



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

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Agenda

- The GRAIL mission
- Project management
- Design
- Development
- ATLO
- Contract collaboration
- Reviews
- Summary

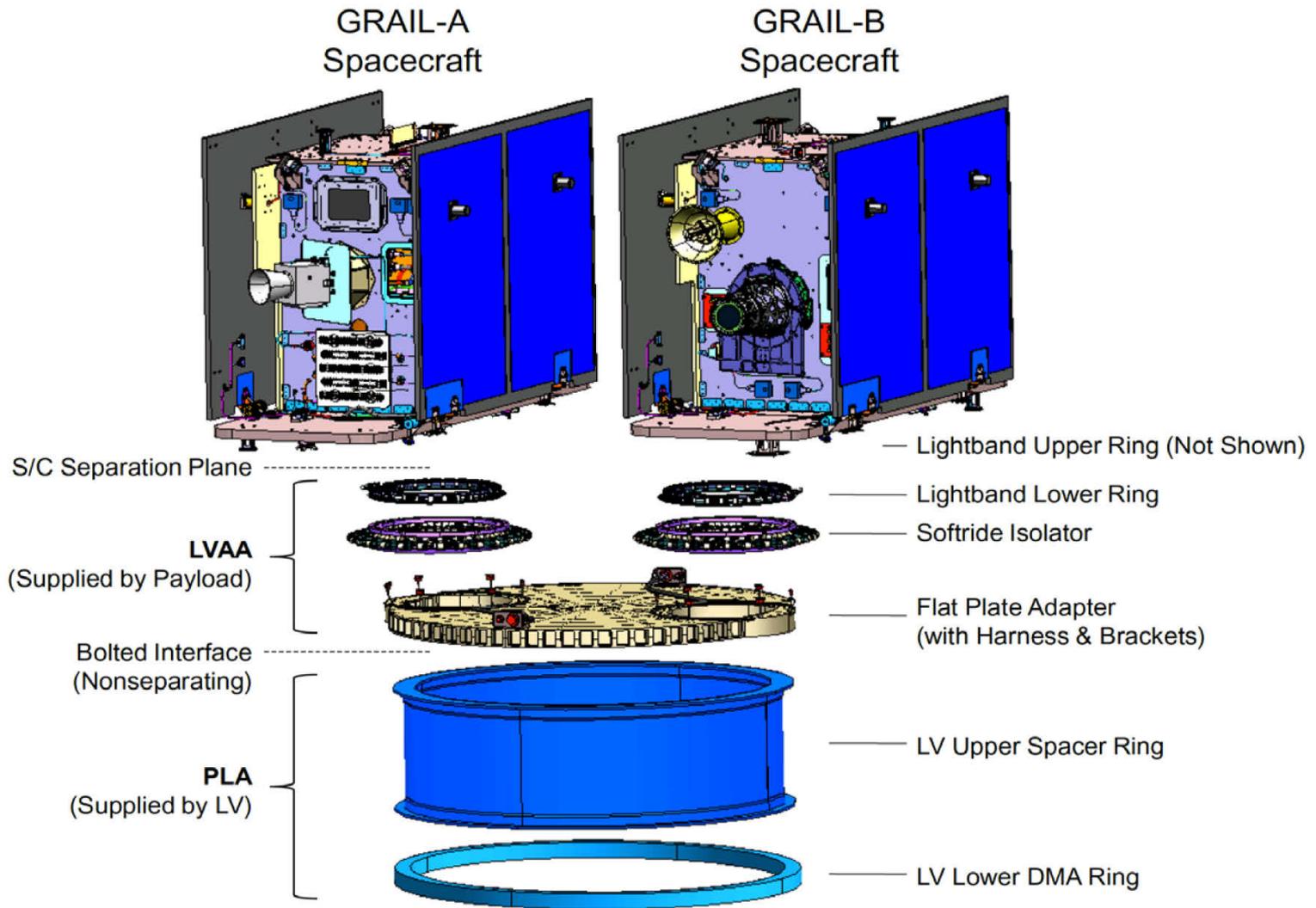
The GRAIL Mission (1/5)

- 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
 - July 2011: Operations Readiness Review (ORR)
 - Aug. 2011: Mission Readiness Review (MRR)
 - Aug. 2011: Mission Readiness Briefing (MRB)/KDP E
 - Sept. 10, 2011: Launch!

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

The GRAIL Mission (4/5)



Spacecraft in launch vehicle payload fairing



GRAIL launch, September 10, 2011

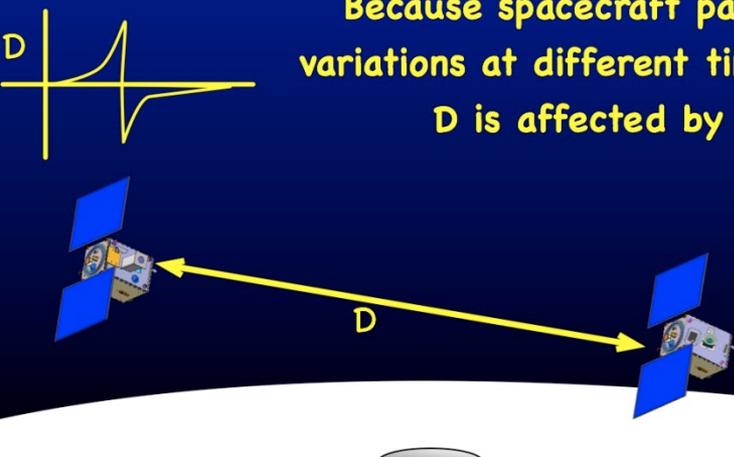
The GRAIL Mission (5/5)



Local mass variations result in orbital velocity changes.

$$a = dV/dt = F/m$$
$$= -GM (r / r^3)$$

M



Because spacecraft pass over mass variations at different times, separation D is affected by gravity.

D

M

- 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

Project Management

- With a project cost cap, GRAIL required thorough yet agile project management processes
 - Fully compliant with NPR 7120.5D, NPR 7123.1, and JPL Flight Project Practices and Design Principles
 - 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 team partnered well with the Discovery Program Office (MSFC) and Program Executive (HQ)
- 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
 - Used JPL's Gravity Recovery Instrument for Planets (GRIP) testbed for early system analysis using GRACE residual hardware and GRAIL prototype electronics
 - Produced preliminary versions of all Phase B gate products
- 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)
 - Challenging due to late start in staffing up
 - Conducted a battery of Inheritance Reviews
 - In most cases confirmed design heritage
 - Failed the IR for Reaction Wheels – resulted in change out of supplier
 - Conducted pre-PDR reviews (38!)
 - Spacecraft subsystems, portions of MOS, cross-cutting areas (e.g., requirements)
- 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!

Development (2/2)

- 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
 - Accommodate late delivery of flight Avionics with ATLO test units
 - Perform workmanship tests on both spacecraft, performance and stress tests sometimes on both and sometimes on only one
 - Incompressible Test List tests all completed
 - Highest-priority risk-reduction tests all completed
- 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

- JPL subcontract to LM for spacecraft and ATLO
 - Phase A: FFP
 - Phase B: CPFF
 - Phase C/D: CPFF/IF (including in-flight performance & cost performance)
 - Phase E: CPFF
 - Few changes; EVM in Phase C/D
- 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 (never solved this one)
- 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
- More information is available in the IEEE paper “Managing GRAIL: Getting to Launch on Cost, on Schedule, and on Spec,” by Randall L. Taylor, Dr. Maria T. Zuber, David H. Lehman, and Thomas L. Hoffman
- You may request a copy from the lead author:
Randall.L.Taylor@jpl.nasa.gov