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CLOSE PROXIMITY AND LANDING ORBITS AT ASTEROIDS

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Abstract

This paper will present results describing the dynamics and control of a spacecraft orbiting close to or landing on an asteroid. The paper will present analytical and numerical results which will illustrate the challenges facing near-asteroid orbiters and will include a variety of formulae which give order of magnitude calculations of relevant dynamical quantities for design and feasibility studies.

First, different strategies for orbiting close to an asteroid surface without landing are discussed. The concept of "hovering" is dealt with in an extensive manner, as this is often tendered as a feasible approach to close asteroid orbits. A precise definition of hovering is often lacking, so an attempt is made to define realistic hovering scenarios. Doing so shows that some delineation between "types" of hovering must be made. The analysis will show that hovering may not be a feasible option in many cases, especially when one wishes to come very close to an asteroid. Alternatively, hovering becomes more feasible if one wishes to "park" the spacecraft some distance away from the asteroid (but not so far as a Lagrangian point). It is hoped that this discussion will give a precise definition of hovering to replace the (usually) vague manner in which it is often invoked.

Other strategies for orbiting close to the surface of an asteroid are also discussed. The most feasible, and safest, approach is to fly the spacecraft in an orbit which is retrograde to the asteroid rotation pole and close to the asteroid equator (as defined by the asteroid angular momentum). Such orbits generally have a strong degree of orbital stability, although one expects large secular motion of the orbit node and argument of periapsis (often 10's of degrees per day or more). A properly designed and targeted orbit of this type can achieve a periapsis altitude very close to the maximum radius of the asteroid. More importantly such an orbit can be very stable in its semi-major axis, eccentricity and inclination, meaning that the spacecraft may hold such an orbit for multiple revolutions. A disadvantage of this type of orbit is the large angular rate between the spacecraft and the asteroid at periapsis, which may make it difficult to take unsmeared, high resolution images of the asteroid surface.

Moving the orbit to higher inclinations with respect to the equatorial plane will decrease the relative angular rate between the spacecraft and the asteroid at periapsis, although this is generally done at a cost of orbital stability. As the orbit inhabits higher inclinations, it begins to interact with

destabilizing resonances associated with the asteroid rotation **rate.** Unlike unstable resonance that act on the orbits of solar-system bodies, these instabilities may cause the spacecraft to crash onto the asteroid or be ejected from the asteroid on a hyperbolic orbit within a few days in some instances. Plots will be presented which characterize the stability of an orbit as a function of inclination and radius about a generic asteroid. Methods of analysis arc being developed **which allow** for the lifetime of a spacecraft orbit to be estimated easily, which in turn will allow for "safety" regions to be mapped out in the orbital element space about an asteroid.

If onc orbits about the asteroid in a direct orbit (with respect to the asteroid rotation) it becomes **possible to achieve low or zero relative angular rates** at periapsis (enabling high resolution imaging). These **specific** types of orbits, however, tend to be very unstable and usually cannot be "held" for more than onc periapsis passage. Also, care must be taken so that the spacecraft orbit is not perturbed so greatly as to crash in onc or two revolutions or be ejected from the asteroid on a hyperbolic orbit. Formulae arc (briefly) derived and stated which allow onc to estimate the parameter values for which such dangerous orbits are likely to occur. To drive home the point of **the** instability of some of these orbits, calculations are made which map a spacecraft position and velocity covariance in time so an estimate of the rate of growth of uncertainty may be made. Space permitting, other, more exotic, orbits close to the asteroid surface will be discussed. These are mostly very unstable orbits and may not be feasible for actual operations, barring sophisticated and accurate on-board autonomous navigation systems.

Then a discussion of landing on an asteroid is given. Analogous to hovering, there arc a variety of approaches to landing. A brief list of these would bc: powered descent to the surface, ballistic descent with a series of slow-down maneuvers near the asteroid surface (both autonomous and pre-programmed approaches arc cons dered), ballistic descent from an elliptic orLit **with** no slow-down maneuvers and direct impact from a hyperbolic orbit. Design formula arc derived and stated for each of these approaches which highlight the specific advantages and disadvantages of each approach. From these formulae it becomes clear that soft landings on asteroids (with speeds less than 1 m/see, for example) will be rather difficult to implement without on-board measurement and navigation capabilities. If higher impact speeds can be tolerated, then a variety of landing scenarios become feasible and may often be targeted with a fair degree of accuracy.

Finally, some specific discussion on the actual landing orbits and final control procedures will be given for a generic asteroid. When considering a realistic problem, it becomes important to model the asteroid shape and gravitational field near the surface. Also, the descent trajectory must be timed to land on the irregular surface of what is often a rapidly spinning body (common asteroid rotation periods range from a fcw hours to 10 hours). Thus, an accurate model of the asteroid rotational dynamics is also important.

This paper will continue the author's research into dynamics about asteroids. It will deal with a ncw area, that of dealing with the specific design and navigation problems encountered when considering c1osc proximity operations (within 2 radii) about asteroids. The applicability of such research is becoming more relevant with the current space science and space hazards interest in near-llarth and rnain-belt asteroids.