第17回宇宙科学シンポジウム

SLS搭載超小型探査機 OMOTENASHI

(Outstanding MOon exploration TEchnologies demonstrated by NAno Semi-Hard Impactor)

“Omotenashi” means welcome or hospitality in Japanese.
It is one of campaign messages for Tokyo Olympic 2020.

2017/1/6

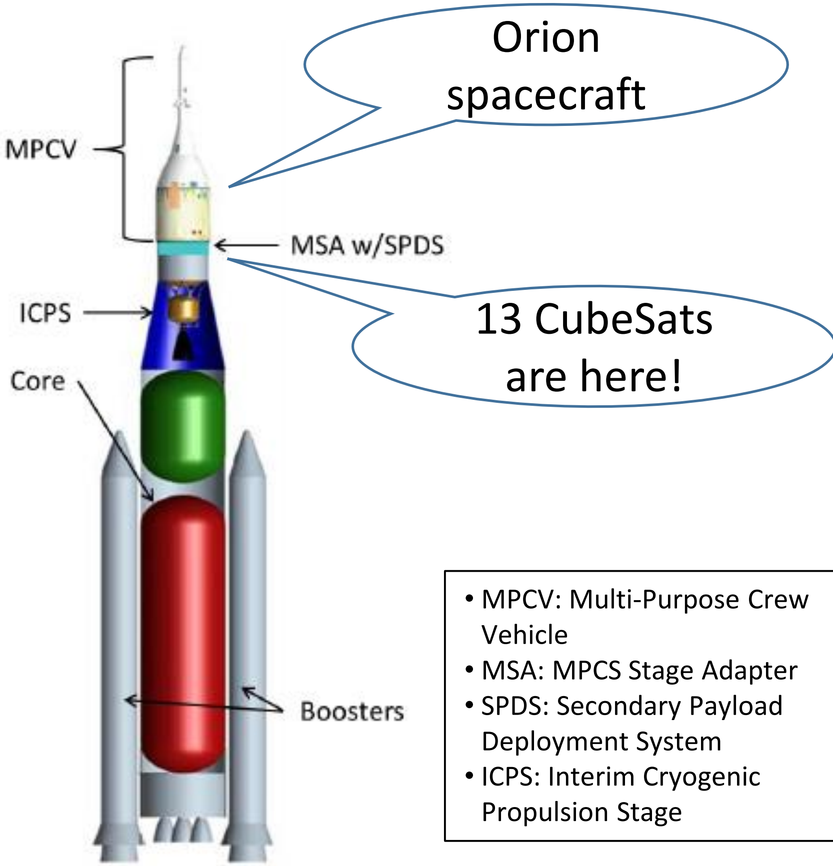
OMOTENASHI project team

Subsystem and technologies are also presented in the poster session.

- P-068 OMOTENASHI探査機のシステム設計
- P-065 OMOTENASHI Onboard Processing System
- P-066 OMOTENASHI軌道解析
- P-067 OMOTENASHI固体ロケットモータの開発
- P-069 OMOTENASHI探査機の着陸装置の検討

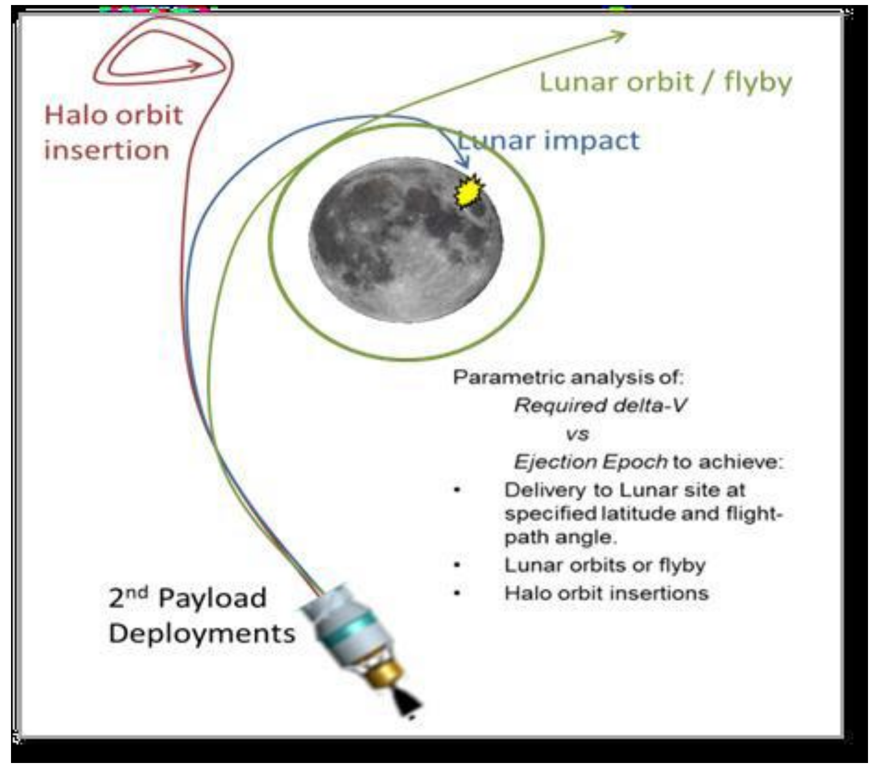
NASA proposal（From SLS Secondary Payload User's Guide）

Launch date: 2018 (TBD)



- MPCV: Multi-Purpose Crew Vehicle
- MSA: MPCS Stage Adapter
- SPDS: Secondary Payload Deployment System
- ICPS: Interim Cryogenic Propulsion Stage

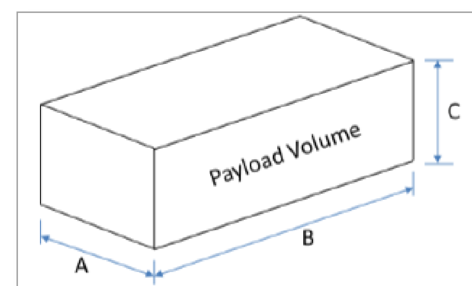
EM-1 configuration



SLS orbit

Size of the secondary payload

Deployer	A		B		C		Volume		Mass	
	in	mm	in	mm	in	mm	in^3	mm^3	lbs	kg
6U	9.41	239.00	14.41	366.00	4.45	113.00	603.41	9,884,562	30.86	14.00
12U	9.41	239.00	14.41	366.00	8.90	226.00	1206.82	19,769,124	44.73	20.29

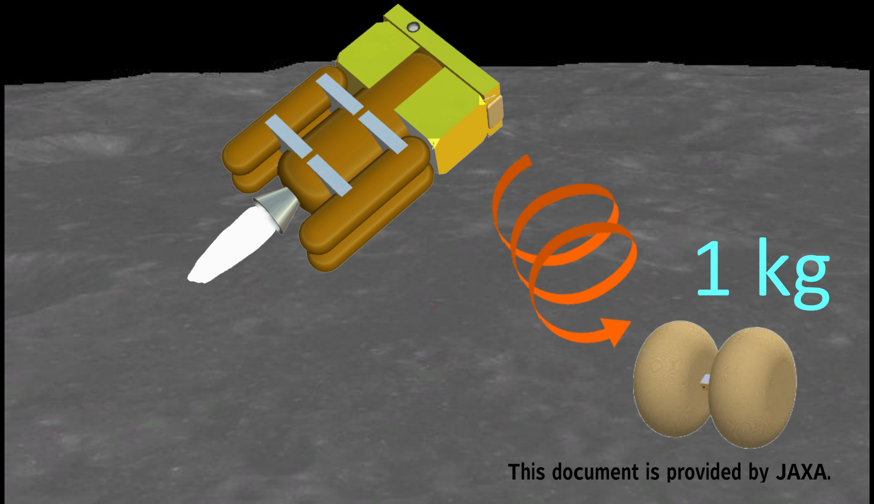


The smallest moon lander launched by the most powerful rocket in the world

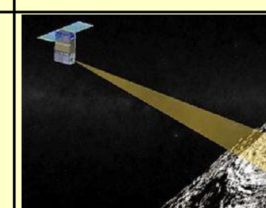
21 ton

10^{-6} scale mission

14 kg

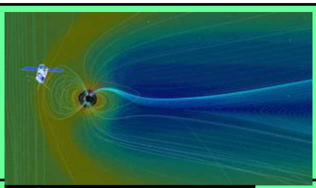
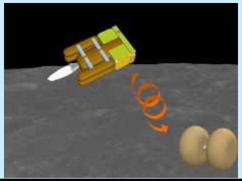
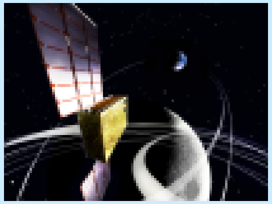


CubeSats（3 CubeSats have not yet been decided） -1-

Project name (Organization)	Orbit	Mission	Artist image
NEAScout (NASA JPL)	Flyby and go to Asteroid 1991VG	Determine its size, movement and chemical composition of the asteroid	
Lunar Flashlight (NASA Marshall, JPL, UCLA)	Moon orbit	Explore, locate, and estimate size and composition of water ice deposits on the Moon	
BioSentinel (NASA Ames, Johnson)	Flyby	Effect of deep space radiation to living organisms over long durations	
Lunar IceCube (NASA Goddard, Morehead State Univ.)	Moon orbit	Electric RF ion engine, prospect, locate, and estimate size and composition of water ice deposits on the Moon	
SkyFire (Lockeed Martin)	Moon close flyby	Spectroscopy and thermography of moon surface	

“Missions for future human exploration” selected by Human Exploration and Operations Mission Directorate

CubeSats（3 CubeSats have not yet been decided） -2-

Project name (Organization)	Orbit	Mission	Artist image
CuSP (Southwest Research Institute)	Flyby	Space weather station. Demonstration for future cubesat network observation.	
LunaH-Map (Arizona State University)	Moon orbit	Mapping hydrogen within craters and permanently shadowed regions	
OMOTENASHI （JAXA)	Moon impact	The smallest moon lander launched by the most powerful rocket in the world	
EQUULEUS (JAXA, Univ. of Tokyo)	Multi-gravity assist and go to EML2	Demonstrate trajectory control in Cis-lunar region and observation of Erath's plasma sphere and lunar impact flash	
ArgoMoon (ASI, Argotec)	Earth orbit	Taking photo of SLS and technology demonstration for communication system.	

Science missions selected by Science Mission Directorate

Missions proposed by international partners

Mission objectives

- Development of the smallest lunar lander in the world and demonstrate the feasibility of the hardware for distributed cooperative nano-exploration system, which Space Exploration Innovation Hub of JAXA plans to realize. Small landers will enable multi-point exploration which is complimentary with large-scale human exploration system. And also they promote the participation of private sectors.

  -> Demonstration of a nano-lander which can be easily carried in any robotic or human orbiters or landers.

- Observation of radiation and soil environment of the moon surface by active radiation monitors and touchdown acceleration measurements. Especially, the measurement of radiation environment helps radiation risk assessment for astronauts and to establish radiation models on the Moon.

  -> Observation of radiation and soil environment are listed in SKG (Strategic Knowledge Gap) of ISECG (International Space Exploration Coordination Group).

SKG summarized by ISECG (Moon)

- Strategic Knowledge Gap (SKG), that is, knowledge to reduce the risk of human exploration, is summarized in Global Exploration Roadmap (GER) ver.2.

(*) This column is added by JAXA

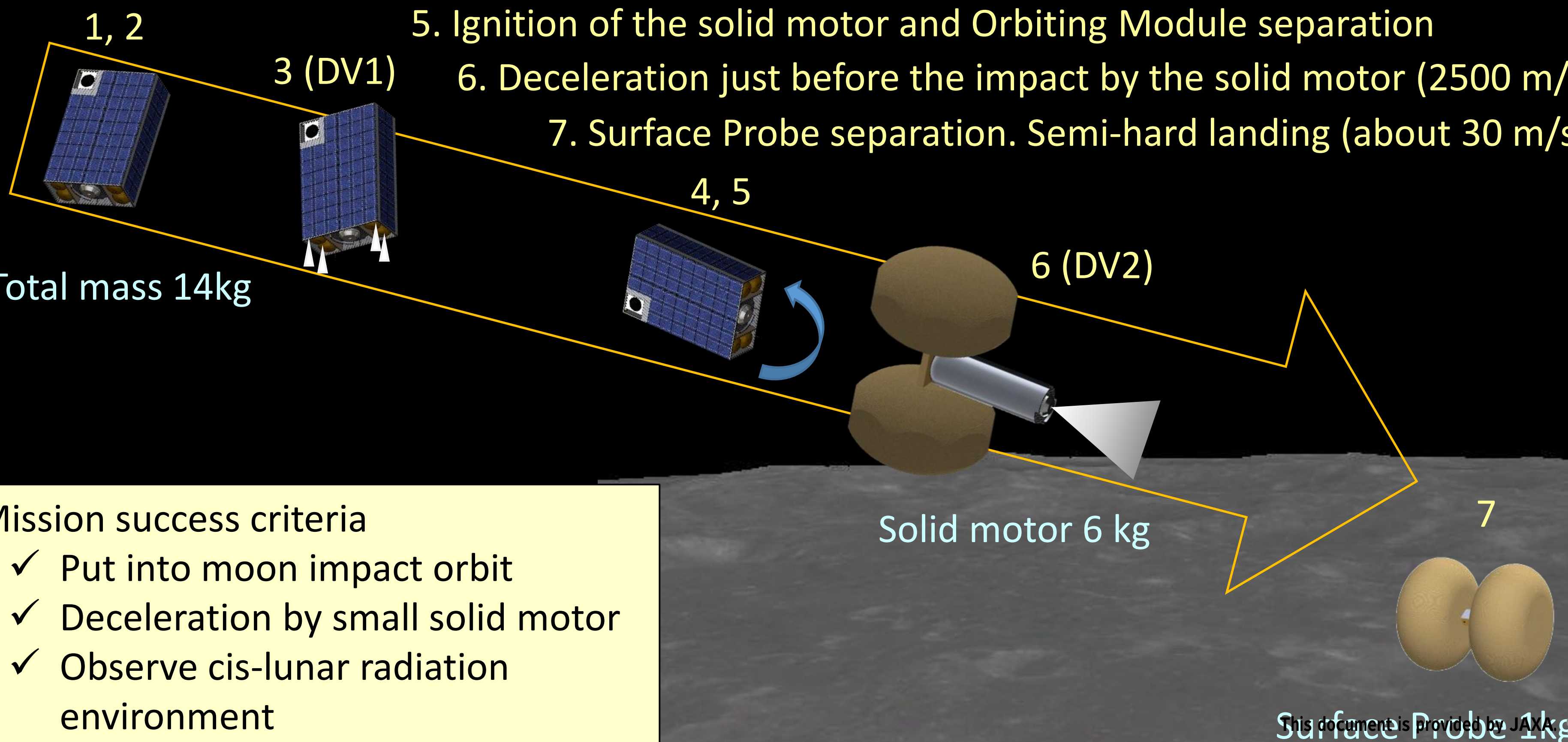
Knowledge domain	Description and Priority	Required mission or ground activity	Japanese mission (*)
Resource potential	Solar illumination mapping	Already enough data	Kaguya (SELENE)
	Regolith volatiles from Apollo samples	Ground activity	NA
	Regolith volatiles and organics in mare and highlands.	Robotic mission, Sample return	Future mission
	Lunar cold trap volatiles (water, etc.) distributed within permanently shadowed area.	Robotic mission, Sample return	SELENE-R
	Resource prospecting in pyroclastic, dark mantle deposits, etc.	Robotic mission, Sample return	Future mission
Environment and effects	Radiation at the lunar surface	Robotic mission	OMOTENASHI, SELENE-R
	Toxicity of lunar dust	Robotic mission, Sample return, Ground activity	Future mission
	Micrometeoroid environment	Robotic mission	EQUULEUS
Live and work on lunar surface	Geodetic Grid and Navigation	Already enough data	Kaguya (SELENE)
	Surface Trafficability	Robotic mission, Ground activity	(OMOTENASHI), SELENE-R
	Dust & Blast Ejecta:	Robotic mission, Ground activity	SELENE-R
	Plasma Environment & Charging	Robotic mission	Future mission
	Lunar Mass Concentrations and Distributions	Already enough data	Kaguya (SELENE)

Mission sequence

1. Deployment form SLS rocket
2. Spacecraft activation and sun pointing attitude acquisition
3. Orbit control to lunar impact orbit by Gas jet thrusters (10 m/s)

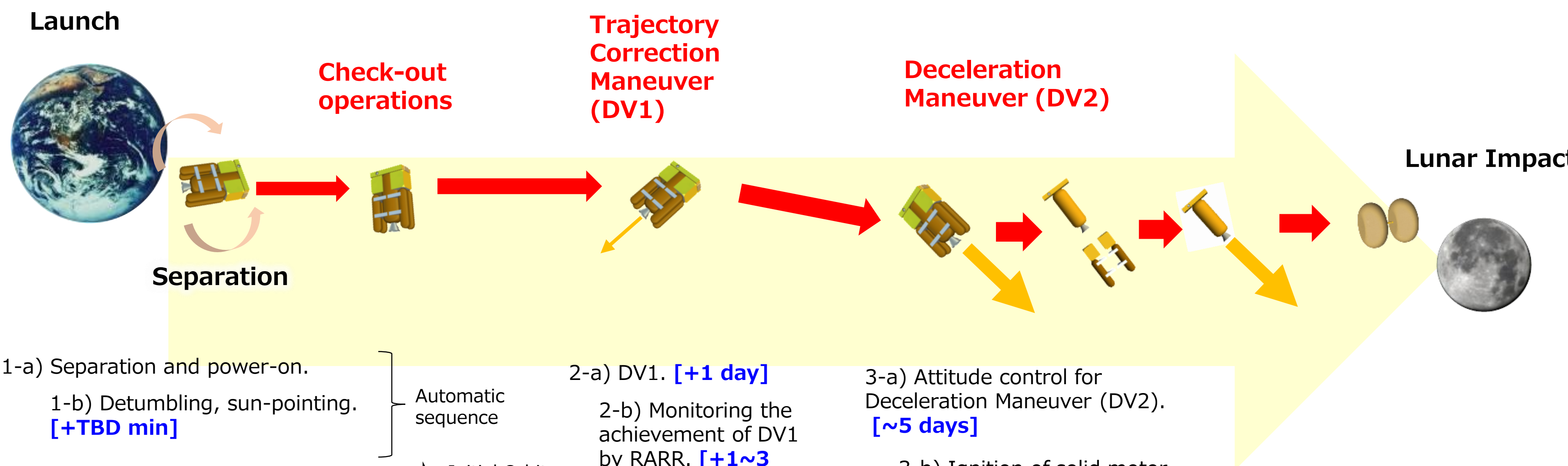
Measuring radiation environment

4. Attitude maneuver and spin-up for the deceleration
5. Ignition of the solid motor and Orbiting Module separation
6. Deceleration just before the impact by the solid motor (2500 m/s)
7. Surface Probe separation. Semi-hard landing (about 30 m/s)



Mission success criteria
- ✓ Put into moon impact orbit
- ✓ Deceleration by small solid motor
- ✓ Observe cis-lunar radiation environment

Concept of Operations Overview



1-a) Separation and power-on.

1-b) Detumbling, sun-pointing. **[+TBD min]**

Automatic sequence

1-c) Initial health checks. power/thermal/comm./attitude Control/propulsion. **[+TBD hour]**

Initial Orbit Determination (OD)

2-a) DV1. **[+1 day]**

2-b) Monitoring the achievement of DV1 by RARR. **[+1~3 days]**

3-a) Attitude control for Deceleration Maneuver (DV2). **[~5 days]**

3-b) Ignition of solid motor.

3-c) Separation of Orbiting Module.

3-d) Solid motor burn-out.

3-e) Surface probe separation.

1) Brief check-out of bus systems

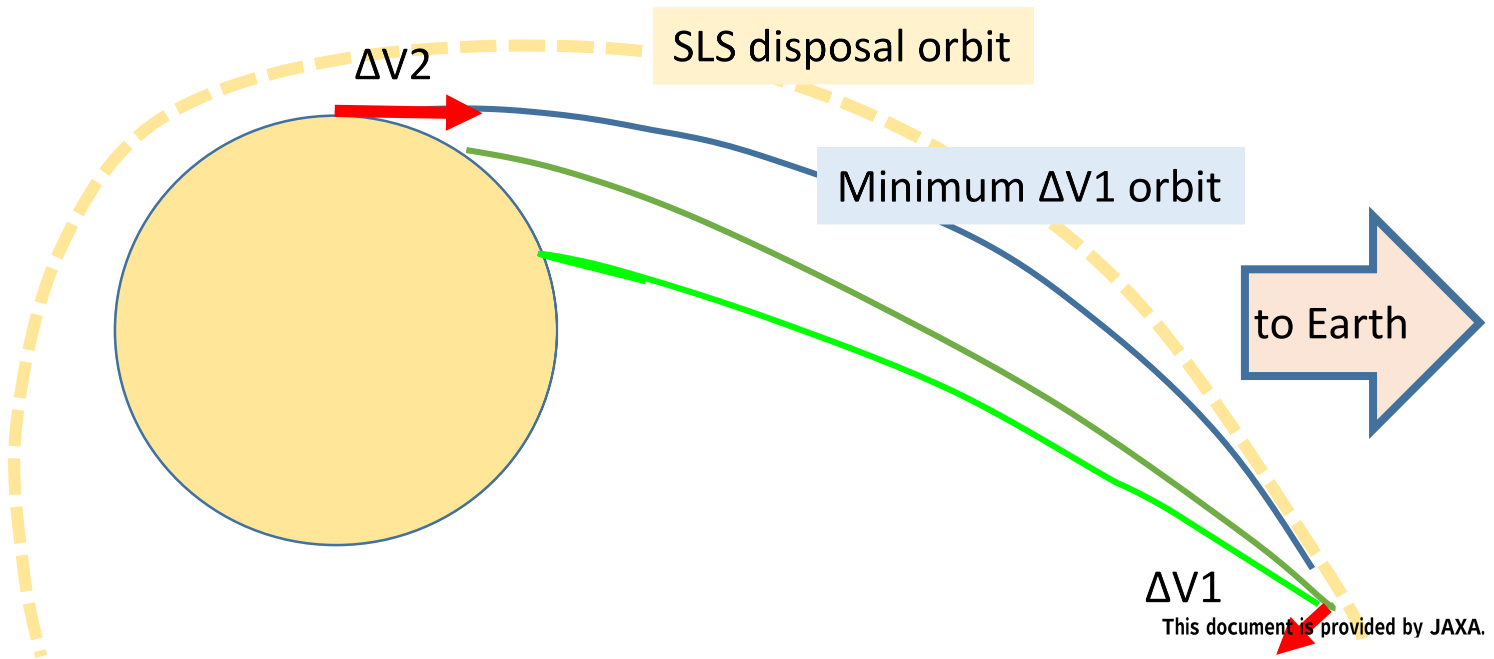
2) Trajectory Correction Maneuver

3) Deceleration Maneuver

[ ]: Time after separation

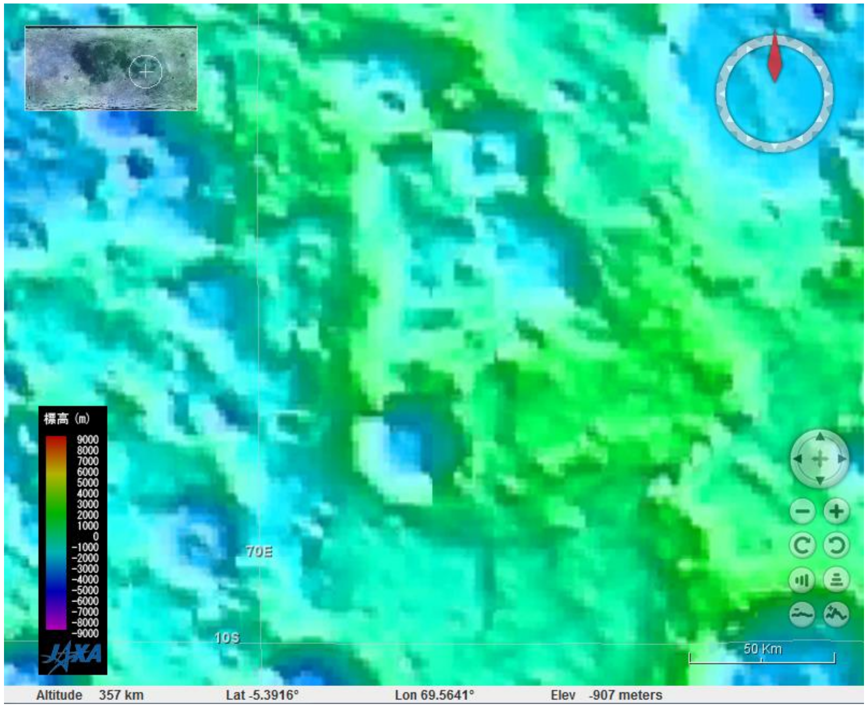
Trajectory design

- Basically, two burns (delta-V1 and delta-V2) are required to land on the moon surface.
- Delta-V1 requires 10 – 20 m/s depending on SLS separation orbit and delta-V timing. Currently, 24 hours after the separation is assumed considering orbit determination time. Delta-V2 is almost 2500 m/s in any case.
- By delta-V1, landing point and impact angle are controlled. But they are not controlled independently. In case of the minimum delta-V1, landing point is (-6.5, 71.9) and the impact angle is 0 deg. Increasing delta-V1, landing point approached to the center of the near side and impact angle becomes big.
- Due to low impact angle, the terrain of the landing point should be considered.



Tentative landing area (-6.5, 71.9)

Generated image

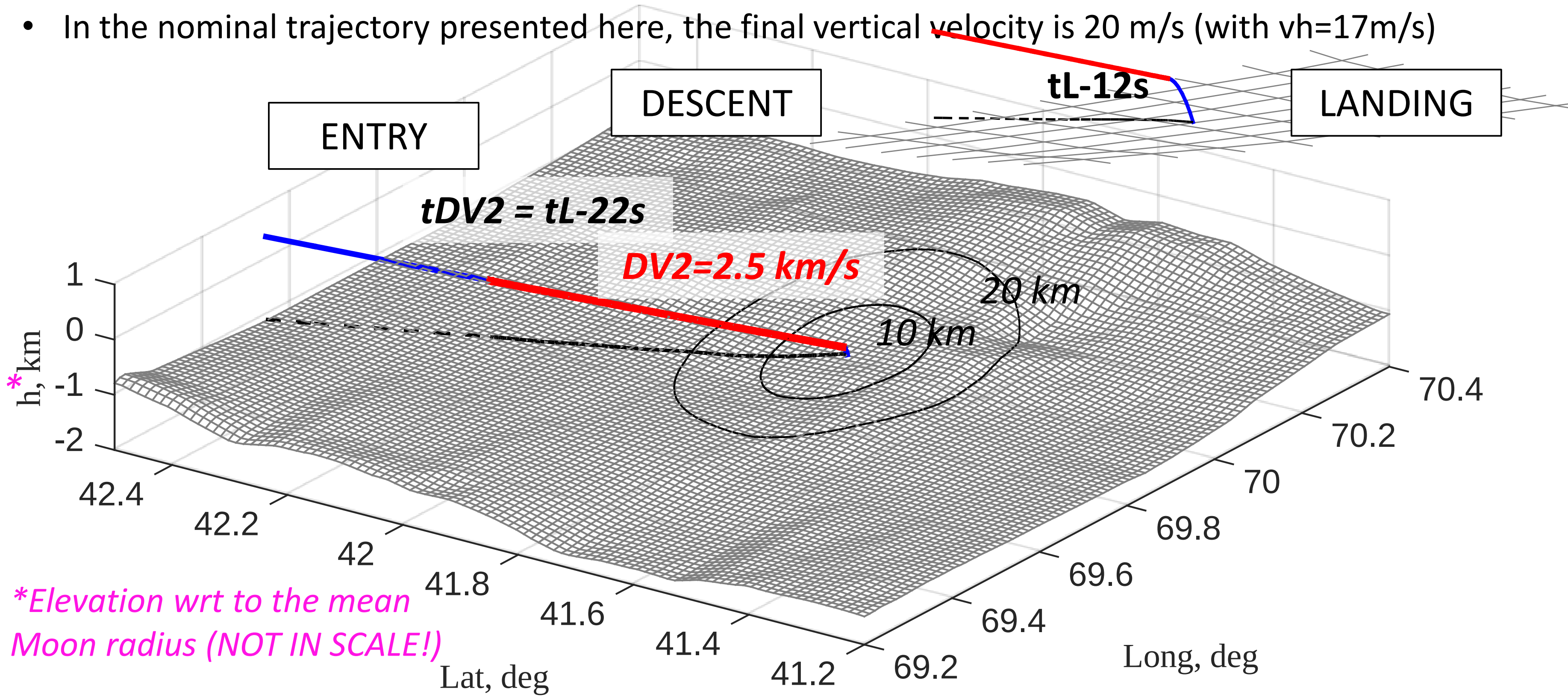


Topological map

Trajectory design

BASELINE (2/2 CLOSE UP OF THE ENTRY, DESCENT AND LANDING)

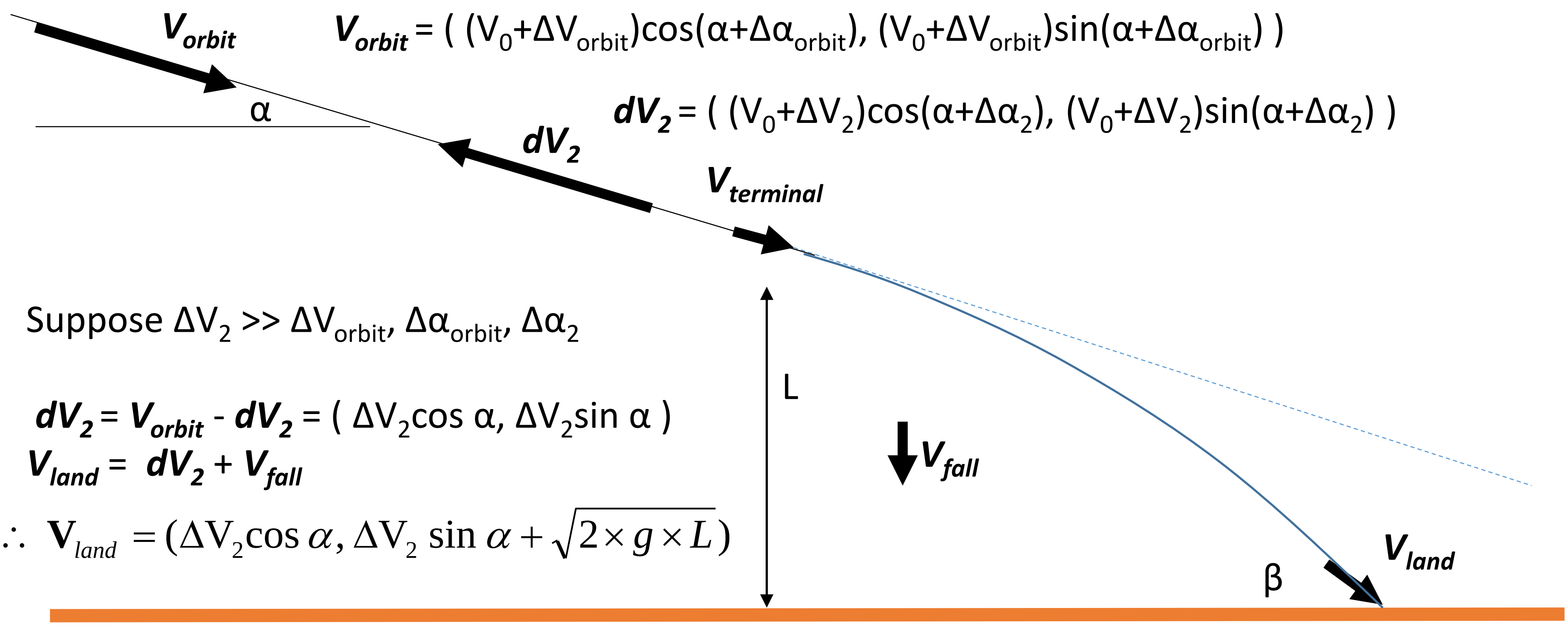
- The solid rocket thrust arc is shown in red; the thrust direction is fixed (almost anti-velocity). The thrust arc terminates at 130 m altitude, with zero vertical velocity.
- A residual horizontal velocity is present because the avail. DV is slightly different from the DV needed to completely stop the spacecraft (which varies from launch date to launch date).
- In the nominal trajectory presented here, the final vertical velocity is 20 m/s (with vh=17m/s)



Simple 2 DOF expression

V_0 : Designed impact velocity before delta-V2
α : Designed impact angle
$\boldsymbol{V}_{orbit}$: Actual velocity vector before delta-V2
$\boldsymbol{dV}_2$: Delta-V2 vector by solid motor

L : Terminal altitude
$\boldsymbol{V}_{terminal}$: Actual velocity vector after delta-V2
$\boldsymbol{V}_{fall}$: Velocity inclement vector by gravity
$\boldsymbol{V}_{land}$: Actual landing velocity after free fall



$$\boldsymbol{V}_{orbit} = \left((V_0+\Delta V_{orbit})\cos(\alpha+\Delta\alpha_{orbit}),\ (V_0+\Delta V_{orbit})\sin(\alpha+\Delta\alpha_{orbit}) \right)$$

$$\boldsymbol{dV}_2 = \left((V_0+\Delta V_2)\cos(\alpha+\Delta\alpha_2),\ (V_0+\Delta V_2)\sin(\alpha+\Delta\alpha_2) \right)$$

Suppose $\Delta V_2 >> \Delta V_{orbit}, \Delta\alpha_{orbit}, \Delta\alpha_2$

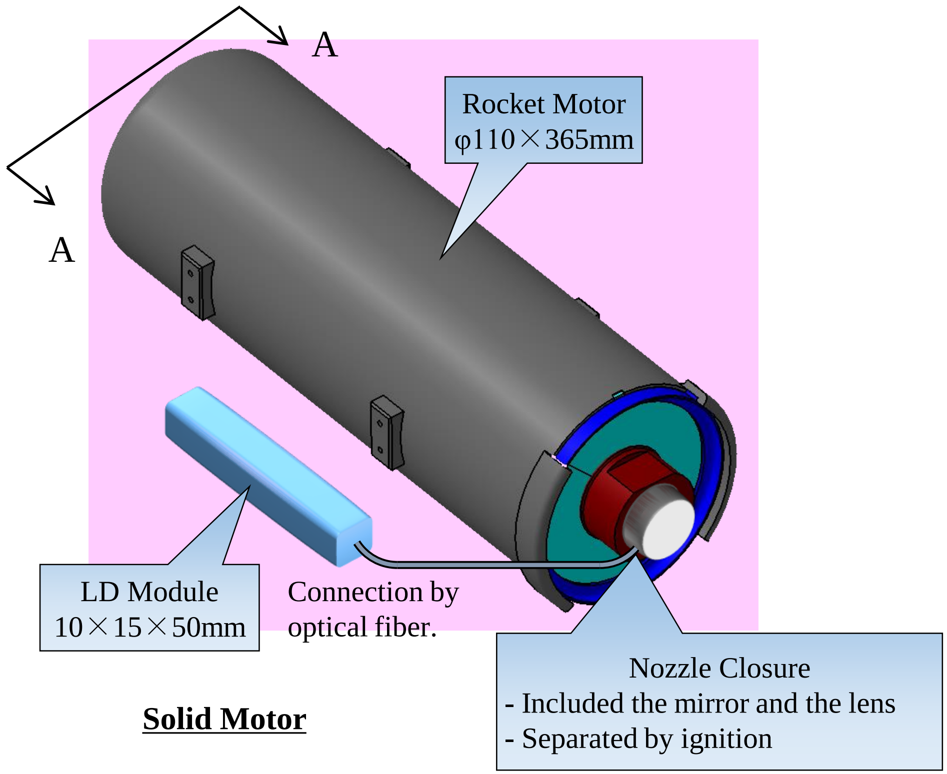
$$\boldsymbol{dV}_2 = \boldsymbol{V}_{orbit} - \boldsymbol{dV}_2 = (\Delta V_2\cos\alpha, \Delta V_2\sin\alpha)$$

$$\boldsymbol{V}_{land} = \boldsymbol{dV}_2 + \boldsymbol{V}_{fall}$$

$$\therefore\ \mathbf{V}_{land} = (\Delta V_2\cos\alpha, \Delta V_2\sin\alpha + \sqrt{2\times g\times L})$$

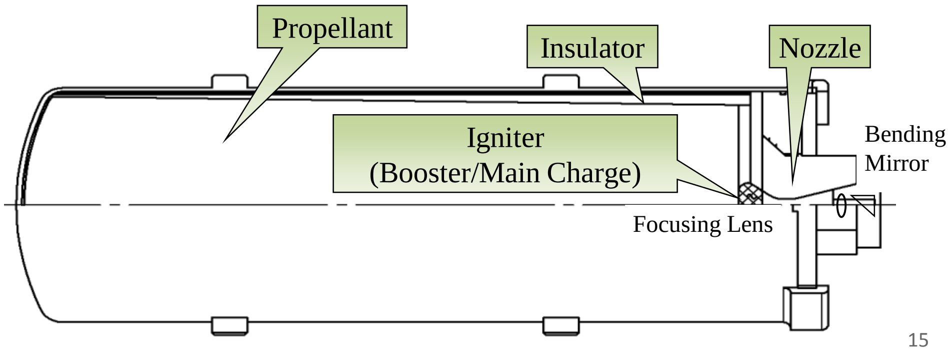
Overview of the solid motor

The Solid motor is ignited by a laser via optical fiber and lens. The nozzle is closed by a nozzle closure which is also used for optical path of the laser. After the ignition, it is automatically removed by the thrust flow.



Solid Motor

Specification of RM	
Propellant	HTPB/Al/AP
Ignition type	Laser
Combustion press.	8 [MPa]
Operating time	15 to 20 [s]
Isp	255 [s] and over
Storage temp.	-30 to 60 [degC]
Operating temp.	T.B.D.



Cross Section (A-A)

Fundamental physics for shock absorption

- 30 m/s (about 1 % of delta V) is considered as relative velocity at landing. From simple physical calculation, required deceleration length is as follows,

$$V \leq \alpha T \quad \cdots(1) \qquad \therefore T \geq \frac{V}{\alpha} \quad \cdots(2)$$

$$L \geq \frac{1}{2}\alpha T^2 \quad \cdots(3) \qquad \therefore L \geq \frac{V^2}{2\alpha} \quad \cdots(4)$$

V: Relative velocity [m/s]
α: Upper limit of acceleration [m/s^2]
T: Deceleration duration [s]
L: Deceleration length [m]

Example	V [m/s]	α [m/s^2]	L_{min} [cm]	T_{min} [msec]
SELENE-2 landing leg	3	100	4.5	30
Surveyor landing leg	3	40	11	75
Lunar penetrator	300	100000	45	3
OMOTENASHI	30	1000	45	30
	30	30000	1.5	1
	100	30000	16.7	3

- If L is smaller than a few cm, shock absorption material can be used. Otherwise, deployable air bag should be used, or penetration in the surface should be allowed.

Candidates of shock absorption mechanism

A. Crushable material
   - When instruments can stand against 3000 G, 1.5 cm crushable shell can absorb the touchdown shock.
   - When the probe digs into regolith, impact acceleration will decrease, but communication problem is anticipated.

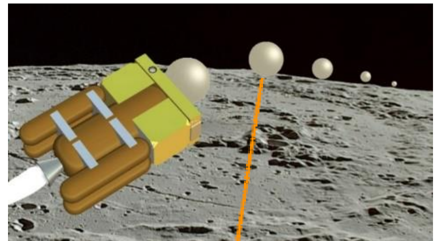
B. Air bag
   - When air bag can shrink 45cm, impact acceleration will be 100 G.
   - When and how the air bag is deployed should be considered.

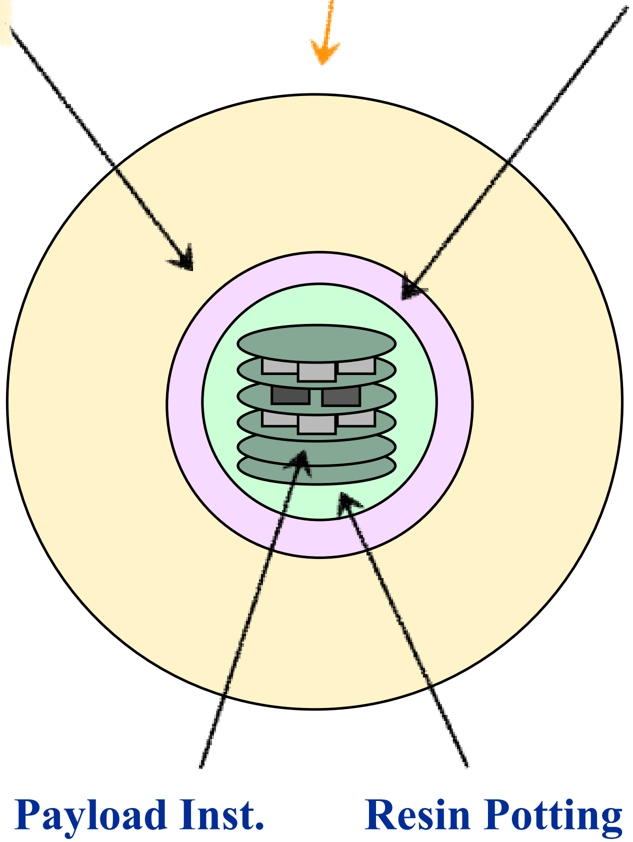
Crashable Material

φ110mm Hemisphere x 2

Outer Crushable Material

- Radio Wave Transparency
- No Particle Scattering
- Outgas within regulation
- No Transformation under Vacuum condition
- Temperature (TBD)
- isotropic
- Brittle Material (no shear stress with plateau)
- Plateau Stress：1.7 MPa

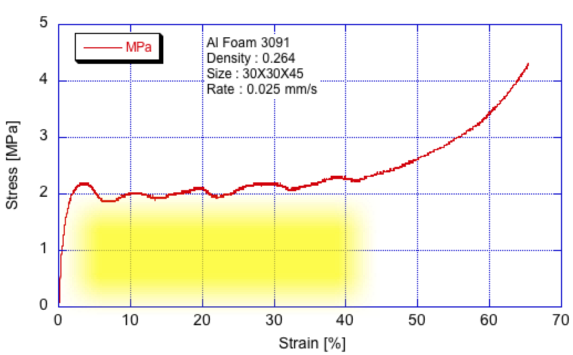




φ60mm Hemisphere x 2

Inner Hard Shell

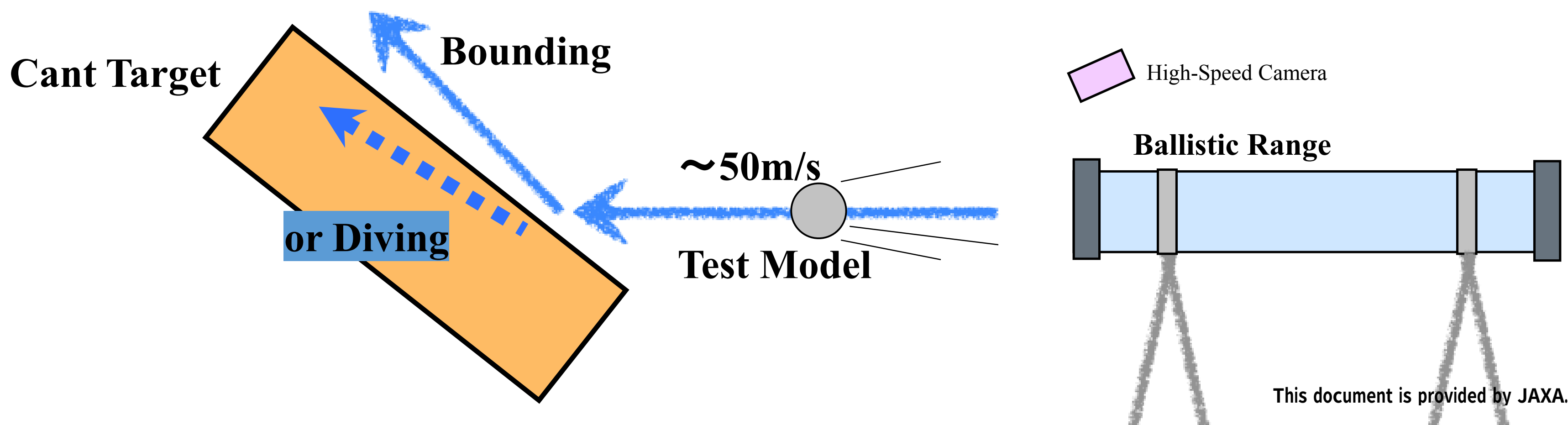
- Radio Wave Transparency
- No Particle Scattering
- Outgas within regulation
- No Transformation under Vacuum condition
- Temperature (TBD)
- isotropic
- Ductil (no-brittle) Material
- Plateau Stress：over 20 MPa



Impact test for crashable material

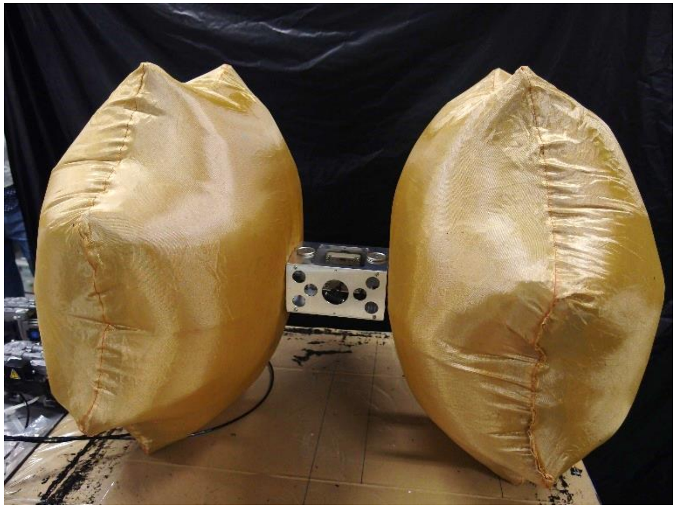
Cant-Target with Ballistic Range

- Frequent and Successive Testing is Possible
  advantageous for Material Screening
- The Tests can Confirm Design Procedure
  by Comparing Predictions and Empirical Data.
- V_{tot} (Norm of V) ~70 m/s *lower than requirements
  surface behavior tendency to be investigated
  under quasi/pseudo "Lunar Soil"
  (Bounding or Diving Behavior Measured)
- 3-axis Acc and Rate sensors installed in the Model

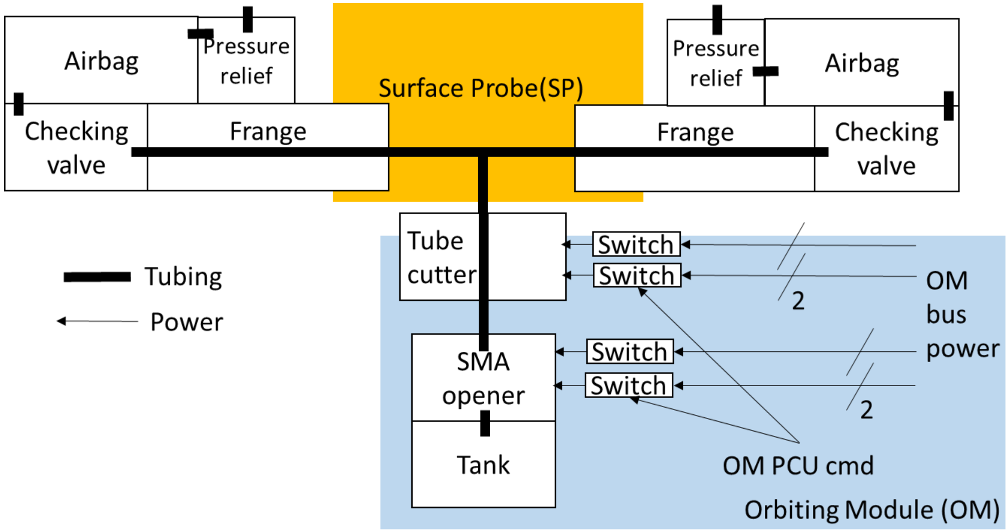


Air bag

An air bag is inflated to a barrel shape (50 cm diameter and 30 cm height) with nitrogen gas within 24 kPa (TBD) and the airbag system consists of the airbag surface membrane (Zylon, Polyimide film), Silicone adhesion, interface plate, passive check valves, pressure regulator valves, gas tank (5.7 MPa*), tubes, SMA (Shape Memory Alloy) opener, electrical driver for the opener, and tube cutter.

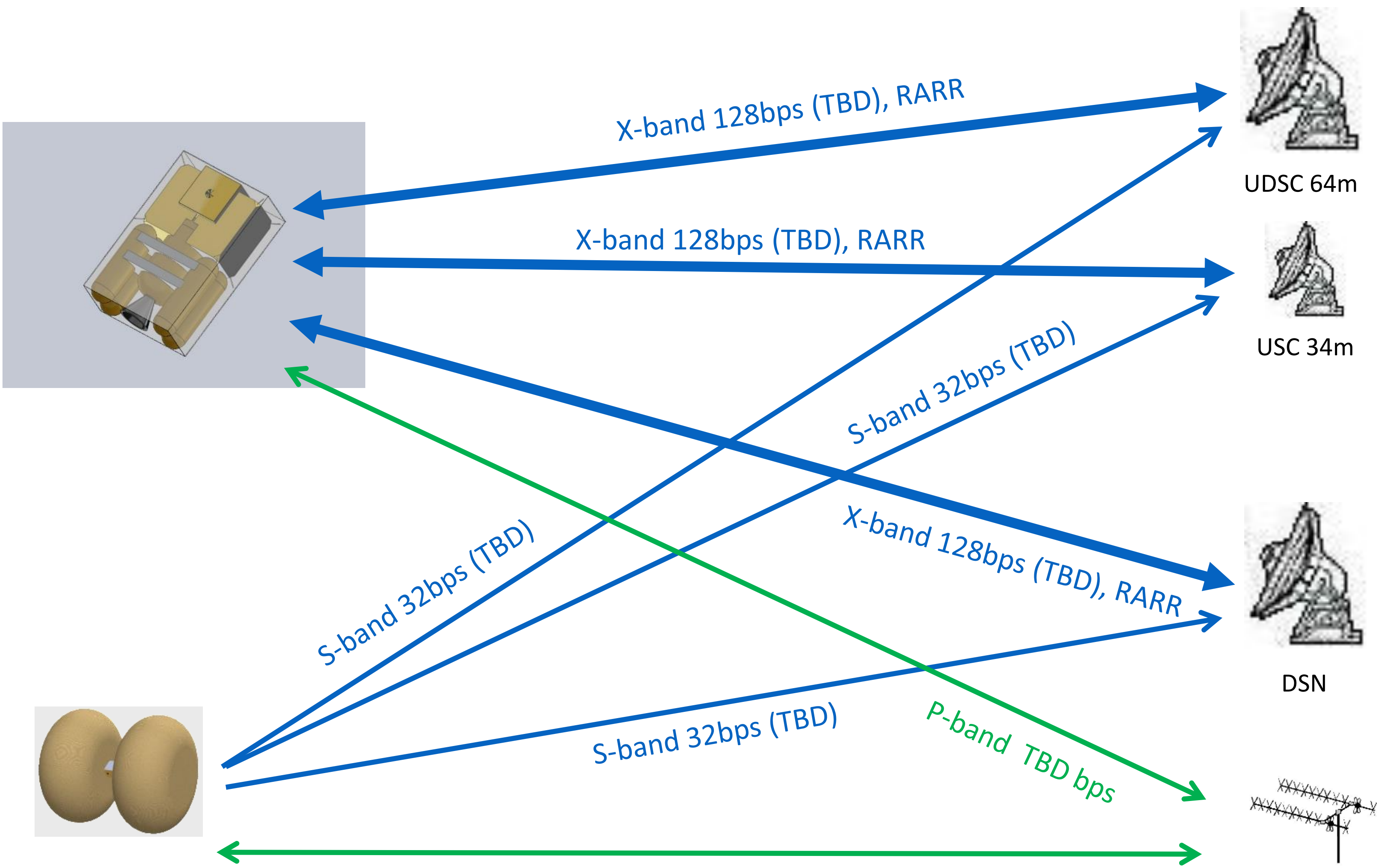


* Proof tested at 56 MPa



Ground tracking system (X-up/X-down, S-down)

P-band is for amateur radio communication.



RARR includes DDOR

Radiation Monitor (D-Space)

Two sets of D-Space Radiation Monitors are installed on both Orbiting Module and Surface Probe. The D-Space is very light and portable alarm meter developed based on commercial personal dosimeters of Fukushima residents suffered from nuclear power plant accident. Some improvements are carried out on D-Space for space radiation dosimetry. It consists of Si-pin photodiode on circuit board, button-shaped battery and the shielding case. Optical communication board with external power supply (3.3 V from Orbiting Module or Surface Probe) are also needed. D-Space can measure absorbed doses every 1 min as the number of current pulses that were caused when particles pass through the photodiode.

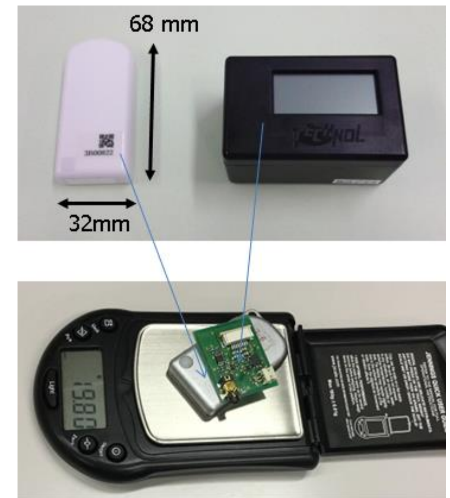


Figure 4-1-7-1 Radiation monitor and Optical communication board

Weight：less than 50 g per one set (2 sensors)
Size: 68 (L) x 32 (W) x 14 (T) mm per each sensor
Battery: Lithium battery (3V, 550mA)
Count rate: every 1 min
Sensor-1: for doses from charged particles,
Sensor-2: for doses from mainly GCR ions in higher LET regions

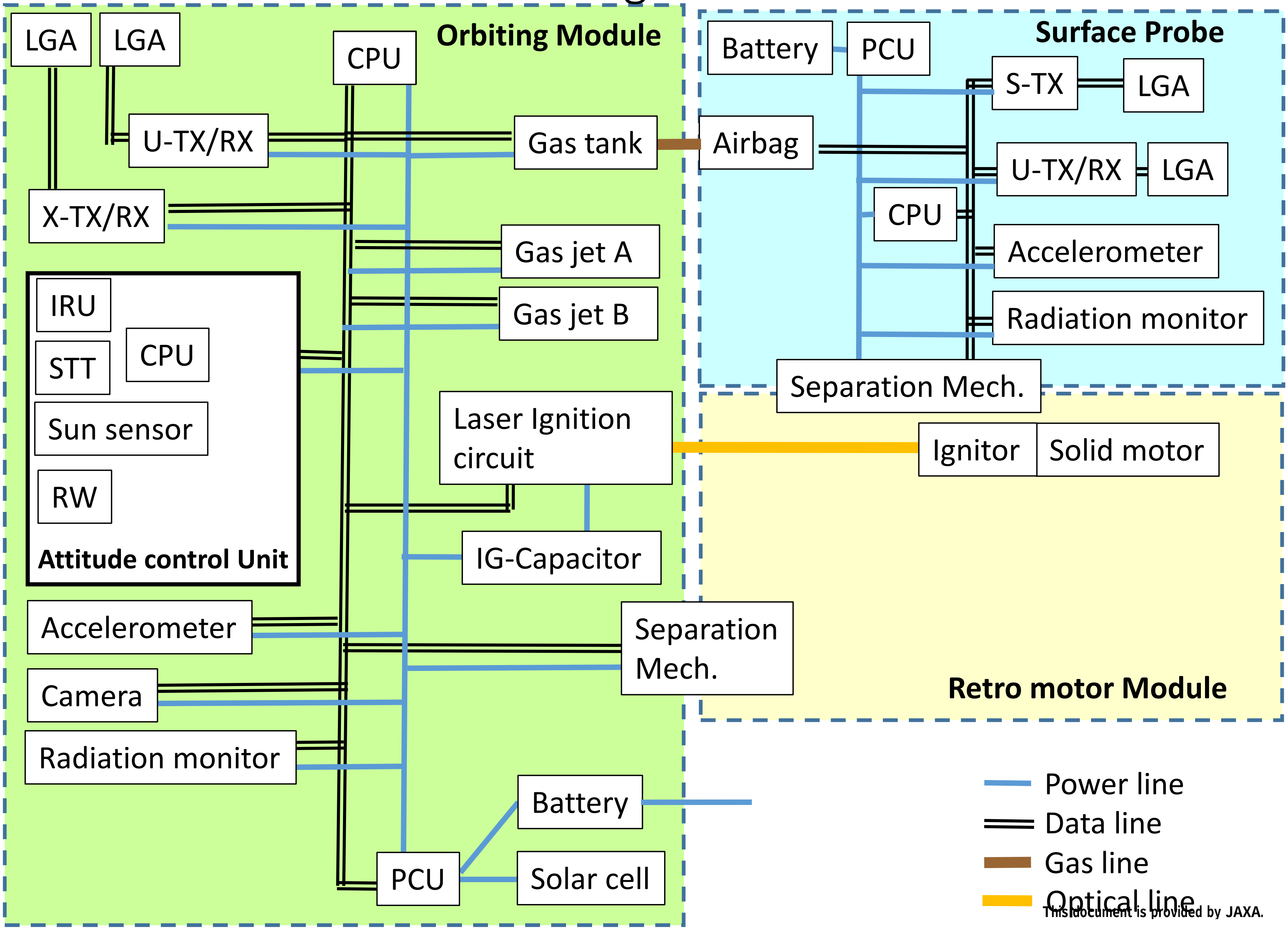
Main specification

Payload	• Radiation monitor (OM and SP) • Shock acceleration measurement (SP)
Mechanical& Structure	6U, 14kg, consists of three modules, Orbing Module, Retro motor Module, Surface probe.
Propulsion	• Solid motor (2500 m/s TBD) • Gas jet (N_2, 20 m/s TBD)
Avionics	• 2 On Board Computer (for OM, SP)
Electrical Power System	OM • Solar cell (body mounted) 30W max, 15W spinning • Secondary battery 30 Wh (TBD) SP • Primary battery 30 Wh (TBD)
Telecom	OM • X-band Up Link • X-band Down Link • P-band Down Link (Amateur Radio Frequency) • Chip Scale Atomic Clock SP • S-band Downlink • P-band Downlink (Amateur Radio Frequency) • P-band Uplink (Amateur Radio Frequency)
Attitude Control System	• Sun Acquisition: 0.1 deg (TBD) • Three axis stabilized: 0.01 deg (TBD) • Spin: 300 rpm (TBD)

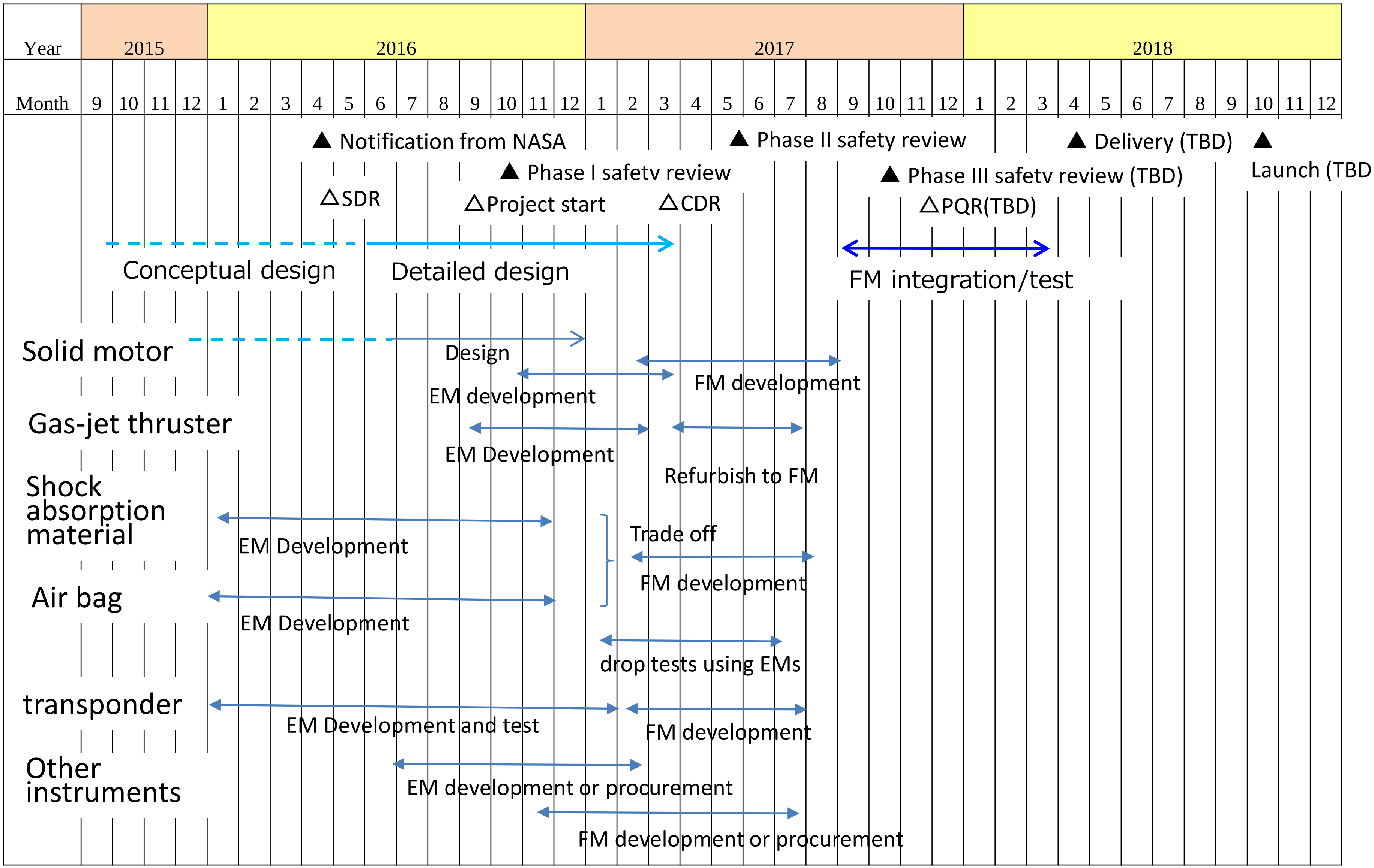
Mass budget (TBD)

	Mass [g]
Orbiting Module	7000
Structure	2000
Propulsion dry (Tank, valve)	1500
Propellant (N_2 gas)	500
Instruments and bus system	2500
Ignitor for RM	500
Retro motor Module	6000
Propellant	4000
Motor case and nozzle	2000
Surface Probe	1000
Shock absorber and structure	600
Instruments and bus system	400
Total	14000

OMOTENASHI block diagram



OMOTENASHI development schedule



References

(1) International Partners Provide Science Satellites for America's Space Launch System Maiden Flight(2016/5/27): https://www.nasa.gov/exploration/systems/sls/international-partners-provide-cubesats-for-sls-maiden-flight

(2) OMOTENASHI: http://www.isas.jaxa.jp/home/omotenashi/index.html

(3) NEA Scout: https://www.nasa.gov/content/nea-scout

(4) Lunar Flashlight: https://www.nasa.gov/launching-science-and-technology/multimedia/lunar-flashlight.html

(5) BioSentinel: https://www.nasa.gov/centers/ames/engineering/projects/biosentinel.html

(6) Lunar IceCube: https://www.nasa.gov/launching-science-and-technology/multimedia/lunar-icecube.html

(7) SkyFire: http://www.lockheedmartin.com/us/news/press-releases/2016/august/ssc-080816-smallsat.html

(8) CuSP: http://mstl.atl.calpoly.edu/~bklofas/Presentations/DevelopersWorkshop2016/4_DonGeorge.pdf

(9) LunarH-Map: http://lunahmap.asu.edu/docs/AIAA.pdf

(10) EQUULEUS: http://issl.space.t.u-tokyo.ac.jp/equuleus/en/

(11) ArgoMoon: http://www.asi.it/en/news/made-in-italy-just-a-click-away-moon

(12) Cube Quest: https://www.nasa.gov/directorates/spacetech/centennial_challenges/cubequest/ground-tournament-3-teams