



Human Mars Entry, Descent & Landing Architecture Study (EDLAS) *Rigid Decelerators*

Tara Polsgrove, Thomas Percy, Jay Garcia
NASA Marshall Space Flight Center

Alicia Dwyer Cianciolo, Jamshid Samareh, Rafael Lugo
NASA Langley Research Center

Ed Robertson, Chris Cerimele, Ron Sostaric
NASA Johnson Space Center

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Study Objectives



- **Develop two evolutionary rigid vehicle concepts to deliver human scale payloads (20 metric ton) to the surface of Mars**

- Capsule



- Lifting body, mid-range lift-to-drag ratio (Mid L/D)

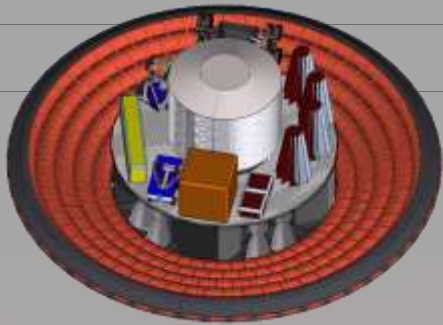


- **Determine vehicle configurations for various mission flight phases**
- **Determine vehicle performance:**
 - Integrated system mass
 - Ability to meet landing constraints
 - Payload packaging and surface access
- **Provide technology investment recommendations to NASA's Space Technology Mission Directorate**

Cargo Elements for Long Duration Surface Stay

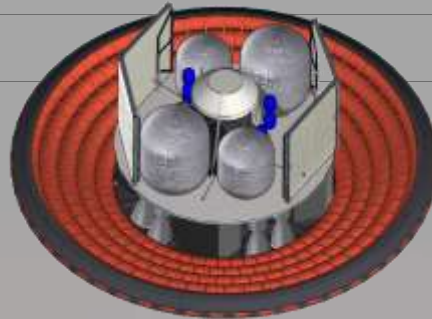


10 m diameter SLS fairing; 300 day stay; Crew of 4; Four 20 t payloads



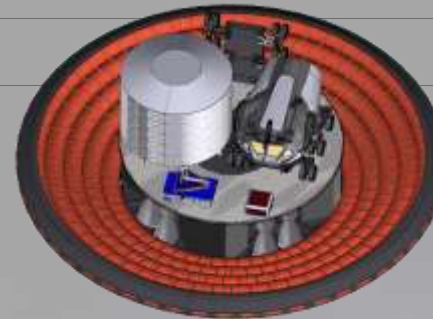
Lander 1

- Surface Power Units
- Unpressurized Rovers
- Cargo Off-loading
- Logistics Module
- Science Payloads



Lander 2

- Mars Ascent Vehicle
- Atmosphere ISRU
- Crew Access Tunnel



Lander 3

- Pressurized Rover
- Logistics module
 - Crew consumables
 - Fixed system spares
 - Mobile system spares
 - EVA spares
- Surface Mobility



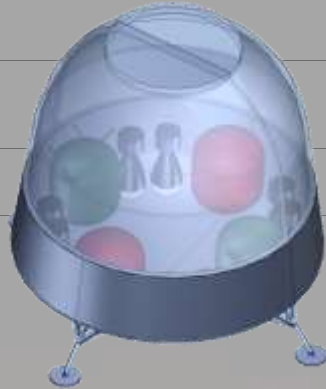
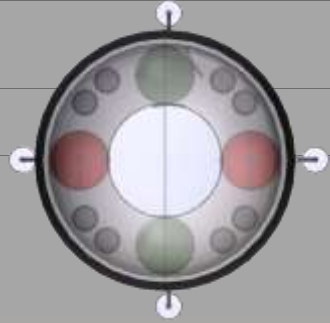
Lander 4

- Habitation

Vehicle Summaries: Capsule



Vehicle Configuration

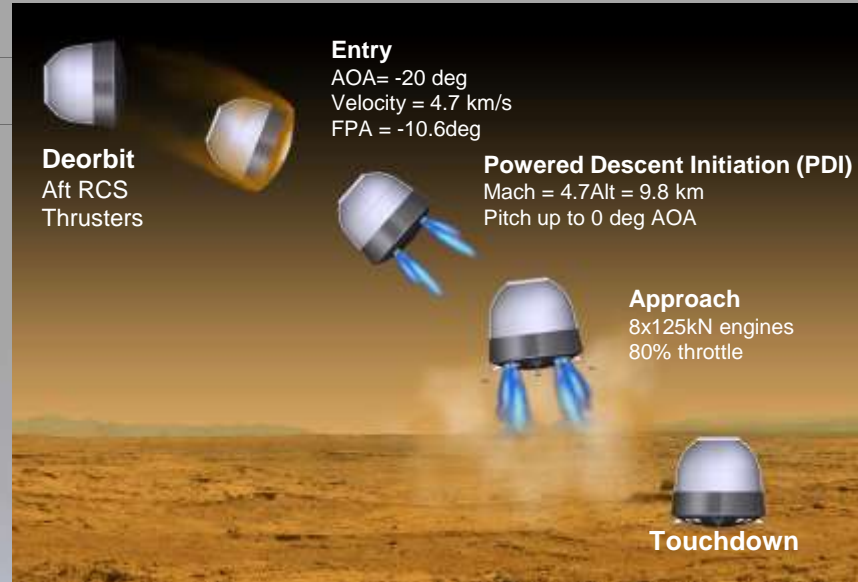


Sizing Assumptions:

- Soyuz Shape
- 3G limit during AC & EDL
- 10 m diameter heatshield - *Fairing interference, but potential to fly without a fairing*
- No Jettison events during EDL
- Ballistic coefficient = 500 kg/m²



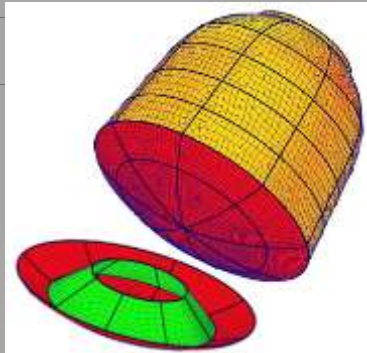
EDL Concept of Operations



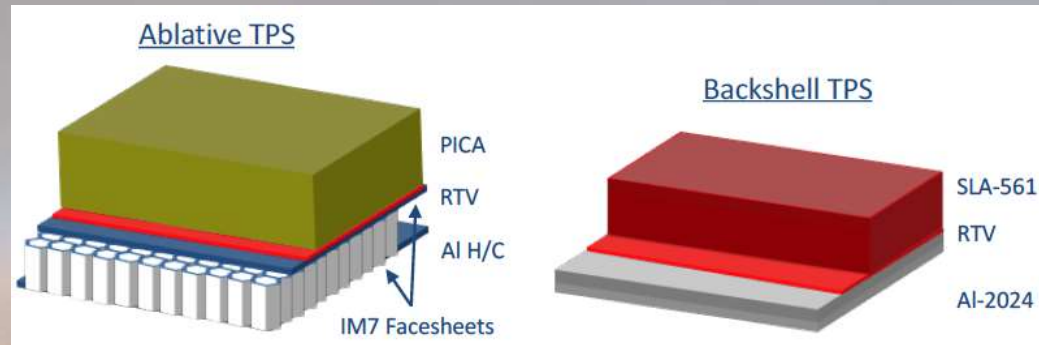
Launch to Mars Landing Vehicle Configurations

Phase 1 Launch	Phase 2 Earth Loiter & Stack Chase	Phase 3 Earth-Mars Flight	Phase 4 Mars Arrival	Phase 5 Mars Orbit Loiter	Phase 5a Crew Transfer	Phase 6 Entry, Descent & Landing	Phase 7 Surface

Capsule Mass



Subsystem	Component	Quantity	Unit Mass (kg)	CBE (kg)	MGA %	MGA (kg)	MEV (kg)
Aeroshell	Heatshield Structure + TPS	1	1,893	1,893	35%	663	2,556
	Backshell Structure + TPS	1	3,310	3,310	35%	1,158	4,469
	TOTAL						7,025

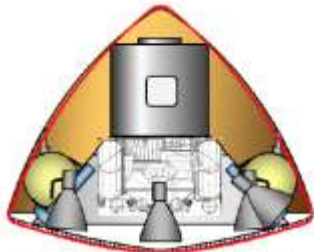


CBE = Current Best Estimate
 MGA = Mass Growth Allowance
 MEV = Maximum Expected Value

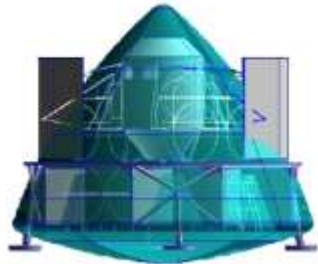
Capsule Vehicle Configurations



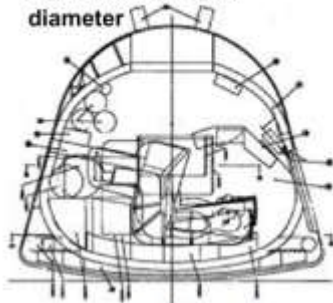
Apollo Class
(AIAA-2016-0219)



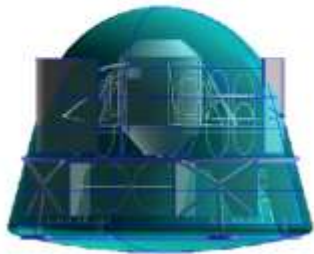
Recent studies considered heritage shapes with storable propellants (10 m diameter)



GE D-2 Apollo Concept
3.9 m (Arthur, 1963)
diameter



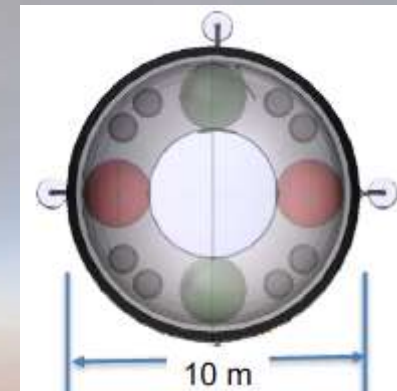
Earth human flight heritage; Shape has not flown at Mars



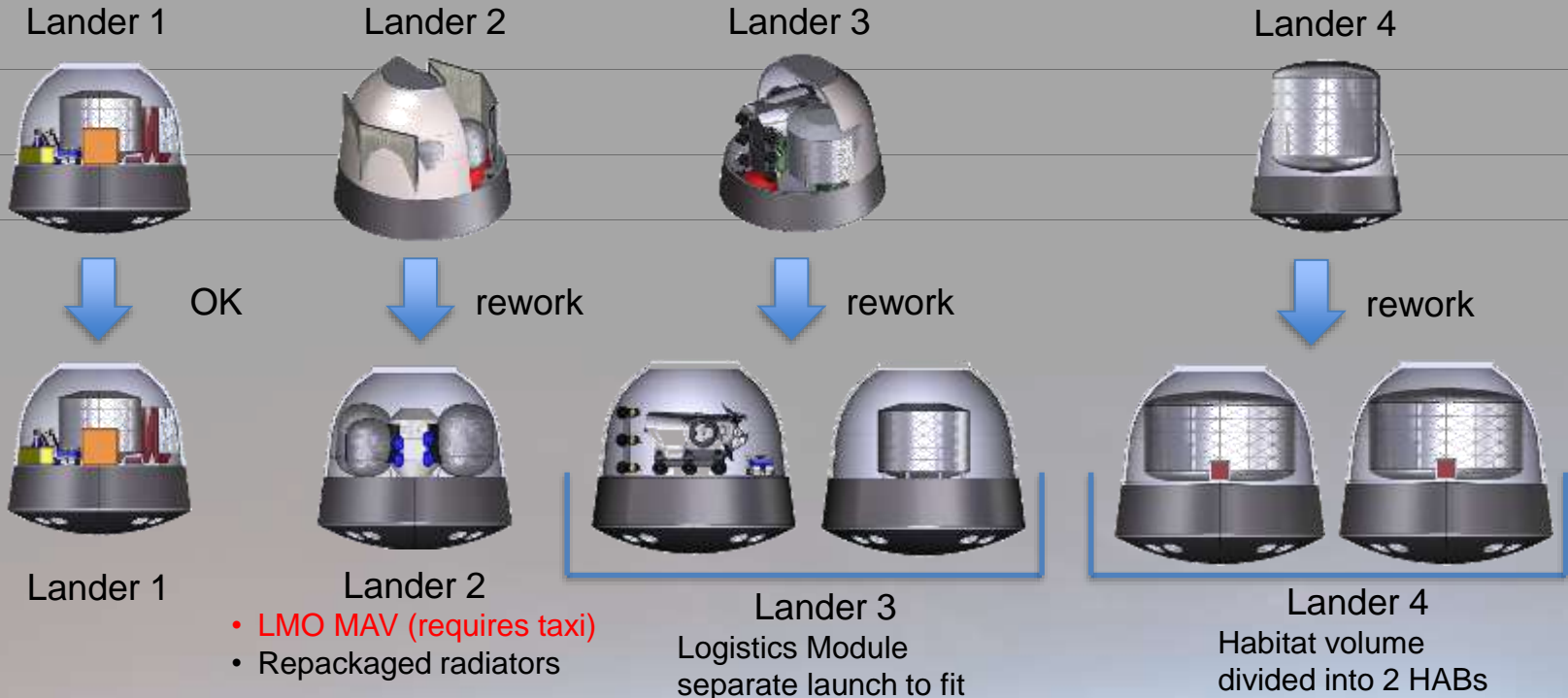
Soyuz Class



2.7 m diameter



Capsule Payload Packaging



Design impacts of adding landers

- More launches (est. 5)
- Larger landing zone
- Modular Habitat; need way to connect them on surface
- Different payload masses per mission
- Additional architecture element (taxi)
- Extended delivery schedule

Capsule Performance



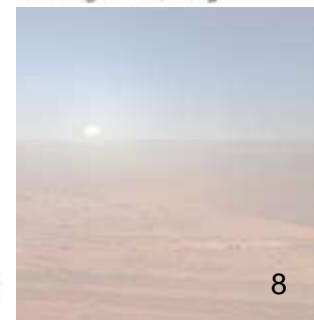
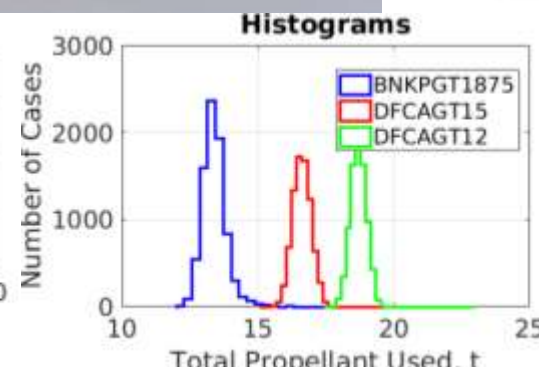
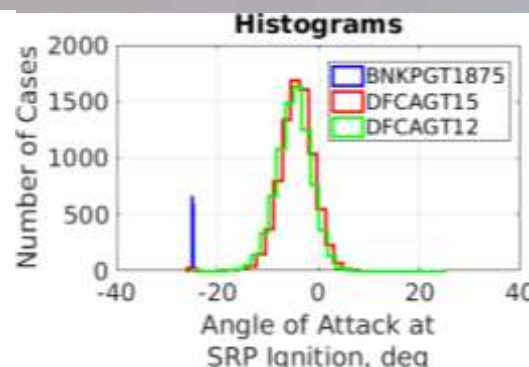
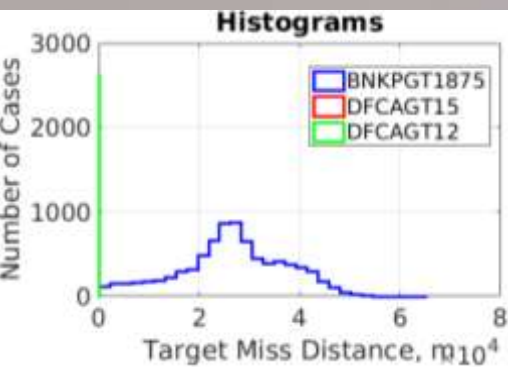
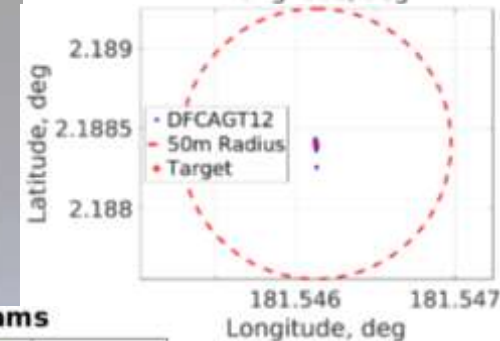
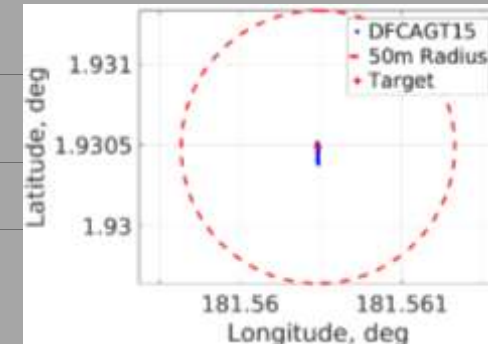
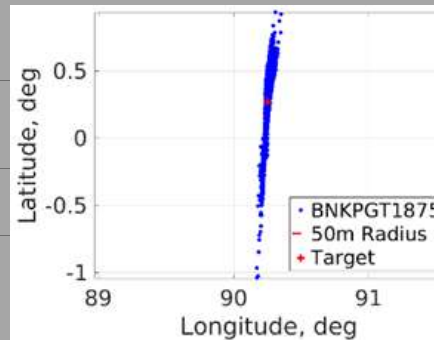
- **Landing Constraints**

- Within 50 m of a target
- At 0 km above reference areoid
- 8-100 kN engines

- **Guidance Approach:**

- Heritage Bank Angle with Pure Gravity Turn, thrust factor 1.875 (BNKPGT1875)
- Direct Force Control with Augmented Gravity Turn, thrust factor 1.5 and 1.2 (DCFAGT15 and DCFAGT12)

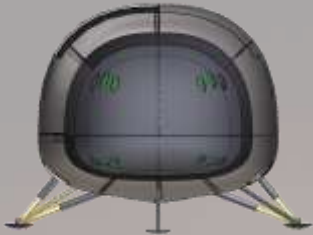
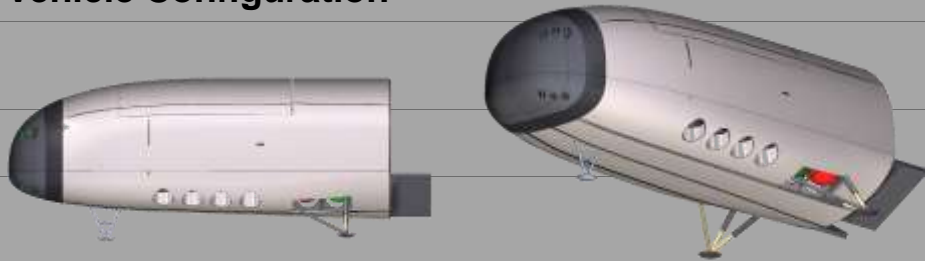
- **Results**



Vehicle Summaries: Mid L/D



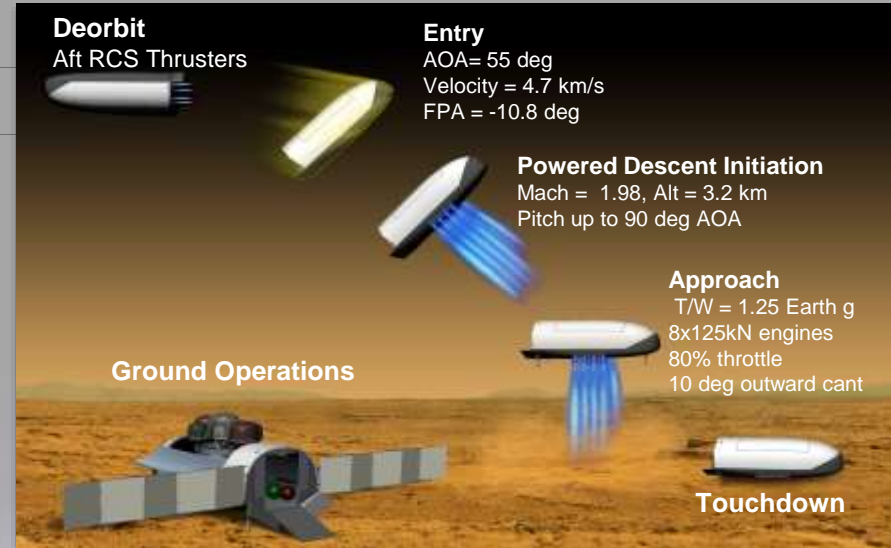
Vehicle Configuration



Sizing Assumptions:

- 5 G axial, 2 G lateral load at launch on all concepts
- ***Payload element structures need to be redesigned for horizontal launch orientation***
- 9.1 m max diameter in 10 m SLS fairing
- No Jettison events during EDL
- Ballistic coefficient = 380 kg/m²

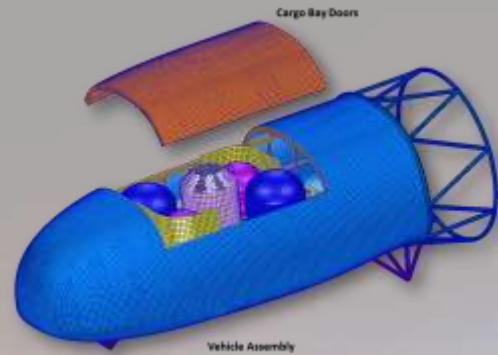
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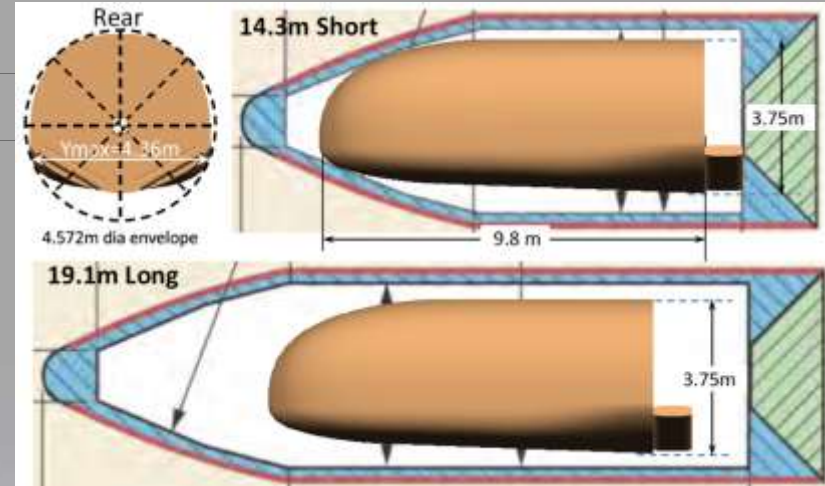
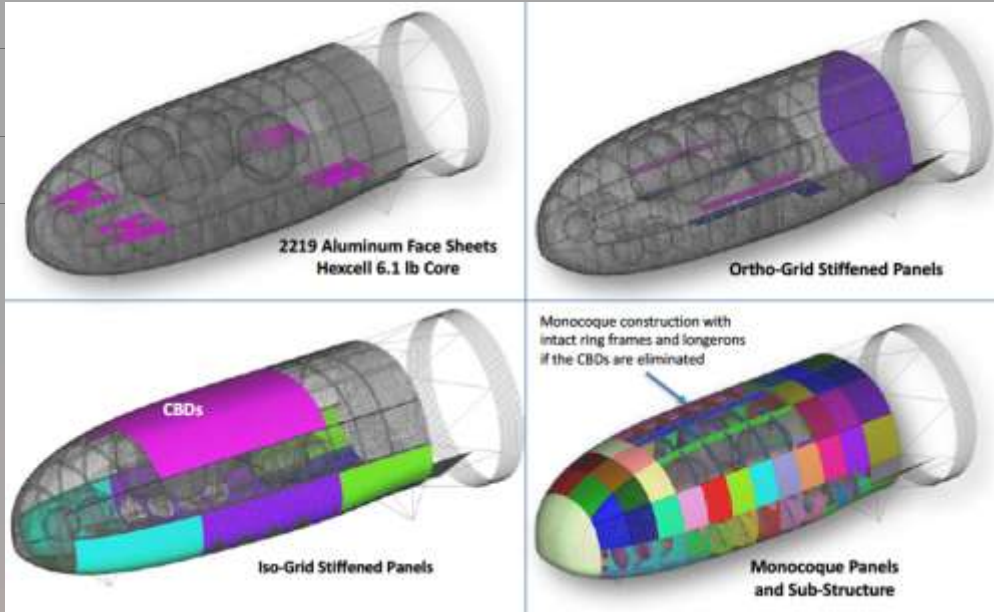
Mid L/D Mass



		Without cargo bay door			With CBD		
ID	System	Basic (kg)	MGA (%)	Predicted (kg)	Basic (kg)	MGA (%)	Predicted (kg)
1.0	Structure	12318	20.0%	14782	12970	20.0%	15564
1.1	Primary Structure	10698.4	20%	12838.1	11482.4	20%	13778.9
1.2	Secondary Structure	1619.7	20%	1943.6	1487.7	20%	1785.2
2.0	Propulsion	4241	24.1%	5263	4241	24.1%	5263
3.0	Power	953	27.7%	1217	953	27.7%	1217
4.0	Avionics	269	23.7%	333	269	23.7%	333
5.0	Thermal	675	25.0%	844	475	25.0%	594
6.0	CobraMRV	4487	22.5%	5499	4027	22.5%	4901
6.1	Thermal Protection System (TPS)	2526.8	20.0%	3032.2	2526.8	20.0%	3032.2
6.2	Aerosurfaces	400.0	30.0%	520.0	400.0	30.0%	520.0
6.3	Mechanisms	740.0	30.0%	962.0	280.0	30.0%	364.0
6.4	Landing Gear	820.5	20.0%	984.6	820.5	20.0%	984.6
DRY		22943	21.8%	27937	22935	21.5%	27871
7.0	Cargo	20000	0.0%	20000	20000	0.0%	20000
8.0	Non-Propellant	911	6.0%	966	911	6.0%	966
INERT		43854		48902	43846		48837
9.0	Usable Propellant	15018		15018	14998		14998
9.1	Usable Propellant (MPS)	9886.2		9886.2	9873.0		9873.0
9.2	Usable Propellant (RCS)	4905.3		4905.3	4898.7		4898.7
9.3	Engine Start/Stop Transient (MPS)	226.6		226.6	226.6		226.6
GROSS		58872		63921	58845		63835

CBD = Cargo Bay Doors
MGA = Mass Growth Allowance

Mid L/D Vehicle Configurations



49% scale version in the Delta IV Heavy
long and short fairings
precursor payloads up to 10t

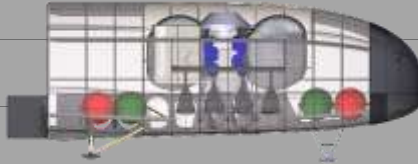
Mid L/D Payload Packaging



Lander 1



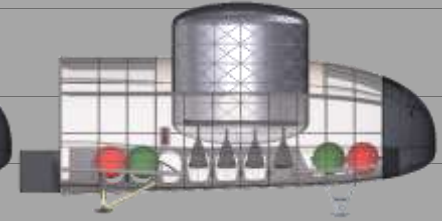
Lander 2



Lander 3



Lander 4



Design impacts

- Habitability of horizontal habitat orientation has not yet been assessed. May require more or less volume.
- Launch and landing loads on payloads are in different directions

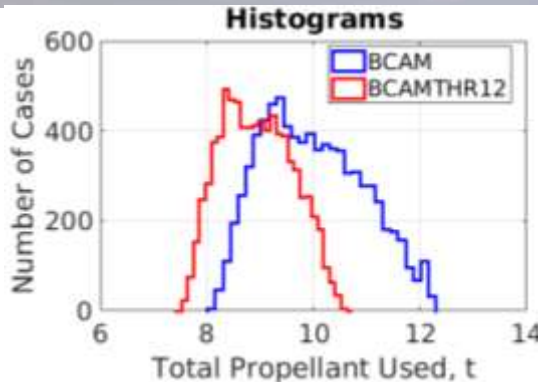
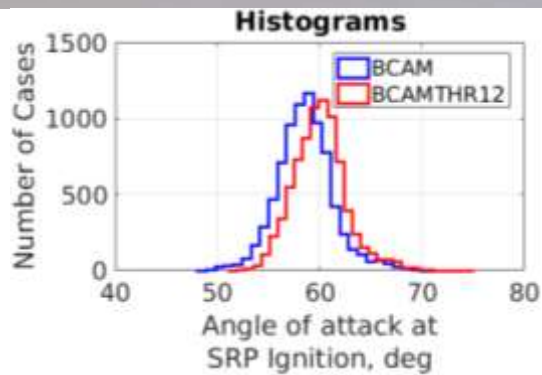
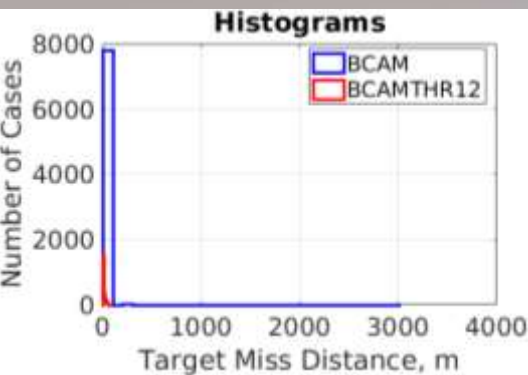
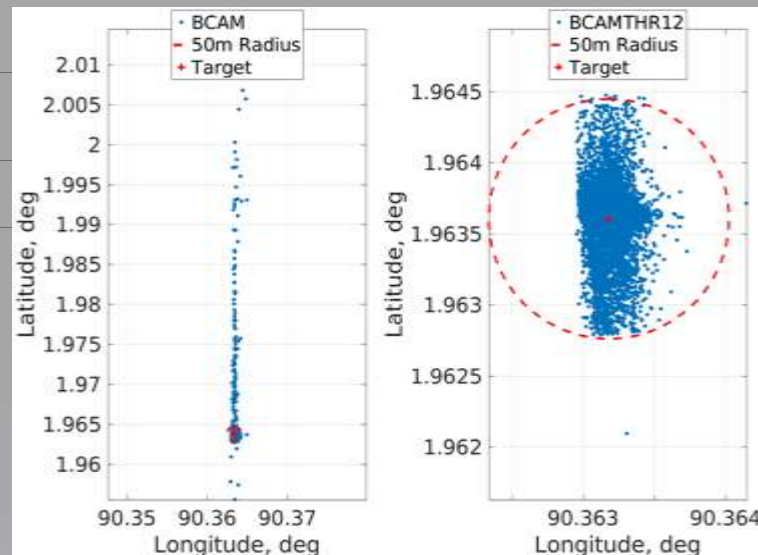


Lander 4
Habitat volume reconfigured to horizontal orientation

Mid L/D Performance



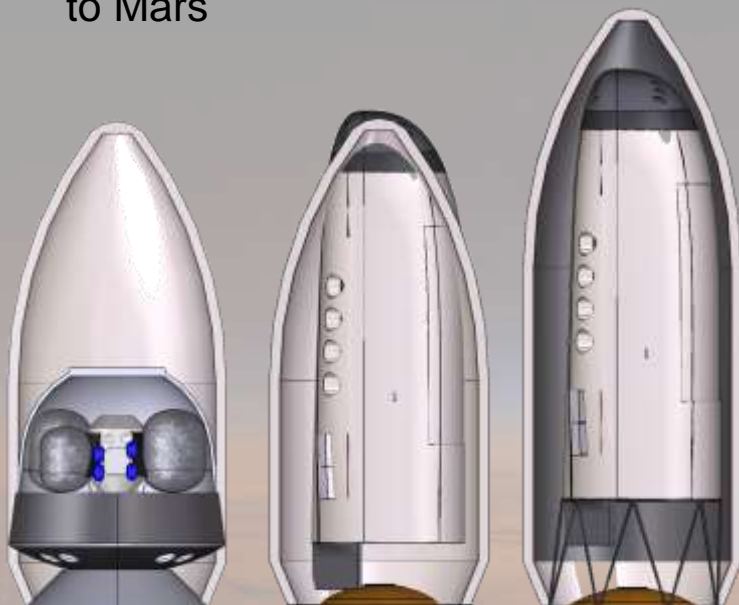
- **Landing Constraints**
 - Within 50 m of a target
 - At 0 km above reference areoid
 - 8-100 kN engines
- **Guidance Approach:**
 - Bank angle Control with Alpha Modulation (BCAM)
 - With thrust factor 1.2 (BCAMTHR12)
- **Results**



Launch Vehicle Integration



- **SLS Launch Fairing Options**
 - 10m diameter x 19 m or 27 m
- **Impacts of Flying Without a Fairing**
 - Launch vehicle aerodynamics & loads
 - Fairing subsystems carried all the way to Mars



ID	Subsystem	No CBDs No SLS PLF Predicted Mass (kg)	No CBD with SLS PLF Predicted Mass (kg)
1.0	Structures	16,066	14,782
1.1	Primary Structure	12,838	12,838
1.2	Secondary Structure	1,944	1,944
1.3	Structural Adjustment for Eliminating the PLF	1,284	0
2.0	Propulsion	5,263	5,263
3.0	Power	1,217	1,217
4.0	Avionics	333	333
5.0	Thermal	844	844
6.0	Aero decelerator	6,790	5,499
6.1	TPS	3,032	3,032
6.2	Aerosurfaces	520	520
6.3	Mechanisms	962	962
6.4	Landing Gear	985	985
6.5	SLS PLF-Specific Components	1,292	0
Dry Mass		30,513	27,938
7.0	Cargo	20,000	20,000
8.0	Non-Propelled Fluids	966	966
Inert Mass		51,479	48,904
9.0	Used Propellant	15,797	15,018
9.1	Usable Propellant (MPS)	10,407	9,886
9.2	Usable Propellant (RCS)	5,163	4,905
9.3	Engine Start/Stop Transients (MPS)	227	227
Total Stage Gross Launch Mass		67,276	63,922

**3.3 t heavier
without fairing**

Integrated Vehicle Mass



ID	Subsystem	Capsule	CobraMRV
1.0	Structures	5,422	14,836
2.0	Propulsion	5,215	5,190
3.0	Power	1,568	1,568
4.0	Avionics	333	333
5.0	Thermal	218	844
6.0	Aero decelerator	7,025	5,499
Dry Mass		19,781	28,270
7.0	Cargo	20,000	20,000
8.0	Non-Propelled Fluids	1,965	1,523
Inert Mass		41,746	49,793
9.0	Used Propellant	26,531	16,399
Total Stage Gross Launch Mass		68,277	66,192

Recommendations



- **Down select to one rigid vehicle design: Mid L/D**
 - Payload Packaging
- **Determine the effects of different launch and landing load paths on payload structural design**
- **Perform extensive CFD analysis on SRP initiation and surface interaction phase**
- **Define *EDL GN&C sensor requirements* matrix (performance and software requirements and vehicle accommodation)**



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MARS

