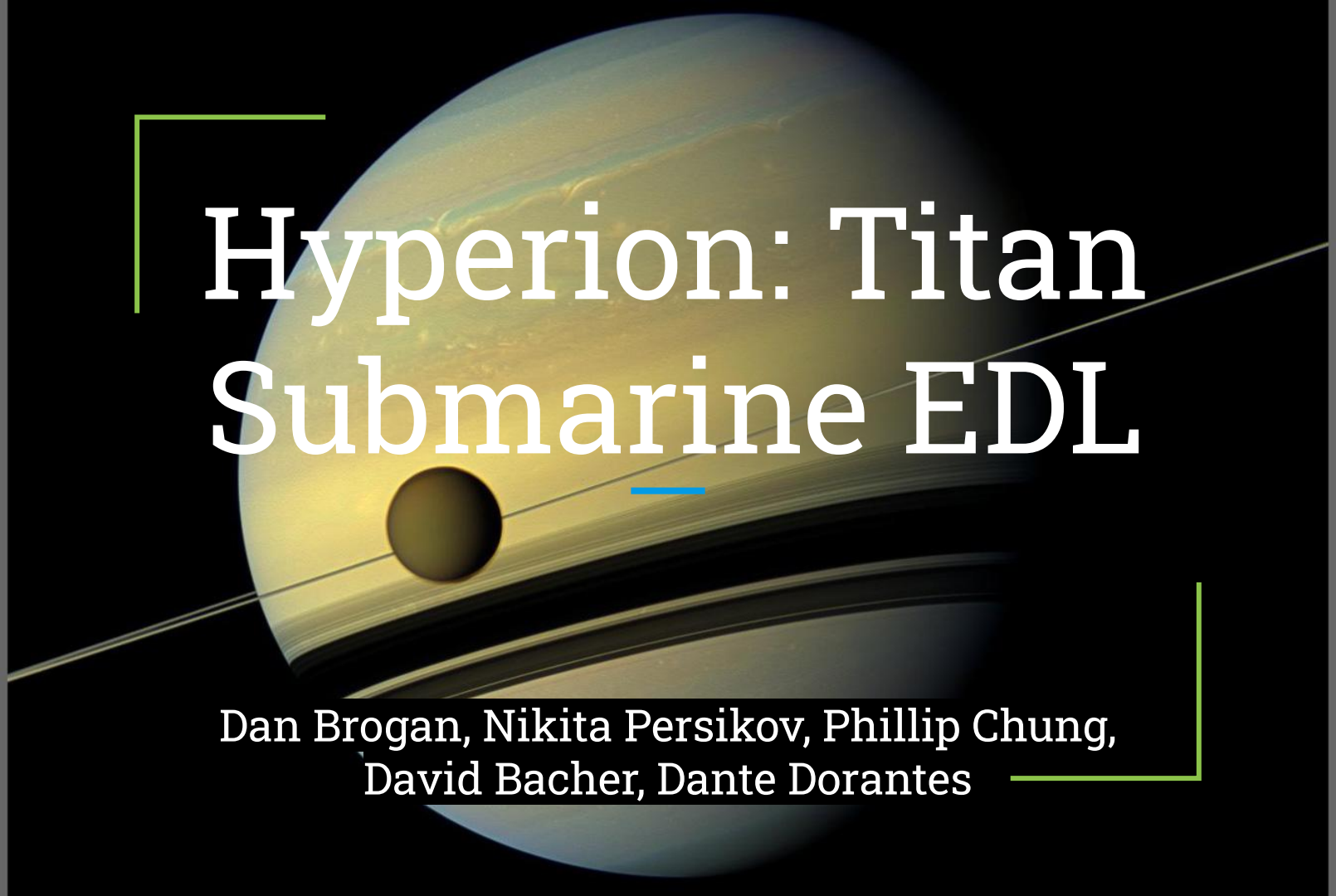


Hyperion: Titan Submarine EDL

Dan Brogan, Nikita Persikov, Phillip Chung,
David Bacher, Dante Dorantes

Part 1: Mission

Why Titan?

- Titan is the only celestial body (besides Earth) with stable liquid bodies
- Lakes of Titan are known to be rich in hydrocarbons, but exact composition is unknown
- These lakes are theorized to allow for possibility of simple life forms (similar to Earth's deep sea vents)
- Mysterious, and relatively unexplored = prime candidate for exploration
- Team Hyperion is proposing unmanned sub to be splashed down into Kraken Mare

Titan EDL Environment

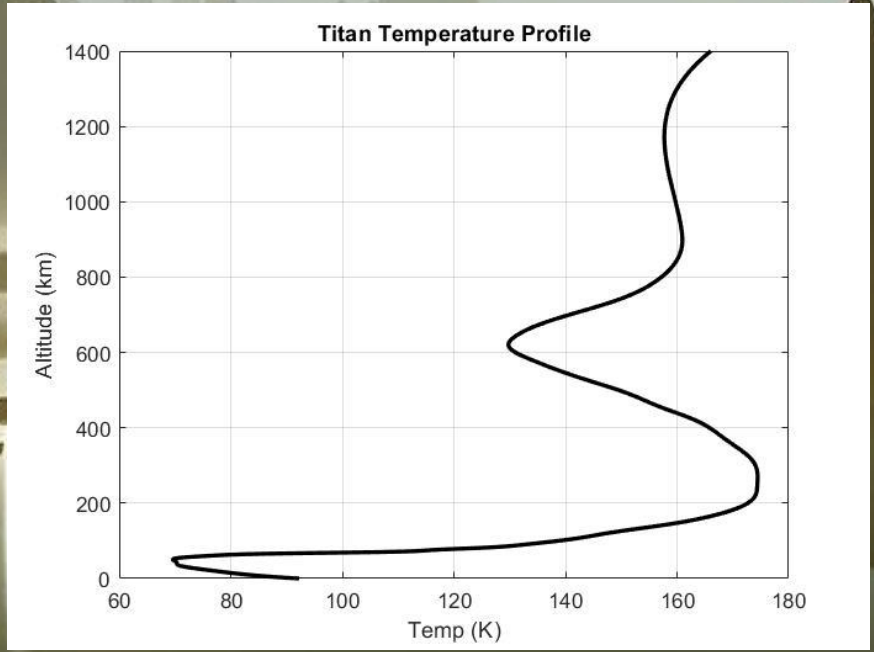
Gravity: 1.354 m/s^2

Atmospheric Composition: 77% N_2, 20% Ar, 3% CH_4

Surface Atmospheric Density: 5.50 kg/m^3

Surface Temperature: 92 K

- Biggest challenge is cryogenic temp of atmosphere and methane lake (will use heat byproduct from RTG power to keep sub warm)
- Benefit from low g and thick atmosphere



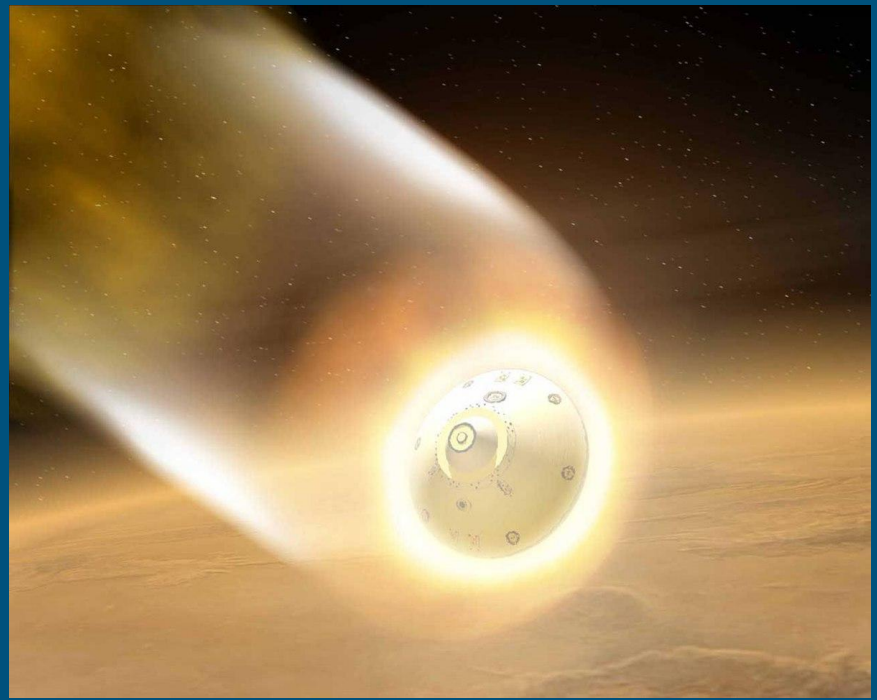
[R. Brown et al., “Titan From Cassini-Huygens.” 2010.]

Level 1: Science and Mission Requirements

- Splash down in Titan's polar liquid methane lake, Kraken Mare
- Must be capable of moving through liquid methane lakes on Titan's surface
- Operate for two years
- Take panoramic pictures of lakebed
- Investigate chemical composition of lake using optical spectroscopy
- Take temperature and pressure measurements (during EDL and in lake)
- Take microscopic pictures of collected samples
- Transmit science data directly back to Earth

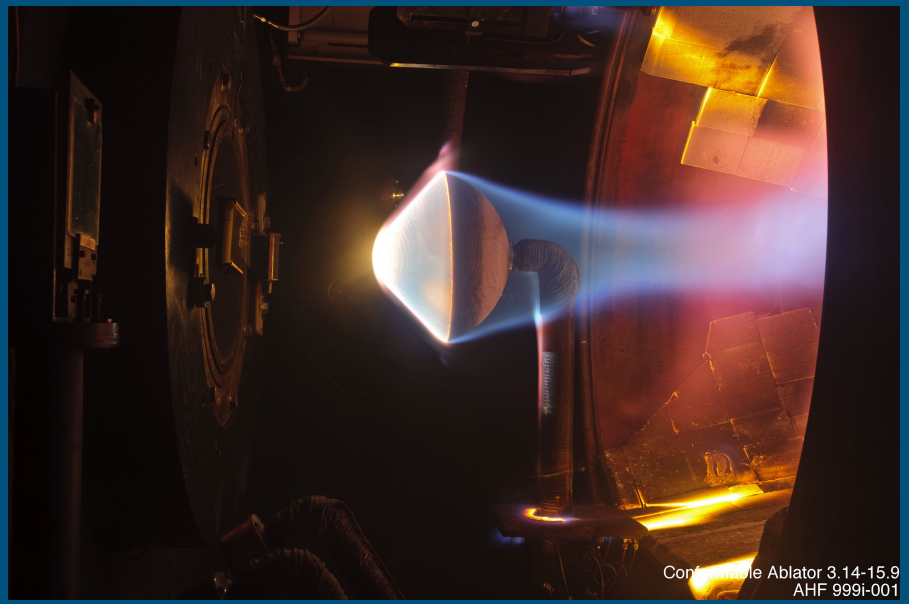
Level 2: Entry System Requirements

- Entry vehicle + sub should not experience more than 5 g's during entry or splashdown
- Collect telemetry data during EDL
- Land directly in Kraken Mare (splashdown required for payload security)
- Withstand peak heat flux of 86 W/cm^2
- Withstand peak heat load of 9,900 J/cm^2
- Speed at splashdown must be no more than 27 m/s
- Submarine shall supply the entry vehicle with 187 W of power to support telemetry data collection and entry ACS



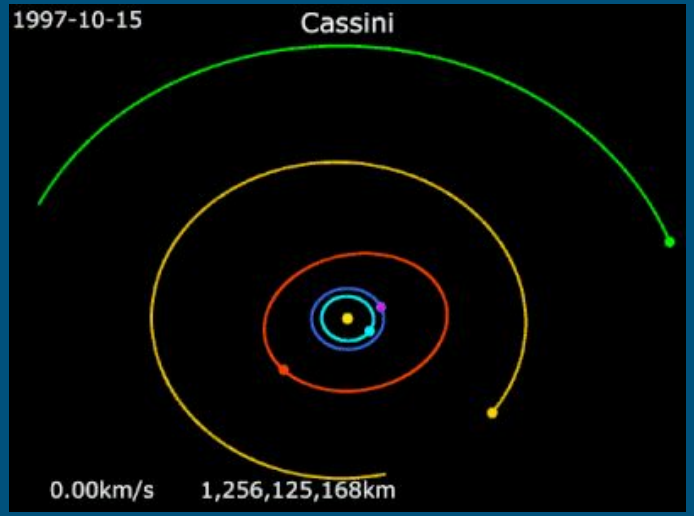
Testing

- Arcjet test to determine recession rate and temp at various heat fluxes (60 to 250 W/cm^2)
- Gases used in test chamber would resemble those on Titan (77% N_2, 20% Ar, and 3% CH_4)
- Thermocouples placed at various depths of heat shield
- Hypersonic wind tunnel for drag testing (loads, stress, stability, parachute deployment)

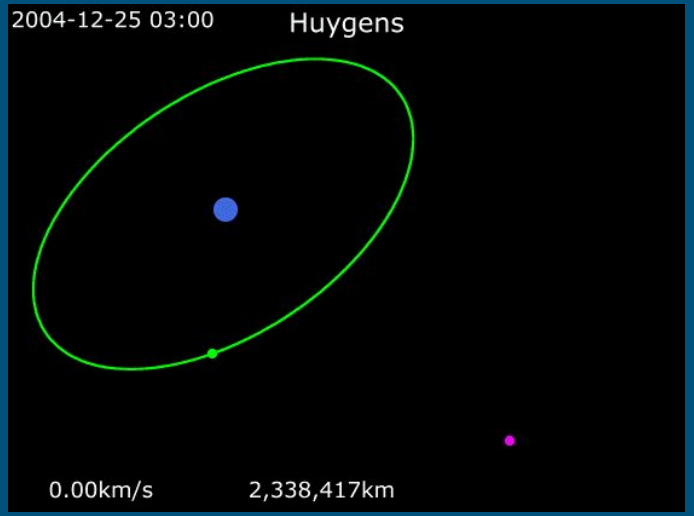


Orbital Mechanics

- Entry Conditions based on the orbital path of Cassini/Huygens
- Entry Velocity - 6 km/s
- FPA - 8.5 degrees



Relative Velocity and Distance to Saturn



Relative Velocity and Distance to Titan

EDL Overview

Ballistic Coefficient Separation

Separation	Stage	Ballistic Coefficient (kg/m^2)
Mach 5	Aftbody	69
	Sub & Heat Shield	377
Mach 1	Sub & Chute	17
	Heat Shield	28

Different EOMs used in each regime to reflect change in dynamics:

Hypersonic:

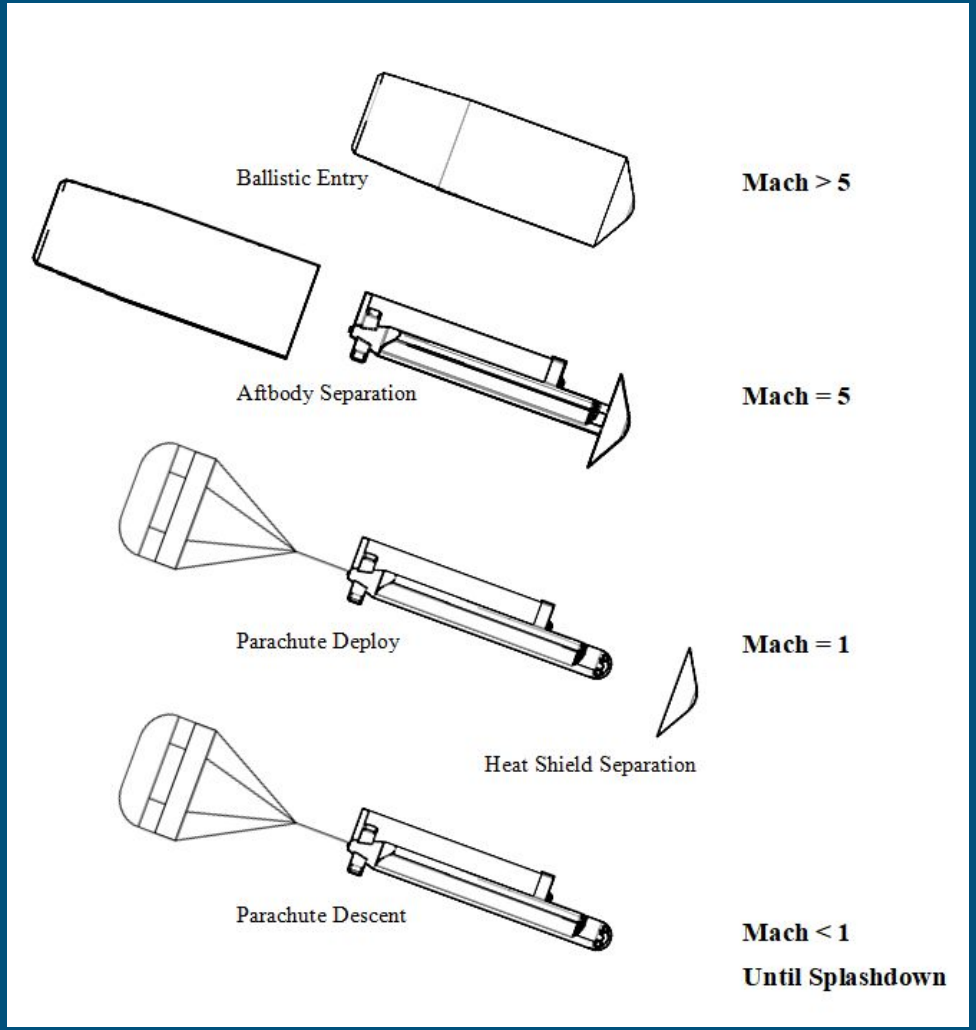
$$V = V_e \exp\left(\frac{\rho_o}{2\beta A \sin(\gamma)} e^{-Ah}\right)$$

Supersonic:

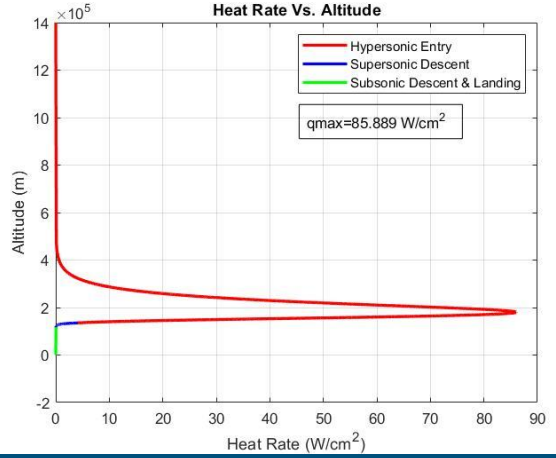
$$V_k = V_{k-1} + [g - \frac{1}{2m_{sub-fore}}\rho_0 exp(-Ah_{k-1})V_{k-1}^2[C_{Dev}S_{ev}]\Delta t$$

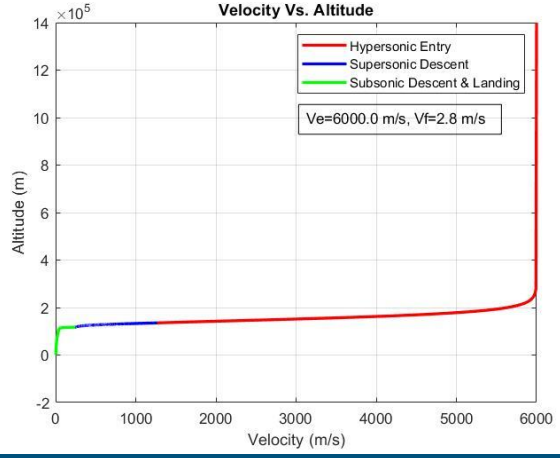
Subsonic:

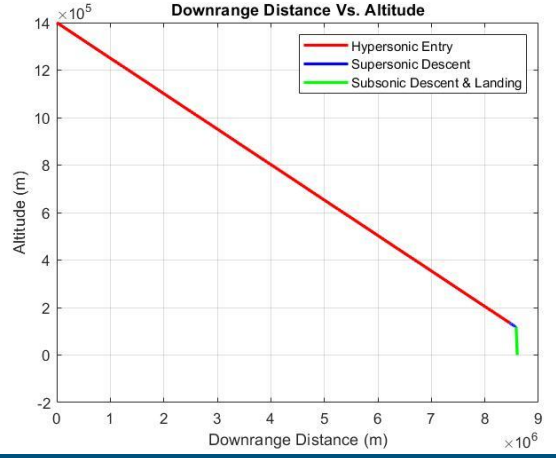
$$V_k = V_{k-1} + [g - \frac{1}{2m_{sub}}\rho_0 exp(-Ah_{k-1})V_{k-1}^2[C_{Dev}S_{ev} + C_{Dp}S_p]\Delta t$$



Key Mission Profiles







Peak Heat Flux:
86 W/cm^2

Entry Velocity:
6.0 km/s

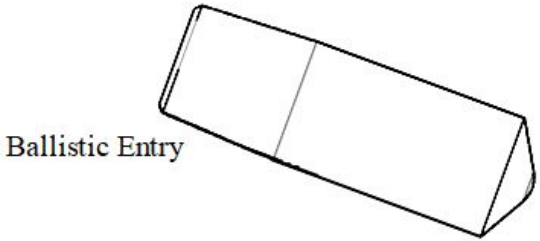
Downrange Distance:
8,600.0 km

Altitude of Peak Heating:
180 km

Final Velocity:
2.8 m/s

Total Integrated Heat Load:
9900 J/cm^2

Hypersonic Entry



Aeroshell Geometry

- Forebody Diameter: 2 m
- Nose Radius: 0.5 m
- Total EV Length: 6 m
- Sphere-Cone Angle: 60°

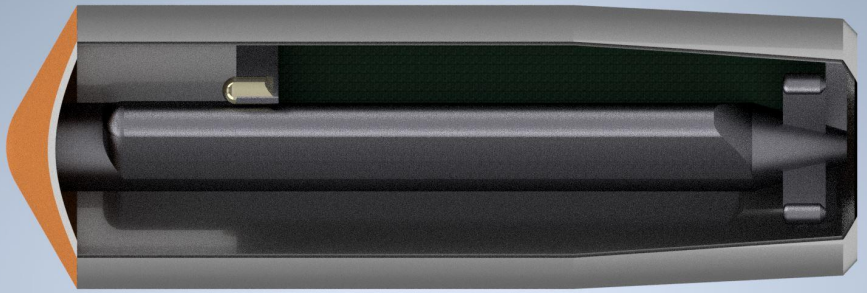
Heat Shield Material: Lockheed Martin MI-15

- Tested heat flux limit: 150 W/cm^2
- Heat of Ablation: 6,276 kJ/kg
- Required Thickness: 3.3 cm
- TPS Mass (1.5 SF): 79 kg

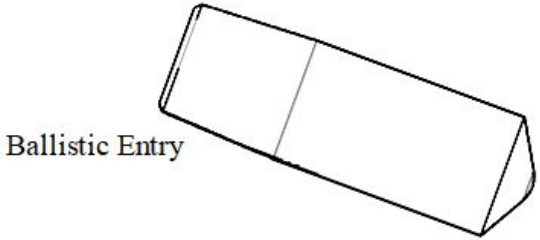
Structure

- Peak Deceleration Load: 51 kN
- Material: Aluminum
- Mass: 302 kg

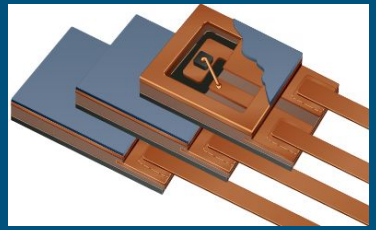
Hypersonic Entry Event	Key Mission Parameter	Key Value	Units
Atmospheric Entry	Altitude	1,400	km
	Mach	23	-
Peak Heating	Altitude	180	km
	Heat Flux	86	W/cm^2
Peak Deceleration	Altitude	158	km
	Deceleration	5	g's

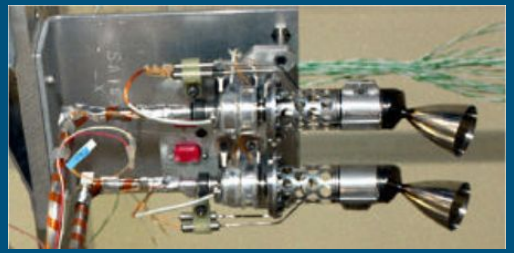


Entry (GNC)



- EV mechanisms are controlled by the submarine computer.
- Submarine computer used to control:
  - ACS
  - Aeroshell separation
  - Parachute deployment
  - Telemetry data collection





MRE-5.0 Monopropellant Thruster

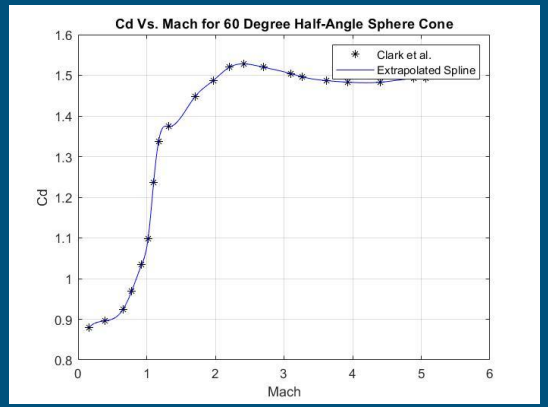
Supersonic Descent

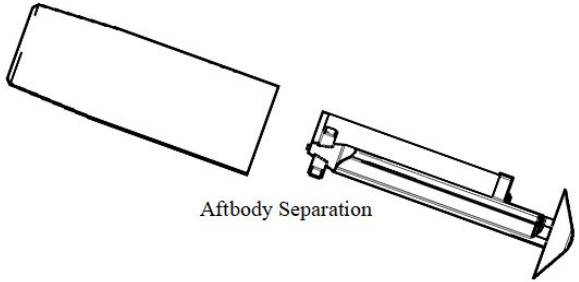
Aftbody Separation

- Ballistic Coefficient Separation Factor: > 22

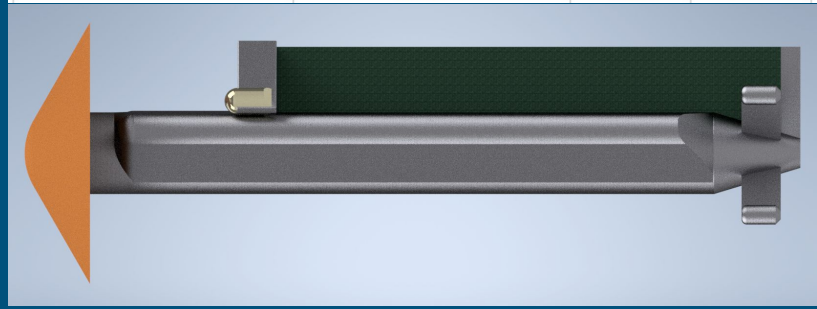
Forebody Drag Coefficient

- Highly Dependent on Mach in Supersonic Regime
- Used Spline of Data to Obtain Proper Values





Supersonic Event	Key Mission Parameter	Key Value	Units
Aftbody Separation	Altitude	135	km
	Mach	5	-



Subsonic Descent & Landing

Simultaneous Parachute Deploy & Heat Shield Separation

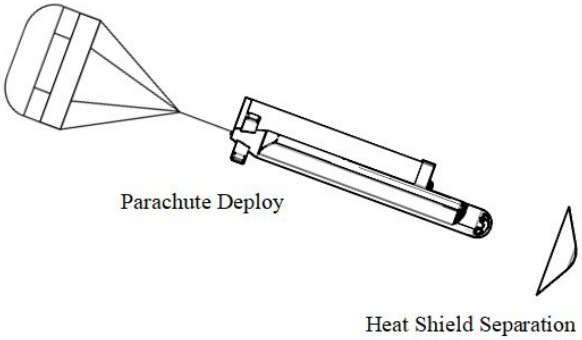
- Ballistic Coefficient Separation Factor: > 1.5

Disk-Gap-Band Parachute

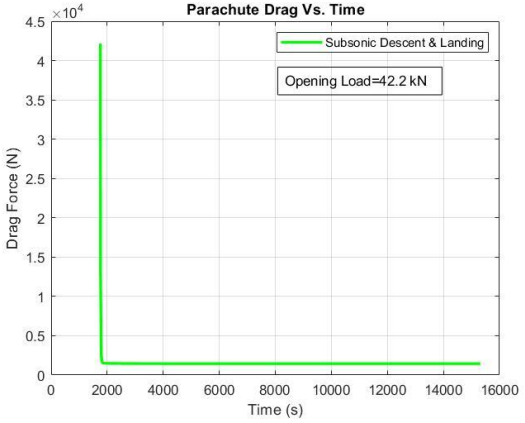
- Diameter: 12 m
- Materials: Kevlar Lines, Nylon Canopy
- Deployment: Mortar
- Trim Angle: 10°

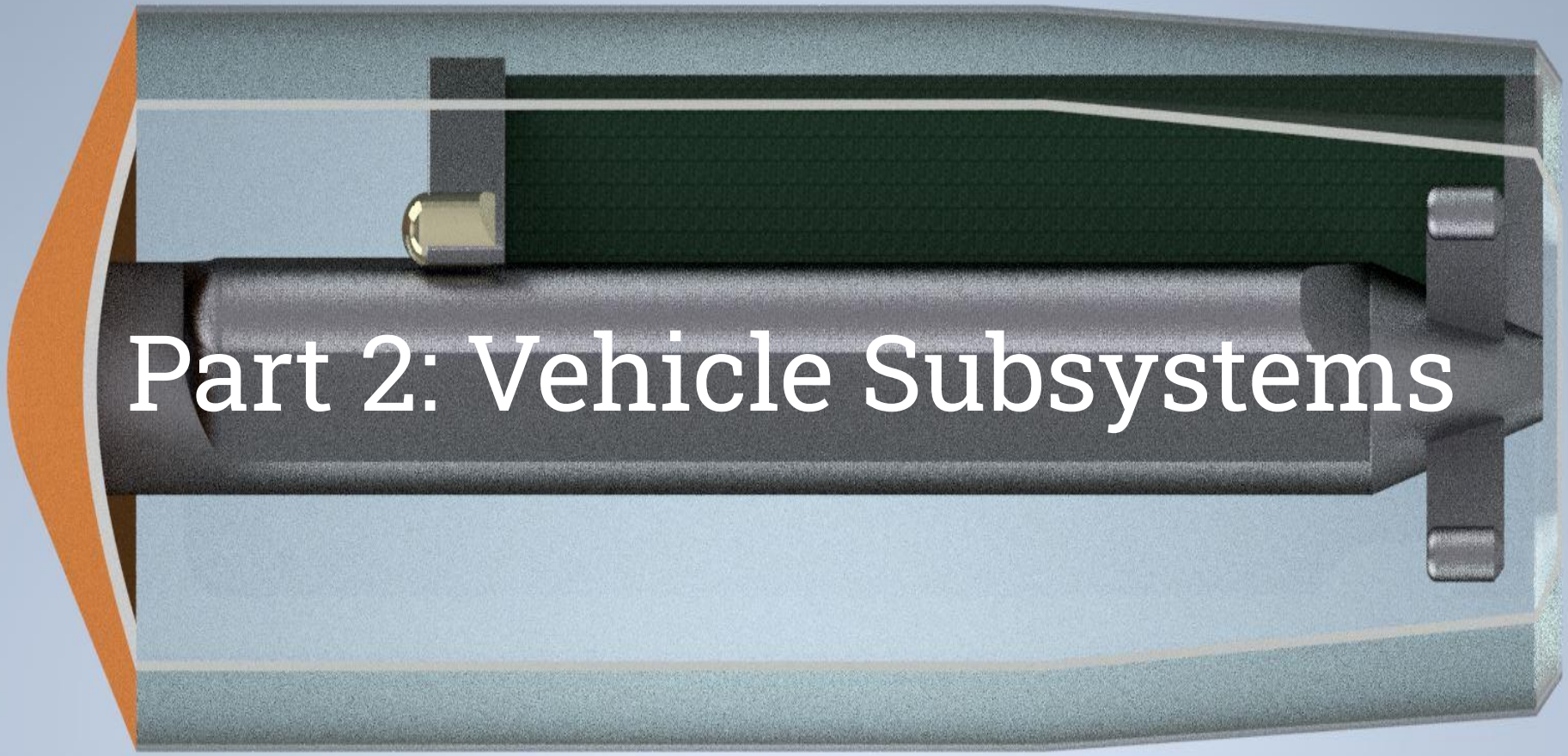
Splashdown Method

- Pencil Dive Approach - Minimizes Impact Area
- 5g Splashdown Velocity Limit: 27 m/s
- Splashdown Acceleration: 0.5 m/s^2



Subsonic Event	Key Mission Parameter	Key Value	Units
Parachute Deploy & Heat Shield Separation	Altitude	117	km
	Mach	1	-
	Chute Opening Load	42	kN
Splashdown	Altitude	0	km
	Final Velocity	2.8	m/s
	Peak Load	524	N

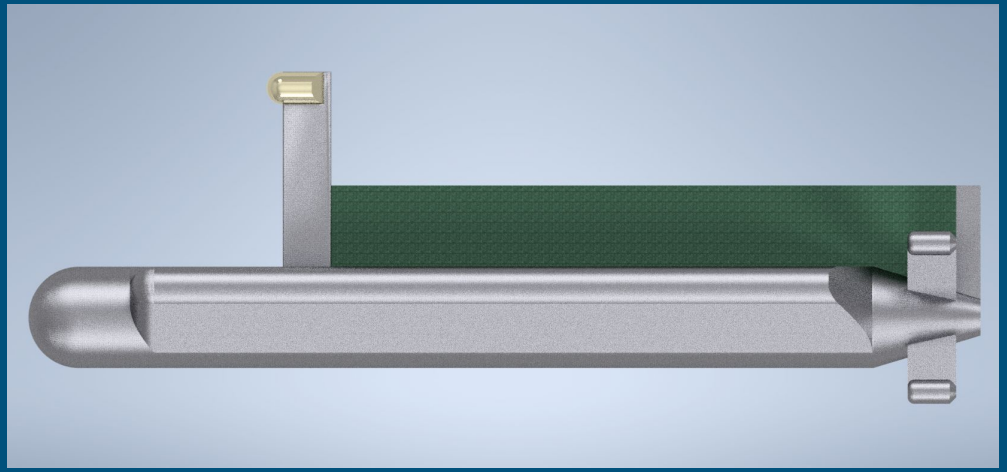


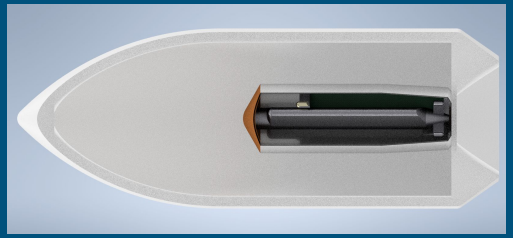


Part 2: Vehicle Subsystems

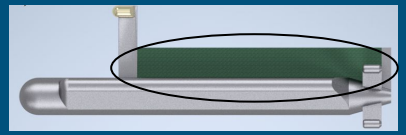
Submarine Specifications

- Mass: 964.41 kg
- Length: 5.87 m
- Maximum Width: 1.75 m





Item	Mass (kg)
Structure	446
Pressure Sensors (8 units)	1.6
Temperature Sensors (10 units)	0.014
Power System	130
Thermal Control	100
Ballast Tanks	15
Compressor	16.5
Microscopic Imager	9
Submarine Telecom	30.5
Panoramic Cameras	0.3
Attitude and Position Sensors	118
Propulsion	20.6
Command and Data Handling (C&DH)	44
Attitude Control System	32.9
Total	**964.4**



Communications Approach

- Autonomous through EDL phases
- Communications link established after landing during surface operations
  - Waits for command from Earth to start a selected mission plan
  - Autonomously navigate through Kraken Mare for 8 hours collecting sensor data
  - Transmit sensor data DTE to Deep Space Network (DSN) for 16 hours (amounts to a total of 288 Mb per day of sensor data) and repeat sequence

- Assumptions:
  - 4-m transmitting diameter to close link (assumes phased array on submarine can provide similar transmitting antenna gain)
  - Selected 9 GHz frequency (X-band) - compatible with DSN
  - Includes standard practice 3 dB Required Link Margin and also 1 dB Uncertainty Link Margin
  - Losses are rough estimates
- Resultant SNR or Eb/No = 3.1 dB
  - Aligns closely with DPSK modulation format at ⅝ code rate (required Eb/No = 2.99 dB)

$$\frac{E_b}{N_o} = \frac{(P * L_l * G_t) * L_s * L_a * G_r}{kT_sR}$$

Parameter	Linear Value	dB Value
Transmit		
Transmitting Antenna Diameter	4 m	
Efficiency of Transmitting Antenna	0.7	
Selected Frequency	9 GHz	
Transmitting Antenna Gain	99.5 kW	50.0 dB
Transmitted Power	90 W	19.5 dB
Line Loss	0.8	1.0 dB
EIRP	7,163 kW	70.5 dB
Range and Atmospheric		
Range	1.27E+9 km	
Space Loss		293.6 dB
Atmospheric Loss		2 dB
Receive		
Receiving Antenna Diameter	34 m	
Efficiency of Receiving Antenna	0.7	
Selected Frequency	9 GHz	
Receiving Antenna Gain	7,188 kW	68.6 dB
Attenuation Loss		3.0 dB
Temperature Noise of Receiving Antenna	200 K	23.0 dB
Data Rate	5 kbps	37.0 dB
Required Link Margin		3.0 dB
Uncertainty Link Margin		1.0 dB
Eb/No		3.1 dB

Submarine Specifications (Power)

- Power required: 723 W
- 2 Stirling radioisotope generators (SRG) power the submarine
- Largest contributor: submarine propulsion
- Thermal Control System only requires the input power to operate the SRG
- Science equipment requires negligible power

Item	Power (W)
Pancam	6.5
Sample Intake System	22
Microscope Camera	2.5
Spectroscope	2.5
ACS and C&DH	123
Thermal Control System	20
Submarine Propulsion	440
Telecommunications	106.3
Total	723

EV Specifications (Mass and Volume)

- EV Mass: 421.1 kg
- Aftbody structural mass is the largest contributor
- Submarine size drove aftbody design
- Heat shield is the second largest mass on the EV
- Other components added negligible mass

Item	Mass (kg)
Heat Shield	79.0
Separation Mechanism (Including Power System)	11.4
Pressure Sensors	1.6
Temperature Sensors	0.014
ACS Thrusters	8
ACS Fuel	0.1
ACS Fuel Tank	1.4
Aftbody Structural Mass	302.1
Parachute and Mortars	17.5
Total	**421.1**

Entry Vehicle Features	
Diameter (m)	2
Nose Radius (m)	0.5
Sphere-Cone Angle (deg)	60
Length (m)	6
Parachute Diameter (m)	12

EV Specifications (Power)

- Power Required: 188 Watts
- The processing and control is outsourced to the submarine computers
- The EV systems will
  - Record atmospheric data
  - Control flight path
  - Detach aftbody
  - Deploy parachute
  - Detach heat shield

Item	Power (W)
EDL Telemetry Data Recording System	123
EDL ACS	63
Aeroshell Separation System	1
Parachute Release System	1
Total	188


Thank You

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