CHALLENGES IN NEAR NAVIGATION


Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

The Near Earth Asteroid Rendezvous (NEAR) Discovery mission is the first to send a spacecraft to rendezvous with and orbit about an asteroid. Launched in February 1996, the interplanetary trajectory of the NEAR spacecraft included a targeted flyby of the asteroid 253 Mathilde in June 1997 and used an Earth gravity assist in January 1998 to enable this low-cost mission. The spacecraft is currently on course for insertion into orbit about the asteroid 433 Eros in February 2000. The navigation for the cruise phase of the mission, even with its stringent requirements, is routine by comparison to the orbit phase of the mission. The navigation challenge for the orbit phase is to devise an adaptive orbit scenario that accounts for the crudely known asteroid physical parameters while maintaining required navigation accuracy. Improving the estimates of Eros' physical parameters such as spin state, shape and gravity potential of Eros as the spacecraft approaches and is inserted into orbit about the asteroid is critical to mission success. Unlike a planetary orbiter, the very low gravity of the asteroid means that the spacecraft can easily escape Eros or crash into its surface with very little change in velocity. This places additional demand on navigation accuracy while also imposing a generally shorter response time than that usual for planetary orbit missions. This presentation details the response of the NEAR navigation team to these challenges in terms of design and execution of the orbit phase navigation. The approach chosen uses both DSN radio metric Doppler and range data and optical landmark tracking data for the normal estimation process. In addition, laser altimeter range is included in the navigation estimates whenever the spacecraft altitude is between about 30 km and 100 km.
Challenges in NEAR Navigation

Bobby G. Williams, James K. Miller,
Peter G. Antreasian, Clifford E. Helfrich,
William M. Owen, Donald K. Yeomans

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
Near Earth
Asteroid Rendezvous
Near Earth Asteroid Rendezvous

Heliocentric Orbits of NEAR and Eros

TCM-19
1999 Aug. 12
21 m/s

End of Eros
Orbital Phase
2001 Feb. 14

RND-1
2000 Feb. 2
9 m/s

Eros Flyby
1999 Dec. 23
152 m/s

DSM-2
1999 Jan. 3
932 m/s

NEAR
and Eros

Sun

Earth

September 23, 1999
1999 International Symposium on Space Communications and Navigation Technologies
NEAR's Motion Relative to a Fixed Sun–Eros Line

1998 Dec. 7

+1,200,000

+800,000

+400,000

0

-400,000

-800,000

-1,200,000

X, km

Y, km

1998 Dec. 20
RND-1 Abort

1999 Dec. 23 Flyby
and 2000 Feb. 14 Arrival

Eros

1999 Aug. 12
21 m/s

July

May

Mar.

1999 Jan. 3
932 m/sec

DSM-2

TCM-18

1999 Jan. 20
14 m/s

September 23, 1999
1999 International Symposium on Space Communications and Navigation Technologies
bgw-6
EROS IMAGE

Simulated Image

Actual Image
NEAR EROS FLYBY DOPPLER RESIDUALS
60 SEC DATA

[Graph showing residuals over time with dates and times listed on the x-axis and frequency on the y-axis.]
Spacecraft Trajectory Profile at Eros (4-7-99 version)

Days since Jan 1, 2000

September 23, 1999  1999 International Symposium on Space Communications and Navigation Technologies  bgw-10
Mapping Orbit Prediction Errors
**Orbit Phase Initial Reconnaissance**

**Eros Physical Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Accuracy (1 sigma)</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Apriori</td>
<td>Estimator</td>
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<tr>
<td>Attitude</td>
<td>10 deg</td>
<td>0.68 deg</td>
</tr>
<tr>
<td>Spin</td>
<td>1 deg/s</td>
<td>9.5 \times 10^{-5} deg/s</td>
</tr>
<tr>
<td>Gravity ($\mu$)</td>
<td>100%</td>
<td>99.5%</td>
</tr>
<tr>
<td>Gravity ($J_2$)</td>
<td>0.1</td>
<td>3.9 \times 10^{-2}</td>
</tr>
<tr>
<td>Inertia Tensor ($I_{xx}$)</td>
<td>0.1</td>
<td>5.6 \times 10^{-2}</td>
</tr>
<tr>
<td>Landmark Location</td>
<td>400 m</td>
<td>150 m</td>
</tr>
</tbody>
</table>

† Data consisted of 3 days of Doppler and Optical Imaging of Landmarks
Body-fixed View of a 4th Quadrant (Trailing Edge) Close Flyby Orbit
The Altitude Vs Time from Periapsis for 1st Close Flyby (59 X 16 km) Orbit
Conclusion

- Navigation for NEAR uses radio metric and optical data types
  - Laser range also available below 100 km alt.
- Unlike planetary orbiter missions, navigation for NEAR depends on rapid estimates of asteroid physical parameters
  - Spin state, gravity field, shape
**Eros Physical Parameters Reconstruction**

**Eros Physical Parameters**

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The Shape Model of Eros Determined from NEAR’s Flyby on Dec 23, 1998