Asteroid explorer, Hayabusa2, reporter briefing

March 5, 2019
JAXA Hayabusa2 Project
Regarding Hayabusa2:

- Future operations objective
- Result of the touchdown operation
Contents

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1. Current status and overall schedule of the project
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• 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.
Mission Flow

Launch 3 Dec 2014

Earth swing-by 3 Dec 2015

Arrival at asteroid June 27, 2018

Examine the asteroid by remote sensing observations. Next, release a small lander and rover and also obtain samples from the surface.

Use an impactor to create an artificial crater on the asteroid’s surface

After confirming safety, touchdown within the crater and obtain subsurface samples

Depart asteroid Nov–Dec 2019

Earth return late 2020

(Illustrations: Akihiro Ikeshita)
1. Current project status & schedule overview

Current status:
- Touchdown operation was performed from February 20 – 22. Touchdown was successful.
- In the week beginning February 28, BOX-C observations were carried out that included observations from an altitude of about 5km.
- In the week beginning March 4, we will conduct a survey descent operation to observe the region around S01.

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<td>6</td>
<td>7</td>
<td>12</td>
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</tr>
</tbody>
</table>

Event:
- EDVeqA
- Initial operation (June 3)
- Earth swing-by (May 21 – 22)
- Southern hemisphere station operations (CAN/MLG) (Oct – May)
- Arrival at Ryugu (June 27)
- Departure from Ryugu (Nov – Dec)
- Capsule re-entry (late 2020)

Ion engine operations (Mar – Jun)

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2. Future operation policy

Following the success of the first touchdown operation (TD1-L08E1), the future operation policy will be as follows:

• The next event is the experiment to form an artificial crater using the Small Carry-on Impactor (SCI).
• The second touchdown will be done inside or outside the artificial crater formed with the SCI. Alternative sites at a different location will also be considered. (It will be decided after the SCI operation whether we will actually execute the second touchdown or not.)
• There is a high probability that a third touchdown will not be performed.

※Reasons for prioritizing the SCI collision experiment
• The first touchdown has been judged to have collected a sufficient sample.
• During the first touchdown, some of the optical sensors in the spacecraft base received a reduced amount of light. There is no problem during normal operations, but this effect means that careful preliminary investigation is necessary ahead of touchdown operations. As this preparation takes time, the SCI operation will be performed first.
# 2. Future operation policy

## Future Schedule

<table>
<thead>
<tr>
<th>Date &amp; time</th>
<th>Operation</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar. 6～8</td>
<td>Descent operation (DO-S01)</td>
<td>Acquire information for touchdown at this new location.</td>
</tr>
<tr>
<td>Mar. 20～22</td>
<td>Descent operation (CRA1)</td>
<td>Preliminary observations near the planned crater formation site with the SCI.</td>
</tr>
<tr>
<td>Apr. week of 1st</td>
<td>SCI operation</td>
<td>Crater formation experiment with the SCI</td>
</tr>
<tr>
<td>Apr. week of 22nd</td>
<td>Descent operation (CRA2)</td>
<td>Observation of the crater created by the SCI.</td>
</tr>
<tr>
<td>After May</td>
<td>2(^{\text{nd}}) touchdown</td>
<td>Sampling</td>
</tr>
<tr>
<td>After July</td>
<td>MINERVA-II2 separation operation</td>
<td>MINERVA-II2 operation</td>
</tr>
<tr>
<td>Nov. ～ Dec.</td>
<td>Depart Ryugu</td>
<td></td>
</tr>
<tr>
<td>End of 2020</td>
<td>Earth return</td>
<td></td>
</tr>
</tbody>
</table>

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2. Future operation policy

Region S01: site of the SCI operation
3. Results of the touchdown operation

Summary

- Touchdown operation
  February 20 ~ 22, 2019
- Touchdown time
  February 22, 2019, 07:29:10
  (Time is JST, onboard time)
- Touchdown location
  L08-E1, within a circle of radius 3m
  Accuracy of guidance control: 1m
  Sample collection point also identified
- Method
  Pinpoint touchdown method using the dropped TM-B.

Image captured around the touchdown point at approximately 07:30 JST (onboard time) on February 22, 2019 immediately after touchdown. Taken with Optical Navigation Camera – Wide angle (ONC-W1), at an altitude of about 25m.

(Image credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST.)
3. Results of the touchdown operation

The planned touchdown point (circle diameter 6m) superimposed on the image captured immediately after touchdown. The white dot at the arrow tip is the target marker.

For comparison, this is an image taken before touchdown. The circle at the planned touchdown point is 6m in diameter. X indicated the position of the target marker. The size of the spacecraft picture is on the same scale as this image.

(Image credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST.)
3. Results of the touchdown operation

Touchdown point

Green circle is the planned touchdown point. The deviation from the circle center to the center of the spacecraft (blue dot) is 1m (Background is from the shape model).

Sampling point

Red circle is where the sampler horn is thought to have touched the surface. Green circle is the planned touchdown site. Background is a real image of Ryugu.
3. Results of the touchdown operation

Value of speed is approximate

During descent

Time of start of descent (original plan)
2/21 08:13

Descent start 2/21 13:13

Nominal trajectory

Descent deceleration 2/21 18:33

nominal trajectory

Time (JST, onboard time)

2/21
06:00 09:00 12:00 15:00 18:00 21:00 00:00 03:00 06:00 09:00

2/22
03:00 06:00 09:00

[Graph showing altitude vs. time with key points marked]

- Touchdown detected by change in attitude.

(note: Touchdown detected by change in attitude.)

2/22 07:29

65cm/s

10cm/s

90cm/s

40cm/s

(40cm/s to 90cm/s)

(90cm/s to 10cm/s)

(10cm/s to 65cm/s)

Value of speed is approximate

3. Results of the touchdown operation

During descent

Time of start of descent (original plan)
2/21 08:13

Descent start 2/21 13:13

Nominal trajectory

Descent deceleration 2/21 18:33

Nominal trajectory return 2/21 17:33

touchdown 2/22 07:29

Note) Touchdown detected by change in attitude.

2/22 07:29

65cm/s

10cm/s

90cm/s

40cm/s

Value of speed is approximate

3. Results of the touchdown operation

During descent

Time of start of descent (original plan)
2/21 08:13

Descent start 2/21 13:13

Nominal trajectory

Descent deceleration 2/21 18:33

Nominal trajectory return 2/21 17:33

touchdown 2/22 07:29

Note) Touchdown detected by change in attitude.
3. Results of the touchdown operation

Time is JST on February 22 (onboard time)

Low altitude

Antenna change HGA→LGA

07:07

LIDAR→LRF takeover

TM tracking during descent

07:10

TM capture

TM relative horizontal motion

07:19

Horizontal movement while viewing TM

Tilt to landing posture

Landing attitude final adjustment (tail up)

07:27

Hover at TM relative offset point

Final descent

07:29

L08-E1

Touchdown

Pinpoint method

45m

8.5m

0m

Antenna change LGA→HGA

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Image credit: JAXA
3. Results of the touchdown operation

Low altitude

Doppler data

(Times with underlines are the onboard time in JST)

(Original credit: JAXA)
3. Results of the touchdown operation

During ascent

<table>
<thead>
<tr>
<th>Event</th>
<th>Onboard time (JST)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Touchdown</td>
<td>2/22 07:29</td>
</tr>
<tr>
<td>LGA→HGA</td>
<td>2/22 07:50</td>
</tr>
<tr>
<td>Deceleration ΔV</td>
<td>2/22 10:40</td>
</tr>
<tr>
<td>Catcher A chamber closed</td>
<td>2/22 11:20</td>
</tr>
<tr>
<td>Attitude: solar orientation</td>
<td>2/22 13:00</td>
</tr>
<tr>
<td>Return to HP ΔV</td>
<td>2/22 13:30</td>
</tr>
<tr>
<td>Attitude: Earth orientation</td>
<td>2/22 13:40</td>
</tr>
<tr>
<td>HP return</td>
<td>2/23 12:00</td>
</tr>
</tbody>
</table>

(image credit: JAXA)

By suddenly reducing the speed of the spacecraft, material caught on the teeth at the tip of the sampler horn is transferred into the catcher.

Rotating cylinder (red part in right-hand figure) was turned to close chamber A and open chamber B.
3. Results of the touchdown operation

About sampling

After ascending after touchdown and checking the telemetry on the ground, it was confirmed from the status and temperature change of the projector that the projectile had been fired.

In order to float the sample that was collected in the inverted horn tip upwards, a $\Delta V$ of -1 cm/s was applied at 10:40.

To allow time for the floating sample to enter the catcher and settle in the chamber, the rotation mechanism of the catcher was employed 40 minutes later at 11:20 and the lid of chamber A was closed. The change of status confirmed that the rotation mechanism was performed normally.

(Time: JST, onboard time on Feb. 22)

(image credit: JAXA)
3. Results of the touchdown operation

Reason for the delay in the descent start time:

- On February 21 at around 07:15 JST, when the descent preparation process for the spacecraft began the Gate 1 check, it was found that the position information recognized by the spacecraft differed from the assumed position.
- Therefore, we delayed the judgement of whether to begin the descent to check the situation, confirming that the spacecraft condition was normal. It was found that this event was due to slight difference in the operation timing of the descent guidance program.
- We adjusted the timing and confirmed that the descent sequence could operate without problems.
- Procedures such as delaying the descent start time and generating a new descent trajectory at the Gate 1 check are part of the training. The new descent plan was ready and confirmed in about 5 hours.
- Since the touchdown time had been decided, we decided to increase the descent speed. As previous ground training had used a descent speed of about 1 m/s down to an altitude of several kilometres, this was no problem.
3. Results of the touchdown operation

The nickname for the touchdown point:

“Tamatebako”

This is a nickname, not an official name.

Reason:

• Proposed name was the most popular suggestion when requesting names from Project Members.

• In the story of Urashima Taro (where Ryugu takes its name), smoke emerges from the tamatebako (treasure box) which is like the ejector flying upwards at touchdown.

• Also because this is the point where the sample (= treasure of Ryugu) was collected.
3. Results of the touchdown operation

Place names on Ryugu (updated)

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.
4. Images from CAM-H

CAM-H (small monitor camera)
- Camera built and mounted using money from donations.
- Images the sampler horn

Location of CAM-H

The rocket coupling ring is always in the upper-right of CAM-H images as it is within the line-of-sight.

Image credit: JAXA
4. Images from CAM-H

Continuous image sequence plan with CAM-H

- Hayabusa2 moves to the final descent position using the TM, while maintaining the immediate below point altitude of 8.5m. (①⇒②⇒③)

- At the final descent position, after changing the attitude of the spacecraft (tail up) (④ in the figure), the final descent $\Delta V$ (about 7cm/s downwards) is performed, then free-fall to touchdown.

- Continuous imaging with CAM-H starts from 59s before the final descent $\Delta V$.

- Automatic sequence capture at 0.2fps (85 sec) ⇒1fps (86 sec)⇒2fps (25 sec)⇒1fps (64 sec)⇒0.2fps(85 sec)

fps = frame per second

(Image credit: JAXA)
4. Images from CAM-H

Prediction of the view from continuous imaging with CAM-H at touchdown

(Image credit: JAXA)
4. Images from CAM-H

Successful imagining before and after touchdown with CAM-H

**Before final descent: during hovering**
- Time: 2/22 07:26
- Altitude: approx. 8.5m

*Target Marker (image credit: JAXA)*

**During descent**
- Time: 2/22 07:28
- Altitude: approx. 4.1m

LRF-S2 reflected light (Time: onboard, JST)
4. Images from CAM-H

Successful imagining before and after touchdown with CAM-H

Moment of touchdown
Time: 2/22 07:29
Altitude: approx. 1.0m

Immediately after the rise $\Delta V$
Time: 2/22 07:29
Altitude: approx. 2.9m

(image credit: JAXA) (Time: onborad, JST)

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4. Images from CAM-H

Successful imagining before and after touchdown with CAM-H

During ascent
Time: 2/22 07:29
Altitude: approx. 8.0m

(Time: onboard, JST)

During ascent
Time: 2/22 07:30
Altitude: approx. 49.6m

(Image credit: JAXA)
4. Images from CAM-H

Successful imagining before and after touchdown with CAM-H (animation)

- Continuous imaging began from 59 seconds before the final descent and images were taken for 5 minutes and 40 seconds while varying the imaging frequency.

- TD moment captured at 1 fps timing.

- Final altitude is about 117m

(Animation plays at 5x speed)

(Image credit: JAXA)
4. Images from CAM-H

Reference: Ryugu-simulant target and the projectile in the experiment to simulate the results of the projectile firing. (From the projectile firing experiment carried out on December 28, 2018)

Simulated Ryugu gravel target after the projectile fired.

※Simulated Ryugu gravel is created at the University of Tokyo & TeNQ

Examples of the Ryugu simulated gravel after fragmentation by the projectile.

Fired projectile

Is the shape similar to gravel on the surface of Ryugu?

(Image credit: JAXA, University of Tokyo)
5. Science comment on the touchdown

• Scientific analysis is in progress, but the following describes initial impressions from the images.

• ONC-W1 images immediately following touchdown
  – There seems to be an area containing a lot of debris / particle scattering / floating material just above the surface.
  – There also seems to be abrasions on the ground made with the sampling bullet and thruster firing.
  – A large quantity of scattered particles / debris can be seen: the potential for sample collection is high.
  – Fine particles may have adhered to the lens of the ONC-W1 camera.

• Images from CAM-H
  – The sampler horn seemed able to make contact with the ground without striking any large rocks.
  – Surface images are similar to those captured by the landers: the surface is covered with rocks of average size about 10cm.
  – After touchdown, rocks reaching sizes of several tens of centimetres in diameter were ejected.
  – Many chips of this released debris are flattened plate-shaped and appear to reach quite a high altitude.
6. Future plans

■ Scheduled operations
  • Mar. 6～8: Descent operation (DO-S01)
  • Mar. 20～22: Descent operation (CRA1)
  • Apr. week beginning 1st: Small Carry-on Impactor (SCI) operation

■ Overseas presentations
  • LPSC (The 50th Lunar and Planetary Science Conference): Mar. 18～22, Texas, USA. There will be a Hayabusa2 session and an explanatory meeting for local media is planned.

■ Press and media briefings
  • Mar. 18 15:00～16:00 regular press briefing session @ JAXA Tokyo Office
Reference material
The approximate position of touchdown will be the red square (■) in the figure below.
The approximate position of touchdown will be the red square (■) in the figure below.
Touchdown Position

The approximate position of touchdown will be the red square (■) in the figure below.
Area around the target marker

L08-B1 and L08-E1 were selected as candidates for touchdown.

↓ Finally L08-E1 was selected.

(TM indicates the position of the target marker)
L08-E1 area

A DEM (Digital Elevation Map) near the touchdown candidate site

Wide region with scattered rocks about 60cm in size. Relatively far from TM.

Narrow but all rocks less than 60cm in size. Relatively close to TM.
Touchdown operation plan

A DEM (Digital Elevation Map) near the touchdown candidate site

L08-E1 area

(image credit: JAXA)
Touchdown operation plan

Touchdown operation plan concept

• During the landing sequence, the spacecraft autonomously monitors whether the sequence is progressing normally. If it is judged as abnormal, abort (urgent rise) is performed automatically.

• If abort occurs, the safely of the spacecraft is ensured.

• The design of this touchdown operation strictly sets the abort condition to not impair safety (in particular, monitoring at check points ①～④ in the low altitude sequence).

• If an abort occurs, the back-up period will be used to re-execute the touchdown operation.

Touchdown operation plan = a series of operation groups up to the completion of touchdown, including re-implementation.
Touchdown operation plan

Touchdown operation points

**Initial plan:**

→ Assumed 100m² possible touchdown area

- Hayabusa touchdown method
- Target marker is used to adjust the horizontal component of the spacecraft’s motion to the velocity of the asteroid surface.
- In addition to measuring the altitude with the LRF, the spacecraft attitude will be rotated parallel to the asteroid surface by the measurement of LRF.

**Reality:**

→ For a touchdown area about 6m wide

- Pinpoint touchdown method
- Control the spacecraft relative to the position of the target marker on the asteroid surface.
- LRF is used for altitude measurement and safety confirmation but not for attitude control.
- Attitude set based on planned values.
**Touchdown operation plan**

**Hayabusa2 pinpoint touchdown feature**

- **“Hayabusa” method**
  - By tracking the descending TM after its separation, we can land with a zero ‘relative speed’ to the ground.
  - By recognising the TM right after separation, tracking is relatively easy.
  - Altitude is lowered while always keeping the TM in the center of the field of view.
  - Only one TM can be tracked at a time.
  - Landing accuracy is determined by the TM dropping accuracy.

- **“Pinpoint touchdown” method**
  - Capture the already dropped TM and land at position specified relative to this TM (it is possible to offset the TM from the screen center).
  - It is possible to recognise the arrangement of multiple TMs.
  - The landing point can be specific regardless of TM dropping accuracy.
  - In this touchdown, pinpoint touchdown using one TM will be carried out.

※TM: target marker

In order to reliably find the dropped TM, it is necessary to guide Hayabusa2 from high altitude exactly above the TM.
Touchdown operation plan

Measures implemented to achieve high precision landing

- High accuracy of asteroid model
- Tuning of autonomous controls
- Expansion of landing safety margin

When approaching a big mountain, the gravity becomes stronger.

As Ryugu is not spherical, the effect of orbital bending due to the mass concentration at the equatorial edge is considered.

Accuracy of gravity model

Adopt tail-up posture during landing

Avoid high boulders by intentionally tilting slightly rather than keeping a straight-down landing posture.

One example

White areas = places where gravity is stronger or weaker than normal
Motion of the spacecraft directly before touchdown (animation, speed x10)

Since we are currently tuning the position and posture, these will change in the future.

(image credit: JAXA)