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Hayabusa2-Ryugu proximity operation planning and landing site selection

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ABSTRACT

This paper presents the robust planning of the Hayabusa2-Ryugu proximity operation and landing site selection process considering unknown asteroid environment and the spacecraft constraints. The proximity operation scenario is described together with the relationship between the selection process and the in-situ observation. The mission constraints are summarized for the possible asteroid environment, including the rotation state, thermal condition and gravity.

1. Introduction

Hayabusa2 was developed and launched by the Japan Aerospace Exploration Agency (JAXA) as an asteroid sample return spacecraft [1–4]. The spacecraft was successfully launched on December 3, 2014 by the Japanese H2A launch vehicle. The destination of Hayabusa2 is asteroid (162173)Ryugu (formally referred to as 1999JU3). Ryugu is a near-Earth C-type asteroid, which is expected to contain organic and hydrated minerals. Thus, it is expected that its successful sample return may provide fundamental information regarding the origin and evolution of terrestrial planets as well as the origin of water and organics delivered to the Earth.

As well as past small body exploration missions, current measurements of Ryugu are limited due to the capability and opportunity of the ground-based observation and thus, most of the asteroid parameters will stay unknown until arrival [5].

In consequence, highly robust planning of Ryugu proximity phase operation is required to adapt to the uncertain asteroid environment and the spacecraft constraints. Since the spacecraft configuration is optimized to be operated in a vicinity of the Earth-asteroid line, the visible and accessible region varies dramatically with the asteroid rotation state.

Therefore, the in-situ observation of Ryugu drives the proximity operation. Hayabusa2 cannot collect samples on the asteroid surface without detailed observations. To perform a safe sampling operation from the asteroid surface, the surface condition of the sampling site need to satisfy certain requirements. Moreover, many spacecraft parameters need to be optimized for the asteroid surface characteristics for the successful sampling procedure. However, the evaluation time of the asteroid environment is limited because of the change of the observable and accessible latitude belt.

Consequently, the landing site selection of Hayabusa2 aims to select an optimal sampling site satisfying both the operational constraints and the scientific requirements within a limited period. Moreover, the landing site selection is not only the sampling site selection of Hayabusa2, but also the exploration site selection of the carry-on surface robots, MINERVA-II rovers and MASCOT lander. This is one of the main differences with past small body explorers, such as Hayabusa and Rosetta/Philae, which makes the process even more complex. Since the optical navigation and guidance system of Hayabusa2 may mix up the target marker with the surface robots, the landing sites cannot be selected independently.

The purpose of this paper is to summarize the asteroid proximity operation of Hayabusa2 and landing site selection procedure. Those two are strongly connected each other. The landing site selection process needs the asteroid observation to evaluate the asteroid environment. On the other hand, one of the most important operation, TD operation, needs a target landing site to prepare its descent sequence. The data flow in the proximity phase operations is also summarized.

Section 2 and 3 describe the overview and the current status of the Hayabusa2 spacecraft, respectively. Section 4 summarize the timeline and constraint of the Hayabusa2 proximity operation in the vicinity of Ryugu. Section 5 explain the joint landing site selection of Hayabusa2 and MASCOT/MINERVA. Section 6 concludes this paper.

2. Spacecraft overview

The Hayabusa2 spacecraft is developed based on Hayabusa spacecraft. Both have four ion engine thrusters, two solar array panel and sampling system. The Hayabusa2 spacecraft has a mass of 609 kg wet

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Acronyms/Abbreviations

AU	Astronomical Units
CNES	Centre National d'Etudes Spatiales
DLR	Deutsches Zentrum für Luft-und Raumfahrt
DSN	Deep Space Network
DCAM3	Deployable Camera
EGA	Earth Gravity Assist
FAA	Final settlement point Acceptable Area
FOV	Field Of View
FD	Flight Dynamics
GCP-NAV	Ground Control Point Navigation
GNC	Guidance, Navigation, Control
HJST	Hayabusa2 Joint Science Team
HGA	High Gain Antenna
HP	Home Position
IES	Ion Engine System
LSS	Landing Site Selection
LSSP	Landing Site Selection Process
LEOP	Launch and Early Orbit Phase
LIDAR	Light Detection and Ranging
LRF	Laser Range Finder
MASCOT	Mobile Asteroid Surface Scout
MINERVA	MIcro/Nano Experimental Robot Vehicle for Asteroid
NIRS3	Near Infrared Spectrometer
JAXA	Japan Aerospace Exploration Agency
RCS	Reaction Control System
RER	Release Epoch Range
RTLT	Round Trip Light Time
SCI	Small Carry-on Impactor
TIR	Thermal Infrared Imager
TM	Target Marker
TCM	Trajectory Correction Maneuver
TD	Touch Down
TD-R	TD-Rehearsal
UDSC	Usuda Deep Space Center

mass and 493 kg dry mass. The dimension of Hayabusa2 main "box" is $1.0 \times 1.6 \times 1.3$ m and it is similar to Hayabusa's. However, there are many updates have been included in Hayabusa2. The Ka-band downlink capability is added in the spacecraft. Hayabusa2 has two HGAs for X and Ka-band, respectively. Four reaction wheels are implemented instead of three in Hayabusa for the redundancy. The thrust

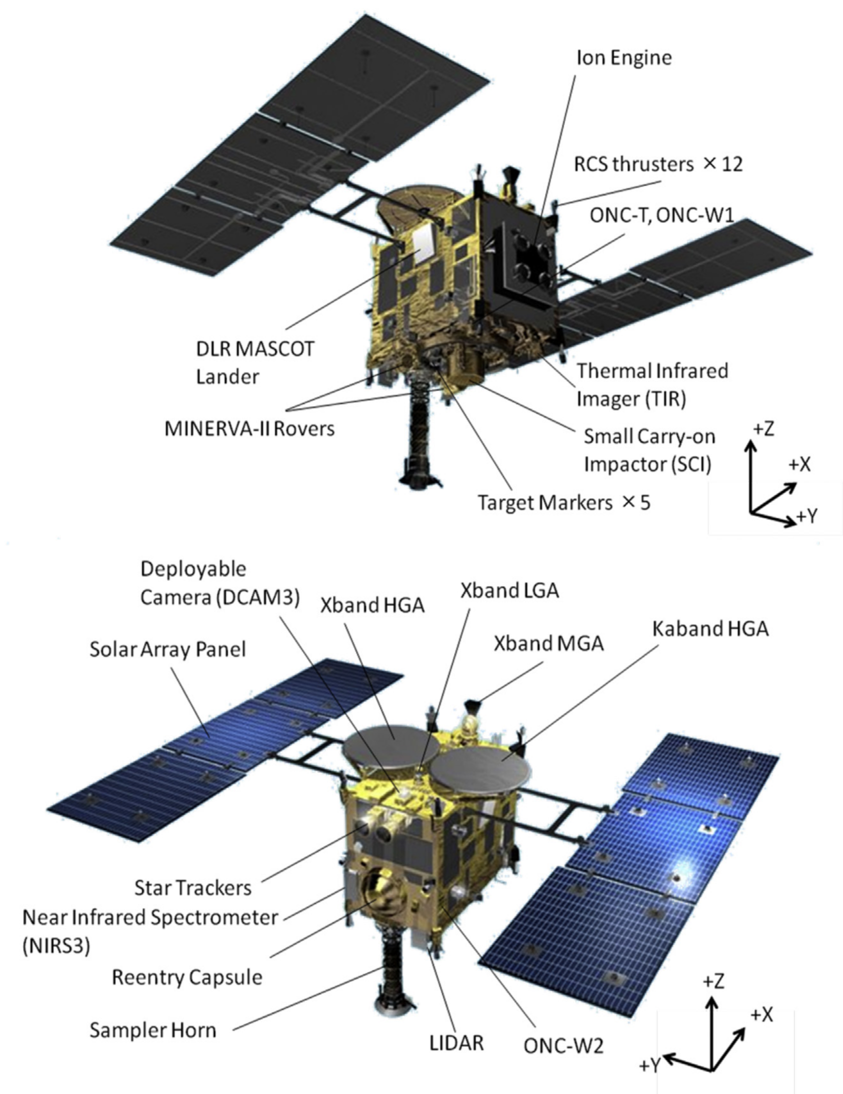

Fig. 1. Spacecraft overview of Hayabusa2.