NAVIGATION DEMONSTRATIONS OF PRECISION S/X-BAND RANGING WITH THE ULYSSES SPACECRAFT

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While Earth orbiting spacecraft navigation has routinely been able to use various sorts of range data at accuracies of 2 meters or better, interplanetary spacecraft navigation using long data arcs has had to artificially deweight range data to 1 kilometer or more, due to difficulties in day-to-day variability of station bias effects and unmodelled spacecraft non-gravitational accelerations. Recent papers have briefly described a technique for adequately modelling range biases and spacecraft accelerations in a manner that permits the range data to fit to the intra-pass data scatter, while still retaining the radio direction finding capability inherent in range data taken from widely separated stations (References 1, 2). This paper applies this technique to two interesting arcs of Ulysses range data and continues to develop it to encompass all separation angles from the Sun.

The Ulysses mission is a cooperative project of NASA and the European Space Agency (ESA). The spacecraft is a science probe designed to measure charged and neutral particles, magnetic fields, electro-magnetic waves, and ultraviolet and X-ray emissions from the poles of the Sun and the heliospheric environment above the ecliptic plane. Following its launch in October, 1990, the Ulysses spacecraft used a gravity assist from Jupiter on February 8, 1992, to rotate its orbit plane 80 degrees out of the ecliptic, allowing the spacecraft to spend a total of 2,34 days over the North and South polar regions of the Sun in 1994-95.

The primary spacecraft radio system is an S-band uplink (2.1 GHz) and X-band downlink (8.4 GHz), which is used for doppler and range measurements, as well as for scientific and engineering telemetry. Radiometric data and telemetry are obtained by the tracking stations of the NASA/JPL Deep Space Network (DSN). While not as insensitive to charged-particle dispersions as an X-band uplink/downlink system, the Ulysses radio system has shown ranging and doppler performance approaching that of an X/X-band system. VLBI data have also been obtained at X-band when the spacecraft radio signal was properly configured. The Ulysses S/X-band range, doppler, and VLBI data comprise the best data set available for any current mission, and will remain so until the capabilities of Mars Observer are fully realized.

Two phases of the Ulysses mission to date will be examined in this paper. The most challenging navigation requirements typically occur at planetary encounters. Ulysses is no exception, so the performance of range and doppler data using the new technique will be compared to VLBI-based solutions during the Jupiter approach phase. Preliminary results indicate that 3-G month arcs of doppler and range data around encounter can be fit to an RMS scatter (fen range data) of about than 1 meter (1 σ), as illustrated by Figure 1, which plots the range residuals from a Ulysses solution based on a six-month data arc centered on Jupiter encounter. The range and doppler based solution accuracy also appears to be comparable with that of VLBI-based solutions, as initially discussed in Reference 3.

The Ulysses Jupiter encounter occurred at solar opposition, which is a very favorable time for radio tracking. Future missions may not be as fortunate, possibly needing high navigation accuracy close to solar conjunction. The second Ulysses data arc studied includes the first Ulysses solar conjunction which occurred in August, 1991. The ability of the range data filtering technique to accomodate the solar plasma effects using current or new methods will be assessed over this arc with the limited amount of dual frequency downlink (S/X-band) data and well-determined solutions from before and after the data arc.

This paper, along with the listed references, will enlarge the current experience base, which indicates that range data can provide a significant amount of spacecraft angular position information, this adding considerable flexibility to mission planning when compared to the previous practice of depending entirely on either doppler data or VLBI data for this function. With this information, future missions such as the Mars Environmental Survey Pathfinder will be able to determine with high confidence whether or not range data allows their navigational requirements to be met.

References:

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FIGURE 1: ULYSSES RANGE RESIDUALS