Acta Astronautica 148 (2018) 260–267

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

A novel orbiter mission concept for venus with the EnVision proposal

Marta R.R. de Oliveira[a,*], Paulo J.S. Gil[b], Richard Ghail[c]

[a] European Space Agency, Noordwijk, the Netherlands
[b] CCTAE, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal
[c] Imperial College London, London, United Kingdom

ARTICLE INFO

Keywords:
Operational orbit
Orbit design
Scientific requirements
Targets coverage
Orbit optimization
Genetic algorithms
Venus

ABSTRACT

In space exploration, planetary orbiter missions are essential to gain insight into planets as a whole, and to help uncover unanswered scientific questions. In particular, the planets closest to the Earth have been a privileged target of the world's leading space agencies. EnVision is a mission proposal designed for Venus and competing for ESA's next launch opportunity with the objective of studying Earth's closest neighbor. The main goal is to study geological and atmospheric processes, namely surface processes, interior dynamics and atmosphere, to determine the reasons behind Venus and Earth's radically different evolution despite the planets' similarities. To achieve these goals, the operational orbit selection is a fundamental element of the mission design process. The design of an orbit around Venus faces specific challenges, such as the impossibility of choosing Sun-synchronous orbits. In this paper, an innovative genetic algorithm optimization was applied to select the optimal orbit based on the parameters with more influence in the mission planning, in particular the mission duration and the coverage of sites of interest on the Venusian surface. The solution obtained is a near-polar circular orbit with an altitude of 259 km that enables the coverage of all priority targets almost two times faster than with the parameters considered before this study.

1. Introduction

Terrestrial planets closest to Earth are popular targets for orbiter missions [1]. Venus is often considered Earth's twin in terms of its size, distance from the Sun and bulk composition; though a great number of fundamental questions, such as the planet's geology and its correlation to the atmosphere are still unanswered [2].

EnVision is a mission proposal that builds on the discovery of geological activity made by Venus Express to identify and measure areas of geological activity on Venus and their relationship to atmospheric and interior processes by providing gravity and geoid data, as well as new spin rate measurements. These science goals lead to specific observational objectives: surface change, geomorphology, specified targets, thermal emissivity, gravity field, spin rate and spin axis, among others [2].

A key objective is the observation of sites of interest on the surface of Venus, to link local surface observations to global features. For instance, surface images captured by Soviet Venera landers reveal pyroclastic or sedimentary deposits and not the basaltic lava flows assumed previously [2].

The major limitation with the present data is resolution: more accurate measurements are needed to distinguish the presence of different surface materials. There are many data issues and missing information. The most significant targets considered are the Venera landers that were launched by the Soviet Union between 1961 and 1984 and consist essentially of approximately 2 m metal spheres with a landing ring and antenna coil. Their size and metallic nature mean that the landers will appear 6 dB brighter than the rest of the surface in high resolution radar imagery [2].

The mission is planned to launch in October 2029 and following aerobraking, the orbiter was nominally interred for a low circular operational orbit. The payload includes [2] (seeFig. 1):

- A phased array synthetic aperture radar (VenSAR)
- A subsurface radar sounder (SRS)
- An infrared mapper and spectrometer (VEM); and
- A 3 m X/Ka band high gain antenna.

This payload will provide topographic and subsurface data with a better resolution than previous missions, and may uncover the reasons for the radically different evolution of Venus and Earth.

The main objective of this paper is to select an operational science orbit around Venus for EnVision. The proposal was submitted to the Cosmic Vision 2015–2025 cal l for a medium-size mission (M-class)

* Corresponding author.
E-mail address: marta.de.oliveira@esa.int (M.R.R. de Oliveira).

https://doi.org/10.1016/j.actaastro.2018.05.012
Received 24 February 2017; Received in revised form 4 May 2018; Accepted 5 May 2018
Available online 10 May 2018

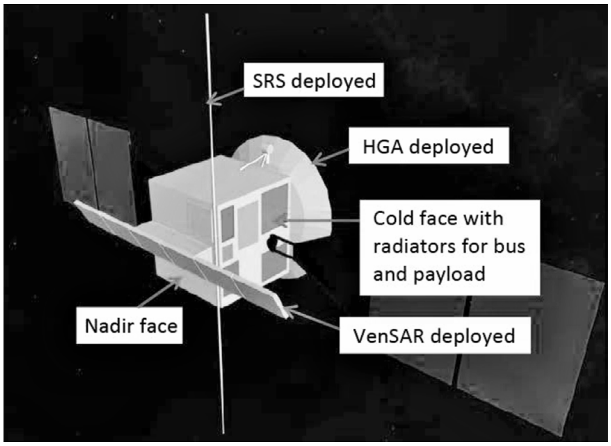

Fig. 1. Preliminary operational configuration of EnVision's orbiter [2].

opportunity in the European Space Agency's Science Programme (M5). Through this call, ESA's Director of Science solicits the scientific community to submit proposals of mission concepts that compete for the implementation of an M-class mission.

After an analysis of the space environment, the operational orbit can be selected to satisfy instruments and scientific requirements — data resolution, coverage, revisit time, link budgets, eclipse duration, among others. Often these requirements are contradictory and a trade-off must be made [3,4].

2. Operational orbit design fundamentals

In this Section, the fundamental concepts behind the orbit design will be introduced to support the orbit analysis and determination.

2.1. Design of an operational orbit around venus

Venus has no natural satellites, simplifying the gravitational environment of the problem, and its rotation is retrograde. Also, the planet's path around the Sun takes around 224 days but takes 243 days to complete a full rotation around its axis, which results in a Venus year being shorter than a Venus day. Indeed the planet's rotation is extremely slow and has the slowest angular velocity in the Solar System (2.99e-7rad/s) [5].

In Venus the gravitational perturbations are very small when compared to Earth. Indeed, the most significant gravitational perturbations term J_2 (4.458e-6) has still a value of only about 0.4 of Earth's value [1]. This reduced perturbations effect is related to the fact that Venus' flattening coefficient is very close to zero [6], so orbit apse rotation and nodal regression are very small. Essentially, Venus is almost perfectly spherical, it's the most spherical planet in the Solar System. This is in turn connected to Venus' extremely low rotation rate.

2.2. Orbit representation

In this work, we used the Classical Orbital Elements to describe the orbits (longitude of the ascending node Ω, argument of perigee ω, inclination i, true anomaly ν_0, semi-major axis a, eccentricity e). We will need to ensure a circular or near circular orbit for the spin axis and rate measurements (eccentricity below 0.001).

In the case of the circular orbit, there is no periapsis, and consequently no argument of periapsis, or true anomaly. In order to correct the absence of the periapsis as a reference, we use the argument of latitude u, which can be related to the argument of peripasis and true latitude through the following expression: $u = \omega + \nu$. Essentially, the argument of latitude u is measured from the ascending node to the spacecraft's position in the direction of the spacecraft's motion [7].

2.3. Orbit propagation

Venus is a complex case to apply the typically used orbits for remote sensing missions. For instance, the extremely low perturbations don't provide the torque that the gravity field of more oblate planets present to generate Sun-synchronous orbits [1]. Venus is the planet for which the spherical approximation is most accurate in the solar system [6].

We only examined altitudes below 350 km and above 230 km as was recommended in the proposal to avoid the sensible atmosphere detected by Magellan and Venus Express below 200 km [2].

For the purpose of this work the perturbations are small enough or corrected in a way that makes it possible to consider only Keplerian orbits, where only the true anomaly element changes, determined by Kepler's equation.

To verify the effect of an oblate Venus, we considered the approximate effects of J_2 on the ascending node and argument of perigee rates, which resulted in an impact of 0.3 km on the spacecraft position vector's magnitude after 500 days, well within the range of the swath correction considered.

For solar perturbations, corrections will be needed and the fact that we have low orbits (below 350 km) will help reduce the fuel requirements for these corrections.

3. Orbit design and optimization approach for EnVision

In this Section, the procedure adopted to implement the orbit optimization will be described, from the provisional orbital parameters computation to the algorithm selection and application(Table 1).

3.1. Mission constraints

As mentioned in Section 2, one of the main objectives of the mission is to observe the specified sites of interest on the surface of Venus, in particular, the Venera and Vega landers. The observation of these targets will give us the ground truth. In Table 2, the targets are listed with the corresponding priority level (1 being the highest level). The key landers are the Venera 9, 10, 13, and 14, since they have surface images, followed by Vega 1, 2, and Venera 8, which have surface composition measurements but no images. Other targets beyond the Venera and Vega landers are interesting but not critical landslides: canali, coronae in Helen Planitia, landslide in Diana Chiasma, Imdr Regio, among others. We will also focus on the North Pole interferometry measurements that will be necessary for many science goals such as spin axis and rate.

The scientific requirements demand a well-controlled near circular orbit (with a maximum eccentricity of 0.001) [2]. Also, the altitude should be as low as possible since the resolution of the gravity field declines rapidly with altitude. In terms of the atmospheric drag effect, previous missions detected sensible atmosphere below 200 km altitude: an altitude above 230 km was considered adequate [2].

The primary instrument carried by EnVision is VenSAR, which has five operating modes. The modes used in this study are interferometry and high resolution strip-mode (Table 3). The geometries for these modes depend primarily on the swath width and incidence angles. The area covered by the antenna is the footprint, and the swath width refers to the strip of Venus' surface from which the mission data is being

Table 1
Venus facts summary [5].

Mass	4.9e24 k
Radius	6051.8 km
Surface Temperature	462°C
Revolution Period	224 d
Rotation Period	243 d
Number of Moons	none
Atmosphere	carbon dioxide, nitrogen