Historical Perspectives: Evolution of Recent Mars EDL Systems Development

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Overview

- **An examination of the EDL system engineering organizations that supported the most recent Mars surface missions**

- **Purpose: to understand what effect the organizational structure and team architecture has on the success of EDL system development**

Acknowledgements

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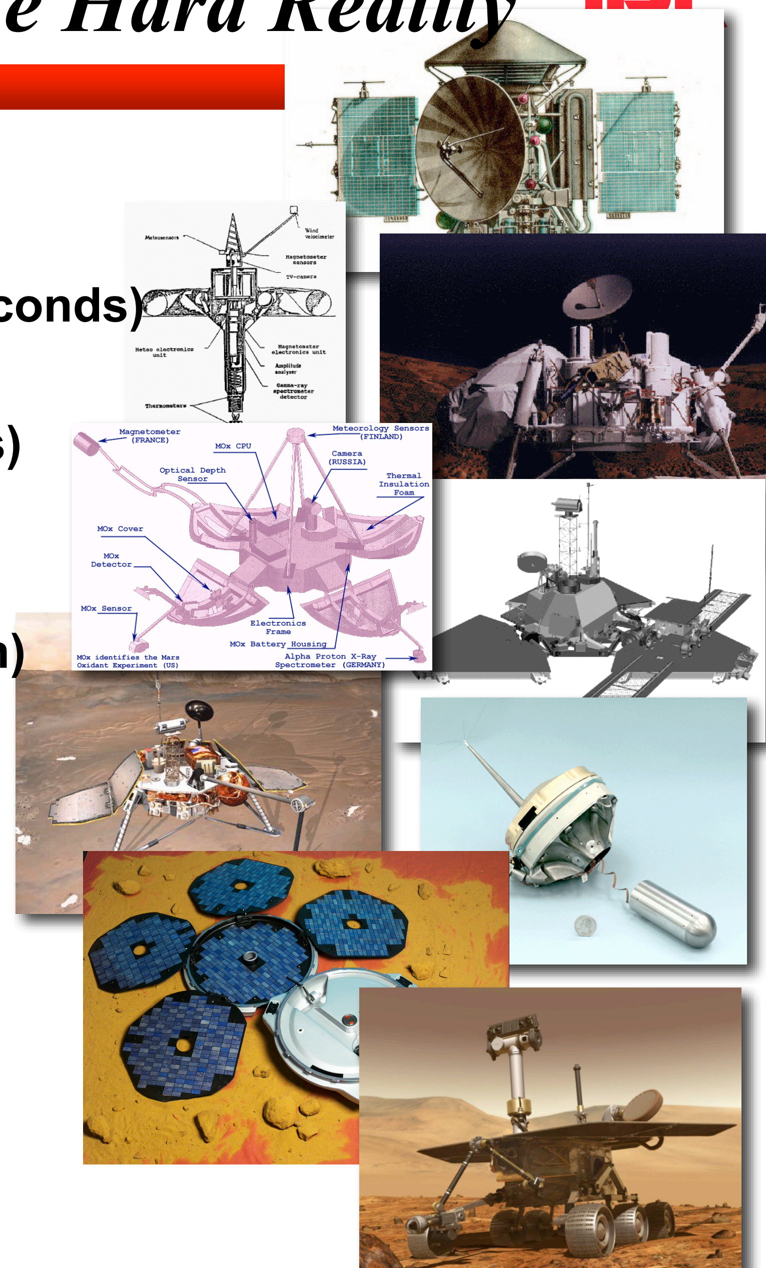
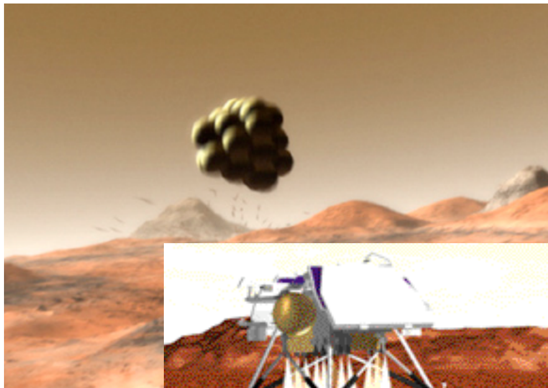
Sam Thurman Jason Willis…

Mars EDL History: The Hard Reality

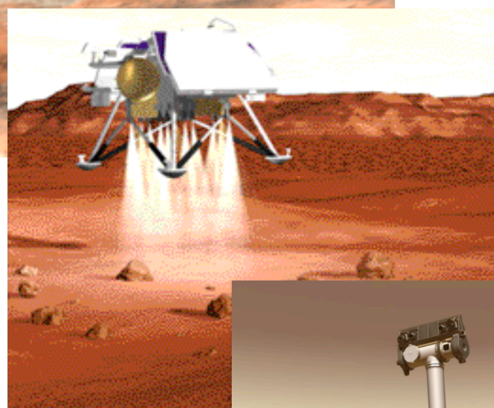
USSR: Mars 2	1971 (crashed)
USSR: Mars 3	1971 (lasted 14 seconds)
USSR: Mars 6	1973 (crashed)
USSR: Mars 7	1974 (missed Mars)
US: Viking 1	1976
US: Viking 2	1976
USSR: Mars '96 (2)	1996 (failed launch)
US: Mars Pathfinder	1997
US: Mars Polar Lander	1999 (crashed)
US: DS-2 Microprobes (2)	1999 (crashed)
Europe: Beagle II	2003 (crashed)
US: MER Spirit	2004
US: MER Opportunity	2004
US: Phoenix	2008



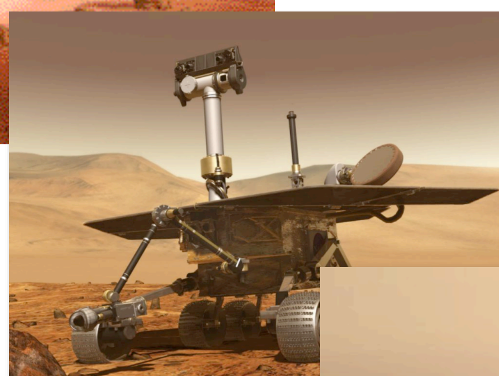
Most Recent Mars EDL History



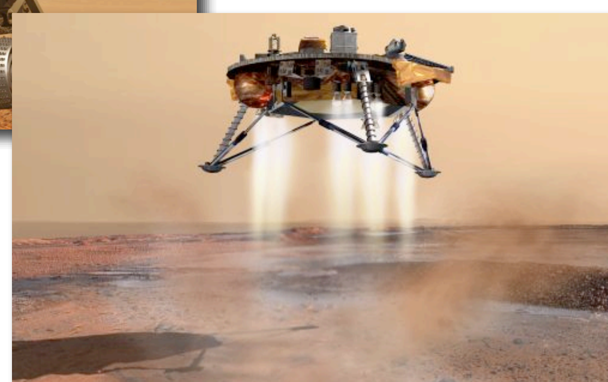
1997 - Mars Pathfinder & Sojourner Rover (MPF)



1999- Mars Polar Lander (MPL) (lost)



2004 - Mars Exploration Rovers - Spirit and Opportunity (MER)



2008 - Phoenix (PHX)

1996: MPF Overview

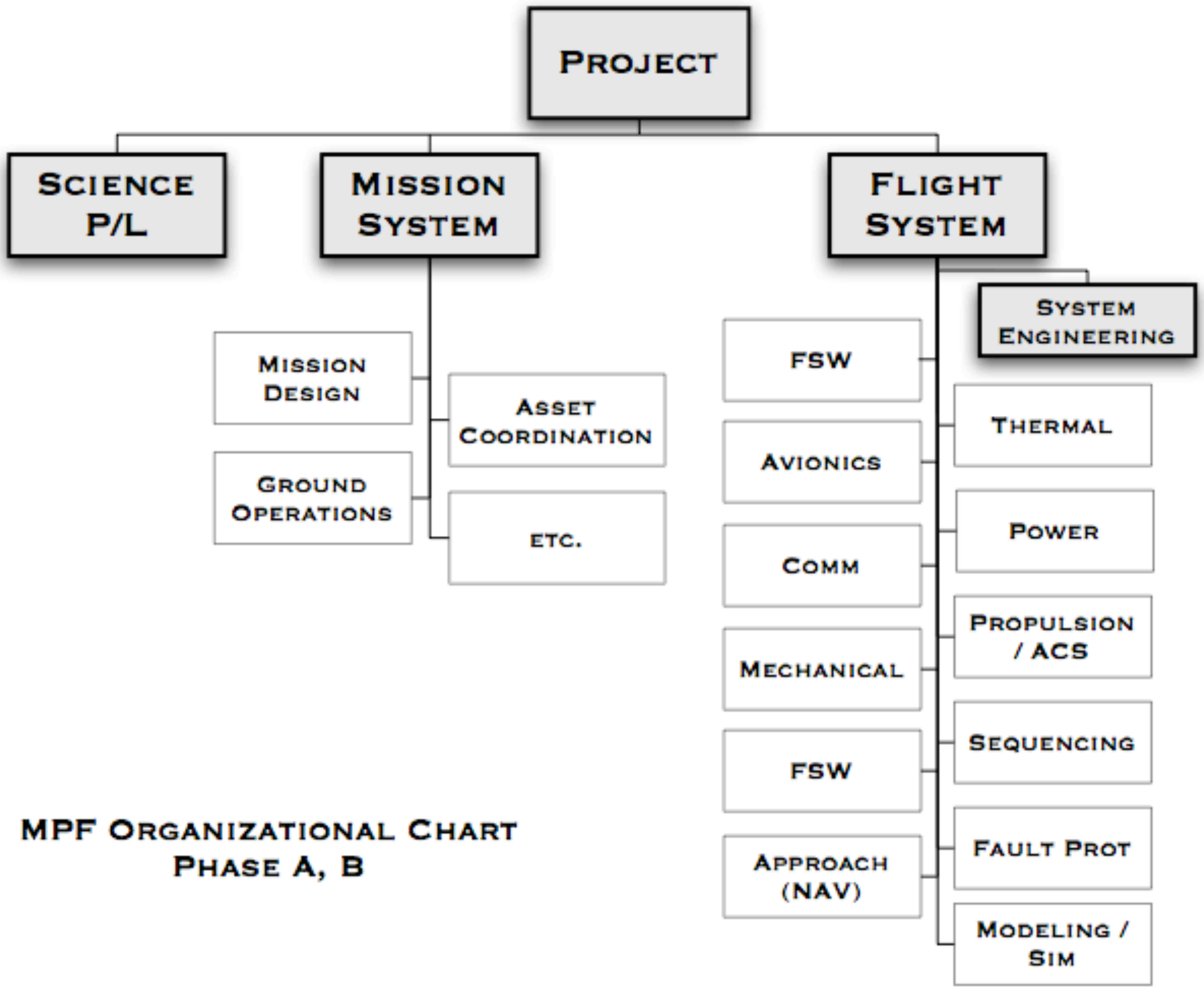
- **Lander and short-range rover architecture**

- **Faster, Better, Cheaper**
  - **Small cost cap, small team**
  - **Failure was an option; ref D. Goldin, NASA Administrator at time**

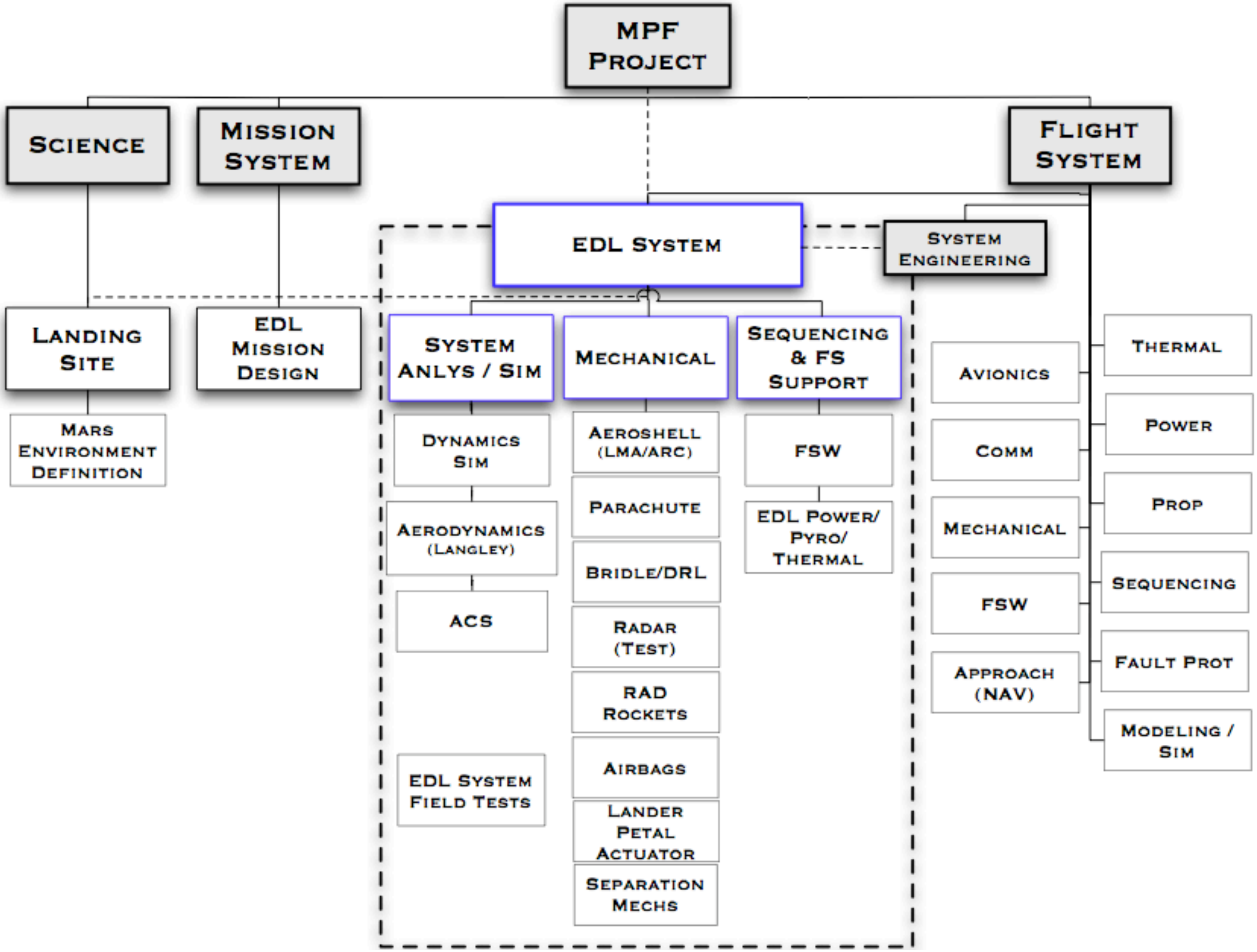
- **20 years had passed since last Mars EDL mission: Viking launched in 1976; led by LaRC**

- **Initial concept was fully mechanical EDL system**
  - **First "airbag" lander**

Generic Project Organization

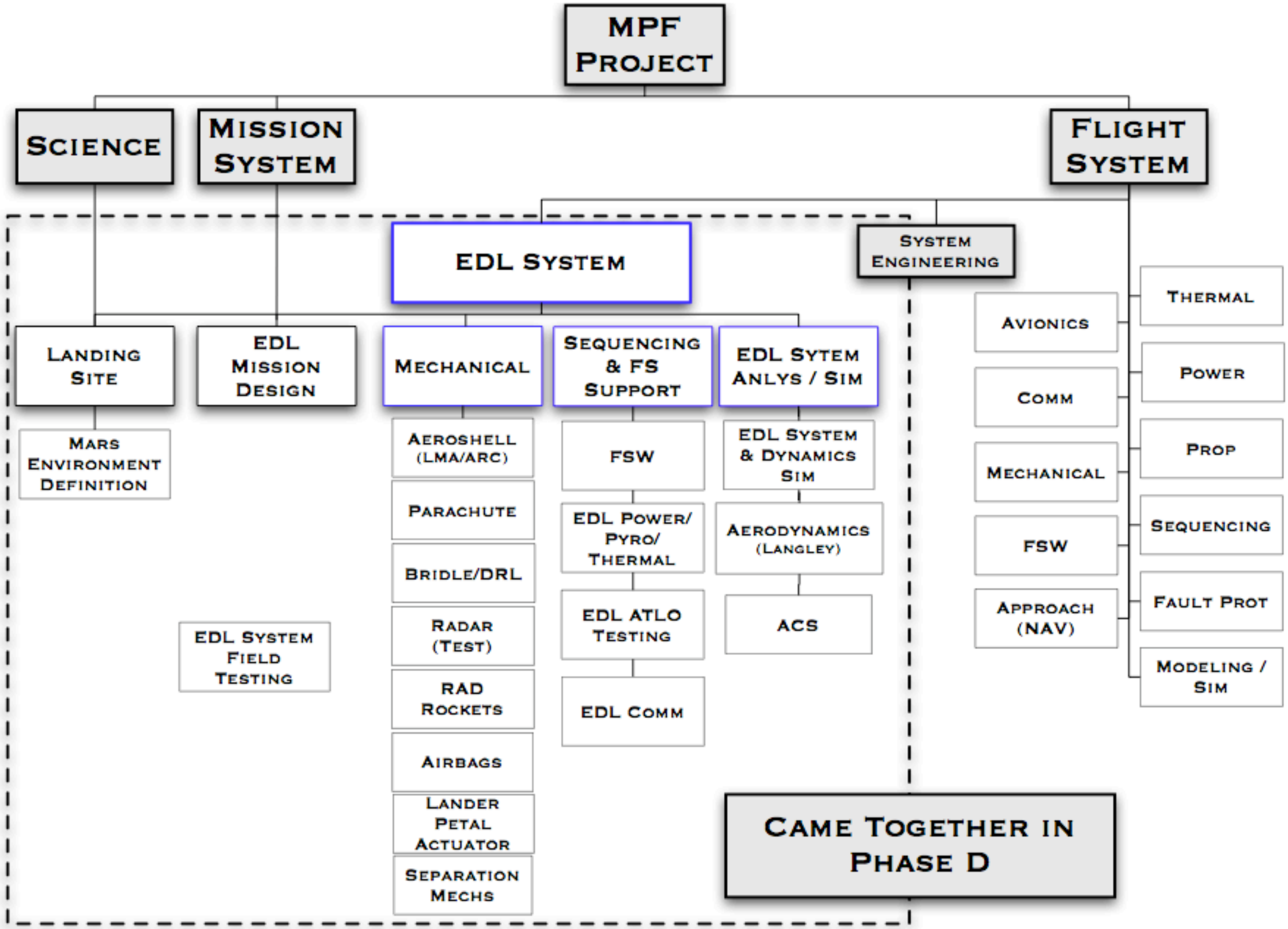


MPF Phase C



MPF PROJECT
SCIENCE
MISSION SYSTEM
FLIGHT SYSTEM
EDL SYSTEM
SYSTEM ENGINEERING
LANDING SITE
MARS ENVIRONMENT DEFINITION
EDL MISSION DESIGN
SYSTEM ANLYS / SIM
DYNAMICS SIM
AERODYNAMICS (LANGLEY)
ACS
EDL SYSTEM FIELD TESTS
MECHANICAL
AEROSHELL (LMA/ARC)
PARACHUTE
BRIDLE/DRL
RADAR (TEST)
RAD ROCKETS
AIRBAGS
LANDER PETAL ACTUATOR
SEPARATION MECHS
SEQUENCING & FS SUPPORT
FSW
EDL POWER/ PYRO/ THERMAL
AVIONICS
COMM
MECHANICAL
FSW
APPROACH (NAV)
THERMAL
POWER
PROP
SEQUENCING
FAULT PROT
MODELING / SIM

MPF Phase D

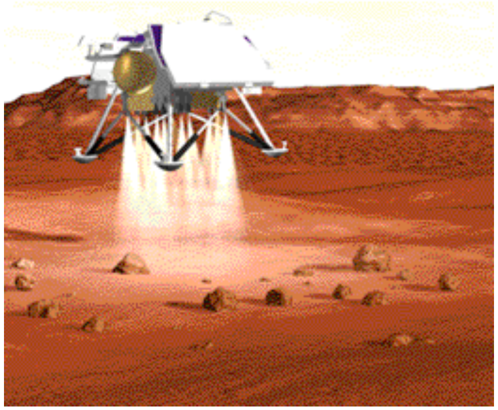

MPF Project
Science
Mission System
Flight System
EDL System
System Engineering
Landing Site
EDL Mission Design
Mechanical
Sequencing & FS Support
EDL Sytem Anlys / Sim
Mars Environment Definition
Aeroshell (LMA/ARC)
Parachute
Bridle/DRL
Radar (Test)
RAD Rockets
Airbags
Lander Petal Actuator
Separation Mechs
FSW
EDL Power/ Pyro/ Thermal
EDL ATLO Testing
EDL Comm
EDL System & Dynamics Sim
Aerodynamics (Langley)
ACS
EDL System Field Testing
Avionics
Comm
Mechanical
FSW
Approach (NAV)
Thermal
Power
Prop
Sequencing
Fault Prot
Modeling / Sim
Came Together in Phase D

MPF Lessons

- Organizational ("No duhs"? Maybe…)
  - Team composition closely integrated and expertise-focused; reliance on partners e.g. Ames, Langley
  - Subsystem participation in system-level meetings made compulsory; co-location facilitated
  - Strong team leadership and technical confidence; provides for resource negotiation e.g. airbag testing at Plumbrook
  - Innovative design was followed by innovative testing e.g. airbag landing system
- MPF Contribution of Firsts
  - First "end to end" attempt at entry, descent and landing phase simulation; discontinuous but laid ground work
  - Introduction of phase leads for Flight System (Cruise, EDL, etc): authority and responsibility to address operational aspects e.g. commanding, telemetry
  - Basic site-selection architecture / process conceived
- "The next time we go to Mars…"
  - Dedicated personnel to Egress (post-EDL) mission phase

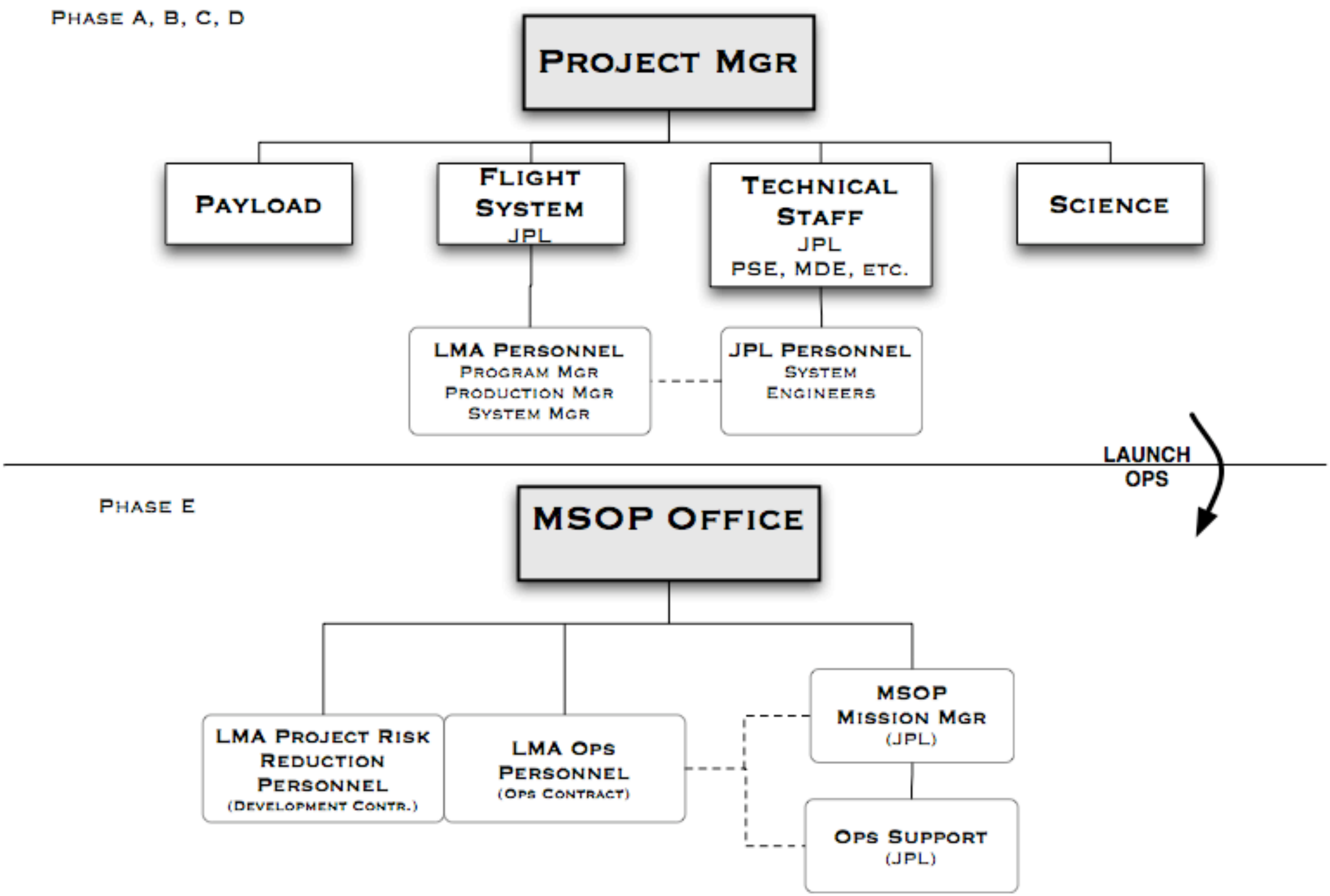
1998: MPL Overview

- **Three-legged soft lander architecture**



- **Cost-capped mission**
  - **Still Faster, Better, Cheaper**
- **Dual-spacecraft program: Mars Climate Orbiter and Mars Polar Lander**
  - **Novel approach to relay orbiter-lander pair**
- **Lockheed Martin development with JPL oversight and operations**
- **MPL mission lost during EDL; MCO lost during orbit insertion**

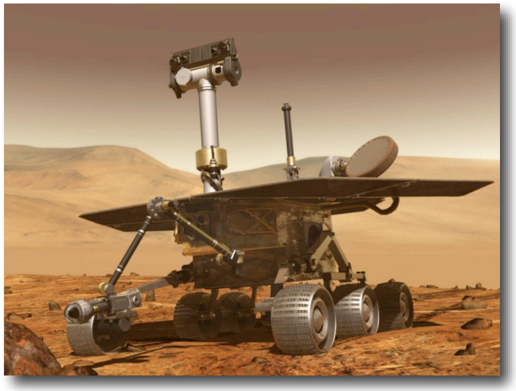
MPL Organization



MPL Lessons

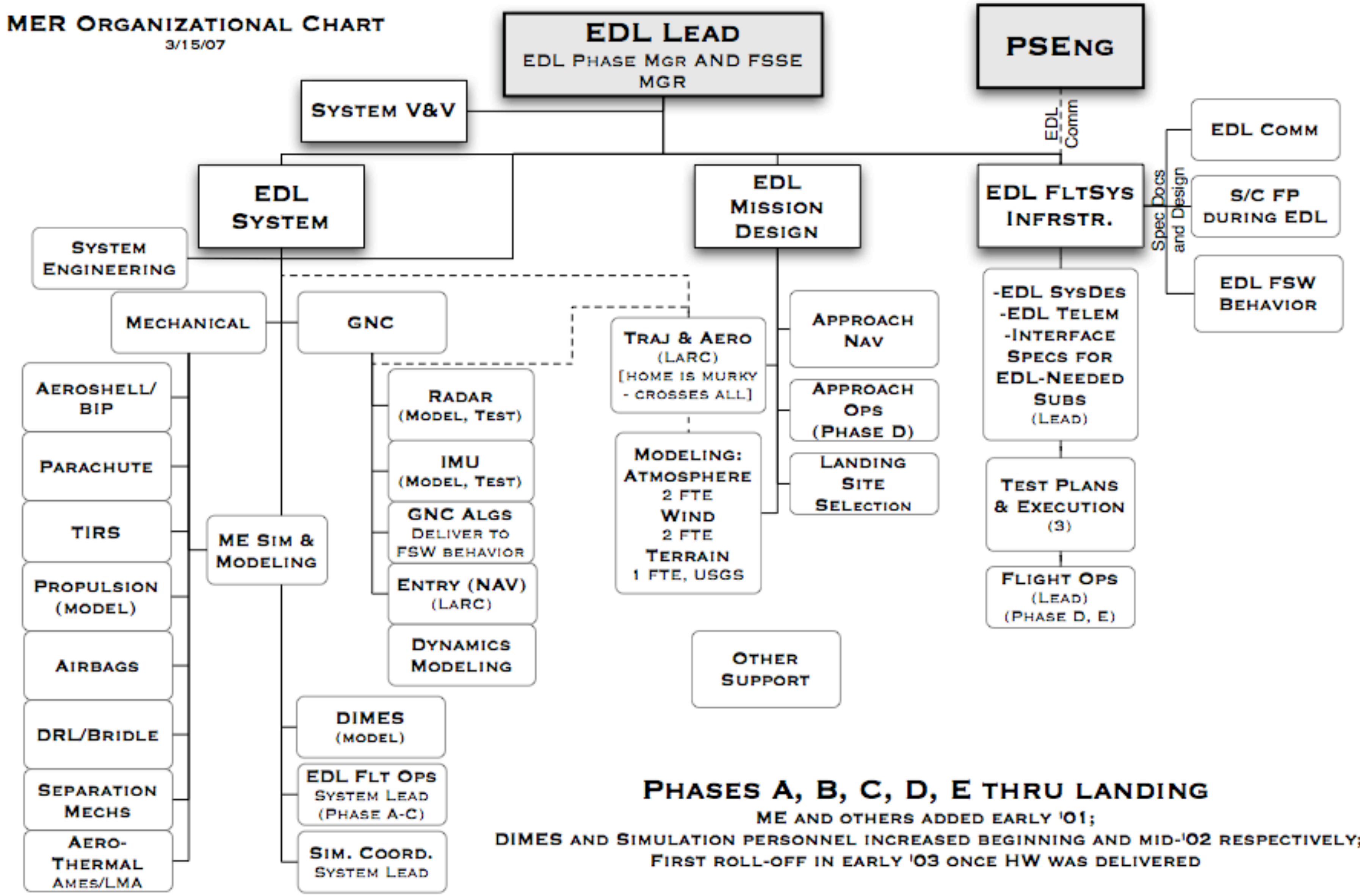
- Organizational
  - Both missions suffered from insufficient (shared) resources; led to lack of personnel
  - Lack of EDL-specific “team” (LMSS) and oversight (JPL) made managing LM work by JPL challenging; no LM/JPL teamwork
  - Phase lead was implemented but lacked knowledgeable “support” team
- Technological
  - Complex design required complex testing but lack of resources forced reliance on un-anchored (idealized) simulation
- “The next time we go to Mars…”
  - Retain personnel / knowledge continuity as project moves across phases, including operations
  - Managing out-of-house does not mean managing hands-off; an integrated NASA/contractor team allows for best of both worlds
  - Require Mars EDL communications for failure reconstruction

2003: MER Overview



- Pair of airbag-landed rovers
- NASA directed mission
- Three year development time (comparatively limited)
  - "Build to print" of MPF or "Athena in a bag"
  - Growing payload requirement impacts
  - Late additions (DIMES, TIRS…)
  - Flown architecture was "conceptual" heritage
- Post-MPL risk posture for Mars missions shifted
  - "Failure is not an option"

MER Organization



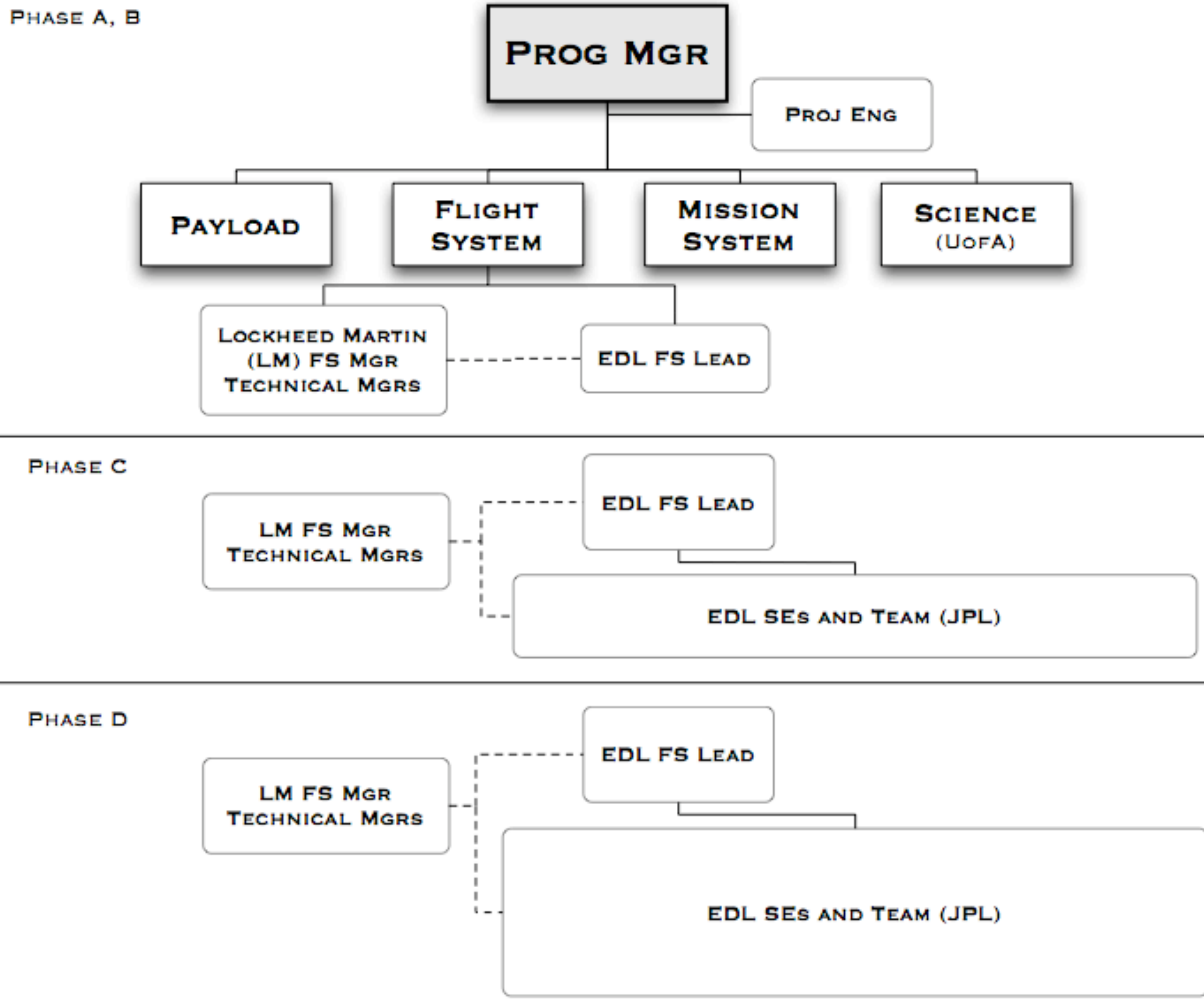
MER Lessons

- **Organizational**
  - **Larger team but still very integrated; subsystems very much a part of the EDL system design (ownership); co-location**
  - **Late-breaking design changes due to growing payload mass were managed due to resource availability and organization strength**
  - **Ability to respond to alarming weather reports (change in atmospheric density profile on Mars) in flight credited to successful ops transition and seamless coupling with knowledge centers / partners e.g. ARC, LaRC, LMA**
  - **With dedicated EDL personnel in a chaotic environment, some flight system interfaces tended to get overlooked or ignored**
- **"The next time we go…"**
  - **Require EDL-specific milestone reviews to manage system maturity, risks**
  - **Ensure that the EDL team is addressing FS interfaces regularly**
  - **Hold a LOT of reserve**

2008: PHX Overview

- **Three-legged soft lander architecture**
- **Scout class mission made possible by using Mars '01 flight hardware**
- **Contracted (proposed and won) to LMSS, program management by JPL**
- **Additional risk reduction funds were allocated by NASA HQ to address residual MPL-heritage failure modes**

PHX Organization



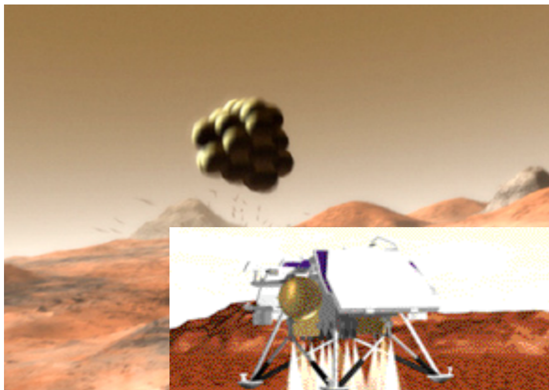
PHX Lessons

- **Organizational**
  - Initial organization was a modified MPL = non-EDL centric organization; minimal JPL interaction
  - LMSS proprietary concerns e.g. radar model made JPL mgmt difficult
  - Eventual LMSS - JPL team co-location, integration led to strong teamwork and proficient problem solving
  - Promoted trust, open communication, simulation collaboration
- **Technological**
  - Physical and political constraints due to heritage of MPL and Mars '01 made posed challenges but also provided the impetus for additional needed resources
  - Technology differences between Viking and PHX meant less heritage than perceived
- **Forward Recommendations**
  - TBD…

Summary

- **Synthesizing / integrating EDL team members in the "virtual" organization (in- and out-of-house missions) provides for strong collaboration and communication = problem solving**
- **Appropriate team composition is critical to adequately addressing challenges**
- **Encouraging system-level thinking by sub-segment engineers can elicit creative system performance solutions**
- **Appointing phase leads provides ownership and authority necessary to transition from development to operations**
- **EDL-specific milestone reviews provide venue to address and manage EDL-specific risks and challenges**
- **"Test as you fly" for Mars EDL is not realizable; therefore, testing <u>successfully</u> requires a team that can develop a creative V&V plan and leadership strong enough to make it happen**

The EDL Organization, Long Term



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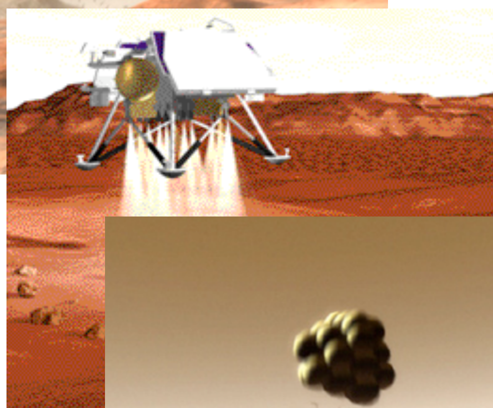

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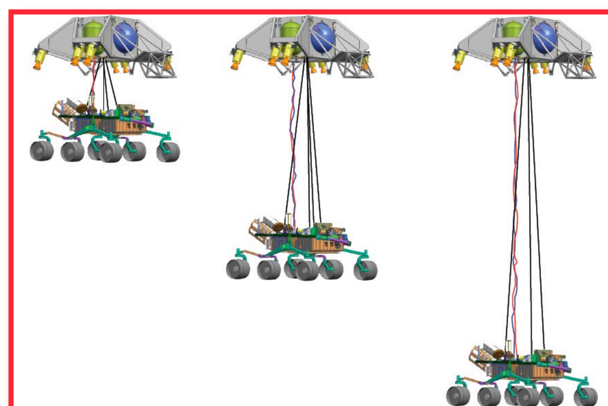

A new experiment in progress (MSL)