National Aeronautics and Space Administration

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

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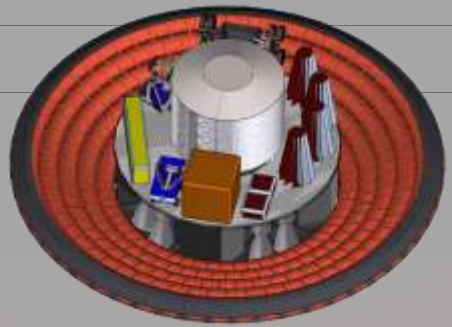
Study Objectives

- **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**

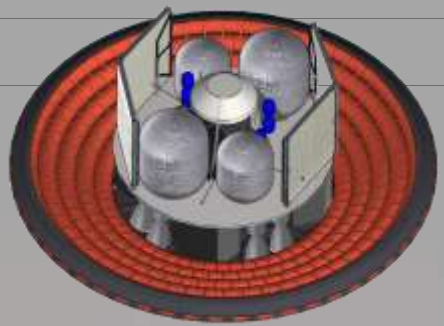
Cargo Elements for Long Duration Surface Stay

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



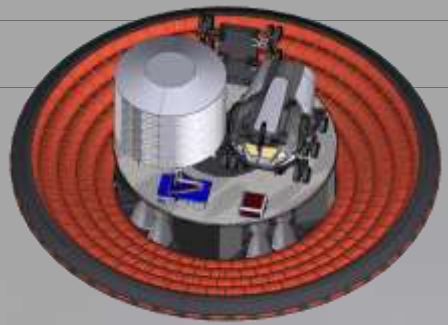
Lander 1

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



Lander 2

- Mars Ascent Vehicle
- Atmosphere ISRU
- Crew Access Tunnel



Lander 3

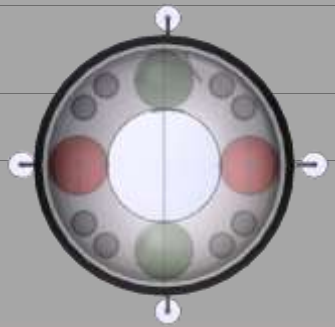
- Pressurized Rover
- Logistics module
  - Crew consumables
  - Fixed system spares
  - Mobile system spares
  - EVA spares
- Surface Mobility

Lander 4

- Habitation

Vehicle Summaries: Capsule

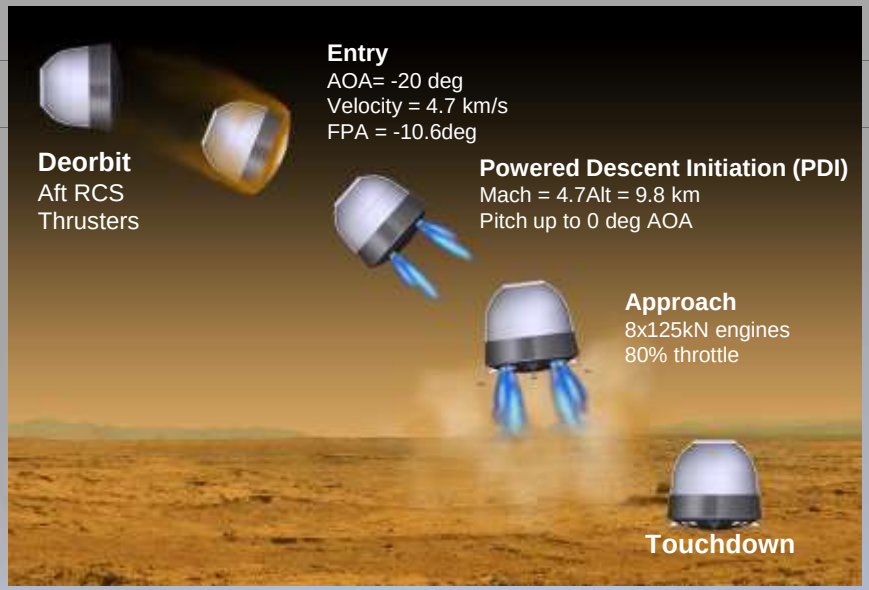
Vehicle Configuration



Sizing Assumptions:

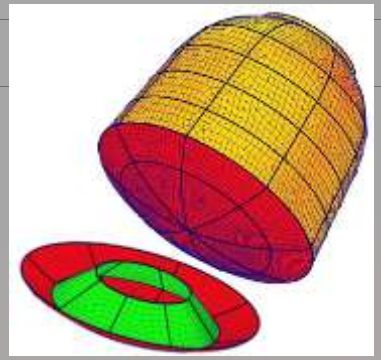
- Soyuz Shape
- 3G limit during AC & EDL
- 10 m diameter heatshield - ***Fairing interference, but potential to fly without a fairing***
- No Jettison events during EDL
- Ballistic coefficient = 500 kg/m^2

EDL Concept of Operations

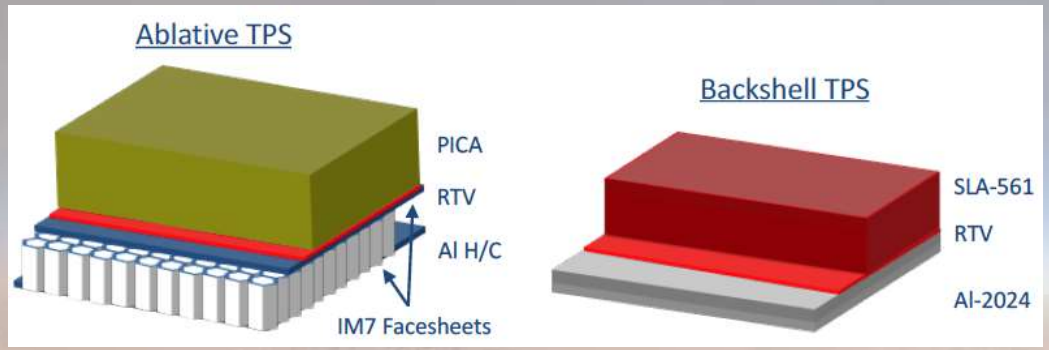


Launch to Mars Landing Vehicle Configurations

Capsule Mass

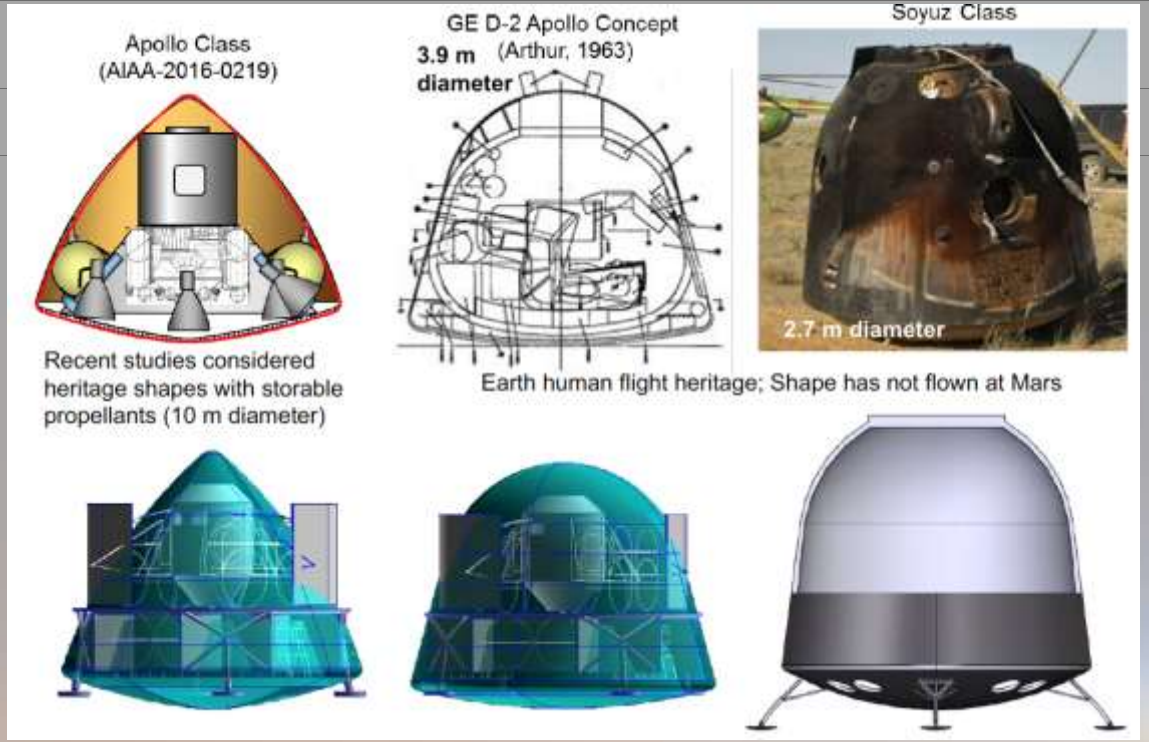


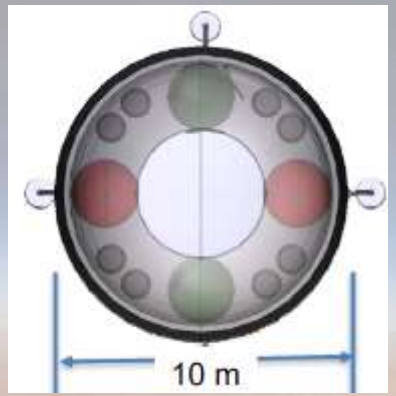
Subsystem	Component	Quantity	Unit Mass (kg)	CBE (kg)	MGA %	MGA (kg)	MEV (kg)
Aeroshell	Heatshield Structure + TPS	1	1,893	1,893	35%	663	2,556
	Backshell Structure + TPS	1	3,310	3,310	35%	1,158	4,469
	TOTAL						7,025



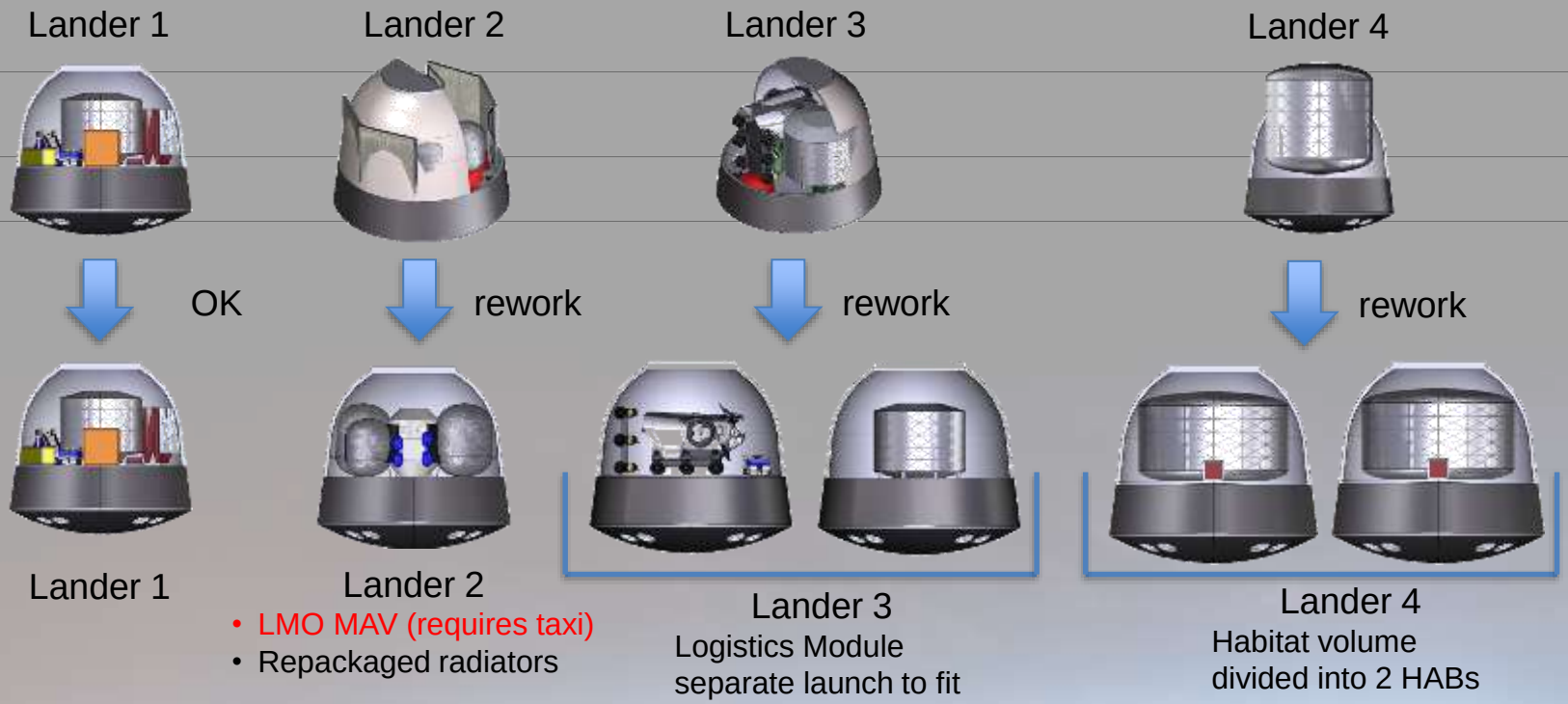
CBE = Current Best Estimate
MGA = Mass Growth Allowance
MEV = Maximum Expected Value

Capsule Vehicle Configurations





Capsule Payload Packaging

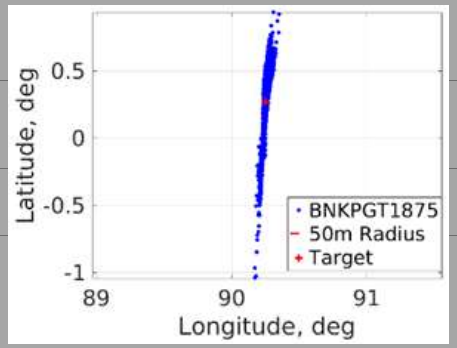


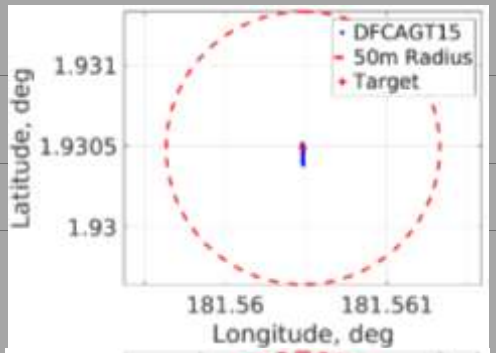
Design impacts of adding landers

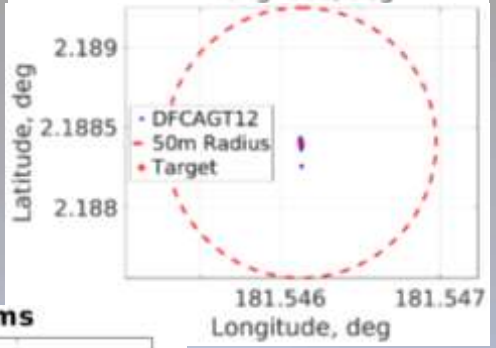
- More launches (est. 5)
- Larger landing zone
- Modular Habitat; need way to connect them on surface
- Different payload masses per mission
- Additional architecture element (taxi)
- Extended delivery schedule

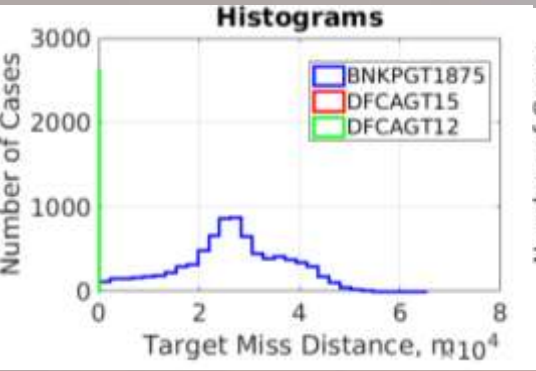
Capsule Performance

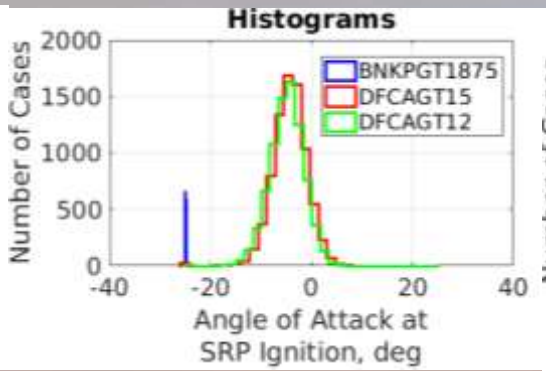
- **Landing Constraints**
  - Within 50 m of a target
  - At 0 km above reference areoid
  - 8-100 kN engines
- **Guidance Approach:**
  - Heritage Bank Angle with Pure Gravity Turn, thrust factor 1.875 (BNKPGT1875)
  - Direct Force Control with Augmented Gravity Turn, thrust factor 1.5 and 1.2 (DCFAGT15 and DCFAGT12)
- **Results**

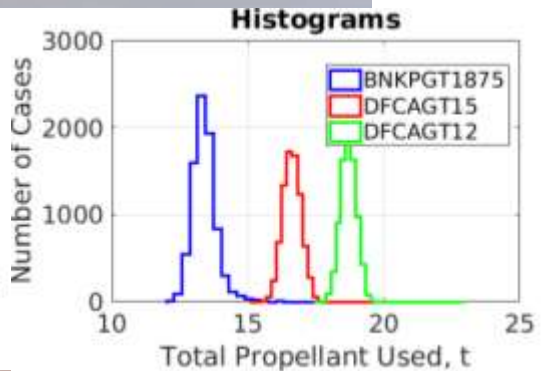












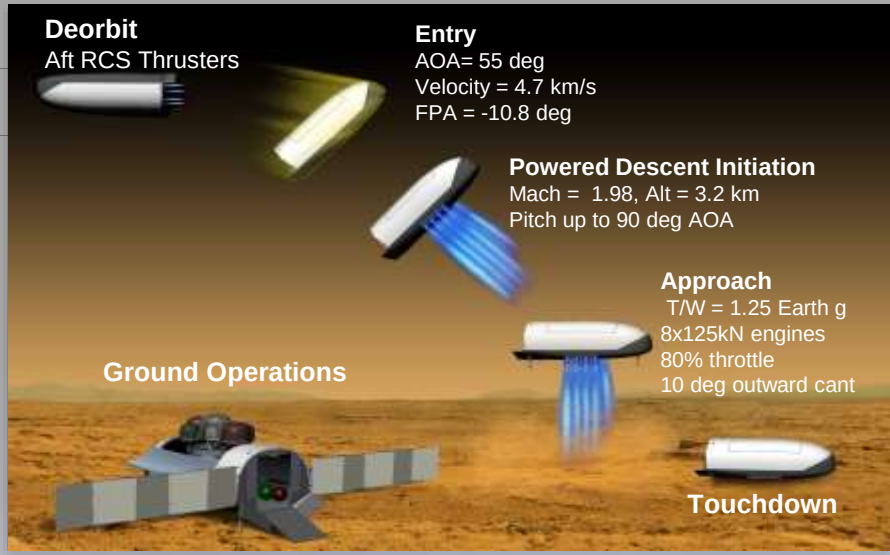
Vehicle Summaries: Mid L/D

Vehicle Configuration

Sizing Assumptions:

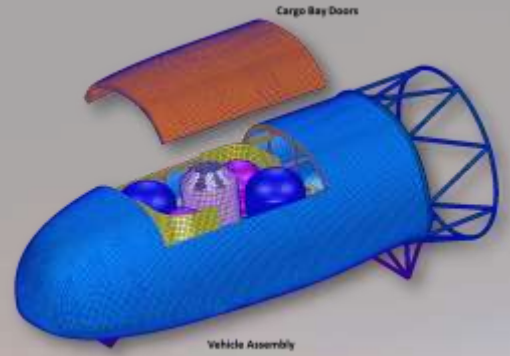
- 5 G axial, 2 G lateral load at launch on all concepts
- ***Payload element structures need to be redesigned for horizontal launch orientation***
- 9.1 m max diameter in 10 m SLS fairing
- No Jettison events during EDL
- Ballistic coefficient = 380 kg/m^2

EDL Concept of Operations



Launch to Mars Landing Vehicle Configurations

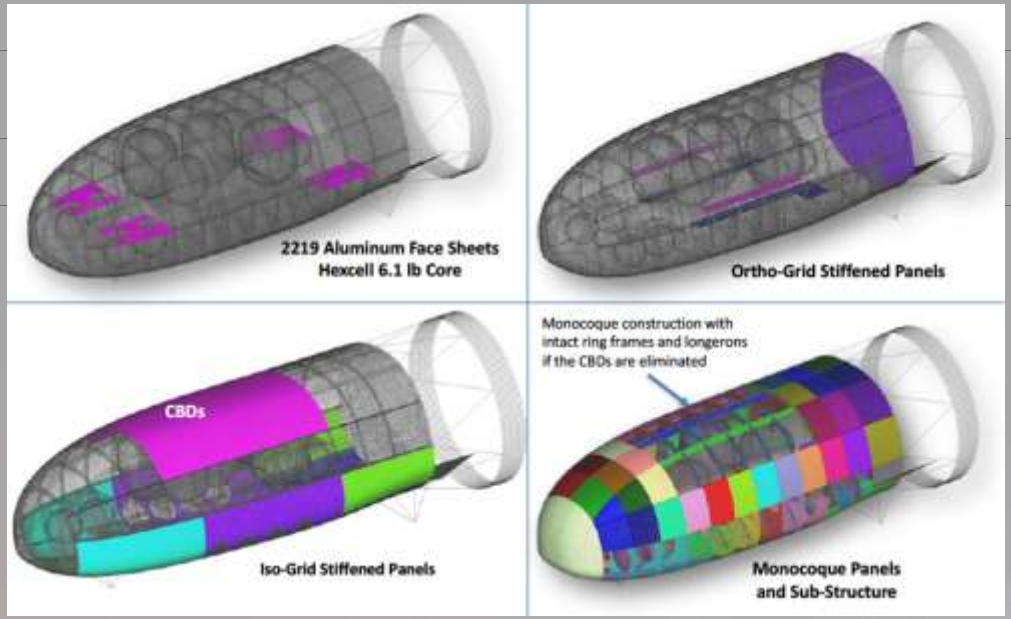
Mid L/D Mass

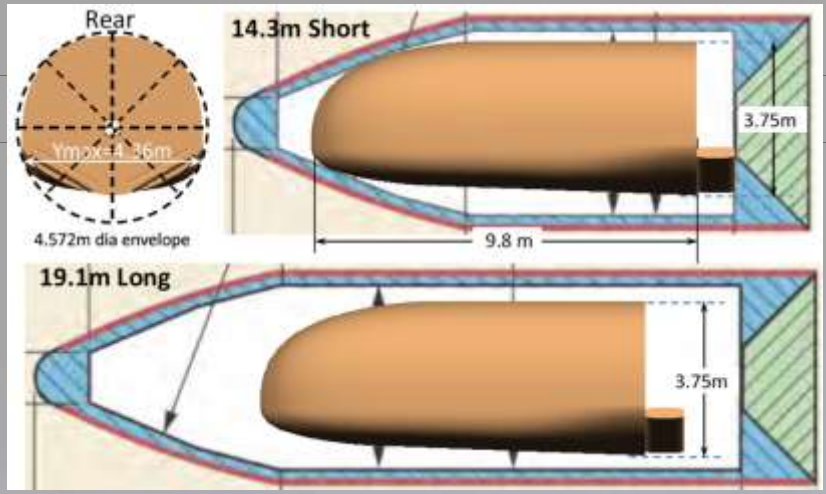


		Without cargo bay door				With CBD		
ID	**System**	**Basic (kg)**	**MGA (%)**	**Predicted (kg)**		**Basic (kg)**	**MGA (%)**	**Predicted (kg)**
1.0	**Structure**	**12318**	20.0%	**14782**		**12970**	20.0%	**15564**
1.1	*Primary Structure*	*10698.4*	*20%*	*12838.1*		*11482.4*	*20%*	*13778.9*
1.2	*Secondary 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

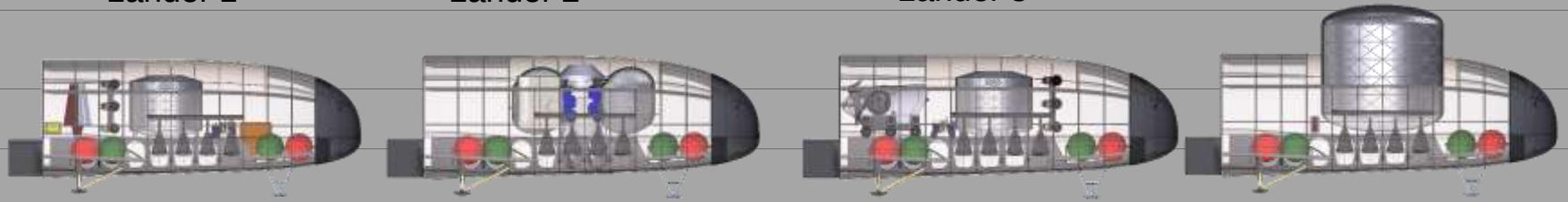




49% scale version in the Delta IV Heavy long and short fairings
precursor payloads up to 10t

Mid L/D Payload Packaging

Lander 1 | Lander 2 | Lander 3 | Lander 4



rework

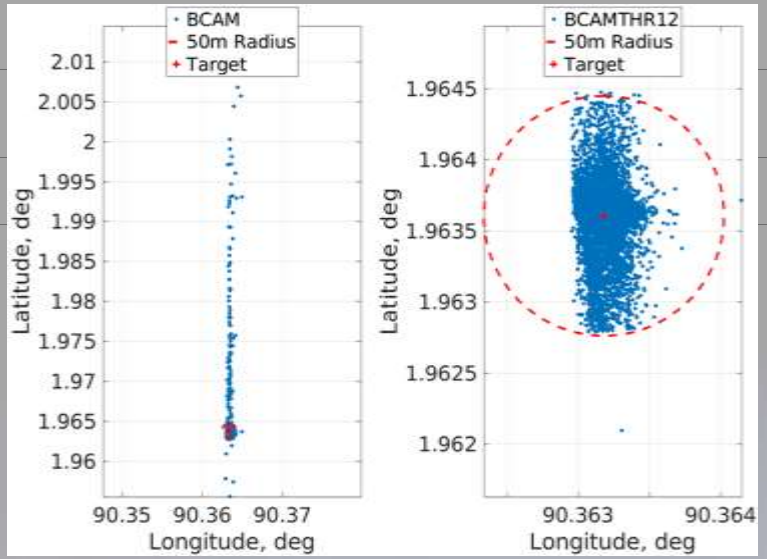
Design impacts

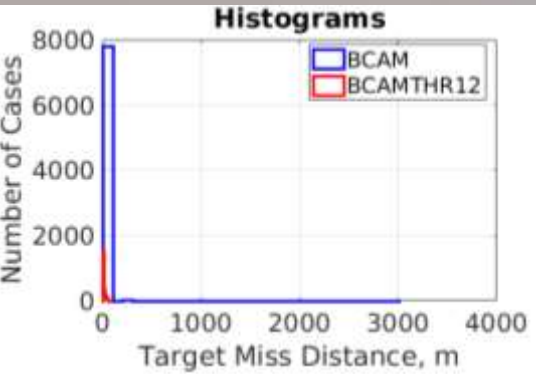
- Habitability of horizontal habitat orientation has not yet been assessed. May require more or less volume.
- Launch and landing loads on payloads are in different directions

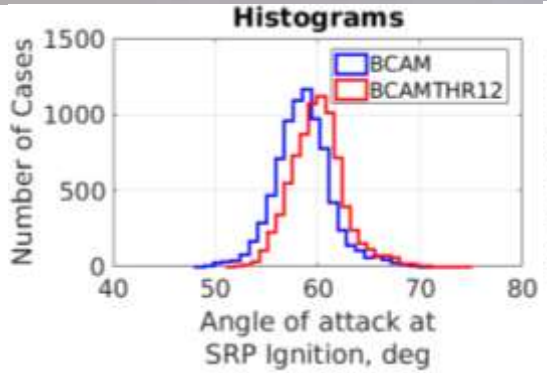
Lander 4
Habitat volume reconfigured to horizontal orientation

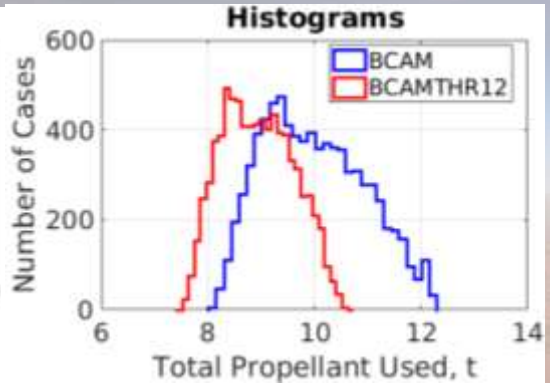
Mid L/D Performance

- **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**



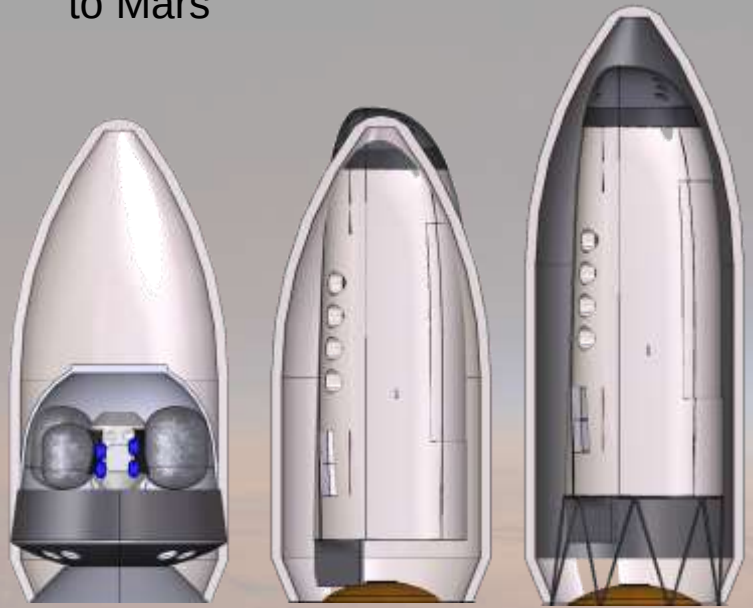






Launch Vehicle Integration

- **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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