).
 - ISS servicing by CEV is estimated to add \$16B (CY05 dollars)



- Exploration \$104B excludes ISS serving costs in FY12-FY16
- All costs are "full costs" (including civil service, Government support, etc.)

Source: NASA's Exploration System Architecture Study, Part 1

What we did:

Applied Delphi Technique to Identify Risks

- Decision was made to apply Delphi technique to identify up front the risks of a complex and safety critical system such as CEV
 - Technique named after the ancient Greek oracle at Delphi that was believed to make accurate predictions about the future
 - RAND corporation developed the modern-day Delphi technique in 1940s through 1950s
 - It assists with decision-making required to reach consensus among the participants (experts in risks and space technology)
 - Anonymity, controlled feedback, and statistical response characterize the Delphi technique

Used Three-Step Process in Delphi Technique

- The Risk assessment team opted to improve the chances of reaching a consensus on risks within the short time, by using a modified Delphi technique.
- The modified Delphi approach differs in that the statistical analyses of responses between “rounds” of inputs were eliminated because of the 90-day time constraint of this task.
- Three-step process was followed:
 - Step 1) Send Questionnaire to a panel of experts
 - Step 2) Iterate on responses from experts and categorize risks
 - Step 3) Facilitate a a face-to-face meeting of experts, using Electronic Meeting System (EMS) at DAU, Ft. Belvoir, VA

List of Risk Experts Utilized

- We coordinated with NASA to come up with a list of experts in risks dealing with space operations
 - Internal to NASA
 - Bryan O'Connor, Assoc Administrator, Safety, NASA HQ
 - Bill Cirillo, Risk analyst, NASA Langley
 - Wayne Peterson, Safety Review panel member, NASA Johnson
 - External to NASA
 - John Karas, Lead, Adv launch vehicle prog; Lockheed Martin
 - Joe Fragola, Risk expert, Apollo, SSP/ISS, Mars Robotics; SAIC
 - Steve Krahn, Systems engineer, US Navy's Safe Sub; Perot Syst
 - George Mueller, Program Manager, Apollo; Kistler Private Launch

 - Karlene Roberts, Safe Sub; Fellow UCAL, Berkeley, CPMR/ USRA
 - Nancy Leveson, cultural safety, CAIB assessment; MIT, CPMR
 - Joe Rothenberg, ex-Assoc Administrator, human flights; CPMR
 - John O'Neill, former Director at JSC, Apollo, SSP; USRA

Initial Questionnaire for CEV Risks Sent to the Panel of Experts

- A Questionnaire on CEV risk profile was developed and sent to our panel of experts (Re: Paper by Mahata, et al). Briefly, the subjects included:
 - Develop generic open-ended risk management questions relating to the CEV in space exploration mission
 - With the 2018 date as a goal for going beyond LEO, what year do you feel the launch propulsion system will be available?
 - What are the risks for CEV's navigation system?
 - What are the risks for crew's environmental system?
 - What are the risks for the "in-flight" propulsion system?
 - What are the risks on critical support systems? When do you feel they will be operational for support to the CEV?

Results of Risk Identification for CEV: Agreed on Categories of Risks

- After three iterations of questions and responses among experts, and conducting an Electronic Meeting System, consensus was reached on categories of risks
 - Following categories (C) of risks were agreed to:
 - C1) Requirements related
 - C2) Systems complexity
 - C3) Systems architecture
 - C4) System/Subsystem design and development
 - C5) Re-entry failure modes
 - C6) Schedule related
 - C7) Integration, verification, validation
 - C8) Other Issues: Programmatic/systems engineering, etc.
 - C9) Others (specify)

Results of Risk Identification for CEV: Agreed on Final Questions on Risks

- After three iterations of questions and responses among experts, and through an Electronic Meeting System, the following questions were found to address most of the risks:
 - Fourteen specific questions addressed each category of risks (shown in previous slide):
 - Q 1: Risks in achieving CEV demo by 2008?
 - Q 2: Risks for meeting program evaluation review by 2008?
 - Q 3: Risks in achieving human-rated CEV by 2014?
 - Q 4: Risks in mating the CEV to human-rated launch platform?
 - Q 5: Risks due to unsound design spec, performance, test margin?

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Results of Risk Identification for CEV: Agreed on Final Questions on Risks (cont)

- Fourteen specific questions (cont)
 - Q 6: Risks due to parts, materials, and components selection?
 - Q 7: Risks due to in-orbit hazards (radiation, debris)?
 - Q 8: Risks issues related to launch?
 - Q 9: Risks issues for CEV related to entry?
 - Q10: Risks due to software development for CEV?

 - Q 11: Risks associated with communications, command, control?
 - Q 12: Risks of on-board life support and power system?
 - Q 13: Risks due to technical quality integration, tests, systems management?
 - Q 14: Risks due to structural design and fabrication of the CEV?
- Special Question 15:** Risks due to technology readiness, propulsion systems, abort capability, GPS, air and life support, medical, cryogenics, storables, thermal protection, docking/berthing, DoD interface?

Results of Risk Identification for CEV: Tabulated All Risks for each Question and Category

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
C1	R1__ R2__ ___														
C2															
C3															
C4								R1__ R2__ R3__							
C5															
C6															
C7															
C8															R1__ ___ ___

Results of Risk Identification for CEV: Risk Profile Developed

- Summary of risks identified for CEV through Delphi technique
 - Average 5 risks per category per question
 - Average 8 categories of risks per question (Few responses on 9th category)
 - Total 15 questions asked
 - Total number of CEV risks identified: 600 (approximate)
- For details of each risk, refer to the Paper by Mahata, et al on this subject
 - Most risks fall under the following categories:
 - C4: System/Subsystem design and development (150+)
 - C7: Integration, verification and validation (100+)
 - C8: Programmatic/systems engineering issues (90+)
 - C5: Reentry failure modes (70+)
 - C1: Requirements (60+)

Results of Risk Identification for CEV: Examples of Major Risks Cited

- Major risks identified for CEV and the crew
 - Q1/C4: Inadequate design of thermal and radiation protection
 - Q1/C4: Inadequate automated rendezvous & docking system
 - Q2/C7: Improper hardware/software integration
 - **Q2/C8: System obsolescence and degradation of performance**
 - Q4/C4: Lack of crew escape and abort system development
 - Q5/C3: Lack of mission abort capabilities in all phases of mission
 - Q6/C2: Insufficient CEV systems reliability and operability

 - Q7/C5: On-orbit debris and on-route meteorite strike on CEV
 - Q8/C5: Failure of Booster solid rockets
 - Q8/C5: Loss of cabin pressure
 - Q9/C4: Re-entry heating larger than expected
 - Q9/C5: Failure of parachute deployment mechanism
 - **Q11/C9: Issues with NASA decision-making culture**
 - Q15c: Unknown effects of long duration missions on astronauts

Our Accomplishments and Conclusions

- Accomplishments
 - Modified Delphi technique helped identify about 600 risks for the CEV system
 - This task was completed in less than 90 days
 - The cost of this task was kept under \$100K
- Conclusions
 - Risk identification task provided timely information to NASA, Acquisition Office, and the proposal teams that wanted to bid on the CEV development
 - We encourage the developers of similar complex systems as well as “system of systems” to conduct an up-front risk identification and assessment of risks. We found that Delphi technique was easy to apply and cost-effective
 - It is well known through NASA’s data on past programs, that initial engineering analysis pays great dividends in terms of reducing overruns and achieving mission success

Updates on Constellation Program

- PDR of CEV (Orion) completed in Aug 2009
- ARES I-X (first stage) test fired in October 2009
- CEV Pad Abort system tested in May 2010
- But Constellation program is in jeopardy due to funding cuts
- Majority of the Astronauts (including Neil Armstrong) support the Constellation program and want it continued



Updates on Constellation Program (cont)

- The US Congress has the authority to fund the Program
- If you are in favor of keeping the Constellation Program, please contact:
 - Sen. Barbara Makulski (MD)
 - Sen. Ben Cardin (MD)
 - US House of Representative for your District

Questions and Answers

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