Managing GRAIL: Launching on Cost, on Schedule, and on Spec

Randall L. Taylor
GRAIL Project Acquisition Manager/Review Captain
Jet Propulsion Laboratory
California Institute of Technology

2012 IEEE Aerospace Conference
March 3–12, 2012
Big Sky, Montana
The GRAIL Mission (1/5)

• The Gravity Recovery And Interior Laboratory (GRAIL) mission was selected by NASA as a Discovery Program project
• GRAIL is PI-led (Dr. Maria T. Zuber, MIT) and JPL-managed
• Key development dates:
  – Jan. 2008: Start of Phase B
  – Apr. 2008: Project Mission System Review (PMSR)
  – Nov. 2008: Project PDR
  – Jan. 2009: Confirmation Review/Key Decision Point (KDP)-C
  – Mar. 2009: Start of Phase C
  – Nov. 2009: Project CDR
  – Jan. 2010: Mission Directorate PMC
  – June 2010: Project SIR
  – July 2010: DPMC/KDP D
  – Aug. 2011: Mission Readiness Review (MRR)
  – Aug. 2011: Mission Readiness Briefing (MRB)/KDP E
  – Sept. 10, 2011: Launch!
  – Mar. 8, 2012: Science Phase begins
The GRAIL Mission (2/5)

- **Science objectives:**
  - Determine structure and interior of the Moon, from crust to core
  - Understand thermal evolution of the Moon
  - Extend knowledge to other terrestrial planets

- **Mission outline:**
  - Twin spacecraft launched on a Delta 7920H-10
  - 9-month mission; launch in Sept 2011
  - Low altitude, 50-km polar orbit
  - 82-day primary mapping mission
  - Spacecraft operates at ~200 km separation
  - Extensive science data analysis
  - E/PO MoonKAM cameras engage public
  - Heritage: GRACE-like mission concept
  - Heritage: Spacecraft from LM: XSS-11 and MRO

- **Science measurements and payload:**
  - Ka-band ranging system (with GRACE heritage) measures relative velocity of CM of two spacecraft
  - DSN used for absolute position determination

- **Mission management:**
  - MIT: PI, SRS contract for E/PO
  - GSFC: Gravity science modeling and data analysis
  - JPL: PM, SE, MA, MO and GDS, payload, LM spacecraft system contract, data processing
The GRAIL Mission (3/5)

GRAIL’s twin spacecraft
Spacecraft in launch vehicle payload fairing

GRAIL launch, September 10, 2011
Local mass variations result in orbital velocity changes.

\[ a = \frac{dV}{dt} = \frac{F}{m} = -GM \left( \frac{r}{r^3} \right) \]

Because spacecraft pass over mass variations at different times, separation \( D \) is affected by gravity.
• Level-1 Science Requirements were proposed in the Step-2 proposal and accepted by NASA
• The measurement requirements reflected spacecraft & instrument capabilities
• The Level-1 Requirements were never changed during the course of Phases B, C, and D
• NASA provided some additional funds at Project Confirmation for science risk reduction
• Due to the importance of error sources management and modeling, multiple gravity modeling and simulation peer reviews were conducted, as well as thorough spacecraft/payload testing

**Science did not drive project design and development**
• With a project cost cap, GRAIL required thorough yet agile project management processes
  – Led by key personnel with the right experience and the right attitude (who stayed on the job)
• PI was “hands-on”
• Project Systems Engineer was the ETA; Chief Engineer (through CDR) led system architecture and trade studies
• Risk Management was not a compliance or audit function; it was a value-added technique to manage the work to go
• SMA was a full partner and a problem-solver on Tiger Teams when issues arose
• Business Management participated in the Technical, Schedule, and Cost (TSC) Control Board, using proactive schedule management in addition to EVM
• Project management focus areas and tools of choice changed through the life cycle
• Phase A (6 months)
  – Completed the required conceptual design, management plan, and cost proposal (in a Concept Study Report aka Step 2 proposal)
  – Got an early start on Phase B

• Phase B (12 months)
  – Demonstration of technology maturation for new Payload elements (e.g., Time Transfer System)
  – Conducted institutional review of readiness to initiate preliminary design (Project Mission System Review)
  – Conducted a battery of Inheritance Reviews
  – Conducted pre-PDR reviews (38!)

• Project PDR was JPL’s first under new NASA SRB rules (more to come)
  – Finding: “Instrument is above PDR level.”
  – Finding: “Spacecraft system is at PDR level.”
  – Recommended additional attention in four specified areas

Project essentially achieved our objective of “No liens going into Phase C”
Development (1/2)

• Final design (12 months)
  – Project CDR preceded by 28 internal reviews, gate products, etc.

• Technical Challenges
  – Reaction Wheels—modifications to existing product line (smaller, electronics integrated)
  – Avionics—Lockheed Martin reversed “make” decision to complete IRAD product development (MRO-Lite)
  – EEE Parts—late ordering, some obsolete, some nonstandard

• Successfully passed Project CDR, with one caveat
  – Finding: “Instrument is above CDR level.”
  – Finding: “Spacecraft system is at CDR level (with full closure of avionics subsystem CDR …)”
  – Completed Delta-CDR for Avionics one month later

Ready to build, but really bad news arrived!
• New launch loads, oh my!
  – GLAST’s Delta II Heavy launch loads were more severe than had been provided as GFI
  – GRAIL spacecraft would be shaken to bits if we proceeded to build
  – Tiger Team; Independent Assessment; authorization of SoftRide launch attenuation system; rapid PDR and CDR by Moog CSA (just in time for SIR)

• System Integration Review
  – Held one week prior to Step 2 proposal commitment – so project still had the originally-planned 65 days of schedule reserve
  – Passed with some liens but approval to start ATLO
    • Finding: “Payload is in terrific shape, and on time!”
    • Finding: “A key post-CDR issue, launch loads, has been successfully mitigated”
    • Liens were Reaction Wheels test failure (the week before SIR), Avionics delivery, and Flight Software schedule

Adequate reserves and an agile team allowed the threat to Launch to be overcome
• GRAIL had the challenge of assembling and testing two spacecraft, while a third (Juno’s) was running ahead in the LM plant
  – Project found a way to make two spacecraft a benefit instead of a handicap
• The ATLO plan changed every week (sometimes more often)
  – Philosophy was to always keep making progress
• Focus on hardware and software development meant that open paper and V&V received lesser attention and resources
  – Project added staff and selective second shift to catch up
  – No deferred development—everything on the Must Complete Before Launch List was completed

Experienced, nimble, bonded workforce prudently applied schedule and cost reserves to reach the finish line
Contract Collaboration

• Surveillance (insight/oversight) approach (streamlined and embedded)
  – Document submittals
  – Reviews
  – People—“team” culture, 24-hr rule, mutual aid

• Surveillance tools
  – Early: trade studies, drawings, procurement specs
  – Middle: HW/SW deliveries
  – Late: ATLO schedule, daily telecons

A strong team playing well together will adapt processes and tools for success
Reviews

• GRAIL was the first JPL flight project implemented under NPR 7120.5D (SRB construct)
• Many, many reviews! (NASA, institutional, peer)
  – Coordinated by Review Captain and support team (see three IEEE papers)
• SRB process learning curve
  – SRB staffing
  – Terms of Reference (ToR)
  – Independent Cost Estimate
  – Independent Schedule Assessment
• SRB successes
  – Regular telecons with SRB Chair and Review Manager
  – Document delivery schedule
  – Monthly project status updating
Summary

- GRAIL had a solid concept from inception—an advantage that we did not squander
- GRAIL adapted institutional best practices and lessons learned to produce culture + processes + tools that worked well for the team, evolving them over the course of project development
- GRAIL team members identified problems early and attacked them aggressively in a collaborative spirit—a critical success factor
- The GRAIL project management approach can be applied to other NASA space flight projects