OrbView-3 De-Orbit

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Agenda

- Briefing Overview
- Regulatory Approvals
- OrbView-3 Spacecraft Status
- Timing
- Execution and Verification Team
- De-Orbit Plan
- Risks and Mitigation Approach
- Summary

Overview

- OrbView-3 is no longer capable of performing its mission
- GeoEye's *License to Operate a Private Remote Sensing Space System* from NOAA includes requirement for proper vehicle disposal
  - Paragraph 11 states

    "…The Licensee will deorbit the spacecraft by means of either a Licensee-controlled de-orbit and re-entry over a broad ocean area, or a natural orbital decay and uncontrolled atmospheric re-entry."
- GeoEye has chosen to complete a controlled deorbit to ensure we remove OV-3 as potential source of orbital debris

Overview (continued)

- ***Regulatory Approvals:*** OrbView-3 satellite (OV-3) de-orbit requires NOAA/FCC regulatory approvals
- ***OV-3 is Non-Operational:*** No imaging operations since 2007; decision has been made to de-orbit
- ***Timing:*** By January 2011; no space for OV-3 flight operations in GeoEye's new HQ facilities
- ***De-Orbit Plan:*** Developed by expert team with de-orbit and flight dynamics experience
- ***Risk Mitigation:*** Risks identified and mitigated

Regulatory Approvals

- OV-3 licensed by NOAA in 1994
  - Regulations require that satellite disposal be in a manner satisfactory to the President and de-orbit plans be approved by NOAA
  - NOAA license requires either controlled de-orbit over broad ocean area or natural orbital decay/uncontrolled atmospheric reentry
- OV-3 licensed by FCC in 1999
  - Regulations require special temporary authority if de-orbit changes the satellite orbital parameters originally authorized

OV-3 Spacecraft Status

- OV-3 was launched June 26, 2003
  - Normal imaging operations until Spring 2007
    - Anomaly experienced and reported March 2007
    - Total loss of camera operations; unrecoverable
  - Satellite attitude and control is fully functional
  - Current altitude approximately 438 km (271 miles)
  - Remaining usable propellant 22.98 kg
    - 150% of calculated amount necessary for deorbit
- Insurance
  - On-orbit insurance claim was paid in 2008
  - GeoEye holds $22M of third party general commercial liability insurance for property damage and personal injury

OV-3 Spacecraft Status cont.

Subsystem	Key Parameters
Mission	• Commercial Imaging • 5 Year Mission
Mass:	• 670 lb launch weight (303.9 kg)
Size:	• 104 x 75 x 45 inch (deployed) • Cylindrical Structure: 40" dia. x 75 " long • Solar Array: 104" x 66", body mounted

Attitude Control	• 3-axis controlled, zero momentum control system
	  • Fiber Optic IRU
	  • 2 x Star Trackers
	  • Coarse Sun Senors
	  • 3-Axis Magnetometer
	  • GPS receiver
	  • Magnetic Torque Rods
	  • 4 Reaction Wheels (3 axes + skew)

Payload	• 1m panchromatic, 4m Multispectral Camera • 32 Gigabit Solid State Recorder • X-band transmiter for payload data downlink • 2-axis gimbal High Gain X-band antenna • Dedicated Payload Interface Processor
TT&C	• UHF Telemetry and Encrypted Command link • Backdoor receiver for limited commanding
C&DH	• Distributed Architecture • Dedicated CDH, ACS, and Payload 80C186 Processors
Propulsion System	• Monopropellant Blowdown • Four x 1.0 lbf thrusters
Electric Power	• Bus Voltage: 22-34 Vdc • 22 Cell Nickel Hydrogen Battery (11 CPV's) • 625 Watt Solar Array (EOL)

Timing

- January 2011: GeoEye moving to new HQ building
  - No space planned for OV-3 flight operations

- [December 15, 2010]: Begin implementation of OV-3 de-orbit plan; complete de-orbit around December 31, 2010
  - Assumes NOAA/FCC de-orbit regulatory approvals obtained

- [January 4, 2011]: Latest start date to complete OV-3 de-orbit before GeoEye HQ move

Execution Team

- GeoEye selected experienced de-orbit contractor
- Applied Defense Solutions (ADS) to perform the OV-3 de-orbit analysis and operations
- Based on experience in de-orbit precision analysis/planning and operations work
  - NASA COTS – International Space Station (ISS) Resupply
    - Re-entry flight dynamics software
    - Re-entry analysis – verified and validated by NASA/JSC
    - Monte Carlo analysis tools development
    - Re-entry documentation
  - NASA's Compton Gamma Ray Observatory
    - Re-Entry Trajectory Analysis
    - Re-entry performed by NASA/GSFC June 4, 2000
  - NASA's Tropical Rainfall Measuring Mission (TRMM) – Feasibility Study
    - Re-Entry Trajectory Analysis
    - Monte Carlo footprint analysis
  - Mir Reentry
    - Re-entry analysis
  - NASA LCROSS Lunar Impact Planning
    - Maneuvering calibration
    - Precision impact targeting
  - Debris Assessment Software

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Verification Team

- Lockheed-Martin Space Systems Company
  - Independent review by orbit / mission experts
    - Mr. R. Tanner – BS/MS Aerospace Engineering
      - » 29 years experience as orbital analyst / mission analyst
      - » Areas of Expertise: orbit adjust planning, orbit adjust modeling, engine performance modeling, orbital mechanics, operational timelines and space vehicle operations.
    - Mr. E. Meek – BS/MS Electrical Engineering / Computer Science
      - » 10 years experience as orbital analyst / mission analyst
      - » Areas of Expertise: satellite GN&C, collision avoidance, maneuver planning, proximity operations, and orbital analysis.
- Independent Auditor
  - Col. J. Lopez (Ret.)– BS/MS Aerospace Engineering
    - » 35 years experience in orbital mechanics
    - » Areas of Expertise: Orbital mechanics, space modeling, satellite tool kit

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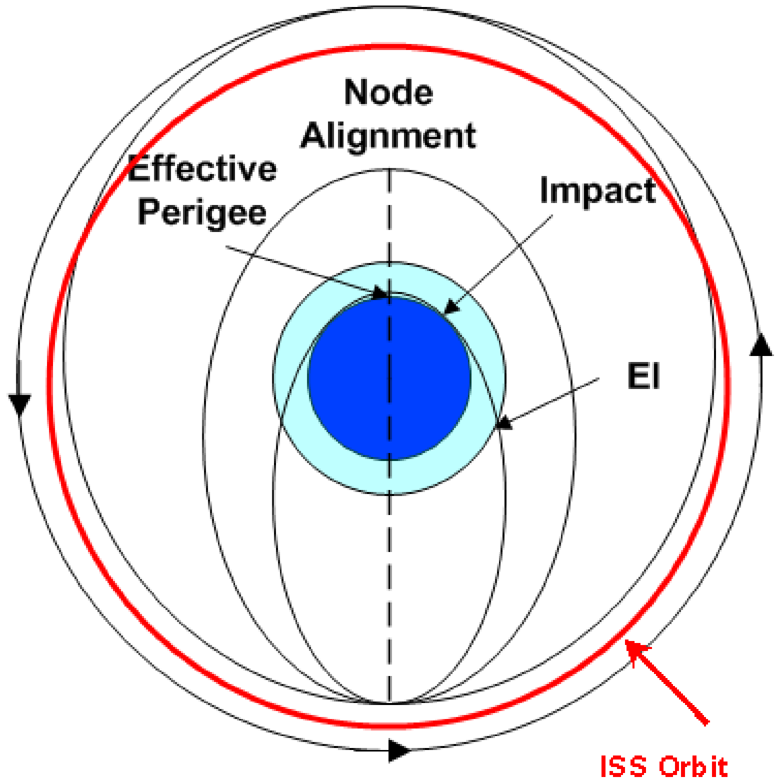
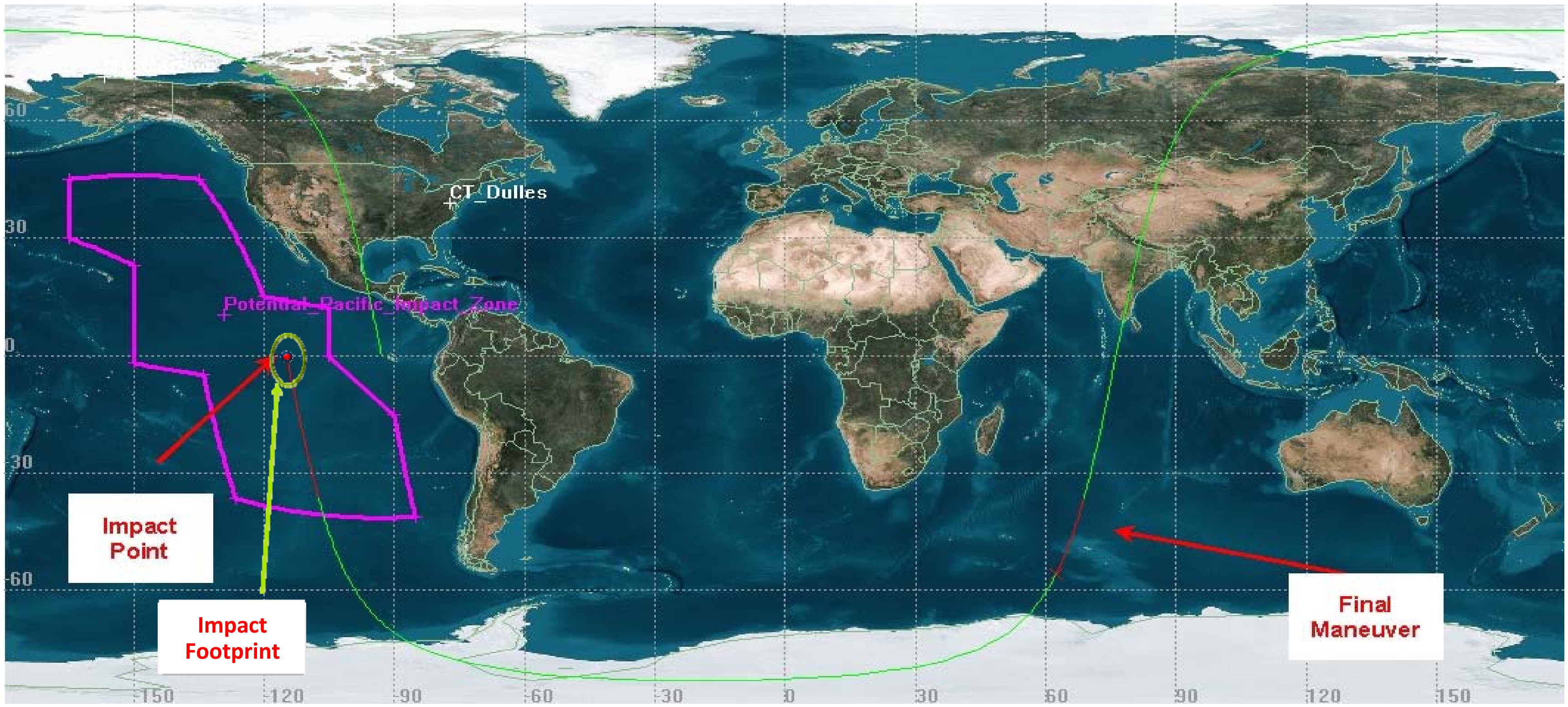
DE-ORBIT PLAN

De-Orbit Planning & Execution Process

- **Conceptual Planning – Completed**
  - Development of a conceptual scenario to showcase how OV-3 will be de-orbited
    - Understand how lowering could occur
    - Identify potential issues and start addressing them
- **Analysis – In Progress**
  - Design Trajectory Plan
  - Orbit Determination Error Analysis
  - Run Monte Carlo algorithm against Trajectory Plan
- **Operations**
  - Maneuver & Trajectory Planning
  - Verification of impact footprint after each maneuver
  - Orbit Determination
  - Conjunction Assessment
    - All burns will be coordinated with JSpOC prior to execution
  - Reporting and notification



OV-3 Final Orbit



- Impact occurs quickly after last maneuver
- Impact location chosen to be near center of potential zone area
  - If maneuver under burns or over burns, the impact point is still within potential area
- Monte Carlo analysis will provide definition of splash down footprint
  - Much smaller than the potential zone area
- Total duration from the first maneuver execution is approximately 17 days and 2 hours

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De-Orbit Plan

- The de-orbit plan contains a iterative process that includes analysis of each step prior to proceeding
  - Ensures operations follow the plan
- 2 to 3 day maneuver execution cycle
  - Plan maneuver and upload commands
  - Spacecraft performs commanded maneuver
  - Ground station contacts the spacecraft and retrieves data
    - May happen more than once depending on time duration post maneuver
  - Maneuver analysis is performed, and orbit solution is determined
  - Verify analyses of executed vs. planned maneuver
    - Details below
  - Subsequent maneuver planned and/or overall sequence plan updated as needed
  - Repeat

De-Orbit Plan
(continued)

- Two phase de-orbit plan
  - Phase 1: Safely lower orbit below the International Space Station (ISS)
  - Phase 2: Continue lowering orbit to atmospheric entry point
- Total of 11 maneuvers are expected to be performed
  - One calibration burn
    - Additional calibration maneuvers added as necessary
    - May be performed at any time prior to de-orbit
  - Ten orbit lowering burns
- Controlled, Measured, and Verifiable
  - Burn plan adjusted to account for prior event actual performance

De-Orbit Plan – Phase 1

- Phase 1 consists of 5 maneuvers
  - 1 Calibration maneuver
    - Additional calibration maneuvers may be needed based on results
  - 4 Orbit lowering maneuvers
- GeoEye will coordinate with NASA on ISS operations prior to plan commencement and prior to each Phase 1 maneuver
- Fail-safe de-orbit strategy
  - Maintain and verify safe distances away from other space objects
    - Primarily the ISS, due to the risk of human life
    - All other space objects contained in the space catalog
  - Provide significant amount of time to recover if a contingency occurs
    - Guarantees recovery time from contingencies without interfering with the ISS
  - Each maneuver contributes to de-orbiting OV-3

De-Orbit Plan – Phase 2

- 6 maneuvers
  - Maneuvers lowers orbit to atmospheric entry interface
- Eccentric orbit provides steep reentry angle
  - Increases impact location predictability
  - Eliminates risk of atmospheric skip
  - Pacific Ocean is the largest broad ocean impact area
    - Deorbit area is 700 km away from any land mass
    - Exceeds 370 km requirement
  - Exact location dependent on time and duration of maneuvers
- Reporting and notification for atmospheric entry to ground propagation
  - Notify FAA and other proper authorities
  - NOAA's assistance coordinating with outer agencies involved in deorbit requested

Risks & Risk Mitigation

- Risk: Calendar time remaining before the GeoEye move from Dulles, VA to Herndon, VA
- Mitigation: Plan in work for over a year.
  - Solicited NOAA's input
  - Plan submittal within sufficient time for USG approval. Pre-de-orbit tasks such as calibration burn, to create margin.

- Risk: To de-orbit OV-3 must pass through the ISS orbital radius
  - OV-3 orbital radius higher than ISS's, inclination is different
- Mitigation: Passing through the ISS orbital radius has been addressed in the technical approach
  - OV-3/ISS proximity avoided with proper maneuver timing and phasing
  - Plan keeps OV-3 and ISS significantly separated at the orbit crossing points
  - This approach also allows for significant time to respond to a contingency event without risk to the ISS
    - Interim OV-3 orbits calculated to provide at least 240 days until next ISS close approach

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Risks & Risk Mitigation Cont.

- Risk: Last orbit adjust maneuver for OV-3 was July 25, 2006
- Mitigation: Incorporate lessons learned from similar case this past summer (OV-2)
  - Fully understand the current state of the spacecraft and what has changed since last maneuver
  - Same ADS personnel working both missions
- Mitigation: Planning on performing a calibration burn to test the engines, ensuring that:
  - The engines fire as commanded
  - Allows for the validation of the maneuver plan and adjust as necessary
  - Verifies spacecraft pointing accuracy and stability

- Risk: Limited amount of fuel remaining
- Mitigation: Fuel usage has been modeled and will be monitored throughout trajectory planning process
  - Sufficient fuel for re-entry
  - Reserve for additional maneuvers if required

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Risks & Risk Mitigation Cont.

- Risk: Modeling uncertainties
  - Maneuver plan verses maneuver performance
  - Desired impact location verses actual impact location
  - Orbit decay
- Mitigation: Uncertainties in impact location will be analyzed in a Monte Carlo analysis
  - Monte Carlo analysis will vary maneuver performance for each maneuver as well as propagation properties
  - Bounds debris impact ellipse
- Mitigation: Planning on performing a calibration burn to test the engines, ensuring that:
  - The engines fire as commanded
  - Allows for the validation of the modeling of maneuver plan and adjust as necessary
  - Verifies spacecraft attitude control system performance

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Risk Mitigation Cont.

- Risk: The possible loss of attitude control authority as the altitude is decreased
- Mitigation: The control torques can be assessed as the altitude is lowered and a minimum altitude for positive control can be estimated based on the max torque available from the wheels

- Risk: The ability to contact the spacecraft as the altitude decreases and contact durations become shorter
- Mitigation: Impact location has also been chosen so that if the actual impact trajectory is long or short the debris will still be within the impact parameters

Addressing NASA-STD 8719.14

- Atmospheric Skip
  - Req 56580 – The final maneuver lowers periapsis altitude into the Earth's atmosphere
    - The design will be verified in a Monte Carlo analysis, with perturbed maneuvers and various atmospheric conditions
- Impact Area
  - Req 56627 – For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, 50 km from continental U.S., U.S territories, or Antarctica
    - The design chooses an impact location in the center in the potential impact zone
    - Potential impact zone meets or exceeds all distance requirements
  - Req 56628 – For controlled reentries, the product of the probability of failure of the reentry burn and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001
    - Further analysis required, but related to the distance requirement

Summary

- GeoEye has developed a prudent plan for the de-orbit of OV-3 with ample safeguards and verification
- Risks are clearly identified and mitigated
- NOAA's assistance requested to ensure GeoEye notifies and coordinates with all appropriate agencies
- GeoEye is ready to execute upon USG approval