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LEARNING TO DEFLECT NEAR EARTH OBJECTS: INDUSTRIAL DESIGN OF THE DON QUIJOTE MISSION

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Abstract

Near-Earth Objects or NEOs include both objects having a likely asteroidal origin, and extinct comets orbiting the Sun in the near Earth Space, crossing the region of the inner planets. Because of their close approach to the Earth, NEOs are the population of the smallest Solar System bodies that can be accessible to detailed physical investigations, but in the same time they represent also a potential threat to our planet. Although impacts of large objects with catastrophic consequences are extremely infrequent, size of few tens or hundreds of meters in diameter can cause severe damage. A direct ground impact is not the sole threat since NEOs might be the origin to a large scale Tsunami whose consequences can exceed those of the Indian Ocean in 2004. The Don Quijote mission has been proposed by the European Space Agency as an asteroid-deflecting experiment with both a scientific and a practical perspective in the context of the management of the NEOs impact hazard. The primary objective of the DQ mission is to impact a given NEO with a spacecraft (Impactor) and to measure the resulting variations of the orbital parameters and of the rotation states by means of a second spacecraft (Orbiter) previously operating in the proximity of the asteroid. A radio science instrument carried by the Orbiter will be used for the precise measurement of the asteroid orbit and of its gravity field. The Orbiter will also perform measurements to determine the asteroid mass, size and surface properties. Secondary mission goals have also been defined, which would involve the deployment of an autonomous surface package and several other experiments and measurements. Three industrial teams have been awarded a contract by the European Space Agency to carry out phase-A studies in preparation for the detail design and development phases. This paper presents the main intermediate results of this design activity.

Background

It is common knowledge that asteroids have been impacting the Earth since its formation, over four billion years ago. There is evidence, like the meteor crater in Arizona or images of the Tunguska forest in Siberia, which reminds us the devastating the effects such impacts can generate. Although the probability of these events is very low (in the order of one every two centuries for a 30-50 m size asteroids [1]), there is unfortunately very limited practical knowledge of the Near-Earth Object (NEO) threat mitigation. In particular, many conceptual studies have been carried out proposing different (and sometimes exotic) mitigation strategies but no specific technological plan have been put in place. Nevertheless, the magnitude of the problem has been recognized in many occasions.

The resolution 1080 of the Council of Europe has provided recommendations on this issue [2] and a task force on the subject was established in the UK [3]. The importance of international initiatives to further our understanding on NEOs has also been highlighted in other international forums at the highest level such as the UN COPUOS [4] and the OECD Global Science Forum [5]. As a consequence, in 2000 the European Space Agency's (ESA) long-term space policy [6] identified NEO research as a task that should be actively pursued by the Agency. In July 2002 ESA decided to found, through the General Studies Programme

(GSP), preliminary studies of six space missions that could make significant contributions to our knowledge of NEOs [7]. Three of these were observatory missions (namely Earthguard-1, EUNEOS and NERO), and three were rendezvous missions (SIMONE, ISHTAR and Don Quijote). Following the completion of the six studies, ESA's NEO Mission Advisory Panel (NEOMAP) was established in January 2004. Its role was to assess the studies and provide ESA with recommendations for future activities. As a result the Don Quijote (DQ) mission concept was selected and given highest priority [8].

Using these recommendations as the starting point, ESA conducted a first assessment in the context of the Concurrent Design Facility (CDF) [9] in December 2004. This study was carried out by a multidisciplinary team of spacecraft engineers and specialists, also with the support from JAXA[1]. The objective was to assess the feasibility of several mission scenarios based on the Don Quijote concept while understanding their cost and technical risk implications. This analysis was then used as the basis for a second assessment [10] (carried out in July 2005) with the intention to define a reference low-cost mission scenario and prepare for the industrial phases-A studies by setting the system requirements and their priorities.

Three parallel industrial phase-A contracts have finally been awarded in March 2006. These are involving Alcatel Alenia Space, EADS Astrium and QinetiQ as prime contractors, supported by several sub-contracted European companies, research centers and universities. These studies, which will end in the beginning of 2007, are assessing the designs and trade-offs performed by ESA and putting forward alternative design solutions for DQ.

1 Industrial phase-A objectives

The industrial studies have been structured in such a way that the first step is to review ESA's NEO2 study [10]. In particular, the attention has been focused on the assessment of the mission requirements and their implications on the mission architecture. Special emphasis has been put on an early integration of simple impact models into the trajectory analysis tool. This is fundamental for a correct understanding of the impact implications on a system level.

The second step focuses on the design of both spacecraft, together with the equipment and operations needed for the characterization of the deflection. The whole mission operations scenario, including the ground segment, will also be finalized.

The last step addresses the identification of development risks and critical technologies in order to pave the way to later phases of the mission. With the intention of producing a "cost-aware" design, a maximum reuse of existing and flight-proven technology was stressed. In particular, by maximizing commonalities between the two spacecraft, enhancing the use of autonomous operations, and baseline the use of small-class launchers (such as Vega), the goal is to combine technology demonstration for a small low-cost interplanetary mission with the technology readiness for an eventual NEO mitigation.

2 The Don Quijote mission

The objectives of the Don Quijote NEO mission are the following [2]:

- primary objective: to impact a given NEA and to be able to determine the momentum transfer resulting from the impact, by measuring the asteroid mass, size and bulk density and the variation of both the asteroid's center of mass orbital parameters and its rotation state.
- Secondary objective: to carry out an Autonomous Surface Package Deployment Engineering eXperiment (ASP-DEX) and perform multi-spectral mapping of the asteroid. An optional extension of this secondary objective is the characterization of the thermal and mechanical properties of the asteroid surface.

As a result, two system options have been defined:

- Option 1: DQ "Light" mission that will address the primary mission objective only. The system comprises an Impactor and an Orbiter, the latter carrying only the minimum payload needed to accomplish the mission primary objective (i.e. to measure the linear momentum transfer resulting from a hypervelocity impact on the target asteroid).

[1] Japan Aerospace eXploration Agency

- Option 2: "DQ+" mission, addressing both the primary and the secondary objectives. To achieve this goals, the Orbiter spacecraft will carry an additional simple suite of engineering and scientific payloads, including the ASP-DEX.

2.1 Mission scenario

The mission will contain the following elements (see figure 1). In both system options, the Orbiter

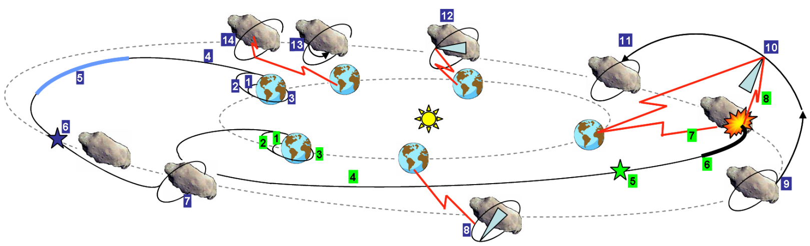

Figure 1: Don Quijote mission scenario

spacecraft (called Sancho) is the vehicle that, following launch 1 and early orbit phase 2, performs an interplanetary cruise 5 by means of a solar electric propulsion system (SEP). It autonomously rendezvous with the target asteroid 6 and is inserted into orbit around it 7. It measures its orbital parameters, the mass, size, gravity field and shape, before 8 and after 11 impact in order to assess the momentum transfer. In addition, the Orbiter shall operate as a backup data relay 10 for transferring the collected Impactor Guidance, Navigation and Control (GNC) engineering data, and image the impact from a safe parking position. In parallel to attaining this primary objective the Orbiter, in the "DQ+" mission option, pursues scientific investigations of the asteroid, addressing part of the mission secondary goals. Finally, after completion of the primary mission 12, the "DQ+" Orbiter will carry out the ASP-DEX 13 and act as data relay for the surface package 14.

The Impactor (called Hidalgo) is the vehicle that, after an interplanetary cruise with minimum ground segment (G/S) support 4, will perform completely autonomous terminal guidance and navigation manoeuvres towards the target asteroid (5 and 6). It relays GNC engineering data and images of the target to the G/S 7 and Orbiter spacecraft 8, while impacting at very high relative speed ($\sim$ 10 km/s) against the asteroid's surface. This spacecraft will demonstrate the autonomous GNC capability based on optical navigation.

As NASA's Deep Impact mission already proved, vision-based autonomous guidance navigation and control can be achieved. However DQ will be a precursor mission as it will be facing additional challenges linked to the target's reduced dimensions.

2.2 Main mission requirements

The main mission requirements can be divided into four groups considering operations, Impactor, Orbiter and technology.

From a system operations point of view, the two spacecraft must be launched separately using a small class launcher (such as Vega) or medium class launchers only if the performances reveal to be insufficient. The Impactor is to be launched only after the Orbiter successful rendezvous with the asteroid and the ASP-DeX must be carried out only at the end-of-mission, not to compromise the mission's primary objective. Finally the Orbiter must allow for at least two months of radio science operations in order to precisely determine the asteroid's orbital parameters before and after impact, hence assess the momentum transfer.

As far as the Impactor is concerned, without taking into account any ejecta effect, the impact must be such that the asteroid's semi-major axis variation is greater than 100 m. Also it must acquire the target two days before impact and perform autonomous navigation in order to impact within 50 m (3σ) from the center of mass.

The Orbiter instead must be capable of measuring such deflection with a 10% accuracy and backup data for the Impactor's GNC. As a technology demonstrator it shall prove advanced autonomy-capabilities during 30 days of interplanetary cruise, the rendezvous phase within 100 km distance from the asteroid, and at least four consecutive orbits when performing radio science measurements.

Technologically, all system elements must meet a readiness level (TRL) above 6 by mid 2007 except for the Orbiter and Impactor's components that are needed for autonomous operations. The latter have to meet a TRL $\geq$ 5 by mid 2008.

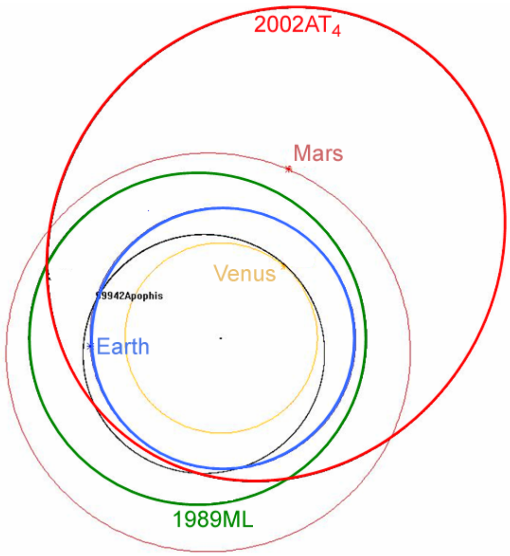

Figure 2: Target asteroids heliocentric orbits

3 Target selection

The selection of an appropriate target for the internal pre-phase A and industrial phase-A studies was based on a set of NEO characteristics that are most relevant for the Don Quijote mission design. These were defined by ESA's NEOMAP and are summarized in table 1. As a result of this analysis two targets have been pre-selected [11], asteroid $2002AT_4$ (baseline) and asteroid 1989ML (backup), represented respectively in red and green in figure 2. Relevant orbital and physical characteristics of $2002AT_4$ and 1989ML are summarized in table 2. 1989ML is more accessible than $2002AT_4$, thus more favorable from an Orbiter design point of view. However, perturbing its trajectory would be more challenging due to its larger mass, therefore the $2002AT_4$ scenario is the sizing case for the Orbiter while 1989ML is the sizing case for the Impactor. Adopting this approach based on two different target bodies, it allows to have a robust design that can adapt to new scenarios (e.g. alternative targets in later phases of the mission) and large uncertainties in the asteroid properties (e.g. in case a similar mission had to be used to asses a real threat from an unknown NEO).

Orbit characteristics	**preferred range**
Rendezvous Δ V	< 7 Km/s
Orbit type	Amor
MOID	large and increasing
Physical characteristics	**preferred range**
Size	< 800 m
Density	~ 1.3 g/cm^3
Absolute magnitude	$20.4 - 19.6$
Shape	nor irregular
Taxonomic type	C-type
Rotation period	< 20 hours
Binarity	not binary

Table 1: Target selection criteria

	$2002AT_4$	1989ML
Orbital period [yr]	2.549	1.463
e	0.447	0.137
i [deg]	1.5	4.4
Δ V [km/s]	6.58	4.46
Orbit type	Amor	Amor
MOID	large	large
Absolute magnitude	20.96	19.35
Taxonomic type	D-type	E-type[2]
Diameter [m]	380	800
Rotational period [h]	6 (assumed)	19

Table 2: Selected targets' main properties

4 Reference design

4.1 Orbiter transfer

This section describes the reference transfer to this baseline asteroid $2002AT_4$. The Earth escape will take place in mid-March 2011 (see figure 3) with an escape velocity of 3.5 km/s. This will be preceded by a typically lengthy escape sequence, which might take about 3 weeks. Arrival will occur in early January 2015, almost 2.5 years prior to impact. Sancho, after a series of short drift-bys for initial target mass estimation, will be inserted into orbit around it. This will happen at the latest in mid-November 2016, when the asteroid is still at over 2 AU from the Sun. It is more than 6 months prior to impact, which in this scenario would take place on 1 June 2017. In total, the Orbiter will perform three revolutions around the sun. Its mission will last until around 6 months after impact in order

[2] based on the results presented in [12]

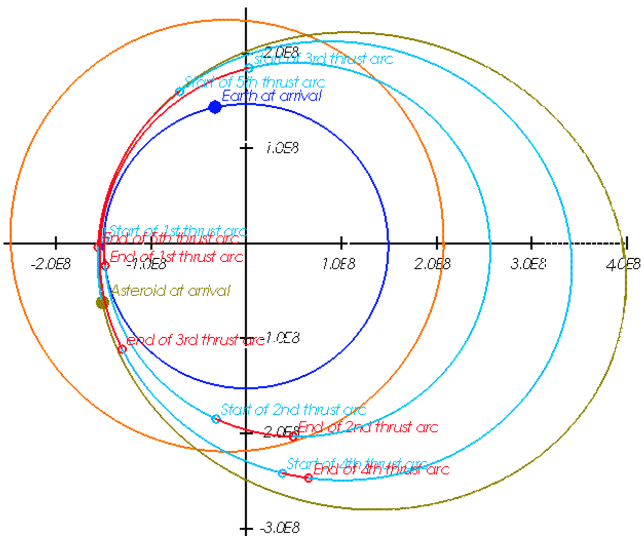

Figure 3: Orbiter transfer trajectory to asteroid $2002AT_4$

to complete the second Radio Science Experiment (RSE) and measure the change in the target's semi-major axis. Hence, the total mission duration is 6 years. The overall Orbiter mission is summarized in Table 3.

The Solar Electric Propulsion system (SEP), as explained later in section 5, is chosen from the SMART-1 spacecraft. It is a Stationary Plasma Thruster (SPT) with input power at 1 AU of 1.78 kW. Due to the large heliocentric distance values, the SEP cannot be operated throughout the whole orbit, two heliocentric revolutions are therefore required in order to complete the transfer. These contain five thrust arcs, mostly around the perihelion. The total propellant consumption is 76 kg, which is still within the SMART-1 tank capacity, allowing for some margin. It is note worthy that the most relevant thrust arcs take place at low heliocentric ranges where the available power, specific impulse, and thrust levels are higher. Following arrival, the Orbiter spacecraft will remain in the vicinity of the asteroid.

Launch vehicle	Dnepr
Parking orbit	300 km
Earth escape date	4.3.2011
V_∞	3.5 km/s
$m_{s/c}$	450 kg
Arrival date	4.1.2015
transfer duration	3.8 years
Xenon consumption	76 kg
thrust time	6312 h

Table 3: Summary of Sancho's transfer to $2002AT_4$

4.2 Impactor transfer

Due to the orbital properties of the target asteroid, a high-velocity impact does not require a Venus swing-by, as it is the case for the mission to 1989ML (which is not discussed here). The Impactor is launched in late December 2015 that is after the Orbiter's arrival. It performs one complete heliocentric revolution and, on the outbound arc of the second one, it hits the asteroid on 1 June 2017 with a relative velocity of over 9 km/s (see figure 4). Earlier launches would also enable possible transfers, starting in September 2015 and arriving as early as April 2017 at 13 km/s. However, a mission scenario in which the impact would take place around perihelion is favored due to the reduced Sun and Earth ranges and the possibility to perform Earth-based observation campaigns of the event. With an escape velocity of 2.26 km/s, no deep space manoeuvres or swing-bys are required. Finally the total transfer duration is less than 18

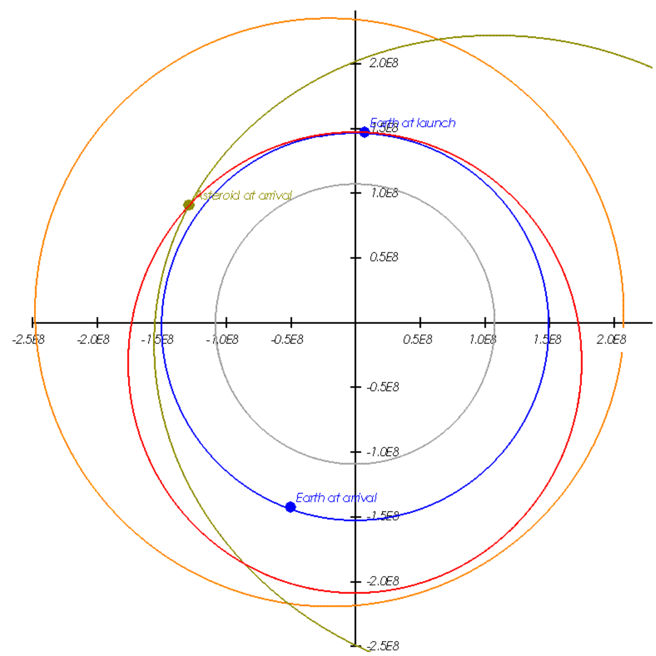

Figure 4: Impactor transfer trajectory to asteroid $2002AT_4$

Launch vehicle	Dnepr
Parking orbit	300 km
Earth escape date	20.12.2015
V_∞	2.26 km/s
$m_{s/c}$ into escape	790 kg
$m_{s/c}$ without CPS	560 kg
Impact date	1.6.2017
Impact velocity	9 km/s
Transfer duration	1.45 years
Deep space maneuvers	none

Table 4: Summary of Hidalgo's transfer to $2002AT_4$

months, which is quite efficient, simple and fast. Table 4 summarizes the transfer properties, notice that impact takes place at an Earth range of 1.64 AU.

Thanks to the final approach on the outbound arc of the trajectory, the value for the sun-spacecraft-asteroid angle[3] remains large throughout the final approach, facilitating autonomous navigation during the final approach. Thus, a major requirement for the mission design is fulfilled.

4.3 Orbiter spacecraft

A re-use of the SMART-1 bus has been considered. Though this approach provides a good reference case to assess mission costs reduction and the maturity of the technologies compatible with TRLs ≥ 8, there are some limitations. These are mainly given by the availability of a single PPS-1350 engine, a fixed xenon tank capacity that limits the propellant mass to 84 kg (at 50°C)[4], and finally the given bus structure. In order to accomplish the mission, the input power to the SEP requires an increased solar array surface consisting in an extra panel per wing. Also a completely different communication subsystem consisting of two-degree-of-freedom (DOF) steerable 70 cm high gain antenna (HGA), medium and low gain antennas and a UHF antenna for the communication with the Impactor during targeting phase and the ASP are required.

Considering the extended payload set (i.e. the DQ+ version), the Orbiter's system mass budget

Total dry mass	395 kg
Payload mass	20.6 kg
Total propellant mass	96 kg
Total wet mass	491 kg
Input power	1.7 kW

Table 5: Orbiter mass budget

is summarized in table 5. Sancho's payload can be considered to be quite basic. It is defined by the navigation camera, the RSE and a radar altimeter addressing the primary objective. DQ+ is however complemented by a set of scientific instruments dedicated to the secondary mission goal, see figure 5. Also being part as this secondary objective, the ASP-DEX will also enable to investigate the mechanical properties of a small asteroid's surface. This knowledge will be important in order to determine the feasibility of coupling devices onto the surface of an asteroid under microgravity conditions, which would be required for the implementation of mitigation strategies relying on a direct contact with the asteroid. The ASP would thus be part of the payload of the Orbiter, which would carry and deliver it to the surface at the end of the mission, from an orbit about the asteroid. This approach has been taken to minimize the uncertainties related to the Orbiter operations during the deployment of this payload.

4.4 Impactor spacecraft

The mission of the Impactor spacecraft is a peculiar one: the spacecraft should remain in a dormant state during most of its lifetime until the last days of asteroid approach where the autonomous guidance takes over and targets it toward the asteroid.

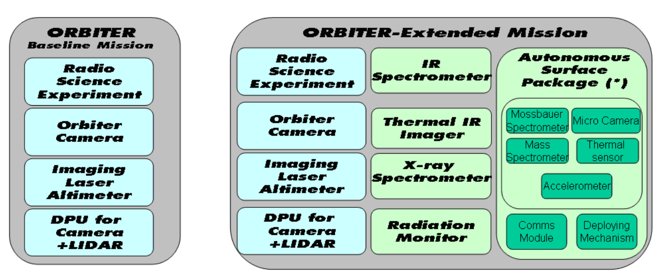

Figure 5: Orbiter's payload

[3]The angle describes the asteroid's viewing conditions, for a value of 180° it appears fully illuminated.

[4]or 91 Kg of Xenon at 40°C

Total dry mass	523 kg
Payload mass	9 kg
Total propellant mass	1162 kg
Total wet mass	1694 kg

Table 6: Impactor mass budget

During the cruise phase only minimum functions are required but before the impact all the subsystems have to be up and functional with high level of reliability.

A major system design constraint is also on the spacecraft mass that (contrarily to what is normally required) shall be above a certain threshold to achieve the required asteroid orbit deflection and lower than the launch system escape performance. This implies that the DQ approach is applicable only to relatively small target asteroids. Its function is to perform the impact with the target asteroid by means of autonomous GNC. Navigation from Earth will in fact be available only up to a few hours before the impact. The propulsion module is not jettisoned at escape but kept attached during the whole Impactor mission duration as ballast. Clearly this strategy would impose specific constraints in the GNC subsystem design. But it would have the advantage of increasing the total momentum transferred to the target, thus maximizing the chances to achieve the required 100 m variation in the target semi-major axis.

The major design drivers for the Impactor are: the optical autonomous navigation system based on advanced on-board computer and high resolution camera, low-cost requirements able to match TRL ≥ 6, and no moving appendages (solar arrays and antennas) to achieve stringent AOCS pointing accuracies. The spacecraft mass budget is summarized in table 6.

No specific scientific objectives are assigned to the Impactor, hence only the camera to support autonomous navigation is considered as payload. It is accommodated on one lateral panel of Hidalgo, together with the relevant electronics. A second lateral panel, this time internal, is dedicated to the accommodation of the COMM equipment. Figure 6 shows the Impactor design both in the launch configuration inside the Dnepr fairing (on top of the propulsion module) and in the flight configuration. As it can be noticed, it is provided with body-mounted solar arrays and fixed high-gain antenna to impart the required structural rigidity during critical targeting phase before impact.

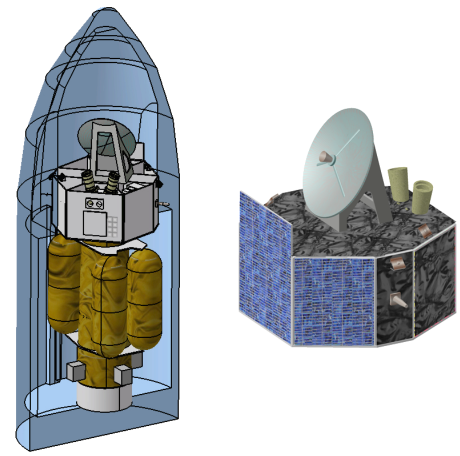

Figure 6: Hidalgo's launch and flight configuration

5 Industrial design

5.1 Alcatel Alenia Space

The design under assessment by the Alcatel Alenia Space (AAS) led consortium is based on the identified main critical issues. These are (1) the radio science experiment (RSE) that involves several elements of the Orbiter (e.g. radio subsystem, HGA pointing mechanism, GNC subsystem . . .) and the calibration of the link delays between the spacecraft and the ground station. Also, (2) the uncertainty in the masses of the largest asteroids (in the main asteroid belt) generates gravitational perturbations having frequency scales not very well separated from the orbital period of the target asteroids. This coupling is dangerous for a correct deflection measurement, especially for the DQ mission where several perturbation require careful modeling. In this respect the (3) gravitational acceleration of the target asteroid is fundamental and it requires a precise knowledge of the spacecraft optical characteristics. Another challenge is represented by (4) the weak orbital stability when maneuvering in proximity of the asteroid, which requires a specific onboard autonomy. Finally (5) the Impactor's terminal guidance before impact involves developing ad

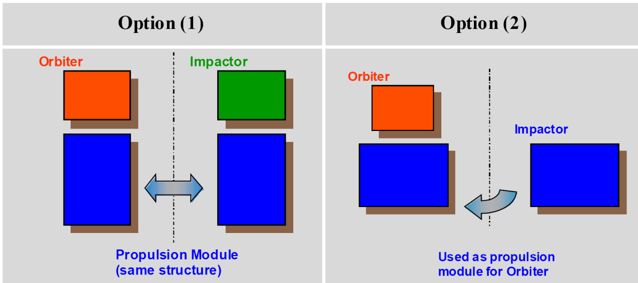

Figure 7: Alcatel Alenia Space design concepts

hoc control laws, elevated levels of autonomy, precise spacecraft pointing, and enhanced processing resources.

Taking these elements into account, the two spacecraft's designs are being optimized with the objective of minimizing the number of different modules to be built (direct impact on cost) and maximizing the re-use of subsystem and equipment between the two launches. Hence, two architectures are under study (see figure 7): (1) the Orbiter on top of an independent propulsion module, which is also used as the propulsion module for the Impactor launch; and (2) the Orbiter on top of an integrated Impactor spacecraft that is used as the Orbiter's chemical propulsion module.

In terms of modules number this gives for option (1): two propulsion modules (with possibly recurrent design), one Orbiter module, and one Impactor module. For option (2) only two Impactor module structures (with possibly many recurrent equipments) and one Orbiter module are instead required. Figure 8 shows a preliminary Orbiter configuration above the chemical propulsion module for option (2).

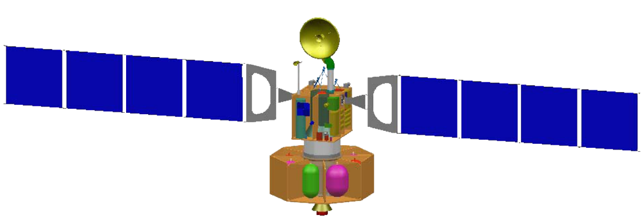

Figure 8: AAS preliminary Orbiter design

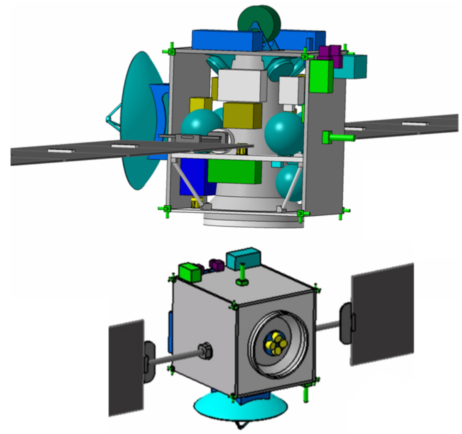

Figure 9: EADS preliminary Orbiter design

5.2 EADS Astrium

In order to comply with the requirements of all mission's phases, namely the cruise by means of SEP system, rendezvous with the asteroid to perform a characterization of the object (remote sensing and radio science), move to a safe parking position to monitor the impact, return to a close orbit and finally release the ASP, the Orbiter candidate configuration (i.e. under assessment) is a Dawn-like design (see figure 9). This involves moveable solar arrays, a fixed HGA and instrument panel on opposite sides of the bus, and a SEP system and camera facing opposite directions to avoid impingement.

As far as the Impactor design, the main driver is to attain a high momentum transfer while keeping the mission cost low. This translates in the choice of a small launcher (e.g. Vega) coupled with a propulsion module to achieve Earth escape. As a preliminary solution to maximize the mass and thus the momentum transfer the propulsion module is foreseen to remain attached to the Impactor also after Earth escape. Here three different Impactor options are currently under study (see figure 10) that are based on different propulsion module (PM) architectures: a so-called "Dead" PM, a "Zombie" PM, and an "Integrated" PM. In the fist configuration, the propulsion module is kept completely passive in all mission phases after Earth escape. This "Dead" PM option has already been discarded, during the terminal approach it is in fact necessary to ensure the thrust authority through the spacecraft's center of mass in all directions.

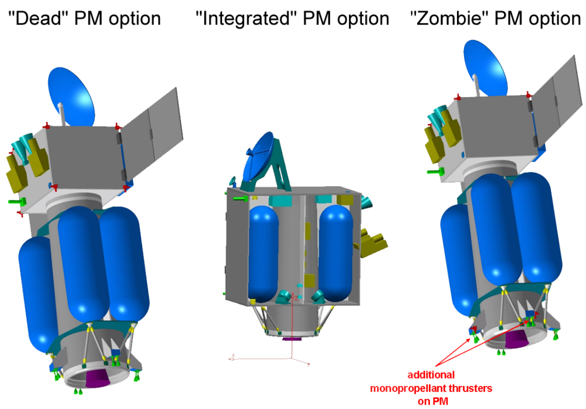

Figure 10: EADS preliminary Impactor design

The "Zombie" PM involves limited changes to the PM, namely the thrust authority for terminal approach is implemented by additional thrusters and the thermal control is to be adapted to other mission phases. This configuration has the advantage that the PM can be procured independently and adapted for the specific purpose. Finally, the "Integrated" PM option is not only the most mass-effective design but it also offers the possibility to optimize the spacecraft's geometry to enhance the generation of ejecta, hence increase the the momentum transfer. Also, it provides optimal solutions to several design challenges such as the protection of navigation cameras against thruster impingement, the HGA placement and compatibility with a cost-efficient approach (based on a suitable PM heritage), and possible integration by the PM manufacturer.

5.3 QinetiQ

The QuinetiQ-led consortium has also completed the mission design driver identification phase. The inter-relation of the mission phases between the two spacecraft as well as the RSE requirements unique to the DQ mission have been given highest priority. This translates in requirements such as the spacecraft's autonomy during interplanetary cruise, the platform's stability during RSE operations (i.e. no parasitic ΔV), camera imagining rates (and implications on the communication system and data storage), autonomous targeting system and platform stability (e.g. no camera "jitter") of the impactor, and "burst" mode communication prior to impact that drives the communication subsystem design (e.g. data rates, power . . .).

As mentioned already in section 5.1, the RSE is the fundamental driver for the entire mission design. This defines the optimal times when the deflection experiment should be carried out. Some of the parameters affecting its success are: a low Earth range (to ensure high signal/noise ration and therefore obtain the the best measurement accuracy), a high Sun range (to reduce solar torques on the Orbiter), and avoidance of Solar conjunction. These translate in optimal Orbiter arrival dates and therefore Impactor's departures, both defining the optimal mission trajectories.

As in the reference scenario (see section 4.3), SMART-1 is currently under evaluation as candidate bus for the Orbiter spacecraft (figure 11). This approach is suitable for implementation of a small, low-cost interplanetary mission. In fact, the size allows the use of a small/medium-class launcher, it is capable of carrying the DQ payload and incorporates an SEP system capable of meeting all the orbital requirements. Some changes have already been identified, principally in the thermal, communication, GNC, and AOCS system. The GNC sub-system could largely benefit from the ESA's PRISMA mission. By adopting the active orbit control developed on a vision-based sensor, autonomous operations such as hovering, fly-arounds and holding points in a rotating asteroid frame can be enhanced.

Three concepts are being investigated for the Impactor: a platform based on the re-use of SMART-1, a bespoke solution and a re-use of a communication satellite bus (e.g. GIOVE A). In all cases body-mounted arrays, in order to provide adequate

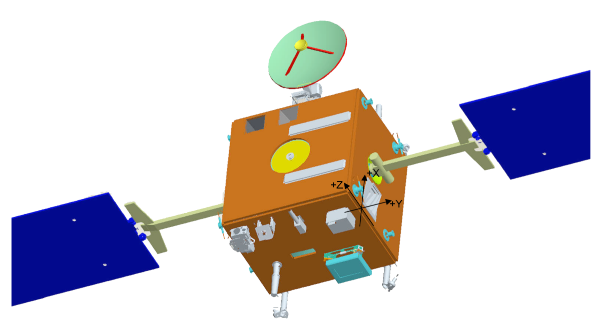

Figure 11: QinetiQ preliminary Orbiter design

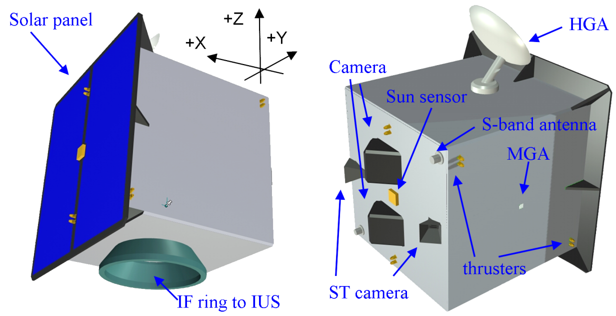

Figure 12: QinetiQ preliminary Impactor design

stiffness for the terminal guidance, and the use of sole chemical propulsion are foreseen. For the bespoke design (see figure 12), a PROBA-like approach is envisaged. This is based on the use of a new structure coupled with space-qualified subsystems to ensure low-cost design and development, centralized architecture around a powerful on-board computer, and considerable flexibility towards mission specific configurations. The spacecraft autonomy shall require only minimum ground operations activities to ensure the nominal mission success. Finally, a high degree of modularity is used both for the hardware and the software.

6 Conclusions

The Don Quijote mission combines a low-cost technology demonstration for small interplanetary mission with technology readiness for an eventual NEO mitigation. It therefore represents an excellent example of a "NEO precursor mission" that could pave the way for an effective NEO deflection mission, independently of the deflection strategy finally being considered. Don Quijote will measure the mechanical behavior of the asteroid as a whole, and determine the orbital deflection triggered by the impact of the Hidalgo spacecraft at a very high relative speed. It will also carry out measurements the asteroid mass and bulk density and constrain its mechanical properties. In addition to this, investigations in the close proximity and the surface of a NEO would provide excellent opportunities for scientific research to be carried out.

The reference scenario demonstrates that the mission can be accomplished within a low-cost technology demonstration program. Currently undergoing industrial studies are putting forward innovative solutions in order to base the design on a "cost-aware" approach. These are based on a maximum re-use of existing and flight-proven technology, identification of commonalities between the Orbiter and the Impactor, and on the development of high degrees of autonomy.

Finally, having independent mission elements, Don Quijote is a mission enabling a flexible implementation strategy from the perspective of ESA. It offers in fact the advantage of distributing evenly the funding effort as the development phase of Hidalgo would start only after that of Sancho is concluded.

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