ASTEROID SAMPLE RETURN MISSION HAYABUSA, ITS ENGINEERING CHALLENGES AND SCIENTIFIC RESULTS. M. Yoshikawa[1], J. Kawaguchi[1], and H. Yano[1], [1]Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan, yoshikawa.makoto@jaxa.jp.

Introduction: The Hayabusa mission (The code name is MUSES-C. The literal meaning of "Hayabusa" is "falcon.") is the first asteroid sample return mission in the world. The spacecraft was launched in May 2003, and it arrived at its target asteroid, (25143) Itokawa, in September 2005. Before the arrival, it was already known by ground-based observation that the size of Itokawa is rather small, about 500 m in length. In fact, what Hayabusa saw was a very tiny object as expected. However the appearance of Itokawa was completely unexpected. At first glance, we could not see any craters on its surface but a lot of boulders. Figure 1 shows the artistic images of Hayabusa mission before and after arriving at the asteroid. As this figure shows, we can say that the concept of small asteroid (small near earth asteroid, in precisely) has been largely changed.

Hayabusa stayed around Itokawa for about three months. In the first two months, Hayabusa carried out detailed scientific observations. And in the third month, November 2005, it tried to approach closely to Itokawa several times and to touch down twice. Although the sampling sequence was not executed as planed, Hayabusa became the first spacecraft that landed and then lifted off from a solar system bodies except the earth and the moon.

After the second touchdown, the fuel of the chemical thruster leaked and the communication was lost for about one and half months. Fortunately, the communication was recovered at the end of January 2006, but the chemical thrusters were broken. In addition to this, Hayabusa had several serious troubles: two reaction wheels out of three were broken, the ion engines have been damaged, etc. However, we can manage the operation of Hayabusa and it will come back to the earth in June 2010.

Engineering Challenges: Hayabusa is the technological demonstrator. Of course, Hayabusa has the aims of scientific research, and the primary purpose of Hayabusa is to develope new technologies for exploration of small solar system bodies. Five key technologies to be demonstrated by Hayabusa are as follows: (1) Interplanetary cruise via ion engines as primary propulsion, (2) Autonomous navigation and guidance using optical measurement, (3) Sample collection from asteroid surface under micro gravity, (4) Direct reentry for sample recovery from interplanetary orbit, and (5) Combination of low thrust and gravity assist for orbit change.

In addition to these key technologies, we also introduced following new technologies: Bi-propellant small thrust reaction control system, x-band up/down communication, complete CCSDS packet telemetry, duty guaranteed heater control electronics assuring heater power constraint, wheel unloading via ion engines, PN-code ranging, lithium ion re-chargeable battery, and multi-junction solar cell, etc.

Up to now, these new technologies except for the reentry capsule have been demonstrated, and most of them are worked properly. However, there are several items that we should modify for future planetary missions. One is the ion engine. The ion engine of Hayabusa basically worked well, but some parts of the ion engine were broken, so we have already started to modify the system of the ion engine. The other important module is the reaction wheel. Since we do not

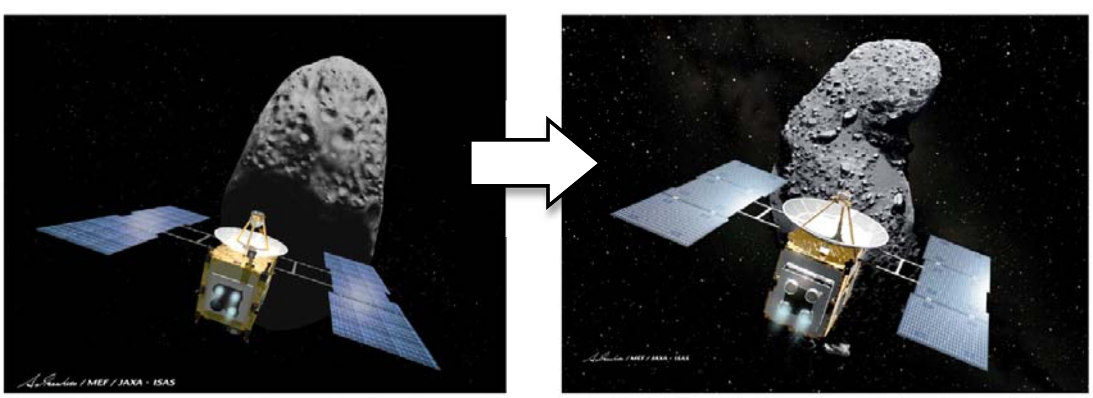

Figure 1. Artistic images of Hayabusa mission before (left) and after (right) arrival at Itokawa. Illustrations were made by A. Ikeshita.

know the exact reason of the trouble of two reaction wheels out of three, the next spacecraft for sample return will have four reaction wheels, one of which is backup. We are also carrying out much further investigation for navigation and guidance in the proximity of asteroid.

Scientific Instruments: Hayabusa got many new results for the small asteroid Itokawa by the remote sensing observations. Hayabusa has four science instruments, AMICA, NIRS, XRS, and LIDAR.

The Asteroid Multi-band Imaging Camera (AMICA) is also called the telescopic optical navigation camera (ONC-T), and it is used both for navigation and scientific observations. AMICA has both a wide band-pass filter and seven narrow band filters, the central wavelengths of which are nearly equivalent to those of the Eight Color Asteroid Survey (ECAS) system as follows: 380 (ul), 430 (b), 550 (v), 700 (w), 860 (x), 960 (p), and 1010 nm (zs). AMICA imaged the entire surface of Itokawa with a solar phase angle of about 10 degrees at the home position (about 7km from the surface of Itokawa). Because the angular resolution is 0.0057 deg/pixel, the nominal spatial resolution is 70 cm/pixel at the home position.

The Near-Infrared Spectrometer (NIRS) has a 64-channel InGaAs photodiode array detector and a grism (a diffraction grating combined with a prism). The dispersion per pixel is 23.6 nm. Spectra were collected from 0.76 to 2.1 mm. The NIRS field of view (0.1deg × 0.1deg) is aligned with the fields of view of LIDAR and AMICA.

The X-ray Fluorescence Spectrometer (XRS) is an advanced type spectrometer with a light-weighted (1.5 kg) sensor unit based on a CCD X-ray detector. The CCD has an energy resolution of 160 eV at 5.9 keV when cooled, which is much higher than that of the proportional counters used in previous planetary missions. In addition, the XRS has a standard sample plate (SSP) for concurrently calibrating the X-ray fluorescence when it is excited by the Sun. The SSP is a glassy plate whose composition is intermediate between those of chondrites and basalts. By comparing X-ray spectra from the asteroid and from the SSP, quantitative elemental analysis can be achieved, although the intensities and spectral profiles of solar X-rays change.

The Light Detection and Ranging Instrument (LIDAR) measures distance by determining the time of flight for laser light to travel from the spacecraft to the asteroid and return. The LIDAR averages the topography within the LIDAR footprint on the surface of the asteroid, which approximates 5 by 12 m at a 7-km altitude for normal incidence. The accuracy of LIDAR ranging obtained from ground calibration was 1 m from a distance of 50 m and 10 m from 50 km.

Scientific Results: From ground based observations, we know some physical features of Itokawa: it is an small Apollo type asteroid of orbital elements a=1.324 AU, e=0.280, i=1.622 deg., q=0.953 AU, Q=1.695 AU, the rotational period is 12.132 hours, and the spectroscopic type is S. Hayabusa confirmed the size of Itokawa, which is 535 x 294 x 209 m, and also confirmed the rotation period (12.1324 hours) and the spin pole orientation (almost perpendicular to the ecliptic plane, retrograde spin).

One of the most important results is that the bulk density of Itokawa is about 1.9 g/cm^3. The results of NIRS and XRS showed that the surface material of Itokawa is quite similar to the ordinary chondrite. Since the density of ordinary chondrite is about 3.2 g/cm^3, the macro polocity is about 40%. This means that there are large empty spaces inside Itokawa, so we think that Itokawa has a rubble pile structure.

Itokawa's global shape appears to be a contact-binary (They are called "head" and "body"). The surface of Itokawa is divided into two distinct types of terrain: "the rough terrain", which exhibits rough topography mostly due to the existence of numerous, large boulders, and "the smooth terrain", which is mainly comprised of flat regolith region. Large impact craters with typical bowl shapes are far less than any other asteroids observed in the similar spatial resolutions. Several very large boulders were found on the surface, and the maximum boulder size is about 50m.

The 3-dimensional numerical shape model, the slope and gravity potential models have been developed. These models show that the gravity potential is high near the ends of the asteroid while the potential minima exist around the "neck" region between the head and the body. These potential minima regions and the regolith regions are strongly correlated suggesting regolith particles moved to these regions through seismic shaking due to impacts.

Short Summary: Although Itokawa is a quite small object, it has a lot of interesting features. And if we can get the surface material of Itokawa, we will have new information to know the origin and evolution of Itokawa. Therefore, we do hope that Hayabusa will come back to the earth in June 2010. And we hope that we can have another sample return mission from asteroid, whose spectral type is different from S. Then our understanding about the small solar system bodies will be much advanced.

Reference: The first scientific papers for Itokawa were published in Science, Vol 312 on 2 June 2006.