Asteroid explorer, Hayabusa2, reporter briefing

July 25, 2017
JAXA Hayabusa2 Project
Topics

Regarding Hayabusa2,

- Results from the 2nd touchdown operation
Contents

0. Hayabusa2 and mission flow outline
1. Current status and overall schedule of the project
2. The 2\textsuperscript{nd} touchdown operation
3. Images from the 2nd touchdown operation
4. Name of the 2nd touchdown point
5. Upcoming events

- Reference material
Objective
We will explore and sample the C-type asteroid Ryugu, which is a more primitive type than the S-type asteroid Itokawa that Hayabusa explored, and elucidate interactions between minerals, water, and organic matter in the primitive solar system. By doing so, we will learn about the origin and evolution of Earth, the oceans, and life, and maintain and develop the technologies for deep-space return exploration (as demonstrated with Hayabusa), a field in which Japan leads the world.

Expected results and effects
• By exploring a C-type asteroid, which is rich in water and organic materials, we will clarify interactions between the building blocks of Earth and the evolution of its oceans and life, thereby developing solar system science.
• Japan will further its worldwide lead in this field by taking on the new challenge of obtaining samples from a crater produced by an impacting device.
• We will establish stable technologies for return exploration of solar-system bodies.

Features:
• World’s first sample return mission to a C-type asteroid.
• World’s first attempt at a rendezvous with an asteroid and performance of observation before and after projectile impact from an impactor.
• Comparison with results from Hayabusa will allow deeper understanding of the distribution, origins, and evolution of materials in the solar system.

International positioning:
• Japan is a leader in the field of primitive body exploration, and visiting a type-C asteroid marks a new accomplishment.
• This mission builds on the originality and successes of the Hayabusa mission. In addition to developing planetary science and solar system exploration technologies in Japan, this mission develops new frontiers in exploration of primitive heavenly bodies.
• NASA too is conducting an asteroid sample return mission, OSIRIS-REx (launch: 2016; asteroid arrival: 2018; Earth return: 2023). We will exchange samples and otherwise promote scientific exchange, and expect further scientific findings through comparison and investigation of the results from both missions.

Hayabusa2 primary specifications
Illustration: Akihiro Ikeshita)
Mass Approx. 609 kg
Launch 3 Dec 2014
Mission Asteroid return
Arrival 27 June 2018
Earth return 2020
Stay at asteroid Approx. 18 months
Target body Near-Earth asteroid Ryugu
Primary instruments
Sampling mechanism, re-entry capsule, optical cameras, laser range-finder, scientific observation equipment (near-infrared, thermal infrared), impactor, miniature rovers.
Mission flow

Launch
Dec 3, 2014

Earth swing-by
Dec 3, 2015

Ryugu arrival
June 27, 2018

MINERVA-II-1 separation
Sep 21, 2018

MASCOT separation
March 10, 2018

Ryugu departure
Nov-Dec, 2019

First touchdown
5 April, 2019

Second touchdown
July 11, 2019

Impactor (SCI)
Feb 22, 2019

Earth return
End of 2020

End of 2020

(image credit: illustrations including spacecraft by Akihiro Ikeshita, others by JAXA)
1. Current project status & schedule overview

Current status:

– Implemented the second touchdown from July 9 – 11.
– Touchdown was carried out safely and Hayabusa2 returned to the home position at about 20 km from the center of Ryugu on July 12.
– BOX-C operation is currently underway (7/20 ~ 31). The lowest altitude will be about 5km during 7/25~27.

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<tbody>
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<td>3</td>
<td>10</td>
<td>12</td>
<td>4</td>
<td>6</td>
<td>7</td>
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<tr>
<td>Event</td>
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<tr>
<td>Initial operation</td>
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<td>12</td>
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<tr>
<td>EDVEGA</td>
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<td>Re-entry</td>
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<td>Swing-by</td>
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<td></td>
<td>6</td>
<td>12</td>
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<tr>
<td>Journey to asteroid</td>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td>7</td>
<td>12</td>
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<tr>
<td>Asteroid proximity operations</td>
<td></td>
<td>6</td>
<td>6</td>
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<tr>
<td>Earth return</td>
<td></td>
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<td></td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

Event details:

- **ESA (MLG/WLH) test operations (May 21 – 22)**
- **Southern hemisphere station operations (CAN/MLG)**
  - May
  - June
- **Optical navigation**
  - May
  - June
- **Solar conjunction**
  - Nov
  - Dec
- **Ion engine operations**
  - Mar
  - Jun
  - Mar
  - May
  - Nov
  - Apr
- **TBD**

2019/07/25

Hayabusa2 reporter briefing
2. The 2\textsuperscript{nd} touchdown operation

- 2\textsuperscript{nd} touchdown operation: 2019/7/9 – 11
- Touchdown date & time: 2019/7/11, 10:06:18 JST (on-board time)
- Touchdown location: C01-Cb (Target marker drop area)
- Implemented pinpoint touchdown targeting TM-A dropped during PPTD-TM1A.
- Touchdown was detected through fluctuations in the LRF-S2 ranging value due to deformation of the sampler horn upon touchdown.
- Touchdown position accuracy is 60 cm.
2. The 2\textsuperscript{nd} touchdown operation

**First release**

Images from the small monitor camera (CAM-H).
Images before and after touchdown (10x animation)

Capture time:
2019/7/11
Start 10:03:54 (altitude 8.5m)
Finish 10:11:44 (altitude 150m)
※image interval between 0.5s~5s

(credit: JAXA)
2. The 2nd touchdown operation

PPTD-TM1 image

PPTD-TM1B image

(animation)

TM = target marker
(The left-hand image is taken prior to dropping the TM and its position is marked. In the middle image, the TM itself is captured.)

H is the maximum estimated height
※ boulder names are nicknames, not official designations.

DEM (Digital Elevation Map) near the touchdown candidate point

(TM, Styx boulder, Rock mass, Small Styx)

(credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST.)
2. The 2\textsuperscript{nd} touchdown operation

<table>
<thead>
<tr>
<th>Challenges for the 2\textsuperscript{nd} touchdown (difference from the 1\textsuperscript{st})</th>
</tr>
</thead>
</table>
| 1. Due to the optical system on the wide-angle Optical Navigation Camera ONC-W1 becoming cloudy, it was necessary to lower the starting altitude for capturing and tracking the TM (45m to 30m).
  | For the TM to be in the narrowed field of view of the ONC-W1, the accuracy of the GCP-NAV guidance had to be high.
  | Managed with the accuracy of the GCP-NAV guidance results |
| 2. The TM brightness decreased due to the cloudiness of the optical system of the ONC-W1.
  | High probability of a bright spot other than the TM being misjudged as the TM
  | Managed by changing the TM threshold recognition time |
| 3. LRF measurable distance decreased due to the cloudiness of the LRF optical system.
  | Starting altitude for LRF use was lower (17m) than for the first touchdown (28m).
  | The descent sequence was therefore shifted to a lower altitude and it was necessary to devise safety measures for the spacecraft.
  | Timeout was applied. |
| 4. Distance measurement error increased due to the cloudiness of the LRF optical system.
  | Since the range error was predictable, on-board software could correct the range value.
  | As a result, there was no issue with the LRF range accuracy. |

TM: target marker
GCP-NAV (Ground Control Point Navigation) → method to find the position and velocity of the spacecraft through observing features on the asteroid surface.
LRF: Laser Range Finder
2. The 2nd touchdown operation

Operation sequence (overall)

Date & time  On-board time  Ground time
7/10       10:46          11:00
7/11       21:06          21:20
7/12       09:40          09:54
         10:06          10:20
(image credit: JAXA)
2. The 2nd touchdown operation

Operation sequence (low altitude)

- After TM autonomous capture, descent acceleration $\Delta V$
- Position / speed judgement at altitude 12.5m
- During descent, 6 degrees of freedom control starts using LRF measurement values at alt. 17m
- Position / speed judgement at altitude 8.5m
- Hover at TM relative offset point
- TM to landing posture (convergence judgment)
- GCP-NAV Start hovering
- Follow TM and perform lateral position control while in free fall

Times shown are actual on-board times in JST on July 11, 2019.

※①～⑥ checkpoints for autonomous judgements as to whether Hayabusa2 continues to the next sequence.

(credit: JAXA)
## 2. The 2\textsuperscript{nd} touchdown operation

<table>
<thead>
<tr>
<th>Item</th>
<th>Ground time: JST () onboard time</th>
<th>Decision item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate 1</td>
<td>7/10 09:58</td>
<td>Decision made on start of descent (@20km)</td>
</tr>
<tr>
<td>Gate 2</td>
<td>7/10 21:36</td>
<td>End of confirmation on whether to continue descent (@5km)</td>
</tr>
<tr>
<td>Gate 3</td>
<td>7/11 09:04</td>
<td>End of final descent judgement (GO/NOGO judgement)</td>
</tr>
<tr>
<td>HGA→LGA</td>
<td>7/11 10:01 (09:47)</td>
<td>Antenna switching</td>
</tr>
<tr>
<td>Gate 4</td>
<td>7/11 10:01</td>
<td>End of confirmation on switching to LGA</td>
</tr>
<tr>
<td>TD2</td>
<td>7/11 10:20 (10:06)</td>
<td>Touchdown</td>
</tr>
<tr>
<td>LGA→HGA</td>
<td>7/11 10:39 (10:25)</td>
<td>Antenna switching</td>
</tr>
<tr>
<td>Gate 5</td>
<td>7/11 11:10</td>
<td>End check of the state of the spacecraft</td>
</tr>
<tr>
<td>Gate 6</td>
<td>7/11 14:46</td>
<td>Judgement on return to home position</td>
</tr>
<tr>
<td></td>
<td>7/12 10:50 (10:37)</td>
<td>Return to home position</td>
</tr>
</tbody>
</table>
2. The 2\textsuperscript{nd} touchdown operation

Flight data
LIDAR/LRF history

At 30m altitude, get LRF altitude (Error about 6m)
2. The 2nd touchdown operation

Position accuracy required for target marker capture

<table>
<thead>
<tr>
<th>Alt.</th>
<th>Required position accuracy</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 m</td>
<td>(\tan(30^\circ)\times 30 = 17 \text{ m})</td>
<td>When the altitude is as planned</td>
</tr>
<tr>
<td>20 m</td>
<td>(\tan(30^\circ)\times 20 = 11 \text{ m})</td>
<td>When altitude is 10m lower</td>
</tr>
</tbody>
</table>
2. The 2nd touchdown operation

Result (descent orbit•hovering altitude)

Final position error in the horizontal direction (X, Y, direction) is estimated to be 3m or less, and the final position error in the altitude (Z direction) is 5m or less. Target marker capture was successful.
2. The 2nd touchdown operation

Countermeasures for decline in camera light reception performance & target marker tracking

The 1st touchdown in February reduced the light reception performance for the Optical Navigation Camera (ONC-W1).

To capture and track the target marker safely and reliably at low altitudes, the image processing parameters (threshold value for digitizing the image into two graduations of black and white) were adjusted.

This step makes it possible to recognize even darker target markers, but also makes it easier to mistake floats (such as dust) around the spacecraft, or bright rocks on the ground, for target markers.

Using images acquired during past operations, the perceived motion of a target marker versus floating and similar objects is determined, as well as other identifying parameters (such as the threshold for the time needed to capture the target marker, given the movement between previous and subsequent frames), the size of the target area etc.

During the actual mission, the target marker could be tracked stably even in the presence of floats.

2019/07/25 Hayabusa2 reporter briefing
2. The 2nd touchdown operation

DBT/NBT image and target marker tracking

DBT (Differential Bright object Tracking)
: image actually used by the spacecraft for measurement

NBT (Normal Bright object Tracking)
: similar image not used for actual measurement (reference)

Final descent target position
Correctly controlled to the target position
Attitude error 2.7 deg
Position error 20 cm
Equivalent box width

TM moves from the west

(Video: 20x)

(credit: JAXA)
2. The 2\textsuperscript{nd} touchdown operation

Final descent below 8.5m & touchdown of the spacecraft

- The final descent $\Delta V$ for touchdown was performed at an altitude of 8.5m. Touchdown detection was enabled 50 seconds after the final descent $\Delta V$. Then touchdown occurred on the asteroid surface. Touchdown was judged by detecting the change in distance with the LRF-S2, which measures the distance to the tip of the sampler horn that compresses slightly during touchdown.
- After touchdown detection, the sequence for firing a 3\textsuperscript{rd} projectile, followed by the sampling sequences, were performed. An ascending $\Delta V$ then caused the spacecraft to rise and leave the asteroid surface.
- As vibration in the sampler horn is generated by the final descent $\Delta V$, the sequence was devised so as not to generate unnecessary sampler horn vibration.
- At the time of touchdown, the ‘tail-up’ posture is adopted around the Y-axis to prevent collision of the spacecraft with the boulders and other protrusions, based on the prediction of the spacecraft behaviour.

### Operation sequence from final descent

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>On-board time (JST)</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>-60</td>
<td></td>
<td>Final altitude control begins</td>
</tr>
<tr>
<td>0</td>
<td>10:04:55</td>
<td>Final descent $\Delta V$ begins</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>RW attitude control begins (sampler horn vibration prevention measures)</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>Touchdown detection judgement begins</td>
</tr>
<tr>
<td>~70</td>
<td></td>
<td>Posture convergence</td>
</tr>
<tr>
<td>82-84</td>
<td>10:06:17-19</td>
<td>Touchdown detection</td>
</tr>
<tr>
<td>82-84</td>
<td>10:06:17-19</td>
<td>Sampling operation (Projectile launch etc.)</td>
</tr>
<tr>
<td>82-84</td>
<td>10:06:17-19</td>
<td>Rising $\Delta V$ begin</td>
</tr>
<tr>
<td>94</td>
<td></td>
<td>RCS attitude control transition</td>
</tr>
</tbody>
</table>

LRF-S2 measurements before and after touchdown detection

Detection threshold: 16mm

(image credit: JAXA)
2. The 2\textsuperscript{nd} touchdown operation

- The LRF-S2 emits a laser towards a reflector attached to the tip of the sampler horn.
- This measures distance and intensity value.

Laser light from the LRF-S2 imaged by CAM-H (At the 2\textsuperscript{nd} touchdown)

(Image credit: JAXA)
2. The 2\textsuperscript{nd} touchdown operation

Final descent below 8.5m & touchdown of the spacecraft

- During the 2\textsuperscript{nd} touchdown, the tail-up posture was adopted to prevent contact between boulders and other obstructions with the spacecraft.
- During tail-up, in addition to the spacecraft posture aligning to the terrain surface, the posture is rotated by 10 degrees about the Y-axis of the spacecraft to give the target attitude for touchdown.

(Image credit: JAXA) Nominal touchdown attitude during operation plans
2. The 2\textsuperscript{nd} touchdown operation

2\textsuperscript{nd} touchdown accuracy and sampler horn ground point

2\textsuperscript{nd} touchdown accuracy

Sampler horn ground point

(Credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST)
2. The 2nd touchdown operation

2nd touchdown sampler horn ground point

Sample horn ground point

CAM-H images

Consistent with CAM-H image

(Image credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST)
2. The 2nd touchdown operation

Projector temperature change

(Image credit: JAXA)
2. The 2nd touchdown operation

Closing the catcher chamber

- Chamber A closed immediately after the 1st touchdown (February 22).
- Chamber B was open after this, but closed in an operation on June 24. (A total of 7 descent operations were conducted while chamber B was open).
- Chamber C was then open but closed after the 2nd touchdown on July 11 at 14:10 JST (onboard time). (The ascent speed was reduced by 2 cm/s at 13:40 JST so that any sample at the tip of the sampler horn would be collected).
3. Images from the 2\textsuperscript{nd} touchdown

Images from the ONC-W1
Capture time:
2019/7/11
10:06:32 JST (on-board time)
Altitude: about 8m

(Credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST)
3. Images from the 2nd touchdown

Images from the ONC-W1
Capture time: 2019/7/11 10:08:53 JST (on-board time)
Altitude: about 90m

(Credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST)
3. Images from the 2\textsuperscript{nd} touchdown

2\textsuperscript{nd} touchdown ONC-W1/W2 composite panoramic image at an altitude of 8m during the final descent.

ONC-W2 2019/07/11 10:04:58
JST (onboard time)

ONC-W1 2019/07/11 10:04:57
JST (onboard time)

(Credit: JAXA, Chiba Institute of Technology, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Meiji University, University of Aizu, AIST)
3. Images from the 2nd touchdown

2nd touchdown final descent ONC-W1/W2 composition panoramic image at 8m altitude

(Credit: JAXA, Chiba Institute of Technology, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Meiji University, University of Aizu, AIST)

ONC-W1 2019/07/11 10:04:57 JST (onboard time)  ONC-W2 2019/07/11 10:04:58 JST (onboard)
Reference: Geometrical relationship between W1/W2 imaging

• ONC concentrates on TM image acquisition until the final descent at an altitude of 8.5m.
• After the final descent from an altitude of 8.5m, imaging was performed with the W1 and W2 at altitude 8m, 4.7m and 4.2m (planned values).

※As the viewing angles for W1 and W2 are slightly larger than 60 degrees, there is a slight overlap.

(Credit: Chiba Institute of Technology)
Reference: positional relationship about the C01 area

Images from an altitude ~0.5km and ~0.6km

W2 view direction is to the south
SCI crater side

PPTD-1 TM1 2019/05/16
Images from an altitude ~0.5km and ~0.6km

PPTD-1 TM1

(Credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST)
4. Name of the 2nd touchdown point

The name of the 2\textsuperscript{nd} touchdown point is:

\textbf{Uchide-no-kozuchi}

Meaning: In Japanese folklore, the uchide-no-kozuchi is a magic hammer that can produce great riches. The samples gathered from this site are expected to produce great scientific results.

(Image credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST)
5. Upcoming events

Operation plans

• BOX-C operation from July 20 – 31. The lowest altitude will be about 5km from July 25 – 27.

Press and media briefings

• 8/22 (Thursday) 15:00～16:00 regular press briefings @ Tokyo office
Reference material
Locations for the 1st (TD1) and 2nd (TD2) touchdown

2019/5/20
Taken from the home position

(Image credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST)
Touchdown locations for the 1\textsuperscript{st} (TD1) and 2\textsuperscript{nd} (TD2) touchdown

Note: Tritonis (landing site for MINERVA-II1), Alice’s Wonderland (MASCOT landing site), Tamatebako (first touchdown point) are nicknames and not recognised by the International Astronomical Union (IAU). Other places names are official names recognised by the IAU.
Optical navigation camera (ONC)

ONC: Optical Navigation Camera

Objective: Images fixed stars and the target asteroid for spacecraft guidance and scientific measurements

Scientific measurements:

- Form and motion of the asteroid:
  Diameter, volume, direction of inertial principal axis, nutation

- Global observations of surface topography
  Craters, structural topography, rubble, regolith distribution

- Global observations of spectroscopic properties of surface materials
  Hydrous mineral distribution, distribution of organic matter, degree of space weathering

- High-resolution imaging near the sampling point
  Size, form, degree of bonding, and heterogeneity of surface particles; observation of sampler projectiles and surface markings

Scientific measurements:

- Elucidation of features of target asteroid
- Distribution of hydrous minerals and organic matter, space weathering, boulders
- Sampling site selection
- Basic information on where to collect asteroid samples
- Ascertain sampling state
- High-resolution imaging of sampling sites

<table>
<thead>
<tr>
<th>Detector</th>
<th>ONC-T</th>
<th>ONC-W1</th>
<th>ONC-W2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D Si-CCD</td>
<td>1024 × 1024 px</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viewing direction</td>
<td>Downward (telephoto)</td>
<td>Downward (wide-angle)</td>
<td>Sideward (wide-angle)</td>
</tr>
<tr>
<td>Viewing angle</td>
<td>6.35° × 6.35°</td>
<td>65.24° × 65.24°</td>
<td></td>
</tr>
<tr>
<td>Focal length</td>
<td>100 m–∞</td>
<td>1 m–∞</td>
<td></td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>1 m/px @ 10-km alt.</td>
<td>10 m/px @ 10-km alt.</td>
<td>1 mm/px @ 1-m alt.</td>
</tr>
<tr>
<td>Observation wavelength</td>
<td>390, 480, 550, 700, 860, 950, 589.5 nm, and wide</td>
<td>485–655 nm</td>
<td></td>
</tr>
</tbody>
</table>
ONC-W2 mounting position

- Mounted on the side. Diagonal-downwards imaging possible.
  - Earth imaging during swing-by
  - MASCOT separation imaging
  - SCI crater search operation on Ryugu

(image credit: JAXA)