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

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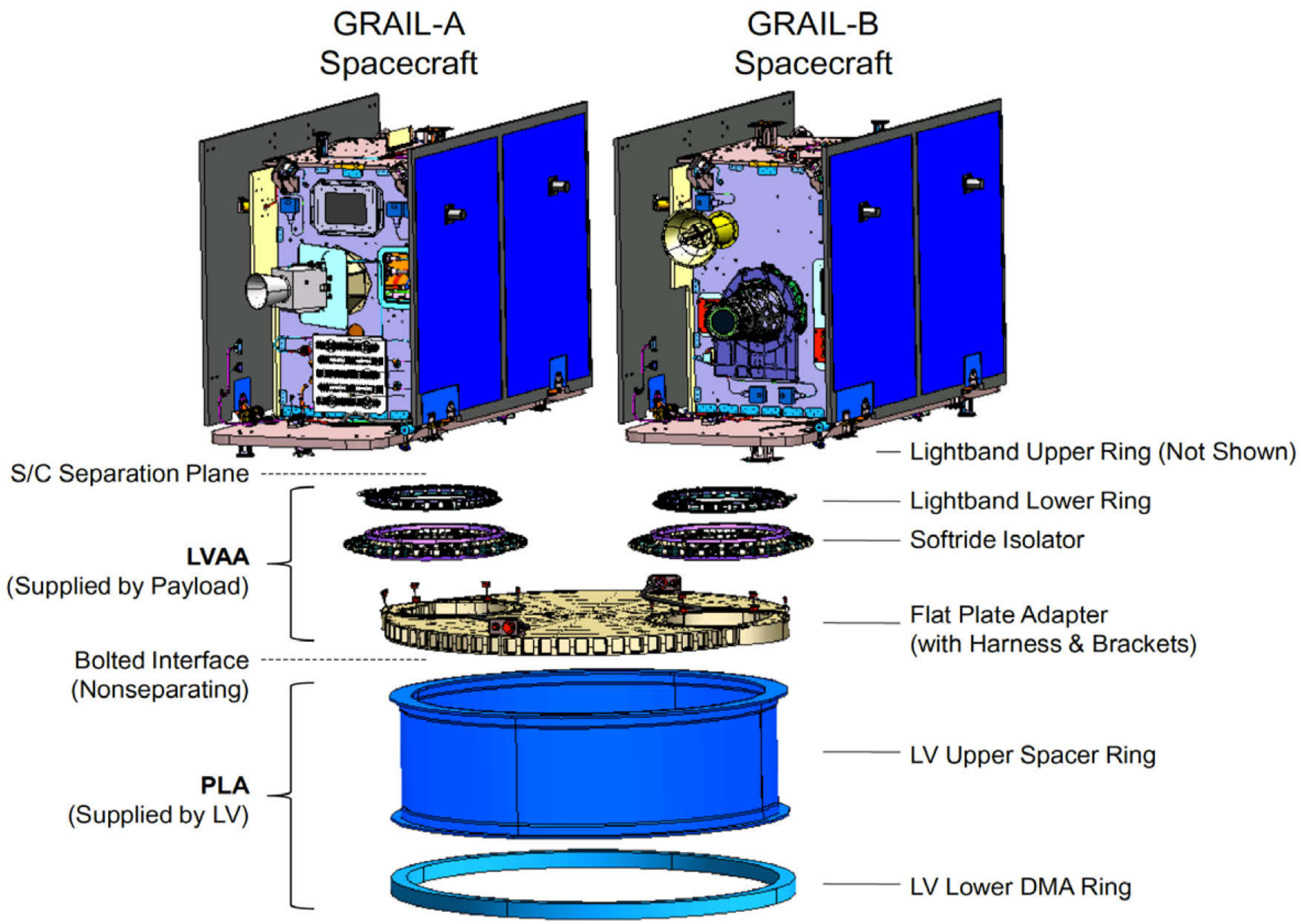
The GRAIL Mission (1/5)

- 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!
  – Dec. 31, 2011/Jan. 1, 2011: Lunar Orbit Insertions
  – 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)



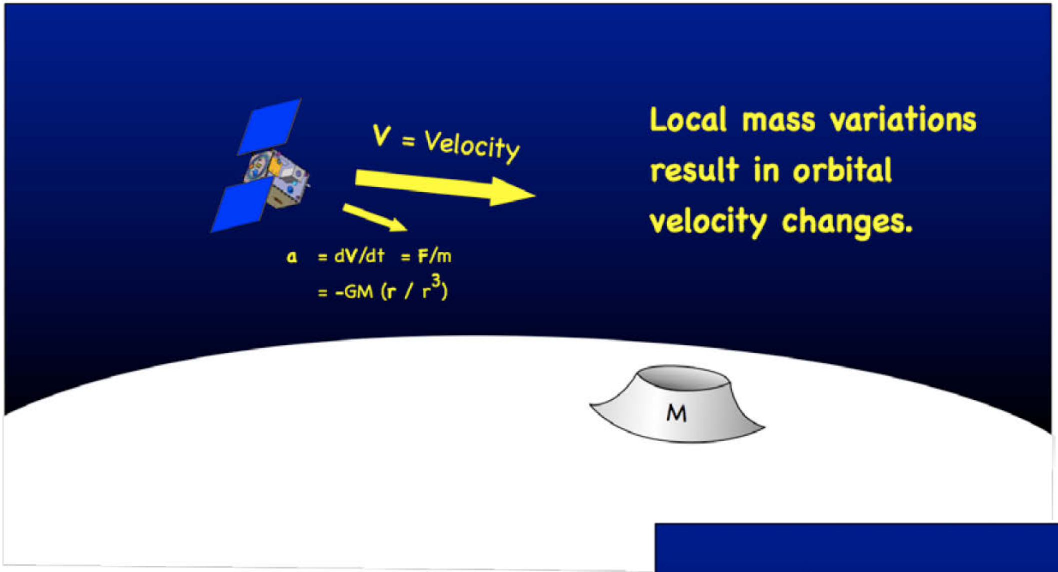
GRAIL's twin spacecraft

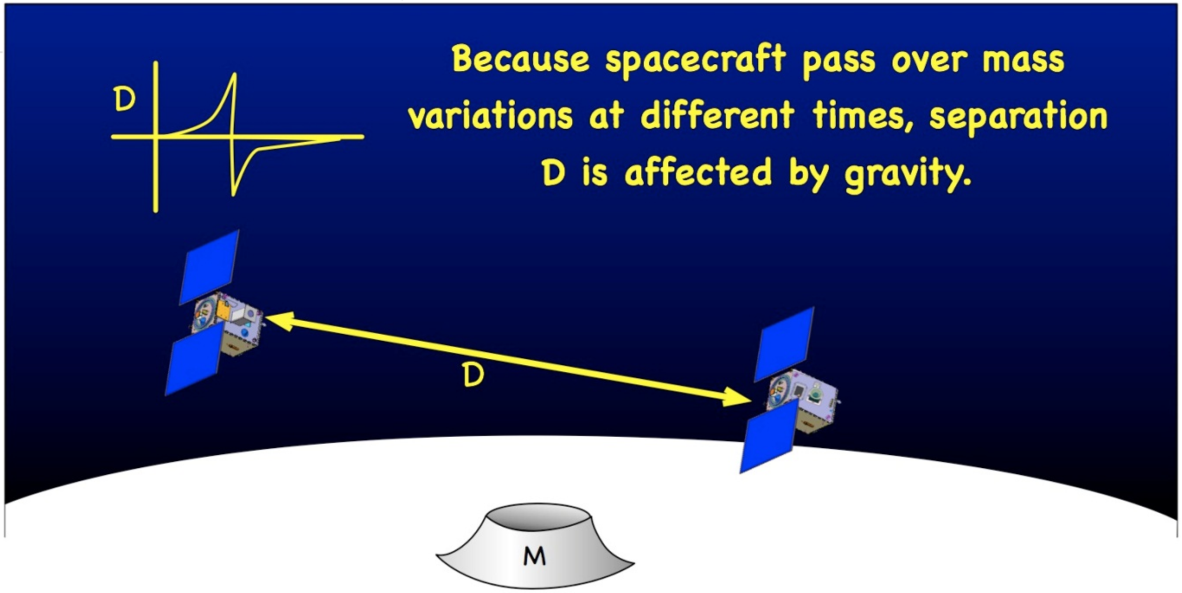
The GRAIL Mission (4/5)

Spacecraft in launch vehicle payload fairing

GRAIL launch, September 10, 2011

The GRAIL Mission (5/5)





Science

- 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
  - 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

Design

- 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!

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

ATLO

- 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