Mars Science Laboratory

Mission Concept Review

October 28-29, 2003

Mars Science Laboratory

Mission Concept Review

Review Purpose

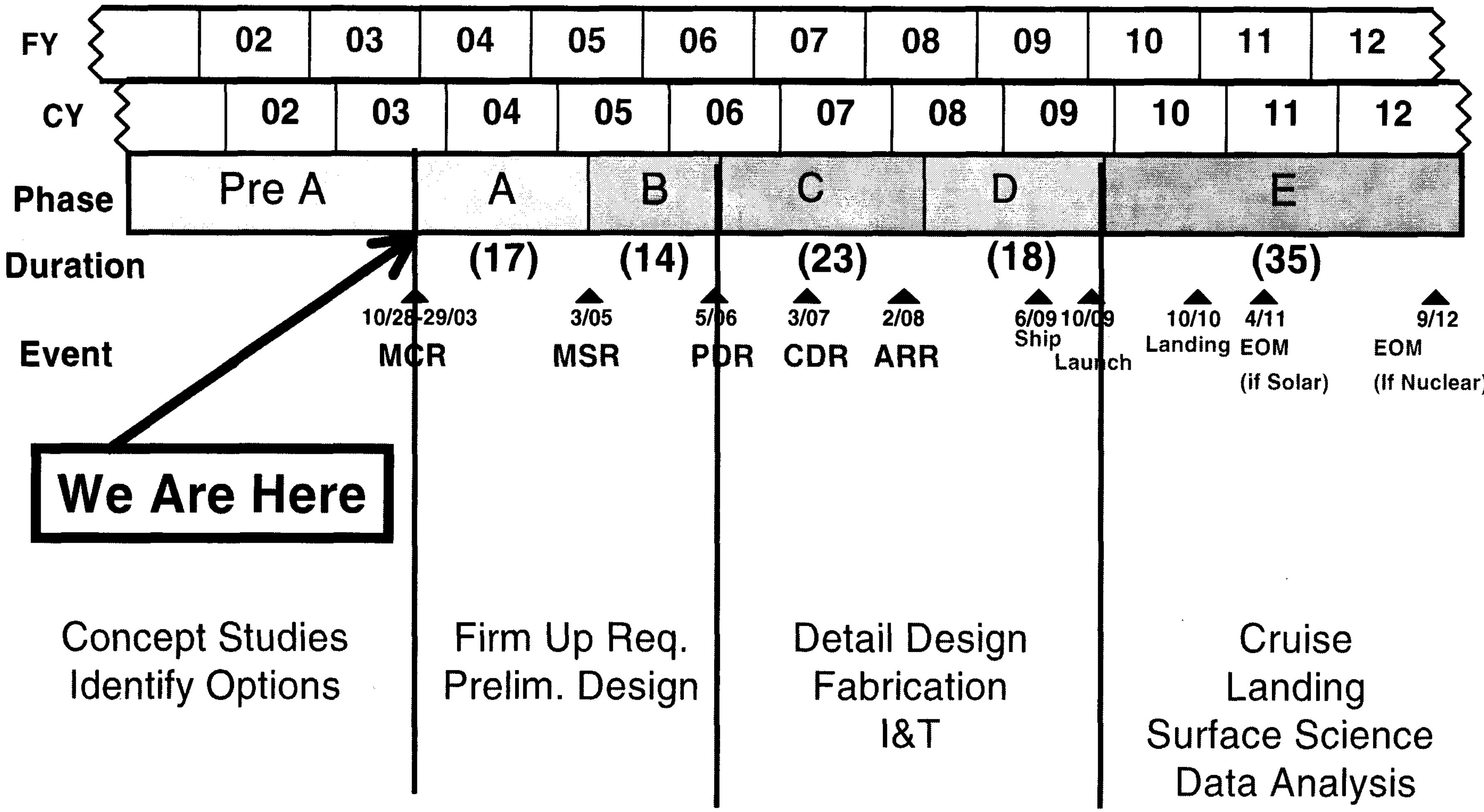
Charter to the Board

Firouz Naderi

October 28-29, 2003

Where Are We Now?

Mars Science Laboratory



Mission Concept Review

- **Mission Concept Review (MCR) is a JPL-instituted review (not required by the sponsor). Its purpose is to:**
  - Advise the Center Director if the current status of the project and their plans are appropriate for a project entering Phase A.

Charge to the Board

Looking Back

- Are the conclusions that the project has come to as a result of the trade studies to date appropriate? Are there options foreclosed that should not be?
- Have the right trades been identified to be completed during Phase A?
- Has the project correctly identified high leveraged items with respect to technical challenge and cost?
- Are the major risks identified?

Looking Forward

- Has the project formulated an appropriate plan to complete the remaining trades to converge to a baseline mission concept?
- Does current technology Program address the high risk areas?
- Given the current status of the Project and their plans, assess the likelihood that the project will be able to arrive at a mission concept by the end of Phase A that will satisfy the science objectives and adhere to the cost target set by the sponsor with acceptable risk.

Success Criteria

- **The review board is able to conclude that:**
  - Project has identified technically feasible options which are able to fulfill the science and mission objectives
  - The development and mission risks are recognized, and the project can be managed with acceptable risk
  - The proposed scope, considering available options to be evaluated during formulation, is consistent with the funding available to complete the mission with acceptable risk
  - The development of enabling technology can be accomplished within the available schedule, or suitable alternatives exist
  - The schedule is adequate to complete the development with acceptable risk

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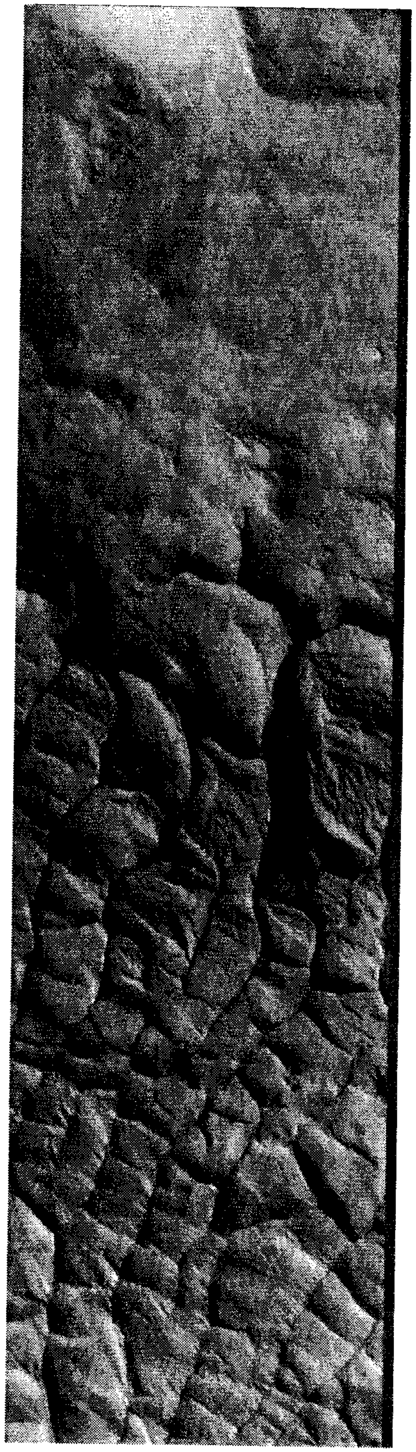
Mission Concept Review

Review Board

Board Members	Affiliation	Areas of Concentration
Noel Hinners, Chair	LMC, Retired	Program/Project Management, Planetary Science
Richard Brace	JPL	Project Management, Mission Assurance
Frank Carr	JPL, Retired	Program/Project Management, Systems Engineering
Mike Carr	USGS	Planetary Science
Phil Garrison	JPL	Systems Engineering, Flight Hardware
Hugh Kieffer	USGS	Planetary Science
Gentry Lee	JPL	Systems Engineering, Viking, Software
Leslie Livesay	JPL	Project Management, Flight Hardware
Bud McAnally	LMC, Retired	Project Management, Systems Engineering
Dan McCleese	JPL	Planetary Science
John McNamee	JPL	Project Management, Systems Engineering
Kevin Rice	JPL	Business Systems
Doug Schmidt	Vanderbilt U	Project Management, Software
Gael Squibb	JPL, Retired	Systems Engineering, Project Management, Flight Operations
David Swenson	JPL	Systems Engineering, Instruments, Flight Hardware
Pete Theisinger	JPL	MER Project Manager, Systems Engineering
Mark Dahl	*NASA/Code SM, Ex officio*	*MSL Program Executive*
Mike Meyer	*NASA/Code S, Ex Officio*	*MSL Program Scientist*



Mars Science Laboratory

Mission Concept Review

Project Overview

Michael Sander

October 28-29, 2003

Discussion Topics

- **Review agenda/Key Questions**
- Project context
- Project Description
- Budget and schedule “Big Picture”
- Key risks/issues/actions and Phase A plan

MSL Mission Concept Review Agenda

October 28-29, 2003

Mars Science Laboratory

Review Purpose/Charge to the Board	Firouz Naderi	8:00 AM	0:15:00
Review Board Introduction	Board	8:15 AM	0:15:00
Project Overview * Project Overview * Enterprise Constraints	Mike Sander	8:30 AM	1:00:00
Science *Science & mission objectives	Frank Palluconi	9:30 AM	0:45:00
Payload * payload accomodation approach	Jeff Simmonds	10:15 AM	0:25:00
NASA AO	Mike Meyer	10:40 AM	0:20:00
break		11:00 AM	0:15:00
Project Engineering *Key driving requirements , trace to science/program needs	John Baker	11:15 AM	0:45:00
Lunch		12:00 PM	1:00:00
Flight System *Flight system **options** and descriptions, trades, margin assessment, areas of new technology and fallback options.	Brian Muirhead	1:00 PM	2:10:00
Planetary Protection Plan	Brian Muirhead	3:10 PM	0:20:00
Break		3:30 PM	0:15:00
Mission System *Mission system and Flight Software **options** and descriptions, trades, risks and mitigations, and new technologies	Charles Whetsel	3:45 PM	1:15:00
Board Wrapup-Day 1	Review Board Chair	5:00 PM	
Day 2			
Technology Plan	Gabriel Udomkesmallee	8:00 AM	1:00:00
Cost Summary		9:00 AM	
*Resource estimate and uncertainty	Annette Green		0:45
*budget options	Mike Sander		0.15
Break		10:00 AM	0:15
Phase A Plan and Options * phase A schedule, studies summary, process	John Baker	10:15 AM	0:45:00
Summary	Mike Sander	11:00 AM	0:15:00
Board Discussion	Review Board Chair	11:15 AM	
Lunch		12:15 PM	1:00:00
Board Discussion	Review Bd Chair	1:15 PM	3:00

Key Questions

• Why this review?	- Naderi
• What's the big picture on this mission?	- Sander
• What does the science community want this mission to do? How does this fit into the overall Mars science program?	- Palluconi
• Since no payload has been selected, how does the project team know it will be able to support the investigations when they are selected?	- Simmonds
• How will NASA go about selecting the investigations?	- Meyer
• How does the reference design relate to the mission needs? How did the team decide on this reference design?	- Baker

Key Questions (cont'd)

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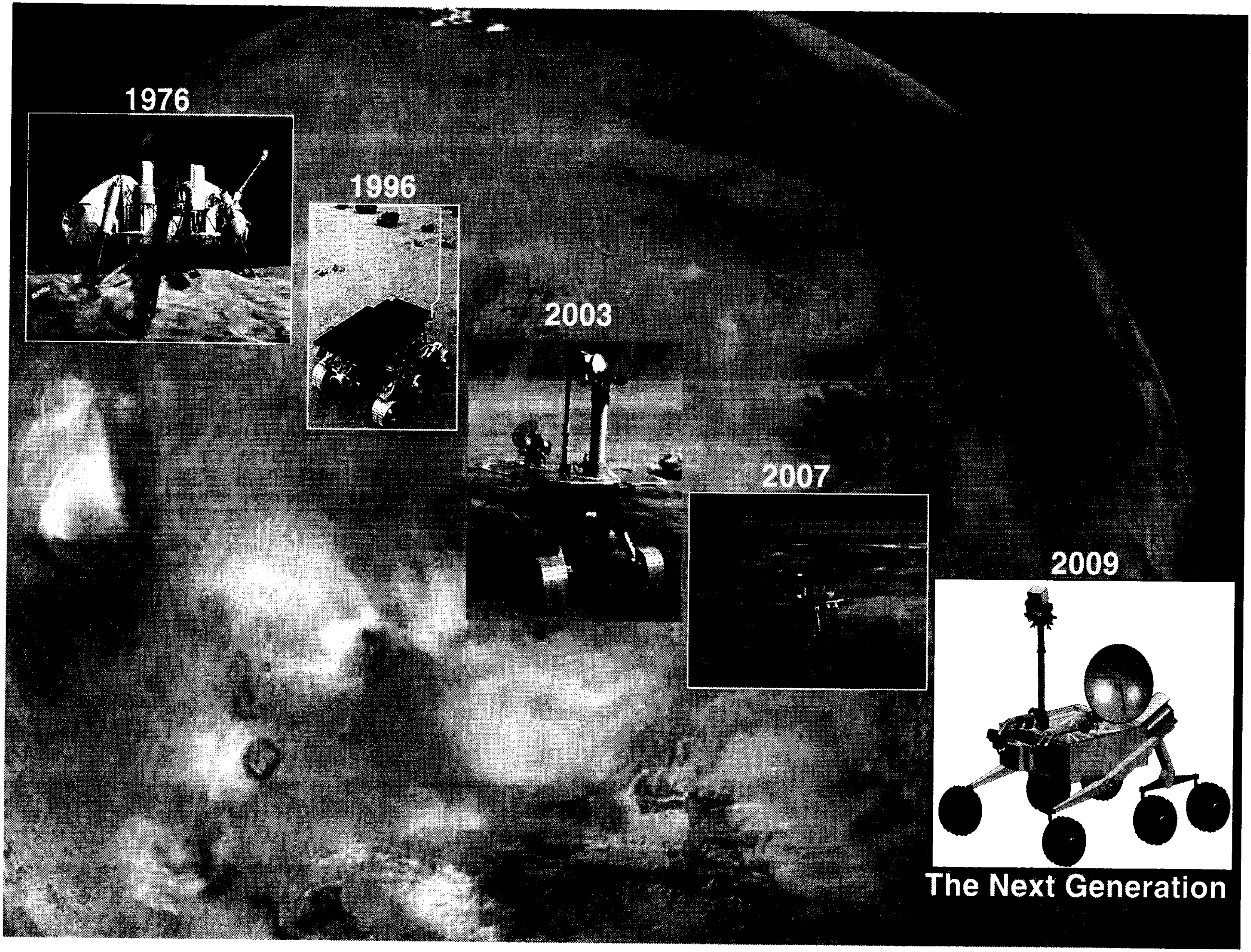
- How is the rover sized? Does the project have adequate margins? What is the project doing about planetary protection? - Muirhead
- How is MSL going to operate a mobile landed asset with daily executable agenda over extended periods? What is MSL doing about the continuing issue of flight software? - Whetsel
- How is the project leveraging the technology program? How will the technology flow to flight? - Udomkesmalee
- What is MSL's reference mission cost, and how does it compare to other cost estimating techniques and NASA identified target cost ? - Green
- What does the project plan to do during Phase A, and how will it prepare for the next major milestone? - Baker

Discussion Topics

- Review agenda/Key questions
- ⇨ **Project context**
- Project description
- Budget and schedule “Big Picture”
- Key risks/issues/actions and Phase A plan

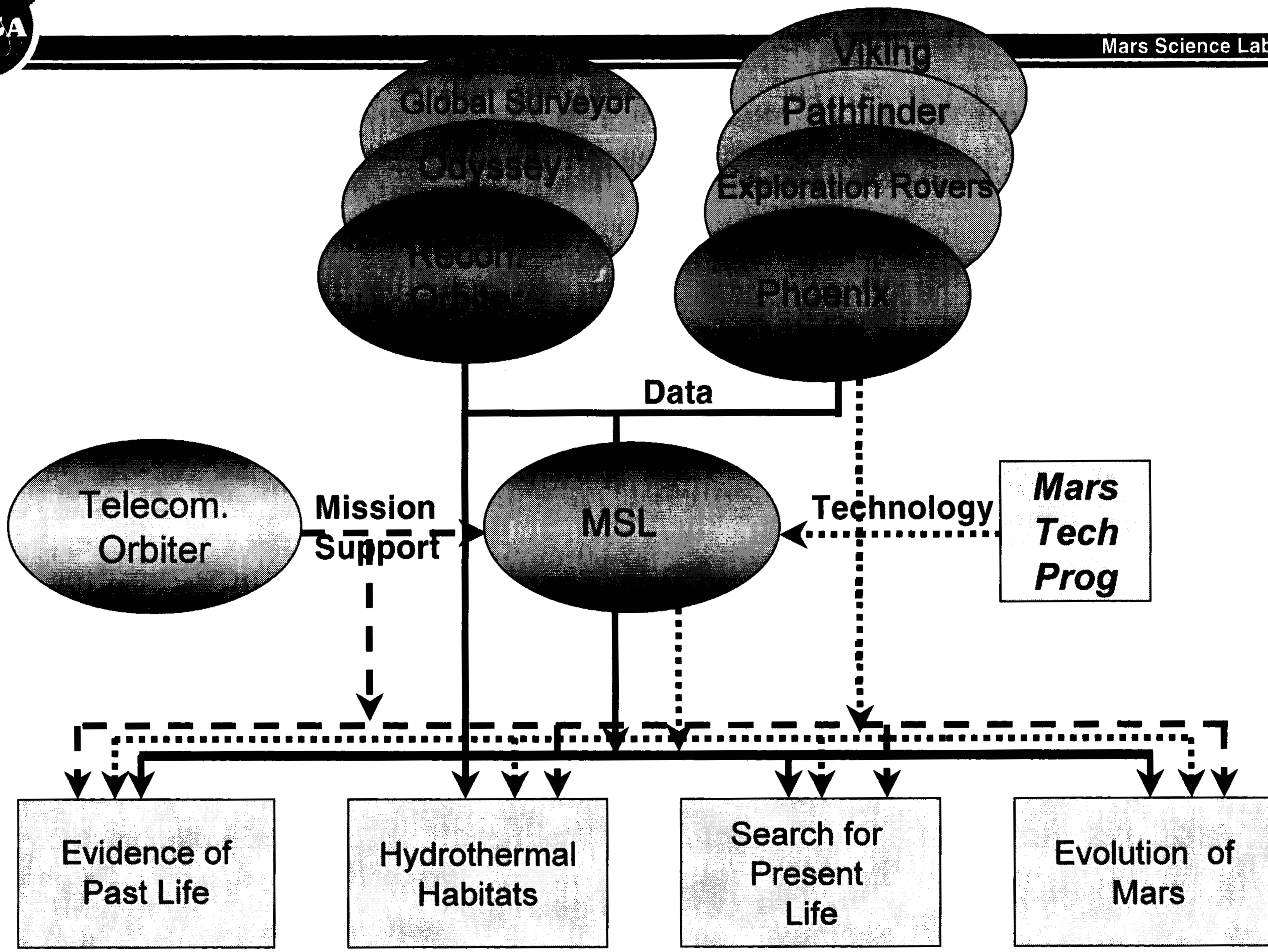

1976
1996
2003
2007
2009
The Next Generation

Comparison with Other Mars Landers

	Viking	*Sojourner/ Pathfinder	MER	Phoenix	MSL
Landing Accuracy	100x200km	100x200km	50x150km	20x20km	5x10km
Landed Mass	690kg	350kg	350/180kg	162kg	900kg
Landed Max Alt	-1.5km	-1.0km	-1.3km	-3.5km	+2.5km
Mobility	None	*30m	600m	None	6000m
Prime Msn Duration	90 sols	30 sols	90 sols	90 sols+60	687 sols
Payload (note 1)	91kg	*21kg	30kg	32kg (note 2)	147kg
PP approach	IVb	IVa	IVa	IVc	IVc
Power/Sol	1920 whr	*50 whr	600 whr	1500 whr	5600 whr
Flight Sets	4	1	2	1	1
Msn Cost (03$)	$4300M	$350M	$850M	$355M+inher.	$1200M

Note 1: Instruments and payload support, including reserve
Note 2: Digging phase + extended meteorology phase
Note 3: MER mass is 180kg; total landed mass, including lander/airbags, is 350kg

How Does MSL Fit Into Mars Program?



Requirements

- Formal Level 1 requirements will be provided by HQ when design and cost implications are better understood
  - Phase A process
- Project has been using a set of working requirements to shape the Reference Design
  - Iterations between requirements, cost, and design are a key part of Phase A
  - Delta off the reference design/cost/requirements set at MCR
- Working requirements are set by
  - Science community via PSIG
  - Mars Program via program plan
- Formulation Authorization Document sets the stage for Phase A
  - In signature cycle at NASA HQ

Working Level 1 Requirements

- **Science mission needs**
  - Produce measurement types consistent with PSIG report
    - New generation analytical instruments
  - Landing site flexibility between 60 deg N and 60 deg S latitude
    - Choice may be made based on MRO data (later site selection)
  - Capable of landing at altitudes of up to 2.5 km
  - Capable of landing in a reduced size error ellipse (5 km x 10 km)
  - 28 samples (minimum) to 74 samples (baseline)
    - Implies 344 sol to 670 sol mission length
    - Implies 3 to 6 km traverse capability
- **Programmatic needs**
  - Target real year development cost: **870M**
  - Provide telemetry stream for diagnostics during EDL
  - Landing mass capability consistent with MSR needs
  - Demonstrate a hazard avoidance capability
  - Planetary protection
- **Key Assumptions**
  - Nuclear power available
  - Telecommunications satellite available

MSL Will Be Precedent Setting in Terms of Its Capabilities

Capabilities	Benefits
• Precision approach • Guided entry	• Precision land (5x10km)
• Guided entry • Dual parachute • Nuclear power	• Access to 75% of the planet
• Nuclear power	• Long-life (3 years rather than 3 mos.)
• Sample acquisition and processing • Analytical instruments	• *In-situ* laboratory
• Hazard detection/avoidance	• Terminal descent flexibility (~100m)
• Long-range mobility	• Sample diversity (2-4km)
• Delivery of a large mass to the surface	• Needed for the future MSR mission
• MDS first application on a project	• Been promised good things

Discussion Topics

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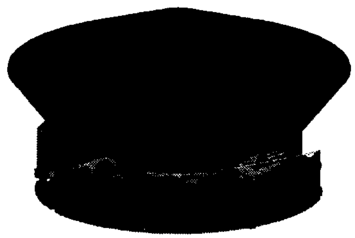
Reference Design

- **Early exploration phase of a mission**
- **Explores range of possible means to satisfy HQ/community vision for a mission opportunity**
  - Requirements/drivers and constraints are iterated
- **Reference design needs to be flexible**
  - Results from other missions
  - Technology insights
  - Implementation insights
- **Define credible concepts with high likelihood to be implementable within constraints; Phase A refines the design and narrows the error margins**

Mission Architecture

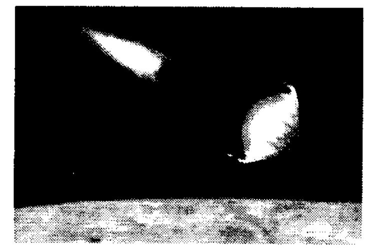


CRUISE/APPROACH

- 10-12 month flight time

ENTRY/ DESCENT/ LANDING

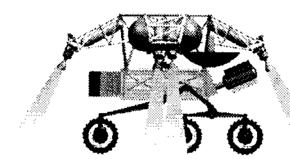
- Direct Entry
- Comm provided by UHF link to MTO and other orbiters



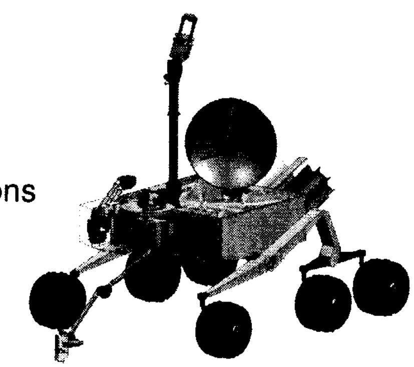
LAUNCH

- Oct. 27, 2009
- Delta IV/ATLAS V w/5-m fairing

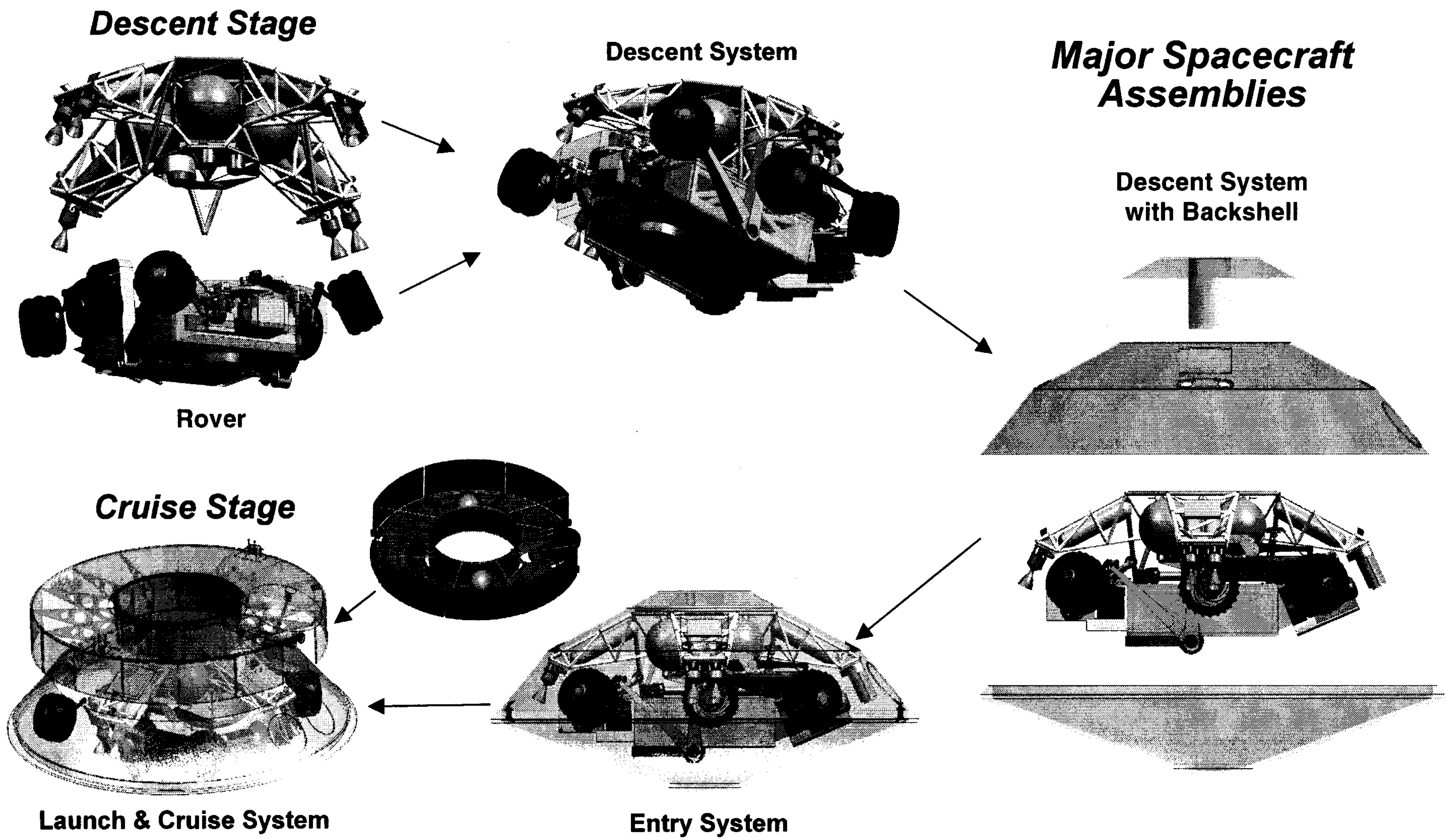
SURFACE MISSION



- Large rover
- One Mars year prime mission
- 2 to 4 km mobility
- Approx 100+ kg payload of instruments and support tools
- Radioisotope Power Source assumed, pending final decisions



Major Assemblies



Key Features of the MSL Rover

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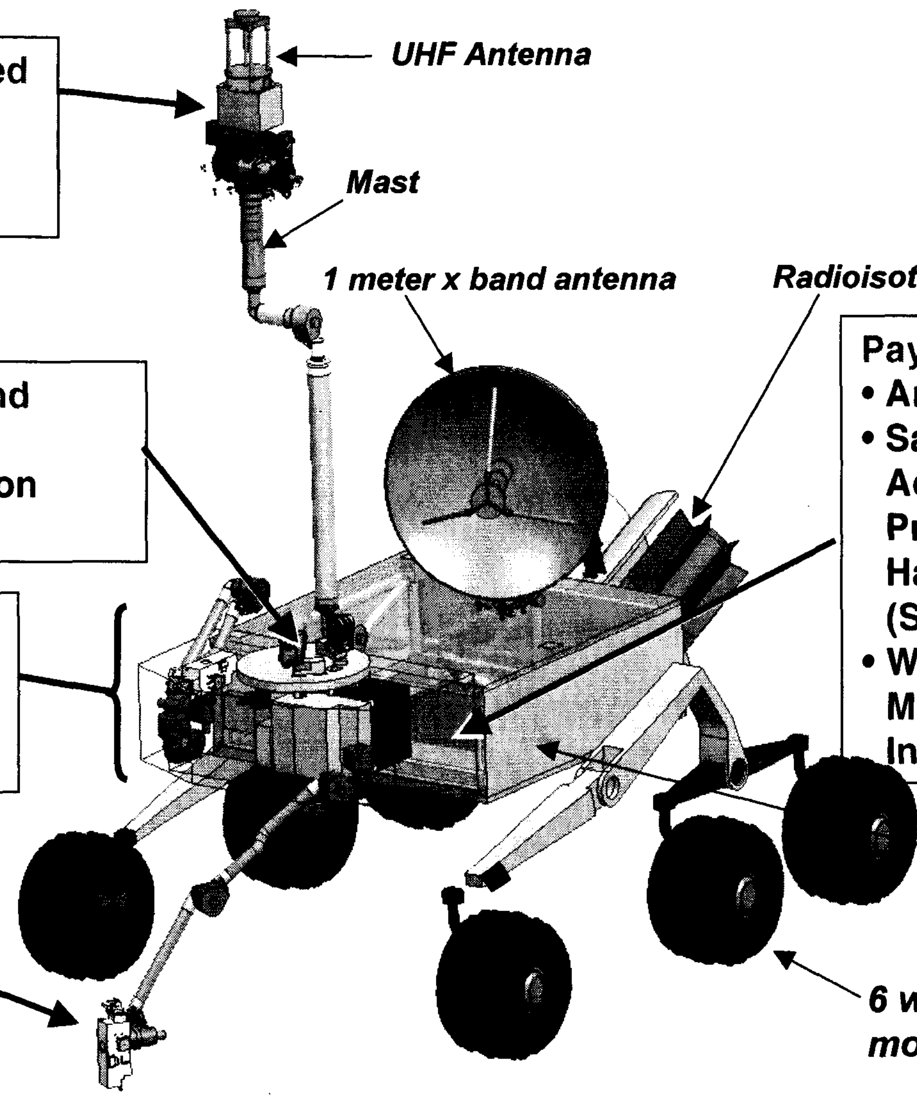

Mission Trades

Level 3 Summary

MISSION

- **LAUNCH**
  - L/V Type
  - L/V Config
- **TRANSFER**
  - Trajectory Type
  - Carrier Sys Design
- **APPROACH**
  - Nav System
  - Entry Method
- **EDL**
  - EDL Comm
  - Entry Vehicle Design
  - Parachute Descent
  - Terminal Descent
  - Descent Propulsion
  - Hazard Detection & Avoidance
- **SURFACE**
  - Rover System
    - SS Trades
  - Comm Strategy
  - Rover Navigation
  - Payload Supt
  - Mission Ops

Mission Trades – Launch

LAUNCH

- L/V Type
  - Delta II/III
  - Atlas 5 - 521
  - Delta IV- 4450
  - Delta IV Heavy
- L/V Configuration
  - 4m L/V fairing
  - 5m L/V fairing

Major Project Trades to Date

- Descent Engine options (type, size/number)
- 1 vs 2 parachutes
- Pallet vs descent stage
- Aeroshell configuration
- Mobility system configuration (4 vs 6 wheels)
- Project Science Integration Group trades
  - Mobile vs fixed
  - High polar (80 deg) vs lower latitude range (60 deg)
  - Ice handling capability vs no ice handling capability
  - Rover range capability (high investment in autonomy vs more instruments)

Technology Tasks

Project Customer Area	Technology Suite
• Entry, Descent, Landing	
– Large landed mass/global accessibility →	Guided entry, new engines, subsonic parachute
– Precision delivery →	Optical navigation, GN&C algorithms
– Autonomous Terminal Descent/hazard avoidance →	Radar, subsonic parachute, GN&C algorithms
– Robust Touchdown →	New engines, skycrane val., GN&C algorithms
• Surface System	
– Robust, flexible flight software – Long-term surface operations →	Flight software architecture, ops design, long-life elec./mech., software validation, surface GN&C
– Advanced sample management →	Sample proc. & distribution

Discussion Topics

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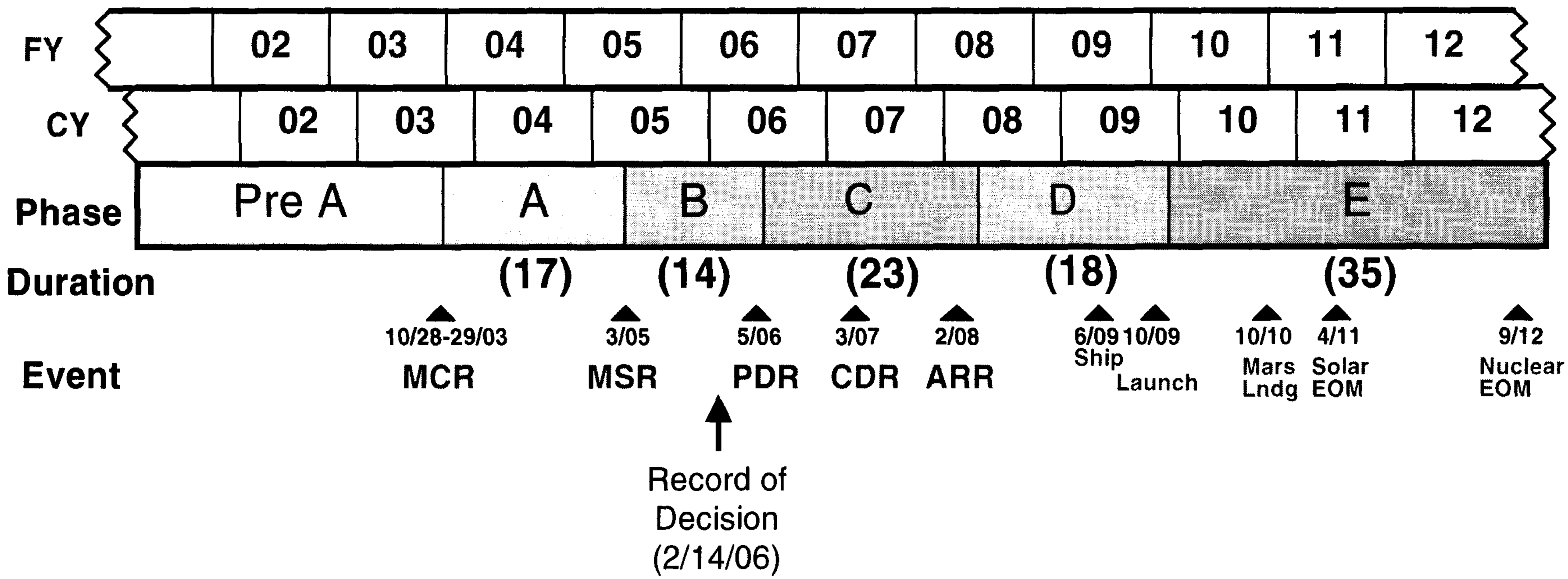
- Project description
- ⇨ **Budget and schedule "Big Picture"**
- Key risks/issues/actions and Phase A plan

Project Schedule



NASA Budget Allocation for MSL

• Technology program	FY 03,04,05	77M
• Launch vehicle		152M
• Phase E (operations)		115M
• RPS-JPL adaptation costs for solar to RPS		24M
• RPS-DOE funds for RPS		171M
• Project development costs to launch		870M
	TOTAL	**1409M**

MER/MSL Comparison of Development Costs in FY03 Dollars:

MSL FY03 Dollars:	780M
MER FY03 Dollars:	667M

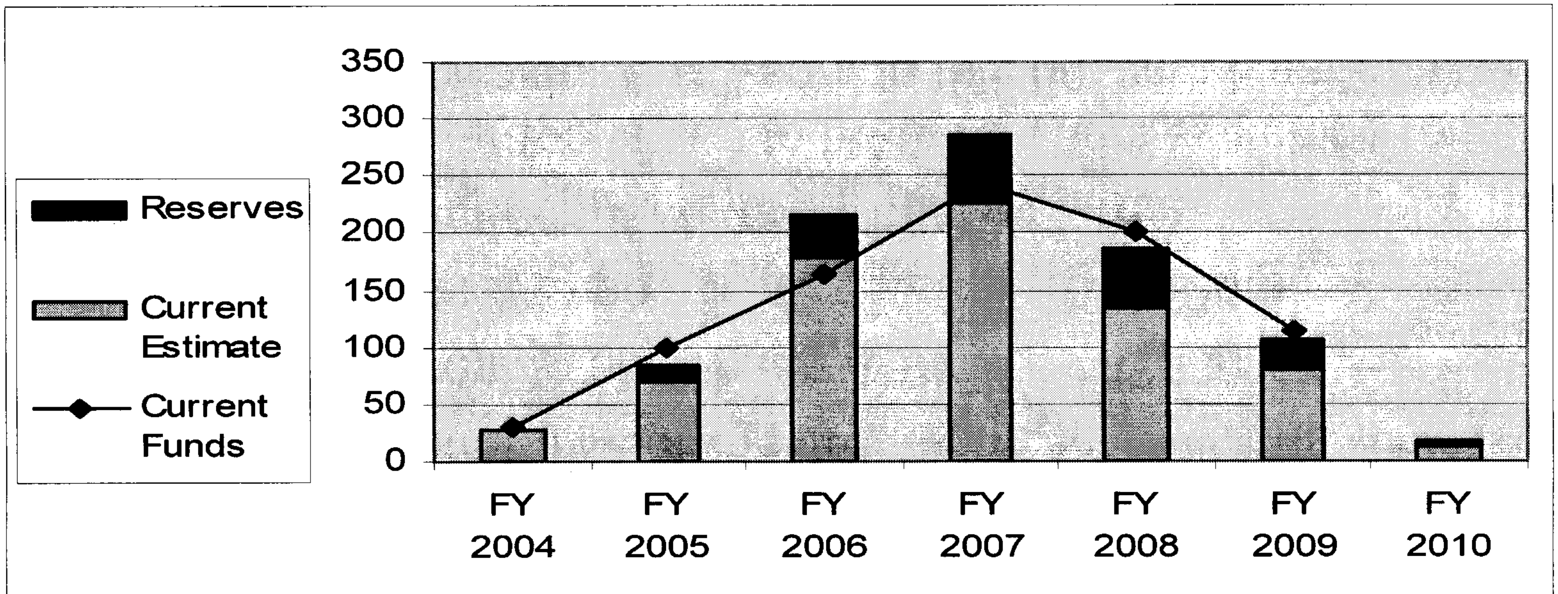
Estimating the Cost of the Reference Mission

- MSL target development cost of $870M has the following components:
  - Sunk cost of Pre-phase A — $15M
  - Cost to go (Phase A-D) — $661M
  - Reserve on cost to go — $194M (~30%)
- This summer the project conducted a detailed grassroots cost estimate (~ 180 cost accounts) involving JPL technical divisions. This resulted in:
  - Estimate of cost to go (Phase A-D) — $730M
  - Reserve on cost to go — $194M

Delta =$69M (~10%)

- Cost estimate exceeded the target cost by ~10%
  - ~1/4 of the overage is due to NASA centers switching to full cost accounting. Project is still sorting this out with Headquarters
- Project will pursue cost reduction in Phase A

Current Development Estimate Profile Including Reserves ($M)



	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	Total
Current Estimate Obligations	27	71	180	225	135	81	12	730
Reserves	2	13	35	62	51	27	4	194
Total Current Est. + Reserves	29	83	215	287	186	108	16	924

Current Funds Profile	30	100	164	244	202	115		855
Delta Funds vs Estimate	1	17	-51	-43	16	7	-16	-69

Annual % Reserve Ratio	8%	18%	20%	27%	38%	34%	32%	
% Reserve on Obs To Go	27%	27%	28%	32%	36%	33%	32%	

Budget Options

- **Team has identified options to address going from current estimate to the target**
  - **High dollar value, high probability** **33-36M**
    - Compress the C/D peak
    - Leverage JPL architectural platform
  - **Low dollar value, high probability** **4-5M**
    - Seven options
  - **High dollar value, medium probability** **25-30M**
    - Drop the phased area radar, use Phoenix radar
  - **Low dollar value, low probability** **10-15M**
    - Nine options

TOTAL 72-86M

Project has multiple options to reach the target budget

Mars Science Laboratory Org (670)

FY03 (Rev.2L)

Project Manager – M. Sander
Project Scientist – F. Palluconi
Deputy Project Scientist – TBD
Deputy Project Manager – TBD
Chief Engineer(Ph A) – B. Muirhead
Project Business Manager – A. Green
Project Secretary – N. Schweiner

Business Office – A. Green

PRA – L. Ramsay
Project Acquisition Manager – P. Easter
Scheduler – S. Gillespie

MAM – J. Newell
Safety – TBD

Tech. Mgr. – G. Udomkesmalee

Project Engineering Office
J. Baker (Acting)

Partners

KSC – A. Sierra
DoE – R. Wiley
LaRC – M. Lockwood
ARC (EDL)
ARC (IT) – M. Drummond
JSC – C. Graves

Science Office
F. Palluconi
Deputy-TBD

Mission Systems and Flight Software Office
C. Whetsel (acting)
Deputy- A. Sacks (acting)

Flight Systems Office – B. Muirhead (acting)
End-to-end life cycle V & V – D. Woerner

Payload & Engineering Sensors
J. Simmonds

Major Participating Organizations

- **Science Community** .... Investigation design, development, operations, data analysis, mission guidance
- **JPL** .... Flight and ground system design, integration and operations
- **Langley Research Center** .... Entry phase analysis, aeroheating predictions
- **Johnson Space Center** .... Entry guidance
- **Ames Research Center** .... Thermal Protection System development and testing/flight and ground IT
- **Kenney Space Center** .... Launch vehicle acquisition, launch campaign host, and supporting staff, facilities, ops
- **NASA HQ/DOE** .... Two flight-qualified, fueled RPS's (GFE)
- **Industry** .... Aeroshell/heat shield, parachutes, flight subsystems

Discussion Topics

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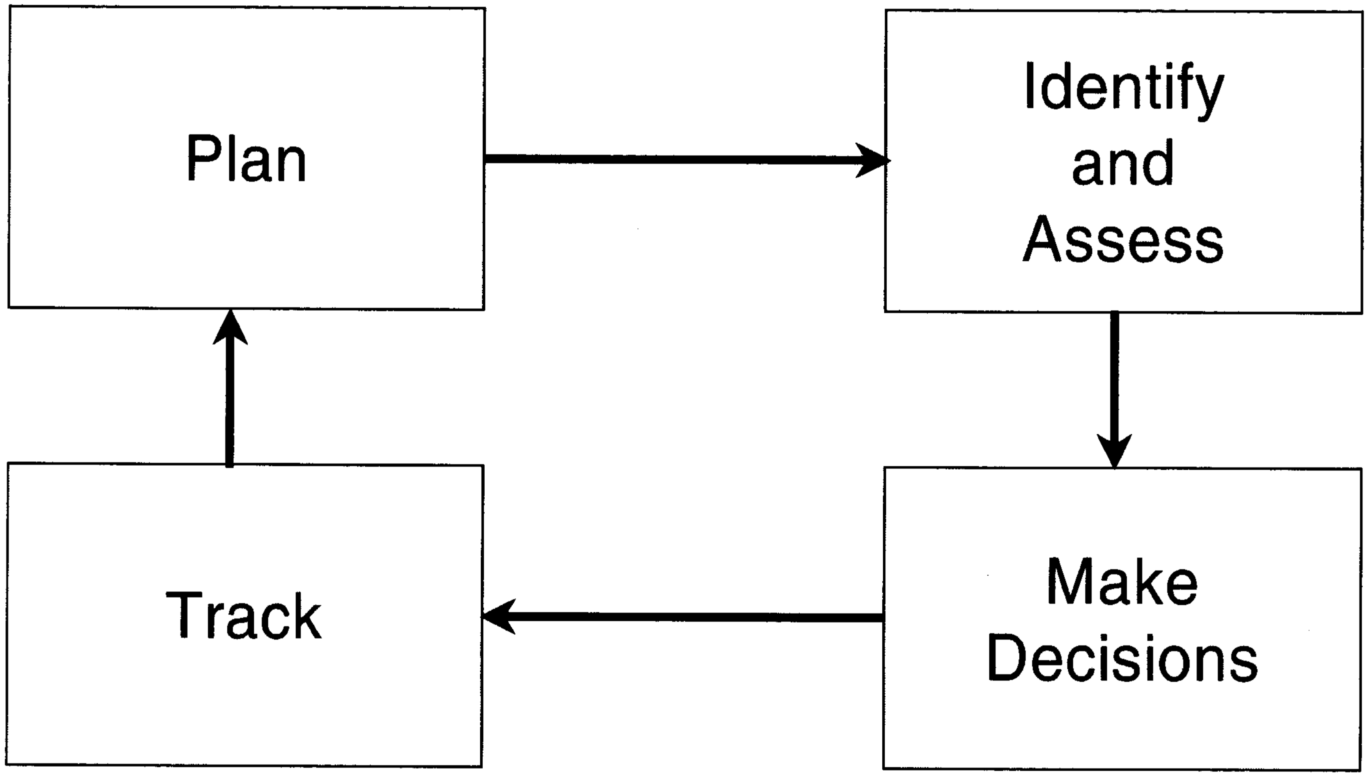
Mission Risks



- Project is using a risk management process
- 87 items identified to date
- Focus on items with significant residual risks

Significant Residual Risk Items

- **Identifying Suitable Bioburden Measures to Cover Planetary Protection** (discussed by Muirhead)
  - Tiger team in place
  - Cost allocation increased
  - Part of a Mars Program issue
- **Instrument Costs** (discussed by Meyer)
  - Cost allocation increased
  - AO considerations in process
- **Efficient Long-duration Operations** (discussed by Whetsel)
  - Phase A design will focus on options
  - Early testing of design elements
- **New Approach to Mission Software** (discussed by Whetsel)
  - Requires changes to systems engineering approach
  - Emphasizes architecture, code reuse, early attention to software

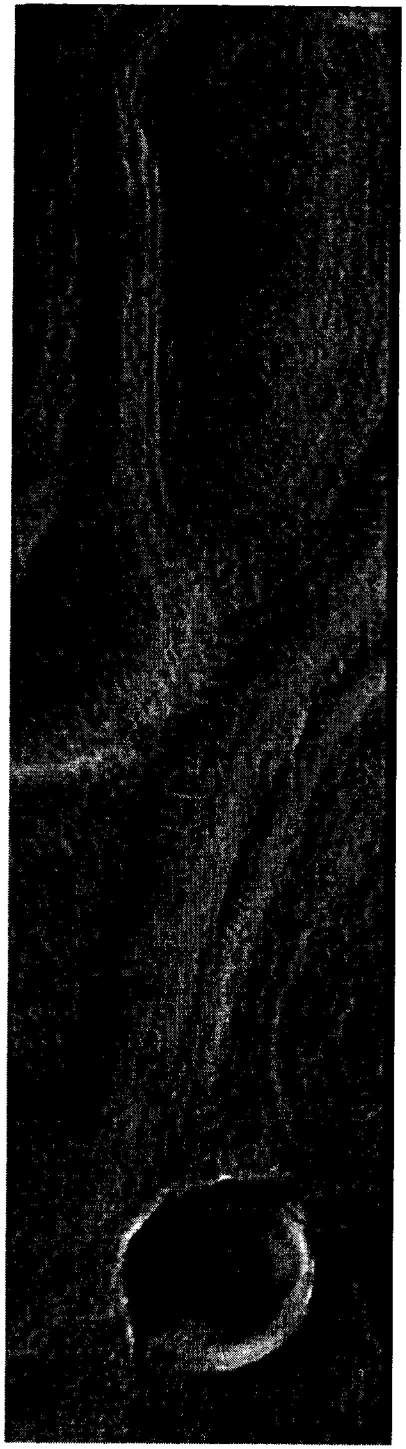
Major Project Trades – Phase A

- Solar mission characterization
- Power system sizing
- Numerous mission design trades
  - Launch dates/arrival dates
  - Landing site flexibility vs EDL and mission design parameters
- Mass vs cost/complexity (mass margin)
- Sample acquisition detailed design trades
- Efficient long-duration mission operations concept
- Planetary protection technologies

Not an exhaustive list – examples only

Summary

- **Huge step in Mars surface science and exploration capability**
  - Entrée to the next decade of Mars exploration
- **Has significant challenges, but**
  - Has upfront time and resources
  - Is supported by a product-driven, focused technology program
- **Project development is within 10% of target costs going into Phase A**



Mars Science Laboratory

Mission Concept Review

MSL Science

Frank Palluconi

October 28-29, 2003

Science Discussion Outline

- MSL Science Relationships
  - MSL Project Science Integration Group (PSIG)
  - MSL Objective/Vision/Investigations
  - Mars Program Science Objectives
  - MSL's Relationship to Mars Exploration Pathways
  - Contribution to Mars Astrobiology
- MSL Science Characteristics
  - Payload Suites
  - MSL Flight System Characteristics
    - Gusev Example
  - Strategy Elements
  - MSL as a Transition Mission

MSL Project Science Integration Group (PSIG)

- The PSIG was chartered by NASA's Office of Space Science (James Garvin).
- The Charter directed the PSIG to work with the MSL Project to define and prioritize options for scientifically exciting, implementable missions that follow Program directives and budget. This included:
  - **Providing recommendations on options and ranking for science objective/investigations/measurements**
  - **Examining cost and scope (e.g. mobile versus stationary)**
- **Activity Period**: November of 2002 through May of 2003 (PSIG I&II)
- **Products**: Thirteen reports on specific topics were produced along with a comprehensive final report.

PSIG I & II Membership

<u>Science Team</u>
Dan McCleese,
JPL Co-Chairman
Jack Farmer,
ASU Co-Chairman
David DesMarais, ARC
Bruce Jakosky, U Colo.
Gary Kocurek, U Texas
Doug Ming, JSC
Paul Mahaffy, GSFC
Scott McLennan, SUNY
David Paige, UCLA
Jeff Taylor, U Hawaii
Hunter Waite, U Mich.

<u>Program/Project</u>
Frank Palluconi (MSL Proj. Sci.)
Leslie Tamppari (Former-MSL Dep. Proj. Sci.)
Matt Golombek (Former-MSL Proj. Sci.)
David Beaty (Mars Sci. Office)
Jim Garvin (NASA, Mars Lead Sci.)
Bruce Banerdt (NetLander Co-I)
Rich Zurek (MRO Proj. Sci.)

<u>Project/Engineering</u>
Mike Sander (MSL Proj. Mgr.)
Jeff Simmonds (MSL Payload Mgr.)
Charles Whetsel (Chief Eng.)
Gentry Lee (Chief Eng.)
Frank Jordan (Mgr. Adv. Plan.)

MSL Science Objective

- The overarching scientific objective is to conduct a Mars **habitability** investigation (to achieve breakthrough science in astrobiology)
  - **Habitability** is defined as the potential of a given environment to support life at some time and should be equated to the phrase "**capacity to sustain life**"
  - This assessment of **habitability** is to be made through multidisciplinary measurements related to **geology, geochemistry, climatology and biology**

PSIG Vision for Mars Science Laboratory

- MSL will open a new era of Mars exploration by:
  - Providing scientific instruments of greatly improved accuracy (Analytic Laboratory)
  - Utilizing mobility and long life to examine multiple samples from multiple locations
  - Definitively characterizing a broad array of geologic materials
  - Beginning the investigation of the building blocks of life, including inorganic and organic carbon
  - Revealing crucial details about the climate and gelogic history of Mars
- This will substantially advance our understanding of Mars and its **capacity to sustain life**

Draft MSL Science Objectives/Investigations

Overall science objective:

Explore and quantitatively assess a potential habitat on Mars

Investigations to support overall objectives:

1. **Assess the biological potential of at least one target environment**
   A. Determine the nature and inventory of organic carbon compounds
   B. Inventory the chemical building blocks of life (C, H, N, O, P, S)
   C. Identify features that may represent the effects of biological processes
2. **Characterize the geology of the landing region at all appropriate spatial scales**
   A. Investigate the chemical, isotopic, and mineralogical composition of Martian surface and near-surface geological materials
   B. Interpret the processes that have formed and modified rocks and regolith
3. **Investigate planetary processes of relevance to past habitability**
   A. Assess long-timescale (i.e., 4-billion-year) atmospheric evolution processes
   B. Determine present state, distribution, and cycling of water and CO_2

In addition, NASA is examining the possibility of adding a contributed active neutron experiment from Russia and a competed surface radiation experiment supported by NASA Code U.

Mars Program Science Objectives

(MEPAG Revised October 2003)

I. Goal: Determine if life ever arose on Mars

- **A. Objective: Identify habitable environments**
- **B. Objective: Characterize carbon cycling in its geochemical context**
- **C. Objective: Search for life**
- **D. Objective: Technology development**

II. Goal: Understanding the processes and history of climate on Mars

- A. Objective: Characterize Mars' lower atmosphere, present climate and climate processes
- B. Objective: Characterize Mars' upper atmosphere, present climate and climate processes
- **C. Objective: Characterize Mars' ancient climate and climate processes for the lower and upper atmosphere**
- D. Objective: Characterize the state and processes of the Martian atmosphere of critical importance for the safe operation of spacecraft

III. Goal: Determine the evolution of the surface and interior of Mars

- **A. Objective: Determine the nature and evolution of the geologic processes that have created and modified the Martian crust and surface**
- B. Objective: Characterize the structure, composition, dynamics, and evolution of Mars' interior

IV. Goal: Prepare for human exploration

- **A. Objective: Acquire Martian environmental data sets**
- B. Objective: Conduct *in-situ* engineering science demonstrations

MSL Contribution to Mars Astrobiology Long-Range Exploration Strategy (from PSIG)

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High-level astrobiology strategy implies the following sequential exploration logic:

1. Global recognizance to define life-related exploration targets
   a) Potentially habitable environments (past or present)
   b) Environments where pre-biotic chemical processes are or were potentially active

MSL

2. **Characterize, prioritize the targets using landed assets**
   a) **Evaluate the potential for habitability (past or present)**
   b) **Understand the potential for preserving carbon chemistry in different geologic environments so that analytic data can be properly interpreted**
   c) **Identify potential biosignatures (chemical, textural, isotopic) in rocks and regolith**
3. **Characterize any pre-biotic carbon chemistry**
4. Determine if target environments were or are inhabited

Mars Exploration Pathways

2009 - 2020 Summary

Pathway	2009	2011	2013	2016	2018	2020	NOTES
Search for Evidence of Past Life	MSL	Scout	Ground-breaking MSR	Scout	Astrobiology Field Lab or Deep Drill	Scout	All core missions to mid-latitudes. Mission in '18 driven by MSL results and budget.
Explore Hydrothermal Habitats	MSL	Scout	Astrobiology Field Lab	Scout	Deep Drill	Scout	All core missions sent to active or extinct hydrothermal deposits.
Search for Present Life	MSL	Scout	Scout	MSR with Rover	Scout	Deep Drill	Missions to modern habitat. Path has highest risk.
Explore Evolution of Mars	MSL	Scout	Ground-breaking MSR	Aerono my	Network	Scout	Path rests on proof that Mars was never wet.

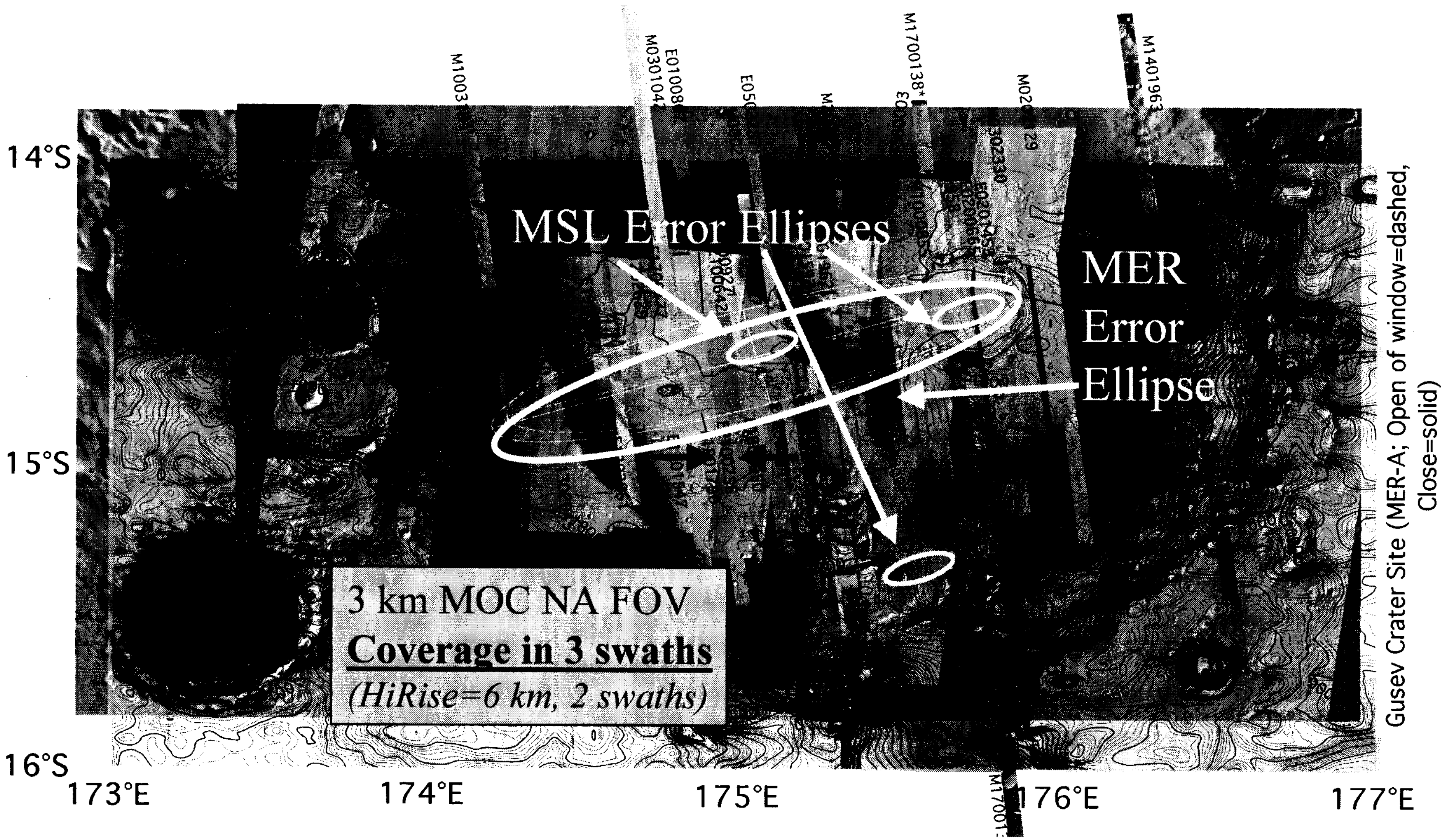
MSL Science Payload Suites

1. **Remote Sensing Suite**
   - Imaging and complementary mineralogy
   - Reconnaissance and site geologic context
2. **Contact Instrument Suite**
   - Complementary mineralogy, chemistry and microscopic imaging
   - Sample selection and supplemental target analysis
3. **Analytic Laboratory**
   - Definitive mineralogy, chemistry and high resolution textural information

Proposed MSL Characteristics
(Enabling Requirements)

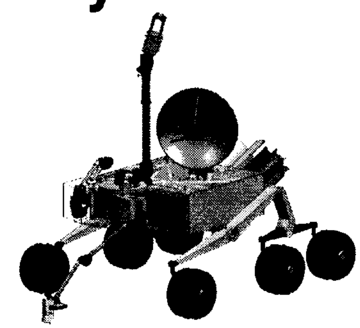
- Next generation landing and surface systems designed to safely access a large portion of the surface
  - **2009** launch with arrival in Northern hemisphere summer
  - **Latitude-independent** power-source [+60/-60 Latitude, from a new generation radioactive power source (RPS)]
  - **High-elevation** landing capability [+2.5 km]
  - **Small landing ellipse**, easily placed to avoid large-scale hazards [5 X 10 km, 3 sigma]
  - **Robust** to landing hazards
  - **Year-round operations**: 344/687 days of surface operations (floor/baseline)
  - **Significant sampling**: 28 samples (floor), 74 samples (baseline)
  - Sufficient **mobility** to reach most of landing ellipse [3km/6km traverse distance (floor/baseline)]
- **Modular** design, facilitating instrument placement

Gusev Comparisons

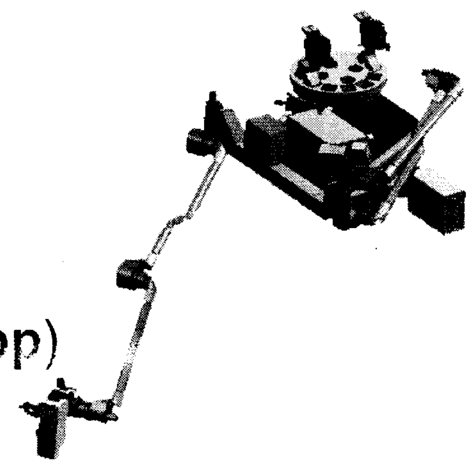


Strategy Elements

1. Site Selection (**safe, scientifically rich, discovery responsive**)
   - Small landing ellipse
   - Wide latitude and altitude range
   - Full use of information from Vikings, Pathfinder MGS, Odyssey, MERs, MEX, Beagle, MRO and Phoenix



2. Analytic Laboratory Sample Selection (**synergistic science, dozens of samples**)
   - Remote sensing
   - Mobility
   - Contact suite with tools (**arm[s], Rock Crusher, Sample Distribution Device, Rock Abrasion Tool [RAT], Corer, and Scoop**)
   - Long life



MSL as a Transition Mission and an Element of an Exploration Program

- MSL represents a **transition mission** in that while it incorporates elements of geology and climatology, it strongly emphasizes definitive geochemistry and a search for carbon in all its forms
- This combination is a **powerful predicate** to future exploration which will likely include a search for extant life, the return of samples and deep drilling
- The flight system has many **attributes** (e.g. latitude & altitude range, life, mobility, modularity, guided entry, low landing velocity, etc.) which are ideal for future extensive surface exploration with lowered development costs

Mars Science Laboratory

Mission Concept Review

Payload Accommodations

Jeff Simmonds

October 28-29, 2003

Discussion Topics

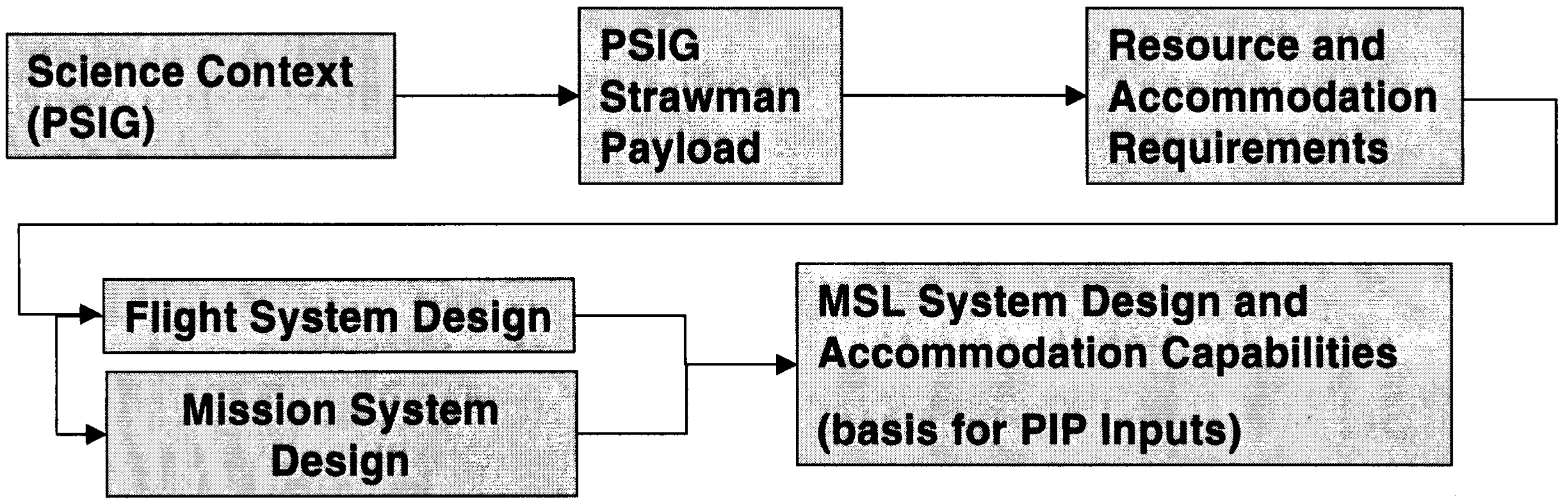
- Payload Accommodation Approach
- Payload Configuration on Rover
- Payload Engineering Support
- Accommodation Resources
- Instrument Development Milestones

A Couple of Necessary Caveats

- **The MSL payload will be selected by NASA HQ/ Code S AO**
  - Details of AO content are embargoed at this point

- **MSL payload accommodations are based on PSIG strawman payloads and accommodation/Instrument technology surveys conducted by MSL Payload Office**
  - This presentation presents process and summary information and excludes details to respect proprietary data

Accommodation Approach



- Based on likely *range* of instruments types (using PSIG and SDT as guides)
- Accommodation capabilities derived from *combinations* of the *types* of Investigations that MSL is likely to fly
- Goal is to NOT be so specific so as to force a point solution
  - Allow the AO process to select best science/best value payload

MSL Strawman Payload Examples

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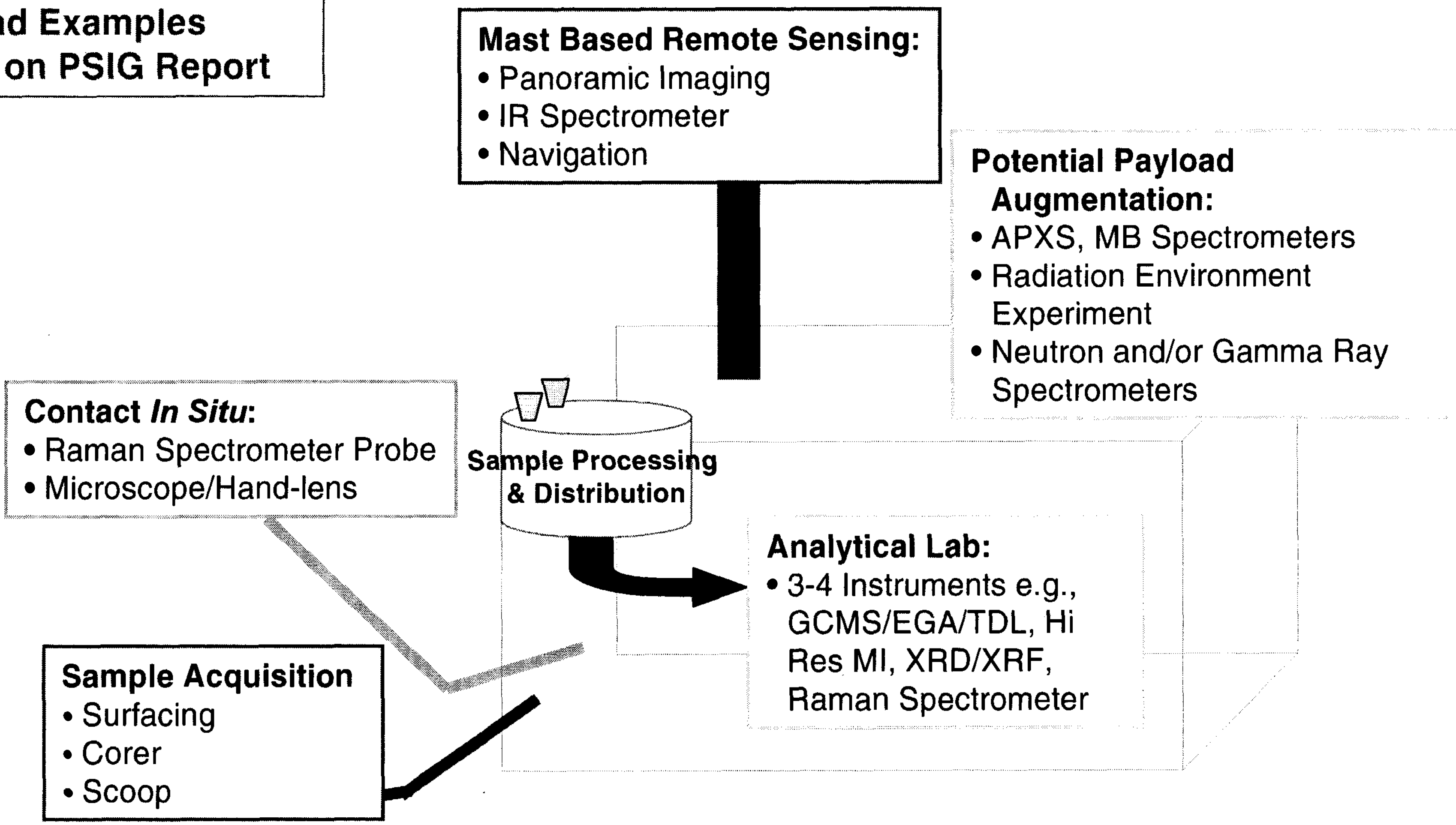
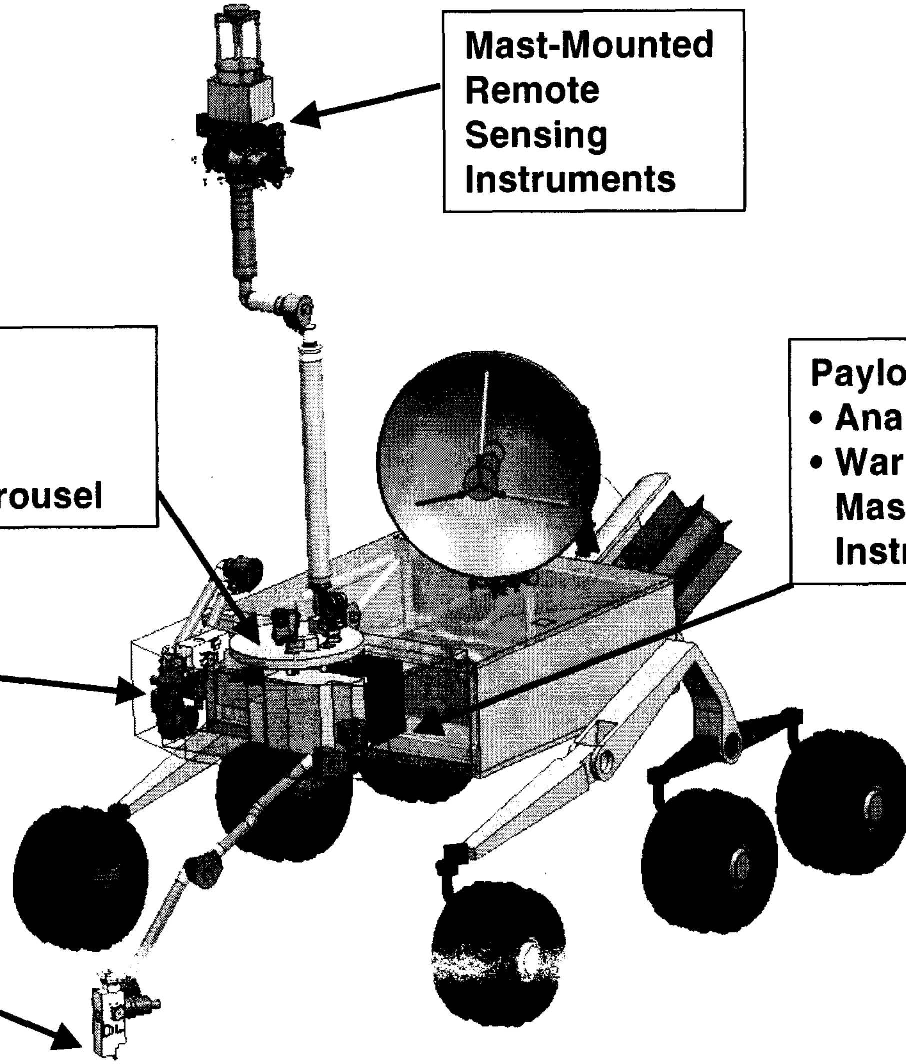
Payload Examples based on PSIG Report



Payload Accommodations on MSL Rover



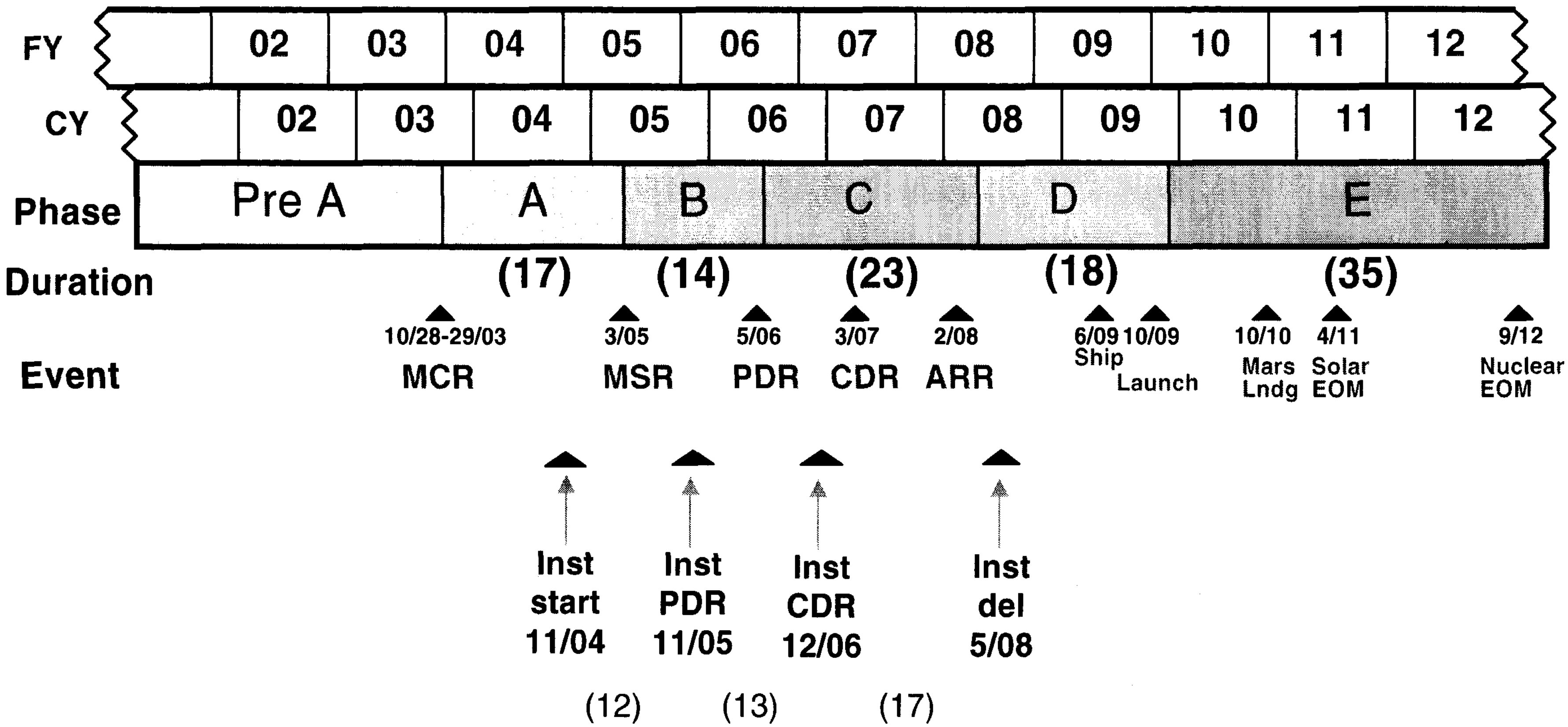
MSL Payload Engineering Support

Instrument Accommodations	
– Mast Mounted Instruments	• Az/El driven – 360º / +90º to -60º • Stability consistent with point-rastered sensor
– Arm Mounted Instruments	• Placement/Repeatability within 1-3 cm • Contact sensing provided by project
– Main Payload Module	• Modular Integration Platform for Payload Elements • Provides Access to processed samples
– Other Body Mount Options	• Options for other instrument types can be accommodated
– Thermal Control Support	• Vehicle provided warm enclosures and heaters maintain benign thermal environment for instrument electronics
Sample Acquisition, Processing and Handling Capabilities	
– Sample Acquisition	• Scoop, Corer, Abrader • 28 to 74 samples (combined corer, rocks, regolith) • Core to 10 cm in 2-5 cm increments
– Sample Processing (Crushing)	• Comminution to <1mm w/ fines for XRD, Microscopy, etc . • Applicable to all samples except ice • Pre/Post Crush stages for triage observations
– Sample Distribution	• Volumetric portioning to 3-4 analytical instrument inlets (~1gm each) • Bypass mode available (esp. for icy samples)
– Contamination Control	• <0.5% sample to sample cross contamination limits • -Organic contamination and PP are in work

Payload Resource Allocations

Resource	PSIG Strawman (CBE)	MSL Allocation (incl. Reserves)
Instrument Mass	31 kg	54 kg
Engineering Support Mass (Mast, Arms, SA/SPaH, etc.)		103 kg
Volume	(Instrument Volume)	(Allowable Packaging Volume)
- **Payload Module**	~65 liter	~425 liter
- **Mast-Mounted**	~7.5 liter	~21 liter
- **Arm-Mounted**	~0.4 liter	13 liter (each arm)
- **Body-Mounted**	TBD	TBD
Power (operational)	~70 w-hr	~200 w-hr / (Scenario dependent)
Thermal	Variable~+/- 30C	Benign environment provided; -Ambient temp ops are available/optional
Data Rate	Variable	3 bus types ~400kbps to 10-100 Mbps
Data Storage (buffer)	Variable	1.3 GByte for Science data
Data Downlink Volume	Variable w/ mode	Scenario/Sol Template dependent
- Low Latency (<2-3hr)		~ 40 Mb/sol
- High-Latency (~8-10 hr to days)		~40-750 Mb/sol

Instrument Development Milestones



Summary

Payload activities during Pre-Phase A have:

- Payload Accommodation based on the *Needs of* PSIG-identified Instruments Payload
- Captured the likely *range* of required Accommodations and Resources and *incorporated* those into the designs for the Flight and Mission Systems
- Articulated payload accommodation *capabilities* to allow NASA to select best-value PI Investigations within programmatic and physical constraints

Mars Science Laboratory

Mission Concept Review

NASA AO Planning and Status

Michael Meyer, NASA HQ

October 28-29, 2003

Discussion Topics

- Science Instruments Budget Allocation
- NASA Instrument Technology Investments
- Scope and Timing of the MSL AO Solicitation
- AO Process and Status

MSL Science Instruments Budget Allocation

- Budget allocation for Science Instruments has been developed and established as a fenced allocation in the MSL Project Cost Estimate
- Allocation is based on Cost modeling and Analogy estimates for PSIG strawman instruments as representative of types of payload that MSL could fly
- AO budget allocation to instruments will be $85M, including reserves allocation
- FBO will provide further preliminary guidance on budget allocations

NASA Investments in Instrument Technologies

- Analytical Instruments are recognized as the biggest challenge area for the MSL Payload
- Significant investments have been made in recent years to enhance community readiness to respond to the MSL AO
- MIDP, PIDDP, ASTEP, ASTID programs have all contributed
  - $17M in FY02 & $39M in FY03
  - instruments ranged from 1-6 TRL, although predominant focus on reaching TRL 6

- As a result of these investments, it is expected that instruments can be selected that will meet the MSL science objectives and represent reasonable risk

MSL AO for PI Investigations

Solicitation and Selection of PI Instruments is a NASA Process

- AO (and FBO) is NASA HQ-led process
- LaRC ESSSO supports NASA HQ
- MSL provides Project planning details as input
- PIP is generated by MSL in coordination with LaRC
- MSL will support Accommodation Assessment
- Strict adherence to Firewalls and FAR requirements is essential and is an integral part of our process

MSL AO for PI Investigations (cont'd)

Early FBO will allow advance concept and team formation activities to proceed in parallel with MER ops

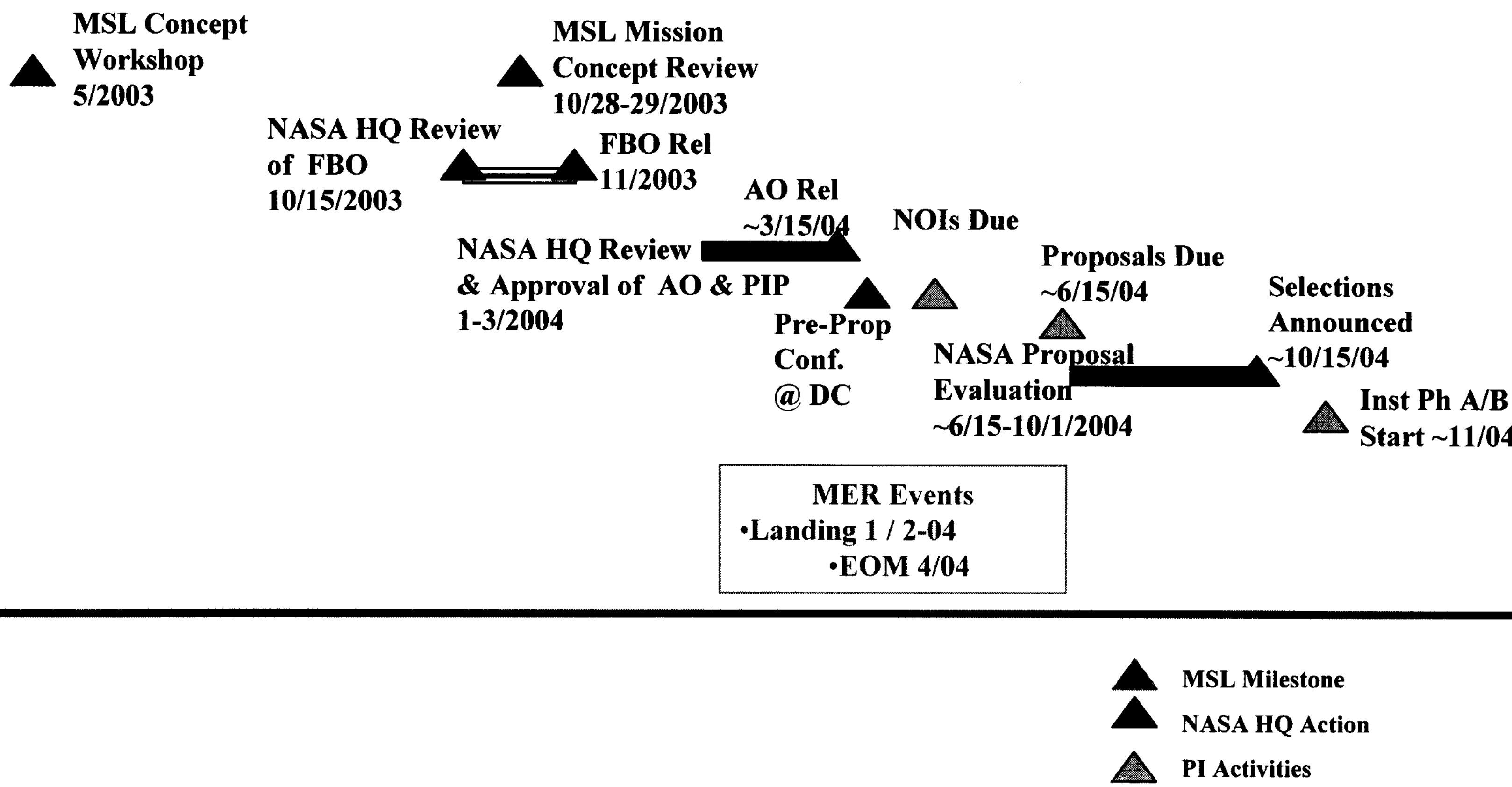
- Timing of AO is directed by Project Schedule requirements
- Early FBO allows early (Pre-MER landing) formation of teams and instrument concept work
- AO being released as late as possible to still allow instrument selection and accommodation reviews prior to Project MSR
- Overlaps during proposal writing period and MER operations are unavoidable

Scope of the March AO Solicitation

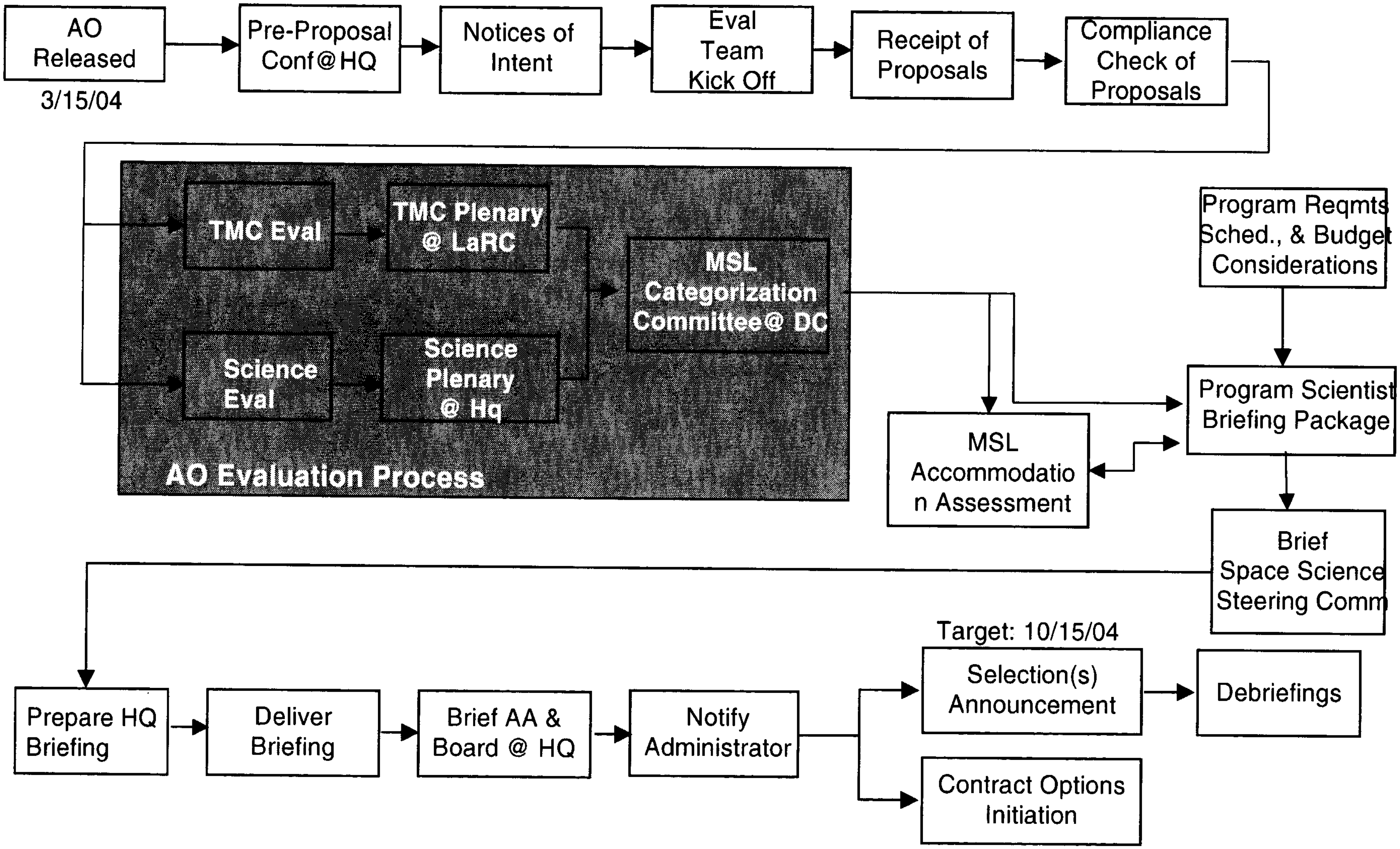
- **PI Investigations of four classes will be solicited**
  - Mast-Mounted Remote Sensing
  - Contact Investigations
  - Analytical Laboratory Investigations
  - "Other" Investigations mounted elsewhere on Rover

- **Interdisciplinary Scientists, Facility Scientists, and Participating Scientists will be solicited later**
  - Interdisciplinary and Facility Scientists @ ~ System PDR
  - Participating Scientists @ L-9 mos

NASA AO Development Timeline



NASA Proposal Evaluation and Selection Process



Summary

- Sufficient money, resources, and schedule have been allocated for MSL instrumentation assuming a prudent selection process
- FBO and AO are timed to minimize conflicts with MER operations and give the community as much time as possible to develop credible proposals for MSL instrumentation
- AO process is established and meets MSL project schedule requirements
- Our expectation is that the combined selected instruments will match or exceed capabilities required to meet MSL science objectives

Mars Science Laboratory

Mission Concept Review

Project Engineering

John D. Baker

October 28, 2003

Discussion Topics

- **Overview**
- Mission Trades Summary
- Draft Level 1 Requirements
- Level 1 Requirements as Key Design Drivers
- Mission Trade Selections
  - Approach
  - Transfer
  - Launch
- Mission Architecture

Mission Trades Overview

- Over 50 trades have been conducted to date which resulted in our current reference design.
- Trades were captured in the Project trade tree and design was captured the Project Baseline Design Document (BDD). Team members created decision packages for key areas.
- The MSL Project then reviewed decision packages and made choices on the basis of:
  - Cost
  - Performance (mass, pwr, data vol, etc.)
  - Risk
  - Schedule (included Technology cutoff of 2005)
  - Peer Review feedback

Mission Trades

Level 3 Summary

MISSION

- **LAUNCH**
  - L/V Type
  - L/V Config
- **TRANSFER**
  - Trajectory Type
  - Carrier Sys Design
- **APPROACH**
  - Nav System
  - Entry Method
- **EDL**
  - EDL Comm
  - Entry Vehicle Design
  - Parachute Descent
  - Terminal Descent
  - Descent Propulsion
  - Hazard Detection &Avoidance
- **SURFACE**
  - Rover System
    - SS Trades
  - Comm Strategy
  - Rover Navigation
  - Payload Supt
  - Mission Ops

Discussion Topics

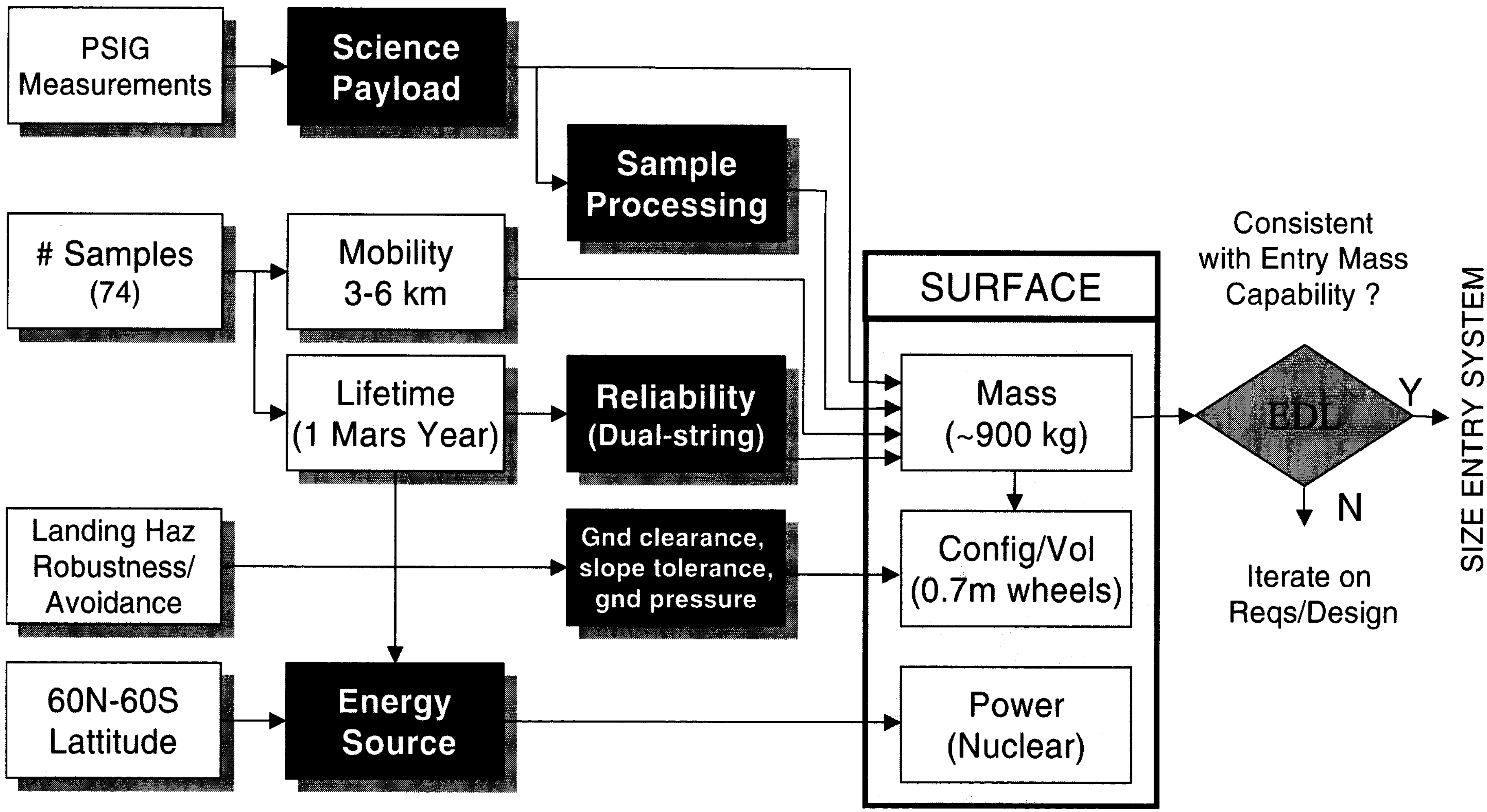
- Overview
- Mission Trades Summary
- **Working Level 1 Requirements**
- Level 1 Requirements as Key Design Drivers
- Mission Trade Selections
  - Approach
  - Transfer
  - Launch
- Mission Architecture

Working Level 1 Requirements

- Science mission needs
  - Produce measurement types consistent with PSIG report
    - New generation analytical instruments
  - Landing site flexibility between 60 deg N and 60 deg S latitude
    - Choice may be made based on MRO data (later site selection)
  - Capable of landing at altitudes of up to 2.5 km
  - Capable of landing in a reduced size error ellipse (5 km x 10 km)
  - 28 samples (minimum) to 74 samples (baseline)
    - Implies 344 sol to 670 sol mission length
    - Implies 3 to 6 km traverse capability
- Programmatic needs
  - Provide telemetry stream for diagnostics during EDL
  - Landing mass capability consistent with MSR needs
  - Demonstrate a hazard avoidance capability
  - Planetary protection

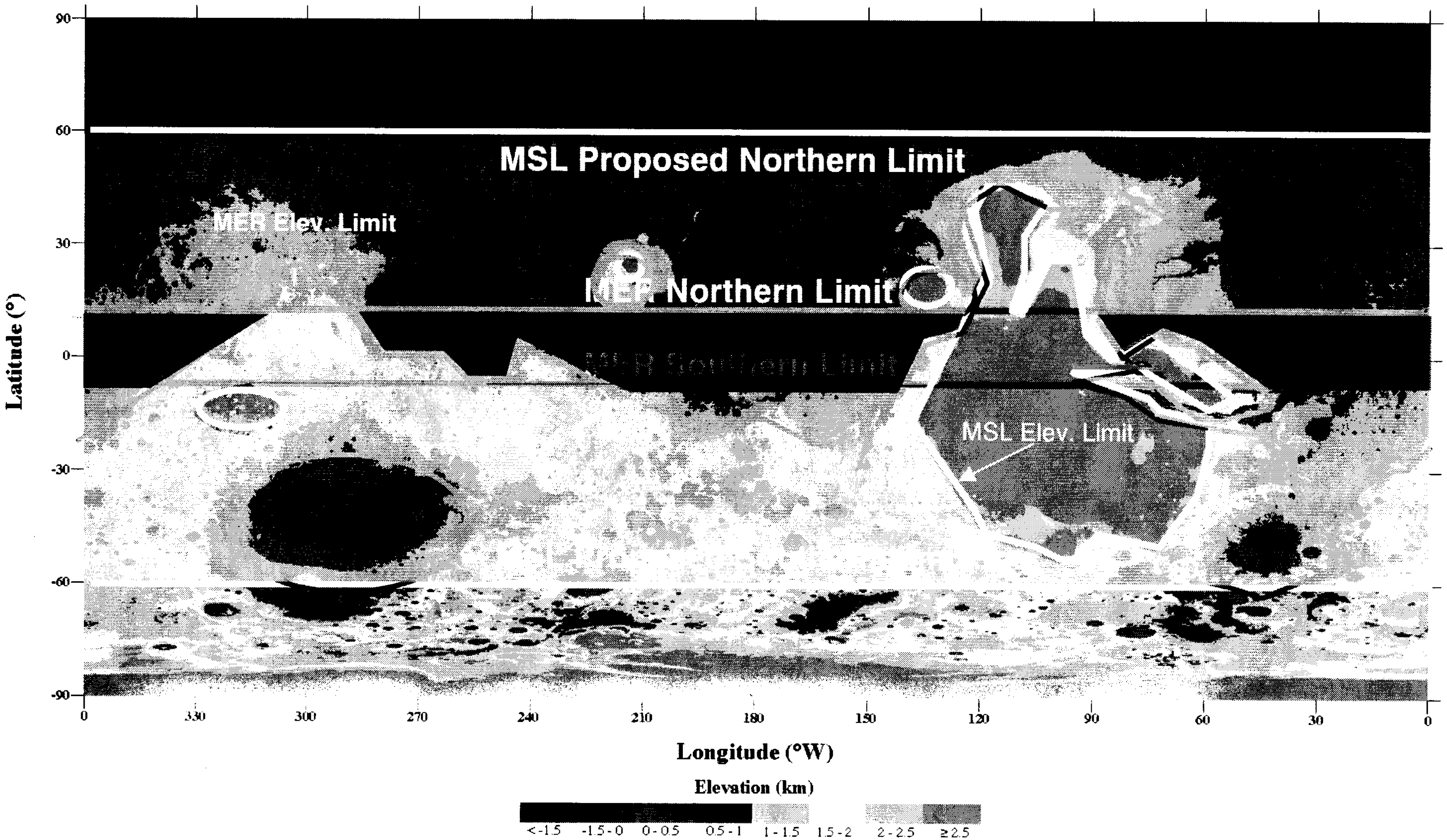
Working Level 1 Requirements as Key Design Drivers

Mars Science Laboratory

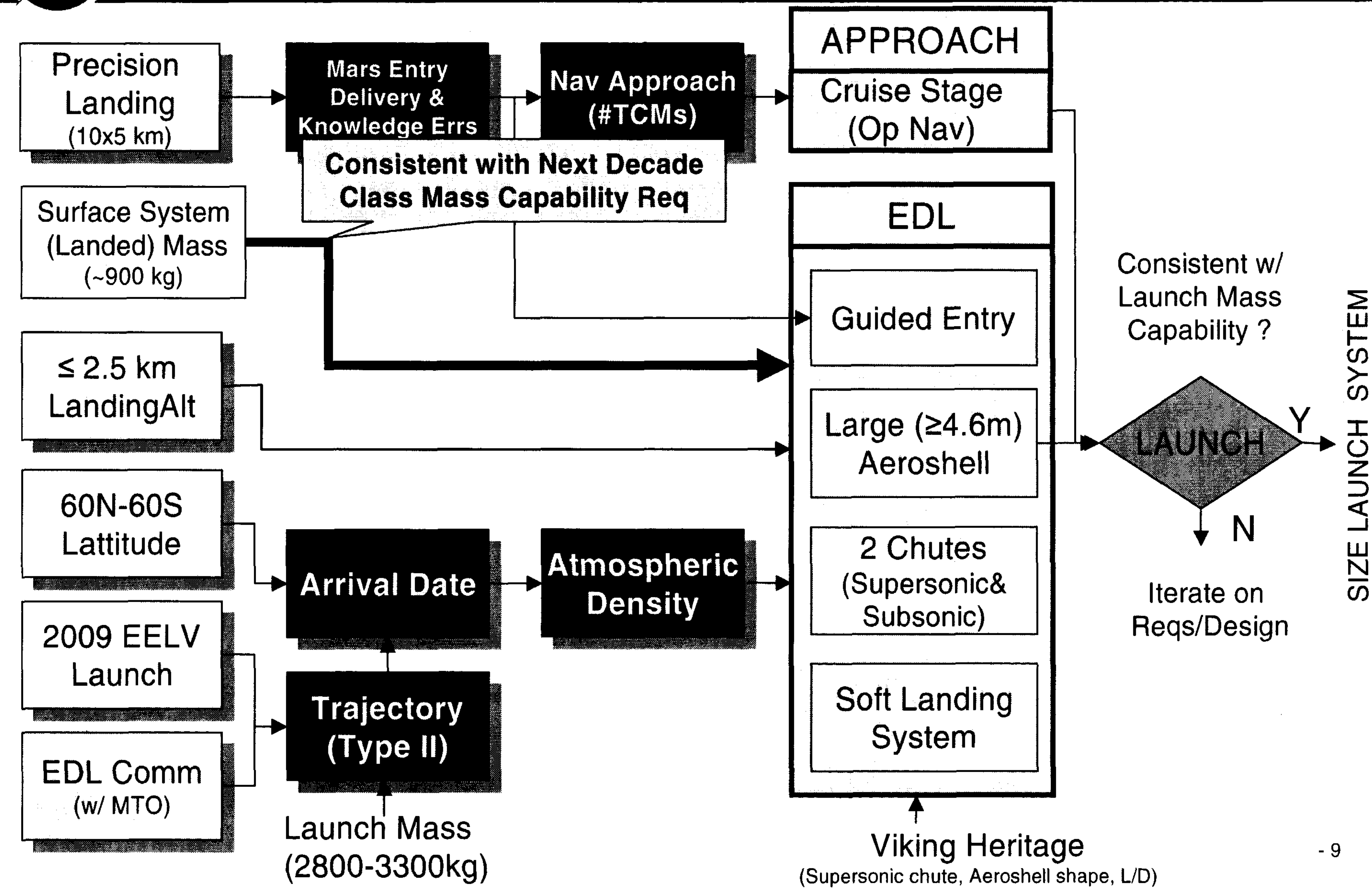


Mars Surface Accessibility

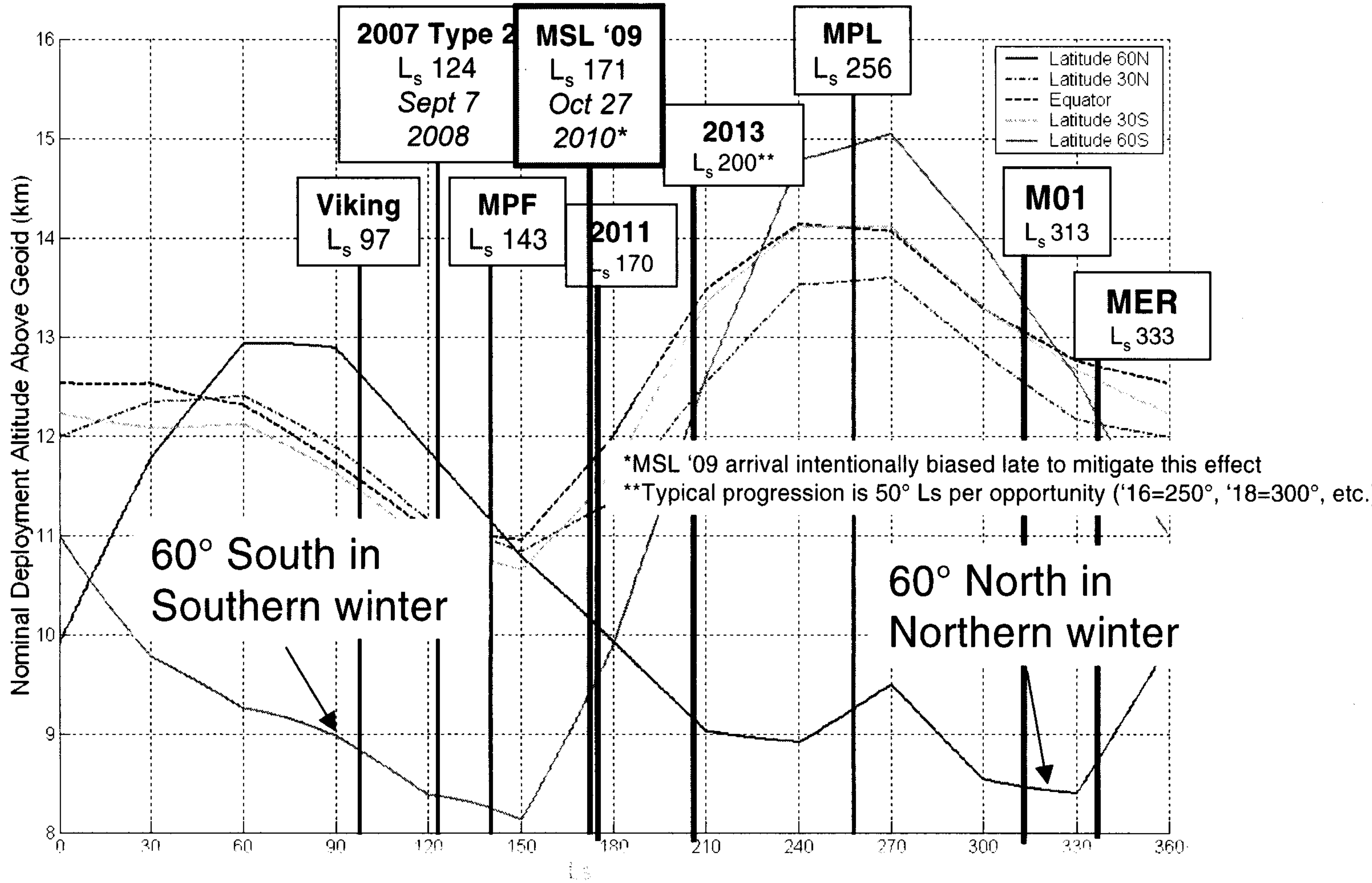
MOLA 1/4° Gridded Topography



Working Level 1 Requirements as Key Design Drivers



Parachute Deployment Altitude Variation with Time of Year and Latitude



Northern	Summer	Winter
Southern	Winter	Summer

Discussion Topics

- Overview
- Mission Trades Summary
- Draft Level 1 Requirements
- Level 1 Requirements as Key Design Drivers
- **Mission Trade Selections**
  - Approach
  - Transfer
  - Launch
- Mission Architecture

Mission Trades – Approach

APPROACH

- Nav System
  - Gnd radio - Delta-DOR
  - Op nav
  - Proximity
- Entry Method
  - Direct
  - From orbit

Supports meeting 10x5 km Precision Landing Requirement (Gnd radio - Delta-DOR, Op nav)

Minimum cost solution (Direct)

Mission Trades – Transfer

TRANSFER

- Interplanetary trajectory
  - Type I
  - Type II
    - optimum
    - stretch
  - Type IV
- Carrier Sys Design
  - Telesat
  - MSL Carrier
    - Smart carrier
    - Dumb carrier

Supports meeting EDL Comm by arriving after MTO

Minimum cost/risk solution

Mission Trades – Launch

LAUNCH

- L/V Type
  - Delta II/III
  - Atlas 5 - 521
  - Delta IV- 4450
  - Delta IV Heavy
- L/V Configuration
  - 4m L/V fairing
  - 5m L/V fairing

Launch mass up to 3300kg (Atlas 5 - 521, Delta IV- 4450)

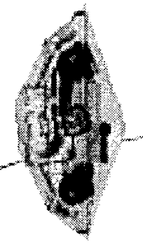
Supports large aeroshell, higher ballistic coef and landed mass (5m L/V fairing)

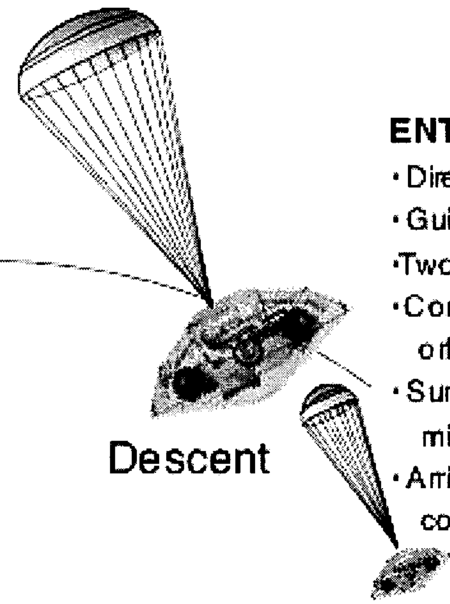
Discussion Topics

- Overview
- Mission Trades Summary
- Draft Level 1 Requirements
- Level 1 Requirements as Key Design Drivers
- Mission Trade Selections
  - Approach
  - Transfer
  - Launch
- **Mission Architecture**

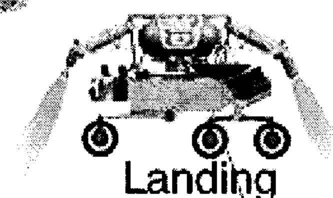
Mission Architecture

CRUISE/APPROACH
- Type-II transfer
- 10-12 month flight time
- 5-6 course corrections
- Optical nav for approach



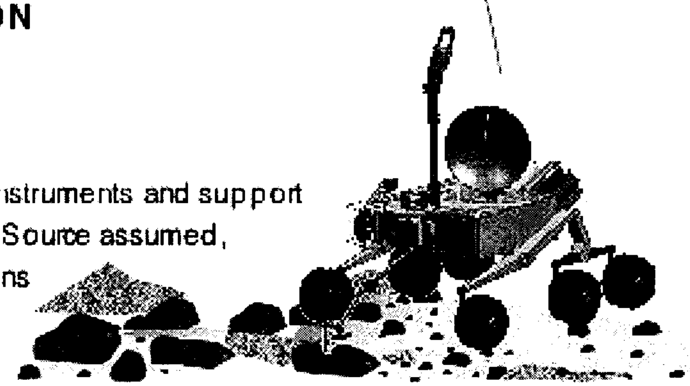


ENTRY/ DESCENT/ LANDING
- Direct Entry on mid- to late-2010
- Guided entry
- Two-stage chute
- Comm provided by UHF link to orbiting asset and DTE X-band
- Sun and Earth constrained to 20° min elevation at landing site
- Arrival 60 days prior to solar conjunction



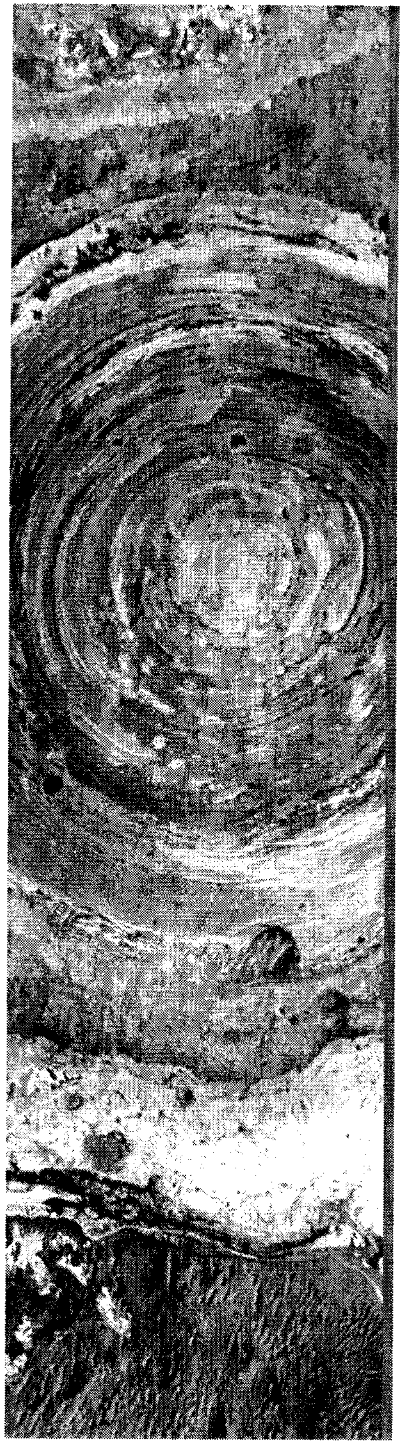
LAUNCH
- Ocober 2009
- Delta IV/ATLAS V w/ 5-m fairing

SURFACE MISSION
- ~900 kg rover
- 670 Sol lifetime
- 3-6 km mobility
- 100+ kg payload of instruments and support
- Radioisotope Power Source assumed, pending final decisions



Summary

- The Project has conducted numerous trades to date which have led to a reference design
- Additional trades will be performed in Phase A to further refine the project systems design
  - This will be discussed on day 2
- We believe we have a reference design that can meet the performance and cost requirements by the end of Phase A



Mars Science Laboratory
Mission Concept Review

Flight System Trade Studies and Reference Design

Brian Muirhead

October 28-29, 2003

Discussion Topics

1. **Introduction and Requirements**
2. Flight System Overview
3. Trade Study Taxonomy
4. Entry Descent and Landing Detailed Trade Studies
5. Surface System Detailed Trade Studies
6. Subsystem Detailed Trade Studies
7. Resource Margins and Schedule

Introduction

- **This presentation will overview the flight system reference design and key trade studies**

- **Includes areas studied, selected baseline, justification, technology contributions, and Phase A study plans**

Mars Science Laboratory Org (670)

Project Manager – M. Sander
Project Scientist – F. Palluconi
Chief Engineer(Ph A) – B. Muirhead
Project Business Manager – A. Green

Business Office – A. Green

PRA – L. Ramsay
Project Acquisition Manager – P. Easter
Scheduler – S. Gillespie

Project Engineering Office
J. Baker (Acting)

MAM – J. Newell
Safety – TBD

Tech. Mgr. – G. Udomkesmalee

Partners

KSC – A. Sierra
DoE – R. Wiley
LaRC – M. Lockwood
ARC (EDL)
ARC (IT) – M. Drummond
JSC – C. Graves

Science Office
F. Palluconi
Deputy-TBD

Mission Systems and Flight Software Office
C. Whetsel (acting)
Deputy- A. Sacks (acting)

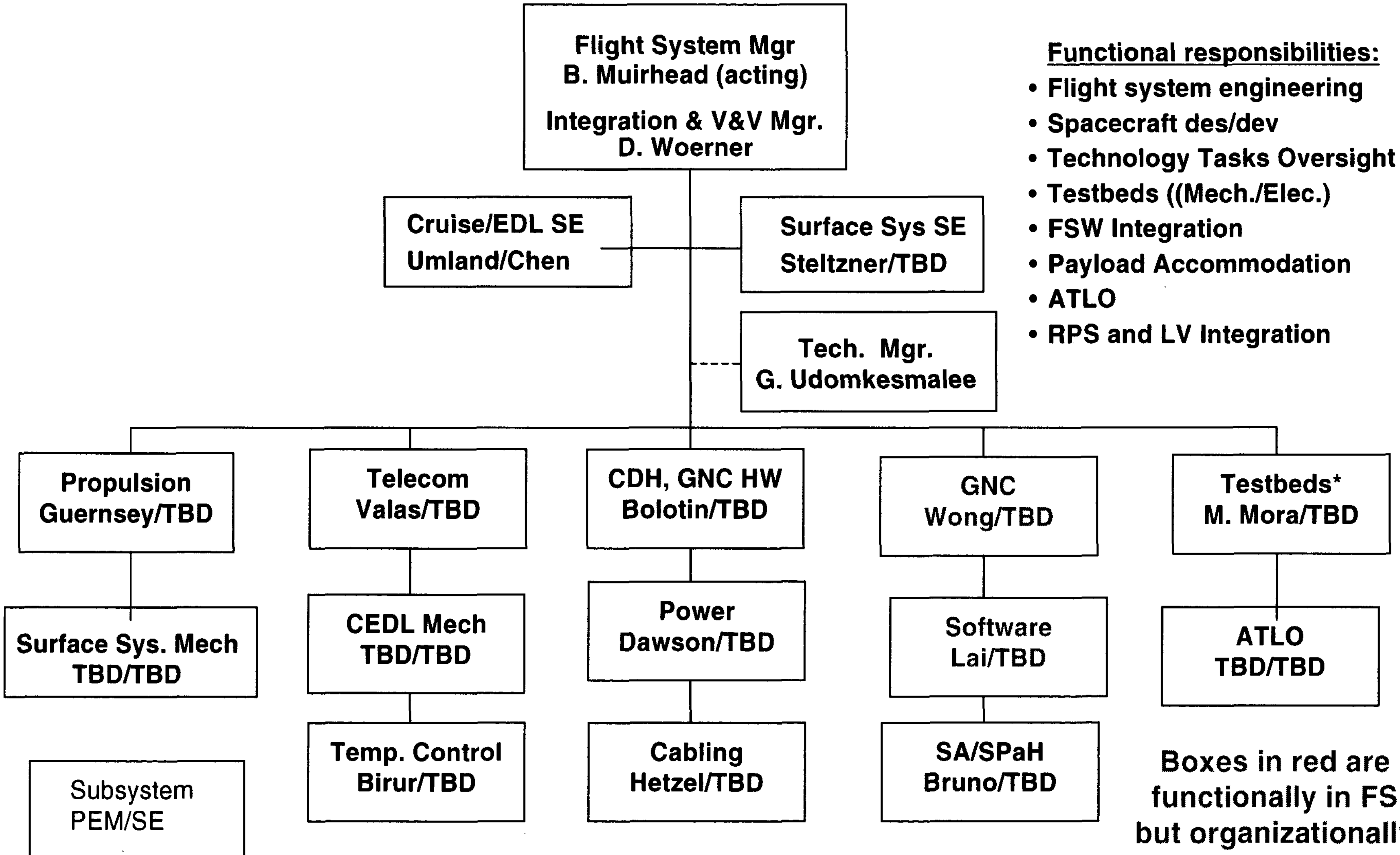
Flight Systems Office – B. Muirhead (acting)
End-to-end life cycle V & V – D. Woerner

Payload & Engineering Sensors
J. Simmonds

Functional responsibilities:

- Flight system engineering
- Spacecraft des/dev
- Technology Tasks Oversight
- Testbeds ((Mech./Elec.)
- FSW Integration
- Payload Accommodation
- ATLO
- RPS and LV Integration

MSL Flight System Org (Rev.1)



Functional responsibilities:
- Flight system engineering
- Spacecraft des/dev
- Technology Tasks Oversight
- Testbeds ((Mech./Elec.)
- FSW Integration
- Payload Accommodation
- ATLO
- RPS and LV Integration

Boxes in red are functionally in FS but organizationally in MS

- Testbeds transfer to Mission System at start of mission system testing

Flight System Driving Requirements

- Long duration mission, high reliability:
  - 687 days + 10+ month cruise
- Precision landing
  - 10 km error ellipse
  - Up to 2.5 km elevation
  - Hazard avoidance capability
- High mobility:
  - Tolerance to a wide range of terrains (+/- 60 deg.)
  - Ranging 3-6 km
- Acquisition of samples of rock, pebbles and regolith
  - Acquisition, processing and handling infrastructure for 74 samples (baseline)
- Telemetry link during EDL
- Nuclear powered
- Planetary protection (assuming categorization of IV-c)
  - MER/MPF class cleanliness for entire spacecraft, plus
  - Better than Viking cleanliness for sampling chain

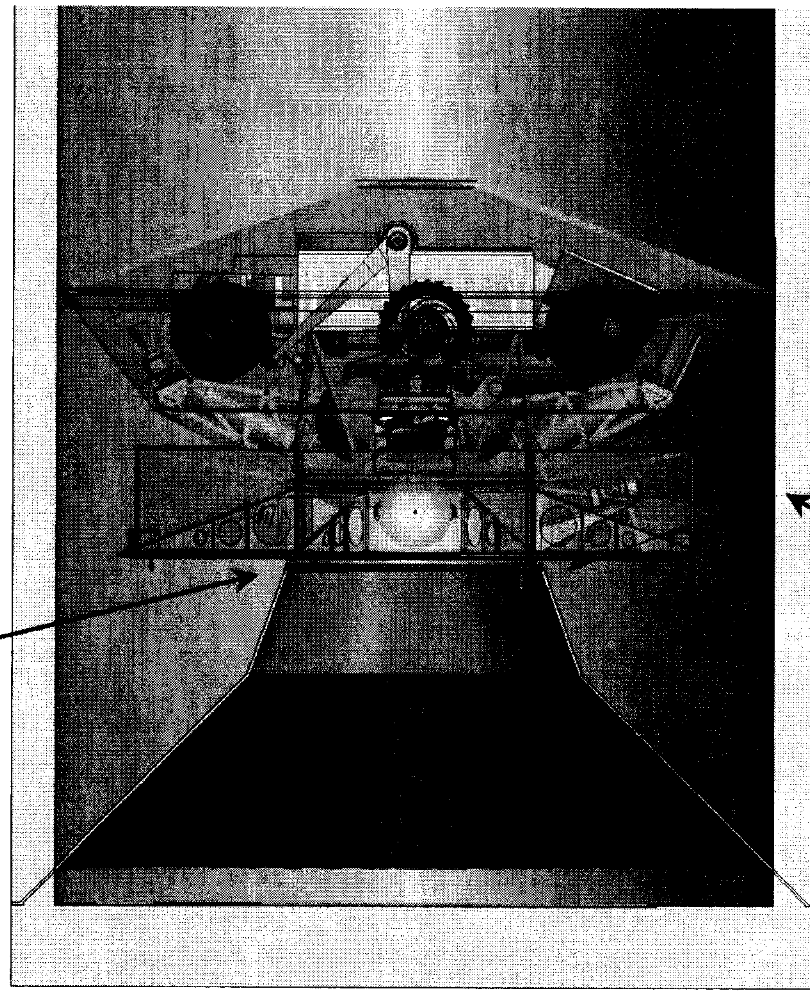
Implementation Highlights

- System Engineering
  - Subsystem system engineers OWN functionality of their subsystem
    - Define requirements
    - Partition functions to HW/SW
    - Responsible for V&V of S/S including operations
  - Flight System engineering owns crosscutting functionality of overall V&V
- Mission Assurance
  - Single fault tolerant
  - Class B electronic parts
  - Designers perform reliability analysis, Mission Assurance reviews & approves
- Testbeds
  - Early and significant use of testbeds for S/W development and validation
    - Payload, Static (EM electronics, H/W in loop), Mobile (EM mechanical w/prototype electronics)
    - Testbeds transfer to Mission System at start of mission system testing
- Significant industry contributions
  - EDL elements
  - Electronics (including Processor, memory, SDST, SSPA, gyros, trackers, etc.)
  - Misc. components (e.g. antennae, actuators, tanks, thrusters, etc.)

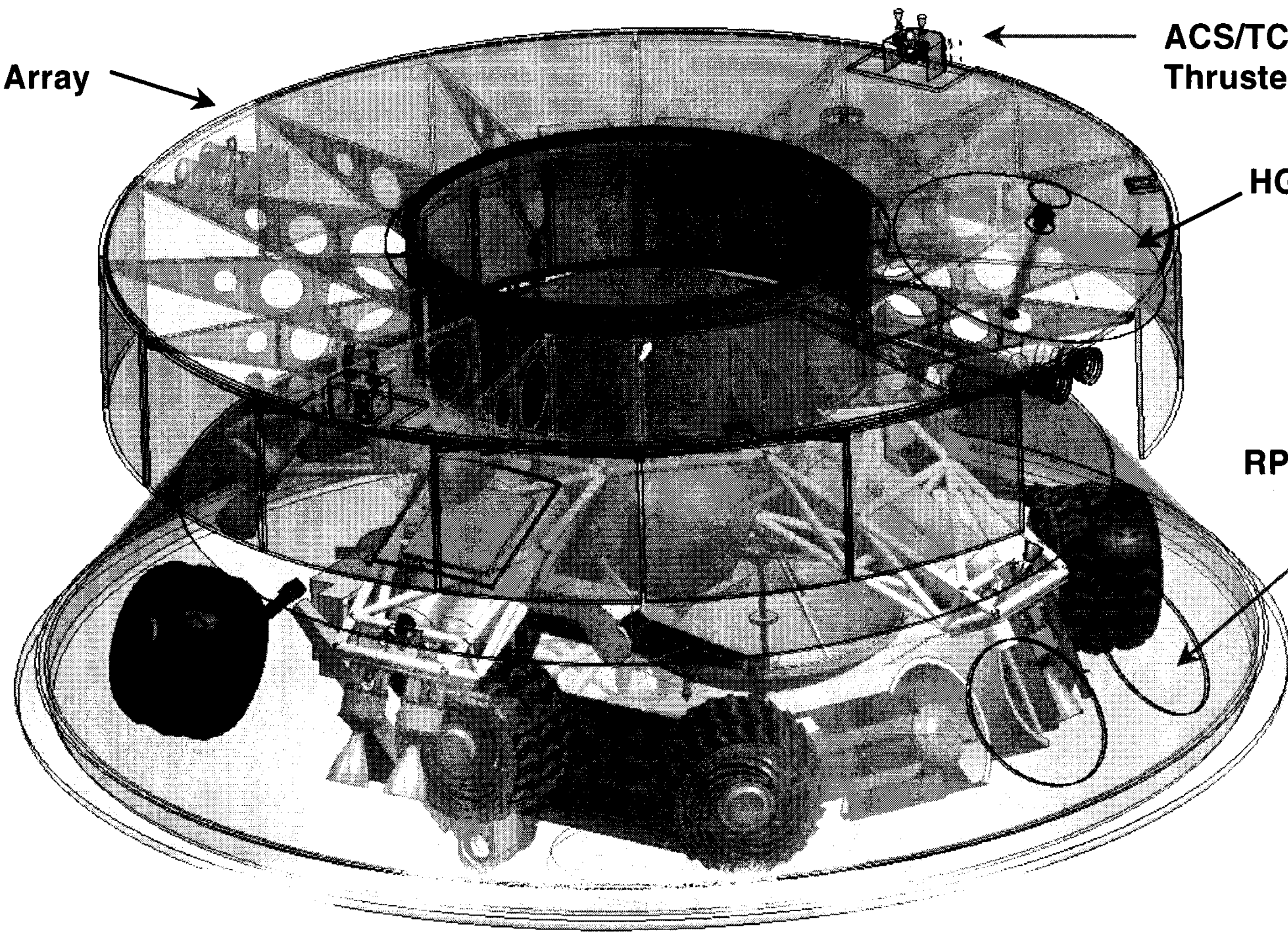
Discussion Topics

1. Introduction and Requirements
2. **Flight System Overview**
3. Trade Study Taxonomy
4. Entry Descent and Landing Detailed Trade Studies
5. Surface System Detailed Trade Studies
6. Subsystem Detailed Trade Studies
7. Resource Margins and Schedule

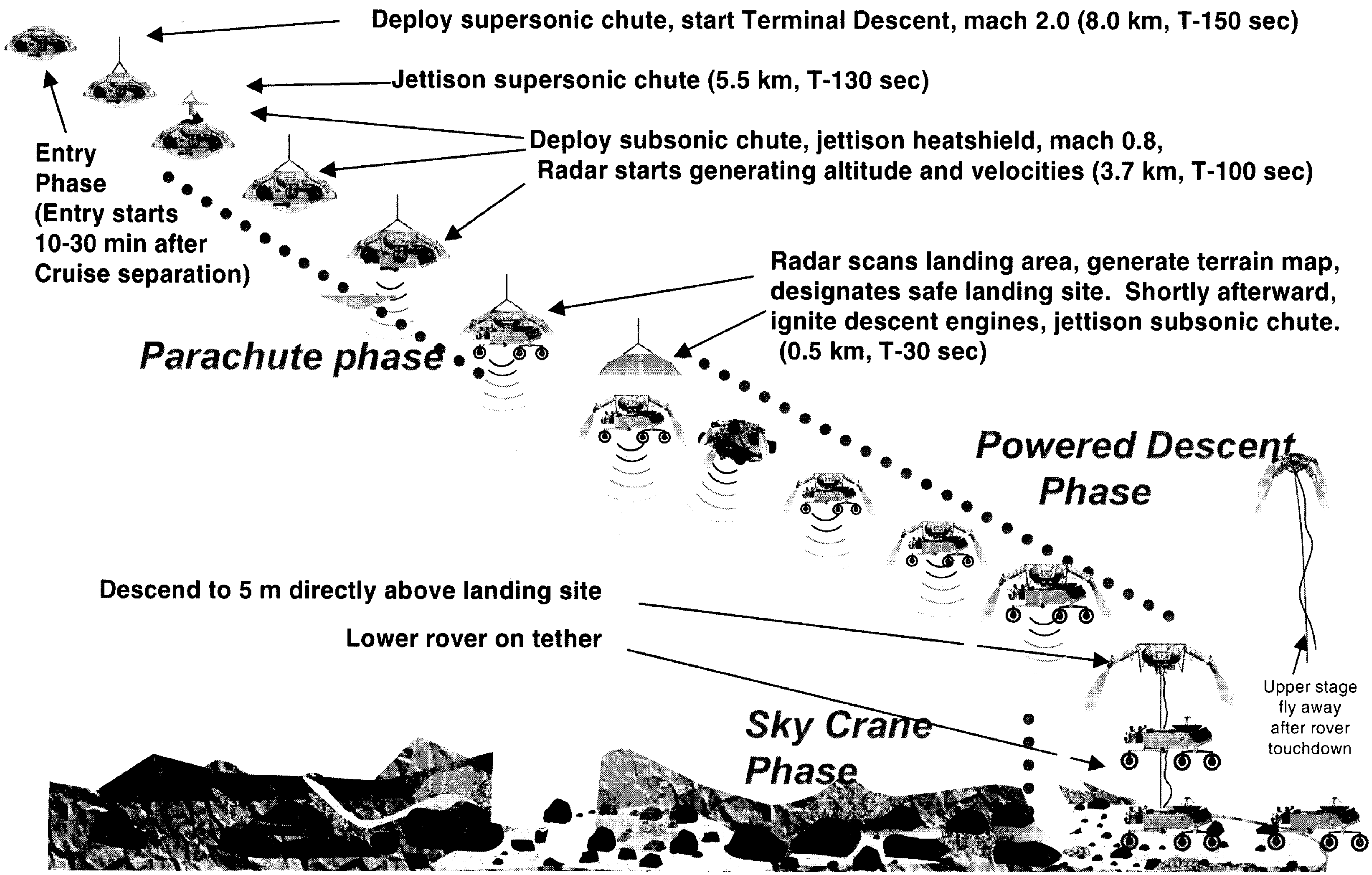
Launch Configuration in Shroud



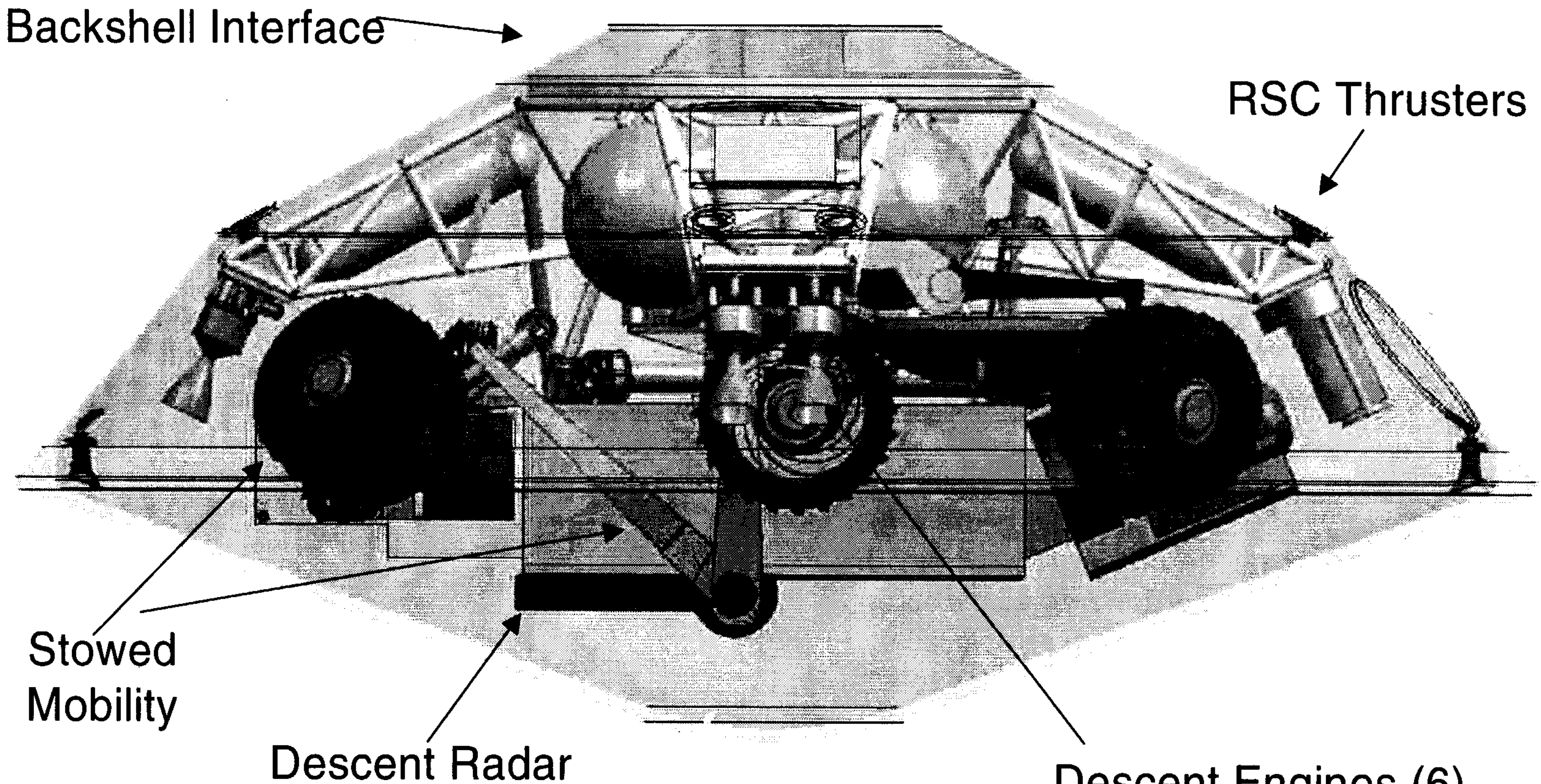
Cruise Configuration



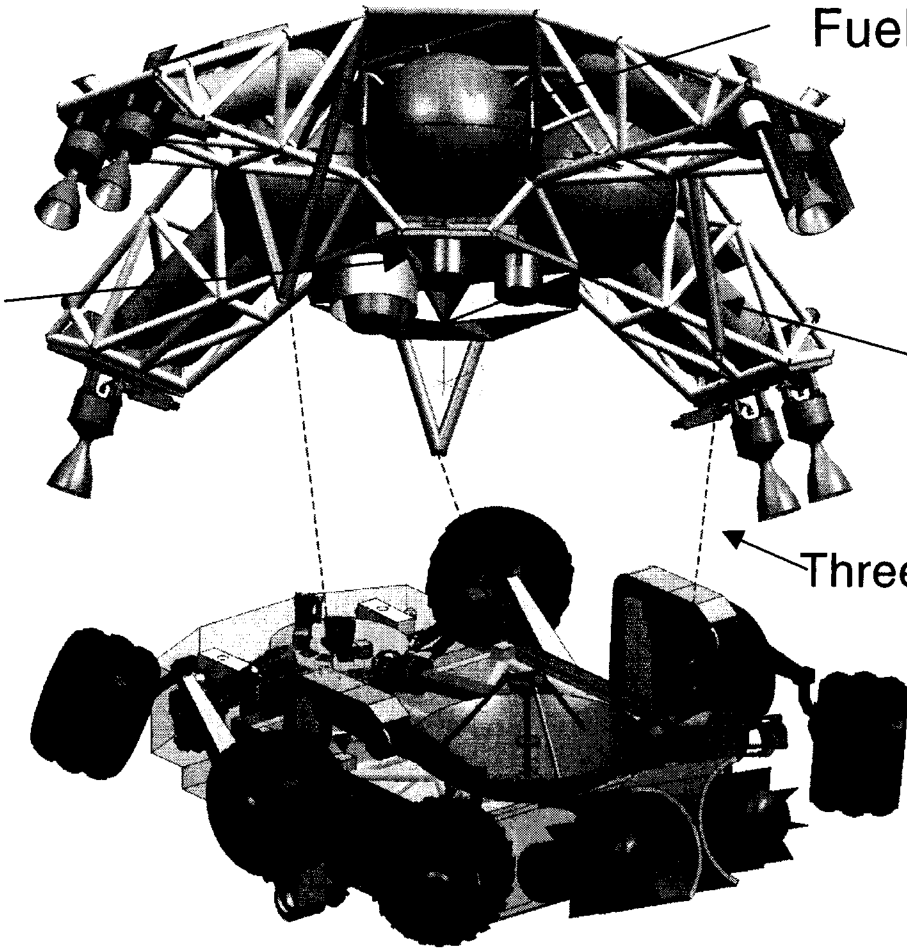
MSL Entry, Descent, and Landing Timeline



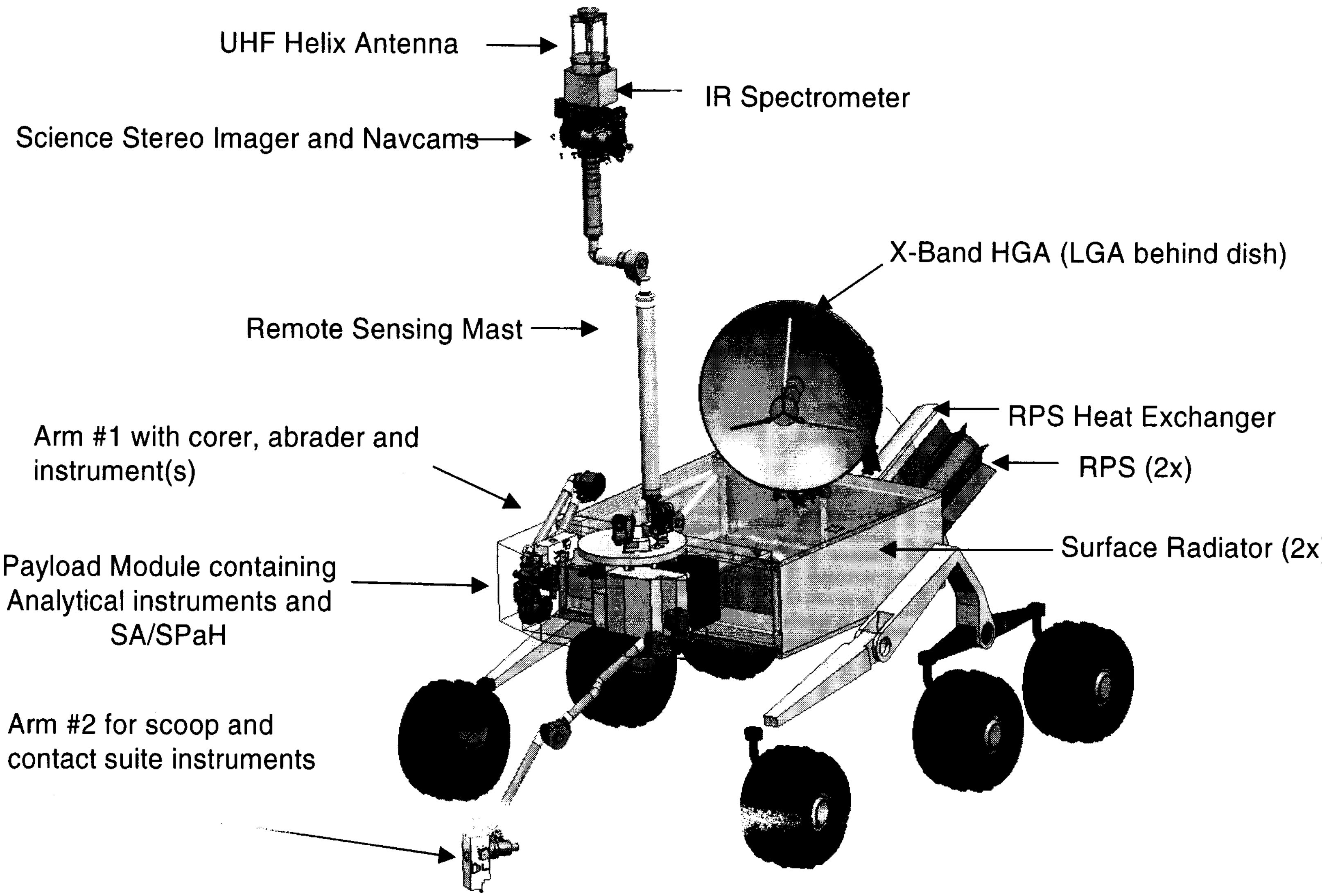
Entry Configuration (w/SkyCrane)



Descent Stage (w/Skycrane)/Rover Assembly

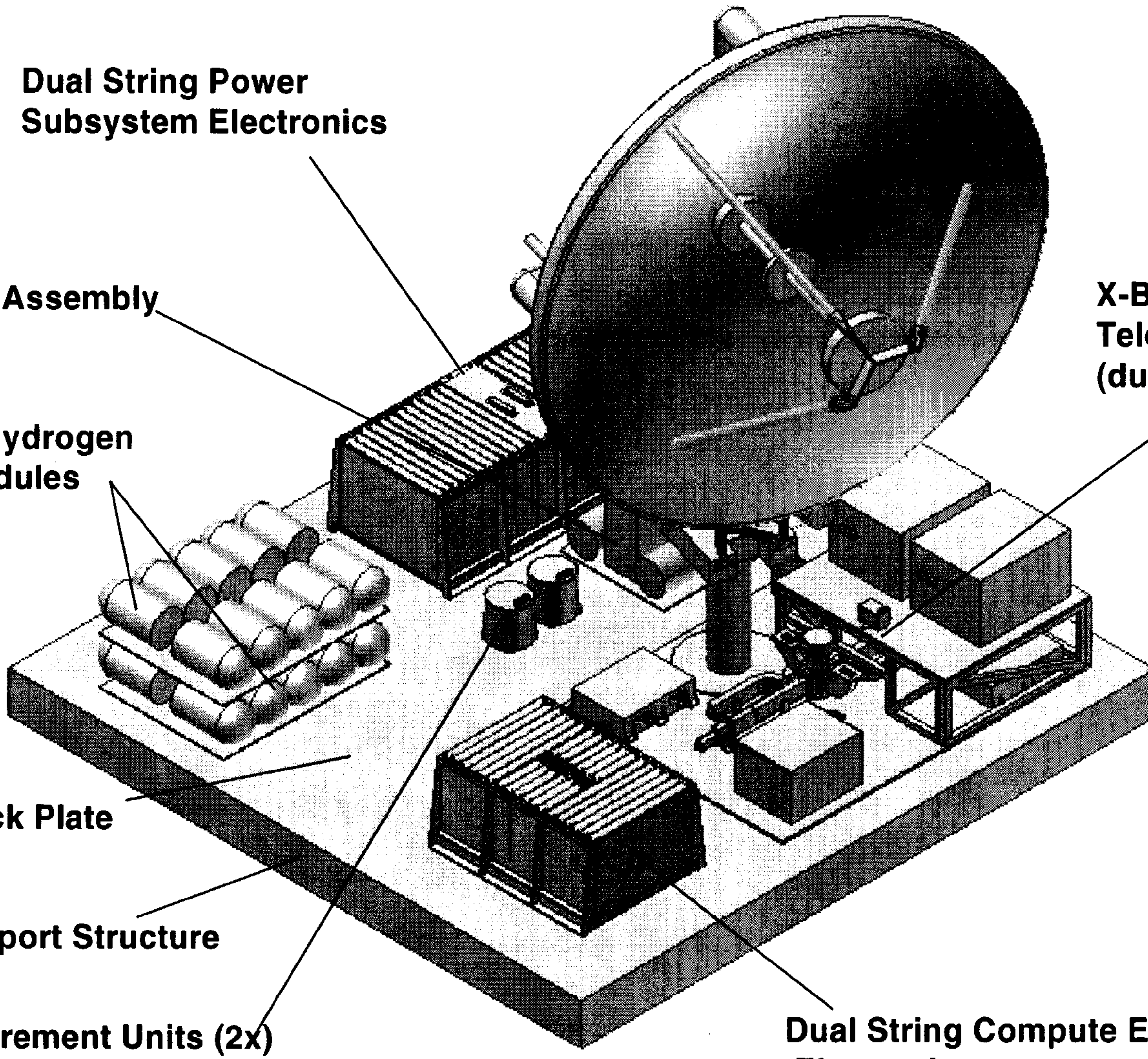


Rover Configuration (Deployed)

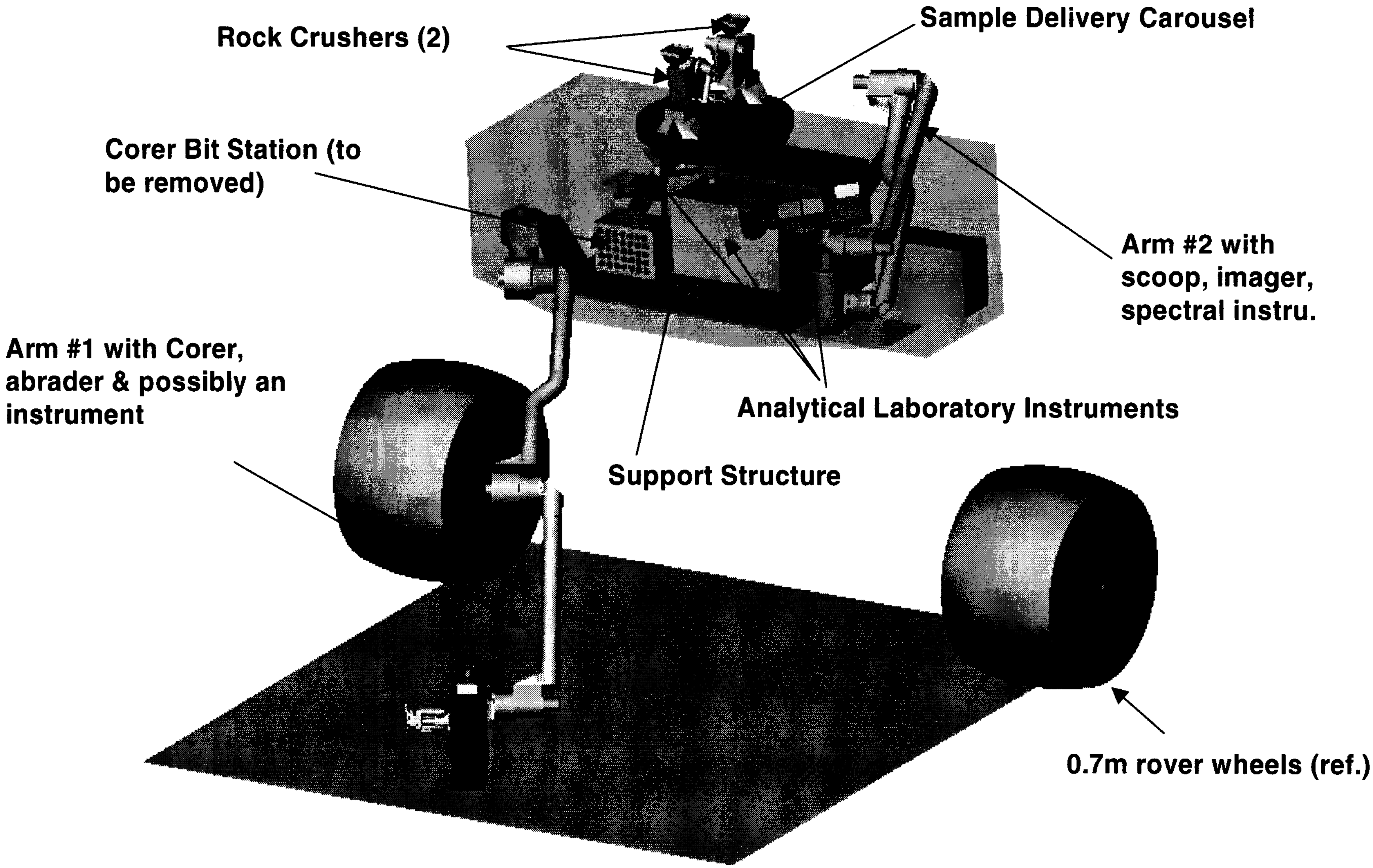


Rover WEB Configuration

Mars Science Laboratory



Payload Module



Discussion Topics

1. Introduction and Requirements
2. Flight System Overview
3. **Trade Study Taxonomy**
4. Entry Descent and Landing Detailed Trade Studies
5. Surface System Detailed Trade Studies
6. Subsystem Detailed Trade Studies
7. Resource Margins and Schedule

Trade Study Introduction

- MSL has a complete reference spacecraft design derived from a large number of trade-studies
  - 17 design areas were evaluated
  - Over 50 options were studied
  - The trade study process involved a combination of detailed analyses, workshops and reviews
  - All baseline decisions were reviewed and ratified by the Mission Engineering Team (including the PM and all office managers)
  - Major design decisions were also ratified by peer review with additional formality for the following:
    - Descent stage
    - Avionics
    - Parachutes

Mission Trades

Level 3 Summary

MISSION

- **LAUNCH**
  - L/V Type
  - L/V Config
- **TRANSFER**
  - Trajectory Type
  - Carrier Sys Design
- **APPROACH**
  - Nav System
  - Entry Method
- **EDL**
  - EDL Comm
  - Entry Vehicle Design
  - Parachute Descent
  - Terminal Descent
  - Descent Propulsion
  - Hazard Detection & Avoidance
- **SURFACE**
  - Rover System
    - SS Trades
  - Comm Strategy
  - Rover Navigation
  - Payload Supt
  - Mission Ops

EDL Trade Space

EDL Communications

- DTE
- UHF w/ orbiter (Telesat, MRO, ...)
- Smart carrier sys UHF

Entry Vehicle Design

- "Sculpted" entrybody
- Entry body config: Viking Aeroshell, Biconic Backshell
- TPS options
  - SLA 561
  - Higher heating alternates

Para-Descent

- Deploy logic
- 1 vs. 2 stage parachute

Terminal Descent

- Legged lander
- Pallet/shock struts
- Airbag sys
- Skycrane

Descent Propulsion

- Pulsed
- Throttled
- VKG Engines
- Modified VKG Engines

Hazard Detection/Avoidance

- Hazard detection
  - Local
  - Regional
    - CSA Lidar
    - PATR
- Hazard avoidance
- Hazard tolerance

Legend: [grey box] Selected, no details; [black box] Selected & discussed here

Surface Mission Trade Space

Rover System

- Avionics
  - Centralized
  - Distributed avionics
  - Hybrid
- Autonomy
  - CARD+HD
  - CARD+HDA
- Mobility range:
  - "go to"
  - 3-6 km
- Power Source
  - RPS
    - sterling, TE
      - 1, 2, 3
  - solar array
    - dust mitigation
  - Hybrid
- Thermal mgmt
  - Passive (heaters)
  - Loop Heat Pipe
  - Active Fluid Loop

Surface Comm Strategy

- DTE (x- or Ka-) only
- Orbiter UHF relay strategy only
  - Odyssey/MRO - backup
  - Mars Telesat Orbiter
    - Orbiter X-band relay strategy
- DTE and UHF +X-band to orbiter

Rover Navigation

- Rover LIDAR
- Navcam/Hazcam
- Night Ops (Yes / No)
  - Mobile
  - Immobile

Payload Support

- Deep Drill
- Drop packages
- Sample cache capability
- Core drill & abrader

Selected, no details

Selected & discussed here

Summary of Early Trades

- EDL Communications
  - Use direct-to-earth (DTE) (carrier only) and UHF
  - Program requirement for reliable comm., including some data capability to reconstruct a failure case
- Entry vehicle design
  - Biconic back shell based on Viking
  - High heritage and provides maximum packaging volume
- Surface communication via DTE and UHF
  - UHF could be to MGS, Odyssey and/or MTO
  - Provides redundancy and high bandwidth
- Rover navigation
  - Via NAV/HAZ cameras per MPF/MER heritage

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Thermal Protection System Trade Space

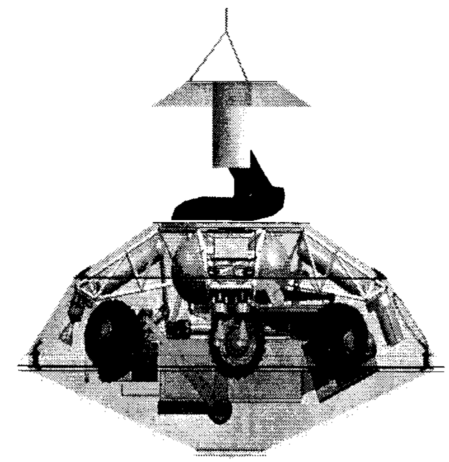
- Options considered
  - Heat shield
    - SLA 561
    - Higher heating alternates
  - Backshell
    - All SLA 561
    - SLA plus SIRCA
- **Selected: Heat shield – SLA 561V; Backshell – All SLA 561S**
- Justification
  - Current nominal heating loads within the limits of SLA-561V (140w/cm^2)
  - Backshell heating rates well within SLA-561S
- Technology Program Contribution
  - In Space Propulsion (ISP) developing other materials to TRL-6 by end of '05
  - MTP supporting aerothermal environment definition (~$.5M)
- Phase A work
  - Settle on aerothermal environments (may represent mission design constraints on arrival season and entry velocity)
  - Specific Trade Studies:
    - Perform shock tube testing to characterize turbulence
    - Options to control around heating rate
    - Tapered thickness
    - Extend qualification of SLA-561V to higher heating rates

Parachute Trade Space

- Options considered
  - Single supersonic chute w/ additional descent engines
  - Dual Chute: Supersonic and sub-sonic
- **Selected: Dual Chute**
- Justification:
  - Robust time line to meet the 2.5 km altitude requirement
  - Enables heatshield release (critical)
  - Supersonic chute remains in Viking qualification range
  - Significant mass savings (~100 kg net)
- Technology Program contribution: ($2 – 4M)
  - Development of subsonic flight design and demonstration by high altitude drop testing
- Phase A work
  - Initiate contracts to develop preliminary design and conduct initial high altitude tests
- Concept was peer reviewed by group of industry experts including Ervin, Pioneer, LaRC, and Sandia. Board unanimously supported design as baseline

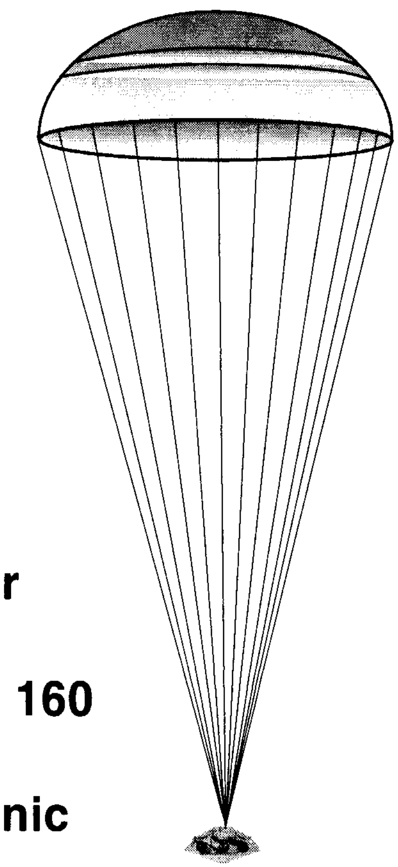
Dual Parachutes

- MSL supersonic parachute system is a direct derivative of the Viking, MPF and MER supersonic parachutes
- Less stringent stability requirements then MPF and MER



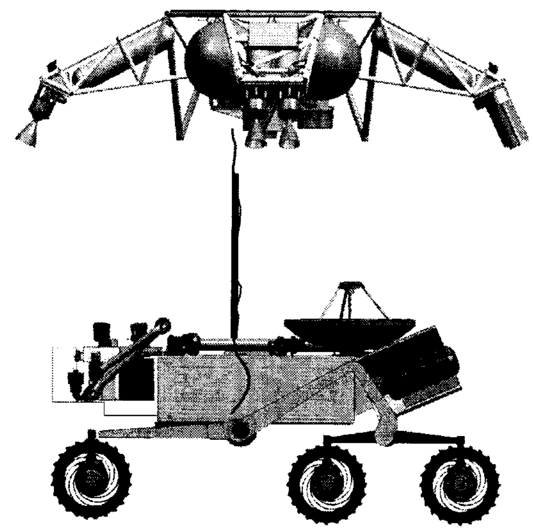
Canister and Mortar

- Terminal velocity near ~50 m/s
- Deploy at M ~ 0.8 (v ~ 160 m/s), q ~ 150 Pa
- Extracted by supersonic chute

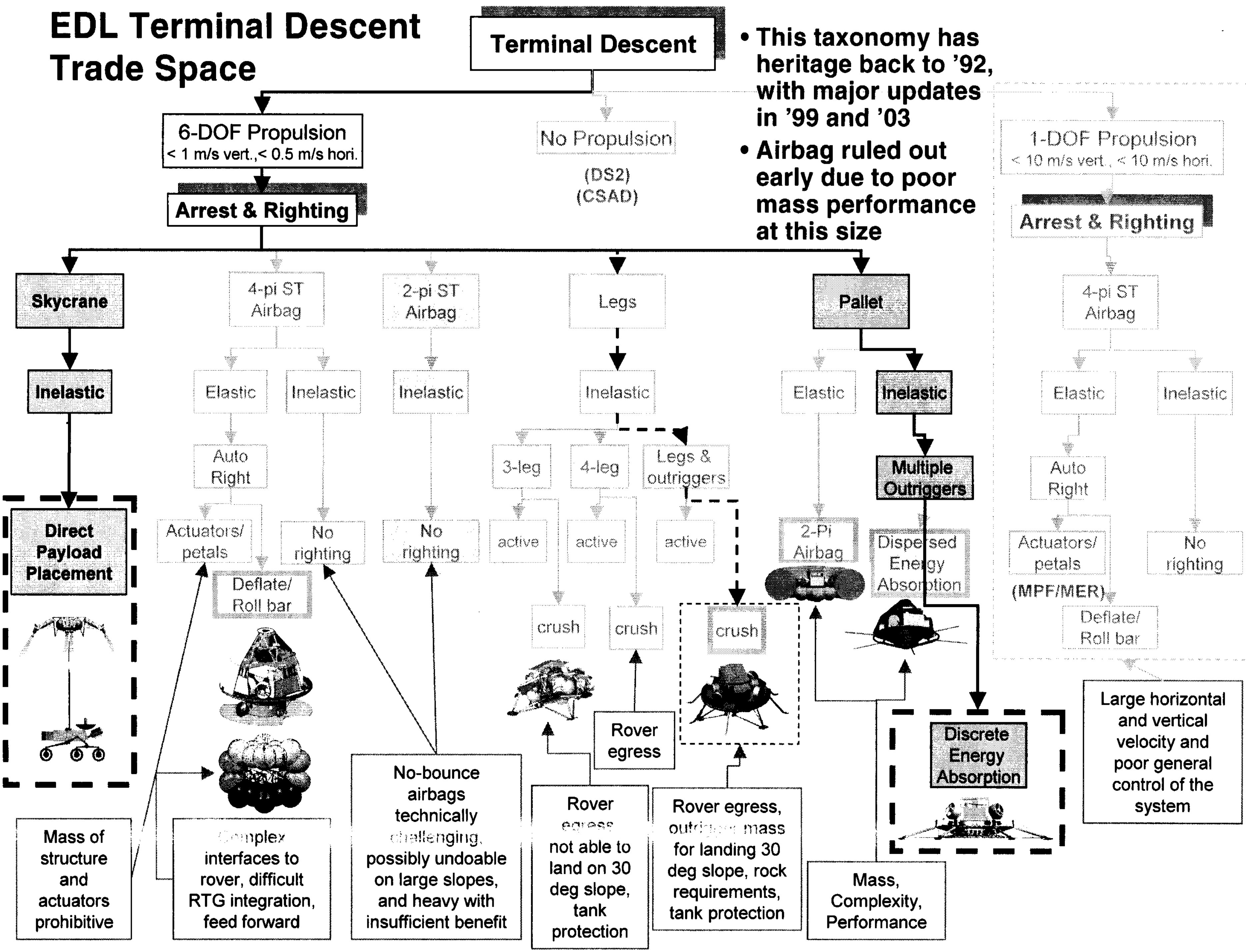


EDL Terminal Descent Trade Study

- Options considered
  - Legs
  - Airbags
  - Pallet
  - Hybrids of legs, airbags
  - Skycrane



- **Selected: Skycrane**
- Justification
  - Best slope and rock tolerance
  - Lowest landing energy and design complexity (highly modelable)
  - No rover egress issues
  - Feed forward to future large payload missions (modular design and clean interfaces)
  - No major unknowns in control design (based on initial simulations)
  - Understood and manageable development and operational risks
- Concept was peer reviewed. JPL: Gentry Lee, Richard Cook, Bob Rasmussen, Sam Sirlin, Bill Layman, Howard Eisen. LMA: Steve Jolly. Board unanimously supported design as baseline

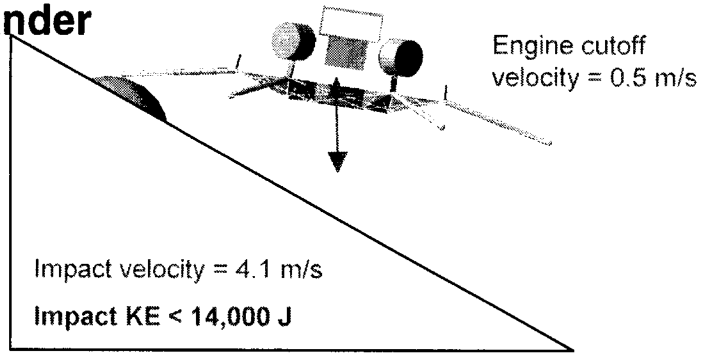

EDL Terminal Descent Trade Space
Terminal Descent
• This taxonomy has heritage back to '92, with major updates in '99 and '03
• Airbag ruled out early due to poor mass performance at this size
6-DOF Propulsion
< 1 m/s vert.,< 0.5 m/s hori.
No Propulsion
(DS2)
(CSAD)
1-DOF Propulsion
< 10 m/s vert., < 10 m/s hori.
Arrest & Righting
Arrest & Righting
Skycrane
4-pi ST Airbag
2-pi ST Airbag
Legs
Pallet
4-pi ST Airbag
Inelastic
Elastic
Inelastic
Inelastic
Inelastic
Elastic
Inelastic
Elastic
Inelastic
Auto Right
3-leg
4-leg
Legs & outriggers
Multiple Outriggers
Auto Right
Direct Payload Placement
Actuators/ petals
Deflate/ Roll bar
No righting
No righting
active
active
active
2-Pi Airbag
Dispersed Energy Absorption
Actuators/ petals
(MPF/MER)
No righting
Deflate/ Roll bar
crush
crush
crush
Discrete Energy Absorption
Rover egress
Large horizontal and vertical velocity and poor general control of the system
Mass of structure and actuators prohibitive
Complex interfaces to rover, difficult RTG integration, feed forward
No-bounce airbags technically challenging, possibly undoable on large slopes, and heavy with insufficient benefit
Rover egress not able to land on 30 deg slope, tank protection
Rover egress, outrigger mass for landing 30 deg slope, rock requirements, tank protection
Mass, Complexity, Performance

Mars Surface Design Environment

- The following preliminary design environments are derived from surface slope and rock models developed by Golombek/Rapp/Bernard
- These environments are used to compare and design landing and hazard avoidance systems
- Combined slope and rock hazard cases
  - Case 1: 30 degree slope and 10 cm rocks (basic physics)
  - Case 2: 10 degree slope and 50 cm rocks (MPF environment)
  - Case 3: 15 degree slope and 30 cm rocks (MPL environment)
  - Case 4: 5 degree slope and 75 cm rocks (Worst case rock size) (<1% of surface)
- Winds
  - Entry, parachute and descent stage designs are insensitive to Mars winds

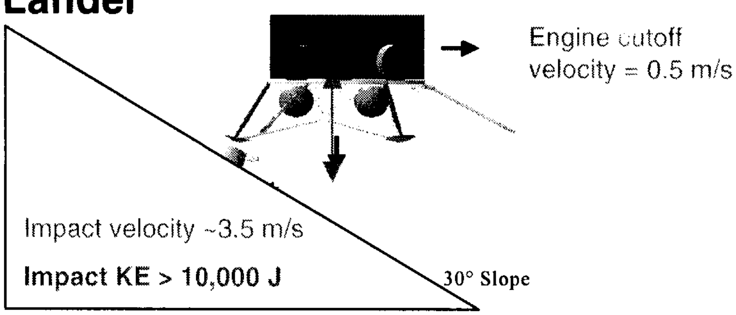
Slope and Rock Landing Environment Tolerance

Pallet Lander



- **Good slope and rock tolerance**
- **Non-linear design, requires high fidelity empirical test process at full scale to design and validate.**
- **Requires TD sensing system for engine cut-off**
- **Plume effects on term. control not well understood**

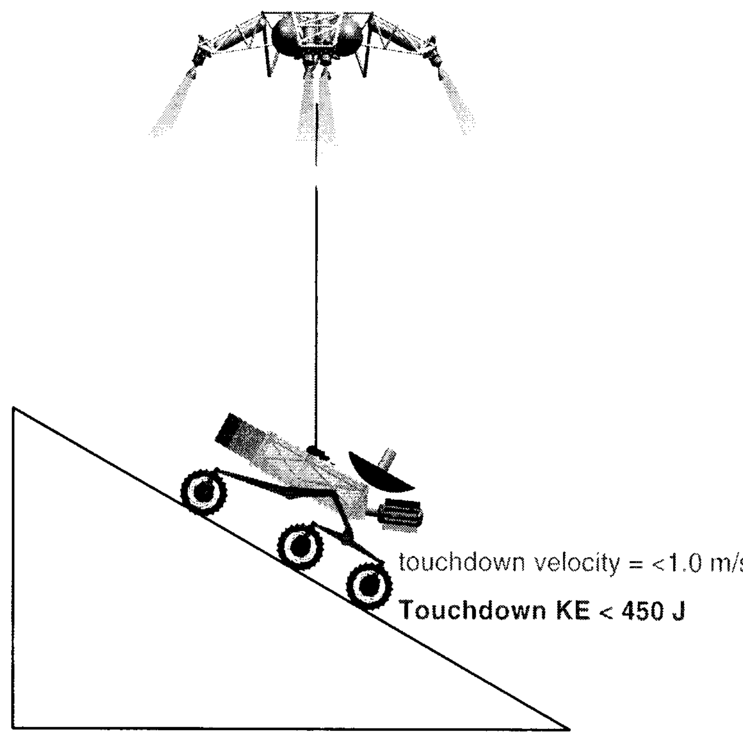
Tripod Lander



- **Marginal slope and rock tolerance. Likely need some kind of outriggers (shown)**
- **Non-linear design, requires high fidelity empirical test process at full scale to design and validate.**
- **Requires TD sensing system for engine cut-off**
- **Plume effects on term. control not well understood**

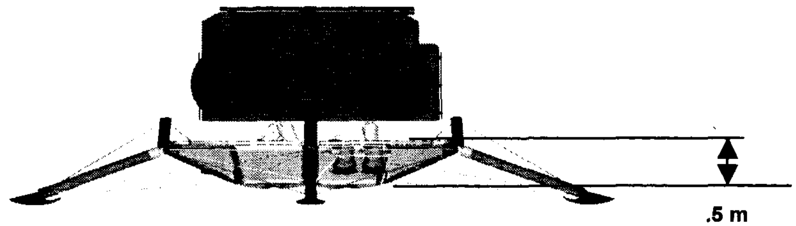
Skycrane

- **Very good slope and rock tolerance**
- **Linear, modelable design, design to worst case environment, validate by test and extensive simulation**
- **No engine cut-off sensing required**
- **Plume ground effects are negligible**



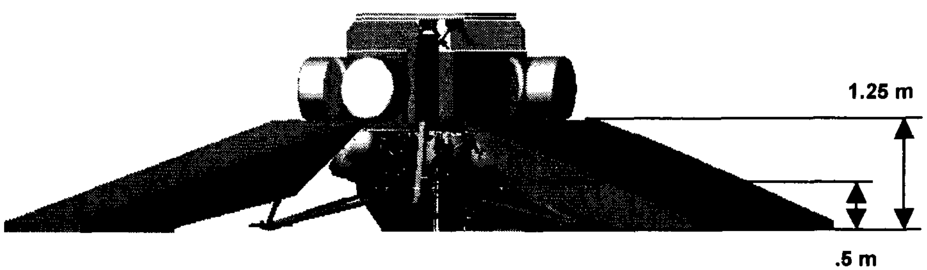
Rover Egress

Pallet Lander



- Moderate drive-off height, 360 egress,
- Significant risk on slopes or large rocks
- Requires dedicated H/W and extensive egress testing.
- Dedicated lift mechanism required

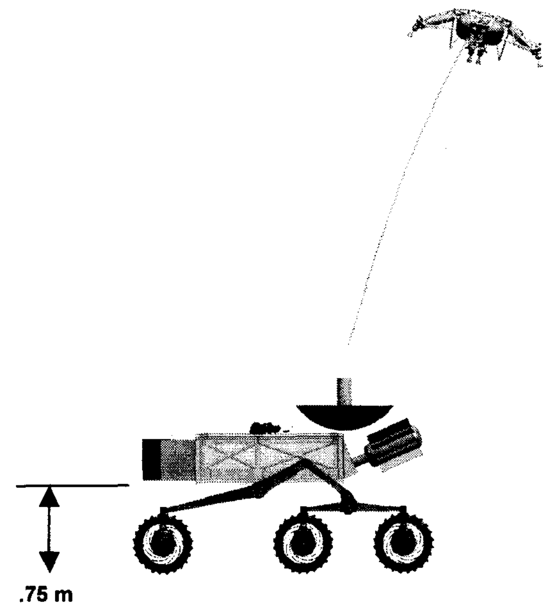
Tripod Lander



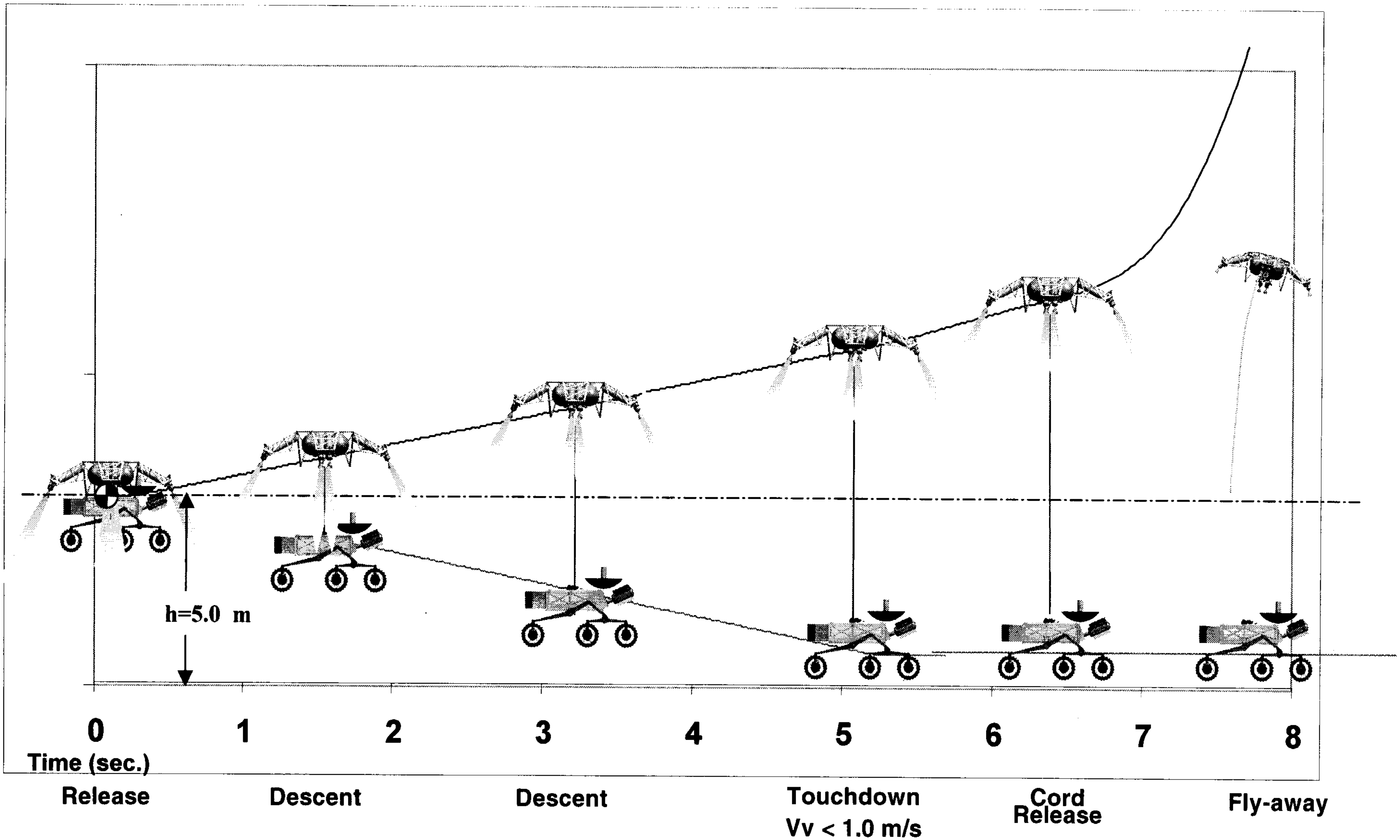
- High drive-off height, high risk egress on slopes or large rocks
- Inflatable ramps needed due to the large size & small stowage volume.
- Limited egress paths: 1 ramp per drive-off direction.
- Dedicated lift mechanism required

Skycrane

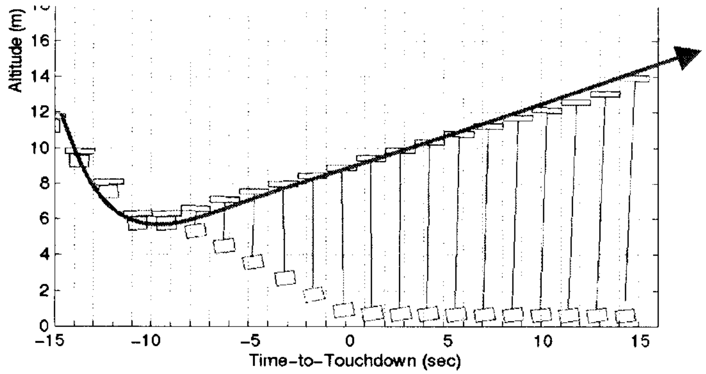
- No egress system required
- Slopes and rocks handled by mobility system
- Touchdown test program handles egress



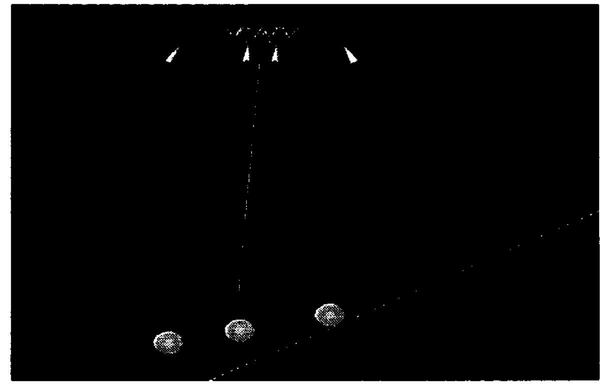
Landing Control Simulation Results



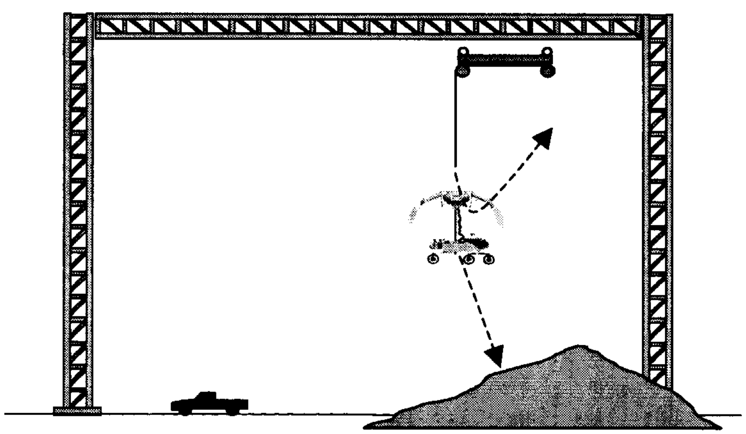
Summary of Design and Test Approach



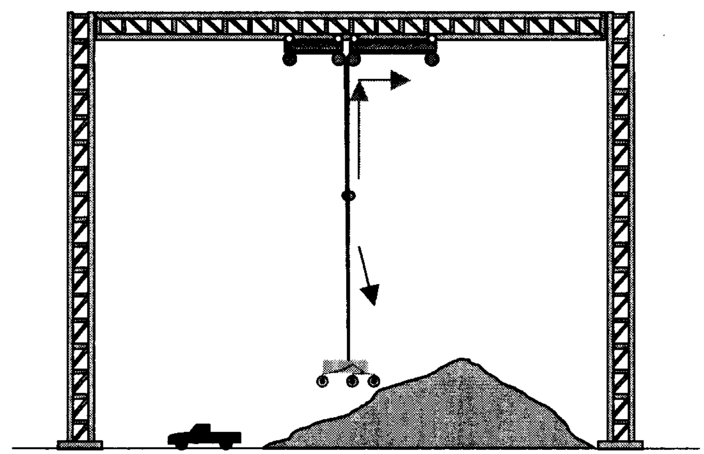
- **Use existing CAST simulation capability to provide dynamics analysis**



- **Use existing ADAMS modeling capability to generate vehicle dynamics and loads**



- **Option: High fidelity closed loop dynamic testing could be pursued if unexpected coupling issues should develop.**



- **Perform gravity offloaded tests of a full-scale vehicle for model validation of vehicle terrain interaction**

EDL Delivered Mass Comparisons

	Viking	MPF	MER	MSL
Launch-kg	1060	894	1049	2800
Entry-kg	936	585	777	2400
Suspended-kg	740	515	623	1800
Landed-kg	610	370	494	900
Usable Equipment-kg	244	92	180	900
Payload-kg (w/ res.)	91	25	18	157
Touchdown Velocity	2.4 m/s	25 m/s	25 m/s	1 m/s
Payload /Landed Ratio	15%	7%	4%	17%
Equipment/Entry Ratio	26%	16%	23%	38%

EDL Terminal Descent Trade Study

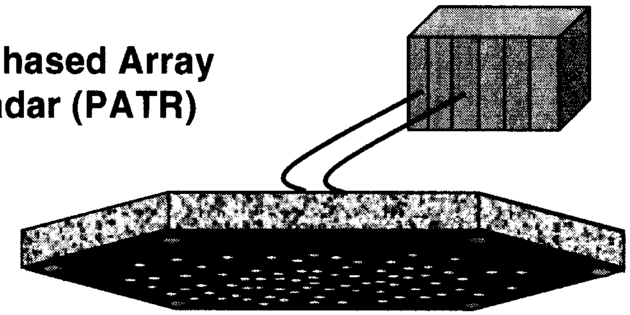
- Technology Program contribution: ($ 12M)
  - Development of descent stage test environment including descent rate limiter
  - Test vehicle for demonstrating landing and mobility
  - GNC algorithms and simulation tools (DSENDS, POST)
- Phase A Work
  - Continue development of descent stage detailed design, especially control system. Include error sources, fault, and disturbance sources
    - Optimum hover design
    - Descent stage fly-away design
    - Guidance and control with error sources, mass properties ranges, etc.
    - Phased array and gyro coupled performance
    - Fault detection and response
    - Plume effects
  - Continued development and validation of simulation tools
  - Define validation test program in greater detail

Hazard Detection and Avoidance Trade Space

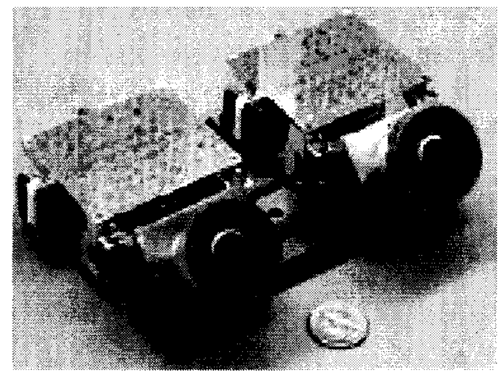
- Sensor options considered
  - Lidar
  - Phased array radar
  - Visual
  - Thermal
- **Selected: Phased array radar**
- Justification
  - Meets 500-1000 m regional hazard detection requirement (issue for lidar)
  - Recognizes 16-150 m OD craters and slopes (issue for visual and thermal)
  - Only system that can provide hazard detection, altimetry and velocity in one package
  - Insensitive to environmental effects (dust, light, etc.)
  - Addition of local hazard avoidance to avoid .75 m rocks adds only 1% to probability of a safe landing and adds significant additional mission risk
  - Best feed forward, can provide 15-100 m local hazard detection capability, if required
- Technology Program contribution: ($4.1M)
  - Development of flight-like, field testable unit of phase array radar
- Phase A Work
  - Complete design and starting build of test unit
  - Evaluate options and risks of eliminating phase array radar in favor of a much lower cost and risk radar (velocity and altitude measurement only, may lead to restrictions in landing sites).

Sensor Pallet Options

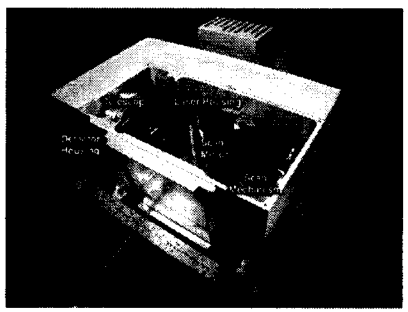
Selected: Phased Array Terrain Radar (PATR)



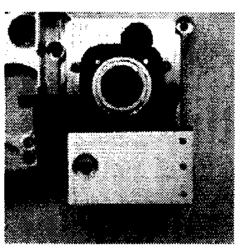
Stereo Vision



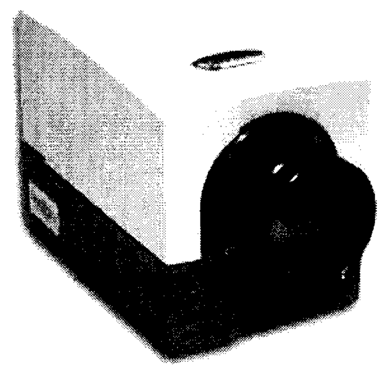
LIDAR



Patterned Light



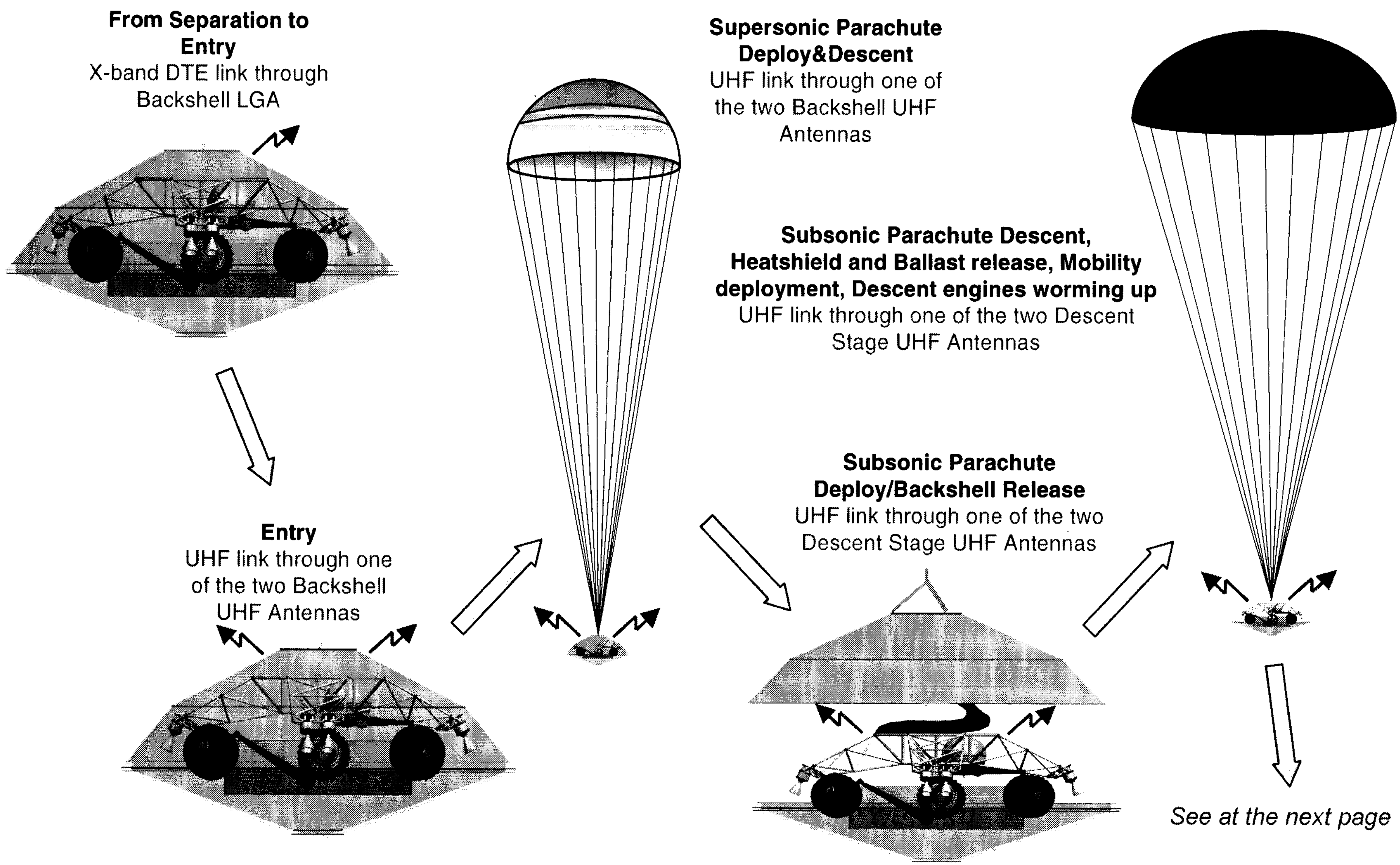
Thermal Imaging



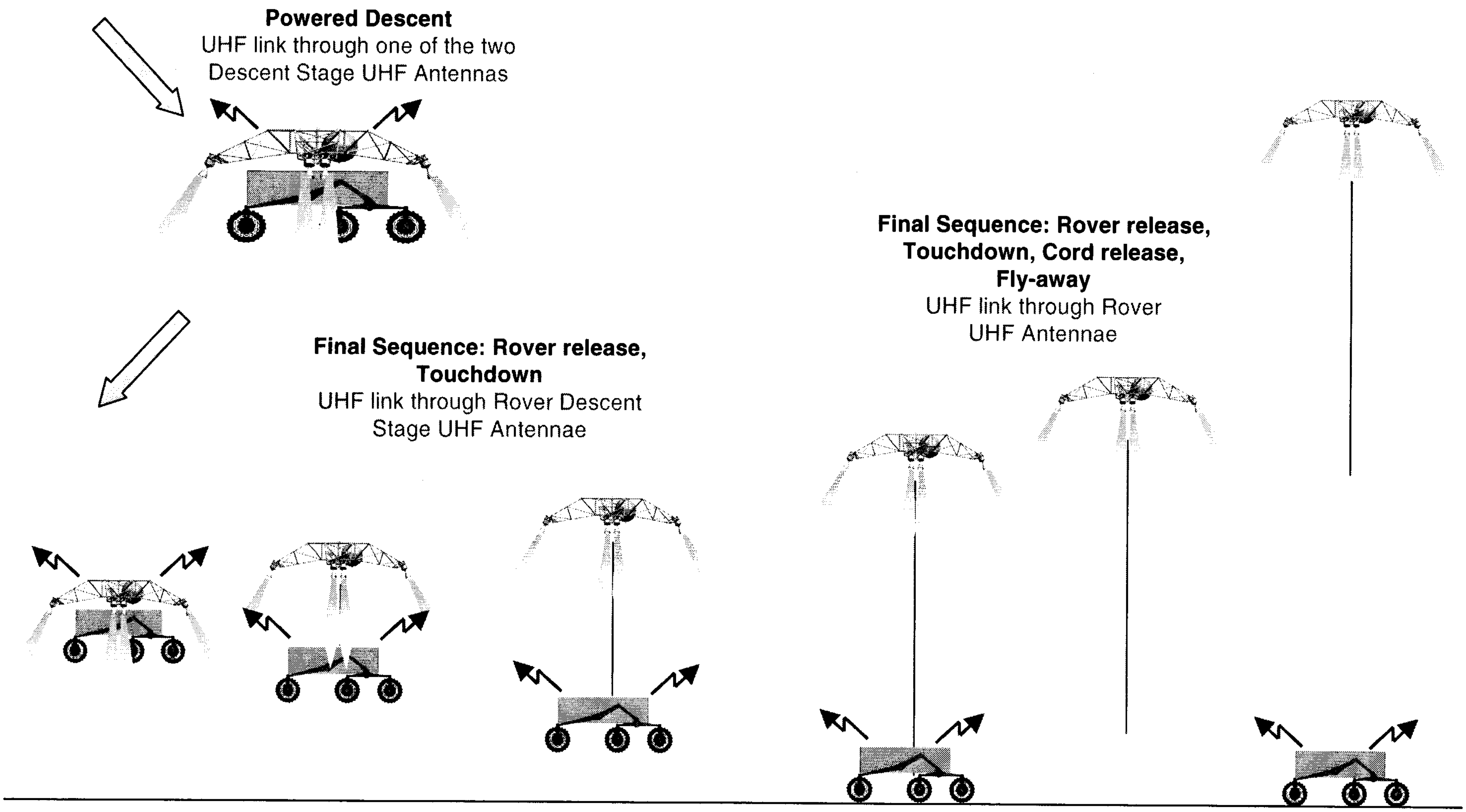
EDL Telecommunications Trade Space

- Options considered
  - All direct-to-earth (DTE) (carrier only)
  - All UHF
  - DTE plus UHF
- **Selected: DTE plus UHF**
- Justification
  - Only way to have potential for providing "continuous" EDL communications
    - DTE performance limited to phase from cruise stage separation to entry
    - UHF limited to period of visibility with orbiting asset
  - Provides most robust communications strategy
- Phase A Work
  - Build of UHF radio (Electra) begins in FY'04
  - Mission design will continue to work options to meet EDL and surface communications needs

EDL Telecom Before Powered Descent



EDL Telecom During Powered Descent



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Rover Sizing Trade Space

- Options considered:
  - Optimize size around known elements, minimize mechanical mass, optimize packaging (e.g. MER)
  - "One pass design," use mass and volume to achieve a robust design and thereby reducing design iterations and cost
- Selected: "One pass design"
- Justification
  - Accommodates large "fixed" equipment masses: ~390kg (including: payload, redundant S/S and supporting elements)
  - Allows use of black box packaging with large integration volume to minimize electronics and cabling costs
  - Allows use of standard materials and design approaches to minimize cost
  - Mobility system robustly sized to meet ground pressure req., clearances, stability, and high ground clearance for obstacles and hazards
  - Provides large mean free path for mobility, allowing vehicle to drive safely as far as operator can see, hence minimizing autonomy requirements

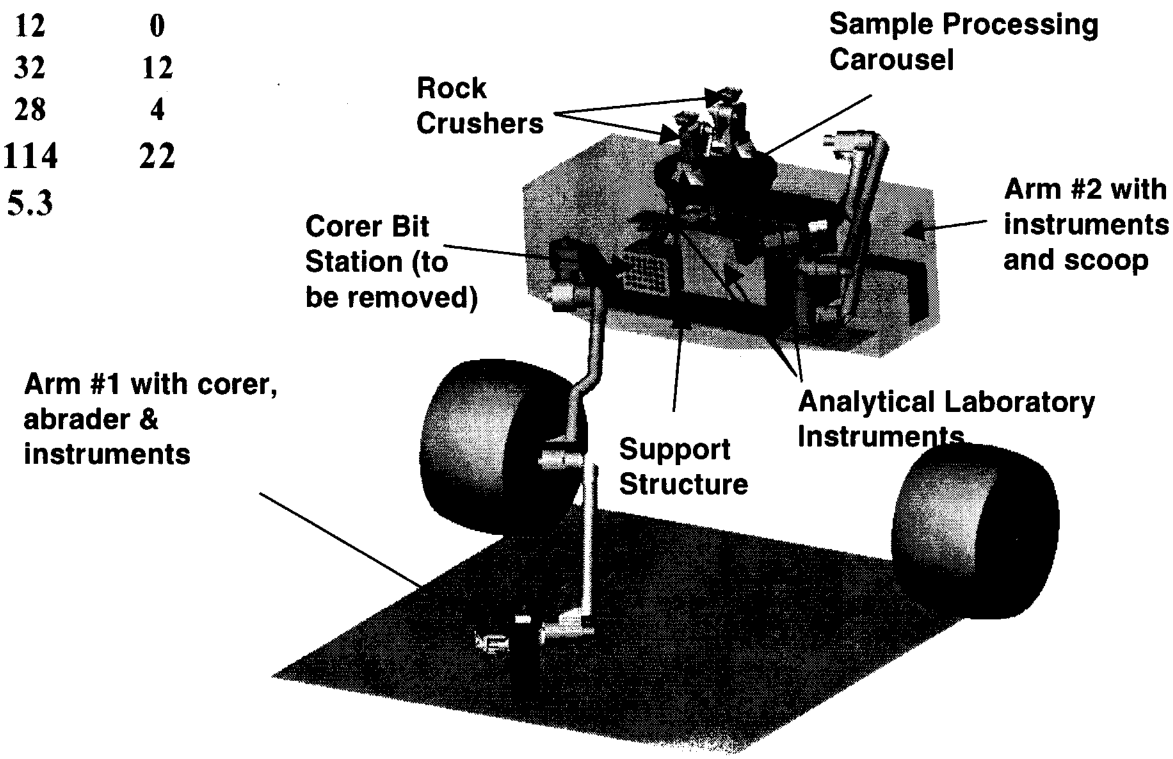
But why is the MSL rover so much bigger than MER?

MER Rover: 180kg

MSL Rover: 900 kg

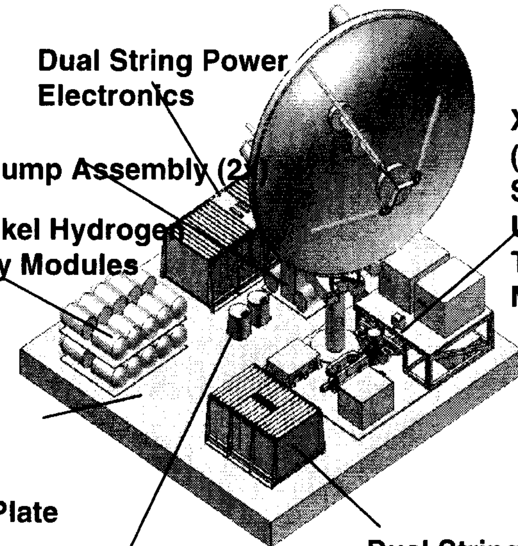
Payload Module Mass

Payload and Infrastructure (kg, w/o margin)	MSL	MER
Remote observation science (appox.)	7	3
Contact Science (approx.)	4	2
Analytical Lab Science (appox.)	31	0
Sample Processor & Handler	12	0
Mast & Gimbal	32	12
Arm(s)	28	4
Total	114	22
Ratio (MSL/MER)	5.3	



Avionics, Power and Supporting S/S Mass

Avionics Subsystems (kg, w/o margin)	MSL	MER
Avionics & Power Electronics	44	28
G&C	11	2
Telecom	31	12
Total	86	43
Ratio (MSL/MER)	2.0	

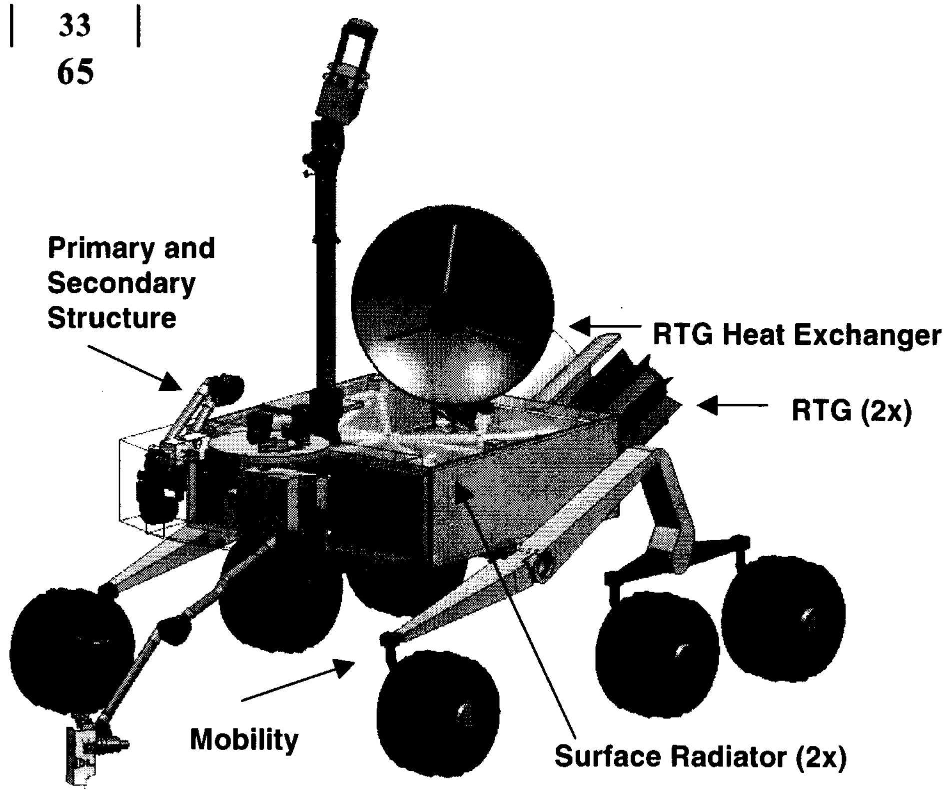


Power and Thermal Subsystems (kg, w/o margin)	MSL	MER
Power Source	78	17
Batteries	25	7
Thermal - Fluid Loop Pumps	20	0
Thermal - Radiators, fluid, etc.	26	5
Total	149	29
Ratio (MSL/MER)	5.2	

Supporting Elements (kg, w/o margin)	MSL	MER
Harness	27	13
Mechanisms (descent	4	0
Antenna Gimbal	10	5
Total	41	18
Ratio (MSL/MER)	2.2	

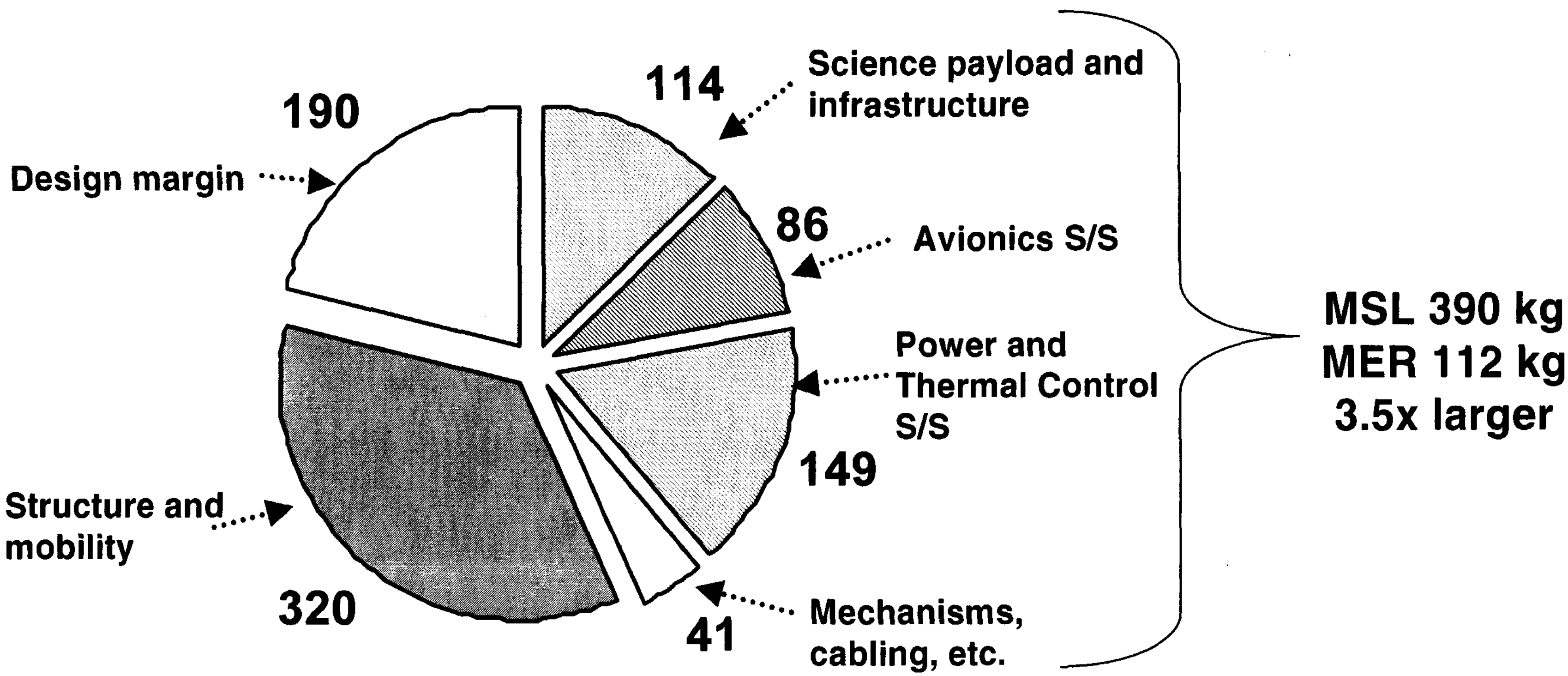
Structure and Mobility Mass

Structure and Mobility (kg, w/o margin)	MSL	MER
Primary Structure	106	32
Mobility (including mechanisms)	214	33
Total	320	65
Ratio (MSL/MER)	4.9	

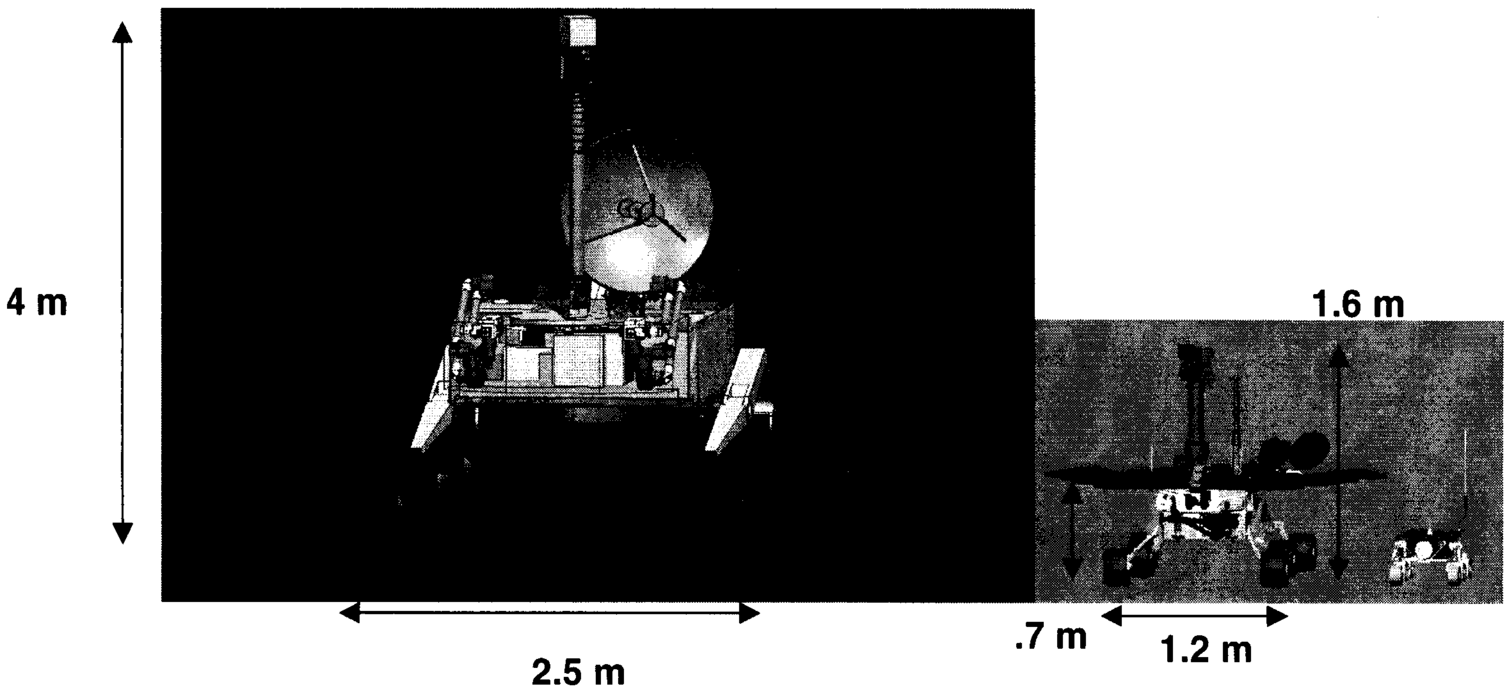


Results of Preliminary Rover Sizing

Total mass allocation: 900 kg



Rover Size Comparison



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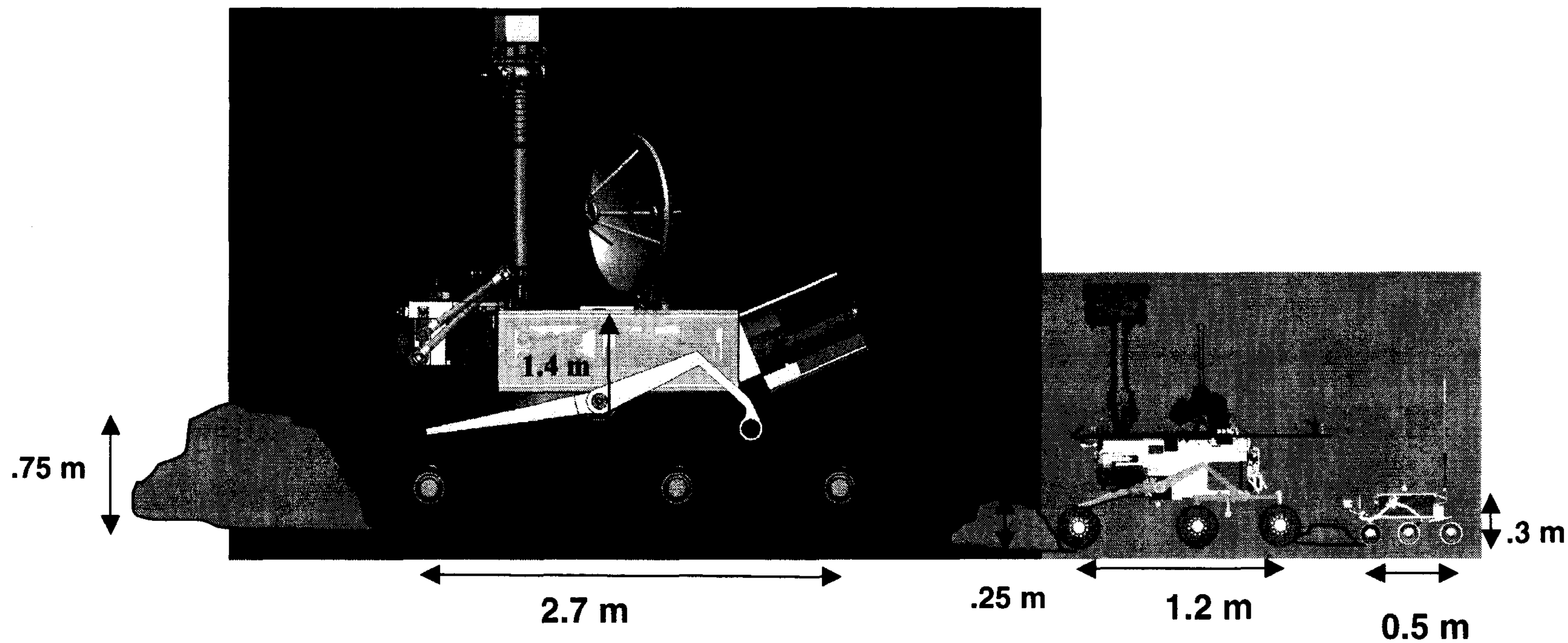


Flight Rover Comparisons

	Sojourner	MER	MSL
Launch Year	1996	2003	2009
Rover Mass (including payload)	10.6* kg	180 kg	900 kg
Payload Mass (w/reserves)	1 kg	25 kg	157 kg
Control scheme	CARD+Behaviors	CARD+Hazard	CARD+Hazard
Rover Life	>90 sols (actual)	90 sols	670 sols
Rover Range	~0.1 km	~1 km	~6 km
Speed	1 cm/s	5 cm/s	5-10 cm/s
Traverse robustness	Low	Moderate	High
Ground clearance	0.1 m	0.25 m	0.75 m

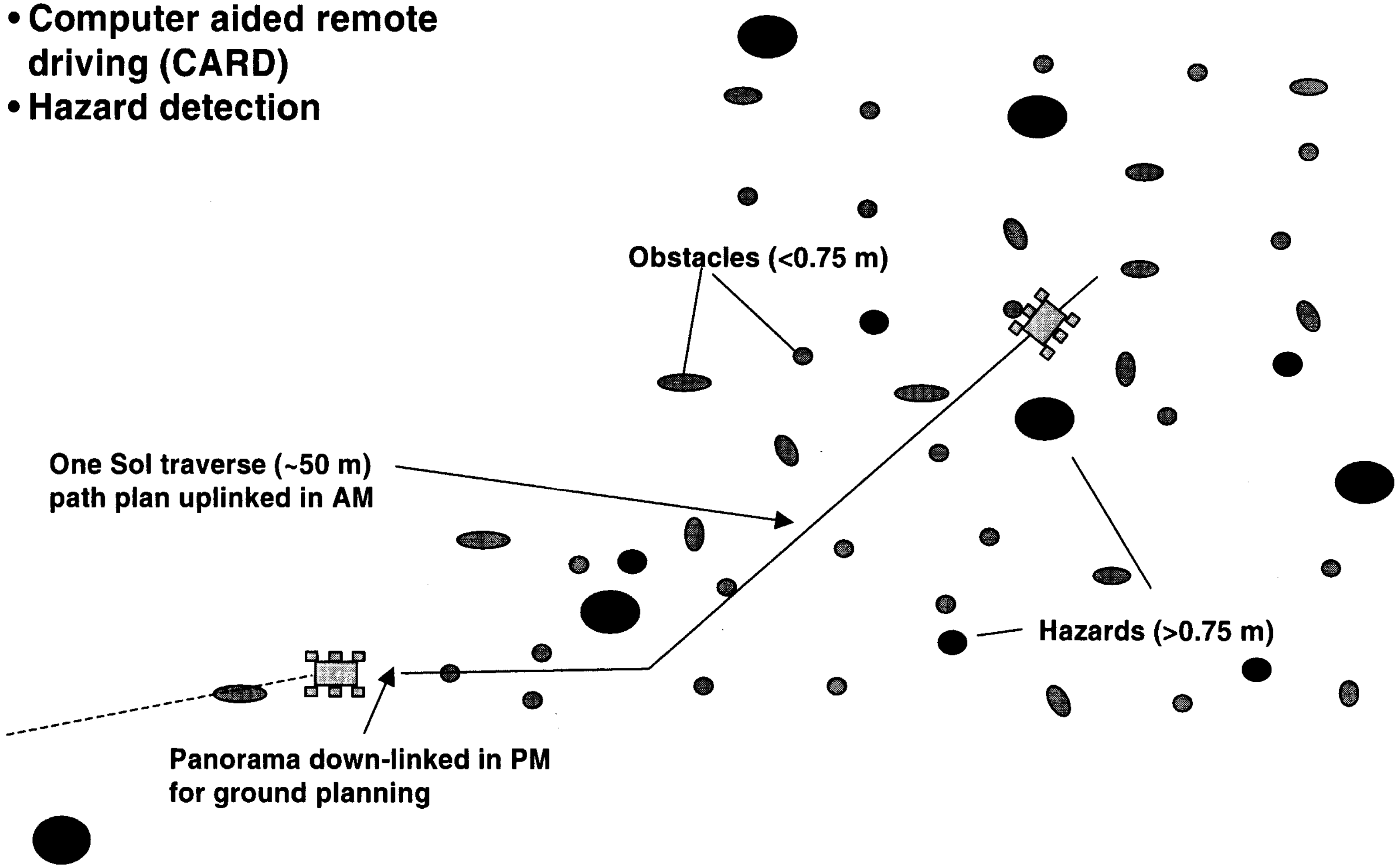
*plus ~4kg on the lander

Mobility/Autonomy/Operations Trade Space

- Options considered
  - High level of surface system autonomy
  - Human-in-loop operation (computer aided remote driving, CARD) with autonomous hazard detection
  - Night operations
- **Selected: Human-in-loop with autonomous hazard detection (MER-class), without night operations**
- Justification
  - PSIG wanted to balance science and engineering sophistication: Mission life driven much less by driving range, speed or hazard detection autonomy than by number of science decisions requiring human interaction at a rock sample site
  - Large vehicle size allows for simple path planning
  - Consistent with an "autonomy to cost" strategy
    - Hazard detection and avoidance test cost could be unbounded
    - Could infuse more autonomy once science objectives are met
- Technology Program contribution: ($4M)
  - Mobility plus SW activities, including: navigation, ROAMS
- Phase A work
  - Refine traverse and science operations scenarios, including consideration of night operations (technology for night/twilight lighting exists)
  - Support and evaluate technology tasks for application to flight development

Path Planning and Execution

- Computer aided remote driving (CARD)
- Hazard detection



Discussion Topics

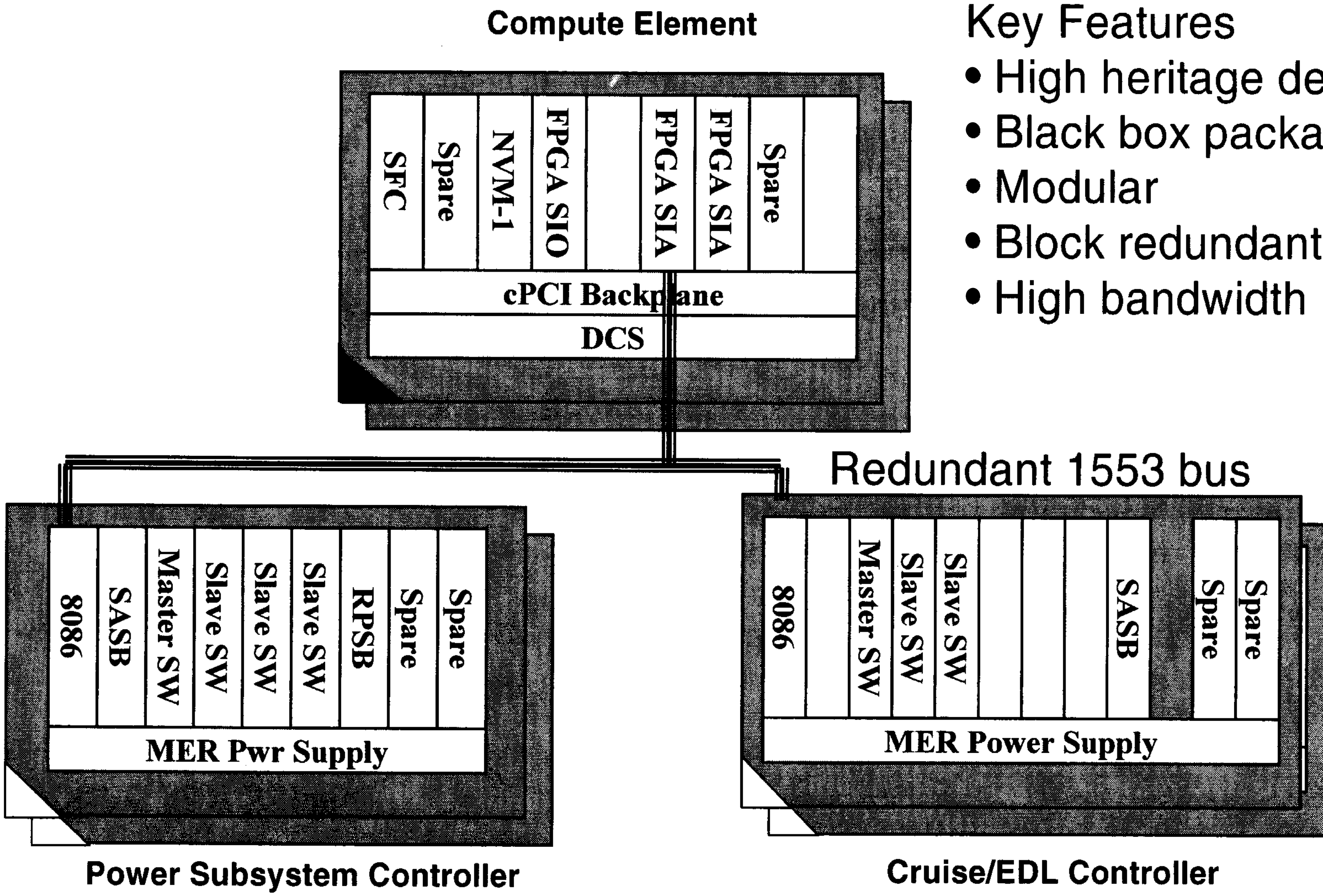
1. Introduction and Requirements
2. Flight System Overview
3. Trade Study Taxonomy
4. Entry Descent and Landing Detailed Trade Studies
5. Surface System Detailed Trade Studies
6. **Subsystem Detailed Trade Studies**
7. Resource Margins and Schedule

Avionics Architecture Trade Study

- Options considered in each of these areas
  - Architecture: Single string vs redundant
  - Processors
  - Bus(s)
  - Power switch type (smart, dumb, combination)
  - Heritage, availability, performance
- **Selected: Block Redundant, high heritage, cPCI & VME architecture, RAD 750, 1553, RS422, dumb switches**
- Justification
  - >3 year mission
  - Known performance and adequate performance margin for minimum cost
- Technology Program contribution: None needed
- Phase A Work
  - Detailed design of switch boards, grounding and other power S/S trades
  - Begin long lead procurement process
- Concept was extensively peer reviewed within Div. 34

Avionics Compute and Power Elements

Key Features
- High heritage designs
- Black box packaging
- Modular
- Block redundant
- High bandwidth



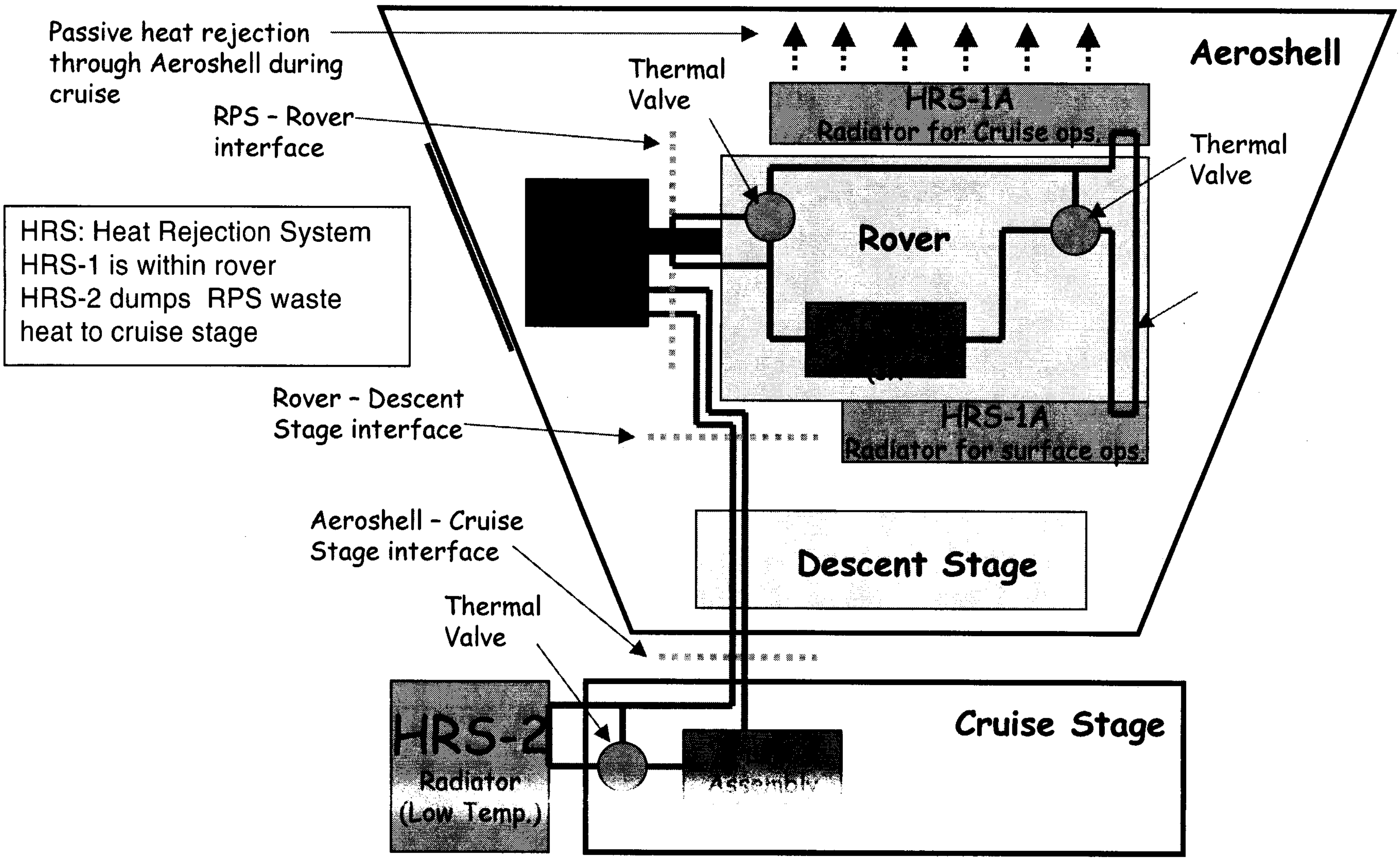
One vs Two RTG Trade Study

- Options considered
  - 1 RTG
  - 1 RTG plus solar augmentation
  - 2 RTG's
- Selected: 2 RTG's
- Justification
  - Surface operations scenarios are very preliminary, prudent to use have high power and energy margin strategy (~45%) to achieve lowest design and operational cost
  - Maximum operational flexibility – simple & robust scenarios
  - Power management strategies and costs (e.g. sleep modes, night modes, etc.) may be significant and are not easy to define at this stage
  - RTG plus solar represents the most complex power system and not feasible for all latitudes
  - Much easier to scale down from 2 than up from 1
- Phase A work
  - Will relook at this trade in phase A to find optimum based on selected RPS and NEPA considerations

Temperature Control Trade Space

- Options considered
  - Cruise: Passive vs active (pumped fluid) heat rejection
  - Surface control of electronics base temperature
    - Electrical
    - Passively use RTG waste heat
    - Actively (pumped fluid) use RTG waste heat
- Selected: Active control for cruise and surface operations
- Justification
  - Only active system can remove 4000w
  - Pumped system has high heritage and significant flexibility
  - Active can maintain electronics in +/- 10 C range
- Technology Program contribution: ($2M)
  - Life testing and flex line qualification
- Phase A Work
  - MTP demonstrating flexline design and lifetime
  - Evaluate options to temperature control extremities (e.g. mast, HGA, arms) using fluid system to save electrical power

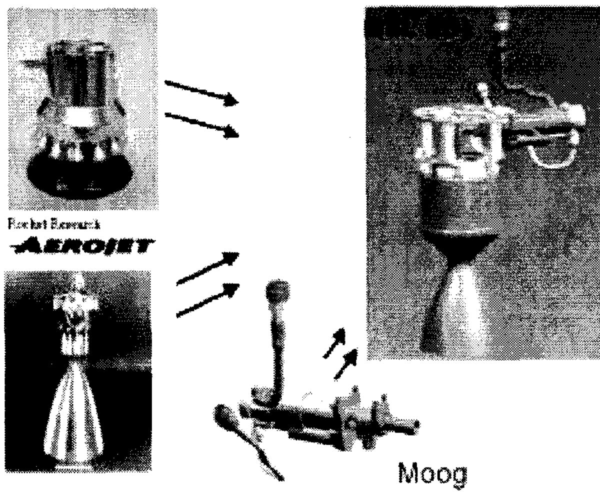
MSL Thermal Control Architecture



Propulsion Trade Space

- Options considered
  - Pulsed engines vs throttled engines
  - Pulsed (bang-bang) regulator vs continuous flow regulator
- Selected: Throttled engines and continuous flow regulator
- Justification
  - Large thrust pulsed engines not controllable (thrust increment too large)
  - Avoids serious water hammer problem (MPL was at knee of curve or beyond)
  - Pulsed regulator pulse rate very high, system performance uncertain
- Technology Program contribution: ($6.4M)
  - Developing and testing test engine and variable flow regulator up to point of formal qualification
- Phase A Work
  - MTP is committed to developing and demonstrating the throttled engine and continuous flow regulator through a flight equivalent model test program (pre-qual)

Entry Block Diagram

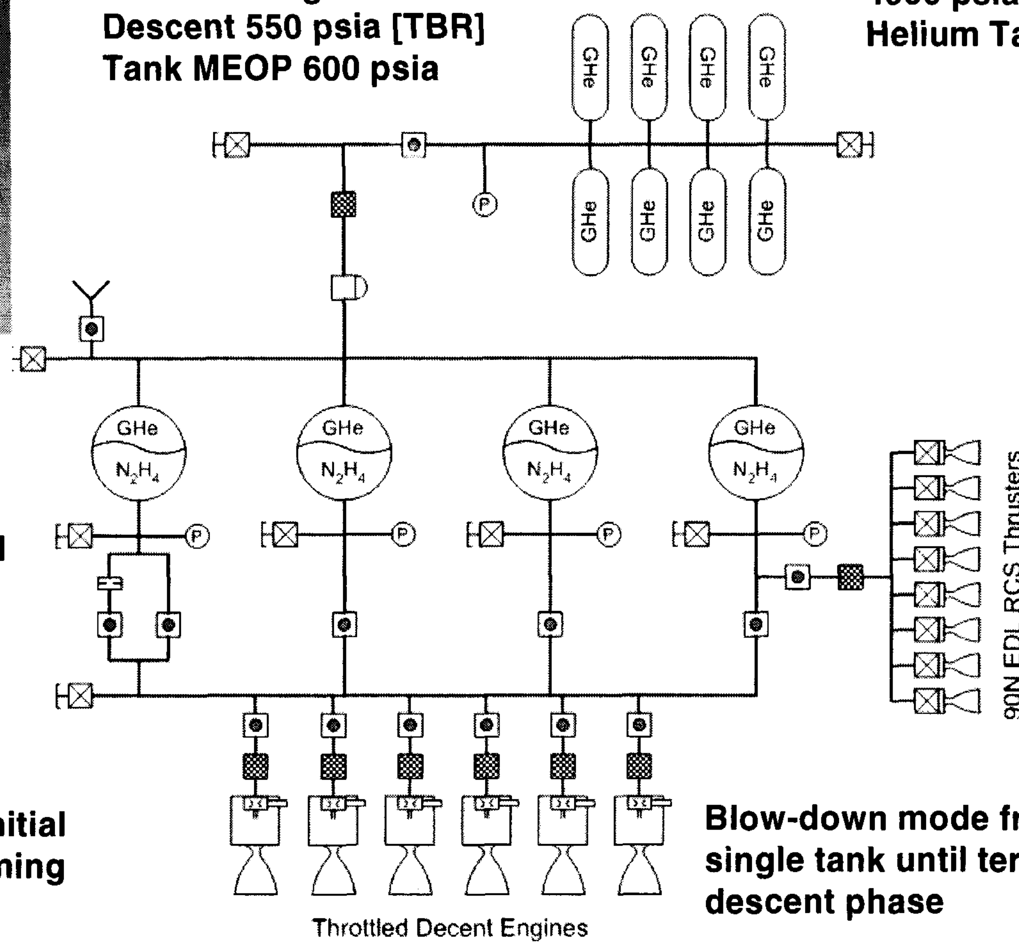


Independently Isolated
Diaphragm Tanks

Descent Engines
Isolated During Initial
Feed System Priming

Pressure Regulated
Descent 550 psia [TBR]
Tank MEOP 600 psia

4000 psia [TBR]
Helium Tanks

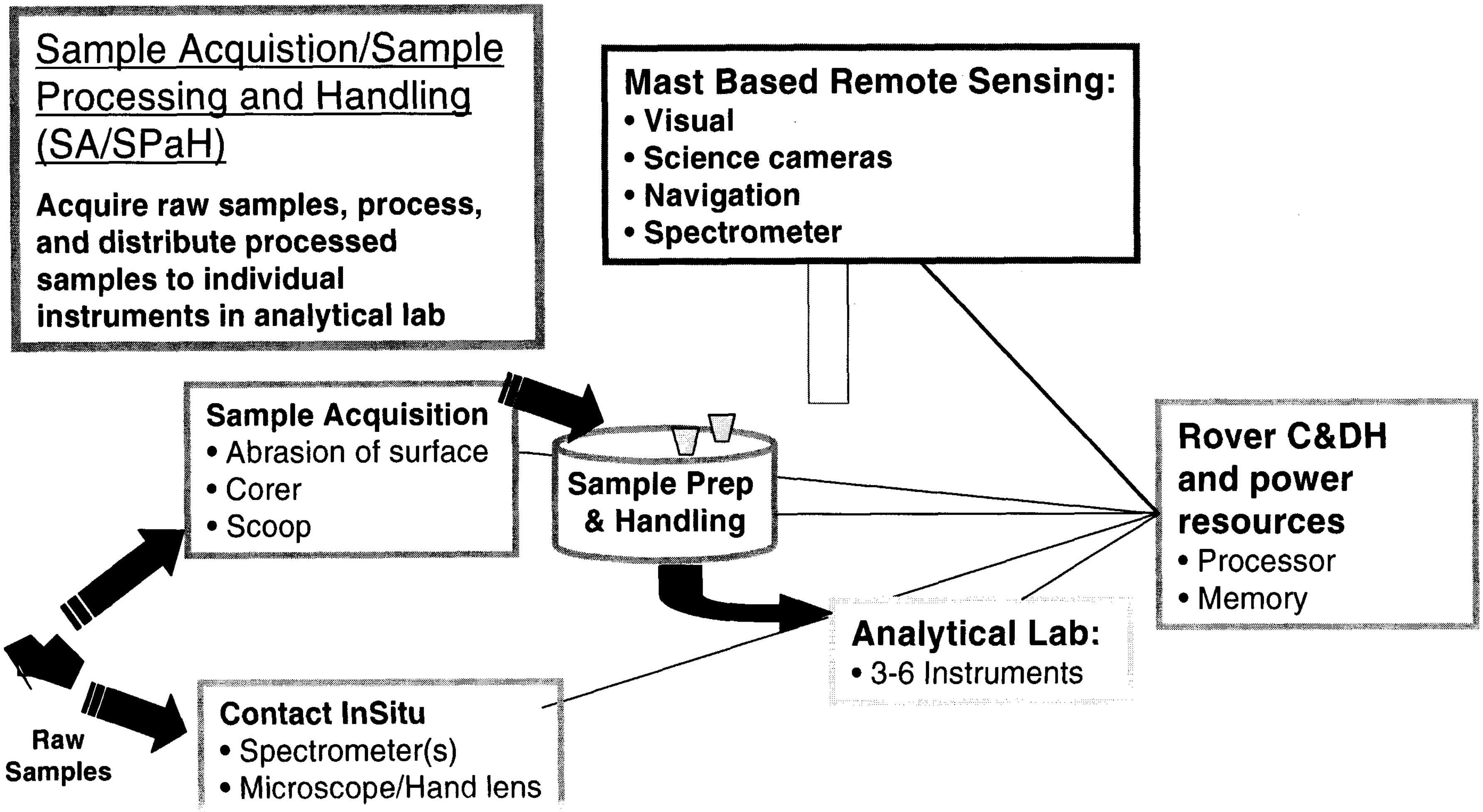


Blow-down mode from
single tank until terminal
descent phase

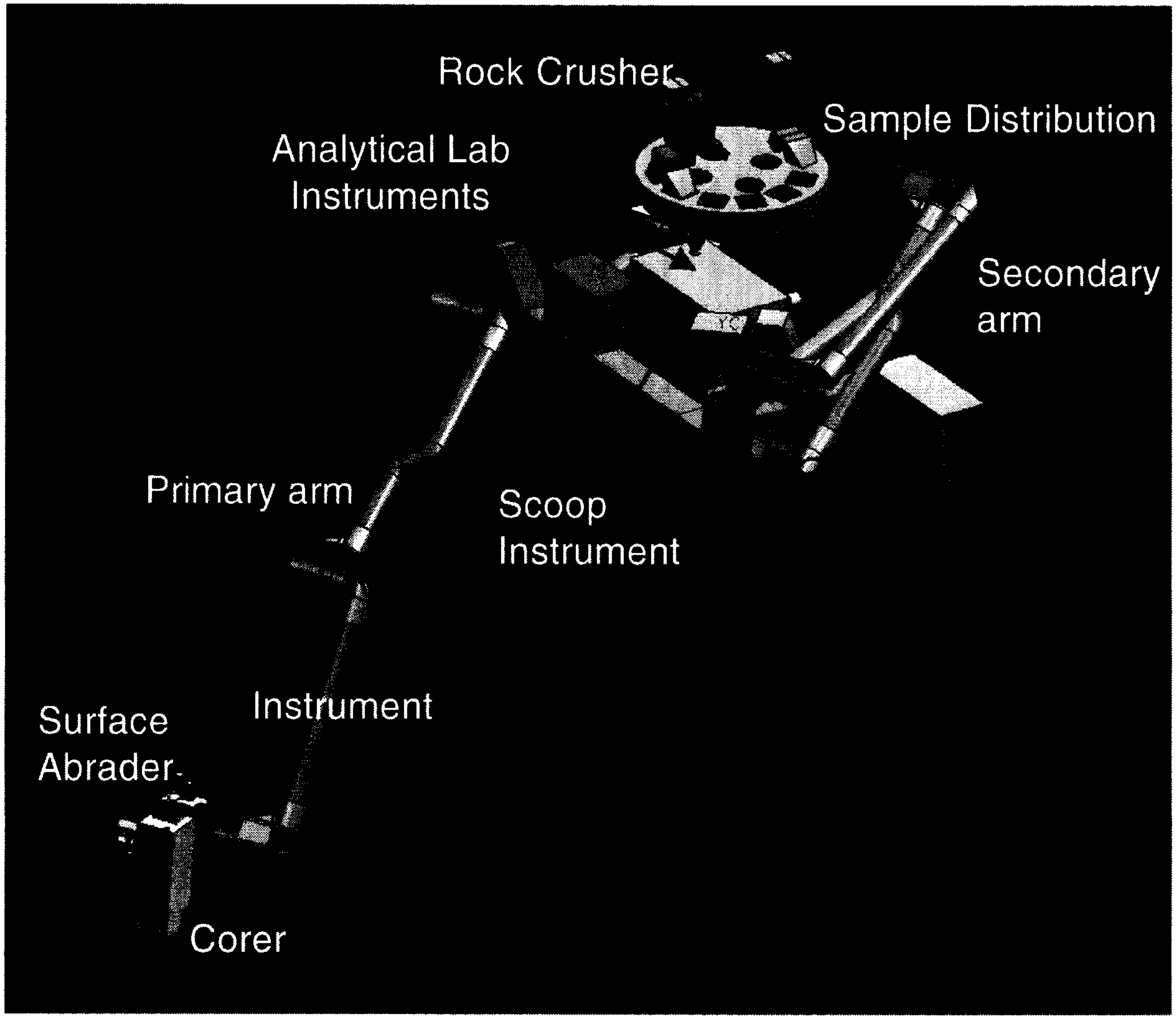
Sample Acquisition and Processing Trade Space

- **Options considered**
  - Single n-DOF arm
  - Two 5-DOF arms
  - One high-DOF + One low-DOF arm
  - Various sample acquisition and processing approaches
- **Selected: Two identical, moderate strength 5-DOF arms w/ rotary/ percussive coring, distributed contact instru. and rock crusher**
- **Justification:**
  - Project single point failure requirement may be best met by providing functional redundancy in sample acquisition through more than one arm
  - Rotary/percussive coring consistent with moderate preloads and moderate power
- **Technology Program contribution: ($5M)**
  - Manipulation and actuators systems
  - Coring and abrasion devices
  - Rock processing and distribution
- **Phase A Work**
  - Define operational environment around low force coring system
  - Complete crusher and sample tray designs
  - Build manipulator and verify force control sensor approach
- **Concept was developed through 3 days of peer workshops, including science, robotics and payload representatives**

Payload Infrastructure Concept
(based on PSIG strawperson payload)

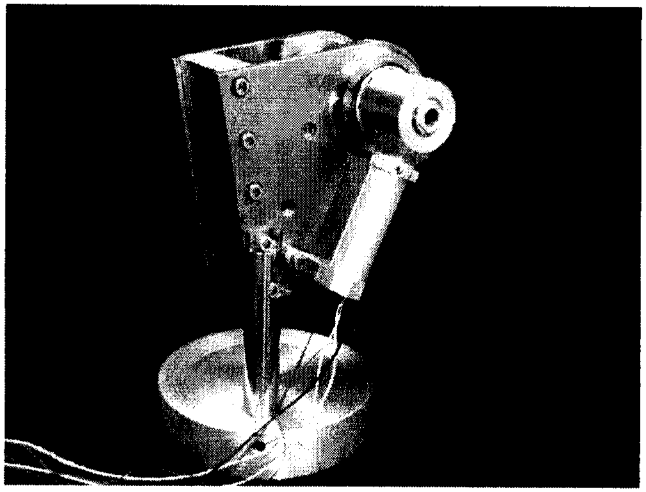


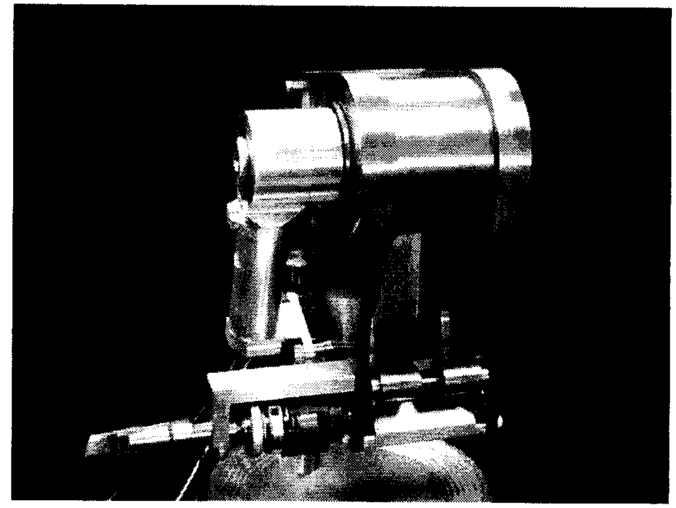
Sample Acquisition Configuration

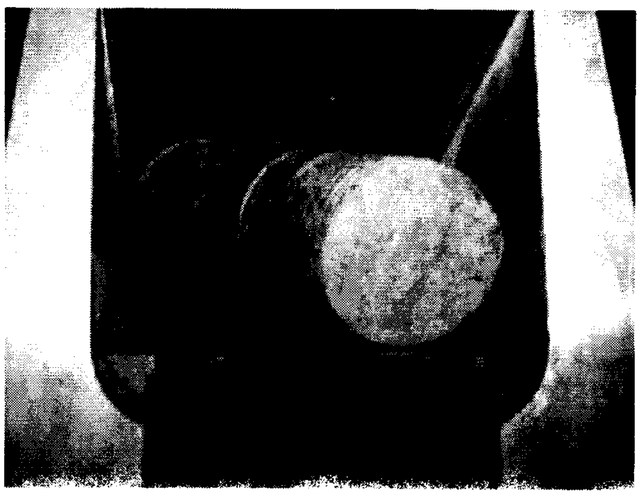


- **2 identical arms**
- **Each arm has a different complement of equipment/ instruments provide a degree of functional redundancy for sample delivery to the analytical lab**

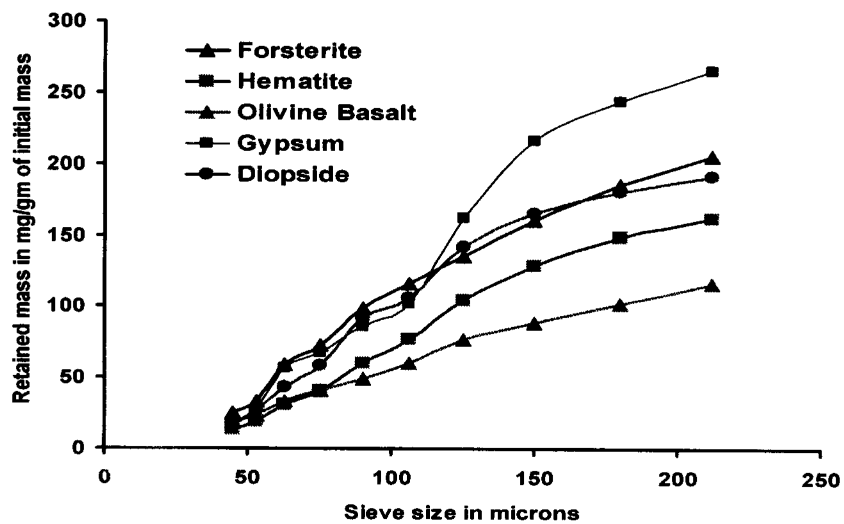
Rock Crusher







Particle size distribution for 0.0625" exit plate



Discussion Topics

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2. Flight System Overview
3. Trade Study Taxonomy
4. Entry Descent and Landing Detailed Trade Studies
5. Surface System Detailed Trade Studies
6. Subsystem Detailed Trade Studies
7. **Resource Margins and Schedule**

Technical Resource Margins Summary

- Technical resource margins tracked by mission phase per JPL principles
- All margins are consistent with requirements at MSR except:
  - Mass (to be discussed)
  - Processor and S/W driven margins are TBD. Developing performance metrics to evaluate margins by mid-Phase A
  - ASIC/FPGA gate margins: TBD
    - Will be specified as a function of component design phase not project phase
- Science data volume
  - Allocating 1200 Mbytes for telemetry and/or data for on-board processing
  - Provides 12 days of data storage and will not be tracked
- Propellant loads based on maximum mass allocations and 3 sigma statistics (traditional approach)

Resource Summary Margin Table

Mars Science Laboratory

\ Epoch\ Parameter	Current	MSR	PDR	CDR	ATLO	Launch	Mars Arrival
Launch mass (%)	21	30	20	10	5	1	0
Entry mass (%)	21	30	20	10	5	1	0
Landed mass (%)	21	30	20	10	5	1	0
Landed CPU cycle (%)	>75	75	75	60	40	20	10
Cruise/EDL CPU cycles (%)	TBD	75	75	60	40	20	10
1553 Data bus capacity (%)	TBD	75	75	60	40	20	10
Processor memory: FSW prog. (includes buffers, tables, etc.) (%)	TBD	75	75	60	40	20	10
Mass memory (FSW image) (%)	>75	75	75	60	40	20	10
Power dist. & pyro relays (%)	>30	30	30	20	5	0	0
Solar array margin as Mars (%)	52	30	20	15	10	10	5
Battery margin above design depth of discharge during launch phase	55	40	40	20	20	10	NA
Thermal Battery margin during EDL	>50	40	40	20	20	10	10
Energy margin during surface operations	44	40	40	30	20	10	10
Deep space telecom link (db)	>6	6	4	3	3	3	1
UHF telecom link (db)	>10	10	10	10	10	10	5

Flight Rover Comparisons

	Sojourner	MER	MSL
Launch Year	1996	2003	2009
Rover Mass (including payload)	10.6* kg	180 kg	900 kg
Rover Power	50 Wh/sol	600 Wh/sol	5000 Wh/sol
Compute power	.25 MIP	20 MIP	>200 MIP
Rover Life	>90 sols (actual)	90 sols	670 sols
Nom. Data Volume/Sol	40 Mbits (70m)	40 Mbits (34m)	>1000 Mbits (34m)

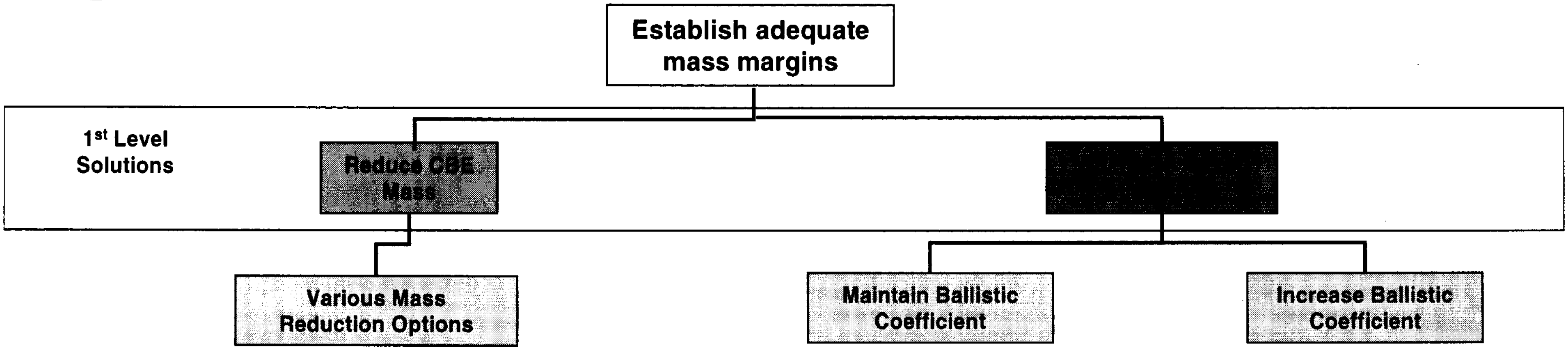
Preliminary Mass Summary and Margins

- Based on a very detailed mass equipment list, using rough initial estimates and detailed sizings of concept designs where time has allowed, the mass margins for CEDL and surface system are lower than desired per JPL principles (Guideline is 30% at MSR)
  - CEDL margin (~400 kg) is 21%
  - Surface system margin (190 kg) is 21%
- The following activities are on-going to improve the mass margins
  - Improve accuracy of mass estimates including preliminary designs and structural sizings
  - Evaluate design options to reduce size and mass
  - Increase entry mass allocation by:
    - Increasing drag area without increasing beta, and/or
    - Increasing beta and improving EDL element performance
- Project expectation is to meet agreed-to mass margin requirements by MSR

Preliminary Mass Summary and Margins Options

	CBE	CBE Margins	Mass Reductions	Mass Reduced Margins	Fixed Beta	Fixed Beta Margins	Increase Beta	Adjusted Beta Margins
Surface System	710		685		685		685	
Margin	190		215		365		365	
Surface System Allocation	900	21%	900	24%	1050	35%	1050	35%
Descent Stage	425		395		395		395	
Aeroshell/Parachute	501		471		543		471	
Propellant	262		262		262		262	
Entry Margin (Dry)	312		372		625		697	
Entry Allocation	1500	21%	1500	25%	1825	34%	1825	38%
Cruise Stage	224		224		224		224	
Propellant	95		95		95		95	
Cruise Stage Margin	81		81		106		106	
Cruise Allocation	400	20%	400	20%	425	25%	425	25%
Launch Total	2800	21%	2800	24%	3300	33%	3300	35%

Mass Margin Option Space



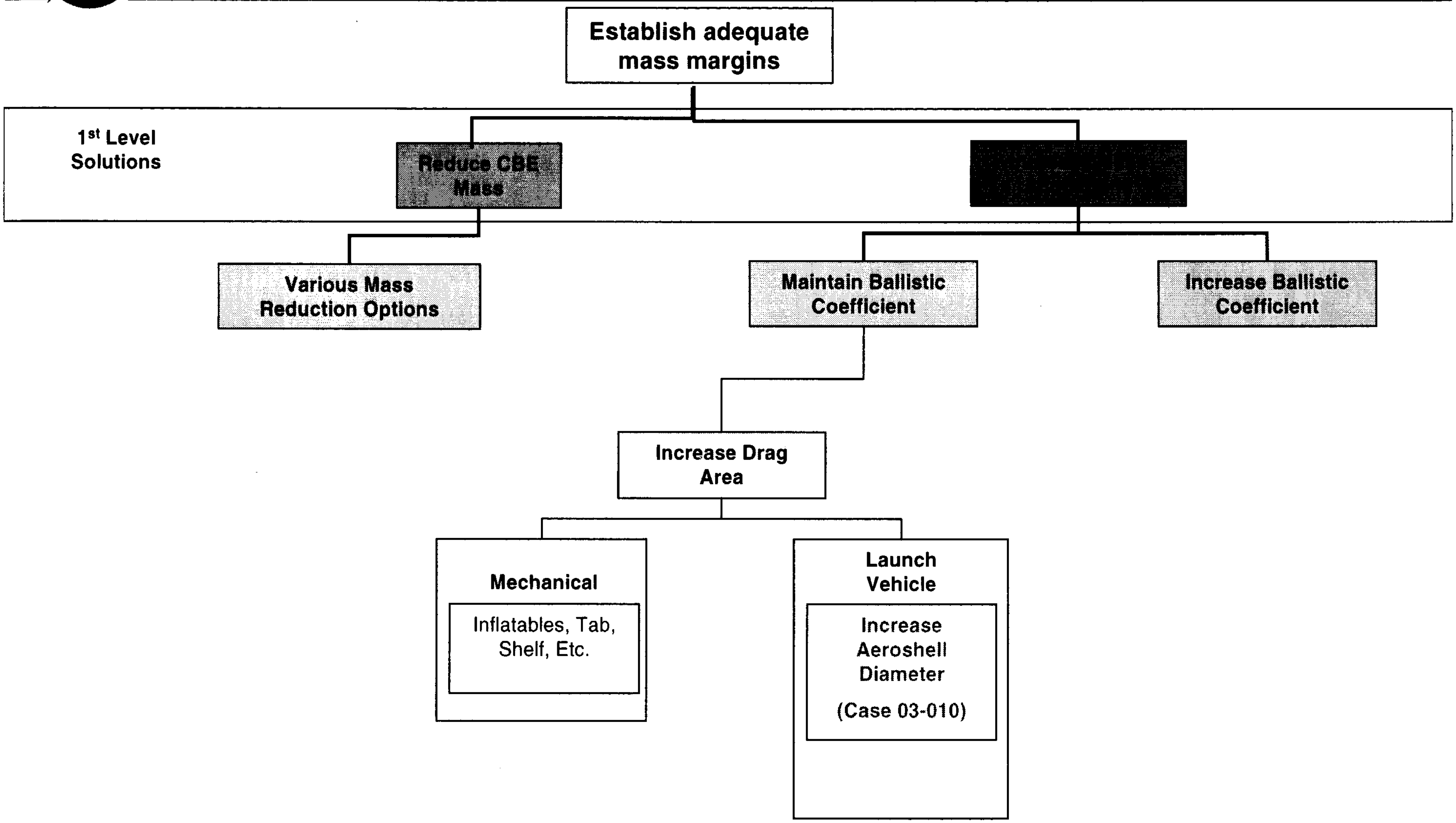
Mass Margin: Reduce CBE

Establish adequate mass margins

1st Level Solutions

- **Reduce CBE Mass**
  - **Various Mass Reduction Options**
    - **Mechanical**
      - Reduce Ballast
      - Composite Members
      - Snubbers to Reduce Aeroshell Entry Loading
      - Panel Design on Descent Stage
      - Optimize PSS/Descent Stage Load Paths
      - Support Backshell Loads with Descent Stage
      - Smart NSIs (reduce cabling)
    - **Prop**
      - Fewer, Larger Pressurant Tanks
      - More Mass Efficient Pressurant Tanks
      - Remove Engine Isolation Pyro Valves
    - **Parachute**
      - Higher Subsonic Chute Cd (Smaller Chute)
- [redacted]
  - **Maintain Ballistic Coefficient**
  - **Increase Ballistic Coefficient**

Mass Margins: Maintain Ballistic Coefficient

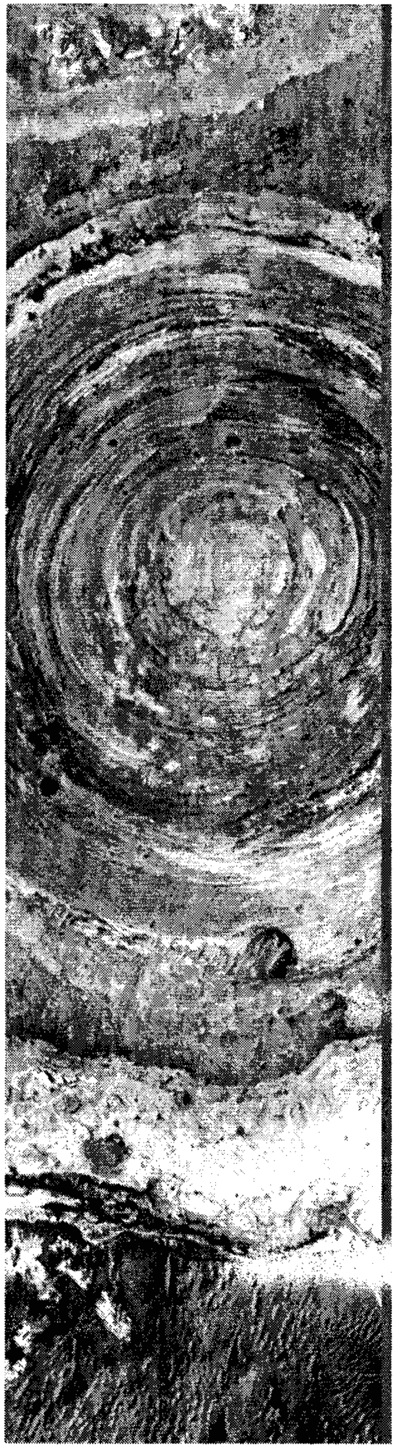


Mass Margin: Increase Ballistic Coefficient

- **Establish adequate mass margins**
  - *1st Level Solutions:*
  - **Reduce CBE Mass**
    - **Various Mass Reduction Options**
  - [redacted]
    - **Maintain Ballistic Coefficient**
    - **Increase Ballistic Coefficient**
      - **Maintain Margins/Capability**
        - **Parachute**
          - Increase Subsonic Chute Size
          - Expand Supersonic Chute Box
        - **Prop**
          - Increase Thrust Capability
          - Carry More Propellant
          - Reduce Engine Cant
          - Reduce Flyaway Distance
        - **GNC**
          - Optimize Sky Crane Profile
          - Reduce Thrust Margin
          - Improve Nav/Late Maneuver
        - **Mechanical**
          - Tolerate Higher Max TD Velocity
          - Variable Speed DRL
      - **Increase L/D**
        - **Higher L/D**
          - Cant Supersonic Chute for Deploy
          - Use RCS for Chute Deploy Attitude/Lifting
          - Variable / Articulated Ballast
        - **Mechanical**
          - **Additional CG offset (Case 03-011)**
          - Deployable Forebody Extensions

Summary

- MSL reference design arrived at after a wide and comprehensive set of trade studies
- MSL flight system reference design meets currently recognized mission and science objectives
- Preliminary system and subsystem designs are consistent with technical resource margin requirements except mass which is being worked aggressively
- Close coupling with the Mars Focused Technology program is helping mitigate technical risk areas including throttled engine, terminal descent/touchdown, actuators, sample acquisition and processing, and software
- Additional trade studies and design tasks have been identified and planned for Phase A
- State of flight system design is well ahead of most (any) projects entering phase A



Mars Science Laboratory
Mission Concept Review

Planetary Protection Plan and Status

Brian Muirhead

October 28-29, 2003

Program Perspective on Planetary Protection

- The Mars program scientific strategy is to "follow the water"
- Recent discoveries by Odyssey make it clear that water ice may exist over a significant portion of the Martian subsurface/surface
- The Mars program aims to have its assets operate for much longer periods on Mars, which implies the usage of radioisotope power sources in the range of 10-100's w
- The presence of an RPS complicates the planetary protection picture due to the possibility that, if crashed, such a perennial heat source could create a liquid water environment for some TBD period
- The above facts represent a challenge for the Mars Program, not unique to MSL
- MSL is pathfinding this issue within the program
  - While Viking also carried a radioisotope source, their level of bio-cleanliness was driven by their search for extant life
  - While sterilization is necessary for missions looking for extant life, there needs to be alternative options for missions with different scientific goals

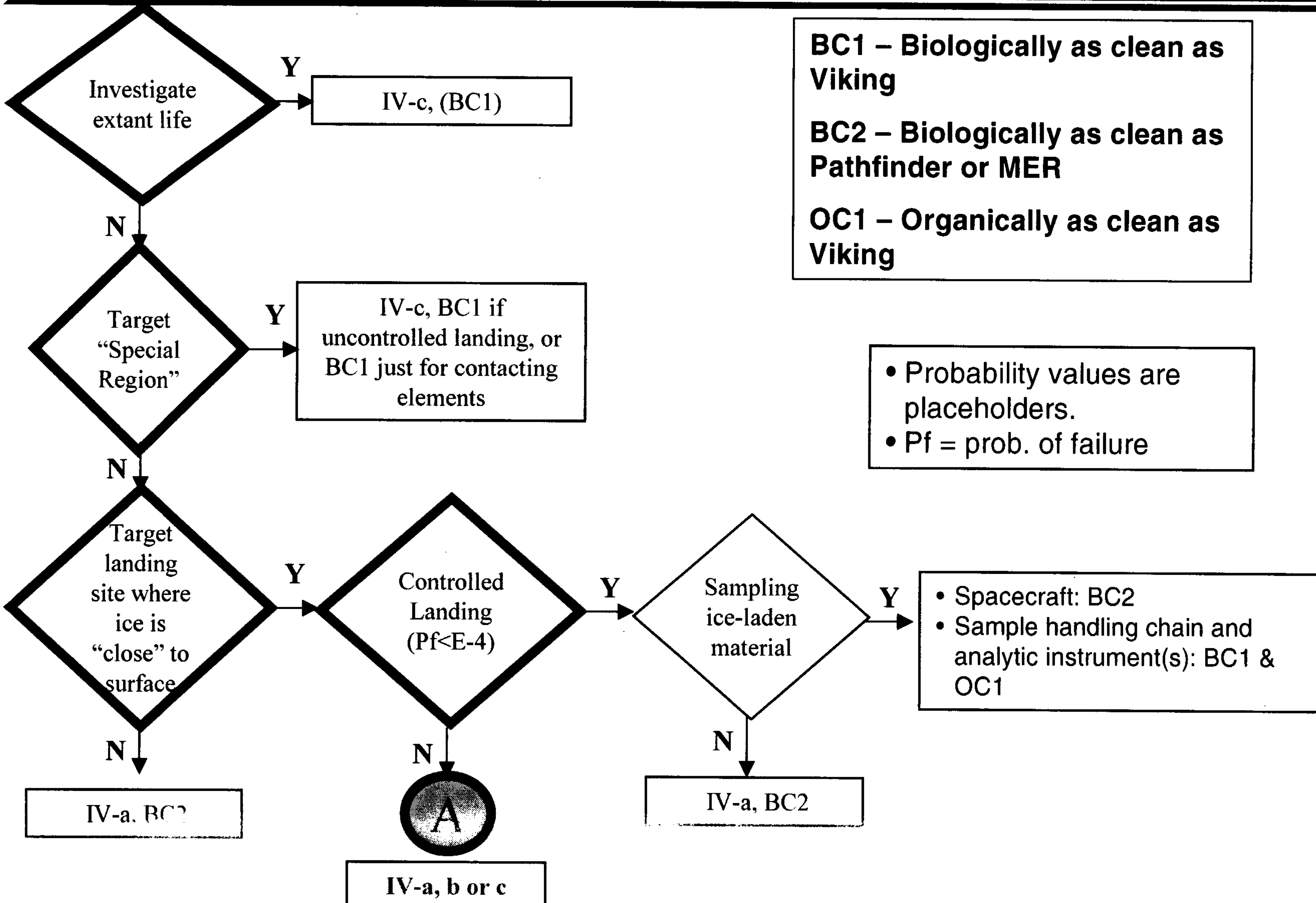
Planetary Protection Baseline

- Project has gone forward, for the purpose of its pre-phase A costing, under the assumption that we are a IV-c mission (same as Phoenix)
  - MSL is not carrying instruments for the investigation of extant life
  - MSL is not targeting a "special region" (Cospar, 10/20/02 policy definition)
  - MSL expected science objectives will require an organically clean sample handling and analysis chain that will be sterile by definition and could sample water ice if encountered
- Major issues associated with IV-c categorization include:
  - Must deal with an "off-nominal" landing with a "perennial heat source" which could create region of liquid water if heat source is buried in an icy region
  - Landing or operating in a region where water ice is present (surface or subsurface) and, possibly, handling samples with ice in them
  - MSL plans to address these issues through engineering analysis and design which will be documented in the Project's PP plan and white paper
- Technology Program contribution: ($2.2M)
  - Rapid assay process (4 hrs instead of 3 days)
  - Development of techniques for achieving and maintaining organic cleanliness for sample handling chain

COSPAR PP Policy Oct 20, 2002

- IV-a: For lander systems not carrying instruments for investigations of extant Martian Life
- IV-b: For lander systems designed to investigate extant Martian life
  - Entire landed system must be sterilized at least to Viking post sterilization biological burden levels, or to levels of biological burden driven by the particular life-detection experiments, whichever is more stringent
  - Subsystems which are involved in the acquisition, delivery and analysis of samples used for life detection must be sterilized and a method of preventing recontamination is in place
- IV-c: For missions which investigate "special regions" even if they do not include life detection experiments, all the requirements of IV-a applyalong with:
  - Definition of "special region": A region where terrestrial organisms are likely to propagate OR a region which is interpreted to have a high potential for the existence of extant life forms
  - CASE 1: If the landing site is within the special region the entire landed system shall be sterilized to at least Viking post-sterilization levels
  - CASE 2: If the special region is accessed through mobility, either the entire landed system shall be sterilized to Viking post-sterilization level OR the subsystems which directly contact the special region shall be sterilized to these levels and a method of preventing their recontamination prior to accessing the special region shall be provided
  - If an off-nominal condition (such as a hard landing) would cause a high probability of inadvertent biological contamination of the special region by the S/C, the entire landed system must be sterilized to the Viking post-sterilization levels

MSL PP Decision Tree



BC1 – Biologically as clean as Viking

BC2 – Biologically as clean as Pathfinder or MER

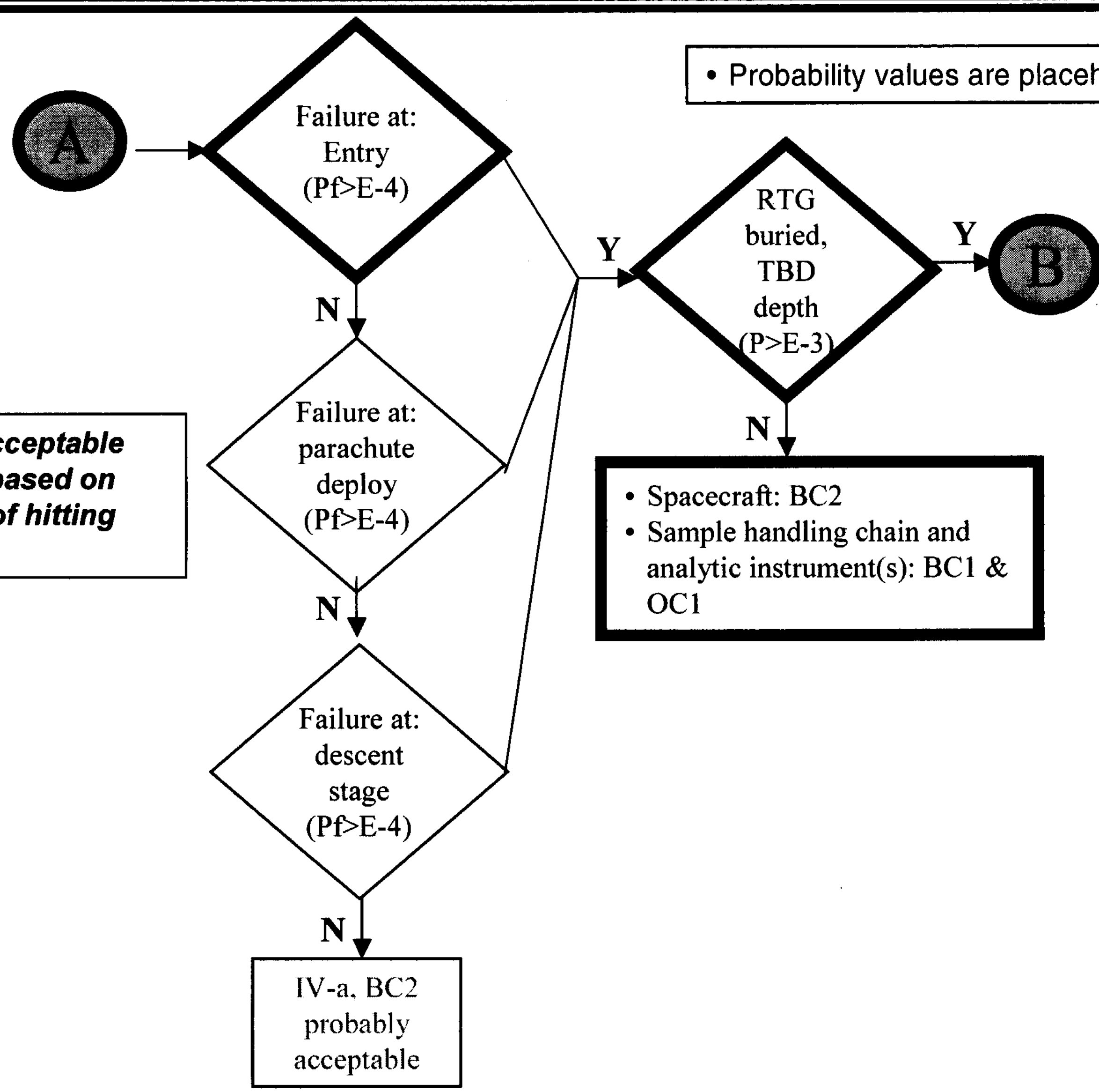
OC1 – Organically as clean as Viking

- Probability values are placeholders.
- Pf = prob. of failure

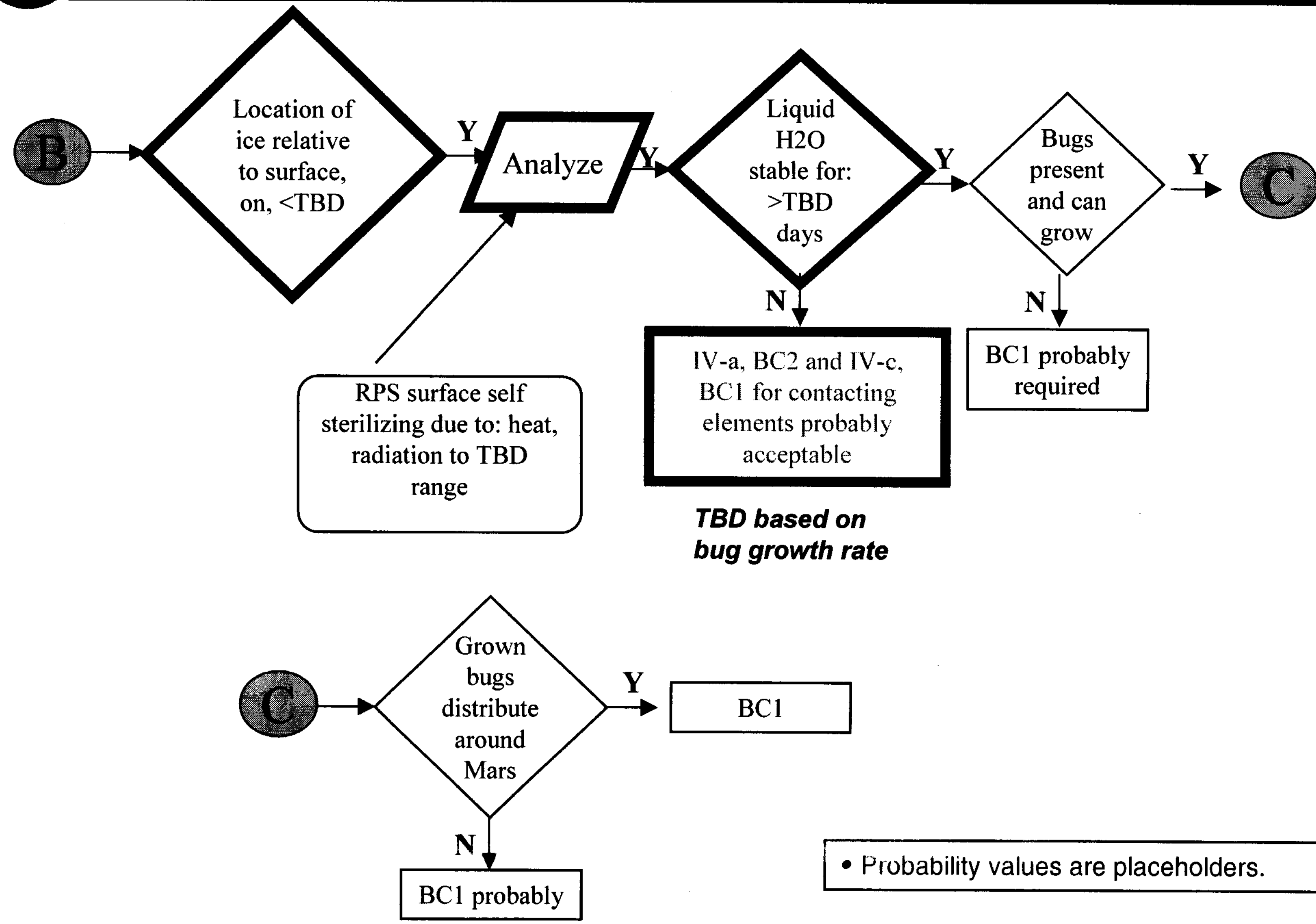
PP Decision Tree (cont'd)

- Probability values are placeholders.

Probability of acceptable failure at entry based on L/V probability of hitting Mars: 10E-4



PP Decision Tree (cont'd)



- Probability values are placeholders.

Near-Term PP Work Plan

- Entry breakup experts to define and characterize scenarios for the conditions of impact on Mars due to failures on approach and during EDL. Develop representative "worst case(s)" from the point of view of creating an environment where the perennial heat source is buried and how deep
- Status:
  - Initial worst case scenarios have been identified
  - First round of analysis completed on conditions of RPS after break-up
  - Performing continued analysis of high altitude breakup, including assessment of other high beta assemblies, and distribution of material along track, including time history of trajectory
  - Researching DOE/DOD experience with bodies impacting various terrains to understand breakup and cratering of RTG and GPHS bricks
  - Evaluating likelihood of bugs surviving on the surface of an RTG after the break event

Near-Term PP Work Plan (cont'd)

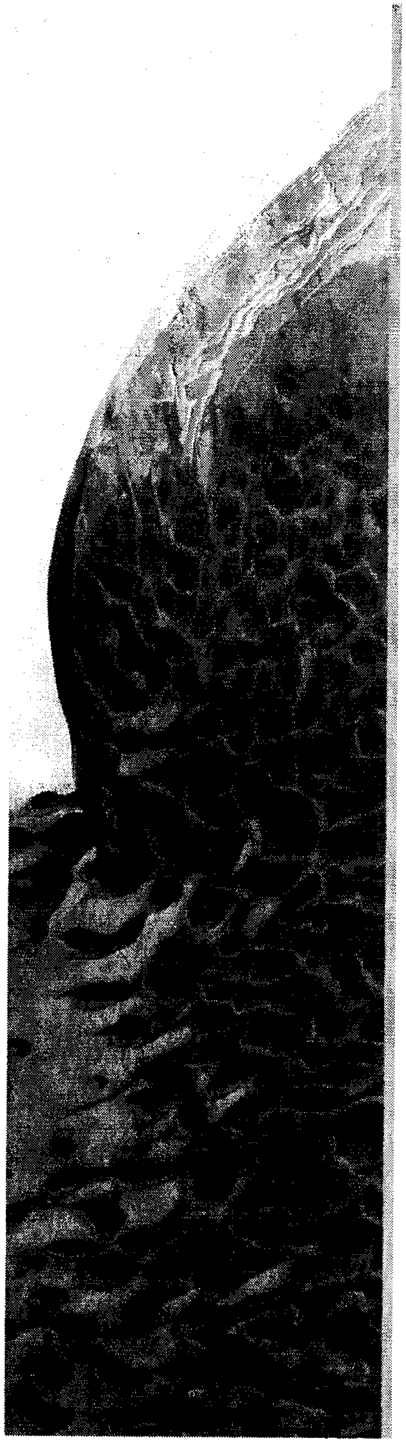
- Conducting analyses of a crash landing with RTG(s), to evaluate potential for creating a "special region within which terrestrial organisms are likely to propagate"
  - Status:
    - Preliminary analyses of various scenarios based on fundamental physics and conservative properties of Martian soils has been completed
    - Additional analysis are being performed including assessment of GPHS modules and RTG on pure ice
- Develop design and techniques to achieve an expected high level of organic cleanliness for the sample contacting elements of the sample handling/processing chain. The design to preclude recontamination
  - Studying cleaning and cleanliness maintenance techniques that could meet a TBD (representative value: 10E- 9 g/cm*2, final level will be a function of actual instruments selected and operational scenarios) cleanliness requirement(s) will be conducted
  - Status:
    - New plan under review for Mars Focused Technology PP task to develop and prove cleaning techniques to achieve cleanliness needed

Near-Term PP Work Plan (cont'd)

- **Perform an initial assessment of technical risks and costs of applying dry heat microbial reduction (DHMR) conditions to all flight hardware at the box and/or system level. A listing of acceptability, issues and programmatic considerations will be prepared**
  - Each element in the project equipment list being assessed for compatibility with the DHMR environment
  - Elements that have issues (e.g. nylon seal in Ni/H2 battery, RPS) are being assessed for design and cost impact
  - Design and test activities associated with achieving/validating all elements and the system under DHMR conditions are being listed and are being ROM costed
  - Capture all possible cost elements and estimate costs (where possible) for various options of assembly bakeout, system bakeout, bio-bag, integrated cooling systems for those items that cannot tolerate DHMR, etc.
  - Status:
    - Preliminary technical risk assessment report is in draft form

Near-Term PP Work Plan (cont'd)

- **Develop preliminary bug budget. MSL has much more surface area and enclosed volume than MER/MPF and therefore, will need better cleaning/control techniques than past missions**
  - Status:
    - Preliminary list with big hitters prepared
  - Prepare a white paper documenting the mission and its justification for a preliminary PP categorization, including
  - Paper (planned for delivery to PP Officer in January 2004) will include the results of all the above analyses
  - At the time the AO goes out, the Project's position will be known but the PP Officer's position may not be known. NASA will make a determination as to the language pertaining to PP
  - Involving Ben Clark (LMA) and Chris McKay (ARC) to assess whether we're on the right track



Mars Science Laboratory

Mission Concept Review

Mission Systems and Flight Software Office

Charles Whetsel

October 28-29, 2003

Discussion Topics

- **Organization Charter and Structure**
- Key Driving Requirements
- Mission Concept Response to Key Challenges
  - Launch/Arrival Strategy for EDL Coverage Across Required Latitudes
  - Precision Arrival Navigation Strategy Across Required Latitudes
  - Effective Long-duration Surface Mission Operations
- Project Software Response to Key Challenges
  - Software Development Approach
  - Ground System Concept
  - Model & Simulation-based Lifecycle Validation Approach
- Summary

Mars Science Laboratory Org (670)

Project Manager – M. Sander
Project Scientist – F. Palluconi
Chief Engineer(Ph A) – B. Muirhead
Project Business Manager – A. Green

Business Office – A. Green
- PRA – L. Ramsay
- Project Acquisition Manager – P. Easter
- Scheduler – S. Gillespie

Project Engineering Office
J. Baker (Acting)

MAM – J. Newell
Safety – TBD

Tech. Mgr. – G. Udomkesmalee

Partners
- KSC – A. Sierra
- DoE – R. Wiley
- LaRC – M. Lockwood
- ARC (EDL)
- ARC (IT) – M. Drummond
- JSC – C. Graves

Science Office
F. Palluconi
Deputy-TBD

Mission Systems and Flight Software Office
C. Whetsel (acting)
Deputy- A. Sacks (acting)

Functional responsibilities:
- Mission Sys. Engr.
- Mission & Nav. Planning and Design
- Mission Ops. Sys. Design
- Flight, Ground, and Simulation S/W Development
- Guidance, Nav., and Mobility Controls
- Technology Tasks Oversight

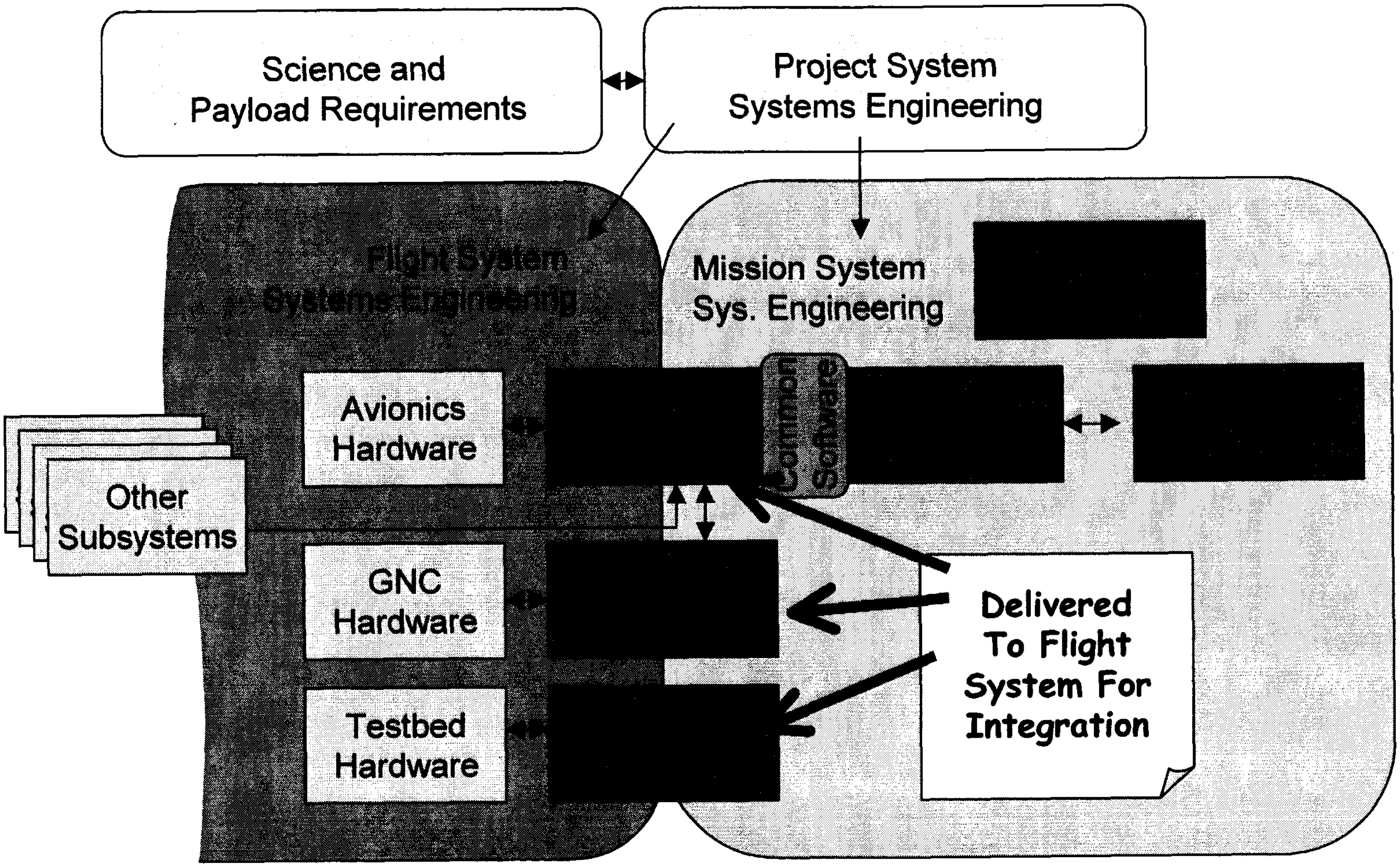
Flight Systems Office – B. Muirhead (acting)
End-to-end life cycle V & V – D. Woerner

Payload & Engineering Sensors
J. Simmonds

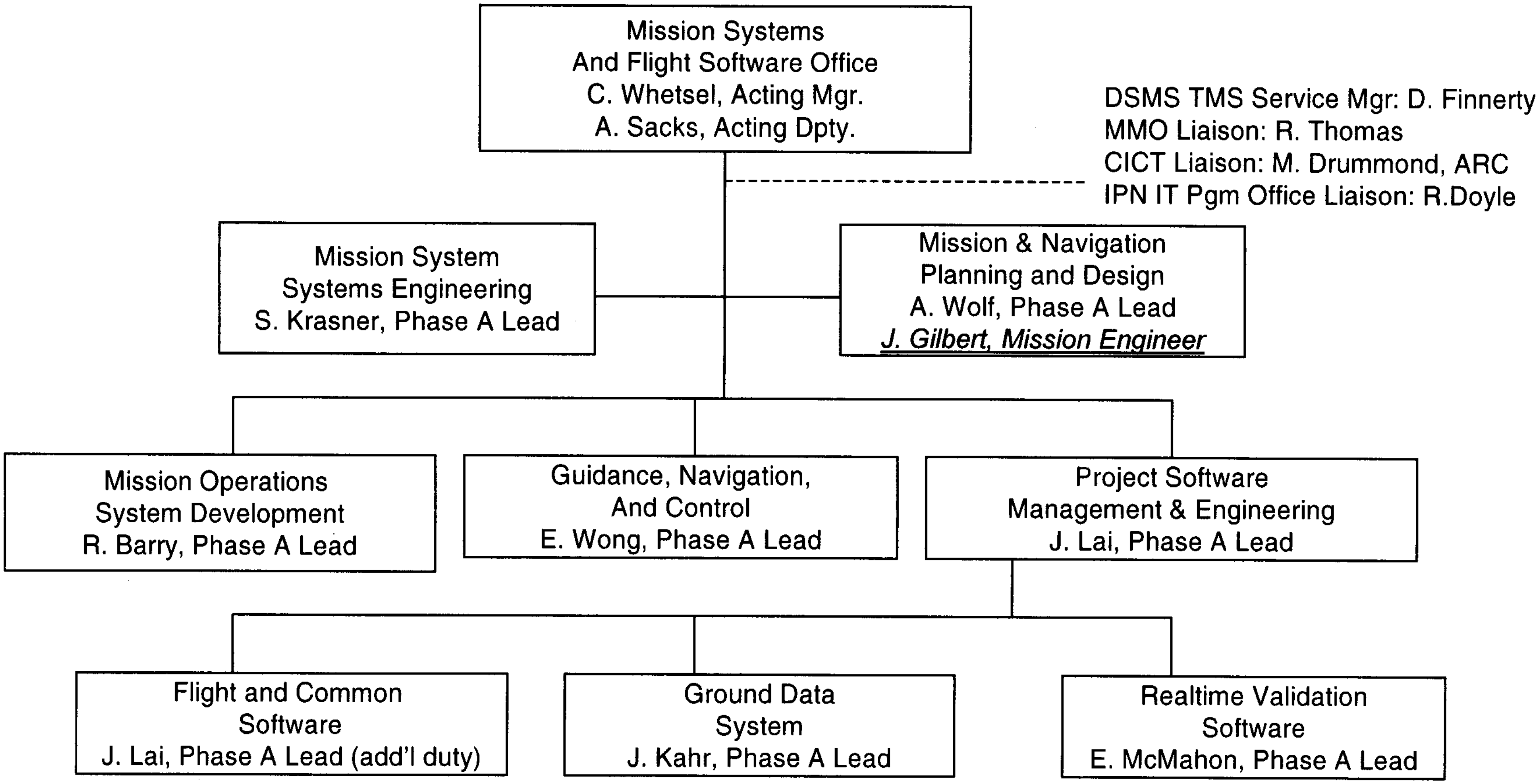
MSFSO Office Scope

- Develop **Mission Design and Mission Plan** for MSL Mission
- Deliver the **Mission Operations System**
- Deliver **Guidance, Navigation and Controls** and **Mobility Controls** System Engineering, Algorithms, and Integration to Flight System
- Deliver the Integrated **Project Software** System
  - **Flight Software**, delivered to the Flight System for integration with Flight Hardware
  - **Ground Data System**, delivered to ATLO and MOS for operations of spacecraft on Ground and in Flight
  - **Testbed, Simulation, and Ground Support Equipment (TSG) Software**, delivered to Testbeds, ATLO, GSE and MOS Environments for Modeling and Simulation "Proving Ground"

MSFSO Functional Flow Representation



Phase A Core Team Leads



Discussion Topics

- Organization Charter and Structure
- **Key Driving Requirements**
- Mission Concept Response to Key Challenges
  - Launch/Arrival Strategy for EDL Coverage Across Required Latitudes
  - Precision Arrival Navigation Strategy Across Required Latitudes
  - Effective Long-duration Surface Mission Operations
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  - Software Development Approach
  - Ground System Concept
  - Model & Simulation-based Lifecycle Validation Approach
- Summary

Working Level 1 Requirements

- **Science mission needs**
  - Produce measurement types consistent with PSIG report
    - New generation analytical instruments
  - Landing site flexibility between 60 deg N and 60 deg S latitude
    - Choice may be made based on MRO data (later site selection)
  - Capable of landing at altitudes of up to 2.5 km
  - Capable of landing in a reduced size error ellipse (5 km x 10 km)
  - 28 samples (minimum) to 74 samples (baseline)
    - Implies 344 sol to 670 sol mission length
    - Implies 3 to 6 km traverse capability
- **Programmatic needs**
  - Target real year development cost: **870M**
  - Provide telemetry stream for diagnostics during EDL
  - Landing mass capability consistent with MSR needs
  - Demonstrate a hazard avoidance capability
  - Planetary protection
- **Key Assumptions**
  - Nuclear power available
  - Telecommunications satellite available

Mission System Key Drivers

Key Mission System Driving Requirements

- Cost Effective Long-duration Surface Operations
  - ***Flight and Ground System Operability at a premium***
  - ***Uplink process (including validation) is a driver, based on MER***
- Critical Event EDL Telemetry Coverage over a large range of arrival geometries (+60/-60 latitude)
- Highly Accurate Navigation Control and Knowledge at EDL over a wide range of latitudes (OD error ellipse polar vs. equatorial)
  - ***Tightly Integrated Navigation and Control System Design***
- Seasonal variations in visibility for Sun (illumination) and Earth (communications) across wide range of latitudes

Detailed responses follow

Discussion Topics

- Organization Charter and Structure
- Key Driving Requirements
- **Mission Concept Response to Key Challenges**
  - Launch/Arrival Strategy for EDL Coverage Across Required Latitudes
  - Precision Arrival Navigation Strategy Across Required Latitudes
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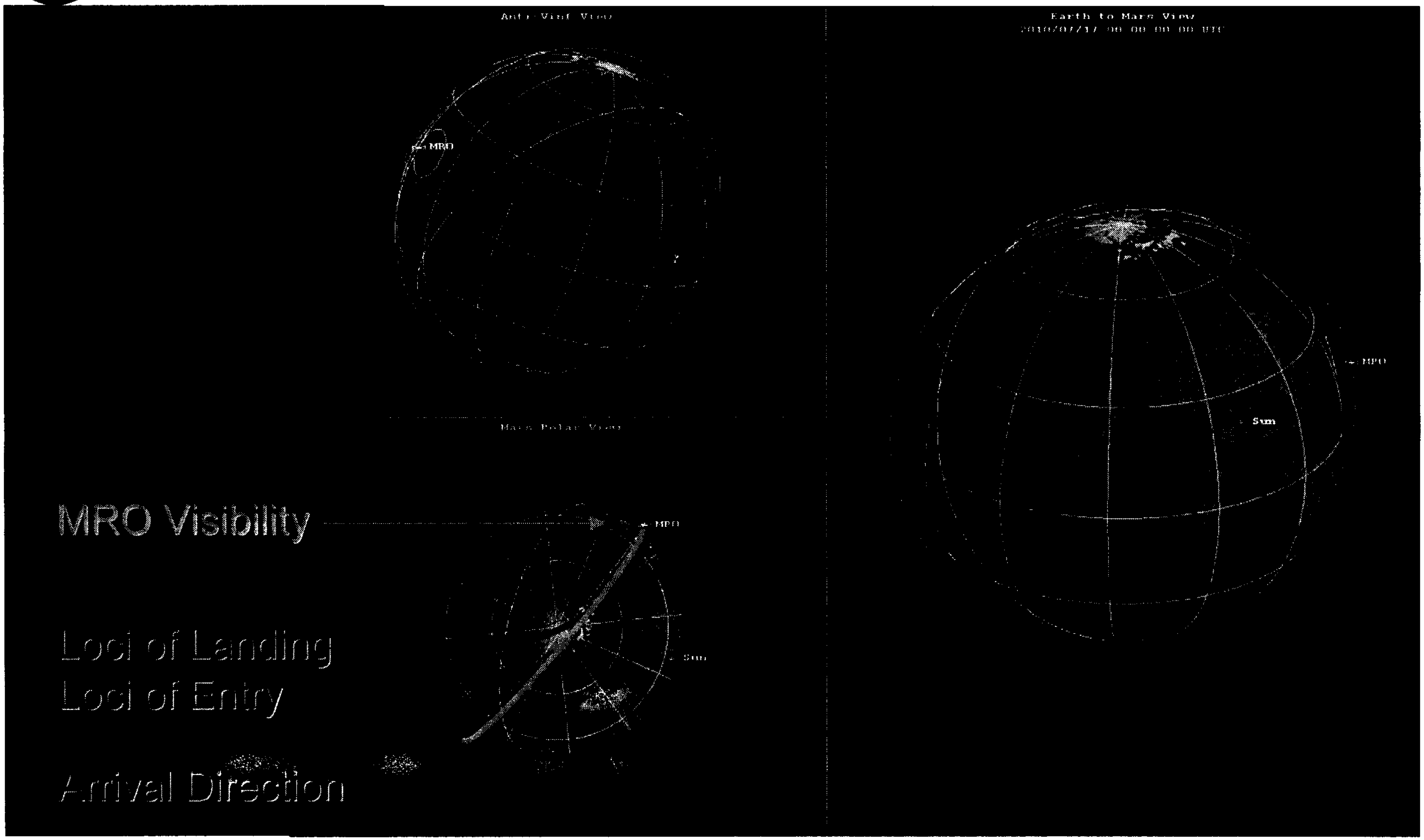
Communications During EDL

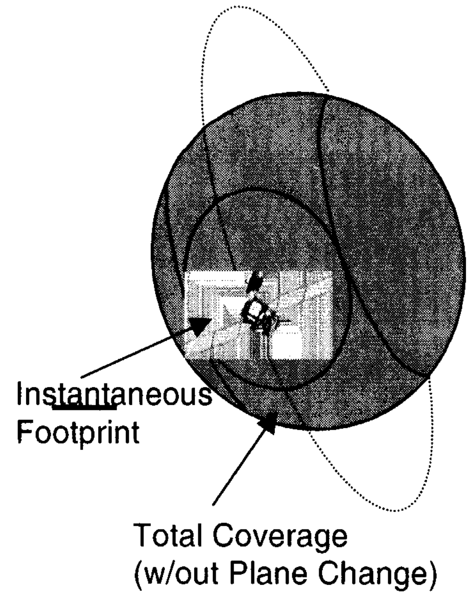
- Direct-to-Earth tones at X-band inadequate for propulsive terminal descent
- Low Science Orbiters (MRO, ODY, maybe MGS) unable to observe MSL entry over entire latitude range
  - Preliminary result: MRO feasible from -60 to Equator in current orbit
  - Requires variable MSL launch date as a function of latitude (selected L-1yr)
- Mars Telesat Orbiter likely to cover entire +60/-60 latitude range
  - Coordinated launch/arrival required for pad usage and MTO on-obit checkout at Mars
  - EDL data return over Latitude Range dependent on MTO
- Phase A work
  - Maximize range of latitudes for which back-ups to MTO are available
  - Assess implications to MSL, MTO, science orbiters, and launch providers of latitude-dependent variable launch dates selected after availability of MRO science data
  - Examine trades associated with "walking" MRO, ODY, MGS to cover MSL EDL

Science Orbiter Visibility of EDL

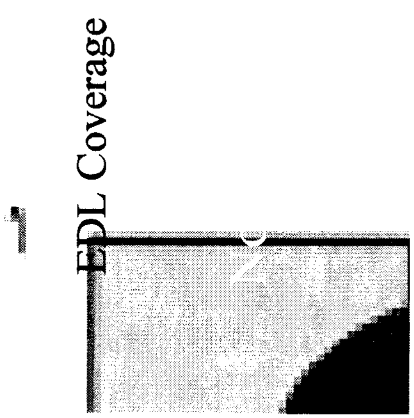


Telesat Visibility of EDL

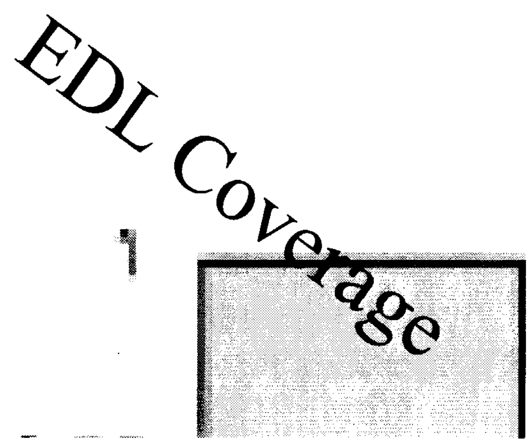
- Higher Telesat Orbit provides intrinsically **wider visibility** over a **variety of arrival geometries**



MRO Coverage
(Representative)



MTO Coverage
(Representative)



Red areas indicate regions in a Mars-centered, sun-fixed reference frame, for which no critical event coverage can be supported; all points in the grey region can be viewed above 15 deg elevations with only an orbit phasing adjustment

Pad Constraints – MSL+ MTO Launch

- Arrivals to be constrained to allow 30 day MTO checkout prior to MSL arrival
- Launch dates must accommodate pad utilization timing constraints
- Current working understanding:
  - 2 Deltas => 23 days separation between MSL / MTO launches:
  - 14 workdays "contract" number (not met yet but promised by 2009)
  - 2 weekends = 4 days
  - RTG integration = 3 days
  - Margin = 2 days

  - 2 Atlases => 34 days separation between MSL / MTO launches:
  - 21 workdays "contract" number (not met yet but promised by 2009)
  - 4 weekends = 8 days
  - RTG integration = 3 days
  - Margin = 2 days

  - One Atlas/ one Delta => 7 days (range constraints only)

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Navigation Considerations

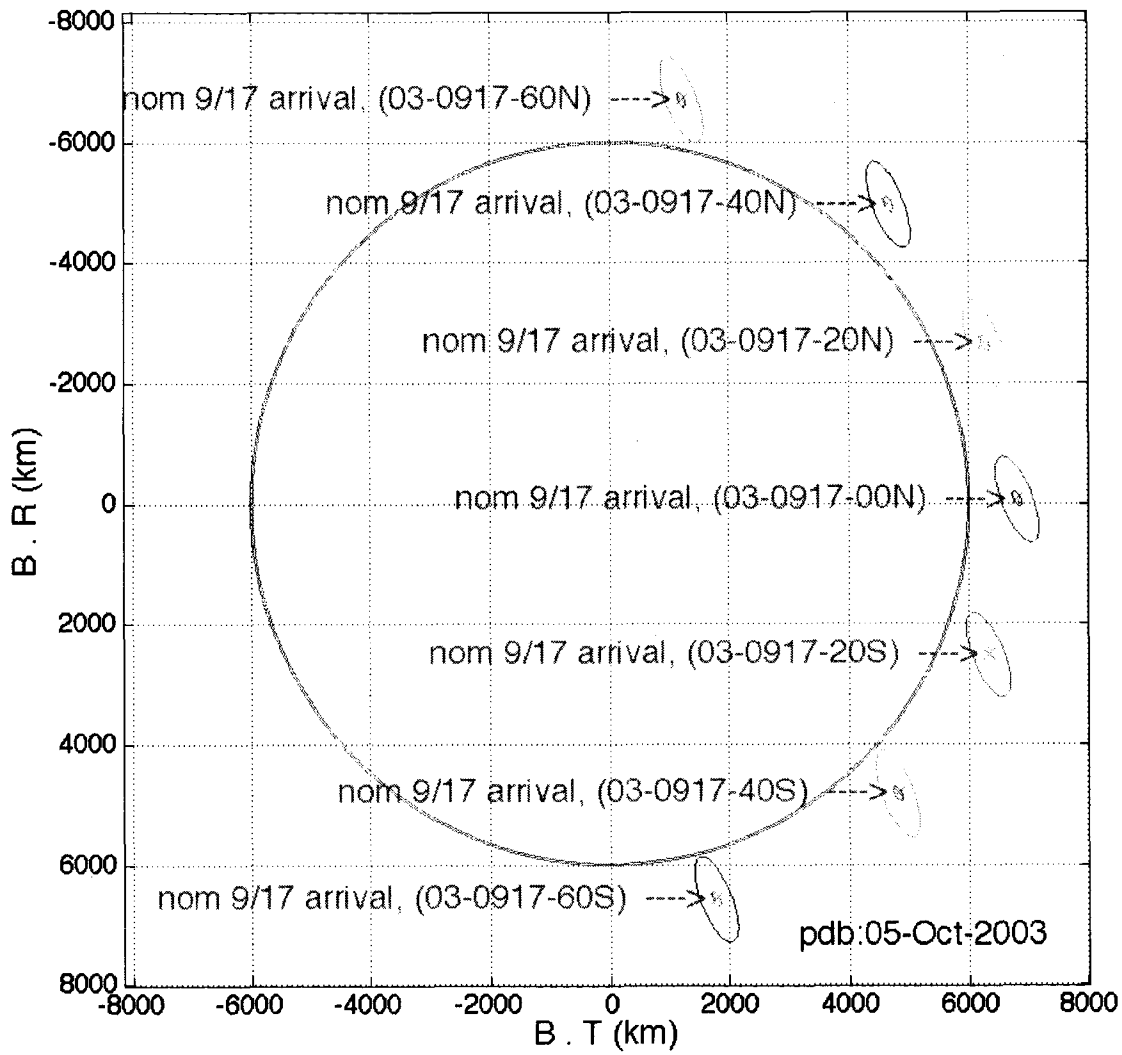
- Variably arrival geometries **creates** variable navigation accuracies **with radiometric approaches**

- Optical navigation minimizes and circularizes these errors
  - OpNav Camera developed by Mars Technology Program to be flight-validated on Mars Reconnaissance Orbiter mission

- Work in Phase A will finalize requirements on observational strategy
  - Includes trades between small forces effects of slewing between imaging and data return attitudes versus cost/mass implications of gimbaled camera (or antenna)

Variation in Entry FPA Uncertainty with Latitude

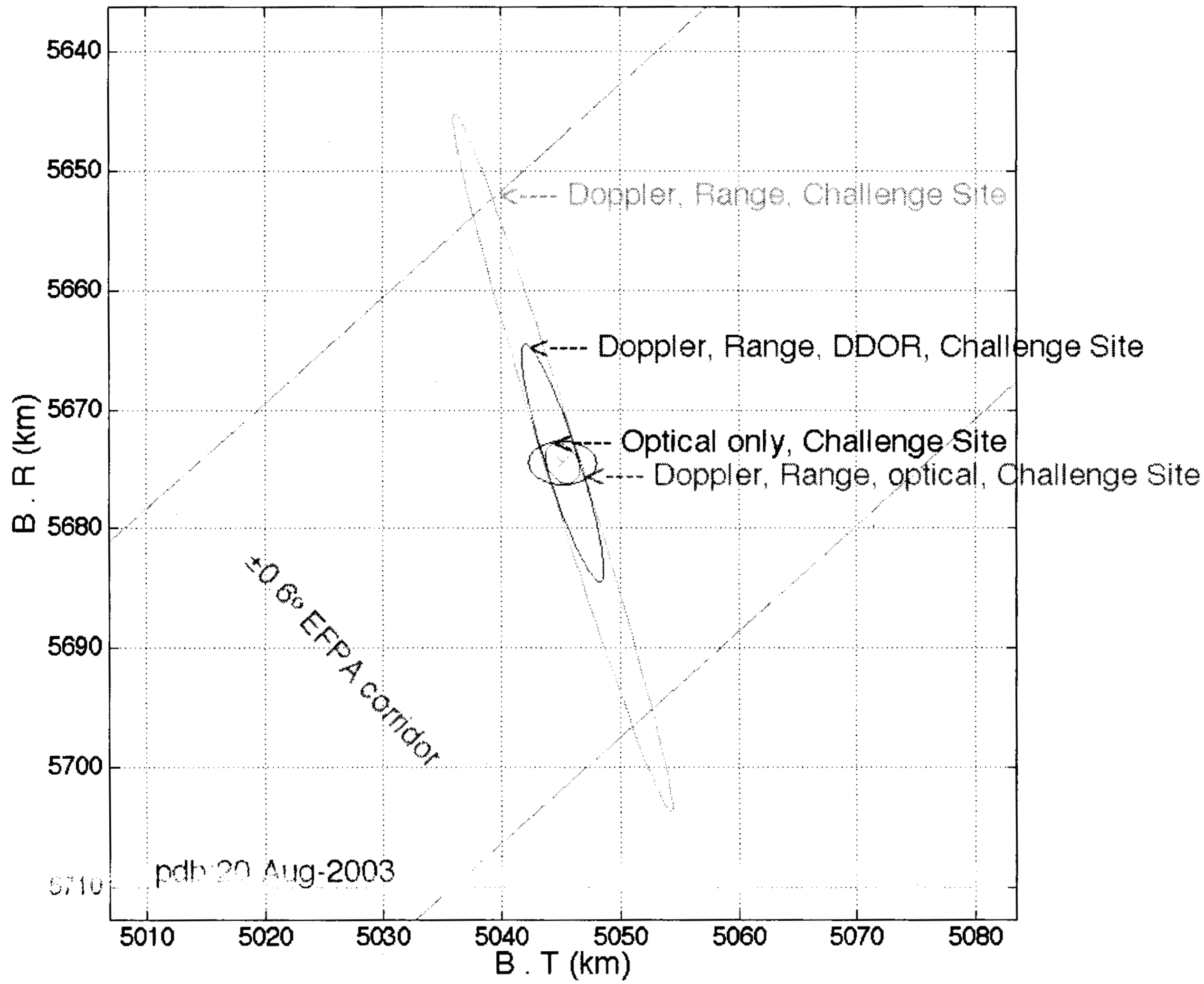
Doppler, Range, optical, 3σ Uncertainties at Encounter - MSL 2009



- Delivery (E-3d) and knowledge (E-18h) errors shown for each latitude
- Ellipse errors scaled by 250
- Mars-centered circle shown with R=6000km for illustrative purposes only
- Arrival errors mapped to the B-plane vary only slightly with latitude

OPNAV Significantly Reduces Entry Uncertainty (Sample Illustration)

E-18h 3σ Uncertainties at Encounter (EFPA=-14.4) - MSL 2009 Challenge Site



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MOS Historical Perspective

Challenges

- *Keep the rover safe*
- *Maximize rover usage for science and public*
- *Sustain operations in a cost effective manner*
- *Avoid 24 X 7 ops schedule*

*Historical Responses **

- Large flight team, co-located
- Complex, low level commanding, subsystem orientation (seq, tlm, fp, limited resources)
- Complex, lengthy uplink process, lots of realtime testbed utilization
- Low-fidelity ground model of flight capabilities, constraints

MSL Response

- **Build on MER and MPF experience**
- **Organize for a Long Duration MOS**
- **Integrated Software Architecture**
- **Capitalize on a Robust Rover**

***** Pathfinder, MER, Cassini, GLL**

Evolution of Surface Operations

Attribute	MER Capability	MSL Goal (Validate by PMSR)	Rationale
Mission Duration	90 days	687 days	Scientific Benefit
Principal Investigator Participation	Daily at JPL	Several times/week from home institution	Human Factors
Engineering Team Structure	Tactical: 1 downlink + 2 Uplink Shifts Strategic: Systems Only	Tactical: 1 downlink + 1 Uplink Strategic: Systems + Selected Subsystems	Cost/Human Factors
Uplink Generation and Validation	U/L: Low-level Cmds expanded from Activity Plan Val: Testbed+Rule Checking in Series	U/L: Activity Plan can be radiated Val: Simulation & Model-base validation in realtime during Activity Plan dev.	Cost/Human Factors (single-shift uplink)

Phase E Cost/Effectiveness Model

- ROM Cost Analysis performed, based on model created from current MER plan, with assumptions varied to explore sensitivities
- Preliminary Results – model to be validated by further study in Phase A

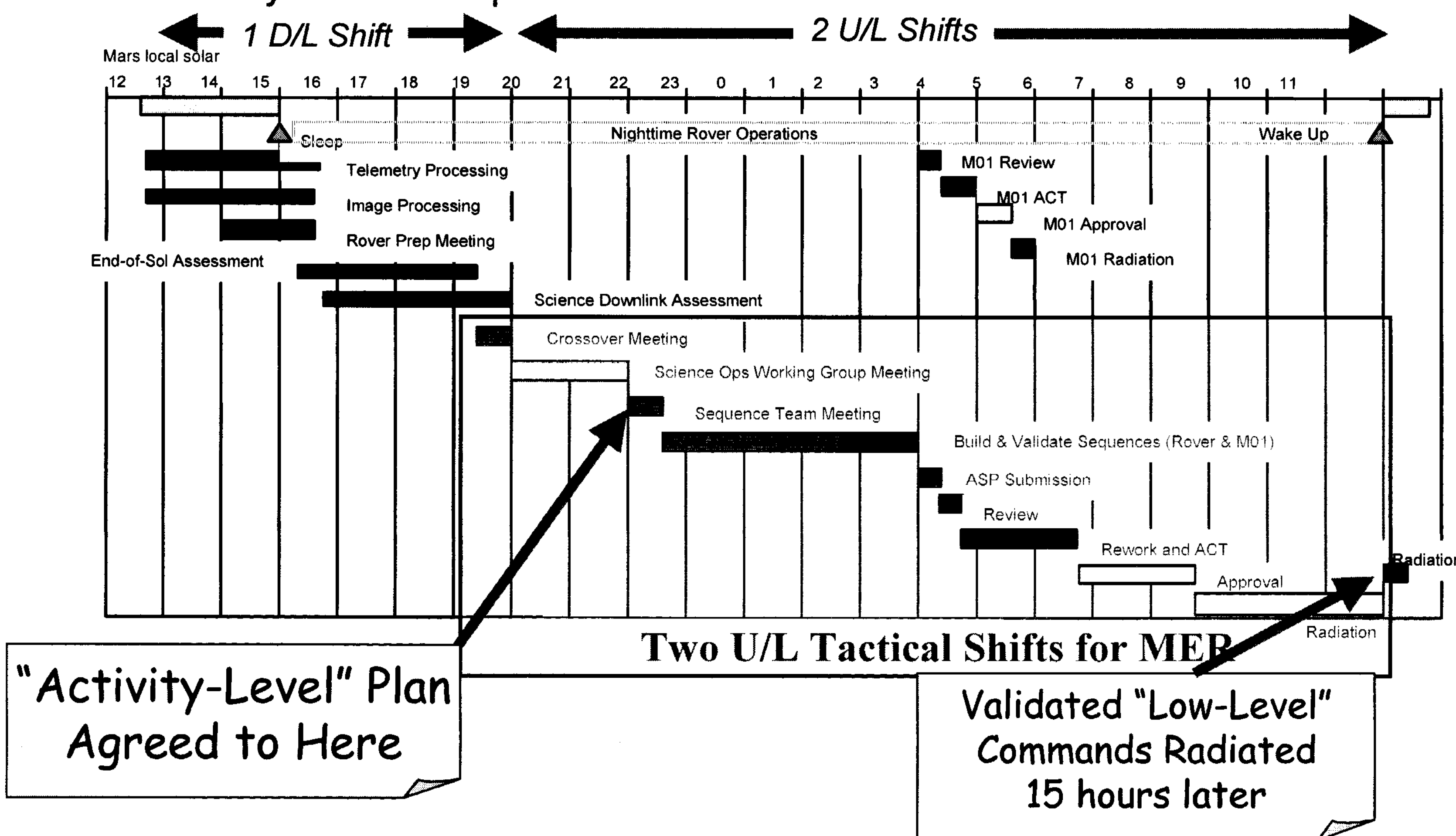
No. Rovers	Payload	No. U/L Shifts	Tactical S/S	Tactical Days/ Week	Annual Cost (FY'03 $'s)	MSL Msn Costs (RY$'s, w. 15% Reserves)
2	MER	2	100%	7	$52M/yr	*N/A*
1	-	-	-	-	$27M/yr	*N/A*
-	***MSL***	-	-	-	$35M/yr	$146M
-	-	***1***	-	-	$32M/yr	$134M
-	-	*2*	***50%***	-	$33M/yr	$138M
-	-	***1***	***50%***	-	$31M/yr	$129M
-	-	*2*	*100%*	***5***	$20M/yr	$83M
-	-	***1***	***50%***	***5***	$19M/yr	$79M

Working Target $115M (RY)

Notes:
1) "-" = Same as Above
2) MER Deferred Development (appr 80 WY) scrubbed from est
3) MSL Payload Assumed to be 2x complicated as MER
4) MSL Msn Costs based on 12 mos. Cruise + 687 days surface
5) Effects of lower science staffing in cruise not included

MER Tactical Turnaround – 3-Shifts/Day

- **Tactical planning templates**
  - 1-day MER template

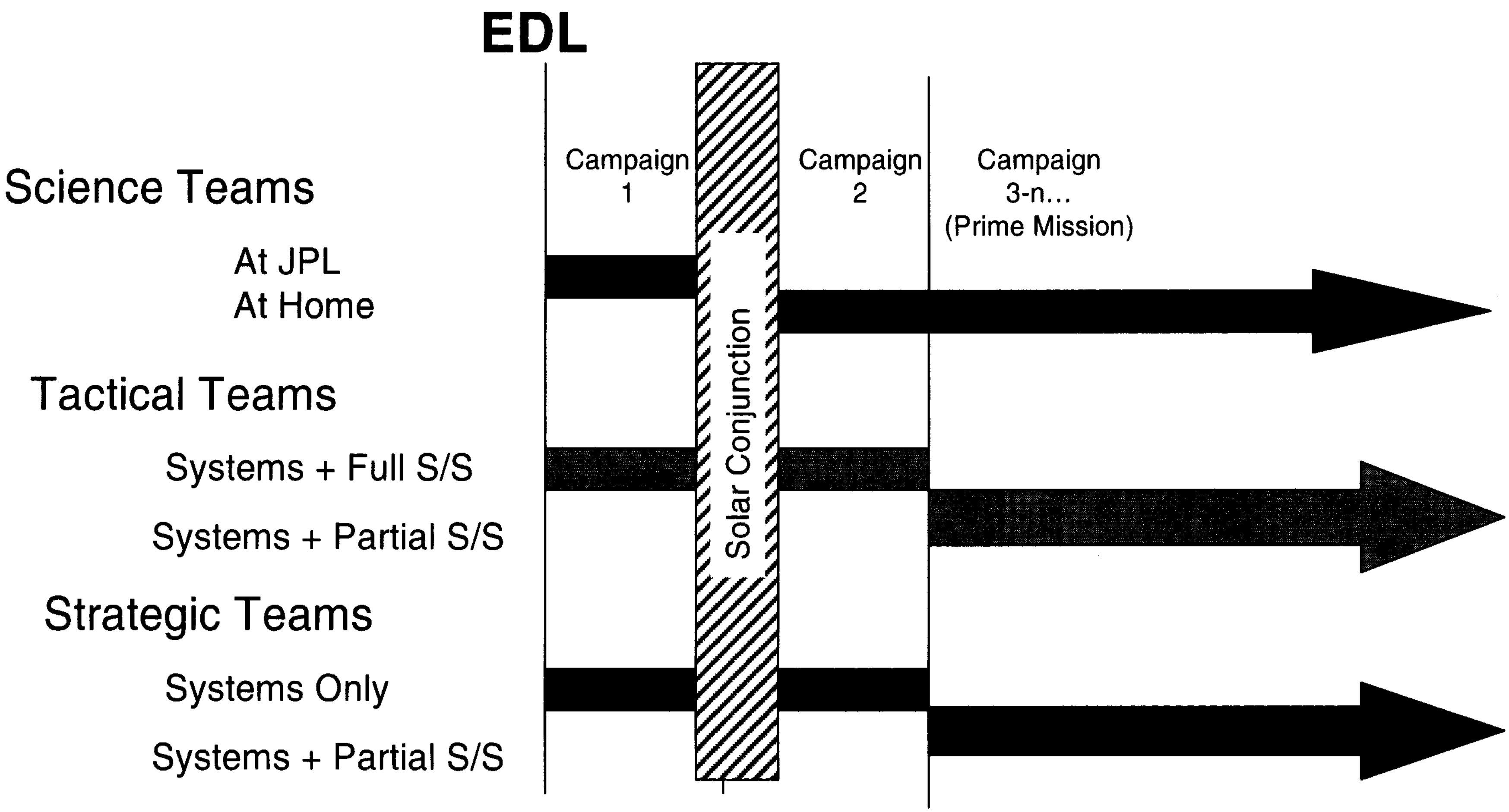


Evolution of Surface Operations

Attribute	MSL Campaign 1 (Commissioning)	MSL Campaign 2 (Transition)	MSL Prime Mission
Mission Duration	90[?] days	30[?] days	567 days
Principal Investigator Participation	Daily at JPL	Several times/week from home institution	Several times/week from home institution
Engineering Team Structure	Tactical: 1 downlink + 2 Uplink Shifts Strategic: Systems Only	No Change	Tactical: 1 downlink + 1 Uplink Strategic: Systems + Selected Subsystems
Uplink Generation and Validation	U/L: Low-level Cmds expanded from Activity Plan Val: Testbed+Rule Checking in Series	No Change	U/L: Activity Plan can be radiated Val: Simulation & Model-base validation in realtime during Activity Plan dev.

MSL Surface Operations Evolution

Mars Science Laboratory



Discussion Topics

- Organization Charter and Structure
- Key Driving Requirements
- Mission Concept Response to Key Challenges
  - Launch/Arrival Strategy for EDL Coverage Across Required Latitudes
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  - Software Development Approach
  - Ground System Concept
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Software Development Historical Perspective

*History**

- *Software Late*
- *Cost exceeds estimates*
- *Extended Development Cycles*
- *High Defect Rates*
- *Staff Overstressed*
- *Info System Defects In Mission Loss*

*Root Causes**

- Lack of S/W engineering
- Insufficient and late requirements
- Inadequate testbeds and test time
- Poor inheritance assumptions
- Lack of reusable code base
- Poor estimates
- Flight & Ground S/W not integrated
- Increasing complexity
- Development distributed across Lab

MSL Response

- **Structured Design & Process**
- **Integrated Software Architecture**
- **Early, Continuous Integration & Test In multiple environments**

New Software Approaches

State-Based Systems Engineering

What the S/W Must DO

Component-Based Software Engineering

What the S/W Must BE

- **State-based requirements capture methodology**
  - Minimize opportunity for miscommunication between programmers and systems/subsystem/science users

- **Component-based software architecture**
  - Move forward to modern software approaches to enforce logical and appropriate interconnections between software object (enforce units and types, timing and synchronization policies)

Discussion Topics

- Organization Charter and Structure
- Key Driving Requirements
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- Project Software Response to Key Challenges
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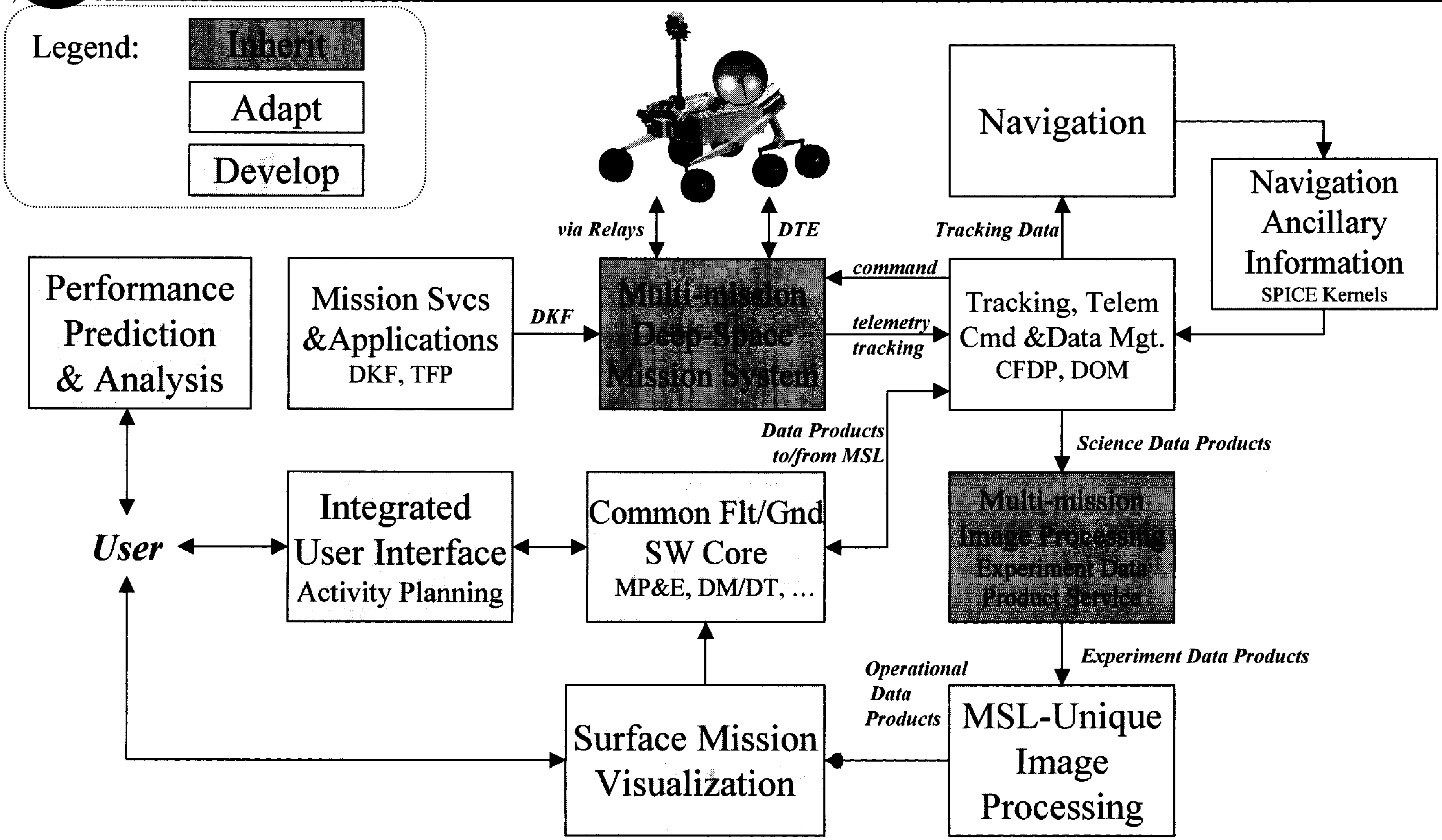
  - ⇨ **Ground System Concept**
  - Model & Simulation-based Lifecycle Validation Approach
- Summary

Ground System Concept

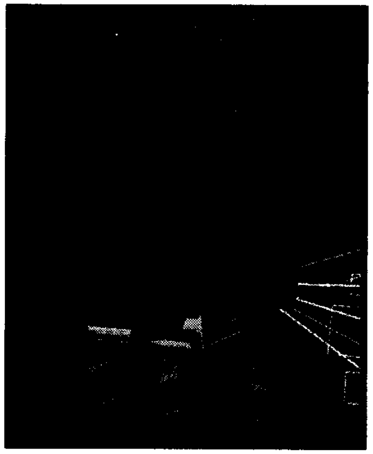
- Begin with MER functional mapping
- Simplify interface to users to allow streamlined operations
  - Activity planning
  - Performance prediction
  - Surface visualization
- Ground Core with high-fidelity commonality to flight software
- Leverage existing infrastructure
  - Data management
  - Image processing
  - Navigation

Ground Data System Concept



Validation Software Overview

- Models and simulations support validations throughout lifecycle
  - First, software against virtual ("idealized") hardware and environments
    - Referred to as "Functional Simulations"
  - Later, Software + Hardware against simulated environments
    - Add "Bit-level" interfaces to existing Functional Sims, when interface details are known
    - Including "Mixed-mode" operations, if required due to hardware availability (or for "virtual driving")
  - Finally, in flight operations, uplink products tested against validated models of flight system and environments



Validation Environment Allows Evolution Throughout Lifecycle

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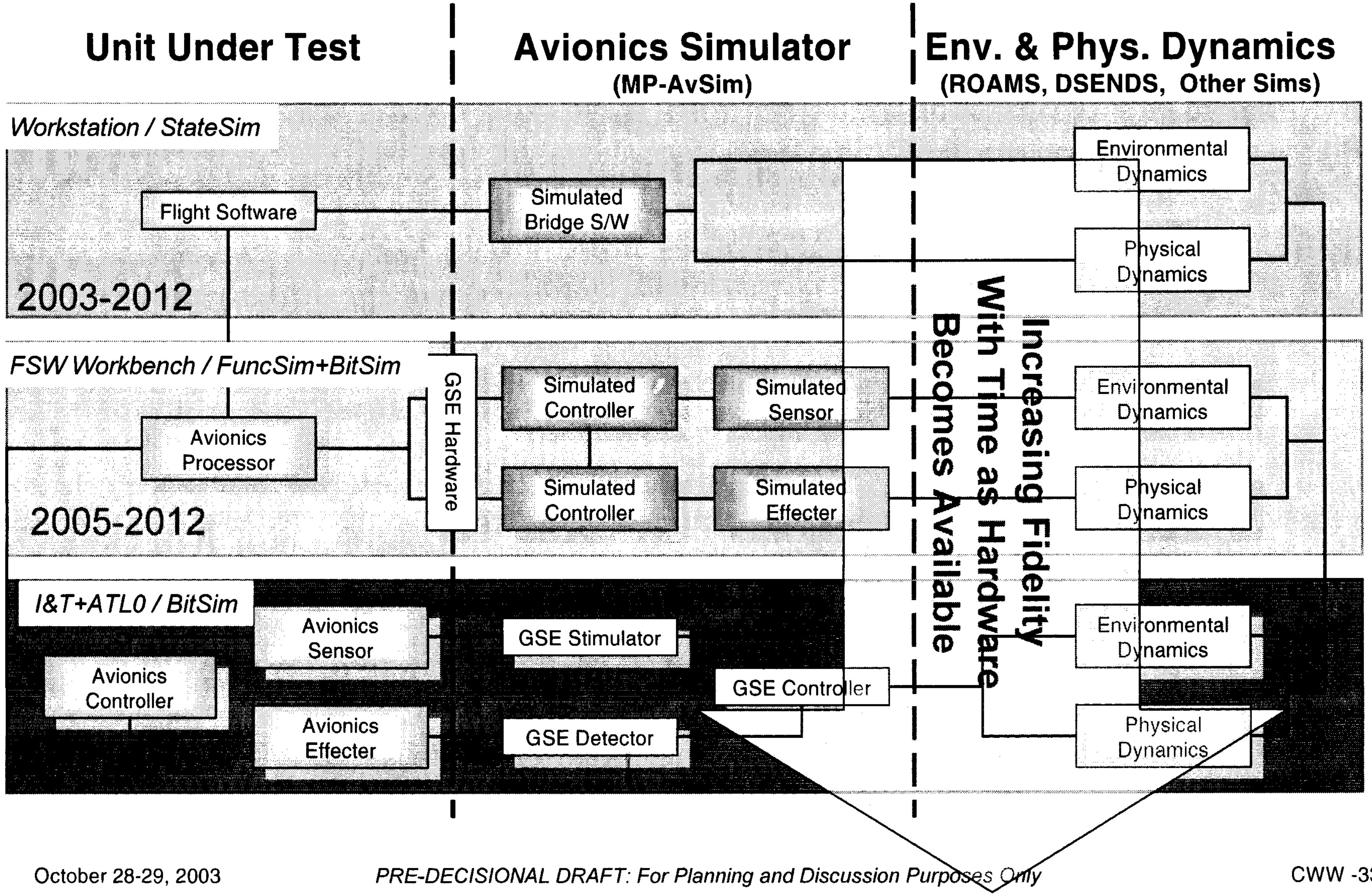


Summary

- Key challenges Identified
- Continuing Design and Trade Studies in Phase A will establish feasibility
  - Long-duration Operations Concept
  - Implications of Ops Concept on Operability and Software
  - Launch/Arrival Strategy to maximize EDL Comm Robustness
  - Integrated Navigation/Controls Analysis to achieve required entry accuracy over entire latitude range
- Organizational structure and technology program investments reflect recognition of these key challenges

Mars Science Laboratory

Mission Concept Review

MSL Focused Technology

Gabriel Udomkesmalee

October 28-29, 2003

Discussion Topics

- **Introduction**
  - Objectives
  - Budget
- **Technology Areas**
- **Key Technology Products**
- **Major Milestones**
- **Organization Chart**
- **Conclusion**

MSL Focused Technology (FT)

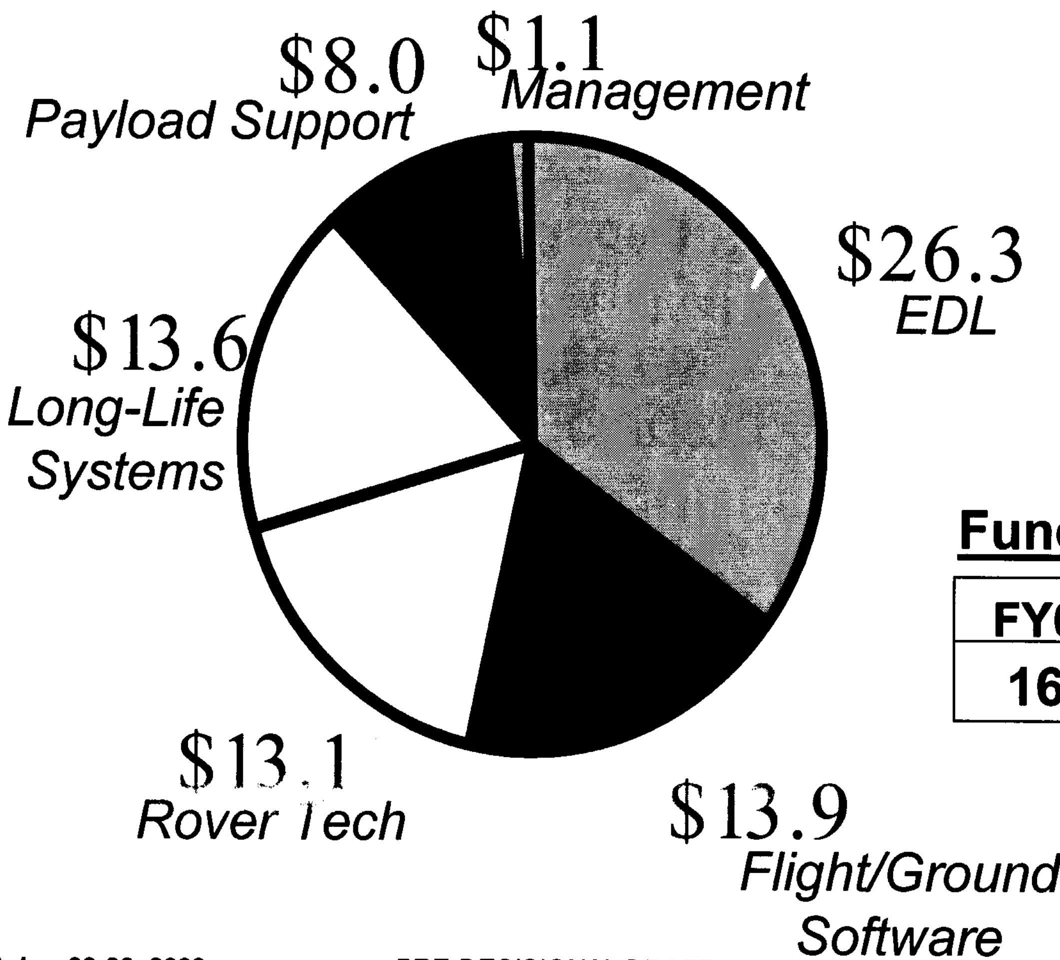
Objectives:

- **Develop technology for** MSL Entry, Descent, and Landing (**EDL**) **and Surface Systems** which will enable new capabilities including:
  - Precision Guided Entry
  - Autonomous Terminal Descent Hazard Detection/Avoidance
  - Efficient Touchdown System
  - Robust Software Architecture
  - Long-lived Mobility Asset
  - Sample Acquisition & Distribution
- **Mature technologies to TRL 6 by MSL PDR**

TRL 6 – System/subsystem model/prototype demonstrated in relevant environment

MSL Focused Technology Budget

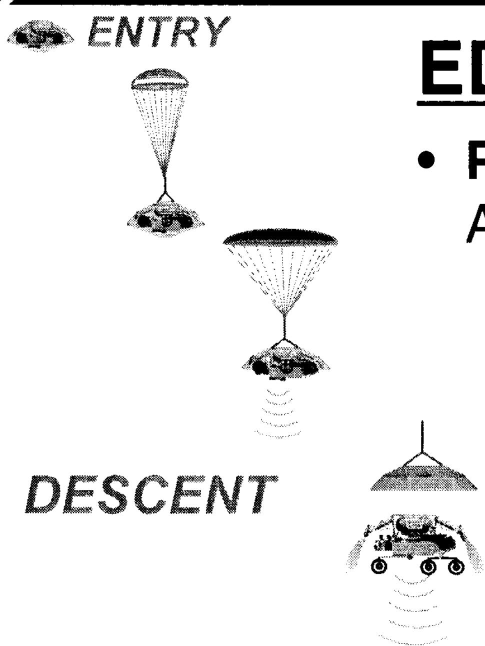
FY'03-FY'05 ($77M)



Funding Profile ($M):

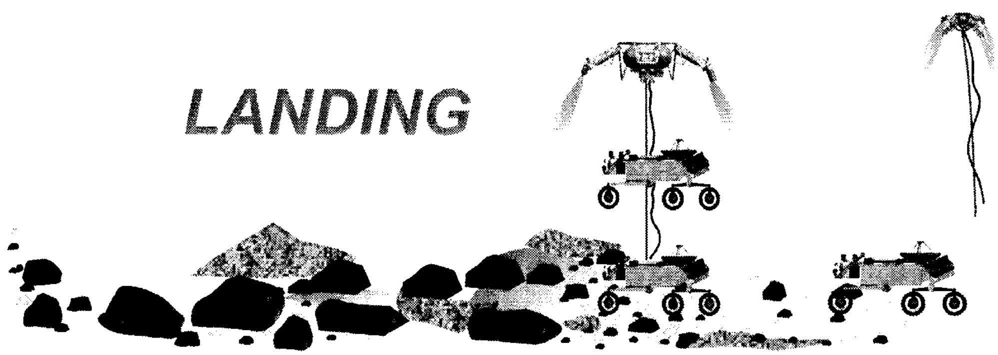
FY03	FY04	FY05	TOTAL
16.9	35.0	25.1	77.0

FT Enables Next Generation Capabilities for EDL



EDL Technology Areas

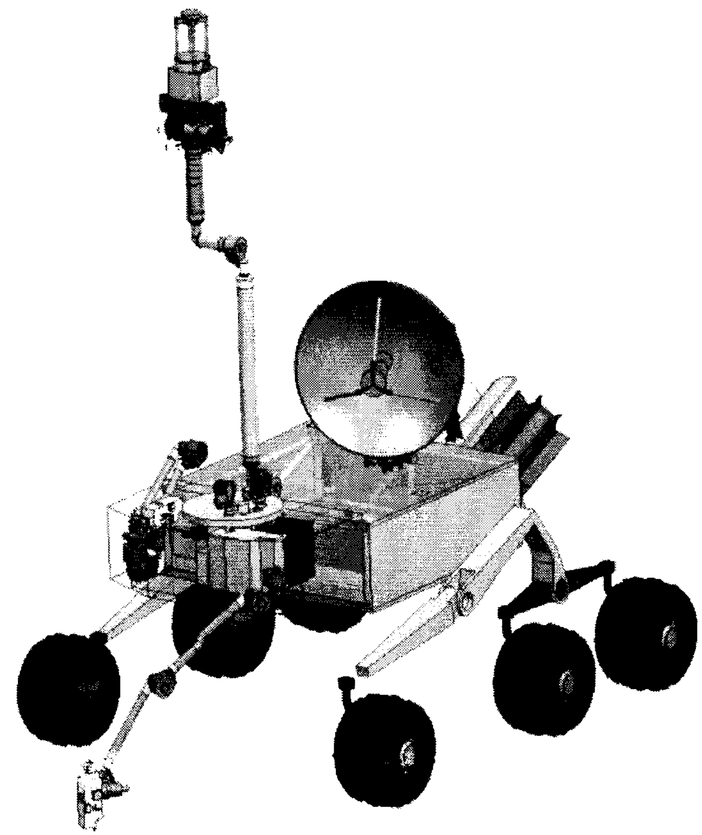
- **Precision Guided Entry** using Hypersonic Aeromaneuver Guidance
- **Subsonic Parachute**
- **Hazard Detection and Avoidance** using Phased Array Terrain Radar
- **Throttleable Descent Engine**
- **Efficient/Robust "Skycrane" landing approach**



FT Enables Next Generation Capabilities for Surface Mission

Surface Systems Technology Areas

- Robust Software Architecture and Systems Engineering Methodology
- Navigation/Placement Technologies
- Long-life Elect/Mech Systems capable of operating for 1+ Mars years in Mars ambient
- Sample Acquisition and Distribution System



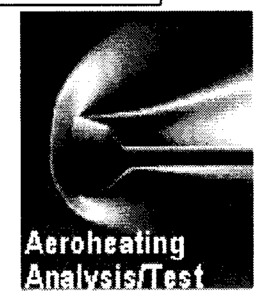
Tech Products – Precision Guided Entry

Expected Capabilities

Improved targeting/landing accuracy to the surface of Mars from hundreds of kilometers to ±5 km.

Deliverables:

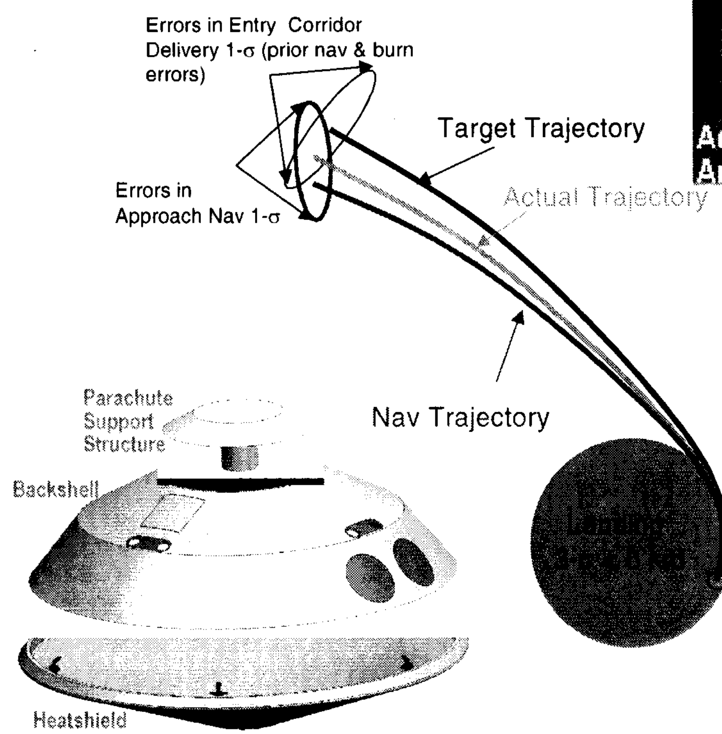
- GNC Algorithms & Analysis Tools
- Aeroshell/TPS Design
- Aeroheating Environments



Investments ($K):

FY03	FY04	FY05	TOTAL
2153	3315	1347	6815

Participants: *LaRC, ARC, JSC, and JPL*



Performance Metric	Current Capability	MSL
Landing Accuracy (km)	±100	±5
Targeting Accuracy at Mars Approach (km)	±20	±2

Tech Products – Touchdown Systems

Expected Capabilities

Robust descent stage and landing systems for delivering a large payload mass (900-1100 kg) and increased slope tolerance (30º).

Investments ($K):

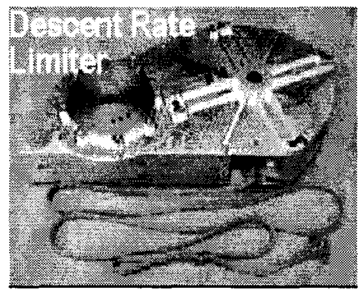
FY03	FY04	FY05	TOTAL
1261	5519	3026	9806

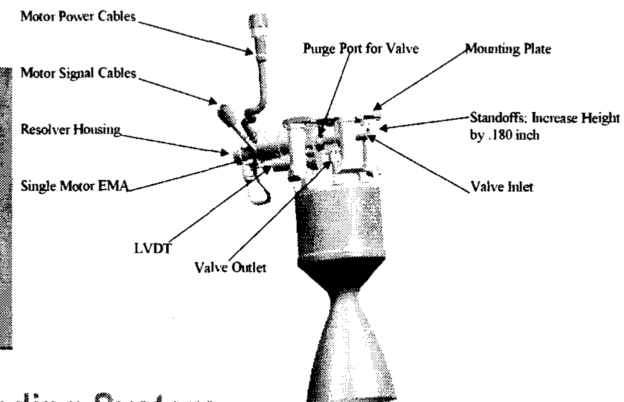
Participants: *JPL, NAWC, WSTF, Moog, Aerojet*

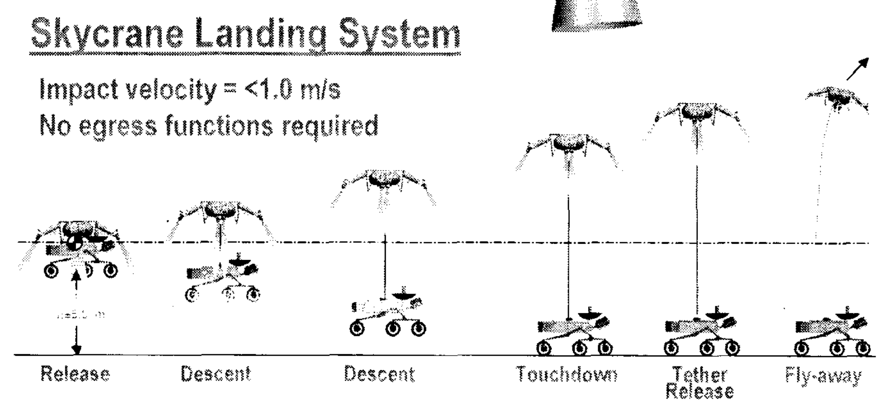
Performance Metric	Current Capability	MSL
Thruster	Pulse-Width Modulation	Continuous Throttleable
Slope tolerance (º)/Rock height tolerance (m)	15/0.5	30/0.75
Landed mass (kg)	300	900-1100

Deliverables:

- Descent Stage Design for Skycrane including Descent Rate Limiter
- Throttleable Engine







Tech Products – Hazard Detection/Avoidance System

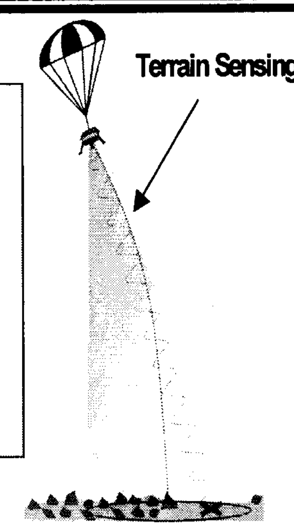
Mars Science Laboratory

Expected Capabilities

Advanced terrain sensing and navigation system for detecting hazardous terrain features and identifying safe landing sites from a descending lander.

Deliverables:

- Subsonic Parachute Design
- Phased Array Terrain Radar
- HDA Algorithms

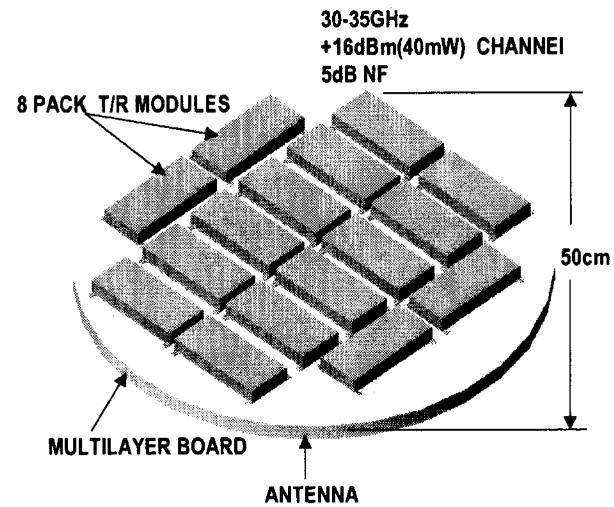


Investments ($K):

FY03	FY04	FY05	TOTAL
1340	4131	4196	9667

Participants: *JPL, JSC, LaRC, NWAC*

MSL PHASED ARRAY TERRAIN RADAR



Performance Metric	Current Capability	MSL
Min pressure at chute deploy (Pa)	250	60
Min hazard detection altitude (m)	none	500
Min crater size (m) detected at 500m	none	50
Altitude(cm)/Velocity(cm/sec) accuracy	100/40	10/10

Tech Products – Rover Software

Expected Capabilities

Robust software architecture using a unified framework for flight/ground software and reusable software components.

Deliverables:

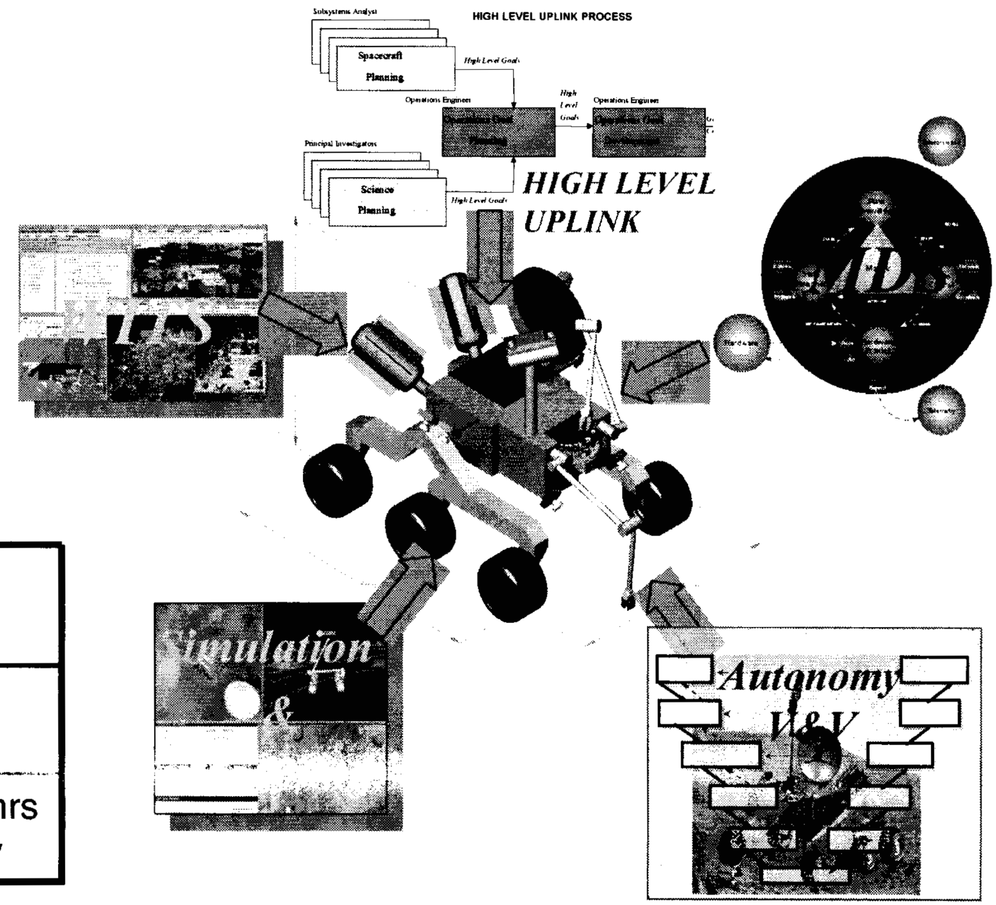
- Robust Flight/Mission Software for MSL Integrated Software Demo (8/05)

Investments ($K):

FY03	FY04	FY05	TOTAL
6572	11557	8930	27059

Participants: *JPL, ARC*

Performance Metric	Current Capability	MSL
Number of uplink products' handoffs	5	2
Surface ops turn-around time	24 work-hrs per day	12 work-hrs per day



Tech Products – Long-Life Electrical/Mechanical Systems

Expected Capabilities

Long-life surface system components designed to survive the extreme temperature range (-120 to +85 ºC) for 1500 cycles.

Deliverables:

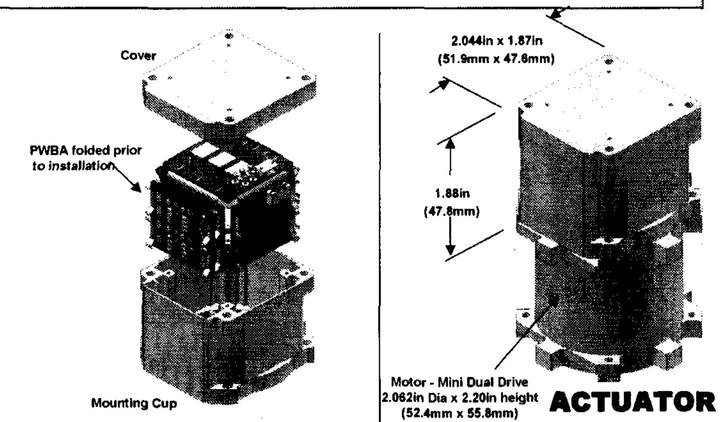
- Actuator Assembly for Wheels/Arms
- MSL Pumped Fluid Loop Design
- Skycrane-capable Test Vehicle including Lightweight Wheel/Differential

Investments ($K):

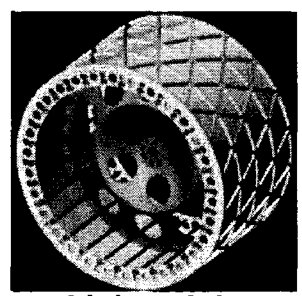
FY03	FY04	FY05	TOTAL
2183	6657	4776	13616

Participants: *JPL, NEPP, APL, PDT*

Performance Metric	Current Capability	MSL
Number of cycles (–120 to +85 ºC)	none	1500
Wheel and differential (Kg)	45	<20
HRS Power (W)/Qual Life(yr)	100/1	10/3



ACTUATOR ASSEMBLY



Lightweight Wheel/Differential

Advanced Pump

Tech Products – Sample Acquisition and Processing Systems

Expected Capabilities

Develop a complete sample acquisition and preparation system for MSL analytical instruments.

Deliverables:

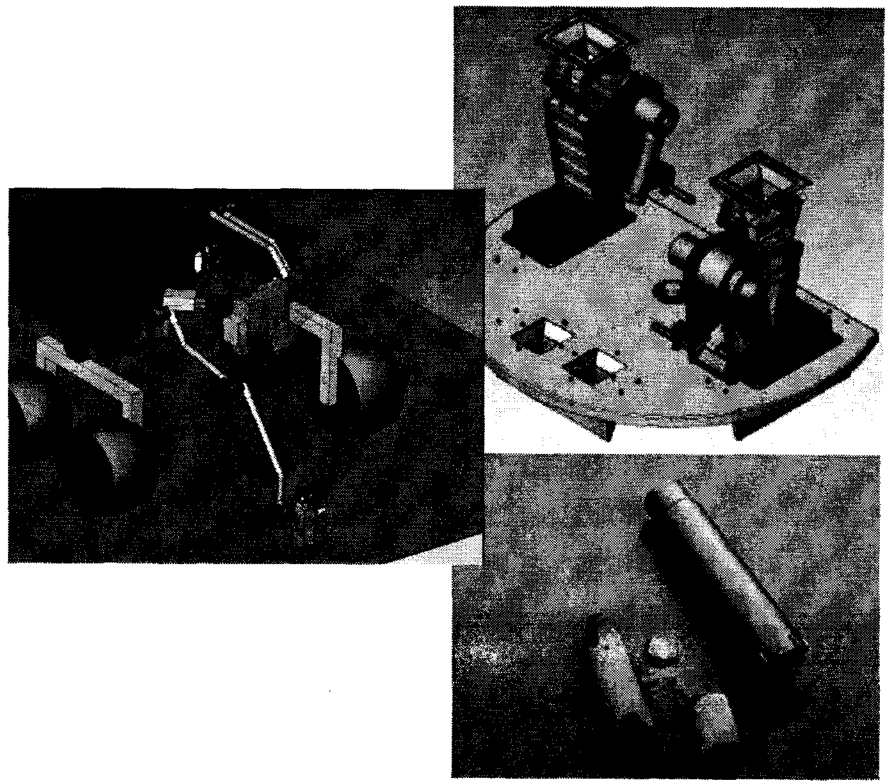
- Sample Processing/Distribution Brassboard
- Manipulation Control Algorithms
- Corer/Abrader Design

Investments ($K):

FY03	FY04	FY05	TOTAL
696	2573	2198	5467

Participants: *JPL, Industry*

Performance Metric	Current Capability	MSL
Rock crusher mass (Kg)/Power (W)	none	1.6/<1
Fragment size (mm)	none	≤ 1
Core/Rock sampling with arm mounted tool	none	yes



Tech Products – Planetary Protection

Mars Science Laboratory

Expected Capabilities

Biological contamination control technologies for meeting planetary protection requirements for MSL.

Investments ($K):

FY03	FY04	FY05	TOTAL
590	892	1090	2572

Participants: *JPL*

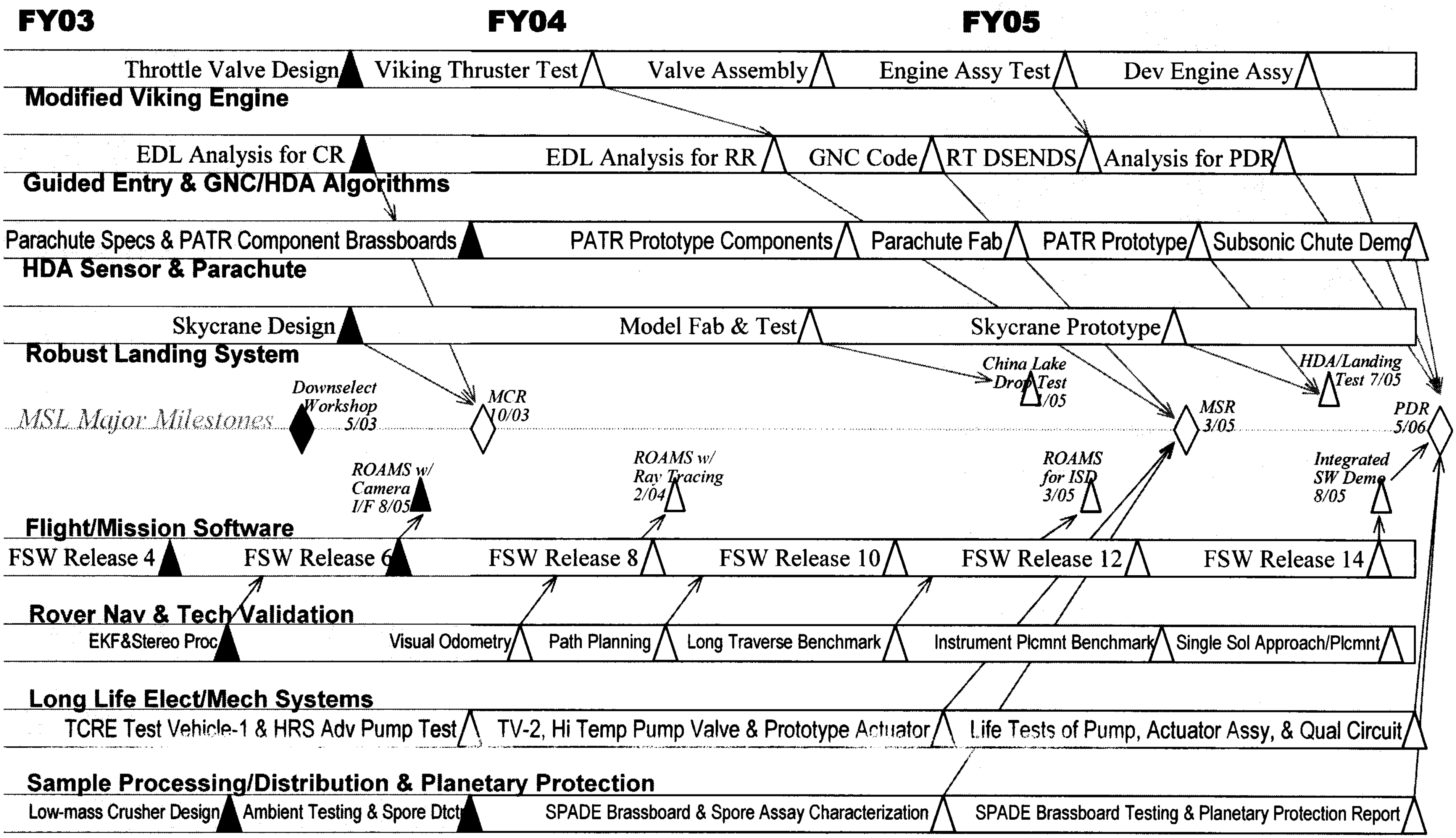
Performance Metric	Current Capability	MSL
Verification assay time	3 days	4 hrs

Deliverables:

- Rapid validation method for enumerating spores
- Cleaning and maintenance methods for achieving organic cleanliness of MSL sample handling/analysis chain

FT Ensures Timely Infusion of Technologies for MSL

Mars Science Laboratory



FT Enables Necessary Project-Directed Technology Infusion

MTP Program Manager – *Samad Hayati*

MSL Project Manager – *Mike Sander**

** denotes MSL project staff*

MSL Focused Technology – *Gabriel Udomkesmalee*

Focused Autonomy Technology – *Sandy Krasner**

EDL Systems – *Jeff Umland**
- Aeroshell–*Lockwood**
- Integrated GNC–*Wong**
- HDA Validation–*Wong**
- Engine Dev–*Carlson**
- Mod & Sim–*Balaram*
- POST–*Striepe**
- Radar–*Pollard**
- Parachute–*Mitcheltree**
- Safe Landing–*Rivellini**

Rover Flight/Grnd Software – *Sandy Krasner**
- MDS adaptation–*Lai**
- Rover tech infusion–*Lai**
- Life-cycle prototyping–*Lai**
- Software validation–*Fesq*
- Rover Ops–*Page**
- MP-AvSim–*McMahon**

Rover Technology – *Rich Volpe*
- ARC Testbed–*Bualat*
- Rover Nav–*Huntsberger*
- Instrument Plcmnt–*Kim*
- CLARAty–*Nesnas*
- WITS for MSL–*Backes*
- Surface Mod&Sim–*Jain*
- Rover Maint–*Baumgartner*
- Onboard Science–*TBD*

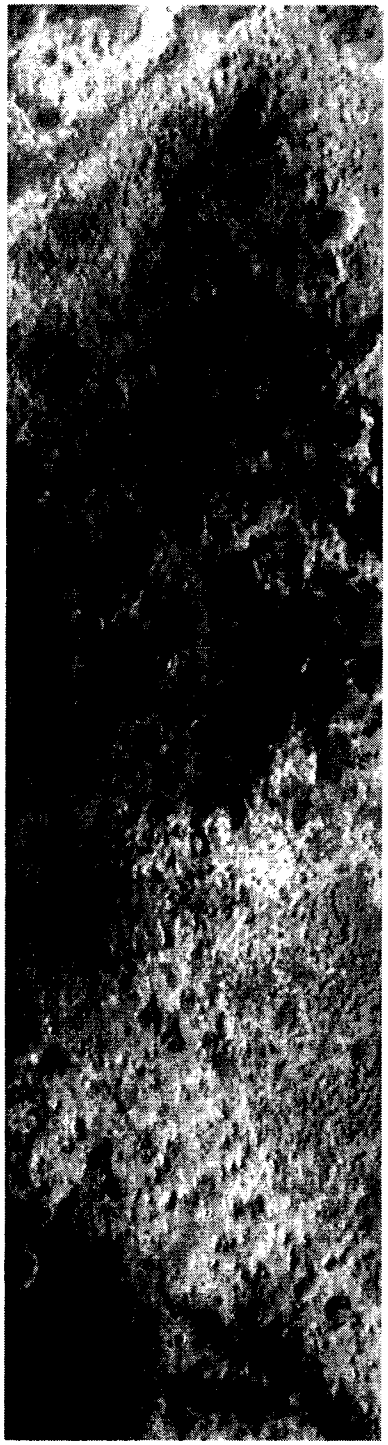
Long Life Systems – *Adam Steltzner**
- TCRE–*Kolawa*
- Actuators–*Johnson**
- Heat Reject Sys–*Birur**
- Thermal Flex Line–*Thoma**
- Micro Sun Sensor–*Mobasser*
- Mobility Technologies–*Voorhees**

Payload Support – *Brian Muirhead**
- Planet Protect–*Kern*
- SPADE–*Bearman*
- Corer/Abrader–*Wilcox**
- Manipulation Tech–*Backes*

Summary

→ MSL FOCUSED TECHNOLOGY ←

- **Retires** MSL risks by delivering mission-critical prototypes/technology products validated in relevant environments
- **Establishes** project-directed/owned technology infusion (Technologies are developed under project staff supervision)
- **Maintains** continual relevance/compatibility via tightly coordinated activities between project staff and technology providers
- **Provides** feed-forward functionalities for future mission



Mars Science Laboratory

Mission Concept Review

Financial Summary

Annette Green

October 28-29, 2003

NASA/Mars Program Office Target Cost for MSL

NASA Headquarters/Mars Program Office target cost for MSL is:

- $870M for development

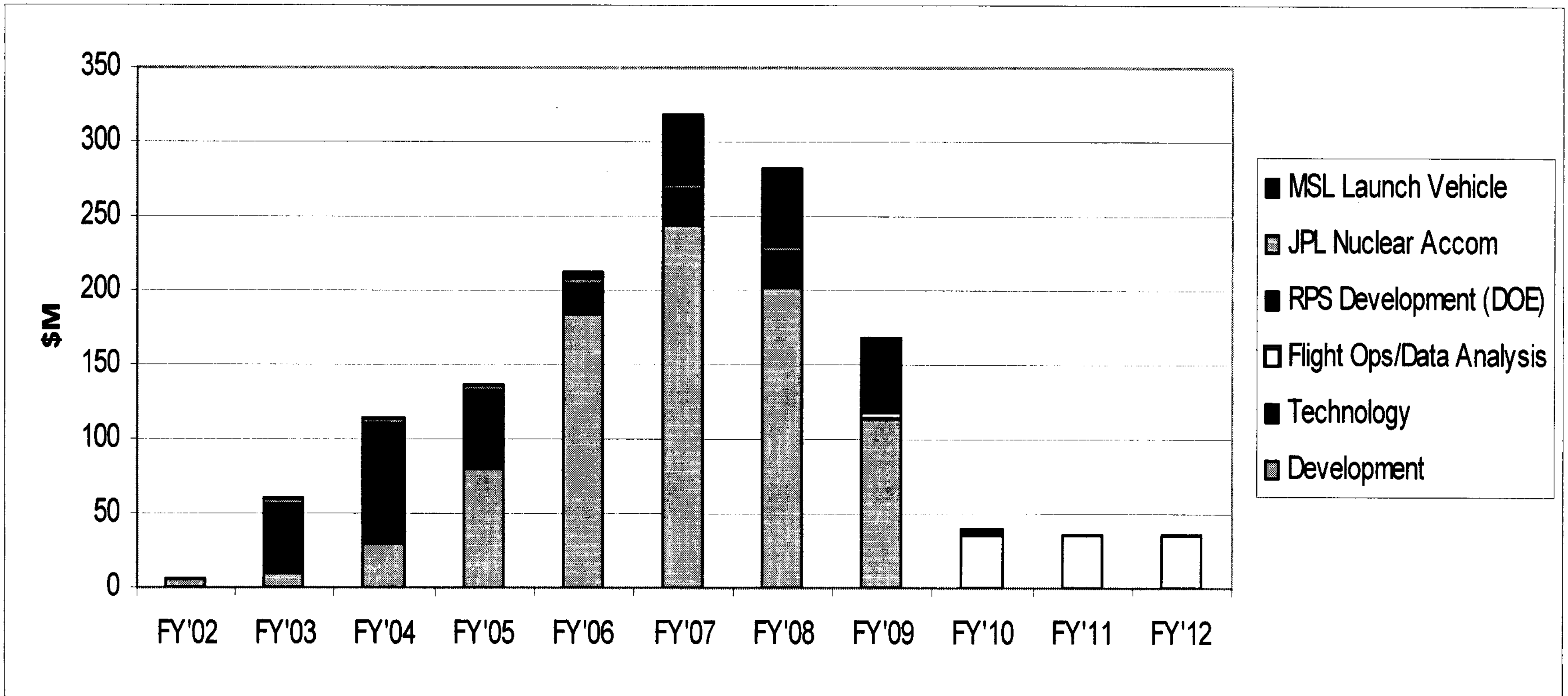
Plus

- $540M for:
  - Focused Technology
  - Radioisotope Power Source (RPS)
  - Launch vehicle
  - Operations

Summary of Funded Efforts ($M)

• MSL Development	
– Includes all development efforts from Pre-Phase A to launch	$870M
• MSL Focused Technology	
– Funded as part of the Mars Technology Program	$77M
• MSL Mission Operations and Data Analysis	
– Funds are allocated, a ROM estimate will be conducted in Phase A	$115M
• RPS Development	
– Bypass to DOE, this effort is managed through NASA	$171M
• JPL Nuclear Accommodation	
– JPL's funding to accommodate a nuclear power source	$24M
• MSL Launch Vehicle	
– Bypass funds to KSC to fund the launch vehicle	$152M
	$1,409M

Time-Phased Total Project Budget NOA ($M)



Pre-Phase A	Phase A	Phase B	Phase C	Phase D	Phase E

Grassroots Estimate by Phase ($M)

Phase	Span	Duration	Total $M	% of Total $
Phase A	11/03 – 3/05	(17 months)	$65M	7%
Phase B	4/05 – 5/06	(14 months)	$192M	21%
Phase C	6/06 – 3/08	(23 months)	$471M	51%
Phase D	4/08 – 10/09	(18 months)	$196M	21%

Estimating the Cost of the Reference Mission

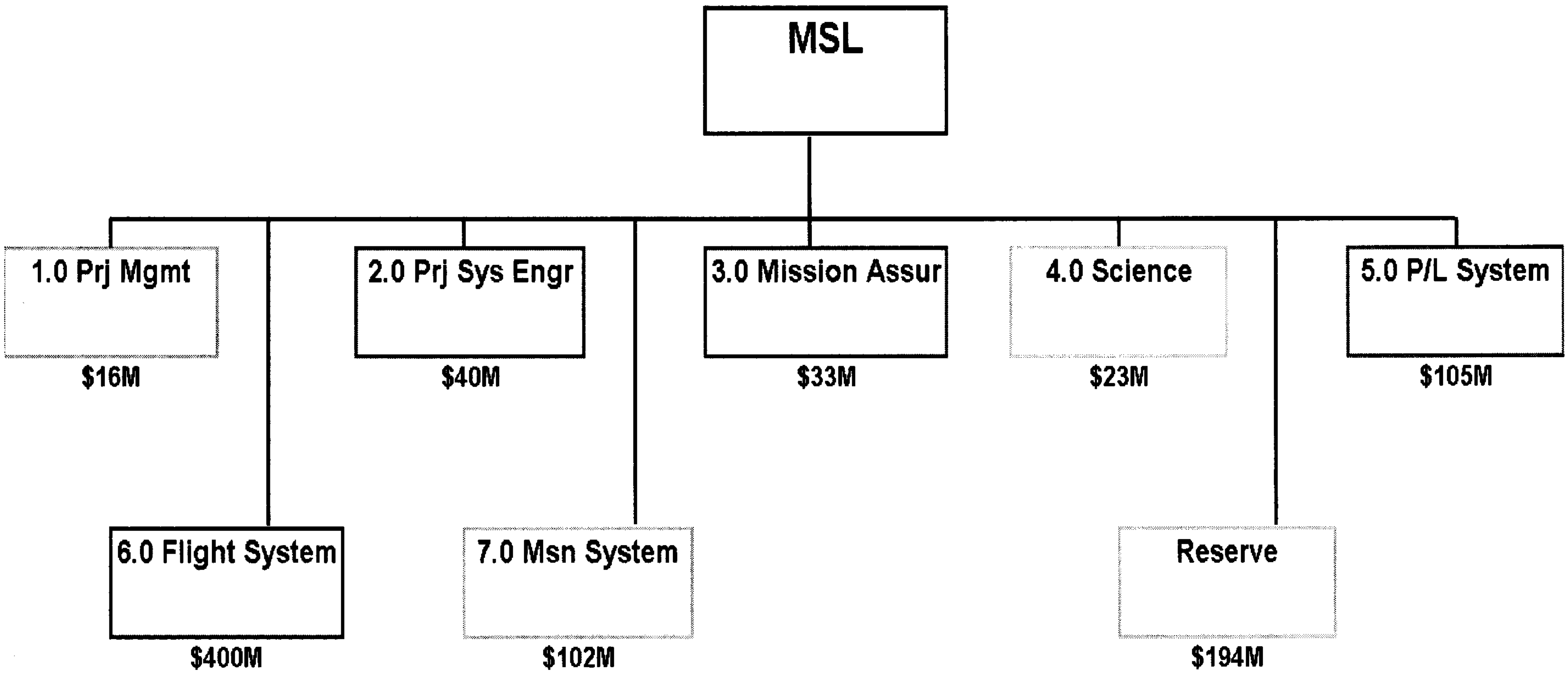
- MSL target development cost of $870M has the following components:
  - Sunk cost of Pre-phase A — $15M
  - Cost to go (Phase A-D) — $661M
  - Reserve on cost to go — $194M (~30%)
- This summer the project conducted a detailed grassroots cost estimate (~ 180 cost accounts) involving JPL technical divisions. This resulted in:
  - Estimate of cost to go (phase A-D) — $730M
  - Reserve on cost to go — $194M

Delta =$69M (~10%)

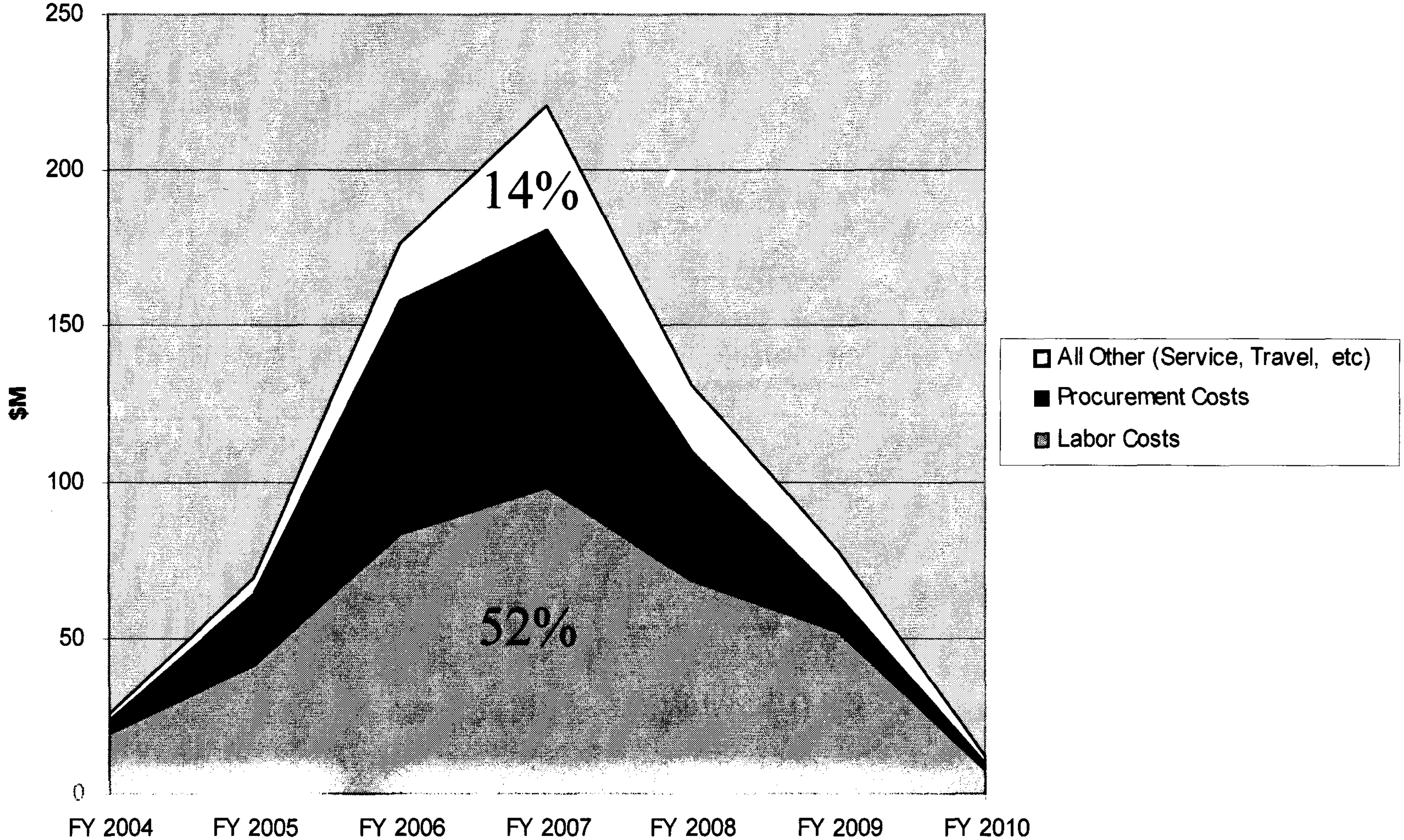
- Cost estimate exceeded the target cost by ~10%
  - ~1/4 of the overage is due to NASA centers switching to full cost accounting. Project is still sorting this out with Headquarters
- Project will pursue cost reduction in Phase A

Current Estimate for Development Costs by Work Breakdown Structure ($M)

$913M + $11M Award Fee = $924M

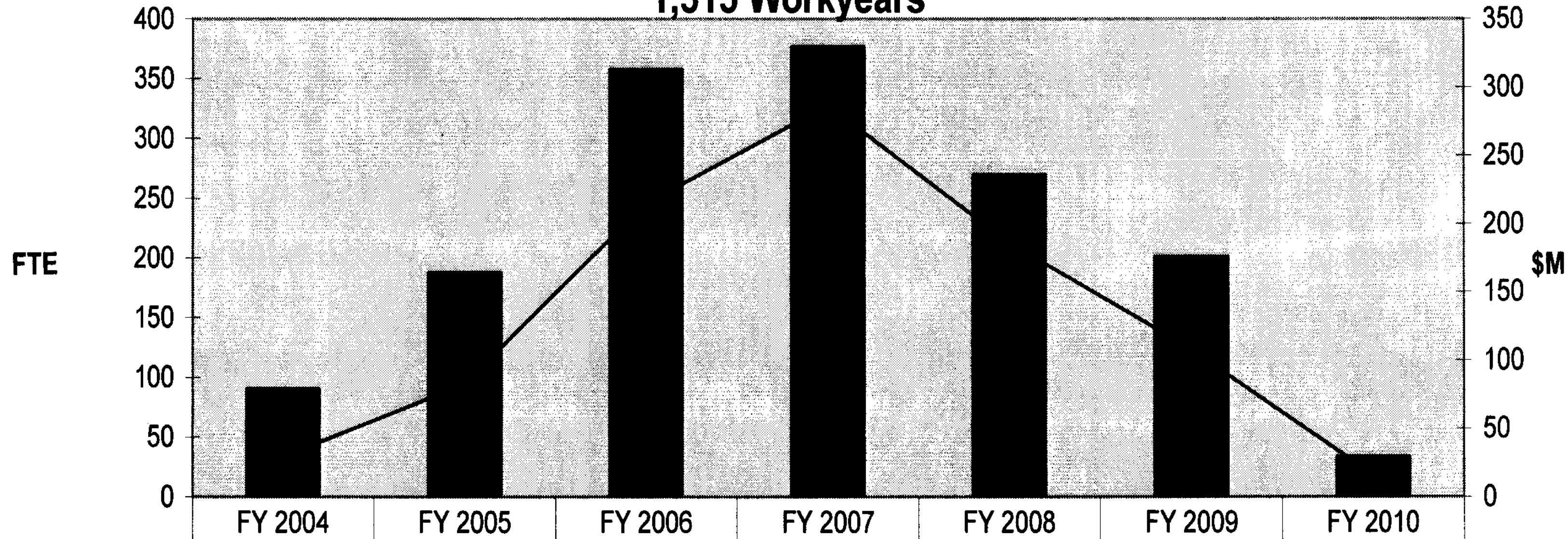


Distribution of Costs by Cost Category ($M) Current Estimate Less Reserves



Development Estimate FTE, Obligations by Year
Compared to Major Schedule Events

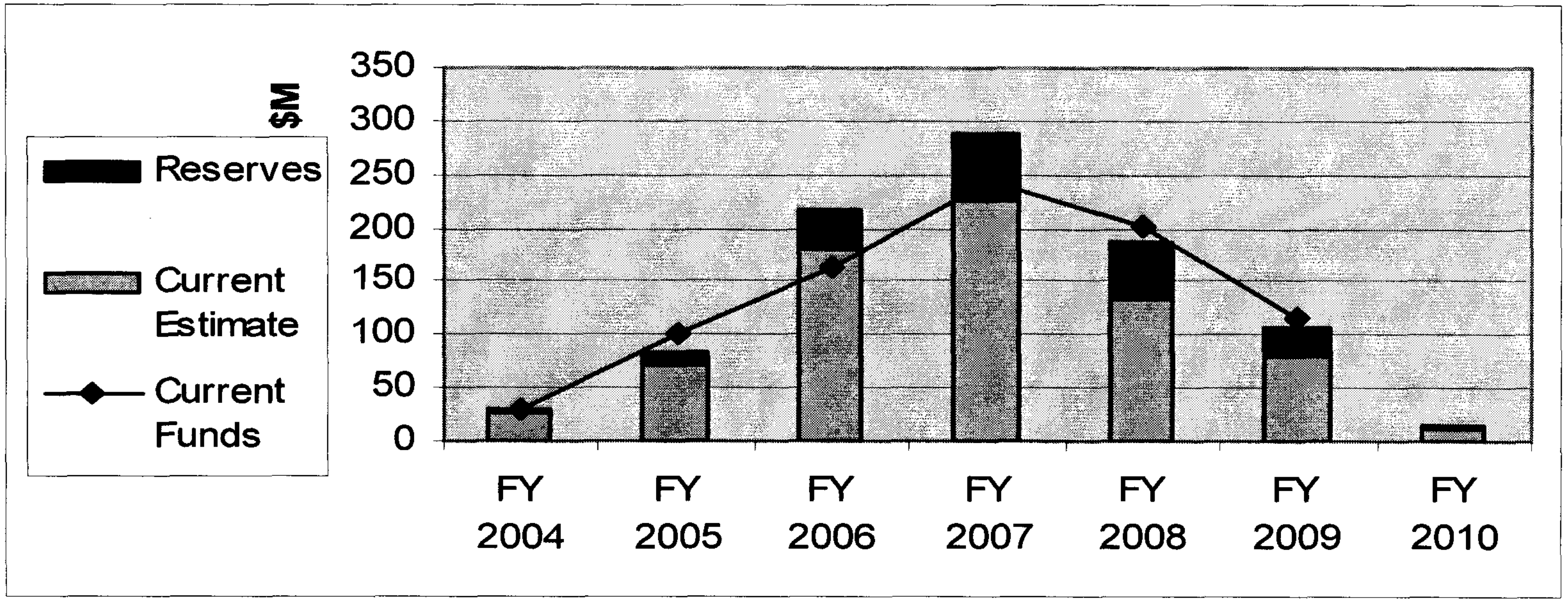
Total Current Estimate $924M
1,515 Workyears



	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010
FTE	90	187	358	376	269	201	33
Oblig	29	83	215	287	186	108	16

Project Milestones	PMSR	PDR	CDR	ARR	Ship	Launch Window
	△ 03/05	05/06 △	△ 03/07	△ 02/08	06/09 △	□ 10/10-11/10

Current Development Estimate Profile Including Reserves ($M)



	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	Total
Current Estimate Obligations	27	71	180	225	135	81	12	730
Reserves	2	13	35	62	51	27	4	194
Total Current Est. + Reserves	29	83	215	287	186	108	16	924

Current Funds Profile	30	100	164	244	202	115		855
Delta Funds vs Estimate	1	17	-51	-43	16	7	-16	-69

Annual % Reserve Ratio	8%	18%	20%	27%	38%	34%	32%	
% Reserve on Obs To Go	27%	27%	28%	32%	36%	33%	32%	

Cost Model Comparison in $FY03M

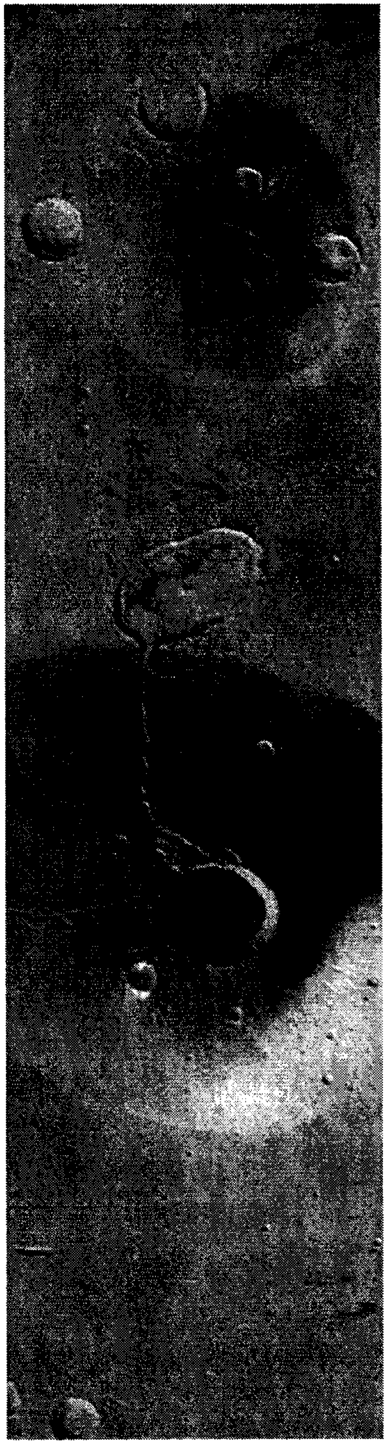
The current estimate of $924M equates to $826M in $FY03 Dollars

Cost Comparison ($FY'03M)	Range		
WBS Title	From	To	MSL Grassroots
Mars Science Laboratory (MSL)	$804	$926	**$826**
1.0 Project Management	$14	$19	$15
2.0 Project System Engineering	$26	$36	$36
3.0 Mission Assurance	$18	$26	$26
4.0 Science	$20	$30	$20
5.0 Payload System (w/ Common P/L Sys HW)	$93	$174	$93
6.0 Flight System	$241	$418	$362
7.0 Mission System	$68	$119	$92
9.0 Reserves	$172	$214	172
Award Fee	$10	$12	$10

Business Summary and Plans for Phase A

- We will continue to work the development costs
  - De-scopes
  - Implementation options
  - Reference concepts optimization
  - Continue NASA center negotiations
- Our target cost is achievable
  - During Phase A, we can reach our development target cost by evaluating and planning the budget options proposed

		($M)
Recap:	**Current Estimate**	**924**
	Development Funding	**855**
	Delta	**-69**
Options:	**High-Probability**	**37-41**
	Medium to Low-Probability	**35-45**



Mars Science Laboratory

Mission Concept Review

Phase A Plan

John D. Baker

October 29, 2003

Discussion Topics

- **The End-Goal for Phase A (MSR in 17 months)**
  - Success criteria
  - Products
- Phase A Convergence Strategy
  - Strategy
  - Trades/Studies
  - Activities
- Phase A schedule
- Summary

Mission and System Review

- Objective:
  - The Mission and System Review (MSR) is held to assess if the project definition is adequate to make an initial commitment to NASA
- Success Criteria:
  - The **cost** estimating method is **credible**, and the basis for the cost estimate is mature enough to be able to predict actual lifecycle cost within a **(+ or -) 15% uncertainty**
  - The driving requirements are identified, and flowed down
  - The technical approach is credible, and responsive to requirements
  - The development and mission risks are understood, and the available project resources are adequate to complete the development with acceptable risk
  - The project planning is sufficiently developed
- The Project is planning to converge to a point design by MSR, though this is not required by the sponsor. This will add accuracy to our cost estimate

Phase A Key Product Summary

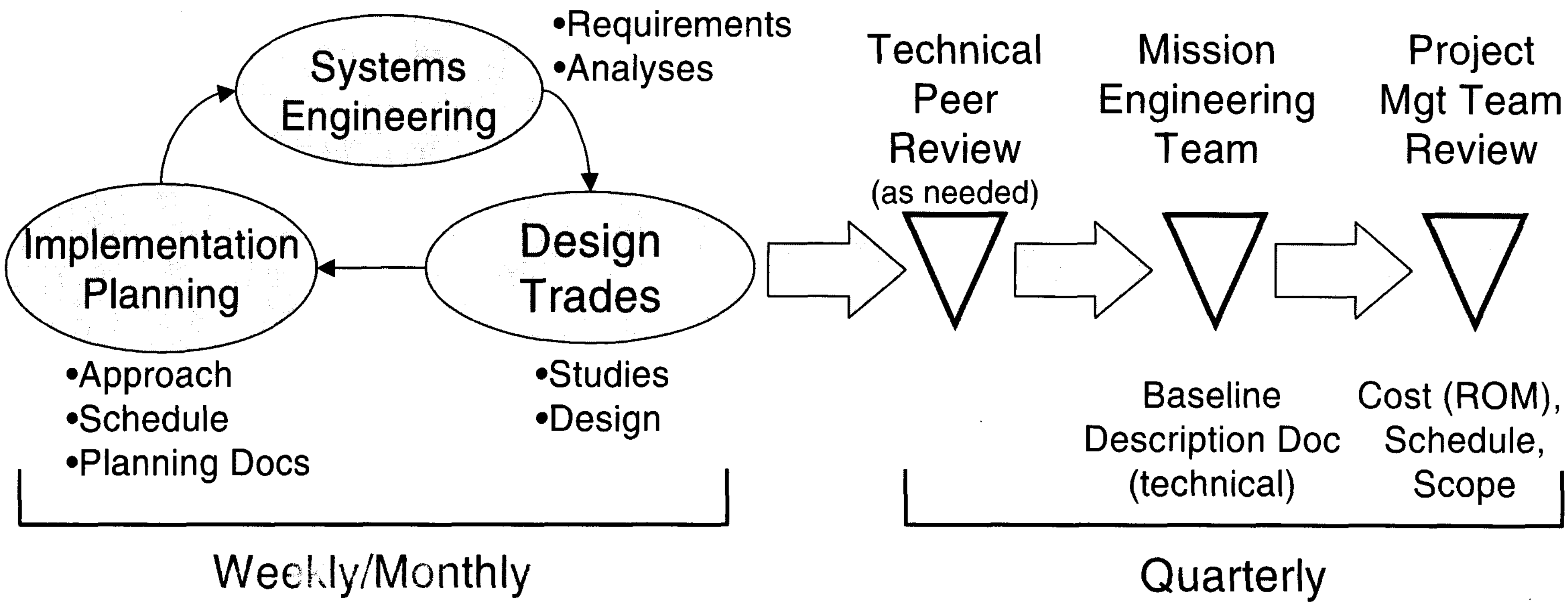
- Project Plan
- Project Implementation Plans (not the complete list)
  - Review Plan, Risk Management Plan, Acquisition Plan, Mission Assurance Plan
  - (System Office) Implementation Plans
  - V&V Plan
- Project Agreements
  - SLAs, MOAs, other NASA Centers
- Project Requirements
  - L1 & Success Criteria,
  - L2, Env Reqs Doc,
  - L3-Draft and SW State Requirements
- Project System Interface Documents (FLT-GND, LV IRD, RPS ICD)
- NASA Selected Science Payload
- Project Design Documents
  - Mission Plan
  - LV Targeting Spec
  - Project Baseline Description Document (includes all systems)
  - Ops Concept Document
- Integrated Cost and Schedule Plan (Detailed scheds, WBS & Dict, Cost)

Discussion Topics

- The End-Goal for Phase A (MSR in 17 months)
  - Success criteria
  - Products
- **Phase A Convergence Strategy**
  - Strategy
  - Trades/Studies
  - Activities
- Phase A schedule
- Summary

Phase A Convergence Strategy

We will trade cost against requirements, performance, scope, schedule and risk to achieve our goal.



Key Phase A Trades Summary

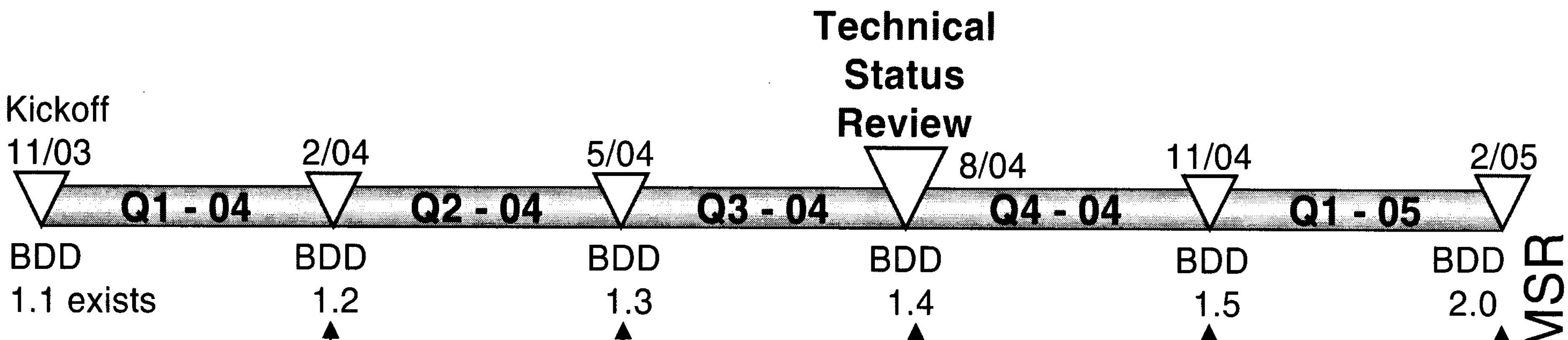
Cost Trades	Objective
Implementation Schedule	Find minimum cost schedule
Planetary Protection	Develop, analyze and document options for achieving, measuring and maintaining minimum biological contamination and organic cleanliness levels.
Landing	Develop and evaluate hazard avoidance options and risks.
SA/SPaH	Define operational environment for low-force coring system and verify and complete crusher/sample tray designs
EDL Communication	Establish robust approach to meet Program EDL Comm requirement and lattitude req.
EDL Nav Performance	Determine required nav performance to meet requirement.
SW Implement Method	Analyze current metrics and develop appropriate alternative options and decision gates
Long Duration Ops	Develop concept for team/shifting approach.
GDS Architecture	Develop architecture to support operations approach.

Mass Trades	Objective
Power Sizing	Evaluate technologies (RPS/Solar) and optimize design to meet requirements
Rover Sizing	Optimize size and design to minimize mass
EDL Sizing	Develop and evaluate options to either increase entry mass capability or reduce

Phase A Activities

Mars Science Laboratory

- The Project trades and work will be phased as follows:



L1 Reqs Draft	L2 Reqs Draft	L3 Reqs Structure	L3 Reqs Draft	L2 Reqs Final
EDL Comm	EDL Nav Perf	Surface Ops	LV Targeting	Inst Scenarios
Planet Protection	Landing	EDL Sizing	EDL Performance	Payload Accom
Power Sizing (rover)	Rover Sizing	ATLO Concept	SA/SPaH Ops	V&V Plan
Implement Opt1	Project Plan Draft	Project Impl Plans	Cost Plan	Independent Cost Assessment
L2 Schedule Draft	L3 Schedule Draft	L4 Schedule Draft		
SW Impl Method	Long Duration Ops	Ops Environment	GDS Architecture	

Phase A Activities

- Schedule
  - Review Implementation Option 1, use this to establish L1-2 schedule
  - Top down schedule development with bottoms-up feedback
    - Quarterly planning at System level
    - Establish Rec-Dels (Product Successors and Precursors)
    - Monthly planning at Sub-System Element level
  - Develop templates for Phase B-D planning (establish consistency across project)
- Project Implementation Plans
  - Use the *new & simplified* documentation structure from the planning office
- Cost
  - WBS structure finalization
  - WBS Dictionary

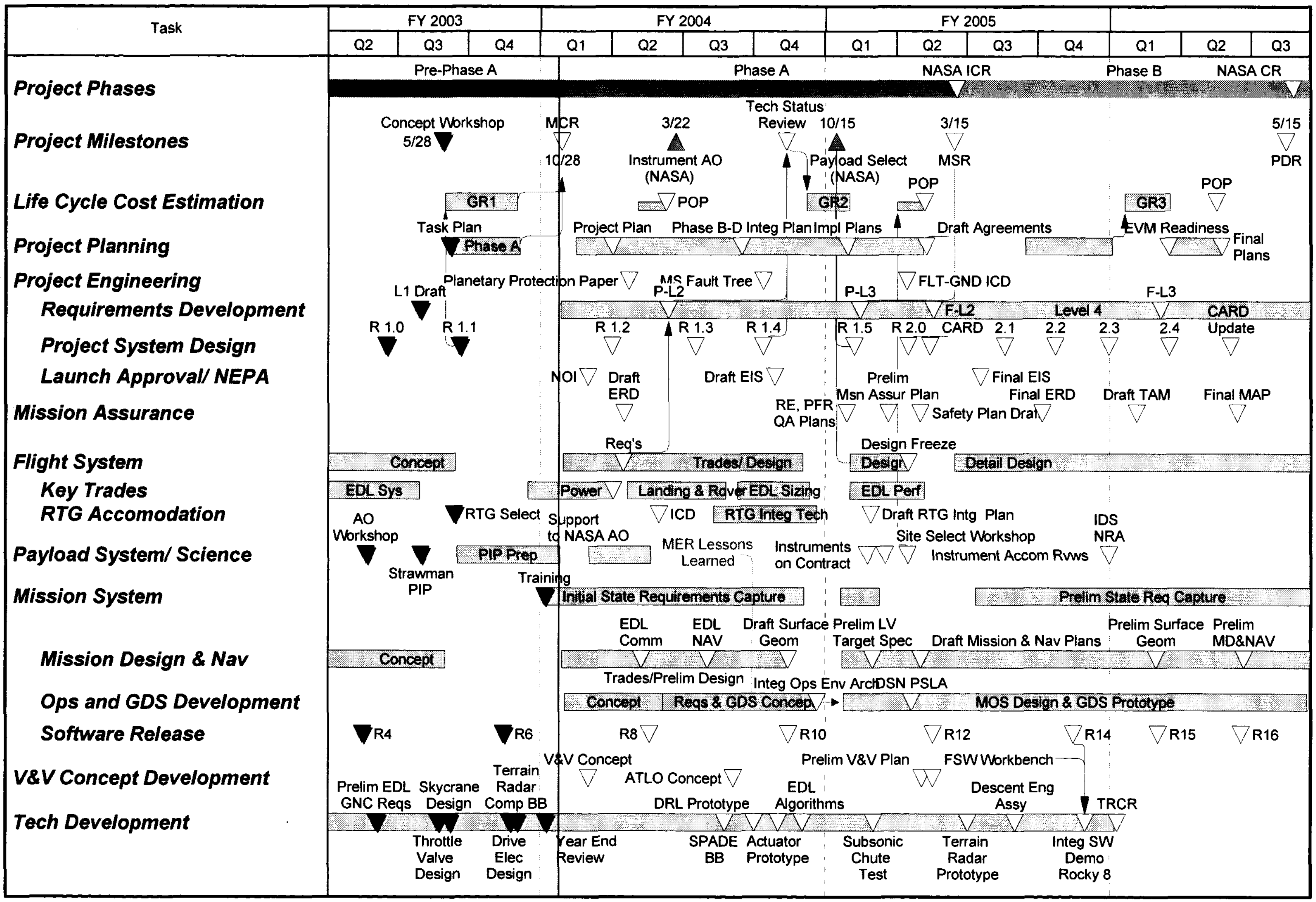
Discussion Topics

- The End-Goal for Phase A (MSR in 17 months)
  - Success criteria
  - Products
- Phase A Convergence Strategy
  - Strategy
  - Trades/Studies
  - Activities
- **Phase A Schedule**
- Summary

Mars Science Laboratory Schedule

Phase A

10/24/03



Summary

- **We have a plan for Phase A**
  - Iterative design approach
  - Structured and disciplined
- **There are some challenges to work**
  - Planetary Protection
  - Cost and Scope
- **We have the resources, people and tools to accomplish the plan**