Jet Propulsion Laboratory
California Institute of Technology

EDL Flight Performance Challenge And Mitigation Strategies For Mars Sample Return Planning

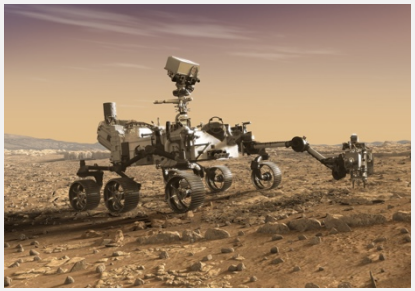
Mark Ivanov, JPL
EDL Flight Mechanics SRL Study Lead +
Aerosciences SRL Study Coordinator

July 9, 2019 (IPPW-2019)

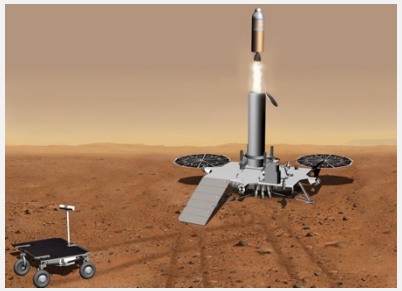
The decision to implement Mars Sample Return will not be made until NASA's completion of the National Environment Policy Act (NEPA) process. This document is being made available for information purposes only.

Mars Sample Return (MSR) Study Campaign Architecture Elements

- **Three flight elements and one ground element**

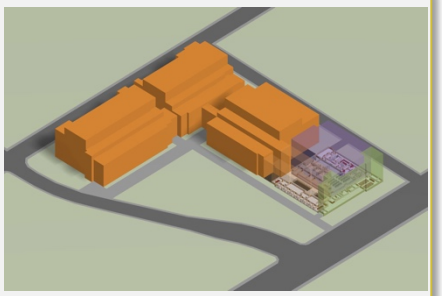


Sample Caching Rover (Mars 2020)
- *Sample acquisition and caching*



Sample Retrieval Lander (SRL)
- *Fetch Rover*
- *Orbiting Sample container (OS)*
- *Mars Ascent Vehicle*

Earth Return Orbiter
- *Capture/Containment Module*
- *Earth Return Module*



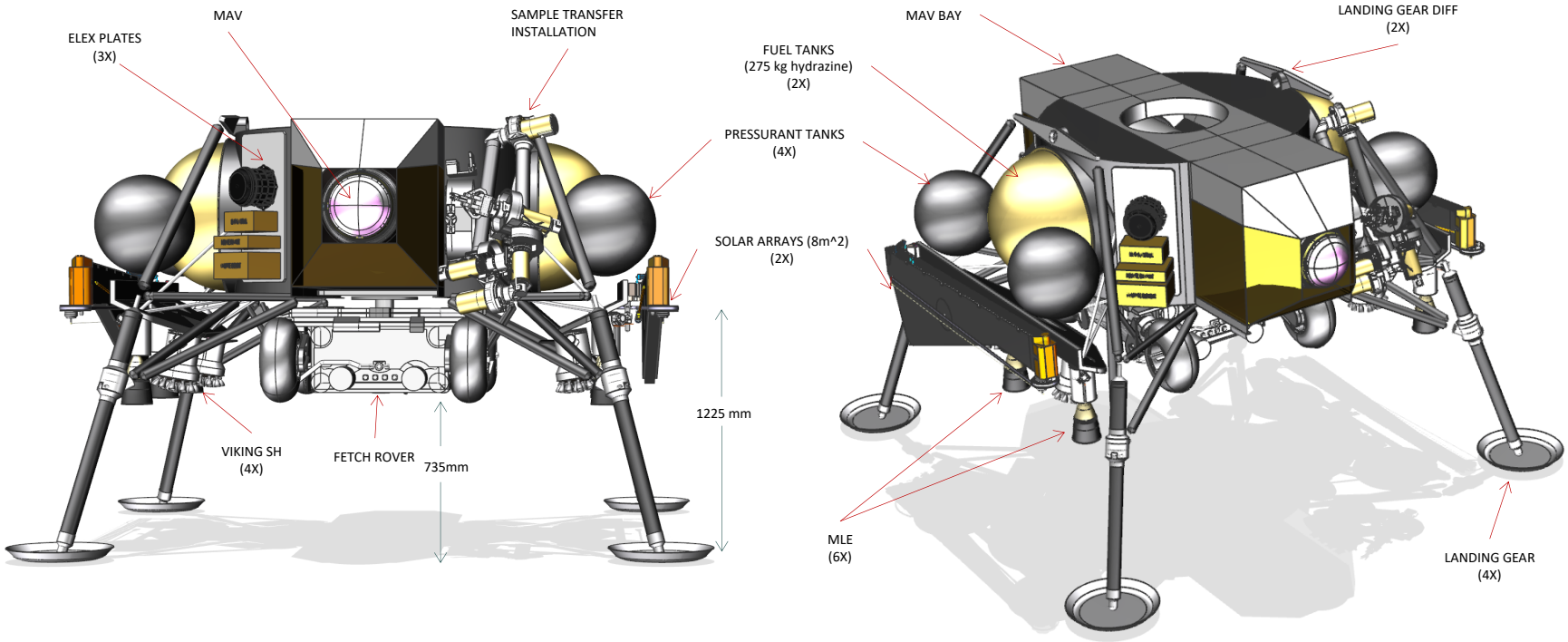
Mars Returned Sample Handling
- *Sample Receiving Facility*
- *Curation*
- *Sample science investigations*

Flight Elements

Ground Element

Concept Drawing(s) Shown

Reference Baseline SRL Lander

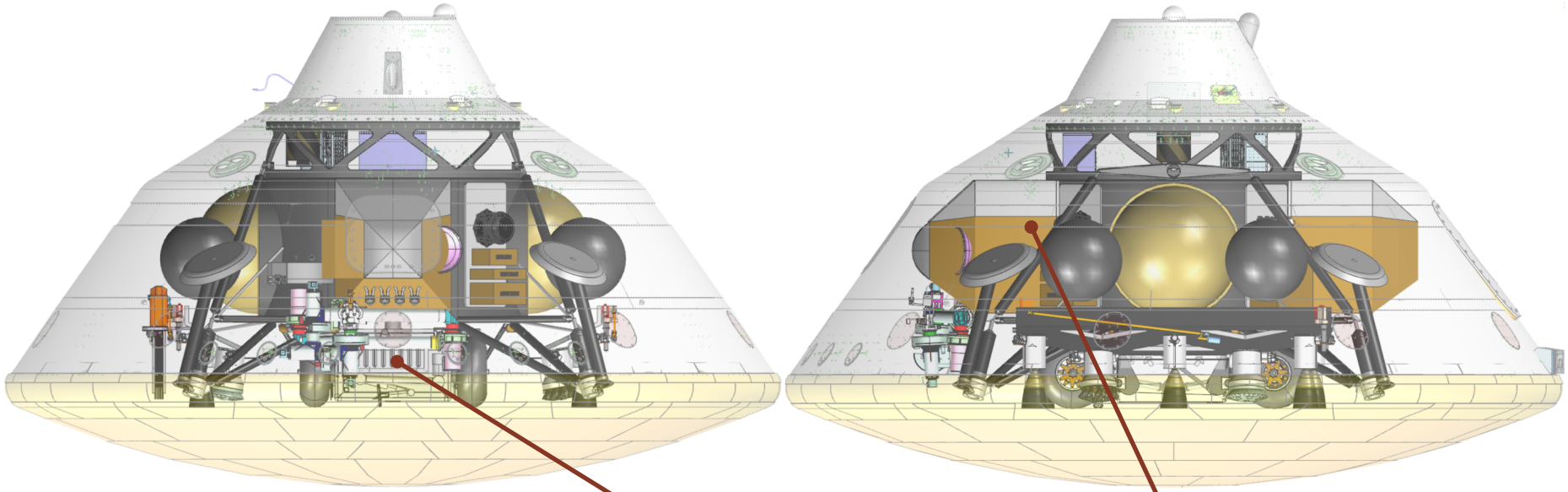


- **Currently Configured As A Powered Lander (vs Skycrane Delivered)**
- **Lander Mass (with Fuel): ~2300 kg With Growth Allowance To 2650 kg**

****** ~ +500 kg Extra EDL Lander Mass Needed Over MSL/M2020 ******
****** EDL Performance Augmentations Will Be Needed ******

Concept Drawing(s) Shown

Notional Mars Entry Configuration



Spherical Orion Style 4.7m Heatshield

Stowed Rover

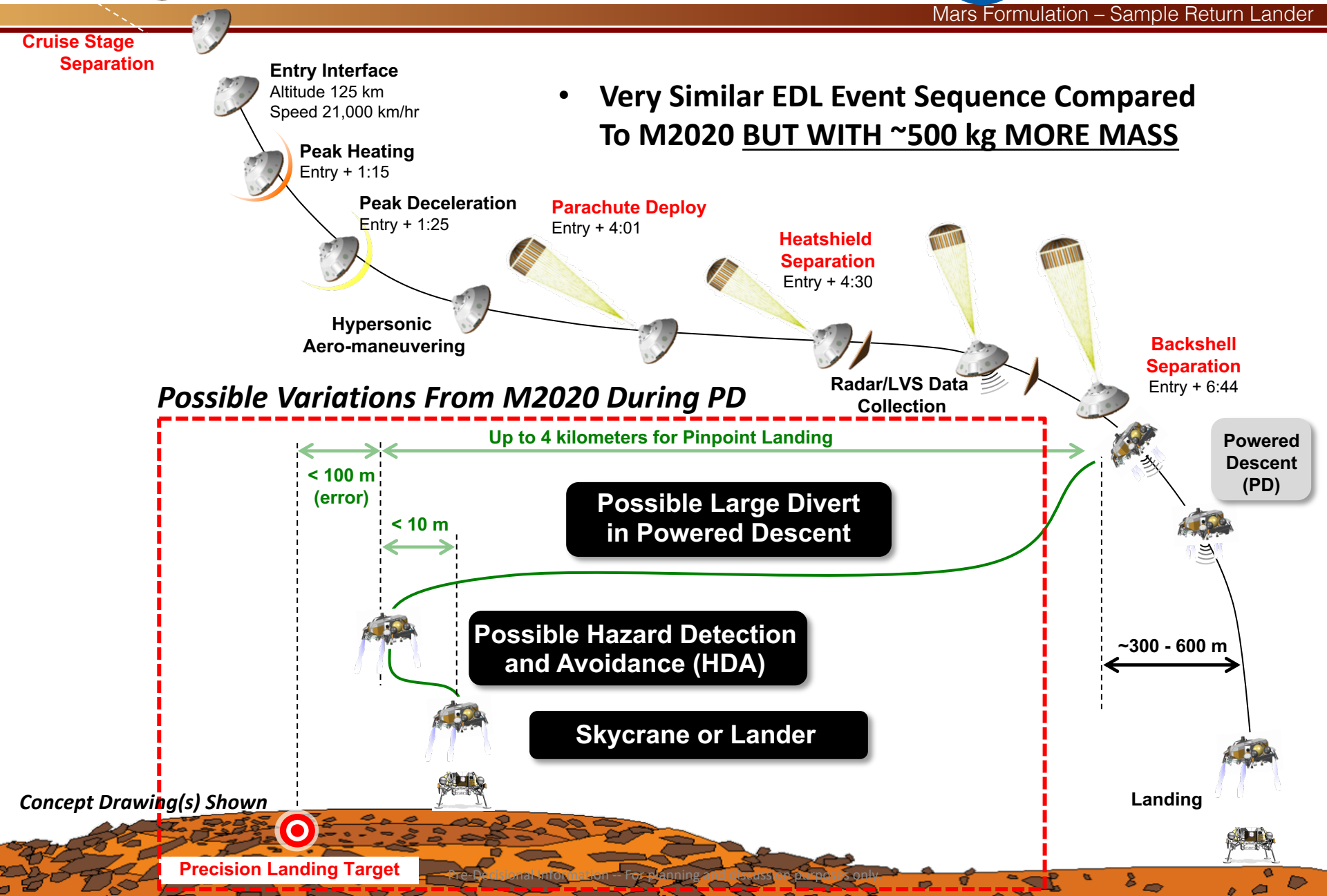
Stowed MAV

Total Entry Mass ~4000 kg
(MSL/M2020 ~3500 kg)

Concept Drawing(s) Shown

Notional SRL EDL CONOPS

- **Very Similar EDL Event Sequence Compared To M2020 <u>BUT WITH ~500 kg MORE MASS</u>**

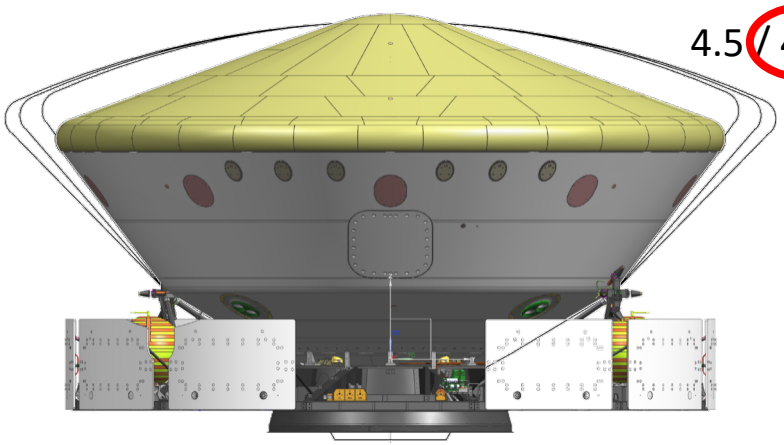


Pre-Decisional Information – For planning and discussion purposes only

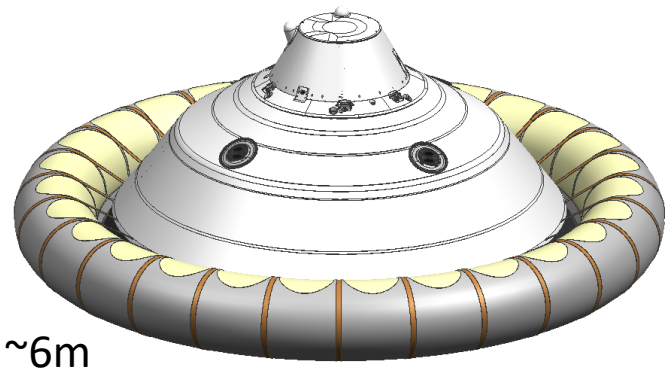
Possible Hypersonic Augmentations

Larger Diameter Aeroshell With Spherical Heatshield & Extended Backshell

4.5 / 4.7 / 5.0 / 5.2m

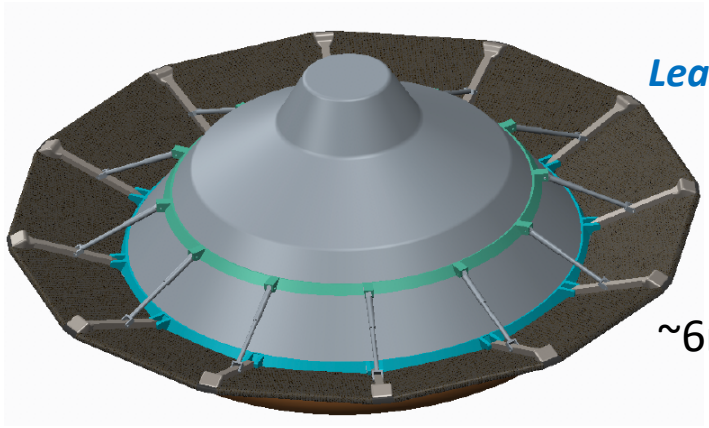


"Small" Hypersonic Inflatable Aerodynamic Decelerator (HIAD)



~6m

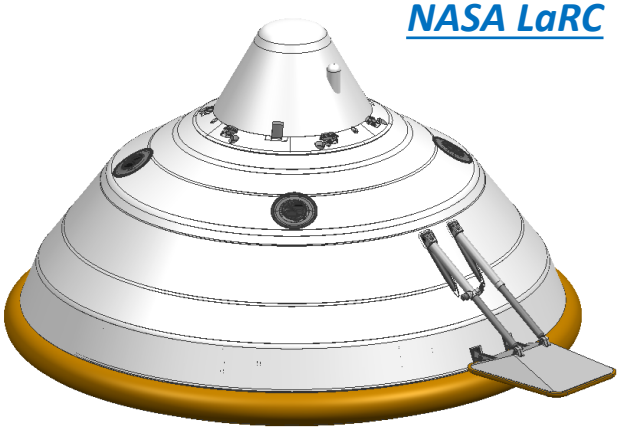
Lead Collaborator: NASA LaRC



Lead Collaborator: NASA Ames

~6m

Deployable Drag Skirt

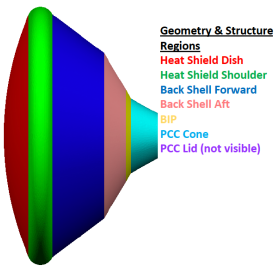


Trim Tab(s)

Concept Drawing(s) Shown

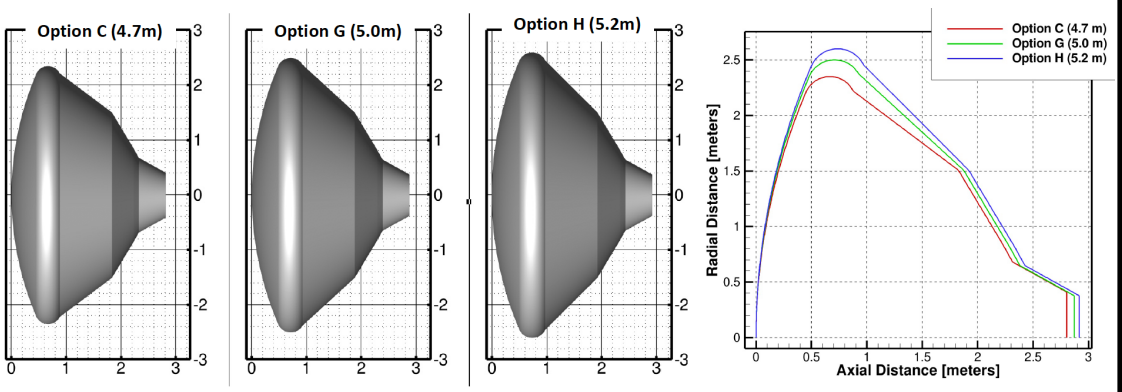
Hypersonic: Larger Aeroshell

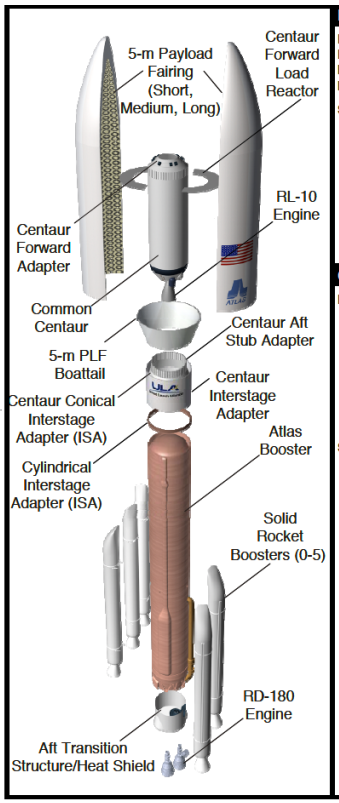
- Spherical heatshield reduces heating
- Spherical heatshield + larger aeroshell improves packing density
- Larger aeroshell reduces entry Bc
- Caveat: Would have to fit inside current launch vehicle fairing sizes
  - Upper limit ~5.0m??



Location	TPS Material	MSL Thickness, inches	SRL July Trajectory Thickness, inches	SRL October Trajectory Thickness, inches
HS Dish	PICA	1.25	1.05	0.95
HS Shoulder	PICA	1.25	1.14	1.05
BS Forward	SLA-561V	0.5	0.41	0.36
BS Aft	SLA-561V	0.5	0.29	0.27
BIP	Acusil II	0.96	0.86	0.83
PCC Cone	Acusil II	0.69	0.67	0.61
PCC Lid	Acusil II	0.79	0.45	0.43

Aerothermal graphics/analysis courtesy of NASA Ames





PAYLOAD FAIRING (PLF)

Features	5-m Short	5-m Medium	5-m Long
Diameter:	5.4-m (213-in)	5.4-m (213-in)	5.4-m (213-in)
Length:	20.7-m (815-in)	23.4-m (921-in)	26.5-m (1043-in)
Mass:	3,524-kg (7,769-lbs)	4,003 kg (8,825 lbs)	4,379 kg (9,654 lbs)

Subsystems

Fairing: Bisector; Sandwich Construction with Graphite Epoxy Face Sheets & an Aluminum Honeycomb Core
Boattail: Fixed, Composite Sandwich Const
Separation: Vertical Separation by a Linear Piston & Cylinder Activated by a Pyrotechnic Cord; Horizontal Separation by an Expanding Tube Shearing a Notched Frame, Activated by a Pyrotechnic Cord

COMMON CENTAUR

Features

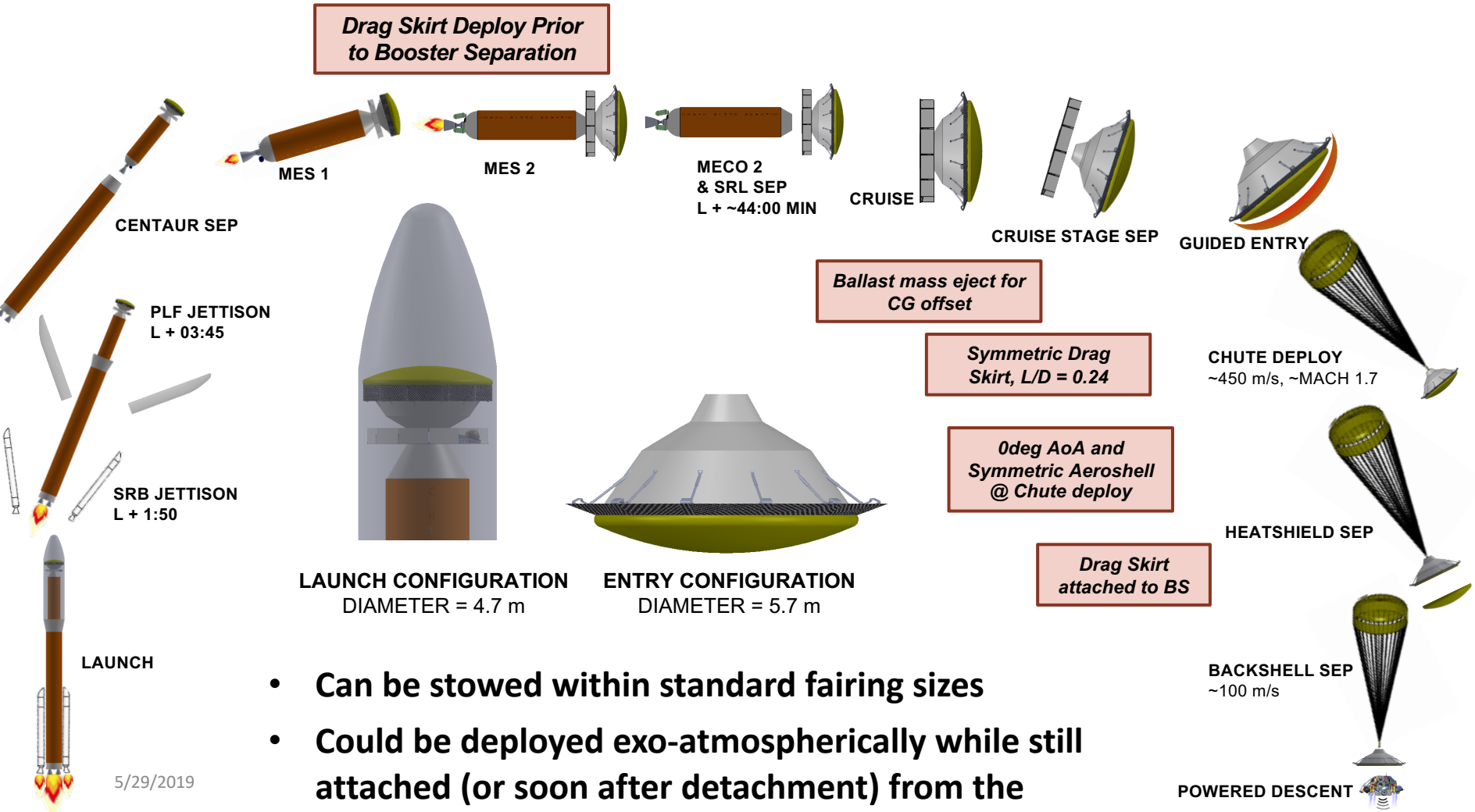
Size: 3.05-m (120-in) Dia x 12.68-m (499-in) Length with Extended Nozzle
Inert Mass: 5X1: 2,247 kg (4,954 lbs); 5X2: 2,462 kg (5,429 lbs)
CFLR: 275 kg (607 lbs)
Propellant: 20,830-kg (45,922-lbs) LH2 & LO2
Guidance: Inertial

Subsystems

Structure: Pressure Stabilized Stainless Steel Tanks Separated by Common Ellipsoidal Bulkhead
Propulsion: One or Two Pratt & Whitney Restartable Engine(s)
— Model: RL 10A-4-2
— Thrust: 99.2 kN (22,300 lbf) (SEC); 198.4 kN (44,600 lbf) (DEC)
— ISP: 450.5 s
(SEC) One Electromechanically Actuated 51-cm Columbium Fixed Nozzle; Four 27-N Hydrazine Thrusters; Eight 40.5-N Lateral Hydrazine Thrusters
(DEC) Two Hydraulically Actuated 51-cm Columbium Extendible Nozzles; Eight 40-N Lateral Hydrazine Thrusters; Four 27-N Hydrazine Thrusters
Pneumatics: Common with Atlas V 400/500 Series
Avionics: Common with Atlas V 400/500 Series
Insulation: Foam with Optional Radiation Shields

Concept Drawing(s) Shown

Hypersonic: Notional Drag Skirt CONOPS

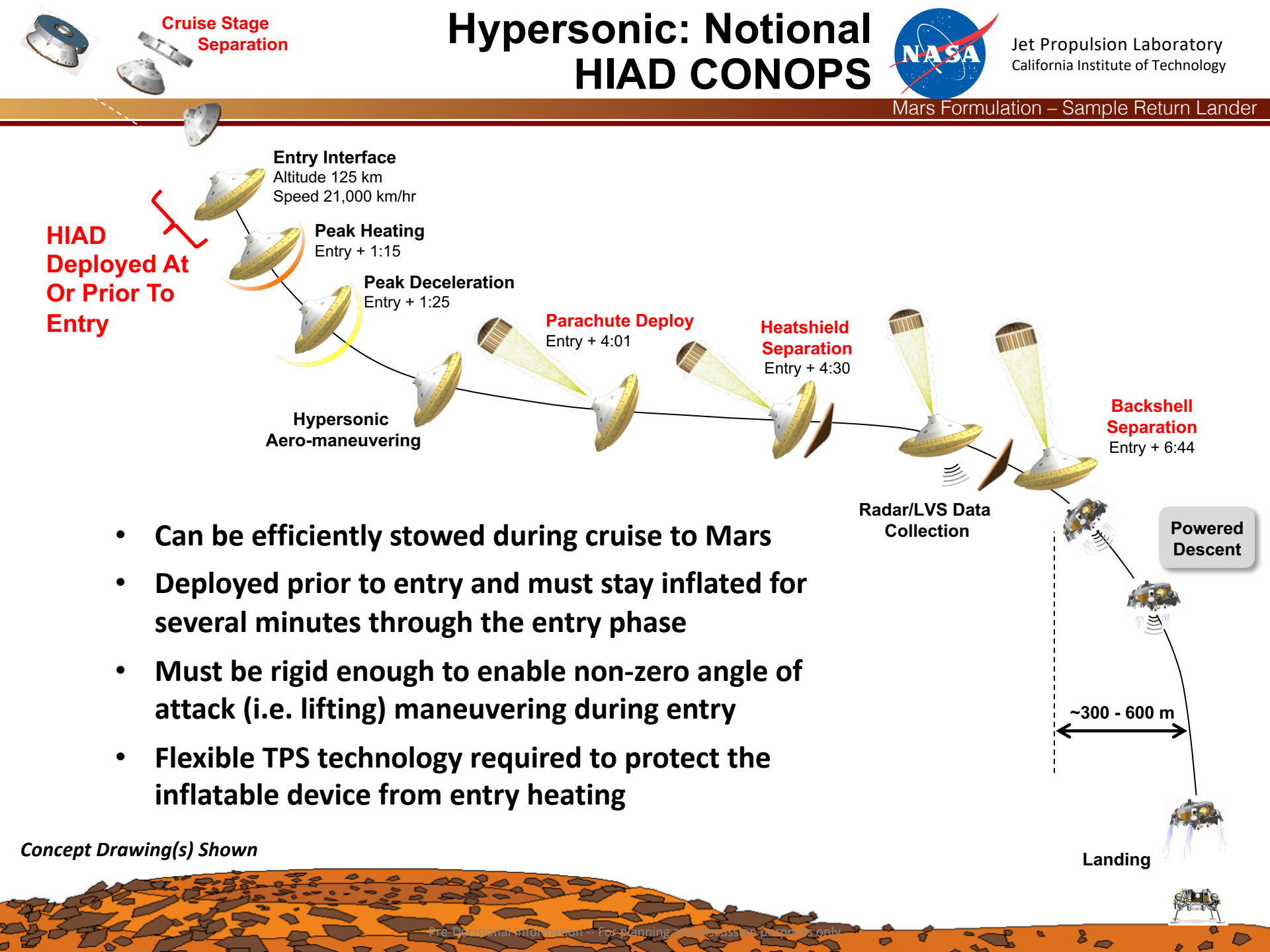


- **Can be stowed within standard fairing sizes**
- **Could be deployed exo-atmospherically while still attached (or soon after detachment) from the upper stage booster**

Graphic Courtesy Of NASA Ames

Concept Drawing(s) Shown

Hypersonic: Notional HIAD CONOPS



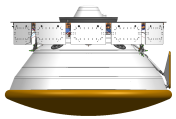
- Can be efficiently stowed during cruise to Mars
- Deployed prior to entry and must stay inflated for several minutes through the entry phase
- Must be rigid enough to enable non-zero angle of attack (i.e. lifting) maneuvering during entry
- Flexible TPS technology required to protect the inflatable device from entry heating

Concept Drawing(s) Shown

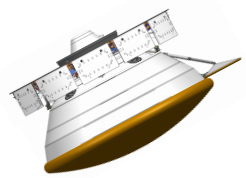
Pre-Decisional Information – For planning and discussion purposes only

Hypersonic: Notional Trim Tab CONOPS

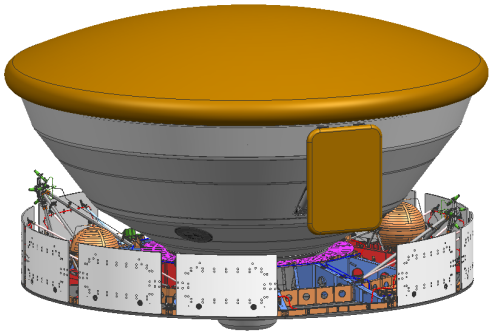
- **~1 x 1 m trim tab**
- **Provides lifting angle of attack during entry**
- **Eliminates entry balance mass**
- **Eliminates cruise balance mass**

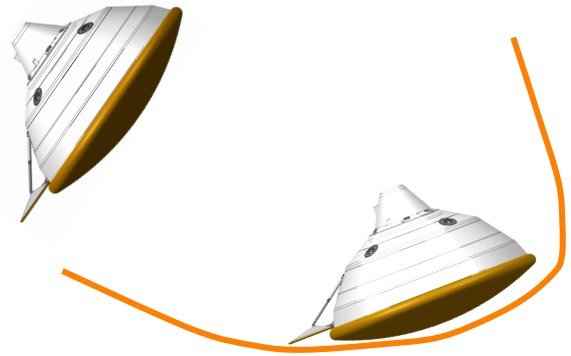


Cruise, Stowed



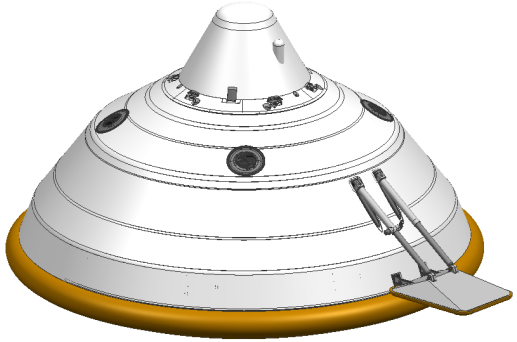
Cruise, Deployed

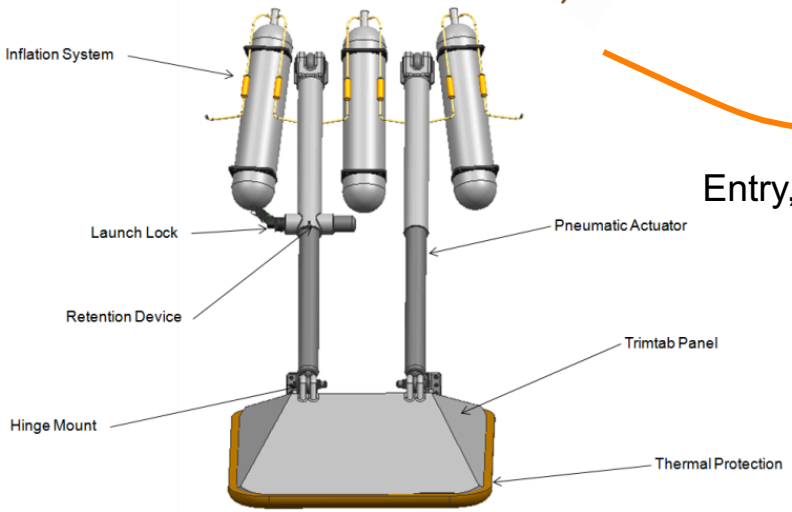


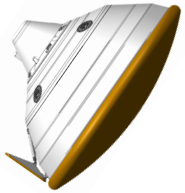


Entry, Start

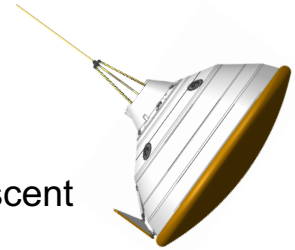
Entry, Peak







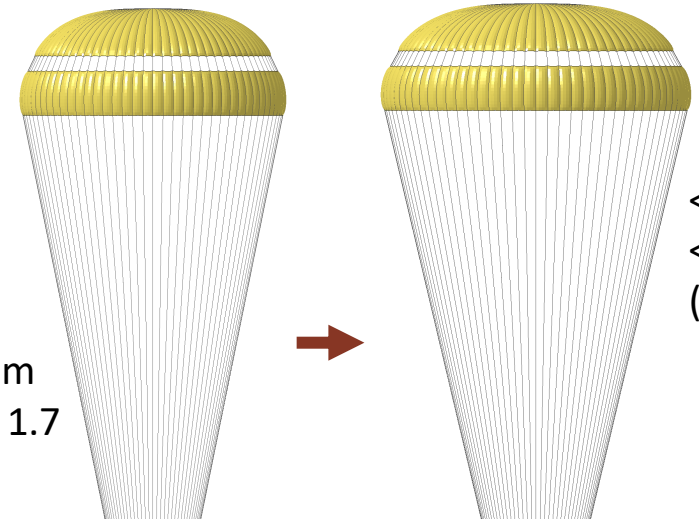
SUFR



Parachute Descent

Concept Drawing(s) Shown

Possible Supersonic Augmentations



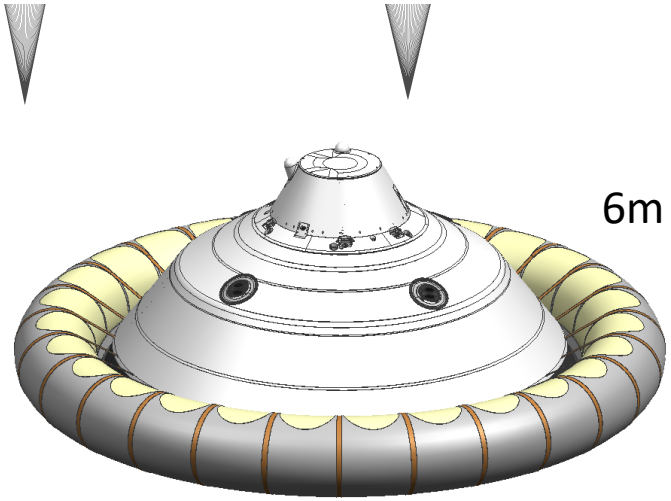
21.5m
Mach 1.7

<= 25m
<= Mach 2.5 (3σ limit)
(~red lines for chute design)

Larger Diameter Parachute And/Or Deployed At Higher Mach

4.4m+
Deployed at
~Mach 2.5 – 3.0
(LDSD Heritage)

Supersonic Trailing Ballute (drag augmentation)

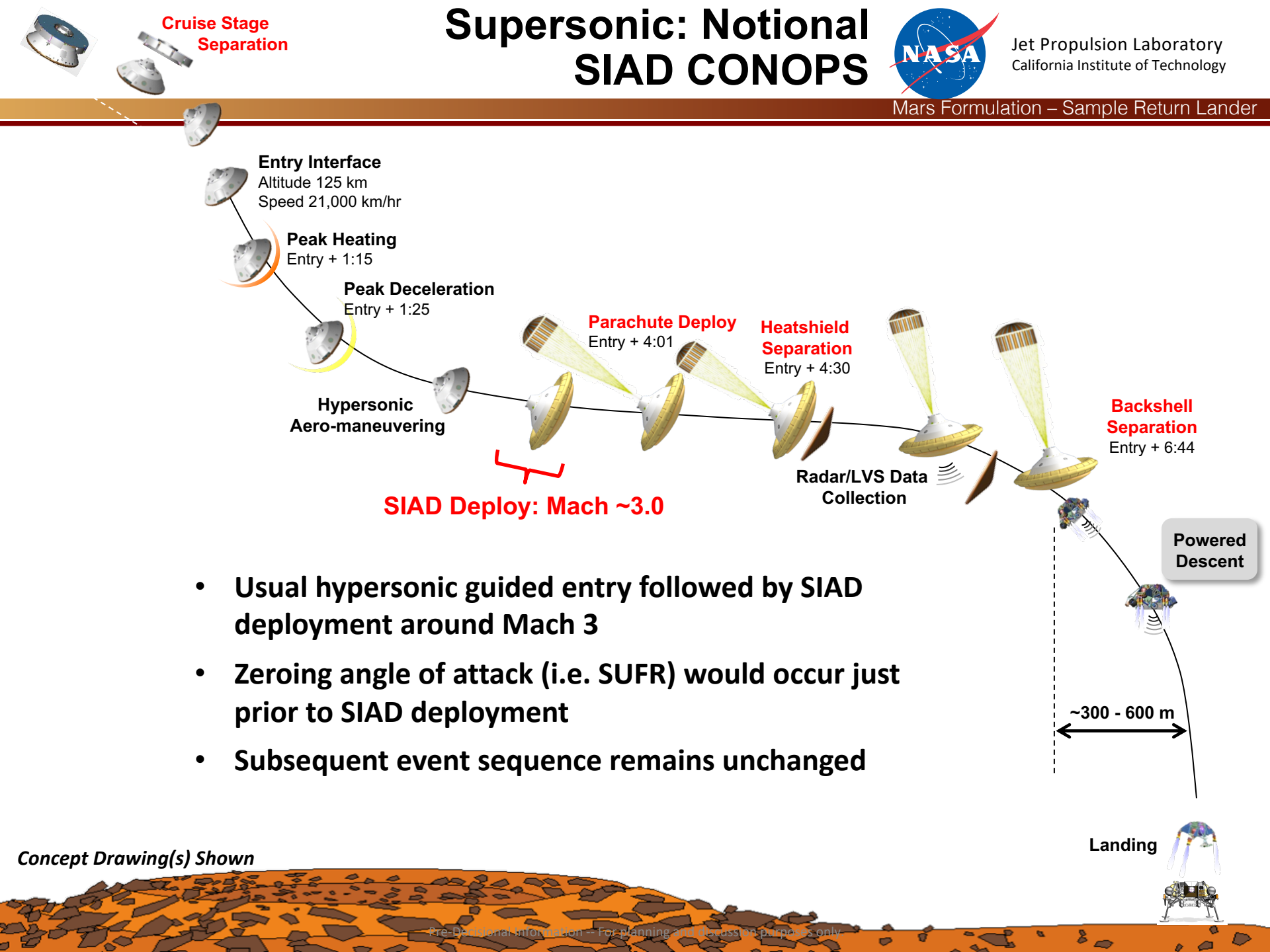


6m Diameter

Supersonic Inflatable Aerodynamic Decelerator (SIAD)

Concept Drawing(s) Shown

Supersonic: Notional SIAD CONOPS



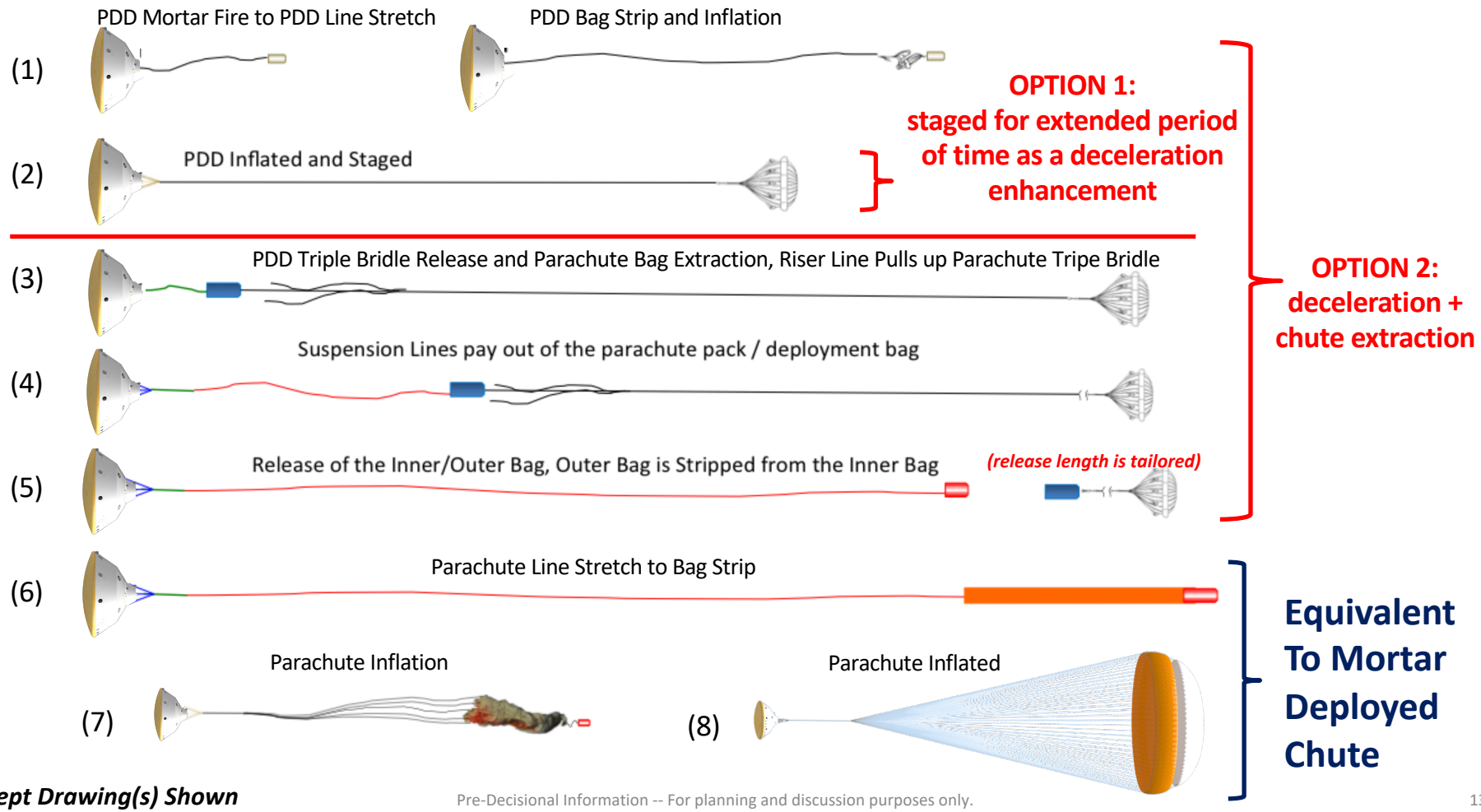
- Usual hypersonic guided entry followed by SIAD deployment around Mach 3
- Zeroing angle of attack (i.e. SUFR) would occur just prior to SIAD deployment
- Subsequent event sequence remains unchanged

Concept Drawing(s) Shown

Pre-Decisional Information – For planning and discussion purposes only

Supersonic: Notional Ballute CONOPS

- **4.4m ballute demonstrated successfully on LDSD**
- **Benefit: enhanced deceleration + (possible removal of chute mortar subsystem)**
- **Will require flight test(s) to qualify the specific SRL deployment strategy**



Concept Drawing(s) Shown

Augmentations Under Study: Need ~ +500kg Total Mass Benefit

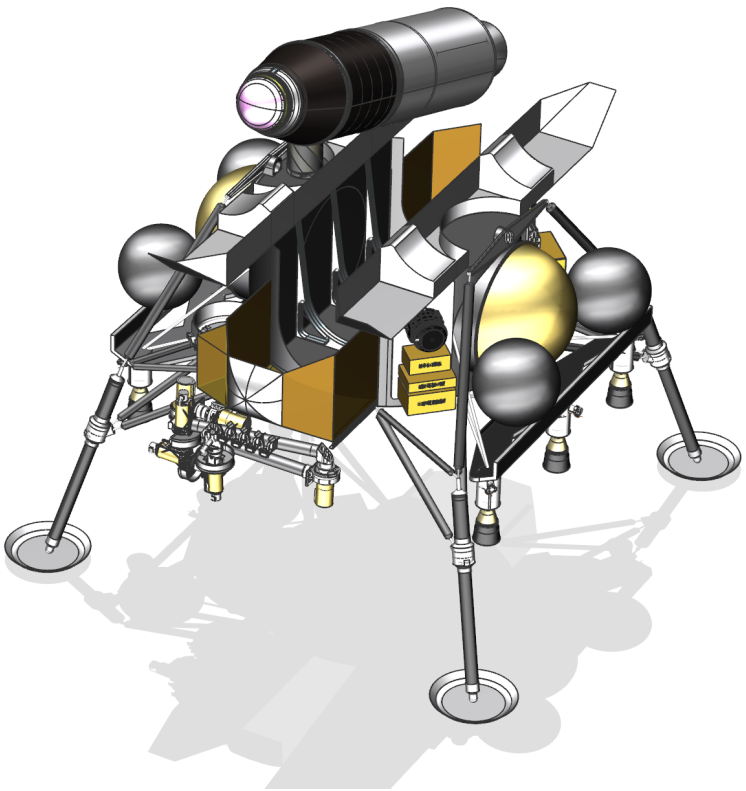
Category (regime)	Possible Augmentation	Ignition Mass Benefit (preliminary estimates)
ENTRY (Hyper-sonic)	Hypersonic Inflatable Aerodynamic Decelerator (6m HIAD)	~ +400 kg
	Larger drag area using drag skirt (6m)	~ +375 kg
	Trim Tab (single; includes drag area and balance benefit)	~ +300 kg (*under review*)
	Larger capsule diameter: 5.0 / 5.2m	~ +125 / +200 kg
ENTRY / DESCENT (Super-sonic)	Increase Mach at chute deploy to 1.85 / 1.95	~ +175 / +275 kg
	Ballute drag (~Mach 3 deployment): 5.4 / 6.4m	~ +125 / 225 kg
	Supersonic Inflatable Aerodynamic Decelerator (6m SIAD)	~ +150 kg
	Increase chute diameter to 23m	~ +125 kg
DESCENT (Sub-Sonic)	~10s timeline relief via upgrade sensor strategy	~ +200 kg

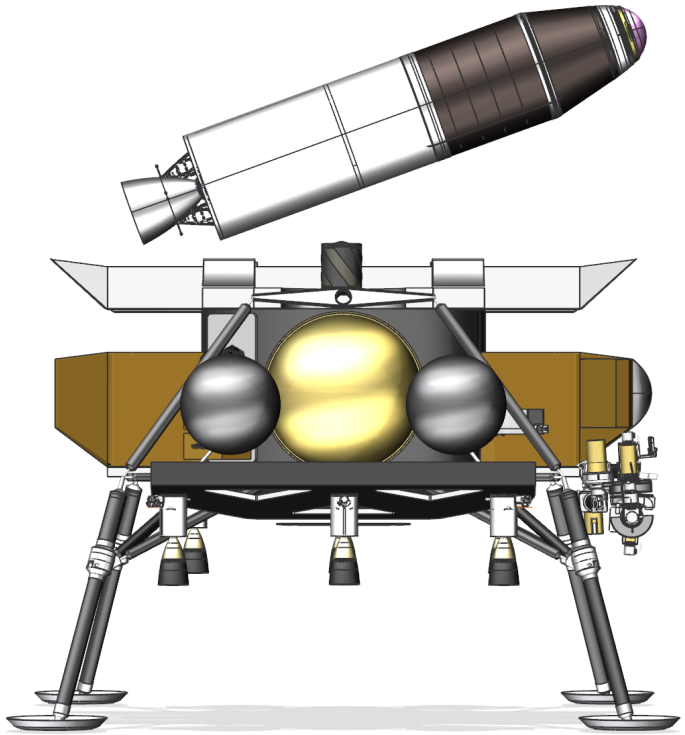
Reference
- **M2020 timeline**
- **21.5m chute**
- **4.7m capsule**
- **Mach 1.75 chute deploy**

	Possible Solution Sets (FYI)					
	Set 1	*Set 2*	*Set 3*	*Set 4*	*Set 5*	*Set 6*
	10s relief	10s relief	10s relief	10s relief	10s relief	10s relief
		23m chute	5.0m capsule	5.4m Ballute	Tab	Drag Skirt
	Mach 1.95	Mach 1.85	Mach 1.85	Mach 1.85		
Performance Benefit:	~ +475 kg	~ +500 kg	~ +500 kg	~ +500 kg	~ +500 kg	~ +525 kg
Chute Dynp:	+25%	~ +25-30%	~ +15%	~ +5%	~ 0%	~ -10%

BACKUP

MAV Launch (Throw'n Go) Concept

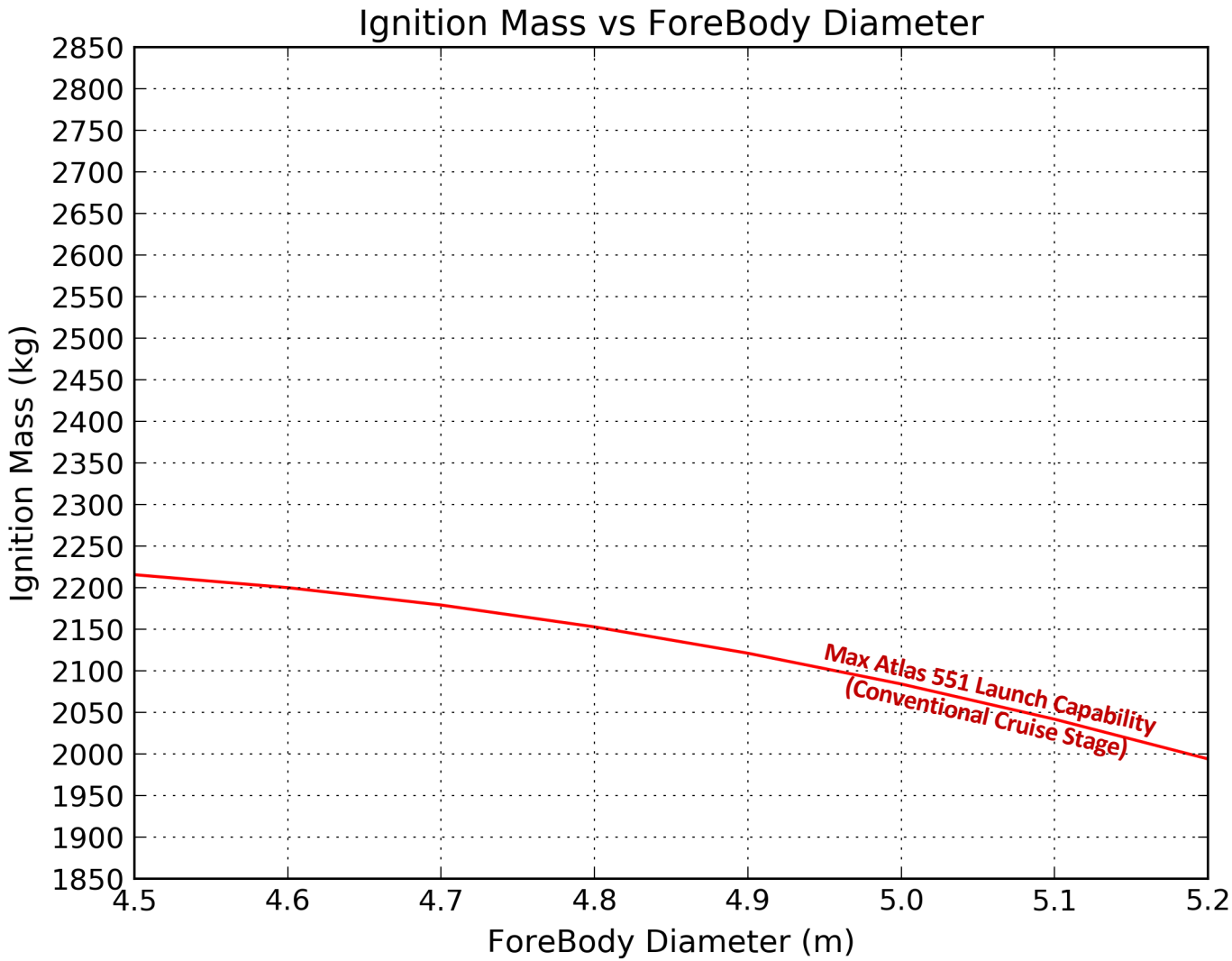




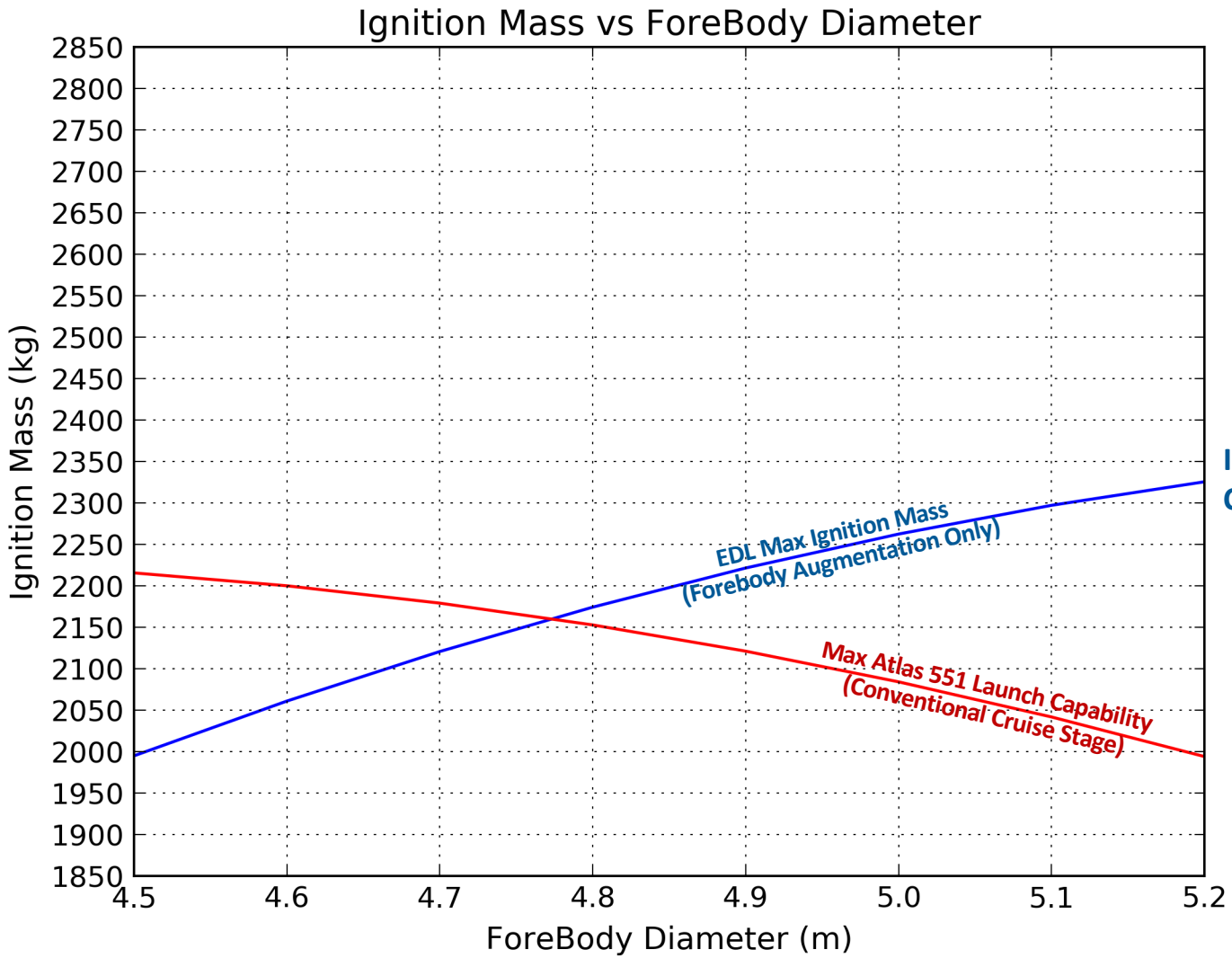
Ejecting And Igniting MAV Above Lander Platform Avoids All Plume Interaction Issues (concept used extensively in military applications)

Concept Drawing(s) Shown

Launch Capability and EDL Capability vs Entry Diameter (Chute Mach/Diam = 1.75/21.5m)

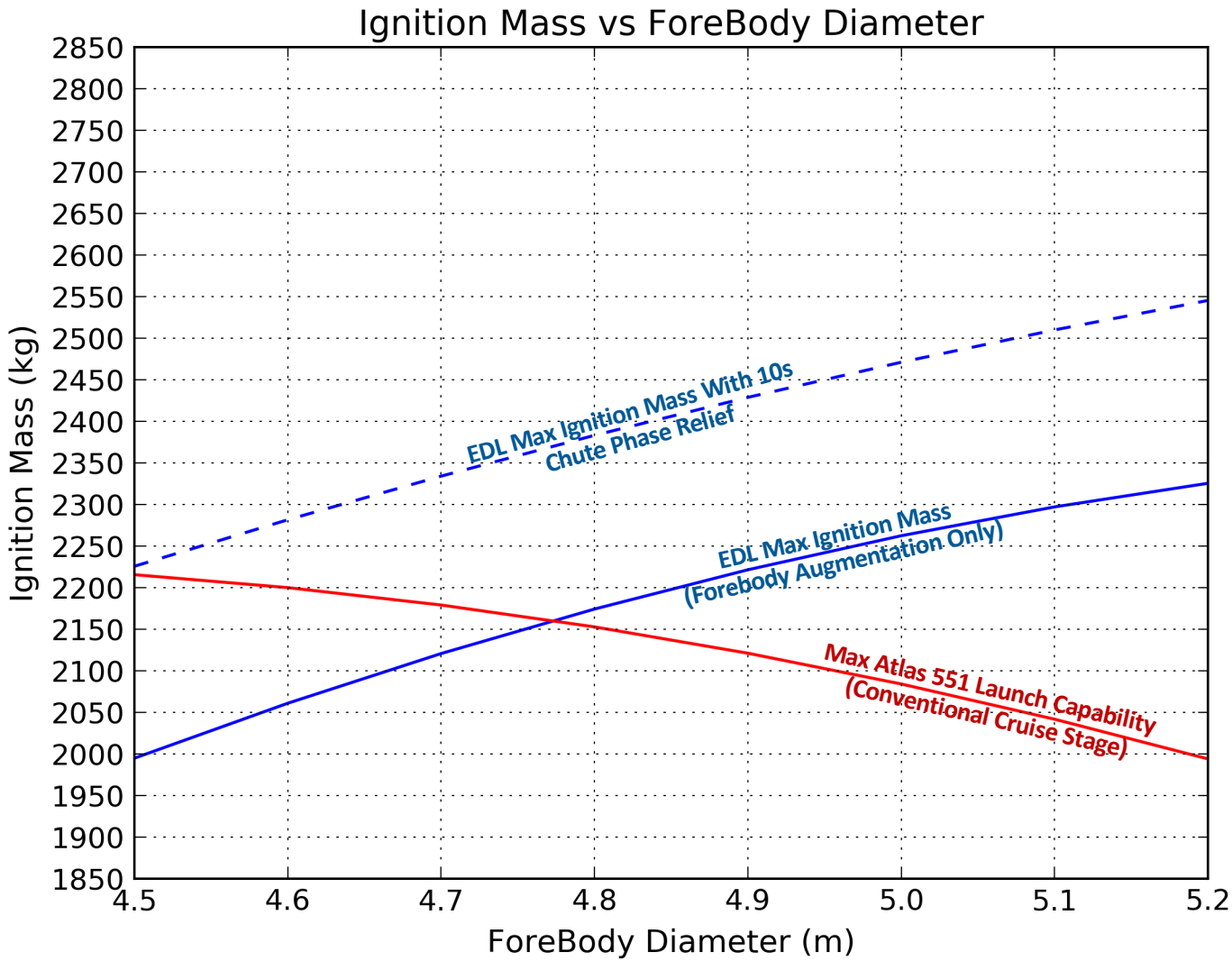


Launch Capability and EDL Capability vs Entry Diameter (Chute Mach/Diam = 1.75/21.5m)

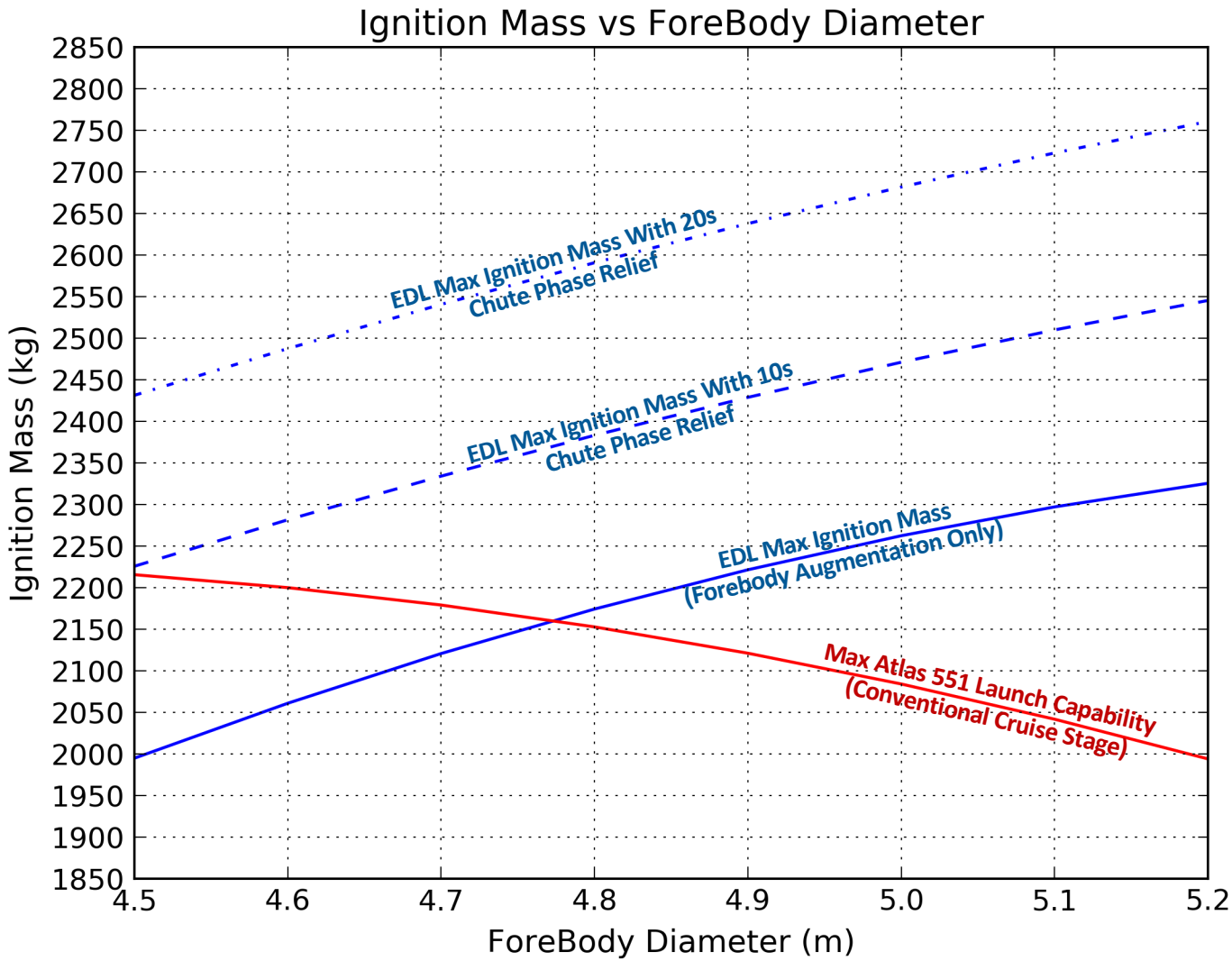


Iso-M2020 Chute Timeline

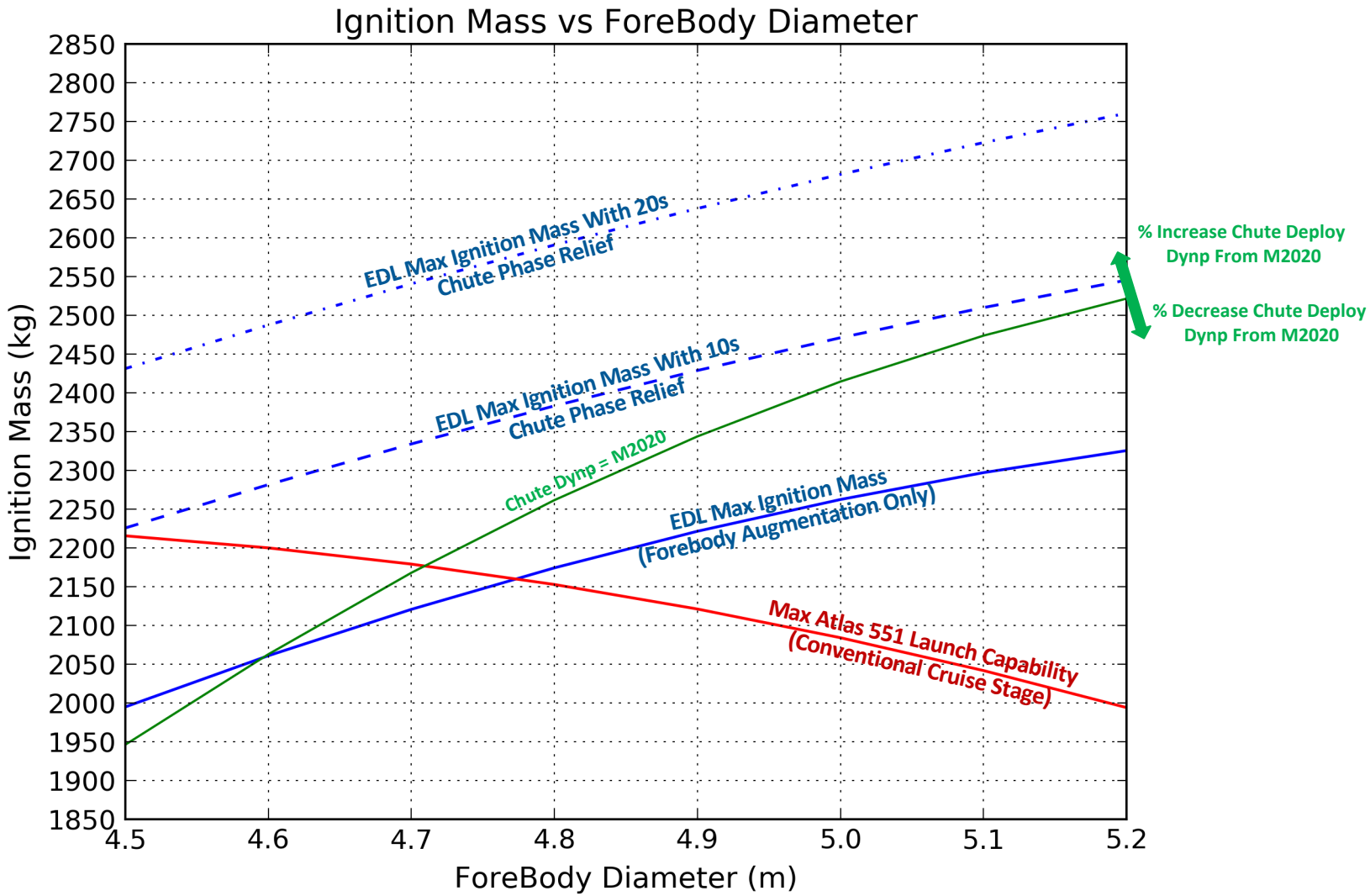
Launch Capability and EDL Capability vs Entry Diameter (Chute Mach/Diam = 1.75/21.5m)



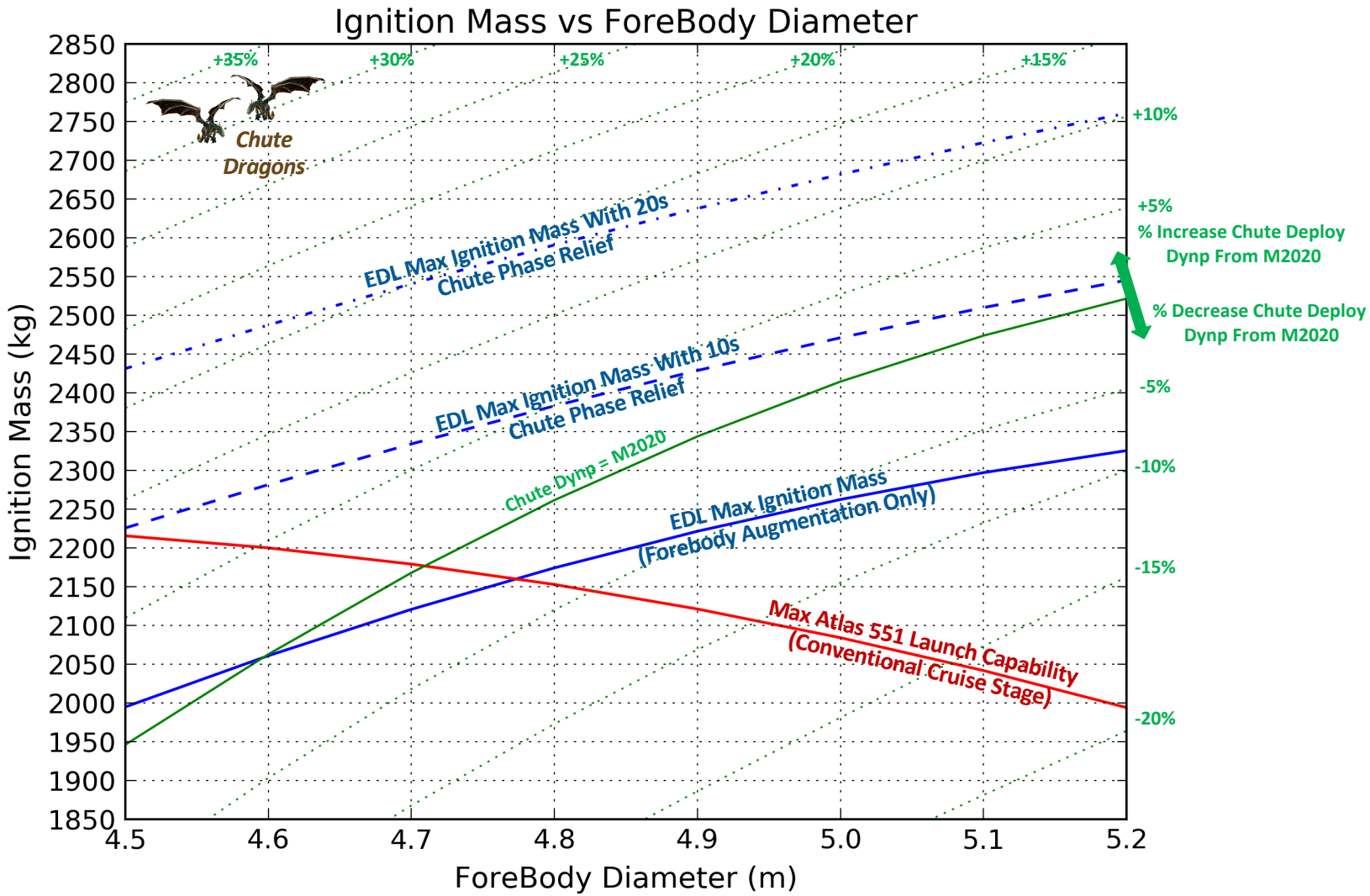
Launch Capability and EDL Capability vs Entry Diameter (Chute Mach/Diam = 1.75/21.5m)



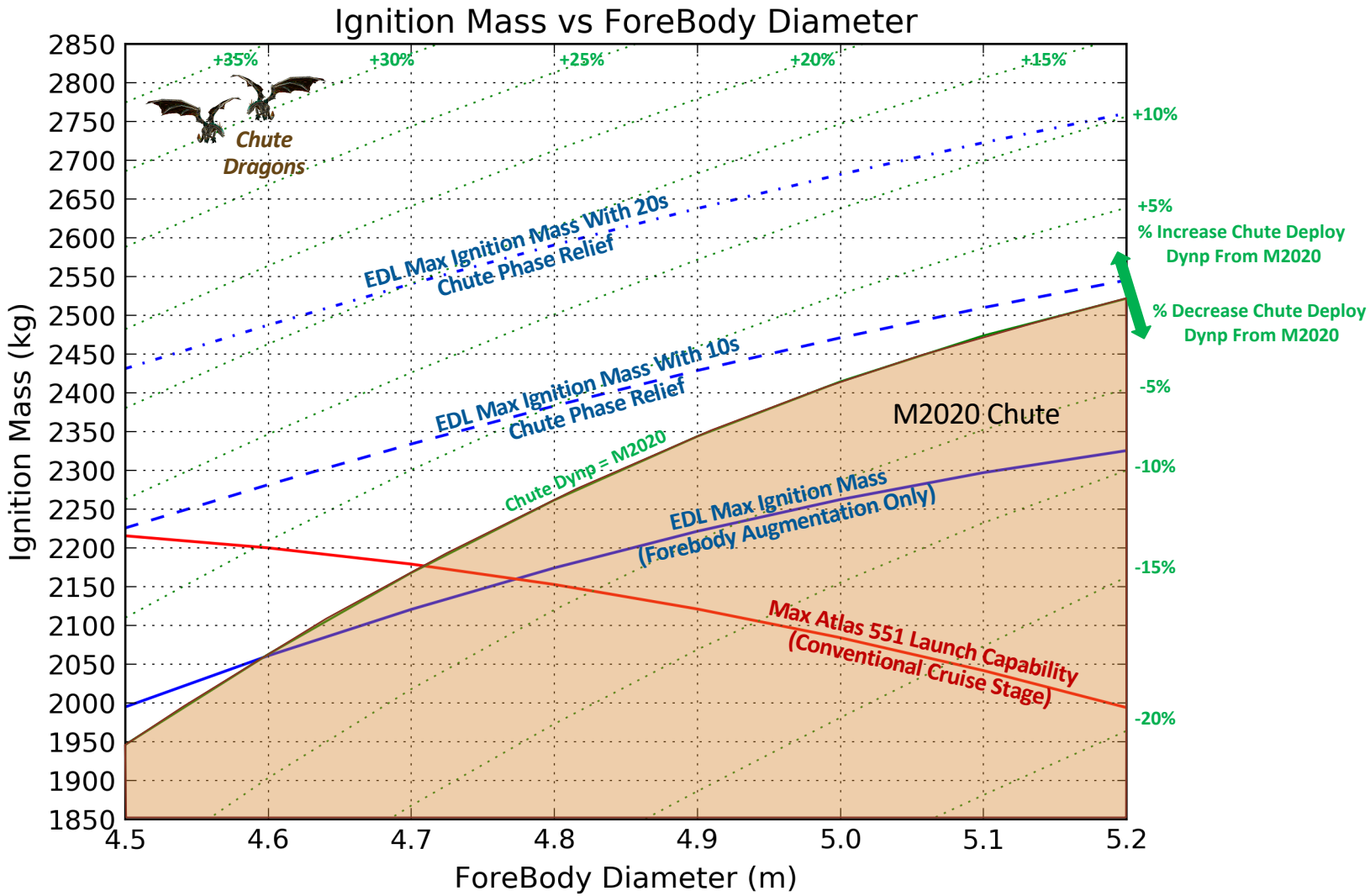
Launch Capability and EDL Capability vs Entry Diameter (Chute Mach/Diam = 1.75/21.5m)



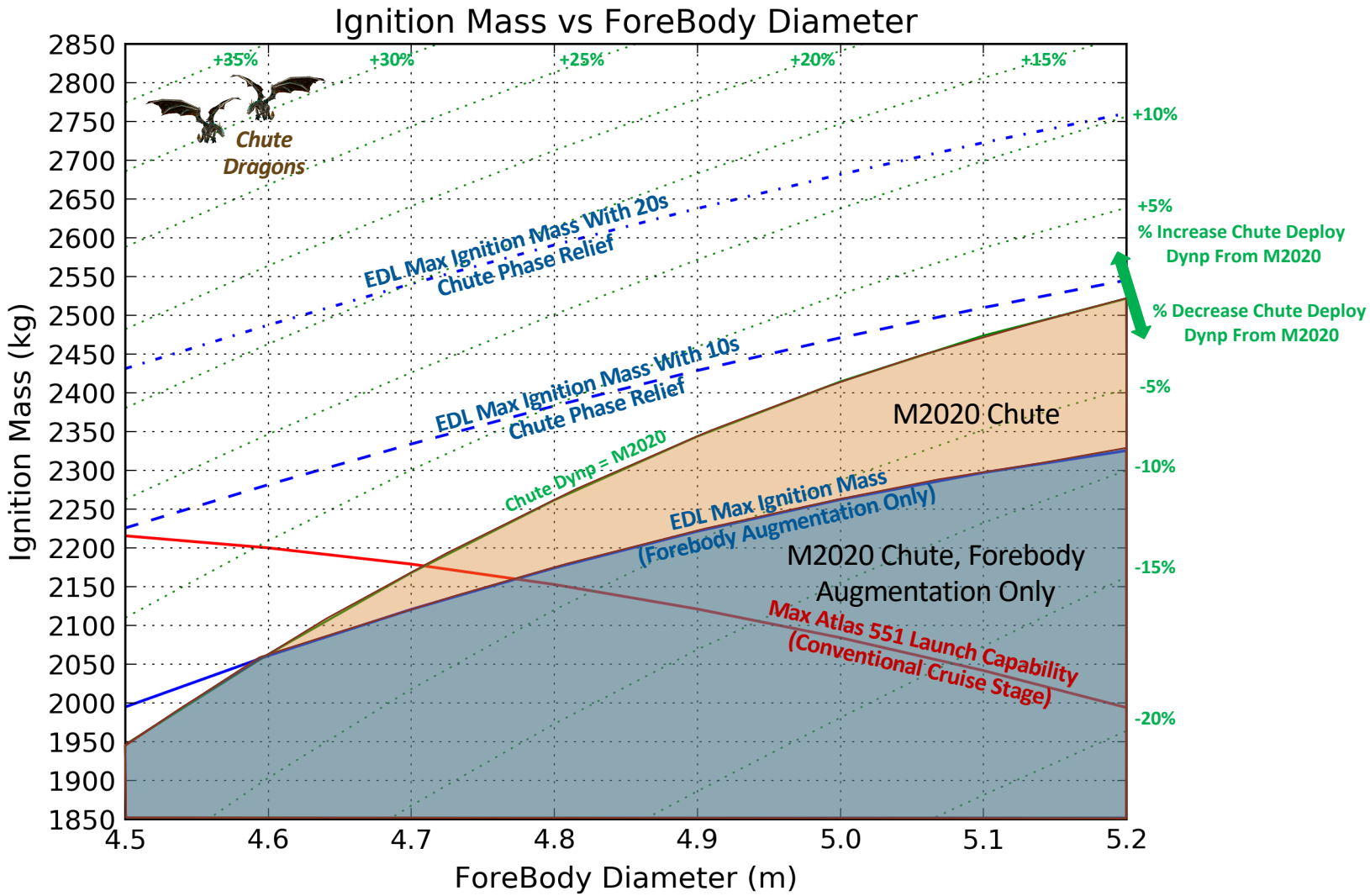
Launch Capability and EDL Capability vs Entry Diameter (Chute Mach/Diam = 1.75/21.5m)



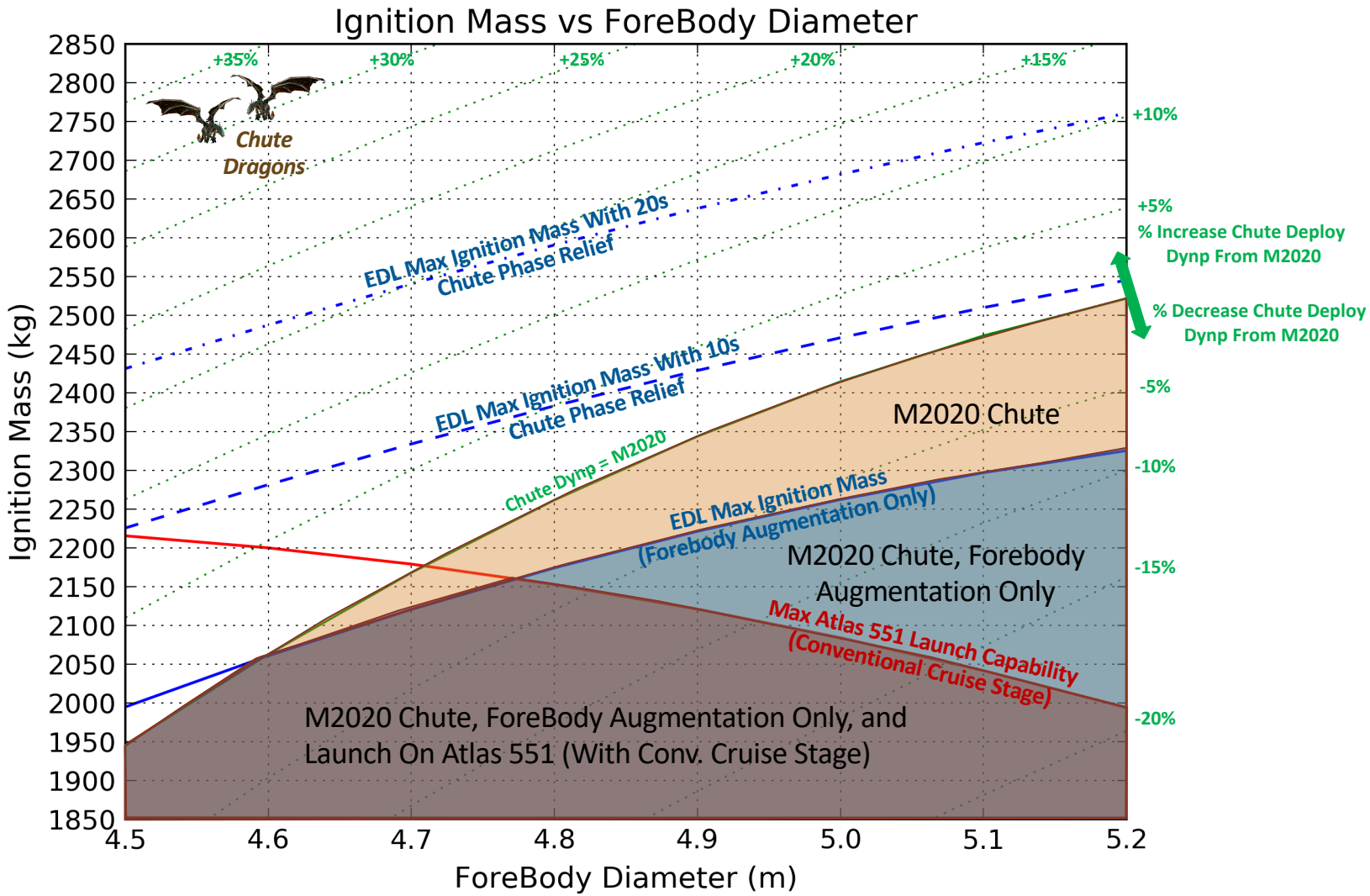
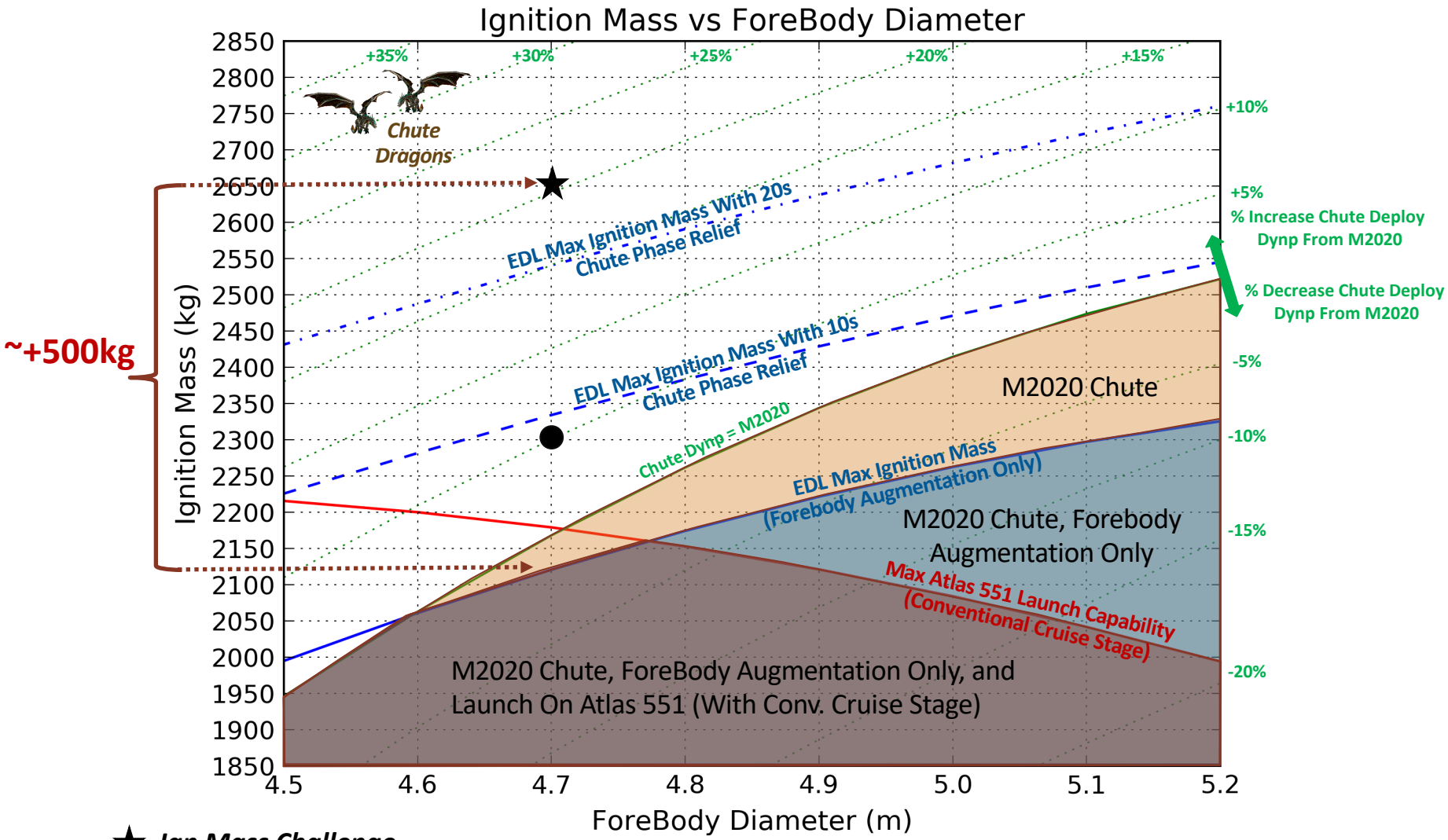
Launch Capability and EDL Capability vs Entry Diameter (Chute Mach/Diam = 1.75/21.5m)



Launch Capability and EDL Capability vs Entry Diameter (Chute Mach/Diam = 1.75/21.5m)



Launch Capability and EDL Capability vs Entry Diameter (Chute Mach/Diam = 1.75/21.5m)



Launch Capability and EDL Capability vs Entry Diameter (Chute Mach/Diam = 1.75/21.5m)