Venus Orbital Radar Mapping in the 1980s—Mission Design and Analysis

SCOTT K. ASNIN*
Martin Marietta Aerospace, Denver, Colo.

Theme

AN existing challenge to our exploration of the solar system is the acquisition of a topographical profile of the planet Venus, where surface features are obscured from optical mapping systems by a dense atmosphere. The application of airborne radar mapping systems and techniques, which have proven effective on Earth during the last two decades, to a spacecraft orbiting about Venus offers the potential for a complete, high-resolution, planet map. The complete paper treats in detail opportunities in the 1980s for a Venus orbital radar mission, the design of the mapping orbit and its interplay with radar system constraints, and the requirements placed upon spacecraft propulsion systems. This condensation presents a few of the major analyses which shaped mission design in the early phases of its continuing evolution. Conclusions are drawn which pertain to the set of all considered opportunities.

Contents

Mission opportunities have been assessed within the timeframe of the early to late 1980s, considering the years 1983, 1984, 1986, 1988, and 1989 (approximately equivalent to 1981). Given current funding expectations, the emphasis here has been toward defining a mission of reasonable cost, implementing state-of-the-art technology with reasonable assumptions of growth into the proposed time period. Attention has been focused on the launch capability of Titan IIIE/Centaur, and on the performance characteristics of Viking Orbiter (VO) class insertion propulsion.

Science objectives for the radar exploration of Venus have set the tone for trajectory design. The principal mission objective is assumed to be that of contiguous area mapping, at surface resolutions near 100 m. The implications for design of the mapping orbit lead to orbit inclinations near polar to gain full latitude coverage, and to a mapping mission duration sufficiently long to access all longitudes. One Venus rotation on axis takes 243 days, and thus an orbiter life at least that long is necessary with an eccentric orbit mapping strategy that sweeps a 180° pole-to-pole swath each pass, or 122 days if 360° is swept each pass in a near-circular orbit. To achieve resolutions approaching 100 m, mapping altitude should be reasonably low consistent with other elements constraining this parameter. The size of the orbit, in eccentricity, has been the principal mission trade and has considerable interaction with radar design.

The role played by the radar system in shaping trajectory design is somewhat analogous to that of an optical imaging system, with a few notable exceptions. For both mapping techniques limits are imposed on the altitude range from which a desired surface resolution can be achieved. In the case of an optical system these limits are directly related to the focal length range of the imaging camera. For radar imagery these altitude limits derive from radar power requirements and signal interpretation (ambiguity) constraints. As is the case for both techniques, design of a circular orbit presents a constant altitude and range profile to the imaging systems and therefore simplifies their implementation. The circular orbit does, however, exact a significant penalty in large Venus orbit insertion (VOI) propulsion requirements and limited payload capability. Design of an eccentric orbit, by contrast, reduces VOI propulsion to a more manageable level but forces the imaging radar to contend with the problems of variable altitude.

Assessment of mission performance was directed toward definition of the orbited payload capabilities associated with the considered Earth-Venus opportunities, given the assumptions of 1) Titan IIIE/Centaur launch, 2) 20-day launch window, 3) Viking class insertion propulsion, and 4) single impulse VOI. A periapsis altitude of 400 km was selected as a nominal target, based on Venus approach dispersion analyses. As the mission study progressed into various performance related areas, the payload in orbit estimate modified to include an allowance for a 20° apsidal shift during insertion to provide an equatorial periapsis in eccentric orbit, and to include rather large finite burn losses. These considerations, to be discussed, influenced the design of the insertion propulsion and ultimately led to the treatment of a 3-engine VO insertion system. Shaped by these factors, payload estimates varying with mission year and orbit eccentricity were generated and are presented in Fig. 1. With a reference non-propulsive weight in orbit of 750 kg (a preliminary design goal), orbit eccentricity would have to be 0.4 or greater for all mission years to be viable. Considering only the better years 1983, 1984, and 1989 (1981), an eccentricity of 0.2 provides payload capability in the 650–800 kg range. For none of the years would a circular orbit design provide an orbited useful weight much in excess of 500 kg. Supplementing this picture, the potential of Shuttle/Centaur for delivering a payload to Venus is about twice that of Titan IIIE/Centaur, opening the possibility of a dual spacecraft mission.

An examination of planet/trajectory geometry at Venus encounter was made to determine the degree to which orbit design could be divorced from mission year dependency. A general similarity in arrival geometry for all cases was observed in the Venus orbit plane. The relatively invariant orientation of Sun,

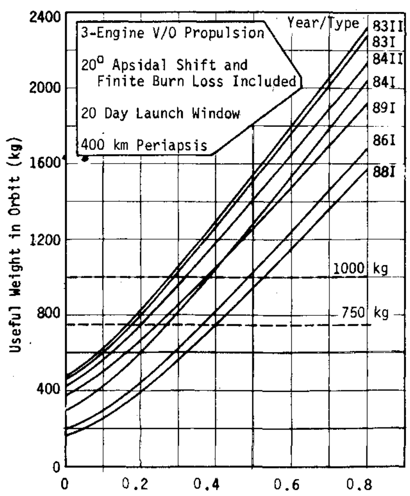

Fig. 1 Mission year performance capability for varying orbit eccentricity.

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* Senior Engineer.

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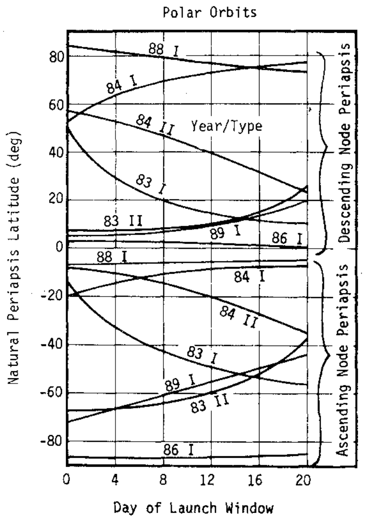

Fig. 2 Natural periapsis latitude for polar orbit inclination.

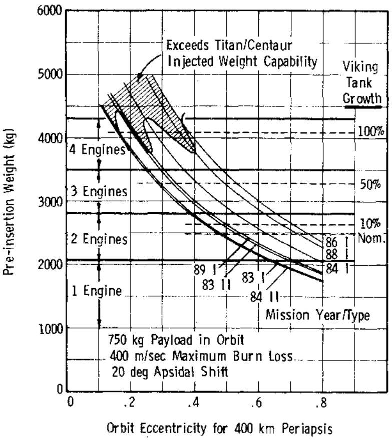

Fig. 4 Preinsertion weight requirements and propulsion system selection for all mission years.

Earth, and hyperbolic excess velocity (Vhp) vector in plane implies that for any specific orbit design, characteristics of occultation patterns, orbit stability, power acquisition, thermal load, and data handling should be essentially independent of mission opportunity. The significant variations in the arrival picture involve the Vhp vector magnitude and declination, which are closely dependent on mission year. There the direct effect is on the orbit insertion ΔV requirements, and on the natural orbit orientations and periapsis latitude locations achieved by coplanar transfer from the approach hyperbola.

Given the attractive orbit insertion propulsion requirements of eccentric orbits, the natural periapsis latitude range for each mission year is an important parameter. In Fig. 2 are illustrated the double-valued periapsis latitude locations for polar orbit inclinations of each opportunity, shown varying over the associated launch window. The curves indicate the amount of apsidal shift which would be required to locate periapsis at some specific latitude for each case. If, for example, with eccentric orbit mapping a balanced treatment of each hemisphere were desired, an equatorial periapsis would then be preferred, and Fig. 2 would indicate the apsidal shift required to gain that location. A nominal shift capability of 20° has therefore been provided in the assessment of performance to ensure an equatorial periapsis for all years, reflecting this assumed science objective.

The range of Vhp magnitudes associated with this mission set yields rather long burn times during insertion for the considered propulsion, suggesting that finite burn losses may be appreciable. Within limits, multiple impulse transfers can be used to reduce these losses, while for this early study the single impulse VOI condition was examined. A convenient parameter for the generalized estimate of burn loss is the pre-insertion thrust to weight ratio (T/W). With T/W as the independent parameter, a family of curves is developed in Fig. 3 which indicates the magnitude of burn loss for a given T/W and impulsive ΔV requirement. Impulsive ΔV can in turn be defined for various

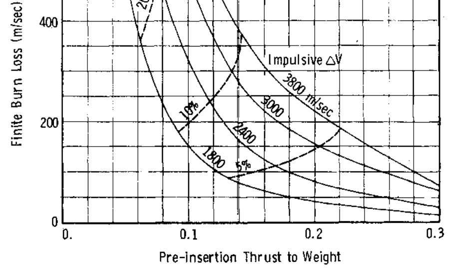

Fig. 3 Finite burn loss parametrics for venus orbit insertion.

combinations of orbit eccentricity and Vhp. For each opportunity, then, these constructs provide a method for relating orbit selection (eccentricity) and propulsion system design (thrust level, or number of VO engines).

Given an assumed constant payload in orbit of 750 kg, this mass is mapped backward through VOI using a nominal propulsion inert definition, a specific impulse of 286 sec, and an arbitrary burn loss maximum of 400 m/sec, varying impulsive ΔV with mission Vhp and orbit eccentricity. These conditions map into pre-insertion weight (W_i) requirements for each case, shown by the curves of Fig. 4. In this treatment horizontal grid lines indicate both constant W_i and constant ΔV. The shaded area indicates launch vehicle limits. To define propulsion thrust levels adequate for various regions of the weight-eccentricity space, an intermediate step is taken. With payload fixed at 750 kg, W_i can be defined for each ΔV, representing one condition. If maximum burn loss is fixed to 400 m/sec, a minimum T/W exists for each ΔV, so that defining constant thrust levels associated with 1, 2, 3, or 4 VO engines produces a second condition of maximum W_i contours varying with ΔV. Points of intersection which are solutions to both conditions then define a maximum preinsertion weight for each considered engine combination (thrust level) and thereby allow Fig. 4 to be divided into horizontal regions of appropriate propulsion design. Numbers indicated under "Viking Tank Growth" in Fig. 4 refer to the percentage increase in nominal VO propellant loading (1405 kg) required as W_i varies.

From Fig. 4, an orbit of 0.5 eccentricity permits all mission years to achieve the desired 750 kg with an insertion system of 2 or 3 engines, and with propellant loads ranging from nominal VO in 1983 and 1984 to a 60% growth in 1986. For orbit eccentricities below 0.2, nearly all years require more launch vehicle capability or higher performance insertion propulsion.

From these elements shaping orbit design, and from additional studies of orbit stability and occultation patterns discussed in the original work, conclusions were drawn for the mission concept. Polar orbit inclinations are necessary to achieve complete mapping in latitude, and appear to present no disadvantages. With the modified VO propulsion system considered, the design of a circular mapping orbit would not yield the in-orbit payload of 750 kg originally thought necessary over the mission year set. Accepting instead radar mapping from an eccentric orbit design led to the selection of a 3-engine VO configuration, influenced by large ΔV requirements, apsidal shift provision, and significant finite burn losses. With an orbit eccentricity of 0.5, the desired payload can be achieved for all years, and for the three better years VO propulsion growth would not exceed 10%. The duration of the eccentric orbit mission must be at least 243 days in orbit at Venus. This design appears compatible with radar implementation and data handling, and offers an exciting Venus mission for a reasonable program cost.