Maneuver Design for Galileo Jupiter Approach and Orbital Operations

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Introduction

Following the successful encounter of the main-belt asteroid Ida on August 28, 1993 by the Galileo spacecraft, the: focus of the Galileo flight team shifted to the primary objective of the mission, namely Jupiter. Up to that point in the mission, much of the Galileo flight team effort had been geared towards flying the circuitous Venus-Earth-Earth gravity assist trajectory (VEEGA) necessary to place the spacecraft on a path that could reach Jupiter, while at the same time taking advantage of the unique science opportunities along the! way. An overview of some of the science highlights is given in Reference 1. At the time of the Ida flyby, and after nearly four years in flight, arrival at Jupiter was still over two years away. However, the planning for approach and arrival events was already moving to the forefront. The success of the December 7, 1995 Jupiter encounter would require a supreme effort on the part of the flight team to ensure that nothing would interfere with the delivery of the Probe into the atmosphere of Jupiter, the! relay of the data from the Probe to the Orbiter, and the! insertion of the! spacecraft into orbit about Jupiter (see References 2 through 4). This paper will address the analysis, constraints, contingency planning and design evolution of trajectory correction maneuvers enabling the completion of these events, which lead to the first ever atmospheric entry Probe and Orbiter of an outer planet. in addition, now that the first three encounters in the orbital tour phase have been successfully completed, a presentation of orbital phase performance and future mission operations plans can also be presented.

Galileo Atmospheric Entry Probe

Following the Ida encounter in August of 1993 (see Reference 5 for a discussion of maneuver design issues for the complete VEEGA trajectory leading up to the approach to the asteroid Ida), a sequence of trajectory correction maneuvers (TCMs) would be required to precisely target the Probe to the required entry conditions at Jupiter. Trajectory corrections during this phase of the mission would place the spacecraft (Orbiter and Probe) on a trajectory properly biased to account for downstream propulsive maneuvers and separation events. Following Probe release, no Probe flight path or attitude corrections were possible as the Probe! did not have a propulsion or attitude control system. This meant that precise modelling of each of the predicted propulsive events leading up to Probe separation, as well as precise! modelling of the Probe separation event itself (pyro activated spring mechanism

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imparting a separation ΔV to the Orbiter and Probe) would be required in order to achieve the Probe entry targets. Separation occurred nearly five months before Jupiter arrival (on July 13, 1995), at which time the Probe was placed on the proper ballistic flight path achieving the required atmospheric entry conditions. Reconstruction of the actual Probe entry conditions into Jupiter's atmosphere will be compared against the delivery accuracy predictions.

Io Approach and Jupiter Orbit Insertion

Following the release of the Probe on its ballistic path to Jupiter, the Orbiter was redirected away from Jupiter to avoid following the Probe into Jupiter's atmosphere (see Figure 1 "for a view of the Orbiter and Probe trajectories on approach to Jupiter).

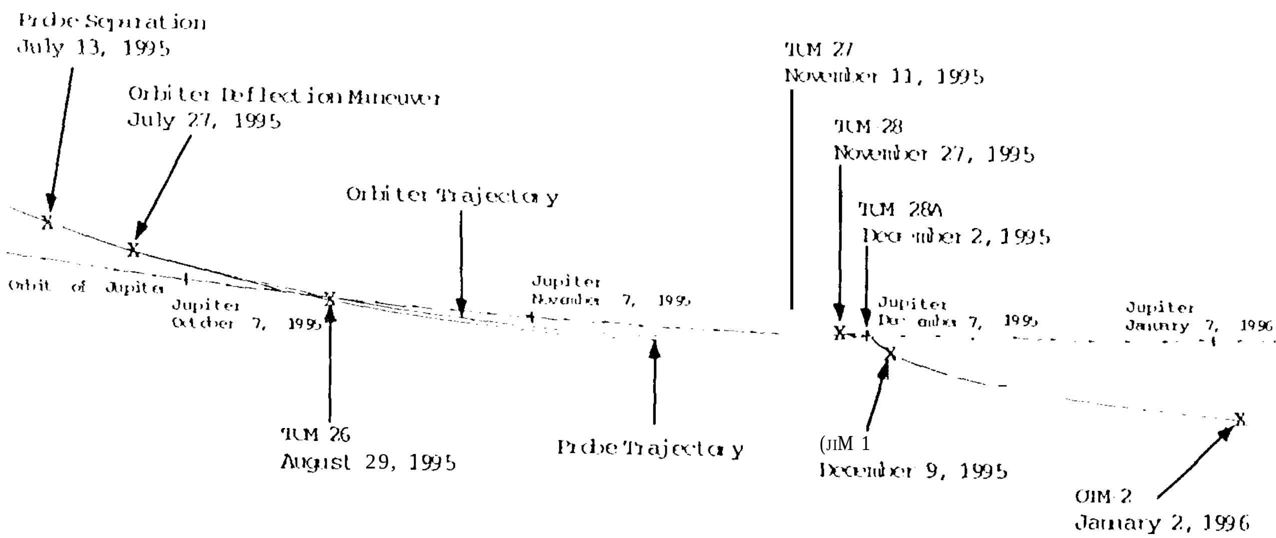

Figure 1: Galileo Jupiter Approach Trajectory

The Orbiter Deflection Maneuver (ODM) accomplished this task by firing the 400-N engine for the first time. Previously, the 400-N engine had been blocked by the Probe prior to its release. The Galileo propulsion system was provided by Daimler-Benz Aerospace (DASA) under contract to the German Space Agency DARA, and consists of twelve 10-N engines and one 400-N engine. The ODM redirected the Orbiter flight path from a Jupiter atmospheric entry trajectory to a flyby of the innermost of the Galilean satellites of Jupiter, Io. The Io encounter was designed to provide a gravity-assist, reducing the ΔV required for Jupiter Orbit Insertion (JOI), which together would result in the desired capture orbit about Jupiter. The accuracy of the Io flyby had a significant interaction with the ΔV required for JOI and the subsequent orbit trim maneuvers (OTMs) necessary to link up with the planned orbital tour. The plans and rationale for maneuver placement and late updates to the insertion ΔV parameters will be discussed.

Just two months prior to the Io flyby and JOI, the onboard tape recorder suffered an anomaly (see Reference 4) that was to have significant implications upon the approach maneuver strategy. The consequences of this anomaly as well as the rationale for the late changes to the maneuver implementation strategy will be discussed.

Orbital Operations and Future Events

Following the highly successful events of arrival day, the Orbiter was in a position to carry out its orbital tour objectives (see Reference 6). One last firing of the 400-N engine was required at apojove in March of 1996 to raise perijove and establish the proper trajectory for the first satellite encounter since being captured in orbit about Jupiter, this one with the most massive of the Galilean satellites, Ganymede. The primary mission plan is for ten close encounters with the three outer Galilean satellites (Europa, Ganymede and Callisto), to be accomplished in eleven orbits about Jupiter (see Figure 2). Note that one orbit has a distant Europa flyby designed to occur during the solar conjunction period in early 1997 when the spacecraft will be maintained in a benign state with no science data gathering planned.

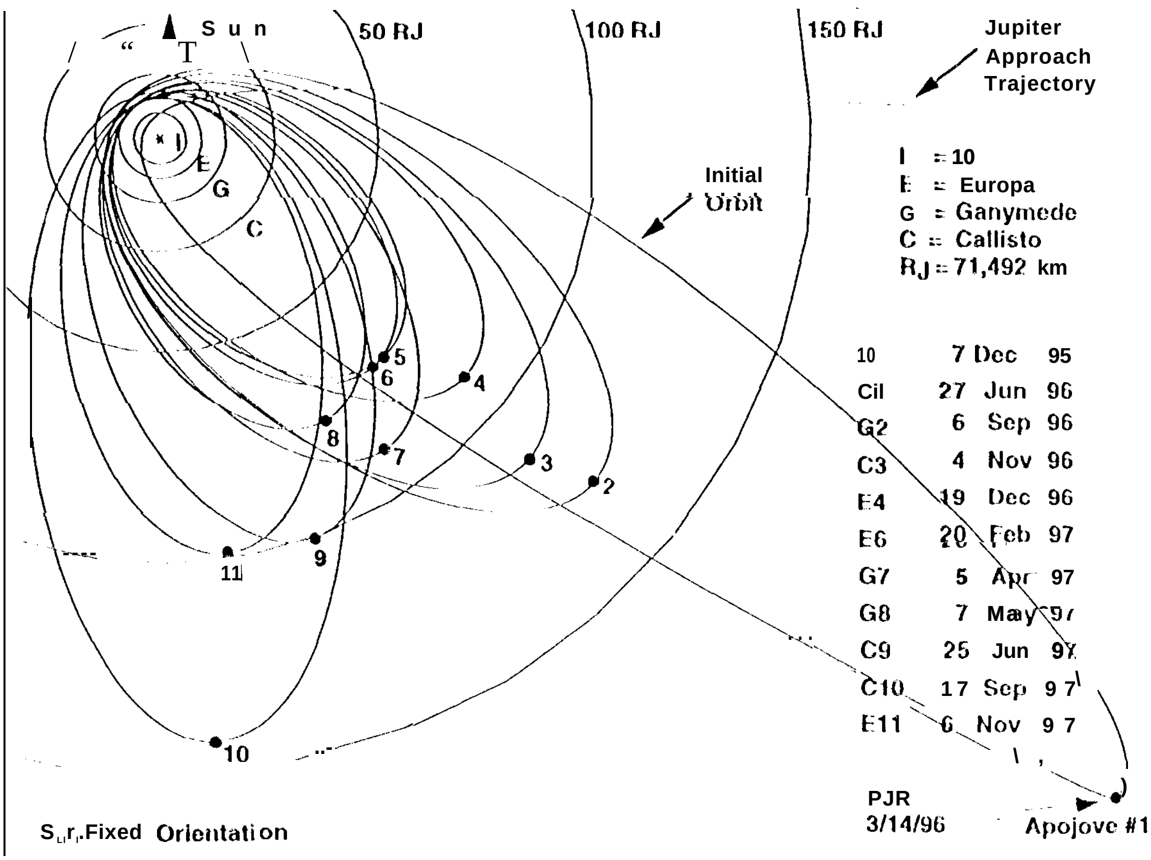

Figure 2: Galileo Orbital Tour Trajectory

During each orbit there are, typically, three OTMs planned. A post-encounter OTM is placed approximately 3 days after an encounter to correct any satellite flyby dispersions resulting primarily from imprecise knowledge of the encounter body ephemeris. An apojove OTM is the! first maneuver which tm'gets to the! fins] desi red aimpoint at the upcoming encounter, typically having a deterministic component resulting from the design of the post-encounter O'J'M. A pre-encounter OTM is planned to occur approximately 3 days before an encounter and is designed to be a small maneuver removing any residual flyby error after the execution of the apojove OTM.

A useful metric for measuring the success of the OTM planning process is through a comparison of actual propellant used in the mission to predictions. This comparison will be provided and will show that the propellant usage in the mission thus far has been very favorable and should allow for sufficient margin at the end of the primary mission to complete the objectives of an extended mission (if it receives funding). A brief' discussion of future events in the mission will be provided as well.

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