Entry, Descent, and Landing System Design for the Mars Gravity Biosatellite

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6th International Planetary Probe Workshop
26 June 2008 – Atlanta, Georgia

Outline

- Program and Spacecraft Overview
- Driving Requirements & Objectives
- Configuration and EDL Timeline
- Subsystem Design

Trajectory Optimization

Thermal Protection System (TPS) Design

Parachute Recovery System (PRS) Design

Event Sequencing

Aerodynamics

Triggers & Mechanisms

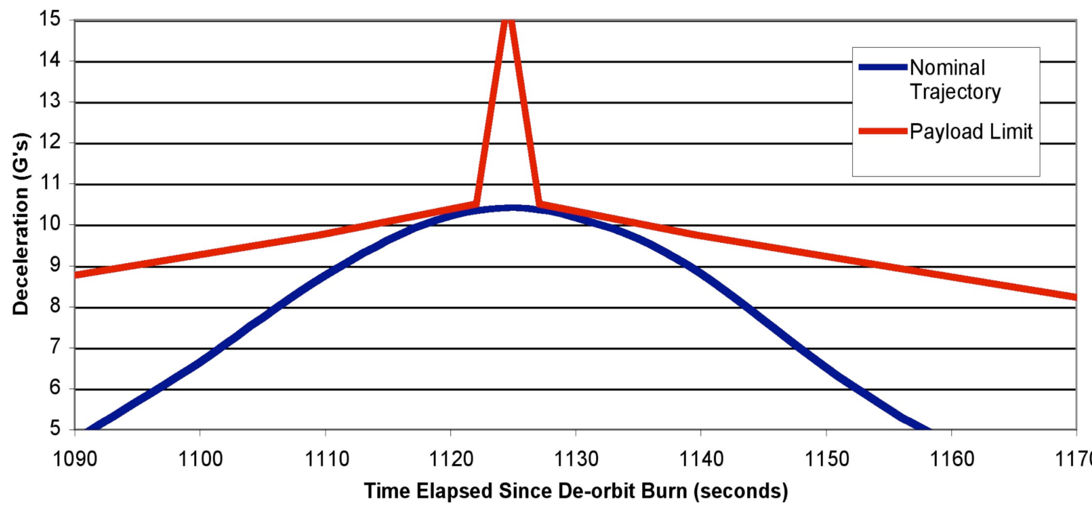
Recovery Operations

Program Overview

- Who?
  - A joint initiative of MIT and Georgia Tech, with industry partners
  - 500+ students to date, with advisors from academia, industry, and government
- What?
  - 35 days in LEO, simulated 0.38-g environment
  - Recoverable payload of 15 BALB/cByJ female mice
  - Free-flyer spacecraft for partial gravity science
  - Estimated total cost: $40M
- Why?
  - Investigation of mammalian adaptation to partial gravity ⇒ Support NASA Exploration goals
  - To educate, inspire, and motivate students through space science and engineering

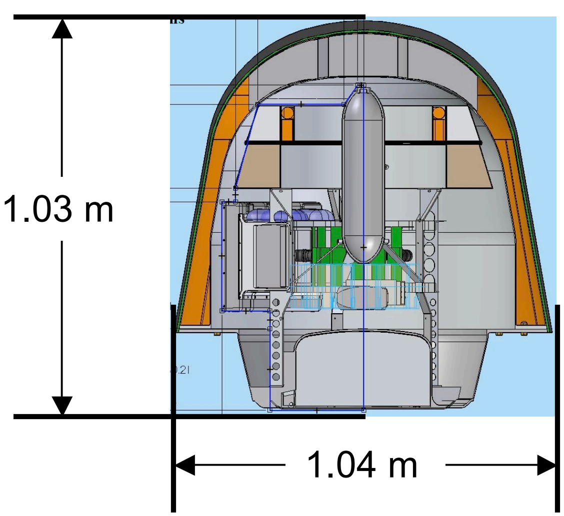
Requirements & Design Objectives

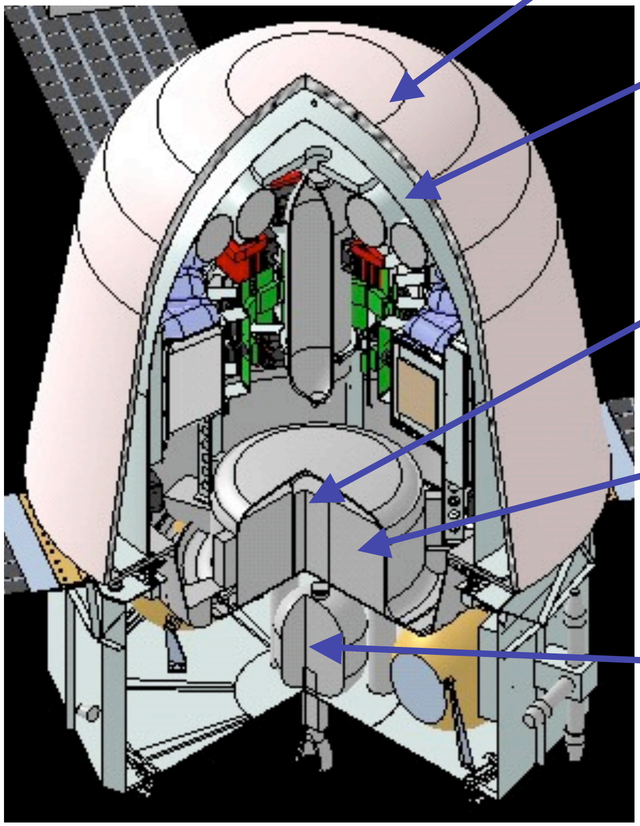
- Recovery of *live* payload from LEO
- Allowable deceleration profile
  - Strict science-derived requirements for magnitude and duration of deceleration events
- Domestic recovery at UTTR
- Recovery time
  - Payload must be fully accessible to science team within 2-4 hours after initiation of de-orbit
- Burn precision for de-orbit
  - *Not an explicit EDL requirement



Entry Vehicle Overview

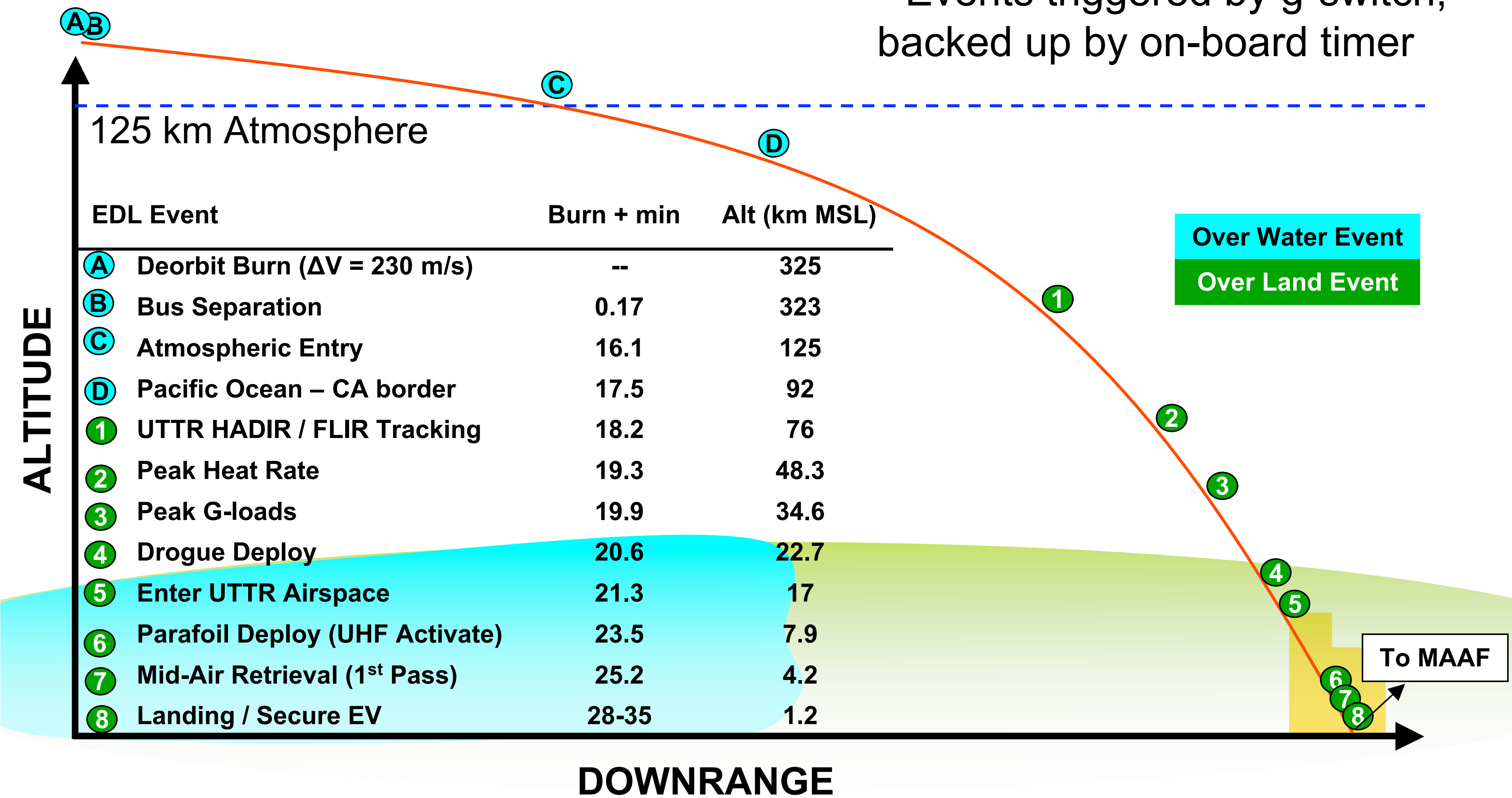
- EV configuration reflects preference for heritage systems and simplicity
- Ballistic LEO return
- EV mass: 260 kg





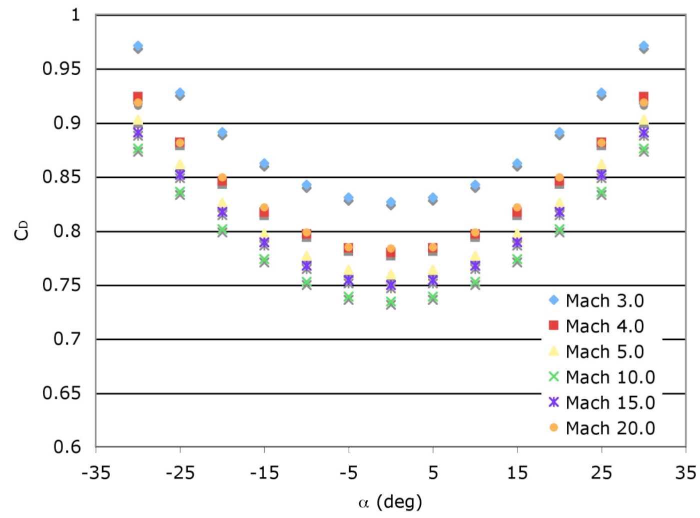
EDL Event Timeline

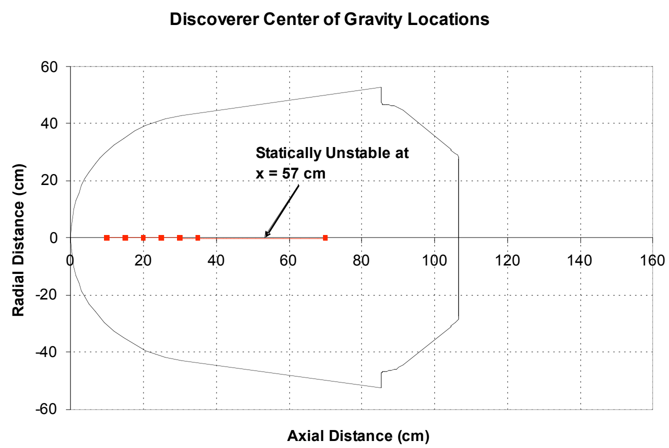
* Events triggered by g-switch, backed up by on-board timer

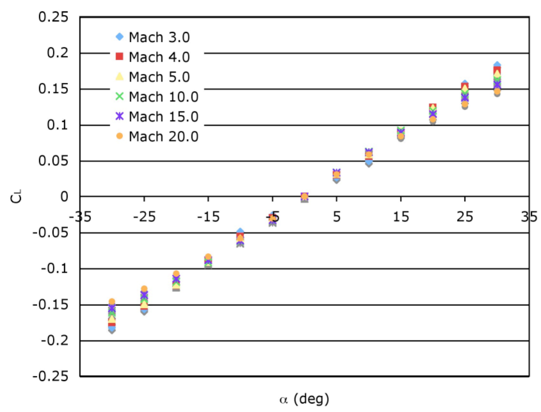


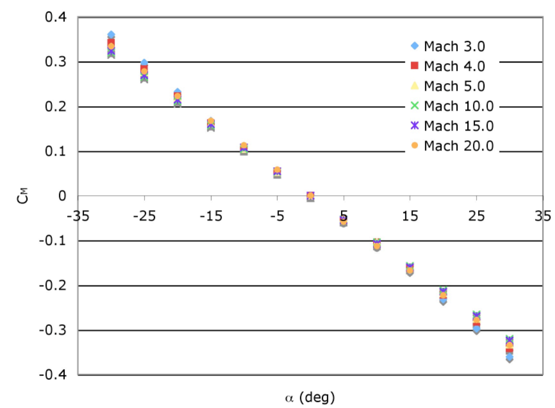
	EDL Event	Burn + min	Alt (km MSL)
A	Deorbit Burn (ΔV = 230 m/s)	--	325
B	Bus Separation	0.17	323
C	Atmospheric Entry	16.1	125
D	Pacific Ocean – CA border	17.5	92
1	UTTR HADIR / FLIR Tracking	18.2	76
2	Peak Heat Rate	19.3	48.3
3	Peak G-loads	19.9	34.6
4	Drogue Deploy	20.6	22.7
5	Enter UTTR Airspace	21.3	17
6	Parafoil Deploy (UHF Activate)	23.5	7.9
7	Mid-Air Retrieval (1st Pass)	25.2	4.2
8	Landing / Secure EV	28-35	1.2

- Discoverer aeroshell geometry
  - Flight heritage from Discoverer, Corona
  - Design heritage from METEOR (COMET)
- Payload configuration requires 20 kg of ballast for static stability





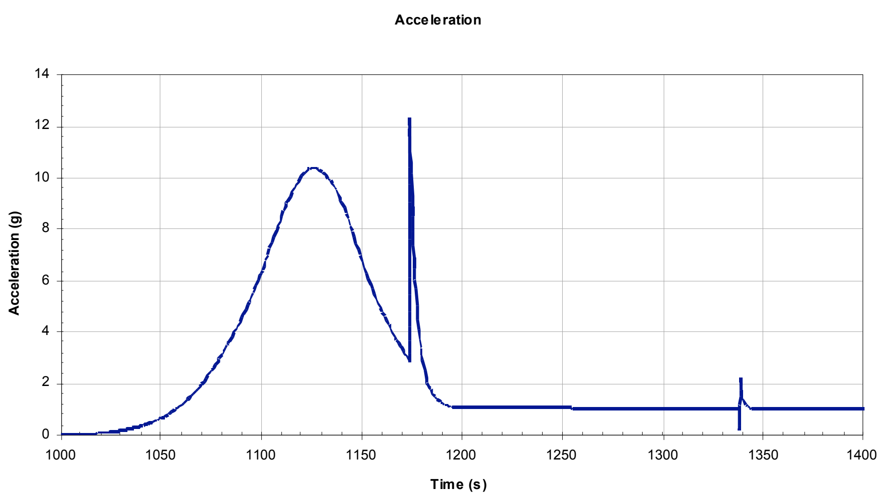




Nominal Trajectory

- Ballistic entry from 325 km altitude
- Definition of nominal:
  - Trajectory with max. ΔV where less than 10% of cases fail
    - Dispersions applied
    - Failed case: exceeds g-limit or outside UTTR
  - De-orbit ΔV: 230 m/s
- Entry corridor: 0.16°
- Landing target:
  - +40.07°N, -113.43°W

Event	Condition
Bus Separation	De-orbit burn complete
Pilot / Drogue Deploy	Mach 2.0
Parafoil Deploy	Mach 0.18

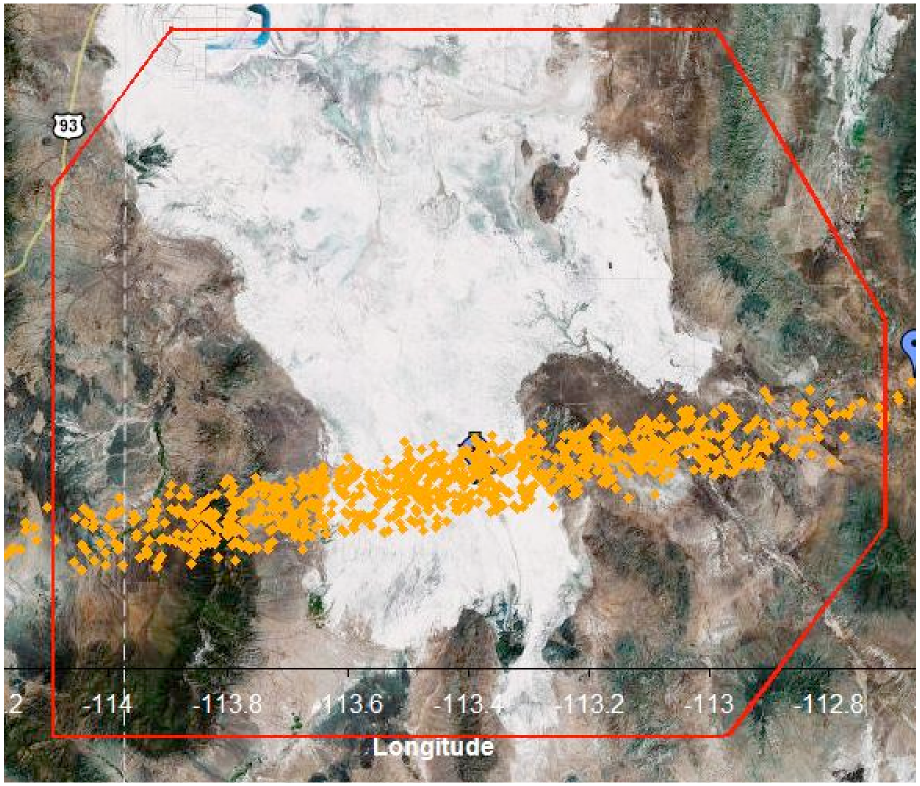


Dispersion Analysis

- 900 cases in preliminary MC
- Dispersions applied to the nominal trajectory

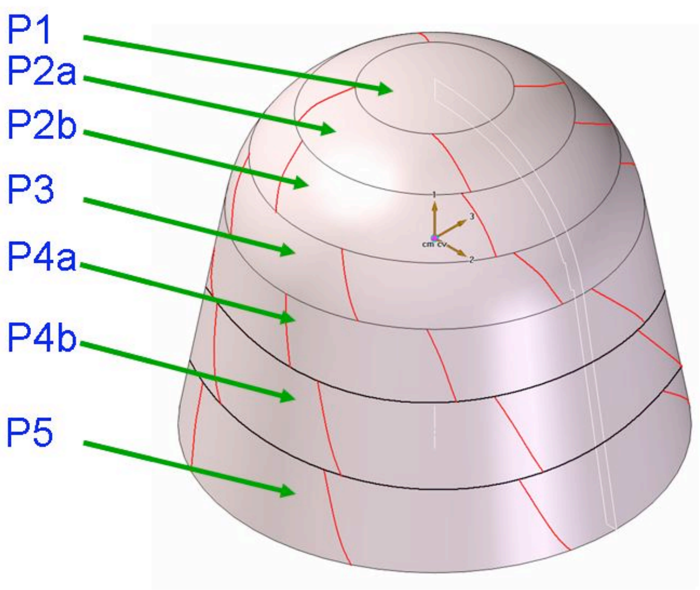
Parameter	Dispersion
EV Mass	+/- 10 %
Altitude at Periapsis (km)	+/- 1 %
Orbital Inclination	+/- 0.05 %
De-orbit ΔV	+/- 1%
True Anomaly	+/- 0.05 %
Longitude of the Ascending Node	+/- 0.05 %
C_D	+/- 4 %
Thrust (mag. & dir.)	+/- 0.3 %
Atmospheric Density	+/- 30 %

Downrange error: 167 km



Thermal Protection System

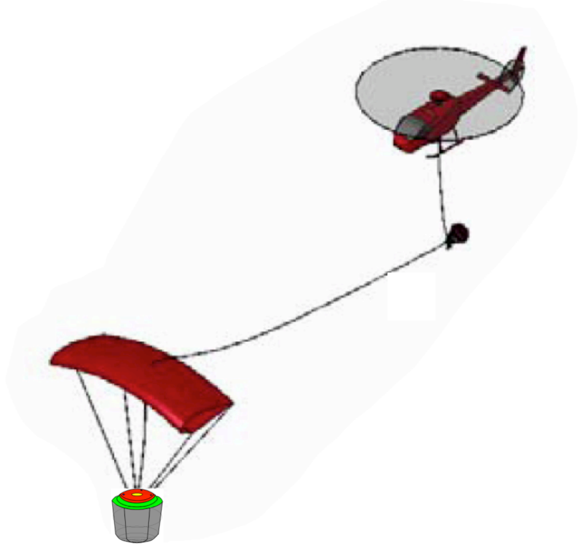
- Benign heating environment
  - Peak heat rate: 191 W/cm^2
- Tiled PICA
  - 36 total tiles (max tile dimension: 50.4 cm)
  - Gaps filled with RTV (2 mm thickness)
  - Gaps angled 25º to flow
- Backshell heating expected to be low
  - ~ 3% of stag. pt. heating (Stardust)
- Aluminum alloy carrier structure



Total TPS Mass:
36.38 kg

Decelerators and Recovery

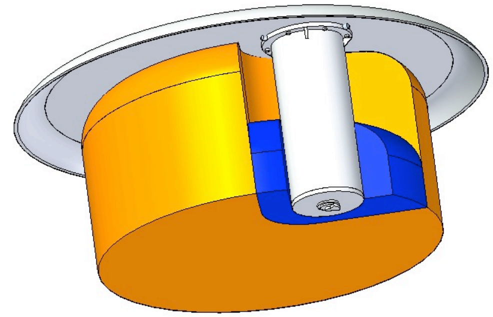
- Baseline: mid-air retrieval (Vertigo 3GMAR)
  - Heritage from 1960s (Discoverer)
  - Genesis sample return
- Three chute PRS
  - Small transonic pilot parachute
  - Stabilization and deceleration drogue
  - Engagement line attached to parafoil
- Retrieval process: three distinct events
  - Intercept
  - Engagement
  - Pickup
- Since 2005:
  - 34 MAR training missions
  - 22 end-to-end parafoil MAR missions
  - 100% success rate on 1st attempt

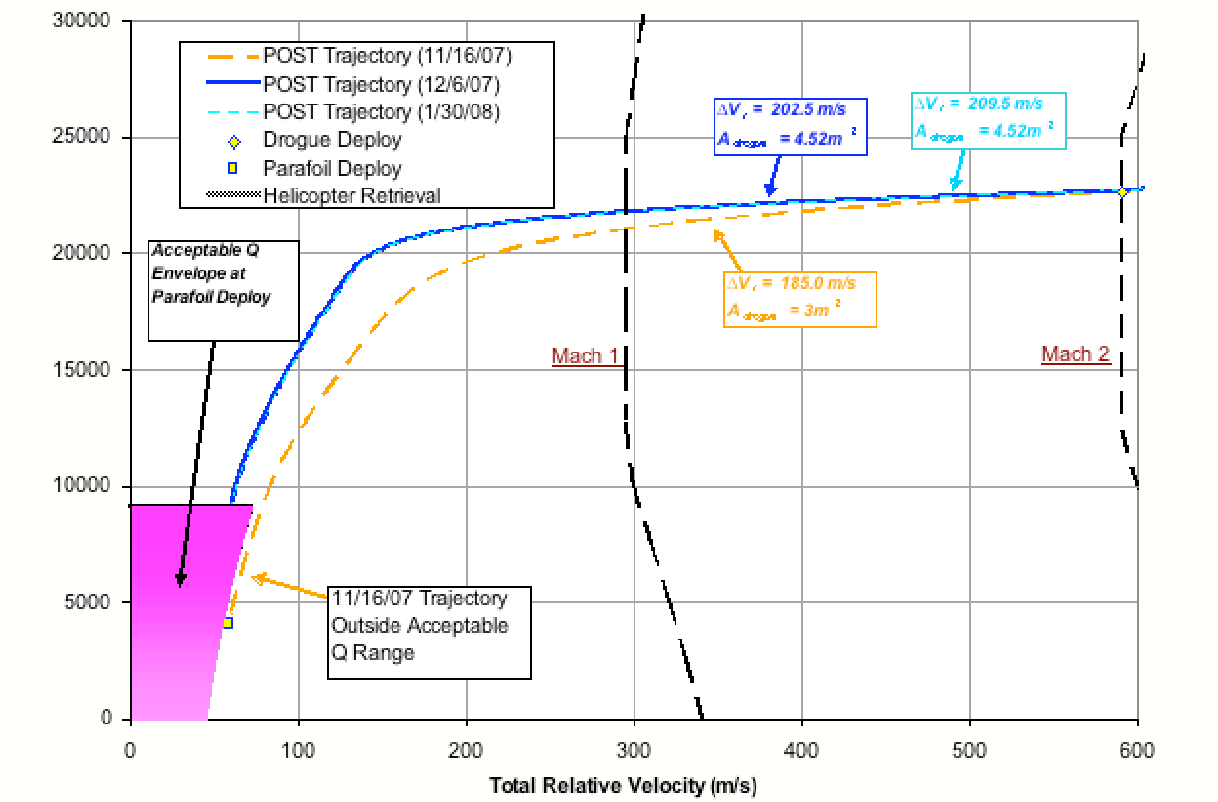


C-119J MAR of Discoverer XIV [AIAA 2005-1676]

Decelerators and Recovery

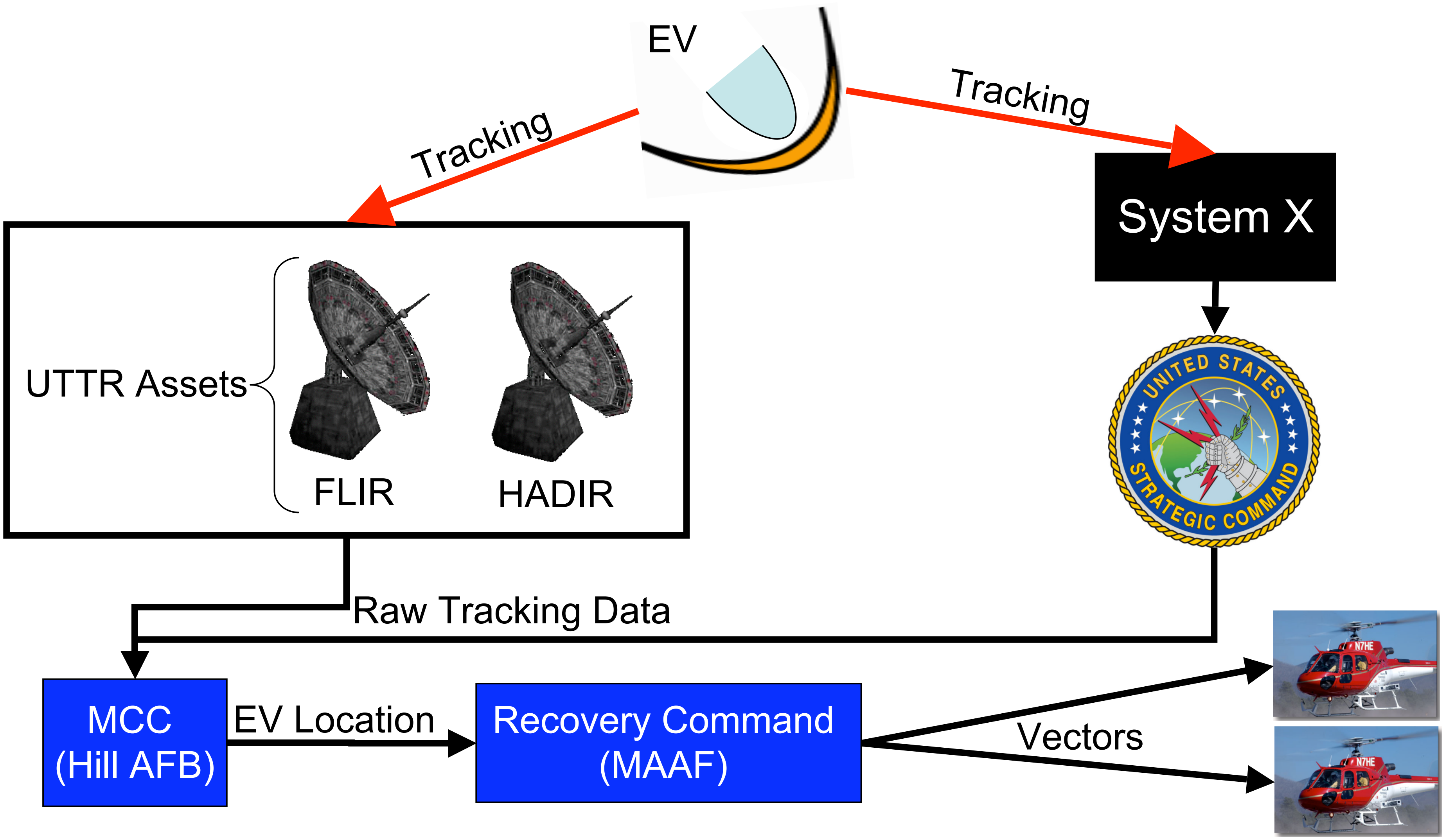
- MAR case study used for initial design point
  - 272 kg study mass vs. 260 kg MG entry mass
  - Fixed parafoil drag area (from study)
  - Optimized drogue drag area





Parameter	Value
Mortar Properties	
Diameter	0.079 m
Length	0.20 m
Mass (structure and fittings)	2.27 kg
Parachute Properties	
Drogue + Pilot + Cabling Mass	0.55 kg
Drogue Diameter (Disk -Gap-Band)	2.40 m
Drogue C_D	0.58
Parafoil Mass	4.68 kg
Parafoil Pack Volume	0.0081 m^3
Parafoil Canopy Area	22.50 m^2
Parafoil C_D	0.3
Total PRS Mass	7.49 kg

Tracking and Recovery



System Summary

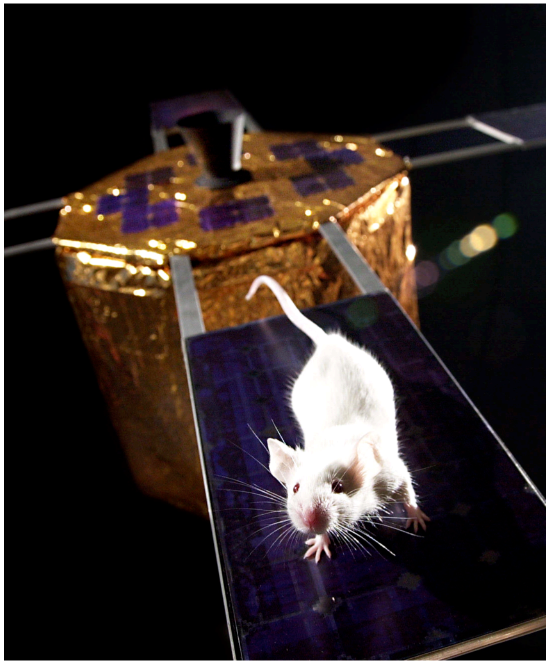
	Component	Units	Unit Mass (kg)	Total Mass (kg)	Margin	Total Mass (kg), with Margin
Structure				**46.47**		**55.05**
	Aeroshell aftbody	1	12.92	12.92	25%	16.15
	Aeroshell forebody	1	11.09	11.09	25%	13.86
	Parachute cover	1	0.5	0.5	25%	0.63
	Aeroshell bolts	4	0.18	0.72	20%	0.86
	Shear pin	3	0.08	0.24	25%	0.30
	O-Ring	4	0.25	1	25%	1.25
	Ballast	1	20	20	10%	22.00
Avionics				**0.5**		**0.63**
	Mechanical Timer	1	0.5	0.5	25%	0.63
Entry				**30.32**		**36.38**
	TPS carrier structure	1	6.4	6.4	20%	7.68
	TPS insulation	1	0	0	20%	0.00
	Forebody TPS	1	20.2	20.2	20%	24.24
	Aftbody TPS	1	3.4	3.4	20%	4.08
	TPS pyrobolts	4	0.08	0.32	20%	0.38
Descent				**7.5**		**9.00**
	Pilot-drogue-cable	1	0.55	0.55	20%	0.66
	Mortar	1	2.27	2.27	20%	2.72
	Parafoil MAR	1	4.68	4.68	20%	5.62

- 8% wiring margin applied
- Batteries for EDL power in payload

Total EDL System Mass (w/Margin): 109.15 kg

(EDL Allocation: 119 kg)

Questions?



www.marsgravity.org