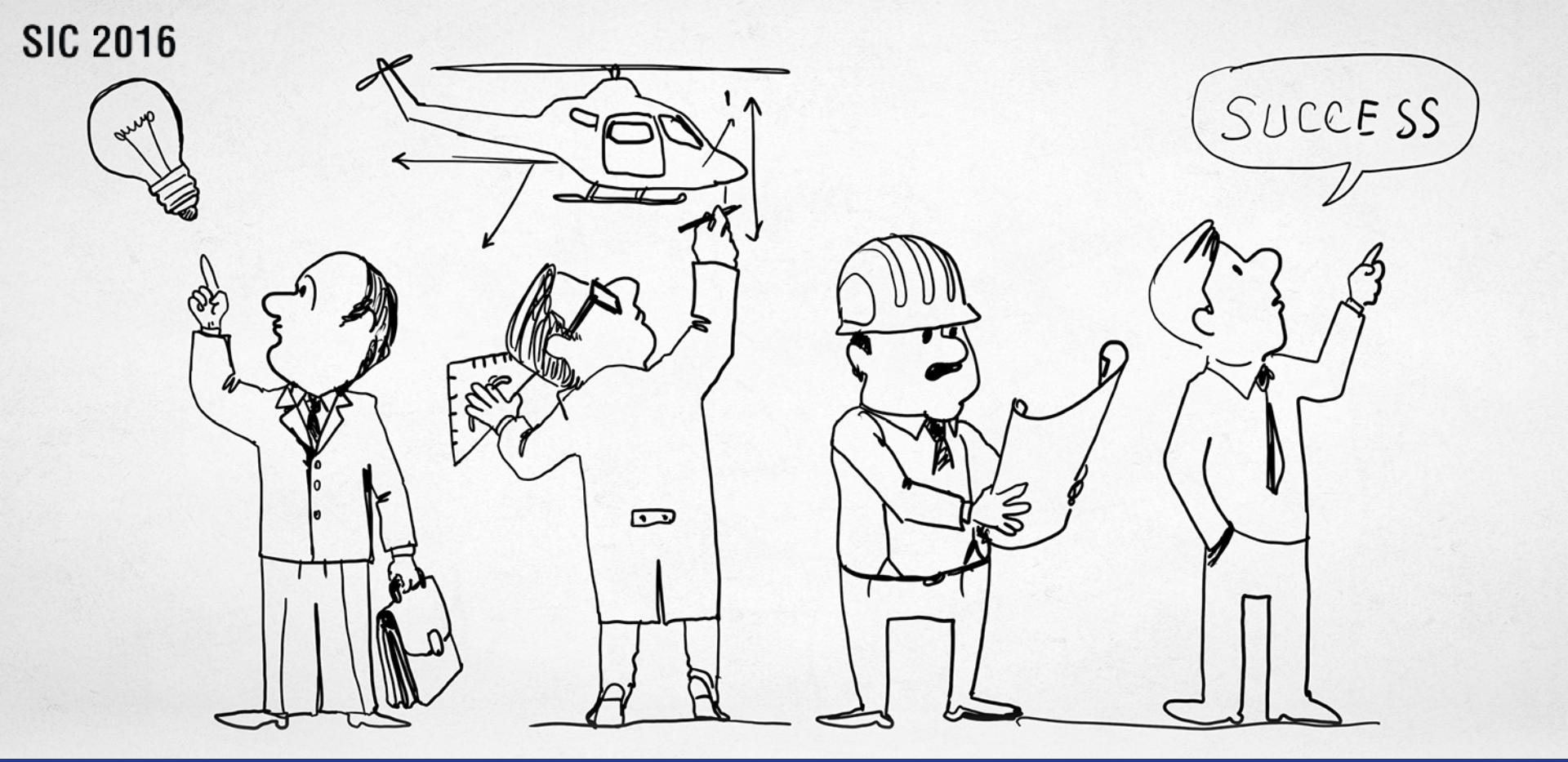
SIC 2016



Critical Reliability Knowledge: Preserve or Perish

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Jet Propulsion Laboratory
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14º SIMPÓSIO INTERNACIONAL DE CONFIABILIDADE

NASA/Caltech Jet Propulsion Laboratory (JPL)

- World's preeminent center for the robotic exploration of deep space
- Some JPL "firsts":
  - In 1958, Explorer 1 was the first satellite launched by the United States
  - In 1965, we did the first flyby of Mars, the following year the first U.S. soft landing on the Moon
  - Voyager 1 and Voyager 2 accomplished the Grand Tour of the Solar System (1989). Last August, we determined that two years earlier, Voyager 1 left the heliosphere– left the solar system-- and is now operating in interstellar space
  - Galileo reached Jupiter (1995); Cassini to Saturn (2004)
  - Mars Pathfinder became the first planetary rover in 1997, and we now have two vehicles operating on Mars
  - In 2005, Deep Impact slammed a copper penetrator into a comet to determine its composition

More JPL "Firsts"

FIRST **ESCAPE FROM EARTH'S GRAVITY**
Pioneer 4 • 1959

FIRST **SUCCESSFUL INTERPLANETARY SPACECRAFT**
Mariner 2 • 1962

FIRST **SUCCESSFUL PROBE TO THE MOON**
Ranger 7 • 1964

FIRST **FLYBY OF MARS**
Mariner 4 • 1965

FIRST **U.S. SOFT LANDING ON THE MOON**
Surveyor 1 • 1966

FIRST **SPACECRAFT TO ORBIT ANOTHER PLANET (MARS)**
Mariner 9 • 1971

FIRST **USE OF GRAVITY ASSIST**
Mariner 10 • 1974

FIRST **TOUR OF THE OUTER PLANETS**
Voyager 2 • 1979–1989

FIRST **INTERSTELLAR MISSION**
Voyager 1 and Voyager 2 • 1989–Present

FIRST **ORBIT CHANGE USING AEROBRAKING**
Magellan • 1990

FIRST **ORBIT OF JUPITER**
Galileo • 1997

FIRST **PLANETARY ROVER**
Mars Pathfinder • 1997

FIRST **ORBIT OF SATURN**
Cassini • 2004

FIRST **SAMPLE RETURN OF SOLAR WIND PARTICLES**
Genesis • 2004

FIRST **COMET IMPACT**
Deep Impact • 2005

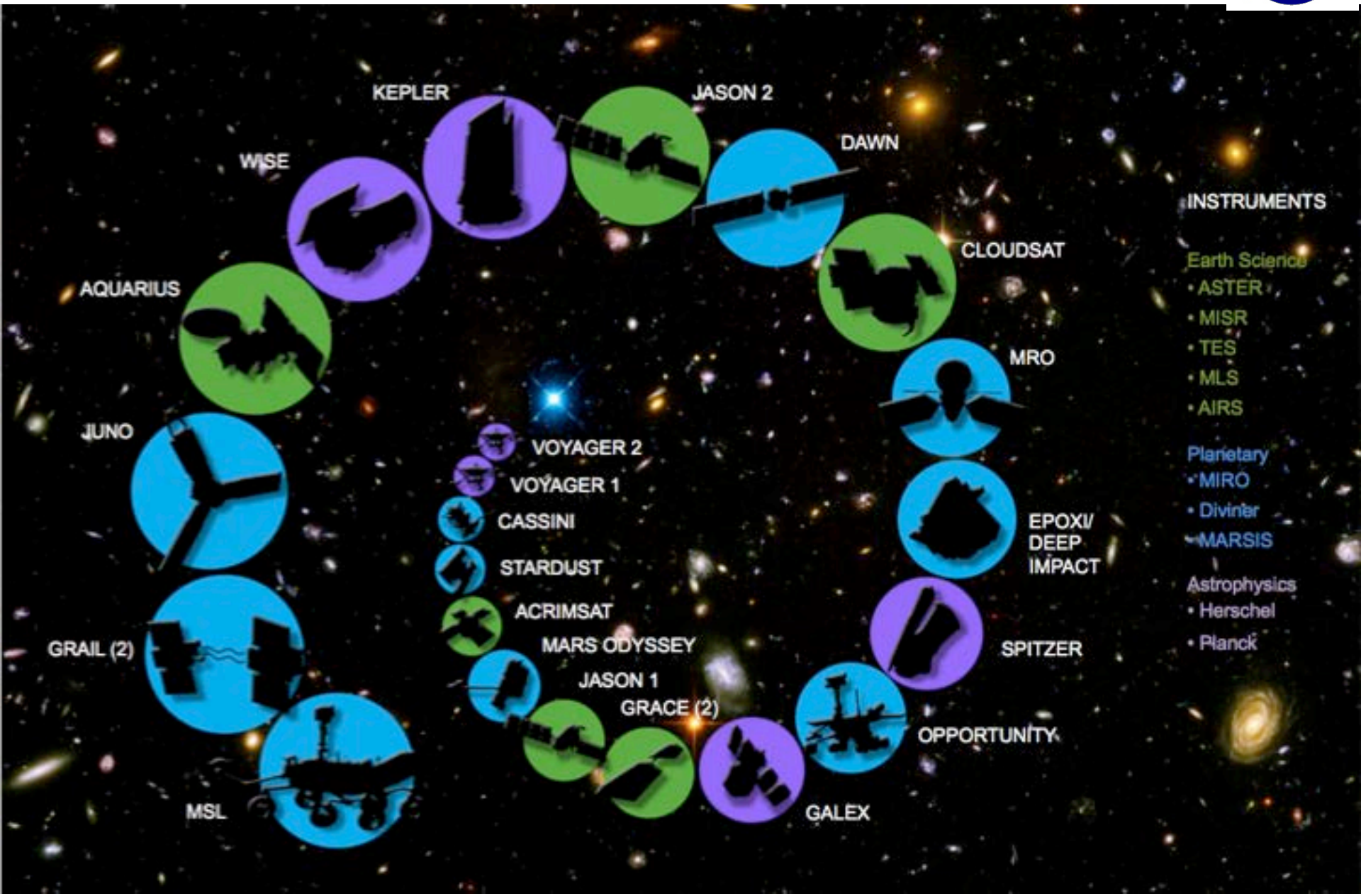
FIRST **SAMPLE RETURN FROM A COMET**
Stardust • 2006

FIRST **SOLAR-POWERED SPACECRAFT TO AN OUTER PLANET**
Juno • 2011

FIRST **TWIN FORMATION FLYING AT THE MOON**
Gravity Recovery and Interior Laboratory • 2011

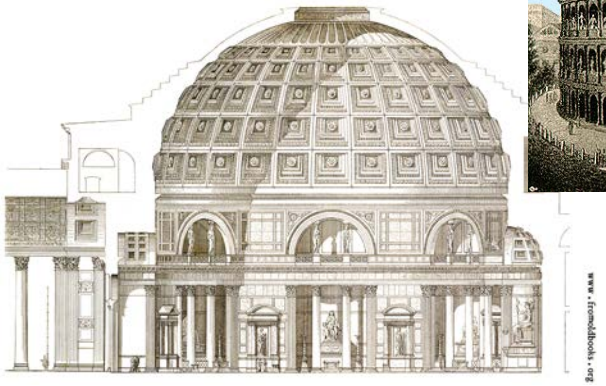
FIRST **SPACECRAFT TO ORBIT TWO SOLAR SYSTEM BODIES**
Dawn • 2012

38 JPL Missions Now in Development or Operation



Knowledge Management

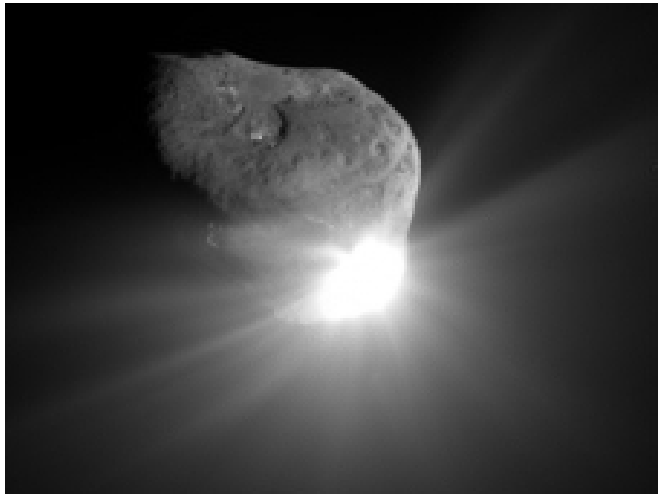
- Corporate knowledge is often treated as if it has little value
- Key corporate knowledge may be lost unless leadership supports active measures to capture and retain it



The ancient Romans used pozzolan concrete to build large structures
--until the technology was lost for 1000 years

The Focus is on Critical Knowledge

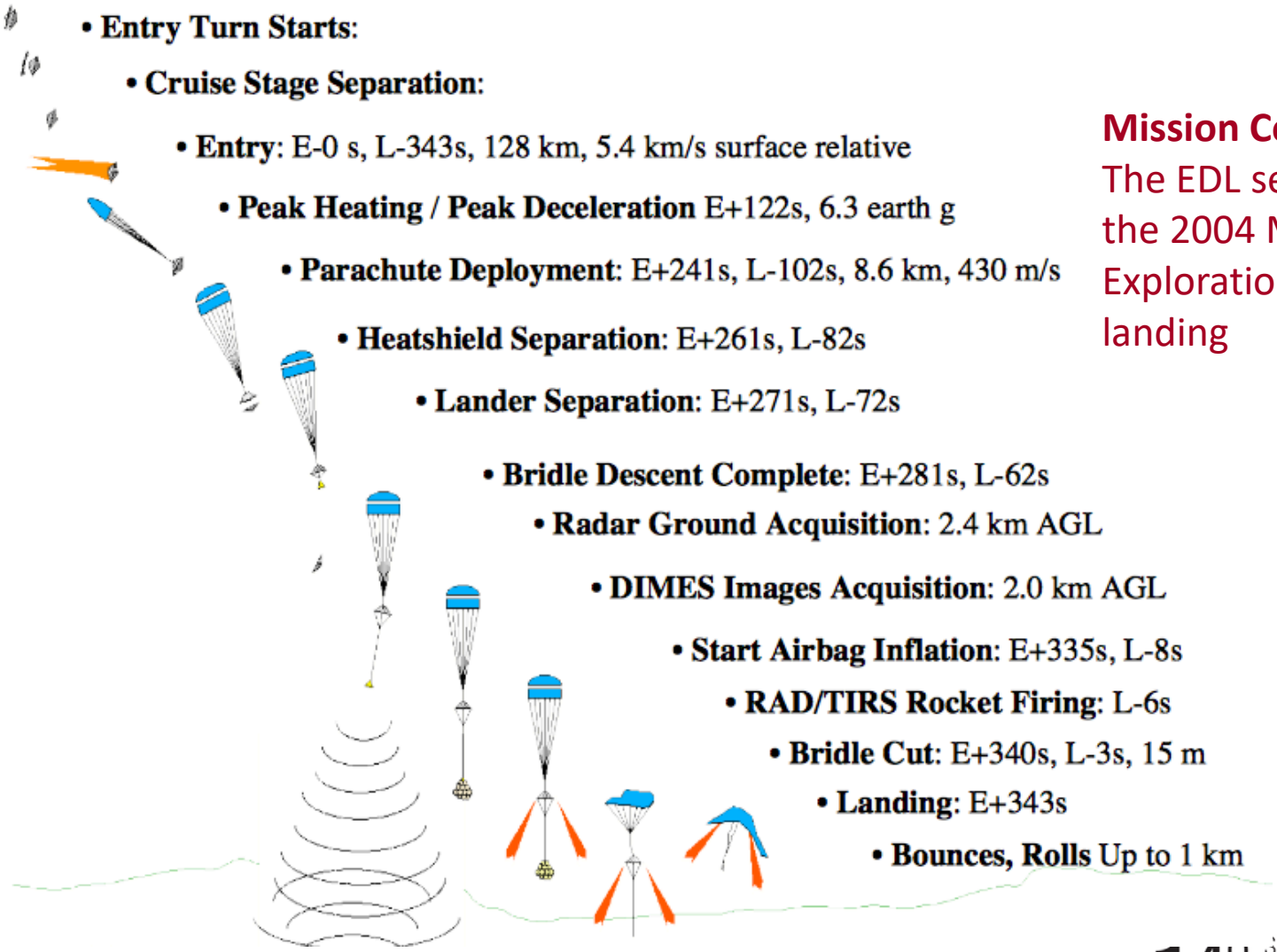
- **JPL systems**: high unit value, often one-of-a-kind, that must operate with precision in an extremely hostile environment
  - **Deep Impact** (2005): An optically navigated flying copper “bullet” ran head-on into a comet while being tracked by the mother ship, all autonomously



Critical to JPL Within the Context of Extreme Engineering

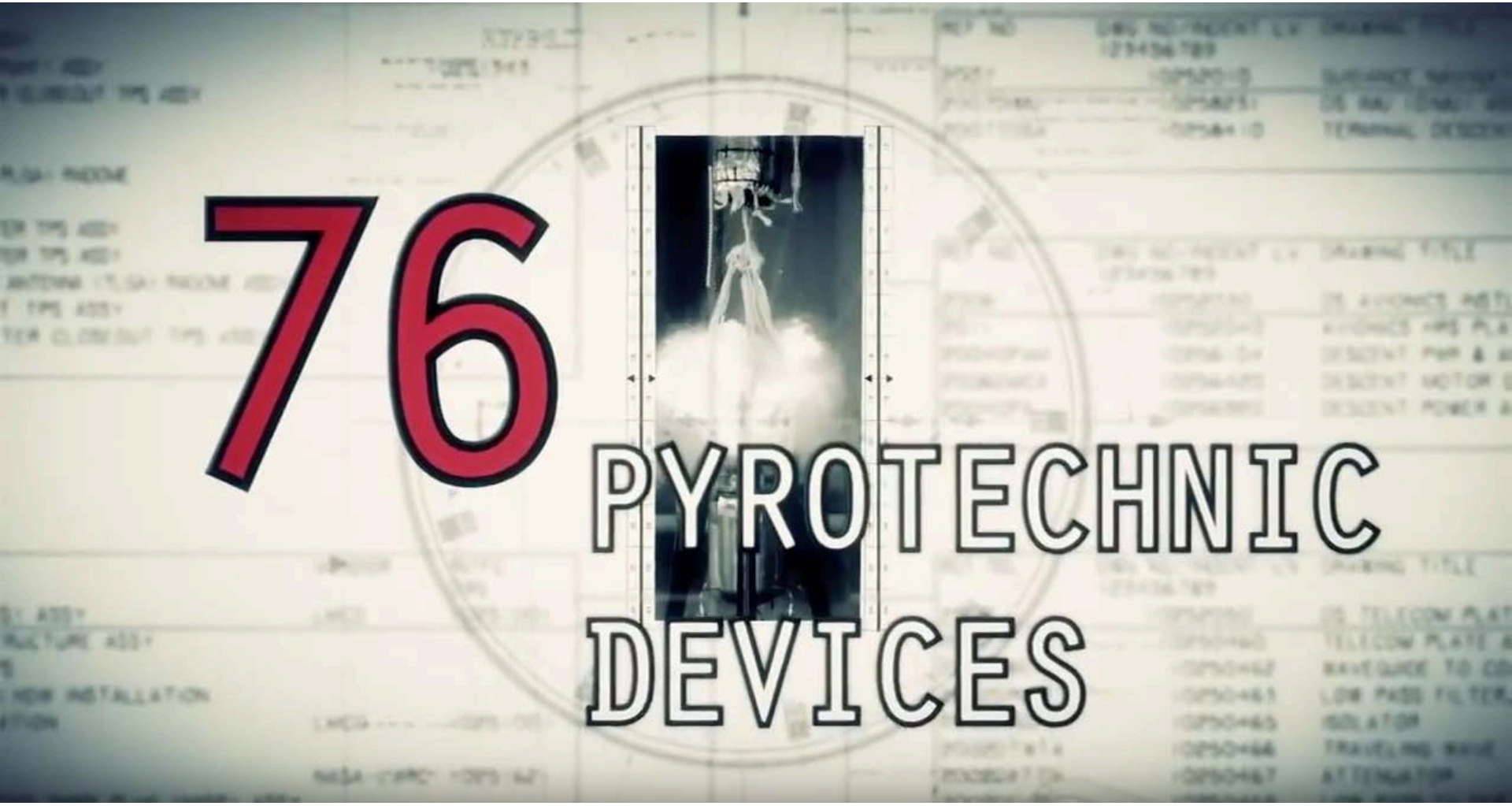
- Spacecraft face environments unique to deep space
  - Zero gravity, solar energetic particles, micrometeoroid/space debris, vacuum, thermal environment, vibroacoustics, etc.
- Spacecraft face failure modes unique to spaceflight
  - Single event effects/upsets, total radiation dose, surface degradation, electrostatic charging/discharge, plasma interference, over/under heating, thermal cycling, etc.
- Potential failure modes are not time-dependent
  - Cruise phase (e.g., 7-yr Cassini) mostly dormant/benign
  - Most risk typically centered in significant events (e.g., deployments, landings) that may last only minutes
- Reliability of complex spacecraft and missions
  - 60 pyros must fire in precise sequence during Mars landing

Mars Entry, Descent, and Landing (EDL)



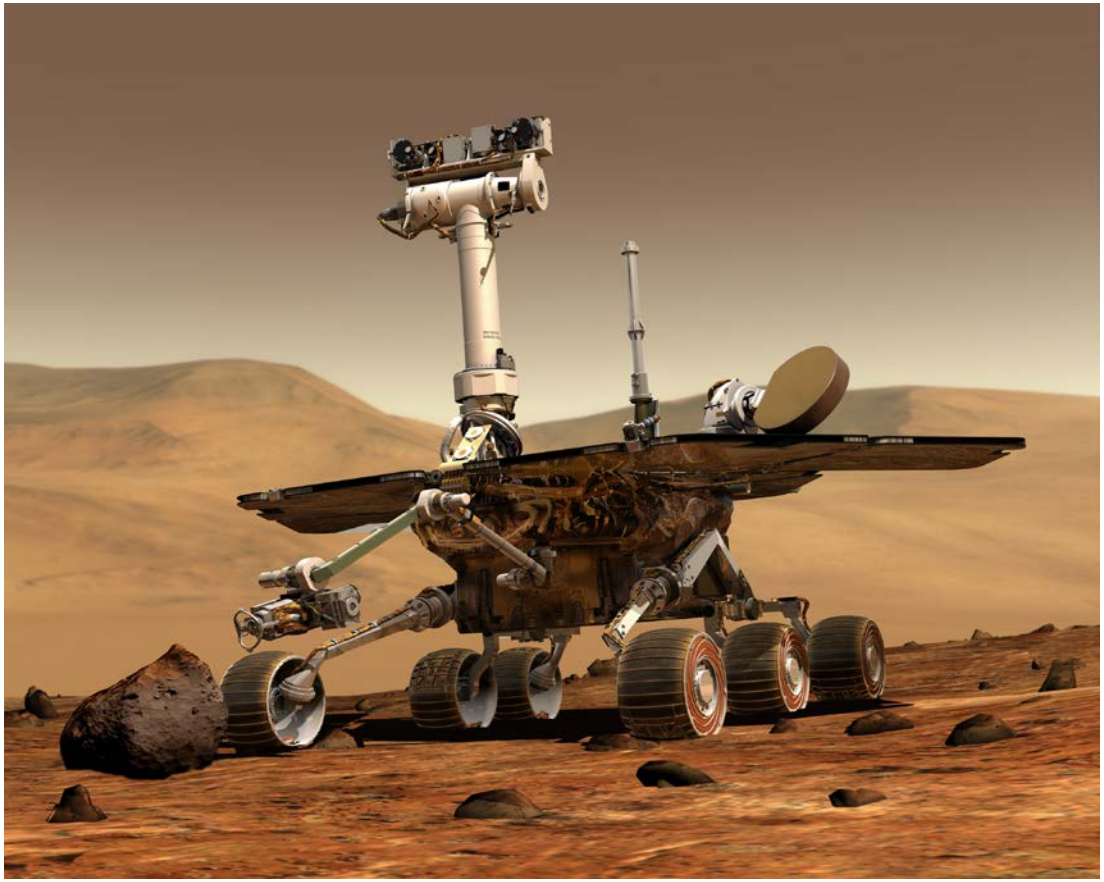
Mission Complexity:
The EDL sequence for the 2004 Mars Exploration Rover landing

The “7 Minutes of Terror”



Design Challenge from Highly Unique Missions

- Mars Exploration Rovers: “Spirit” & “Opportunity”



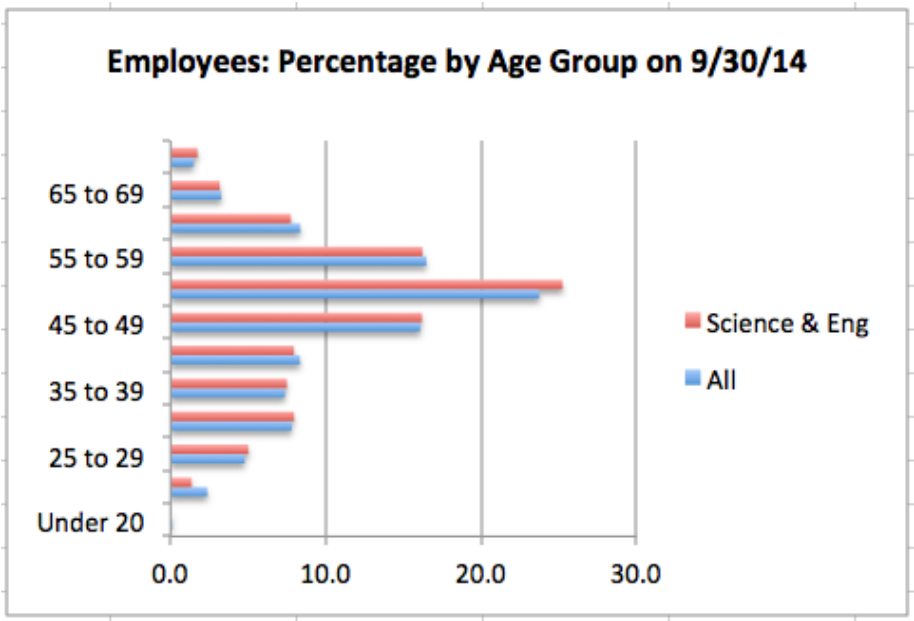
Reliability Engineering in Ultra-Extreme Environments

- Mars has a hostile environment in terms of pressure, temperature extremes, thermal cycling, radiation, winds, dust, terrain (rocks, cliffs, quicksand); there's also high uncertainty
  - Design must encompass uncertainty/worst case environment
  - Winds could have damaged Spirit rover on landing

Sensor was added: 3 photos taken seconds before landing so transverse thrusters could counteract winds/ground speed over Gusev Crater's sharp rocks

- The Mars Exploration Rovers' design life was 90 days
  - But the "Spirit" rover lasted 6 years,
  - and the "Opportunity" rover is still active after 12 years

The “Silver Tsunami”



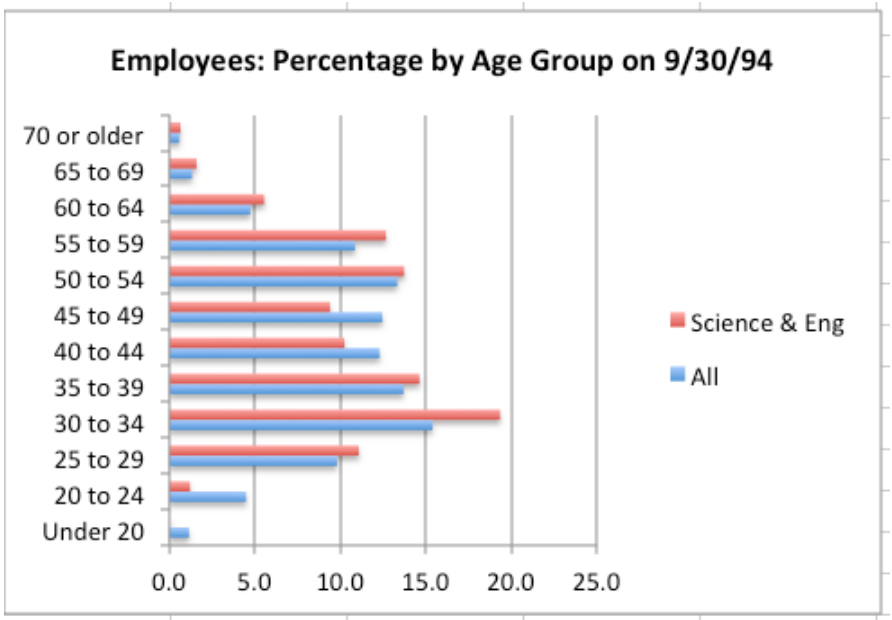


Figure 1. Today’s workforce distribution (bell curve) peaks for employees in their late 40s and in their 50s.

Figure 2. The workforce distribution of 20 years ago was relatively level for the various age groups.

What is Your Risk Posture?

- What value are you losing?
- Risk comparable to failing to maintain capital equipment
- Reliability engineers may be “single string” individuals
- Turnover of personnel or projects causes knowledge loss
- Remaining personnel may not know what they don’t know
- Once lost, knowledge key to corporate success cannot be reused
  - Impact on your business from “losing your smarts”
  - Cost of restoring key knowledge that was not retained and shared
  - Replaced knowledge has not been proven in application
  - “Tacit” knowledge may be more difficult to capture, or to restore

Effective Knowledge Management Practices

- Obtain your leadership's commitment to knowledge husbandry
- Prepare a knowledge management strategic plan
  - Identify (1) what knowledge is critical, (2) gaps in capturing/retaining/sharing it, and (3) activities needed to address the gaps
- Adopt industry-wide knowledge management "best practices"
  - Institute a formal **lessons learned** process
  - Encourage your subject matter experts to **mentor** junior staff
  - Investigate tools (e.g., case studies, video capture, Pause & Learn)
  - Collect metrics to show continuous improvement
- Serve as a knowledge champion by advocating knowledge husbandry and reuse within your organization
- ***Make good use of what your company knows***