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Formation flying and mission design for Proba-3

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ABSTRACT

The Proba-3 mission is an ambitious European mission to test the design, implementation and operation of a two-spacecraft formation flying system with a high degree of autonomy with a launch foreseen in the 2015/2016 time-frame. It comprises two spacecraft, the coronagraph and the occulter, which are to be inserted into a highly elliptical orbit. It is intended to perform the formation flying demonstration around the apogee and use the perigee pass for telemetry, orbit determination, orbit correction, and formation configuration manoeuvres. The design of the target orbit is driven by the minimisation of disturbances to the spacecraft formation, and is constrained by the rather low Δv capability of the spacecraft of less than $100\,\mathrm{m\,s^{-1}}$ as well as the characteristics of the selected launch vehicle. The secondary mission objective of Proba-3 is to operate the formation as a coronagraph with one spacecraft being the occulter and the other carrying the optics and detectors. The alignment of the formation with the Sun-direction has as a consequence that the geometry of the formation relative to the orbit is prescribed for the perigee pass. This geometry also determines the relative dynamics of the formation. The relationship between formation configuration and orbital parameters is typical for formation flying missions on elliptical orbits and requires a careful choice of the launch time such that the constraints on the angle between the Sun-direction and the orbital plane are fulfilled. Here we present the design of the operational orbit and transfer phase of Proba-3 together with an analysis of the separation, formation acquisition, and target formation maintenance. Also the benefit of available tracking data for contingency situations in the Proba-3 missions is discussed.

1. Introduction

1.1. Background

The Proba-3 mission is an experimental mission of the ESA GSTP programme (general support technology programme) dedicated to the demonstration of new technologies and techniques related to high precision formation flying. Through Proba-3, technologies relevant for future formation flying missions will be developed to flight level and tested in orbit. This includes GNC algorithms and formation management methods, metrology systems, communication links, operational methods, etc. The development and validation of engineering approach, ground verification tools and facilities required by formation flying will also be developed.

Proba-3 consists of a space segment, a ground segment and a launch service, with a mission lifetime of two years and a launch around 2015–2016. The space segment consists of two small satellites launched into high elliptical orbit to demonstrate formation flying with high precision and to characterise sensors and other related technologies.

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The ground segment includes the flight operations and the exploitation part.

Proba-3 will demonstrate formation flying in the context of a giant (150 m) solar coronagraph science experiment. The main purpose of the Proba-3 coronagraph guest mission [1] is to provide a realistic science mission case for the formation flying demonstration. In this way a demonstration with the full complexity of a full science mission is performed, including aspects such as timing, calibration, alignment, science data handling and delivery. The result of this part of the mission can be appreciated in terms of scientific return.

The project is an ESA mission. It has seen a certain amount of evolution with changing mission designs [2]. As an ESA project it is currently in phase B and is lead by a consortium of industrial companies in several ESA member states.

1.2. Mission objectives

The overall mission objective is to perform the in-orbit technology demonstrations and proof of concept formation flying demonstrations to build sufficient confidence in the European space industry in order to embark on future missions based on formation flying.

Given this overall mission objective the purpose of the mission can be divided in the following four categories:

- *Formation flying demonstration*: The primary objective of Proba-3 is to demonstrate formation flying with high precision and to demonstrate it for future formation flying missions.
- *Equipment qualification*: Precision formation flying and efficient use of propellant calls for technology development in metrology, e.g. RF metrology systems and high accuracy optical metrology systems. The Proba-3 mission will demonstrate these technologies.
- *Development, design and validation principles for formation flight*: The distributed character of formation flying systems calls for new development, design, implementation and validation principles. Proba-3 will contribute towards the establishment of these principles, and the development of required tools.
- *Guest payload*: In addition to the formation flying experiments and demonstrations a scientific guest payload will be flown—a large (length about 150 m) solar coronagraph instrument distributed over the formation. Using the Proba-3 generic formation flying capabilities, the formation flying of this distributed single virtual instrument will constitute a convincing demonstration of formation flying in addition to provide scientific mission return.

2. Mission design

2.1. Orbit selection

For the orbit selection the relevant mission requirements have to be considered. In general orbits far from gravity sources are ideal for formation flying mission due to the low gravity gradient environment. Also a constant or little varying Sun–Earth geometry would be beneficial. Depending on the scope of the mission such an environment is presented by the libration points of the Sun–Earth three body problem. For a Sun observer the co-linear day-side libration point L_1 would be ideal. However, due to the limited scope of the Proba-3 mission, the orbit selection is finally driven by the capability of the launcher, so that the maximisation of the mass into final orbit following a launch by a small to medium sized launch vehicle is the driving requirement for the orbit selection.

The orbit selection for the operational phase is thus a compromise solution, which is required to minimise the detrimental effects of a near-Earth environment. Such a compromise solution is a highly elliptical orbit (HEO), which provides a benign environment at the apogee and still can be reached by small or medium launchers with a sufficient payload mass. The inclination of that HEO will be prescribed by the constraints of the selected launch vehicle. What remains to be determined are the apogee and perigee altitudes. The right ascension of ascending node can be chosen freely by selecting the lift-off time. Here we report the status of the orbit selection at the start of phase-B. For the launch vehicle the European VEGA launcher and the Indian PSLV have been studied as suitable candidate launch vehicles. Here we will focus on the latter option for brevity. The maximum performance departure trajectory of the PSLV delivers the spacecraft into a HEO with an inclination of 17.8°. For the PSLV also the argument of perigee is prescribed to be equal to 180°. The initial perigee altitude is 300 km. Another driver for the orbit selection is the ground-station availability. It is assumed here that the available ground-station for Proba-3 is the ESA station Redu at the geocentric coordinates 50.001°N, 5.145°E. In order to achieve visibility of the apogee (the latitude of which is 0° due to the prescribed argument of perigee), the initial longitude of the apogee must be chosen to be close to the longitude of the Redu station and also the orbital period must be chosen to be commensurate with the Earths sidereal day of 86,164 s.

In phase-A a number of options for the HEO were discussed and the current baseline for the HEO calls for a geo-synchronous orbit, i.e. an orbital period of exactly 86,163 s. This requires a semi-major axis of 42,164 km. The perigee altitude shall be chosen as small as possible in order to minimise the size of the perigee raising manoeuvres in transfer. The minimum value is however by the requirement to avoid reentry into the Earth's atmosphere under luni-solar perturbations during the required mission lifetime of two years. For this minimum a value of 800 km was found. Given the semi-major axis and perigee altitude the apogee altitude can be calculated to be 70,786 km. The right ascension of ascending node is calculated such that the local time of the apogee and the Redu station are identical in the middle of the mission given the drift of the node due to the oblateness of the Earth. The orbit of Proba-3 during the operational phase is visualised in Fig. 1. A summary of the baseline orbit for Proba-3 is given in Table 1.

2.2. Transfer

Two objectives must be met in the transfer: (a) the longitude of the apogee must drift from its prescribed initial