Near Earth Asteroid Rendezvous

First Launch of Discovery Program

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Near Earth Asteroid Rendezvous

Launch
Feb 1996

Earth swingby

NEAR – 433 Eros

Mathilde
June 27, 1997

Eros
December 23, 1998

Eros 1998 and 2000

Feb 12 2000 00:45:00
NEAR

• The first asteroid mission
• The first spacecraft visit to a C-type asteroid (flyby of 253 Mathilde)
• The first asteroid rendezvous (433 Eros)
  – First orbital operations around a small, irregular body
• The first asteroid landing (433 Eros)
More “firsts”

• Programmatic and institutional firsts
  – First planetary mission at APL (also a first for NASA)

• First use of internet for internal and external project communications as well as outreach
  – A.F. Cheng blog, NEAR image of the day

• First missions with open data policy requirements and archive requirements to the Planetary Data System
“faster, cheaper, better”

• NEAR: a new way of doing business, at lower cost, with acceptable risk

<table>
<thead>
<tr>
<th></th>
<th>Discovery Requirement</th>
<th>NEAR Performance</th>
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</thead>
<tbody>
<tr>
<td>Development Time</td>
<td>&lt;36 mo</td>
<td>&lt;27 mo</td>
</tr>
<tr>
<td>Cost to Launch +30 days (FY-92 $)</td>
<td>&lt;$150M</td>
<td>&lt;$112M</td>
</tr>
<tr>
<td>Spacecraft and Payload</td>
<td>Acceptable risk</td>
<td>Highly redundant</td>
</tr>
<tr>
<td></td>
<td>Limited scope science</td>
<td>spacecraft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Comprehensive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>payload</td>
</tr>
<tr>
<td>Launch Vehicle</td>
<td>Delta equivalent or smaller</td>
<td>Delta 7925</td>
</tr>
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</table>
NEAR Implementation

• APL responsible for project management
• APL spacecraft
• APL provided facility instruments
  – NASA selected facility instrument science team
  – NASA selected a participating scientist team
• APL responsible for mission operations
• JPL responsible for navigation and DSN support
Management Principles

Practices for Inexpensive, Short Development Cycle Spacecraft (a’la JHU/APL)

• Schedule from start to launch must be ≤ 36 months
• Establish small, experienced technical team with authority to do mission
• Design spacecraft and instruments to cost
• Use lead engineer method for all subsystems
• Reliability and redundancy must be designed-in (not expensive)
• Have R&QA engineer report directly to project manager
• Single agency manager to interface with contractor
Simple Spacecraft

- Three-axis stabilized
- Total weight: 805 kg
  - Propellants: 320 kg
  - Experiments: 60 kg
- Science payload
  - Multispectral imager
  - Near-infrared spectrometer
  - X-ray spectrometer
  - Gamma-ray spectrometer
  - Laser altimeter
  - Magnetometer
- Dual-mode propulsion system
  \[\Delta V \text{ capability: } 1450 \text{ m/s}\]
- Solar array power @ 1.00 AU: 1800 watts
- Two solid-state recorders: \(1.7 \times 10^9\) bits
Focused Mission

Near Earth Asteroid Rendezvous

Measurement Objectives

- **Bulk Properties**
  - shape
  - mass
  - density
  - gravity field
  - spin state
  - magnetic field

- **Surface Properties**
  - Elemental and mineralogical composition
  - Heterogeneity of structural and compositional units
  - Physical, geological and morphological characteristics

[original slide scanned from hard copy which predates Powerpoint]
### Facility Instrument Characteristics

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Characteristics</th>
</tr>
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<tbody>
<tr>
<td>Visible Imager</td>
<td>95 x 161 μm resolution</td>
</tr>
<tr>
<td></td>
<td>2.25° x 3° FOV</td>
</tr>
<tr>
<td></td>
<td>8-position filter wheel</td>
</tr>
<tr>
<td>X-ray/γ-ray Spectrometer</td>
<td>Al, Mg, Si, Fe, Ti, Ca</td>
</tr>
<tr>
<td></td>
<td>U, Th, K</td>
</tr>
<tr>
<td>NEAR IR Spectrograph</td>
<td>~0.8-2.7 μm spectral range</td>
</tr>
<tr>
<td></td>
<td>spectral resolution 22/44nm</td>
</tr>
<tr>
<td>Magnetometer</td>
<td>sensitivity &lt;1 nT</td>
</tr>
<tr>
<td>Laser Altimeter*</td>
<td>range 50 km</td>
</tr>
<tr>
<td></td>
<td>Resolution 6 m</td>
</tr>
<tr>
<td>Radio Science*</td>
<td>two-way Doppler to 0.1 mm/s</td>
</tr>
</tbody>
</table>

*Engineering subsystems
PI Mission Management

• How to balance the tensions of PI mission management (who does what)
  – The PI
  – The PM (and PS if you have one)
  – The institution (project management and line management)

• The challenges of leading a strong team
  – You don’t know everything
  – You must make decisions
  – You need your team
  – Your team needs you
How it was done

Near Earth Asteroid Rendezvous

Technical Approach

- **Approach suited to Discovery Mission**
  - Optimized to schedule
  - Consistent with program cost, propellant mass fraction

- **Design to schedule approach**
  - Modularity in propulsion system
  - Distributed architecture
  - Large (50%) use of off-the-shelf components
  - 1533 data bus
  - Qualification of subsystems prior to spacecraft delivery
Schedule set in 1992 and followed through launch
Mission Operations learned in flight

- Concept of operations developed after launch for a small team
  - There was no good model for NEAR (the last orbital mission was Galileo)
- Little or no simulation of orbital operations
  - No previous orbital mission around an irregularly shaped, small object
  - Navigational accuracy could not be predicted
  - Spacecraft predicted to safe often (which did NOT happen)
- Eros flyby was in some sense a blessing
PDS Archive Delivery

- PDS was in its infancy when NEAR was organizing and implementing its delivery
  - PDS was defining its processes, procedures, and archive definitions
- NEAR data successfully archived
- Lessons Learned:
  - NEAR had different data format for Science Team than PDS (re-create data for archival purposes)
    - learned to define project data formats in a PDS approved format
  - Review of PDS data formats with PDS began past mission midpoint
    - learned to start review process at mission start (with data format definitions) and team with PDS (Data Archive Working Group) to facilitate intermediate reviews
Mathilde Encounter

Mathilde Encounter: June 27, 1997

Encounter Parameters
- Sun Distance: 1.99 AU
- Earth Distance: 2.19 AU
- Approach Phase Angle: 140 degrees
- Flyby Speed: 9.93 km/sec

NEAR Spacecraft
- Wide-angle camera
- Limited power
- No scan platform

253 Mathilde
- 50 x 50 x 70 km
- C-type
- Rotation period: 17.4 days!

Expected Science Return
- 534 Images
  (Best resolution ~ 200 meters)
- Mass determination
  (uncertainty ~ 5%)
One very bad day

**Aborted Rendezvous Burn**
**December 20, 1998**

- On board autonomy system shut down main engine at onset
  - Accelerometer normal to thrust vector
- Spacecraft went into “Safe Mode” as planned
- Spacecraft tumbled
  - Expended 28 Kg. of fuel; not as planned and still unexplained
- Spacecraft went deeper to “Sun Safe Mode” as solar arrays exceeded angle to sun
- Recovered spacecraft 27 hours later, as planned
- Eros flyby on December 23, 1998
- Successful main engine burn on January 3, 1999
- Rendezvous with Eros delayed until February 2000
U-turn After Burn Abort
The First Asteroid Landing

- Spacecraft not designed for landing
- Touchdown at ~1.6 m/s, 316 million km from Earth
- Spacecraft acquired scientific data for two weeks after landing

Descent to the surface of Eros: the last four images

NEAR
February 12, 2001
Near Earth Asteroid Rendezvous

- Feb 2001 - mission completed with landing on 433 Eros
  - All data in PDS, September 2001
- Science Objectives fulfilled
- Mission Extras
  - Mathilde fly-by
  - Two low altitude passes of Eros surface (< 5km)
  - Landing
- Final Cost within 3% of total mission cost given to NASA in 1994
  - Includes thirteen month delay due to burn anomaly, December 1998
Science Success

• All science objectives met or exceeded
• More science and data returned than originally planned
  – More than 10x number of images
  – Two low altitude flybys (under 5 km)
  – Landing and science operations on the surface
• No major spacecraft anomalies at Eros
Mission Milestones

- Launch (February 17, 1996)
- Mathilde Encounter (June 27, 1997)
- Earth Flyby (January 23, 1998)
- Eros Flyby (December 23, 1998)
- Eros orbit insertion (February 14, 2000)
- Eros landing (February 12, 2001)
- Landed science operations through end of mission (February 28, 2001)
Geologically Active Surfaces

Lobate, downslope-oriented bright streaks at 2.5 m/px in crater Selene
January 28, 2001

A pond and a nearby debris flow
Stereo Close-ups

Ponds and split boulders?  The NEAR landing site