Extreme Engineering:
Adventures in Deep Space

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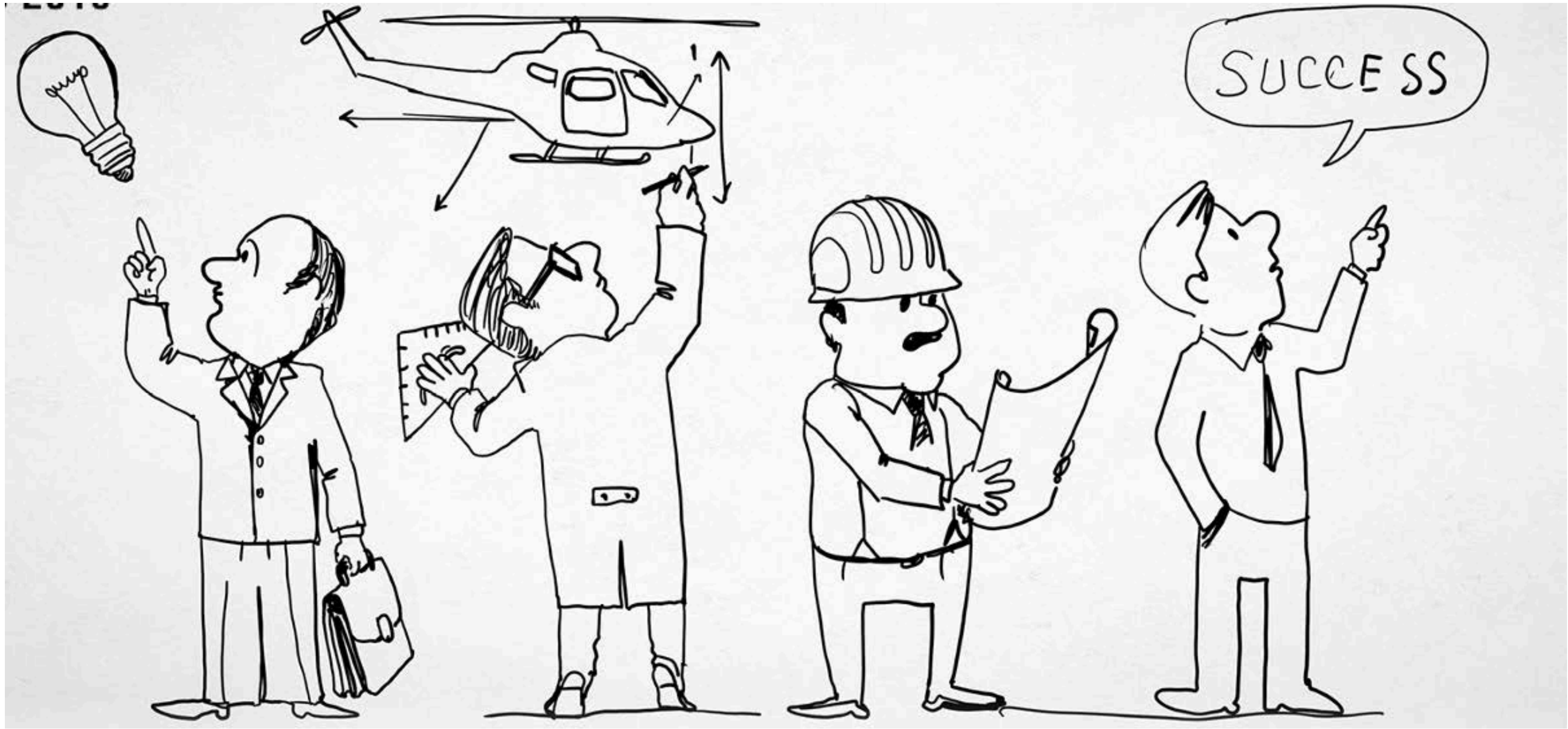


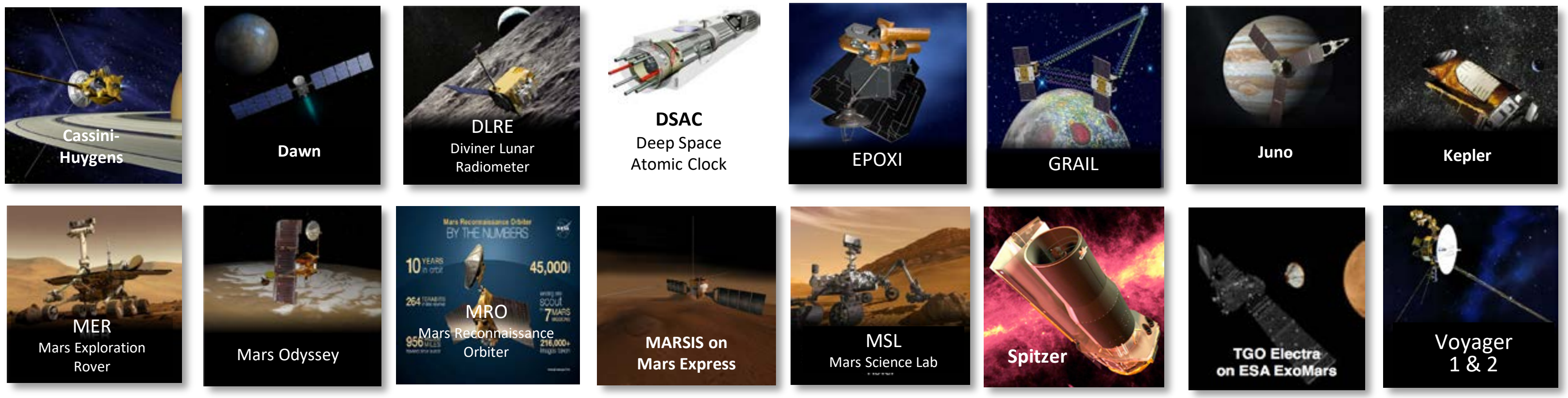
NASA Jet Propulsion Laboratory (JPL)

- JPL is the lead NASA Center for the robotic exploration of the solar system… and beyond
- JPL has visited every planet, e.g., 4 rovers on Mars
- NASA assigns to JPL high risk exploration missions that have never before been attempted

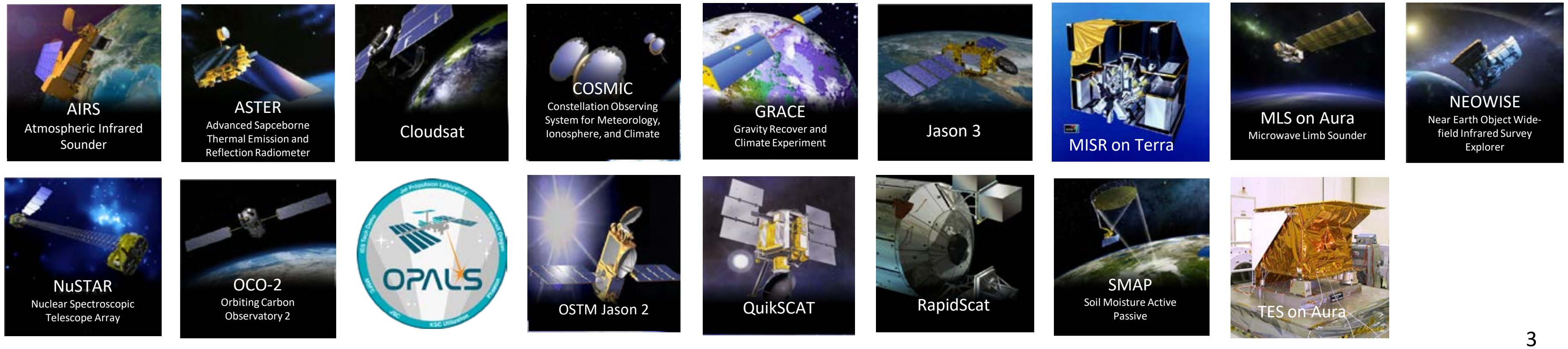
- ✓ **JPL invents products where it may make only a single unit,**
- ✓ **which may cost a billion dollars,**
- ✓ **that is designed to go somewhere previously unreachable.**

Current JPL Spaceflight Projects

Deep Space Missions



Earth Orbiting Missions



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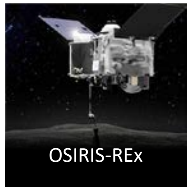
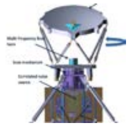
JPL Spaceflight Projects in Development

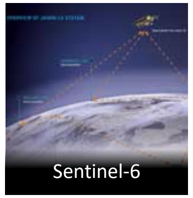
Deep Space Missions

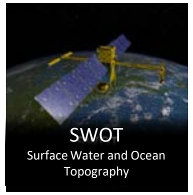


Earth Orbiting Missions


COWVR
Compact Ocean Wind Vector Radiometer


RBI
Radiation Budget Instrument



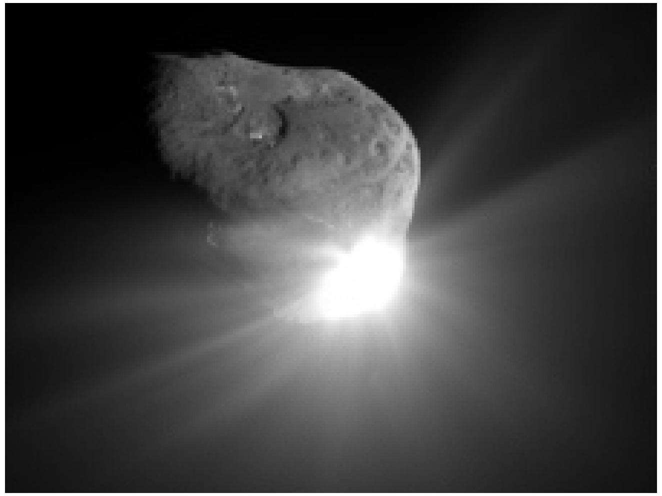


Extreme Design Challenges

- Spacecraft face environments unique to 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
  - 72 pyros must fire in precise sequence during Mars landing

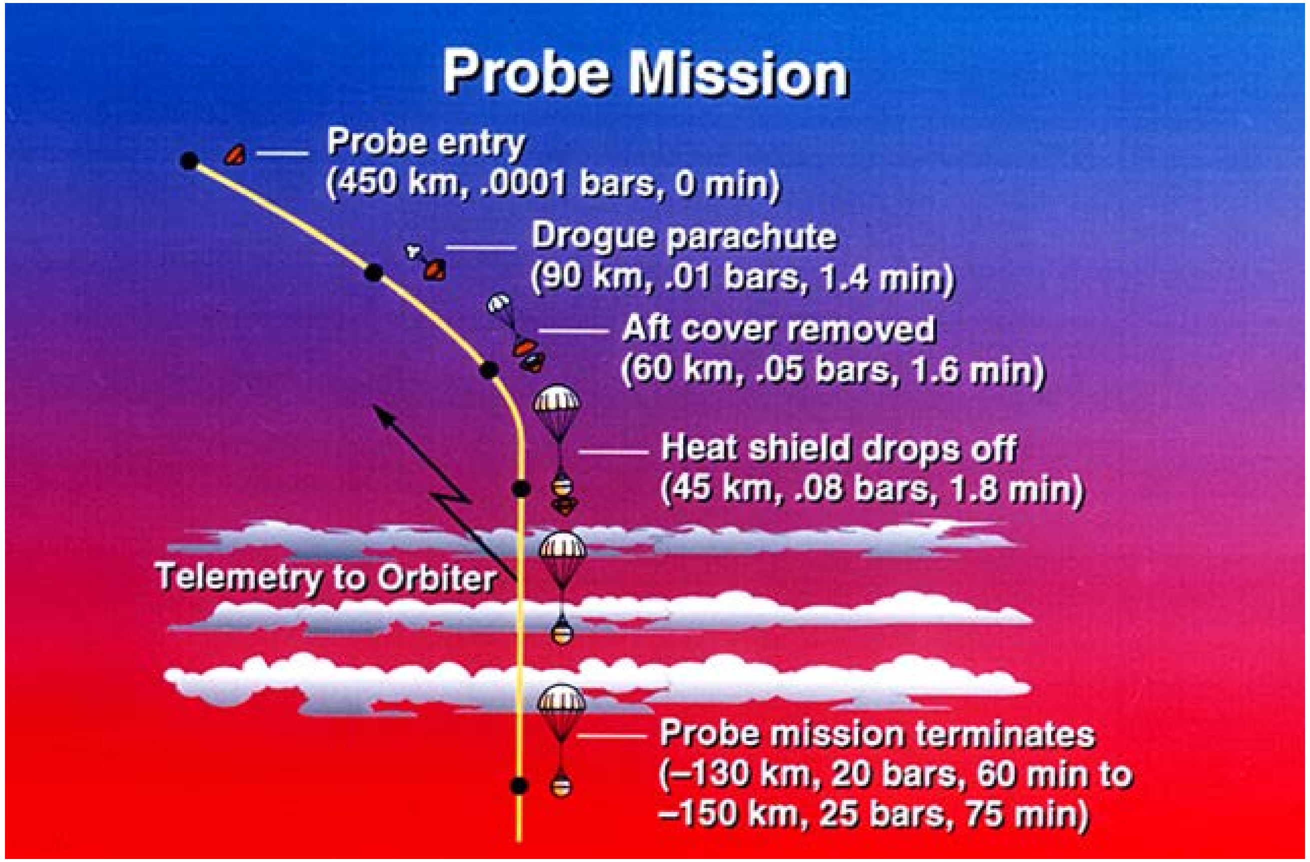
Extreme Risk → Extreme Engineering

- **JPL systems**: often one-of-a-kind, high unit value, 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 on the mother ship, all autonomously



Another Extreme Engineering Example

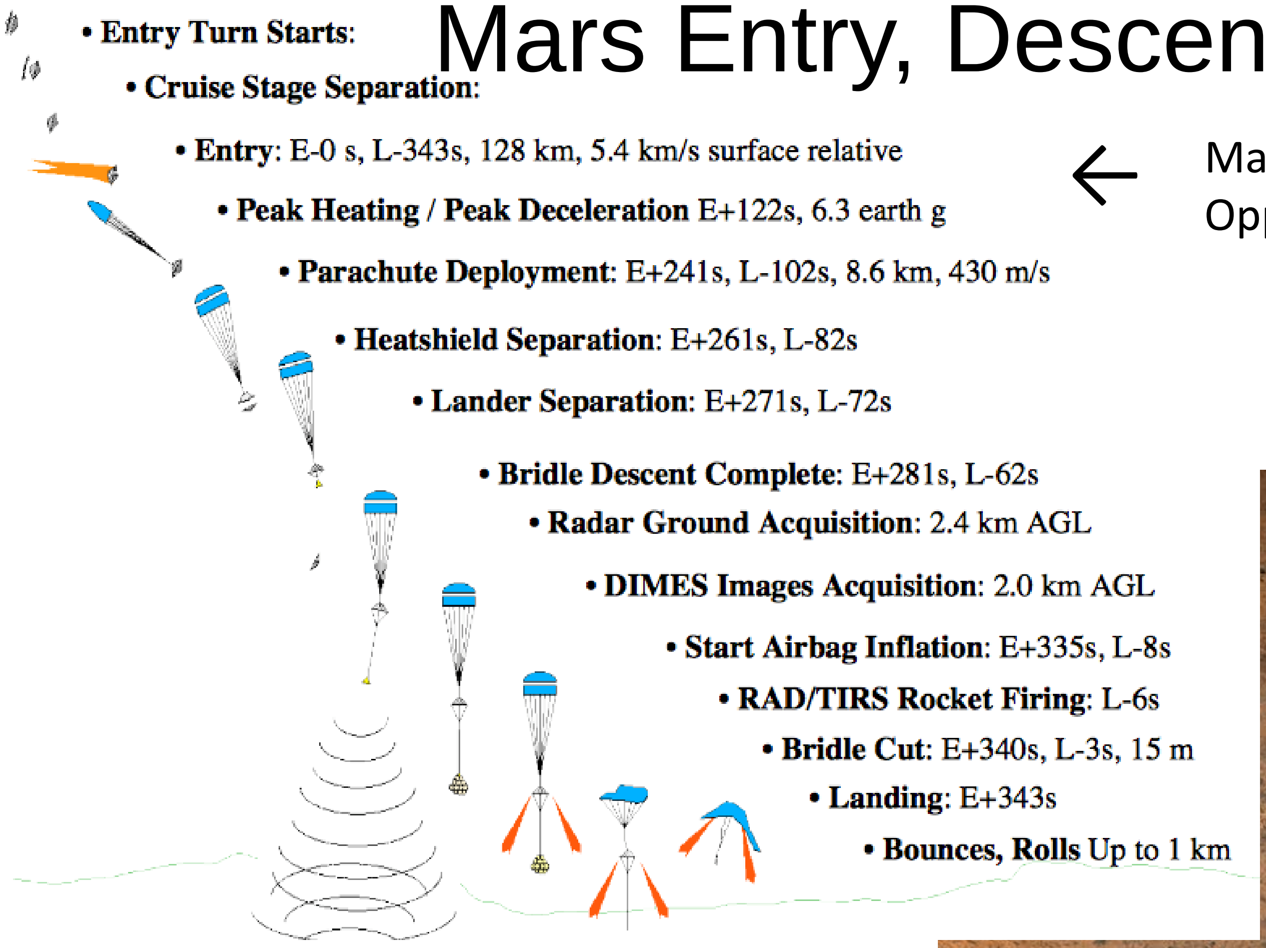
- Galileo Jupiter Probe



Design Challenge from Highly Unique Missions

- Mars Science Laboratory, aka “Curiosity” rover

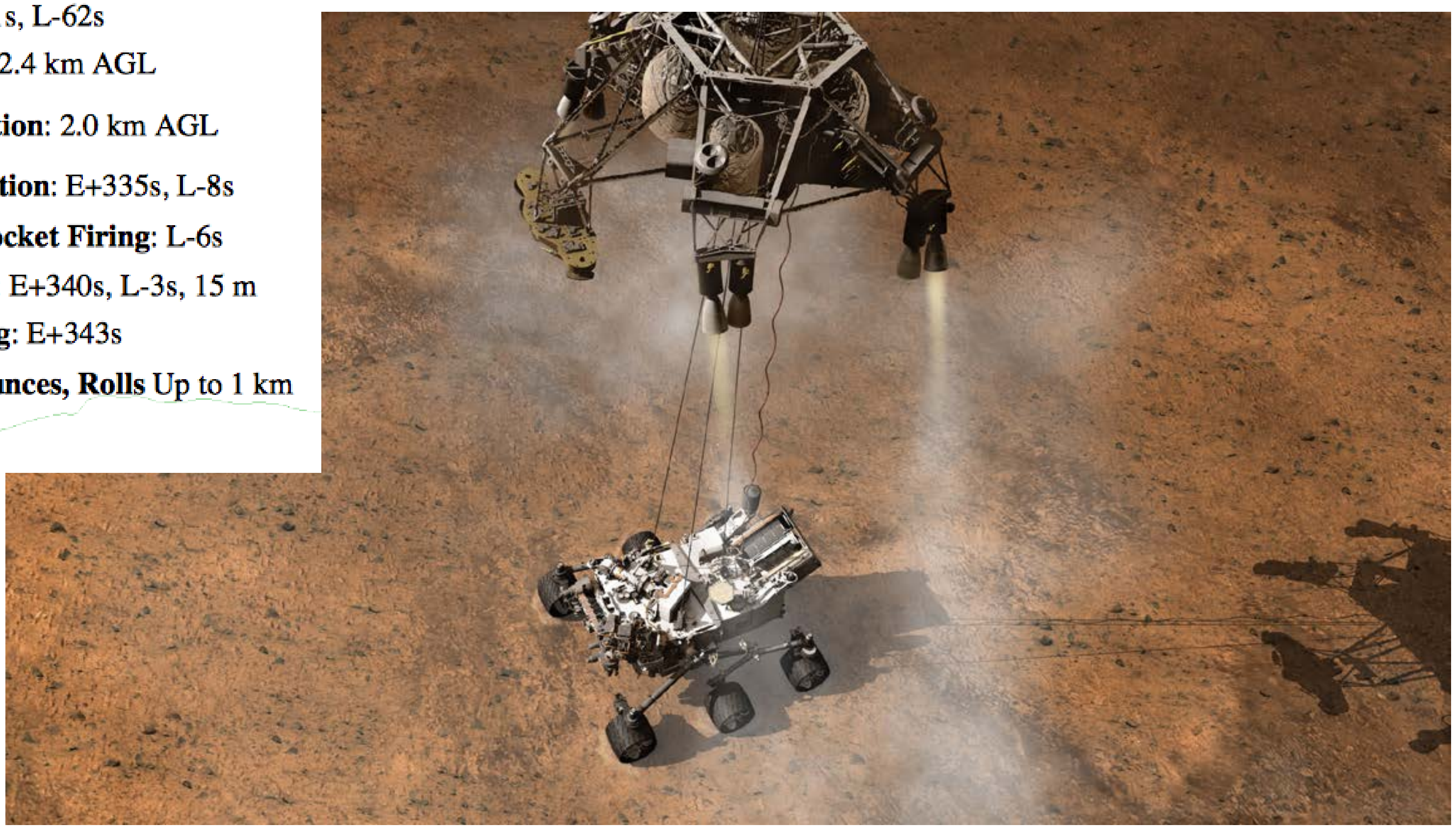
Mars Entry, Descent, and Landing (EDL)



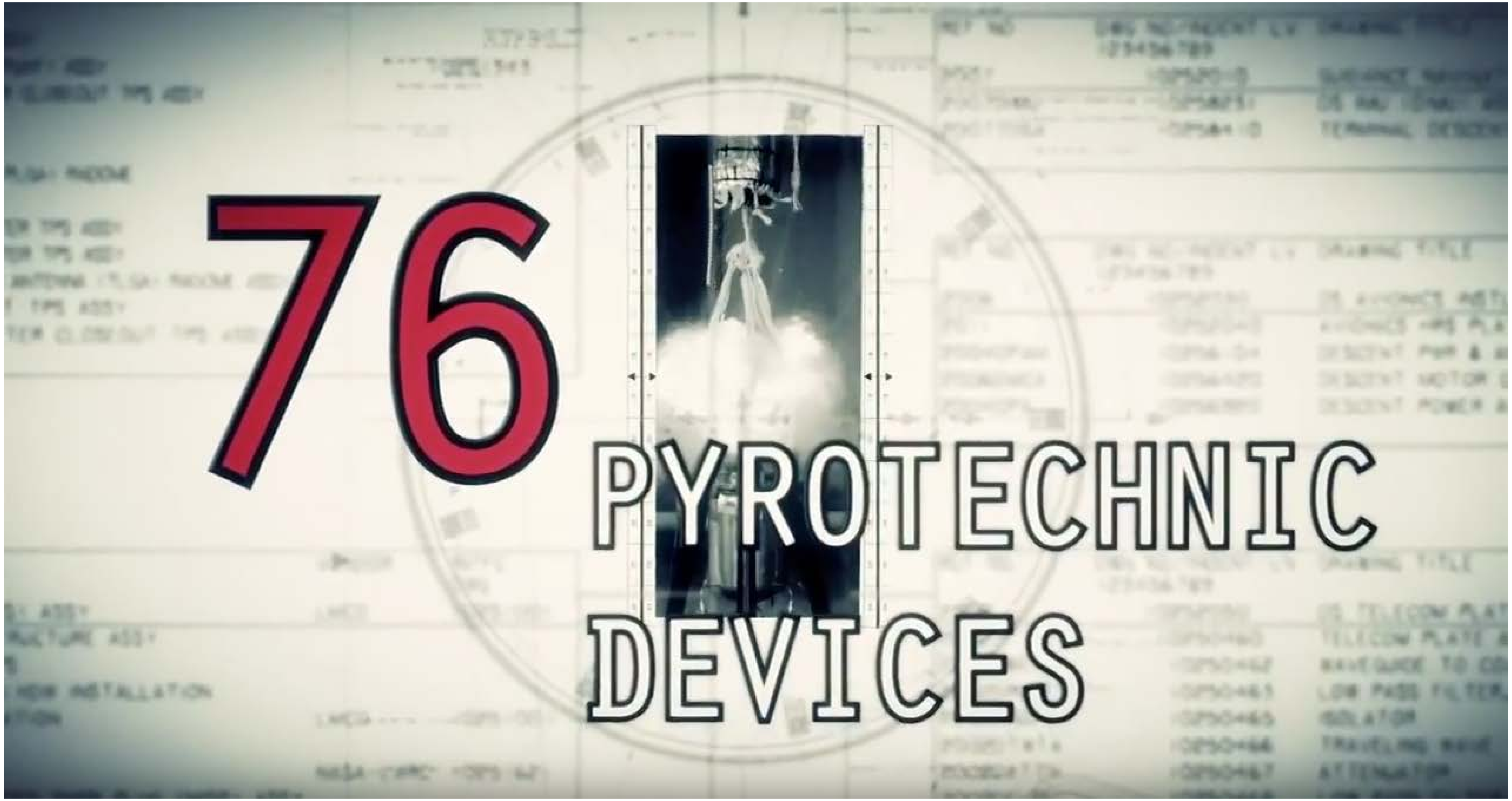
← Mars landing sequence: Spirit and Opportunity rovers in 2004

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

Mars landing sequence: "Sky Crane" maneuver for 2012 landing of Curiosity rover →



The “7 Minutes of Terror”



Risk Necessitates Extreme Innovation

- Curiosity rover was too massive to land on airbags, hence “sky crane” design solution

Curiosity lander (above) & rover (below)

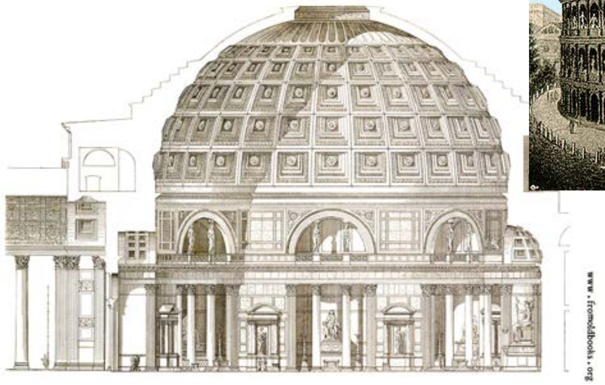
- Year-round/all latitude operation ruled out use of solar panels

So How Do We Mitigate Risk?

- "Preventions"
  - Robust design (e.g., margins), redundancy, fault tolerance, fault detection & recovery, thermal control, design rules
- Analyses
  - Structural stress, reliability (FTA, FMEA, PSA, WCA, SCA), software safety/reuse, peer reviews, modeling (thermal, radiation, micrometeoroid, 3D), pyroshock, IESD, RVA
  - Active risk assessment/mgmt throughout the project lifecycle
- Controls
  - Quality assurance, vendor inspection, materials/parts selection, verification & validation, engineering standards
- Test, Test, Test!
  - Technology qualification, assembly testing, system-level testing, life testing, mission simulation (testbed)

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



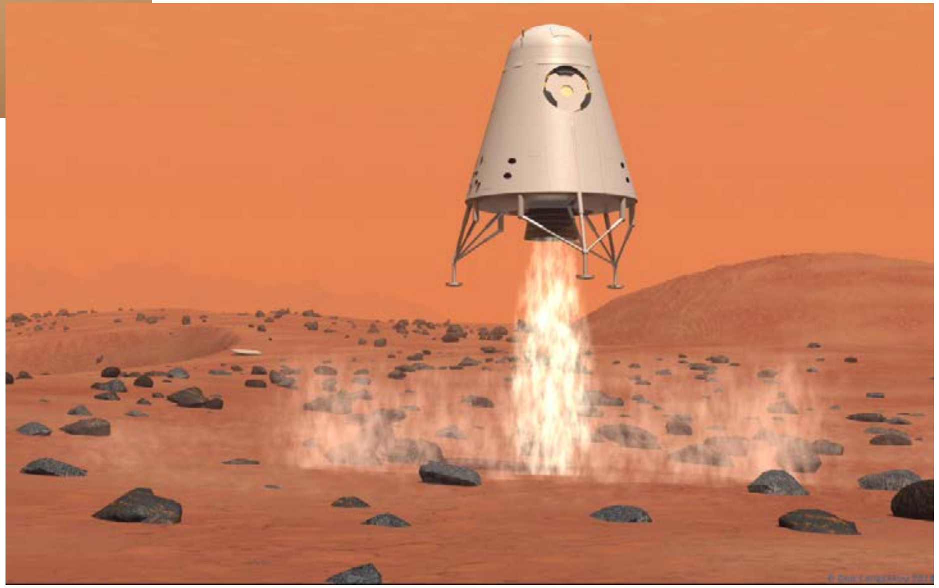
The ancient Romans used pozzolan concrete to build large structures
--until the technology was lost for 1000 years

Lost Knowledge Example: Throttleable Thrusters

Mars Science Laboratory: launched in 2011

Hovering "sky crane" ↑ required the recovery of "lost" knowledge that had been used 36 years earlier on →

Mars Viking: launched in 1975



The "Silver Tsunami"

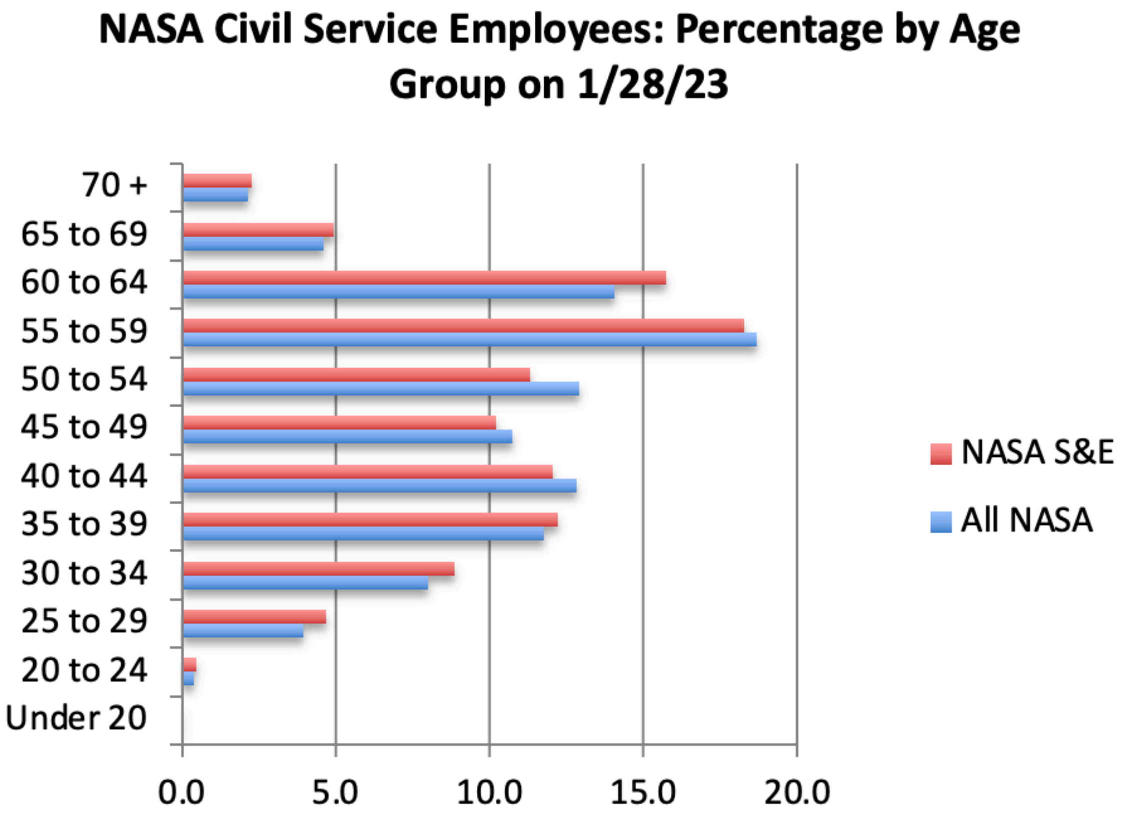


Figure 1. Today's NASA workforce distribution peaks for employees in their mid-50s to mid-60s.

S&E: Science & Engineering personnel

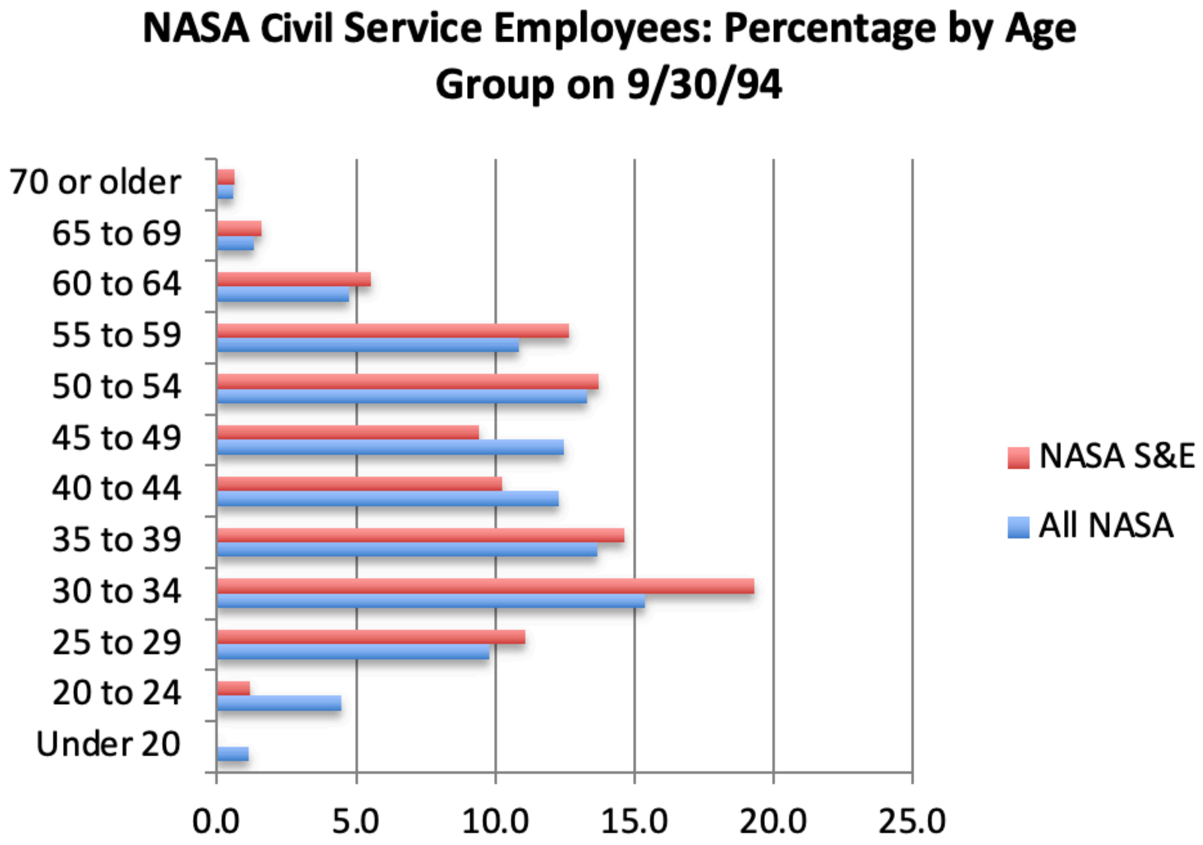


Figure 2. The NASA workforce distribution of 30 years ago was relatively level for the various age groups, with the early 30s predominating.

Source: https://wicn.nssc.nasa.gov/

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
- And lastly…

Make good use of what your company knows

Dare Mighty Things

"Far better is it to **dare mighty things**, to win glorious triumphs, even though checked by failure...than to rank with those poor spirits who neither enjoy much nor suffer much, because they live in a gray twilight that knows not victory nor defeat."

- Theodore Roosevelt, 26th
President of the United States

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