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Trajectory and GNC Strategy Design for a Fast Development Mission to Apophis

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Extended Abstract—

ESA has recently identified a potential smallsat mission to Apophis as one of its future objectives. In this paper, GMV presents its trajectory and GNC design proposal for such a mission based on its experience with the HERA GNC developments.

The trajectory options and GNC strategies for an Apophis orbiter are addressed with focus on the realistic consideration of constraints that arise for a smallsat platform and a low cost mission, namely: 1) consideration of tight system constraints (thermal, communications, and reduced sensor suite) in the trajectory and GNC strategy designs; 2) Re-use of existing technologies to reduce mission developments costs and to ensure schedule compliance for a mission arrival before Apophis fly-by to Earth on April 2029; 3) minimization of the operational costs by increased AOCS/GNC autonomy.

In this context five options were analysed:

- Hyperbolic arcs
- Terminator-to-Terminator Orbits
- Pseudo-hovering
- Self-Stabilised Terminator Orbits
- Lagrange point Orbits

Hyperbolic Arcs

These trajectories are the backbone of the proximity operations designed in HERA. They are particularly interesting due to their passive safety – a missed manoeuvre would never result in a collision-course trajectory. They are flown above the escape velocity of the system and there is a large degree of freedom in determining their geometry. Their shape and distance is varied according the phase within the proximity operations.

In order to reduce operational cost, the arcs are designed with a 3-4 day cycle to match the week schedule.

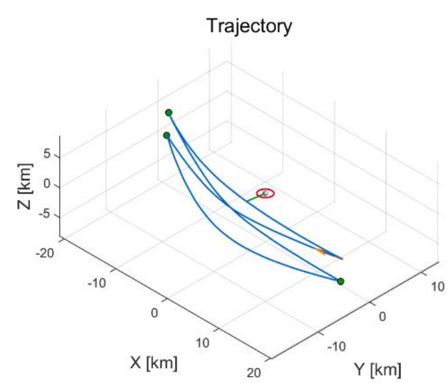

Figure 1: Hyperbolic Arcs.

Terminator-to-Terminator Orbits

These trajectories provide very good observability conditions for maximum scientific return. They are arcs of a circular orbit or a hyperbolic arc that start and finish at the terminator plan.

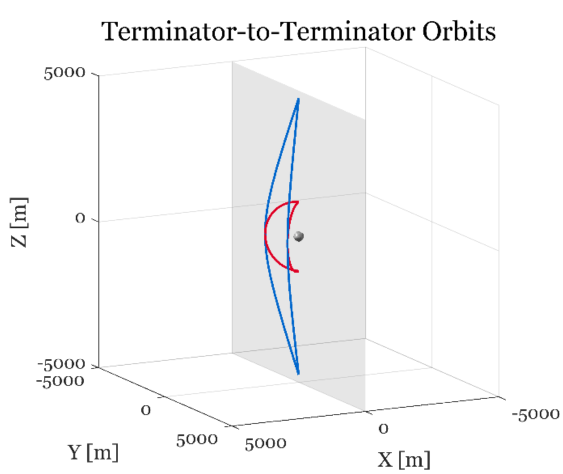

Figure 2: Terminator-to-Terminator Orbits.

However, they do require quite frequent manoeuvring increasing the workload on the ground operational team. In the case of Apophis this manoeuvring would have to be approximately every 20h for a 1km orbit.

Pseudo-Hovering

Pseudo-hovering looks to keep a fixed position in the Sun-Apophis line or, alternatively, a fixed point in the Sun-Apophis synodic system. This provides trajectories the selected illumination conditions to optimize scientific return.

The disadvantages of this system are the need for a dedicated GNC hovering function and the lack of robustness against failed manoeuvres. An issue with the SC would see the SC fall into the asteroid. However, a vertical motion can be included with a larger control sphere in order to ensure that a SC issue would not result in a collision course fall trajectory.

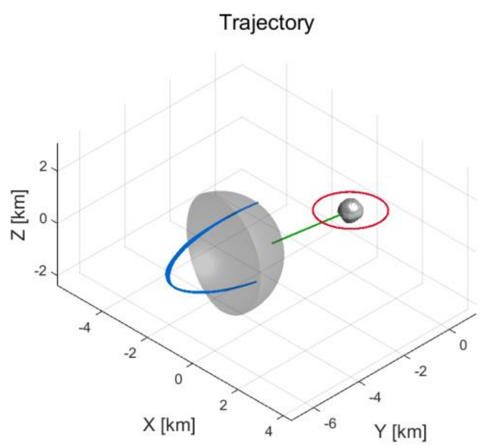

Figure 3:Pseudo-hovering w/ an introduced vertical motion for increased robustness.

Self-Stabilised Terminator Orbits (SSTOs)

Closed orbits around asteroids are usually quite unstable due to the relatively high perturbations (SRP, non-spherical gravity, third-body). However, one type of trajectories is able to remain remarkably stable – the SSTO. This is a polar circular orbit that is just offset from the asteroid's centre of mass to counter the SRP (solar radiation pressure) perturbation. This equilibrium between SRP and asteroid's gravity also increases its robustness to other perturbations.

SSTOs, however, exist only in a plane perpendicular to the Sun direction and, thus, their collected data, when optical, comes at high phase angles (~90deg). Furthermore, although these orbits are very stable, the spacecraft approach to perform the manoeuvre to insert in this type of trajectories is a critical and sensible operational phase due to the relatively high manoeuvre dispersions typical of small body missions.

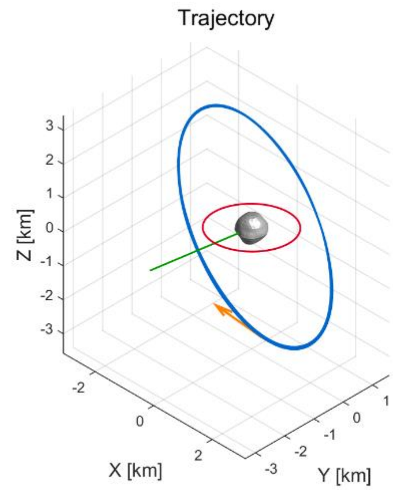

Figure 4: SSTO at an asteroid.

Other Options

Other types of orbits such as three-body problem trajectories such as halo, QSOs (quasi-satellite orbits), and NHRO (near horizontal rectilinear orbits) were studied but deemed not suitable for an Apophis mission due to the large distance of the Lagrange points to the asteroid's surface.

Navigation Strategy

The Apophis mission navigation strategy will start with a farther away orbit fully navigated by ground using asteroid centroiding measurements and, possibly, landmark navigation. However, due to the ground large turnaround time and the relatively high manoeuvre dispersion due to the very low speeds in the asteroid environment, ground cannot successfully navigate the SC at closer distances – the dispersions would make the SC lose Apophis from its instruments field of view.

In order to navigate Apophis, then, a similar GNC system to the one used in HERA is applied – the SC will have an on-board filter estimating its position based on optical measurements (via centroiding techniques) and, with that information, command the SC's attitude to capture Apophis within its instruments field of view.

This will allow the navigation at much closer distances, including the presented orbital options. This way scientific return is significantly increased. However, there is a point at which the target will completely fill the navigation camera's field of view (for Apophis this happens around 4km) which will prevent the use of simple image processing techniques such as centroiding. The solution is to use feature tracking – a technique developed for HERA that identifies distinguishable shapes in the asteroid surface and follows them. Their path provides enough information for the on-board navigation filter to successfully command the SC's attitude.

The performance of such on-board system can be further enhanced by the use of an altimeter providing direct range measurements.