Abstract: AAS/AIAA Space Flight Mechanics Meeting
February 9 – 12, 2003
Ponce, Puerto Rico

Navigating CONTOUR Using the Noncoherent Transceiver Technique

Eric Carranza, Anthony H. Taylor, Bobby G. Williams, George D. Lewis,
Dongsuk Han, Cliff Helfrich, Ramachand Bhat, Jamin Greenbaum,
J. Robert Jensen, Karl Fielhauer

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109

ABSTRACT

The Comet Nucleus Tour (CONTOUR) spacecraft was launched on July 3, 2002 from Cape Canaveral, Florida. CONTOUR was the sixth mission flown in the National Aeronautics and Space Administration's Discovery Program. The objective of the CONTOUR mission was to conduct scientific fly-by studies of comets, Encke and Schwassmann-Wachmann 3, with the option of changing targets in-flight or visiting an additional target after the SW3 encounter. CONTOUR was designed, built, operated and managed by the John Hopkins University's Applied Physics Laboratory. The spacecraft was navigated by the California Institute of Technology's Jet Propulsion Laboratory (JPL).

The paper will describe the mission's planned trajectory, the navigation challenges, as well as the navigation tasks that were involved in achieving mission objectives. The challenges include transceiver issues, orbit determination of the spacecraft during the six-week Earth orbit phase, maneuver design, and post Solid Rocket Motor (SRM) burn reconstruction.

The challenges of navigating CONTOUR are discussed below:

<u>Transceiver Issues</u>

CONTOUR was the first spacecraft in the experience of JPL navigation to use a transceiver instead of a transponder. This resulted in a number of departures in the task of obtaining Doppler and range data for use in orbit determination. To use transceiver-based tracking data, new procedures and software were established and exercised prior to launch. The primary data type that was received was 2-way noncoherent Doppler. The correction process used both radiometric data and spacecraft telemetry data to obtain corrected 2-way noncoherent Doppler data, which could be treated as equivalent to coherently transponded 2-way Doppler data. The details of this treatment will be described.

The ranging system used by the Deep Space Network (DSN) was originally designed to use coherent Doppler data to "rate aid" the correlation of the received ranging modulation code with the local code. Without rate aiding, the received and local waveforms drift with respect to each other and the correlation fails. In order to achieve correlation using CONTOUR's noncoherent system, it was necessary to continually ramp the uplink frequency from the DSN so that the signal arriving at the spacecraft was pre-compensated for the Doppler shift on the uplink leg. Thus, the spacecraft oscillator's downlink frequency approximated the frequency that would result from a transponder-equipped spacecraft receiving the same ramped signal and turning it around to the downlink. This technique required precise control of the uplink frequency. It introduced a vulnerability to small frequency errors in the uplink signal or the spacecraft oscillator, which resulted in failed correlations. About half of the total range measurements were unusable due to miscorrelations that may be associated with an unusual ranging system configuration that was needed to provide extra margin for successful range data acquisition. The ranging system used for CONTOUR will be discussed in more detail, and the latest analysis of the ranging anomalies will be presented.

<u>Orbit Determination Issues</u>

Orbit Determination (OD) for CONTOUR was performed using corrected 2-way noncoherent Doppler and 2-way noncoherent ranging data collected by the DSN 34m network. Doppler data were collected and corrected at 1-second intervals, then compressed to 60 second intervals. Ranging data were collected at typical sample rates of about 30–40 seconds, depending on the specific ranging system parameter values used. Both data types were calibrated for media effects (troposphere and ionosphere). Additionally, the Doppler data were calibrated for spin-polarization biases, and the ranging data were calibrated for the timing delay at the spacecraft.

Treatment of the Doppler data was a concern during the times that the forward low-gain antenna was in use, because that antenna had an appreciable offset from the spacecraft spin axis. The antenna offset, coupled with the spacecraft spin rates, modulated a sinusoidal signature onto the Doppler signal. During the first hours after launch, the forward low-gain antenna introduced a modulation on the 1-second Doppler in excess of 0.5 m/s, which had the potential of corrupting the first Navigation solution. We will describe the effect of spacecraft spin stabilization on the Doppler data (both the polarization effect and the sinusoidal modulation), and discuss the strategy used for minimizing the effect on the OD solutions.

Maneuver design

The spacecraft maneuvers performed during the Earth orbits were designed to achieve proper conditions at the Earth departure maneuver. Because of the large DeltaV (1.9 km/s) and the resonant nature of the CONTOUR trajectory, the SRM had to be executed at the exact conditions determined from optimizing the interplanetary trajectory. Failure to achieve these conditions would require large clean-up maneuvers following Earth departure. A discussion of the statistical DeltaV analysis for the orbit phase will be presented.

Post SRM reconstruction

The Solid Rocket Motor burn on August 15, 2002 was intended to terminate CONTOUR's Earth orbit phase and inject it into a heliocentric orbit, and was performed at a point where the spacecraft was below the horizon for all DSN stations. The spacecraft was last seen, in apparently good order, by DSS 65 at Madrid at the nominal end of its pass about an hour before the burn. About 40 minutes after the burn, CONTOUR would have risen for DSS 25 at Goldstone and DSSs 34 and 46 at Canberra. It was not seen.

On the evening of August 16, the Spacewatch 1.8 m telescope at Kitt Peak, Arizona observed two objects, denoted A and B, in the general vicinity of the nominal post-maneuver trajectory. Later, in some of the Spacewatch images of the same date, a third object, denoted C, was discovered. Thereafter additional images of all three objects were obtained by Spacewatch, the LINEAR facility in New Mexico, the University of Hawaii's 2.24 m telescope at Mauna Kea, JPL's Table Mountain 1 m telescope in California, and at the Farpoint Observatory's 0.3 m telescope in Kansas.

These observations were used as astrometric data to estimate separation DeltaVs near the end of the SRM burn and accelerations due to solar radiation pressure for each of the three objects. The paper will present these results and describe the details that went into their determination, as well as the results from the Earth orbit phase.

Acknowledgments

The work described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Navigating CONTOUR Using the Noncoherent Transceiver Technique

Eric Carranza, Anthony H. Taylor, Bobby G. Williams, George D. Lewis,
Dongsuk Han, Cliff E. Helfrich, Ramachand Bhat, Jamin S. Greenbaum,
J. Robert Jensen, Karl Fielhauer

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive, M/S 301-276
Pasadena, CA 91109 - 8099

Navigation of the Comet Nucleus Tour (CONTOUR) spacecraft was performed at the Jet Propulsion Laboratory and was conducted with the use of the new noncoherent transceiver technique developed by the Applied Physics Laboratory. A description of the mission and its trajectory will be provided, followed by a discussion of the data conditioning performed on the 2-way noncoherent Doppler data, as well as a discussion of the orbit determination estimation procedure, models and accuracies. The orbit determination was performed using X-band 1-way, corrected 2-way noncoherent Doppler data and 2-way noncoherent SRA range data, collected primarily by the DSN 34m network.

Corresponding Author:

Eric Carranza
Jet Propulsion Laboratory
4800 Oak Grove Dr., M/S 301-276
Pasadena, CA 91109 - 8099
Tel: (818)354-4585 Fax: (818)393-6388
email: Eric.Carranza@jpl.nasa.gov

Date: Fri, 20 Sep 2002 10:56:44 -0700
From: Eric Carranza <Eric.Carranza@jpl.nasa.gov>
Subject: My Abstract Status...
X-Sender: carranza@pop.jpl.nasa.gov
To: docrev@techreports.jpl.nasa.gov
Reply-to: Eric Carranza <Eric.Carranza@jpl.nasa.gov>
Delivered-to: docrev@techreports.jpl.nasa.gov
X-Lyris-Message-Id:
<LYR2195408-178955-2002.09.20-10.56.51--David.E.Fulton#jpl.nasa.gov@list.jpl.nasa.gov>

My secretary informed me that my group supervisor Dr. Bobby G. Williams will be out of the office today but will be checking his email messages from home. In the event that you do not heard back from Dr. Williams by noon time today, I ask that you send the approval request email from my section's deputy manager Dennis Byrnes at Dennis.V.Byrnes@jpl.nasa.gov .

If you have any questions, please feel free to call me at 4-4585.

Thanks,
Eric
--

Eric.Carranza@jpl.nasa.gov
Navigation and Mission Design Section
Jet Propulsion Laboratory
California Institute of Technology
W: (818) 354-4585