RADARSAT-2 and RCM Conjunction Analysis and Mitigation Operations

Casey Lambert (MDA), Camille Decoust (MDA), Bryan Cooke (SED)
Presentation Outline

- Introduction to RADARSAT-2
- Collision Avoidance (COLA) Strategy
- Conjunction History
- Advanced Screening
- RADARSAT Constellation Mission (RCM)
- Conclusions
Introduction to RADARSAT-2

- Launch: December 14, 2007
- Routine Operations: April 27, 2008
- C-Band Synthetic Aperture Radar (SAR) mission
- 20 beam modes
  - Resolution from 1 m to 100 m
  - Scene size from 18 km to 500 km

**Design life of 7 years**

**Acquired over >500,000 images**
Introduction to RADARSAT-2

**Orbit**

- Sun-synchronous, dusk-dawn orbit
- Altitude of 781 - 797 km
- 24 day repeat ground-track (343 orbits)

<table>
<thead>
<tr>
<th>Orbit parameter</th>
<th>Value</th>
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<tbody>
<tr>
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<td>Inclination</td>
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<tr>
<td>Argument of perigee</td>
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</tr>
<tr>
<td>LTAN</td>
<td>18:01</td>
</tr>
</tbody>
</table>

Source: STK, AGI
Introduction to RADARSAT-2

Propulsion

- Six 1-N Reaction Control Thrusters
  - Four in nadir direction (+Z)
  - Two in velocity direction (-X)
    - Used alternatively for drag make-up and COLA maneuvers

**Fuel Budget**

<table>
<thead>
<tr>
<th></th>
<th>Original (kg)</th>
<th>Current (kg)</th>
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<td>Margin</td>
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</tr>
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</table>

**ORIGINAL FUEL BUDGET DID NOT INCLUDE ANYTHING FOR COLA MANEUVERS**

**CURRENTLY ENOUGH FUEL MARGIN FOR EXTENSIVE COLA MANEUVERS AND DE-ORBIT**
Collision Avoidance Strategy

- RADARSAT-2 was launched with no formal collision avoidance strategy
- Orbit is now in one of the most populated debris zones
  - 2007 - Fengyuin-1C satellite destroyed (2600 pieces of trackable debris)
  - 2009 - Iridium and Cosmos collision (1250 pieces of trackable debris)
  - 2015 - US weather satellite, DMSP-F13, exploded (147 pieces of trackable debris and RADARSAT-2 identified as one of ten at-risk satellites)

- First conjunction alert received in March 2009 from Canadian Space Agency (CSA)
- Email communication with JSpOC to confirm orbit data
- Initial effort made (2009) to develop effective procedure for analyzing and assessing risk

Source: NASA UNOOSA Report, 2011
Collision Avoidance Strategy

**Originally**
- Risk assessment based on miss distance and uncertainty
- Collision avoidance box – miss distance of 200 m radial and 1000 m in-track and cross-track
- Data quality box – combined covariance must be below a certain threshold

**Currently**
- Primary assessment based on Probability of Collision (PoC)
- Data quality is still an important factor
- Consider other factors including PoC sensitivity, geometry, Time to Closest Approach (TCA)
Collision Avoidance Strategy

**COLA Tools and Notification:**

- Notification of close approaches comes from JSpOC Conjunction Data Messages (CDM)
  - Recently switched from Emergency Screening to Advanced Screening
- Two different tools to poll SpaceTrack website
  - CRAMS – Canadian Space Agency (CSA)
  - JAC – Centre National d’Etudes Spatiales (CNES)
- CRAMS filters CDMs based on PoC, miss distance, and time to TCA
  - Alerts via message to control-room screen, sends email to operations team
  - Email includes an Excel spreadsheet with CM data and value-added analysis results including PoC and delta-V tradespace
- JAC sends alerts by email for all new conjunctions
  - Flexible in-depth analysis tools frequently used
Collision Avoidance Strategy

JSpOC www.Space-Track.org

CRAMS - CSA
- Regularly polls Space-track website
- Sends Excel spreadsheet by email with conjunction analysis
- Sends alert to screen in Control Room

JAC - CNES
- Regularly polls Space-track website
- Sends notification email
- Provides several interactive tools to assess risk and plan maneuver

Mission Operations – MDA
- Receive alerts/CDMs from redundant systems
- Assess risk using JAC/CRAMS interactive tools
- If risk is high and JSpOC tracking data is good, plan a maneuver (ΔV, time of burn) using JAC
- ~8 hours notice needed to plan/execute emergency maneuver
- To minimize deviations from ground-track, follow-up maneuvers are planned/executed shortly after conjunction if necessary
Conjunction History

- As of October 6, 2016:
  - 11 collision avoidance (COLA) maneuvers performed

<table>
<thead>
<tr>
<th>#</th>
<th>COLA Date</th>
<th>PoC</th>
<th>ΔV  (cm/s)</th>
<th>Object</th>
<th>Maneuver Time (hrs before TCA)</th>
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<tr>
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<td>3</td>
<td>Oct. 6, 2011</td>
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<td>6</td>
<td>Jan. 30, 2014</td>
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<td>7</td>
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<td>Cosmos 2251 Deb</td>
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Conjunction History

- Retroactive analysis using PoC instead of miss distance, reveals three maneuvers were performed for low risk cases

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</table>
Conjunction History

July 1, 2013 – COLA Maneuver #5

- First maneuver ($\Delta V = 0.17$ cm/s) performed 32 hours before TCA, based on miss distance of 110 m
- Expected in-track miss distance to increase to 270 m
- 16 hours before TCA, new CDM arrived with in-track miss distance of only 127 m
- Second COLA maneuver ($\Delta V = 2.0$ cm/s) performed 6 hours before TCA
- PoC was not known at the time, but looking back $\text{PoC} < 1 \times 10^{-10}$
- In hindsight, second COLA maneuver was not necessary
## Conjunction History

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<th>PoC</th>
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<td>1066</td>
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</tbody>
</table>

**Looking Back:**

22 events with \( \text{PoC} > 1 \times 10^{-4} \) maneuvers performed for 8

**Not Inclined to Maneuver When Secondary Uncertainty is Large**
Advanced Screening

- Signed up for JSpOC Advanced Screening in August 2016

**Advantages**
- Longer lead times for high risk conjunctions
- More conjunction history available at decision time
- Better understanding of limitations of JSpOC data

**Disadvantages**
- Longer lead times for high risk conjunctions
- Many more notifications received = more noise
- Better understanding of limitations of JSpOC data
Advanced Screening

Example of COLA maneuver with Advanced Screening results

- Routine maneuver executed 137 hours prior to TCA
  - CDMs 1 to 5 used pre-burn tracking data
  - CDM 6 used both pre-burn and post-burn tracking data
  - CDMs 7 to 19 used post-burn tracking data

Image from JAC
Advanced Screening

- First planned COLA maneuver based on CDM 7 to 12, to be executed 43 hours prior to TCA
- CDM 13 and 14 showed shift in primary position and planned maneuver was cancelled
- After CDM 15, decision was made to perform COLA maneuver 19 hours prior to TCA
RADARSAT Constellation Mission (RCM)

- Earth Imaging Mission – Synthetic Aperture Radar
- Developed by MDA for the Canadian Space Agency (CSA)
- Mission Objectives:
  - Support the operational requirements of Government departments
  - Will provide greatly improved operational capability and ensure data continuity for existing users of RADARSAT-2
- Main application areas are:
  - Maritime Surveillance (ice, oil, wind and ship monitoring)
  - Ecosystem monitoring (forestry, agriculture, wetlands, coastal changes)
  - Disaster management (mitigation, warning, response, recovery)

12 day repeat cycle per satellite
Constellation repeat period of 4 days
RADARSAT Constellation Mission (RCM)

**Orbit**
- Dusk-dawn sun-synchronous frozen orbit
- Repeat cycle – 12 days (179 orbits)
- Four day revisit

**RCM Orbit Characteristics**

<table>
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<tr>
<th>Characteristic</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Altitude</td>
<td>593 km</td>
</tr>
<tr>
<td>Inclination</td>
<td>97.74 deg.</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>0.00106</td>
</tr>
<tr>
<td>LTAN</td>
<td>18:00</td>
</tr>
</tbody>
</table>

- Requirement is to maintain orbit within a 100 m radius tube
Propulsion
- Six 1-N thrusters on –x panel
- All are canted +/-45° off –x axis
- No slew for drag make-up maneuvers
- Slew required for inclination maneuvers
RADARSAT Constellation Mission (RCM)

- Orbit control simulations suggest high frequency of maneuvers required to maintain tube
  - Solar maximum – one or more per day
  - Solar minimum – one maneuver every two to three days
RADARSAT Constellation Mission (RCM)

**Challenges**

- Due to high frequency of maneuvers, JSpOC tracking data may never be reliable
- Must rely on our predicted orbit data
  - New maneuvers planned twice a day so predicted orbit always changing

**Questions**

- How often to send ephemeris to JSpOC?
- Send predicted ephemeris or reference orbit or both?
Conclusions

Mission level

- COLA operations evolved from zero at start of mission
- Tools and expertise built up slowly over time
- Recently switched to Advanced Screening, which required adjustment in Operations

Tools

- JSpOC notification – heavy reliance, single-point failure
- CRAMS – valuable for notification, pre-screening, and analysis
- JAC – valuable for notification and analysis
Conclusions

Lessons Learned

- Using miss distance and uncertainty to assess risk resulted in occasional maneuvers for low PoC events
- PoC on its own leads to more maneuver candidates, but we avoid maneuvering when uncertainty is excessive

RCM

- Currently developing ground system for operations
- High frequency of maneuvers poses new challenges for operations
Acknowledgements

I would like to thank other people involved in developing and implementing RADARSAT-2 collision avoidance strategy:

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- Telesat – John Holland
- MDA – Camille Decoust, Philippe Rolland
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