1. INTRODUCTION

The Hayabusa spacecraft was launched via the fifth M-V launch vehicle from Uchinoura Space Center, JAXA on May 9, 2003. Soon after the touchdown on Asteroid Itokawa in 2005, Hayabusa lost its attitude control due to the leak of RCS (Reaction Control System) propellant, the communication link was lost until the miracle restoration that occurred 46 days later, next year. While the ion thrusters reached their life in November of 2009 owing to either of an ion source or neutralizers at each engine, and the return was jeopardized, an incredible combination of the neutralizer-A with the ion source-B was devised and the spacecraft resumed the propulsion. This enabled the spacecraft to have returned to the earth. The mission went through several troubles and hardships during the 7 years of interplanetary flight, the spacecraft returned to the earth and completed the powered-flight by the ion thruster until the end of March, 2010. Successive trajectory correction maneuvers were performed from April until June in 2010, the Hayabusa mother spacecraft was maneuvered into the planned orbit bound for the Australian desert to release a small sample-return capsule with asteroid Itokawa sample contained in the sample canister aboard. The capsule has entered the earth atmosphere in the desert of the Australia on June 13, 2010, and was successfully recovered by June 15.

Fig. 2 Hayabusa Spacecraft waiting for Launch

The sample return capsule (SRC) entered the earth atmosphere over the desert of the Australia June 13, 2010 and was successfully recovered by June 15. This paper overviews the return operation of the Hayabusa mother spacecraft and reentry flight and recovery operation of the SRC. The paper also elaborates how the reentry guidance and navigation were performed with a new targeting scheme introduced.

Fig. 3 Asteroid Itokawa Visited by Hayabusa
2. RETURN OPERATION

Authorization of Return of SRC
One of the peculiar operation performed for the reentry of the Hayabusa SRC (Sample Return Capsule) lies in the fact that it planned to land in the Australia, a different country from the launch country. The reentry operation needed to comply with the Australian law or act and the Space Licensing and Safety Office (SLASO) was responsible for issuing the Authorization of Return of the Overseas Launched Space Objects (AROLSO). JAXA submitted all requested documentations and was issued the ARLSO in April, 2010, from the Australian government. As for the tracking and orbit determination, JAXA was supported by NASA’s DSN (Deep Space Network) in addition to JAXA’s ground stations. The return operation was thus carried out under the international collaboration.

3. GUIDANCE STRATEGY AND MID-COURSE CORRECTION TO EARTH
The spacecraft commenced the Entry, Descent and Landing (EDL) activities from last March when the spacecraft terminated its continuous ion engines propulsion. The EDL consisted of five Trajectory Correction Maneuvers (TCMs) before the reentry into Woomera Prohibited Area (WPA) in Australia. Those TCMS were executed also via ion engines propulsion instead of the chemical propulsion, since the fuel had already leaked out the spacecraft completely. The guidance and navigation newly introduced strategy to precisely target the recovery area in WPA. The guidance ended 4 days prior to the reentry and could target the landing point approximately 25 kilometers from the intended point. The error was accurately known even before the reentry, but was left uncorrected intentionally, since the dispersion was well within allowable range. The landing point was predicted by the previous day when the wind predict was provided. The capsule payload portion was well localized via 4 Radio Direction Finding sites deployed in WPA, and the helicopter discovered the payload only 30 minutes after it took off.

Where the payload landed was only 500 meters off set from the predicted point calculated. Fig. 4 presents the reentry of both the spacecraft and the capsule.

Return Cruise and TCM Strategy
Fig. 5 shows how the spacecraft had been guided back to earth through the ion engine propulsion. Fig. 5 also presents the major sequence of events associated with the guidance targeting the Woomera area in Australia. Up to TCM-3, the trajectory was supposed to just fly by the rim of earth, while the TCM-3 retarget the landing point shifted across east coast of Australia.

Fig. 4 Reentry of the Hayabusa mother spacecraft and the SRC observed in Woomera.

Fig. 5 Schematic Illustration of Guidance Sequence of Events.

Fig. 6 Recovered Objects; Instrument Module (Main body of SRC), Forebody and Aftbody Heatshield (Left)
Reentry Flight and Recovery Operation

Both of the forebody and the aftbody heatshields were separated from the instrument module simultaneously at a single action of the pyrotechnic chute-separation mechanism. Eight seconds after the chute deployed, the SRC started transmitting beacon signal. During slow descent of the IM suspended by the chute, localization was carried out relying on the beacon signal received by DFS’ (Direction Finding Stations), in which the point where the azimuth direction vector from each DFS intersects each other was identified. Until the longest landing time of the SRC, the helicopter hovered in the air outside a given impact probability ellipse, and beyond that the helicopter started flying for the position indicated by DFS’ combining the onboard direction finding system aboard it. The beacon signal from the IM was right detected during the descent by 4 all direction finding stations located around the landing dispersion ellipse. According to the azimuth direction information, landing point of the IM was analyzed at the JAXA onsite HQ located in the range control center (RCC) in Woomera Range Head. The helicopter (S-74), under the contract between JAXA and the AOSG/RAAF (Aerospace Operational Support Group/ Royal Australian Air Force) took off and arrived at the estimated landing point very quickly. The IM was discovered in about 1 hour after the S-76 took off. It carried a bright floodlight and the beacon receiver installed. The forebody and aftbody heatshield should have been searched out by an infrared camera mounted on the helicopter during the night before the heatshields becomes illuminated by the daylight, when the heatshields’ relatively hot temperature may not be distinguished from the ground temperature. If such happens, it makes difficult to discriminate them. (Note: heatshields were not discovered during the night-time by IR camera, they have been recognized on the video reproduction later.) Landing position of the other 2 objects, namely forebody and aftbody heatshields were searched based on the actual landing point of the IM using the wind data supplied through the website of NCEP (National Centers Environmental Prediction, NOAA):

Parachute deployment point was predicted by fitting the most probable descent trajectory so as it can account for the actual landing point, and the landing point of heatshields were, in turn, analyzed.

When the metrological predict especially wind predict was obtained, the landing analysis concluded the wind dispersion anticipated and 4 sigma dispersion ellipse as well. The heatshields were discovered within 200 m from predicted landing point thanks to relatively weak wind on the day. Three scheduled landing objects were discovered within 12 hours after reentry and recovered within 36 hours.

Fig. 6 presents the recovered items on the ground.

4. SAMPLE ANALYSISYS

The IM was disassembled at the RCC on the day of recovery and the sampler container was removed and carefully accommodated in the special transportation container with Nitrogen purge capability. It was transported and arrived in Japan in the midnight of June 17. JST (Joint Science Team) is in charge of the sample analysis. JST is the team consisting of the international scientists organized by JAXA. The container was carefully investigated in the Curation Facility of JAXA. A lot of particles about several tens μm size were found in the sampler catcher as shown in Fig. 7 and the their origin has been identified as Itokawa through intensive investigation.

5. CONCLUDING REMARKS

The return and recovery operation were carried out in the framework of international collaboration consisting of JAXA, Japan, Commonwealth of Australia, and NASA. The authors and JAXA would like to acknowledge the collaboration and supports poured for the Hayabusa project.