Operational Collision Avoidance at ESOC


9.11.2018
Outline

• Introduction
  • Collision avoidance at ESA
  • Avoidance manoeuvre reaction threshold
• Current process
  • Drivers
  • Back-end database and tools
  • Front-end
  • Process control
• Statistics
• Summary
Covered missions

ESA's MASTER-2009: Spatial Density of objects > 10cm [1/km³]

Other missions:
- ERS-2
- Envisat
- Proba-1,2,V
- Cluster-II
- XMM
- Galileo/Giove
- METOP-A/-B/-C
- MSG-3/4
- Artemis
At varying support level

Altitude [km]
Avoidance manoeuvre reaction threshold

- Requires a management decision
- Trade ignored/accepted risk vs. risk reduction
- Estimate cost i.e. manoeuvre frequency for selected reaction threshold
  - Depends on orbit uncertainties of the secondary (chasing) objects
- ESA’s ARES tool, part of DRAMA SW suite, https://sdup.esoc.esa.int
- Need consistent setup of operational and analysis approach (SC area)
- Typical managerial target function:
  - avoid 90% of the accumulated collision probability
- Typical result:
  - Threshold of $10^{-4}$ one day to TCA using encircling sphere
  - for 90% risk reduction at cost of 1-3 manoeuvres per year

Assessment of Risk
Event Statistics
https://sdup.esoc.esa.int
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Operational process - drivers

- CDM information for enlarged screening volumes used as baseline
  - CDM superior to TLE in accuracy and its knowledge
- Automation of CDM processing due large number of CDMs
- Including combined/mixed processing using OO information on target and JSpOC CDM information on chaser ("Mini-Catalogue")
- Interface to mission control teams streamlined
  - Simplifying data provision and interpretation
  - Providing concise status display to missions
- Internal coordination within collision avoidance support team simplified with help of a conjunction management tool and manoeuvre monitoring system
- Overall driver: support of task automation thereby reducing process risk
Collision avoidance process

- JSpOC
  - Automated retrieval
  - CDMs

- Flight Dynamics
  - Interface monitoring
  - Target orbits & covariance

- Debris Analyst
  - SCARF/Visualisation

- SC Operators
  - Flight Dynamics
  - Alert SMS

- "MiniCat" based on CORAM and CRASS

- CORAM
  - DISCOS object properties
  - Solar & geomag activity

- ODIN
  - Orbit tracks
  - Chaser orbits & covariance

- Automated retrieval
  - CORAM

Risk assessment and manoeuvre planning

Collection of Algorithms for collision risk assessment among two objects (CORCOS):
- Alfriend Akella
- Maximum Probability
- Covariance scaling
- Algorithms for low delta-v approaches
- Non-spherical objects
- Monte-Carlo

Support of manoeuvre planning (CAMOS)
- Minimising risk or maximising (radial) separation at TCA
- Varying size, direction, epoch
- Constraints (bounds, fixed, free)
- Parametric or evaluation mode
- Trajectory parameters (latitude/longitude, eclipses, SAA crossing)
Web-frontend to CDM/Event database

- Mission dashboard view
- Sortable event list
- Escalated events
- Switch between screening options
- Last update times
- Informative charts
- Event view
- Analyst view
- Actively development
Conjunction visualisation

- Web-based 3D dynamic visualisation of close approaches: Earth, trajectories, covariance ellipsoids, CDM data, ...
- Interactive control of camera position, view angle, time, zoom, ...

![Conjunction visualisation diagram](image_url)
Manoeuvre Monitoring System

- Process control and tasks allocation system
  - “ticket” per manoeuvre
  - Assignee management
  - Status transitions
- Views:
  - Status filter
  - Gantt
  - Calendar
  - Wiki (procedures)
- Redmine-based
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Evolution of supported missions
Classes of chasers

Year

2015 2016 2017 2018

Percentage of conjunctions

0 20 40 60 80 100

Payload
Rocket Debris
Iridium 33 debris
Fengyun 1C debris
Payload Fragmentation Debris
Payload Mission Related Object
Rocket Mission Related Object
Unknown
Rocket Body
Rocket Fragmentation Debris
Cosmos 2551 debris
Payload Debris
Frequency of events per risk level

- Highest risk of all CDMs for a given event
- CDMs received from JSpOC (SP vs SP)
Time evolution of high risk levels
Summary

• **Well-established collision avoidance process for more than 15 years**
  • supporting several own and third party missions
  • Excellent collaboration with USSTRATCOM/JSpOC for years

• **Operational toolchain evolved significantly to meet growing needs**
  • Approach centred around database of processed CDMs
  • Automation of CDM mixed CDM/OO processing (needed due to large number of CDMs)
  • “minicat”: flexibility, manoeuvre support with short turn-around times for small delta-v
  • Web-based interfaces for visualisation/coordination (Space Debris experts and FCT/FDT)
  • Support tools for specific analysis in back-end
    • Improved/expanded risk assessment and avoidance manoeuvre planning
    • Maintain capability to acquire dedicated tracking

• **Statistics show that the challenges differ over time and for each orbit type**
  • Feedback to operational procedures
Thank you!
Database of conjunction events

- **Central DB** for all automatic and manual processing
- Grouping by conjunction event ID: unambiguous description by 2 conjunction partners and TCA
- **DB content**
  - **CDM data** obtained from JSpOC
    - Augmented by collision risk and other analyses results/sources
    - Automated insertion and standard analysis
  - "Mini-Catalogue" screening results against operational ephemeris/cov.
    - Same data model as CDM (but different originator)
    - Automated insertion and standard analysis after each update
  - **Scenario results** for collision avoidance
    - Same data model as CDM (but different originator, multiple eph.)
    - Fed manually by analyst
SCARF - Event view

- Core event data (objects, TCA, CDMs)
- Trend plots or tabular view
- Status (ownership, escalation level)
- Single CDMs display
- E-mail / screening trigger
- Reporting: statistics on high risk events
- CAMOS results (plots)
SCARF – future enhancements

- Multi-mission dashboard view
- Event group view, for connected events (i.e. repeating conjunctions)
- Add activity triggers: configure and launch CORAM runs
“The aim of DRAMA is to support the objectives of the ESA Space Debris Mitigation Requirements by enabling satellite programs in Europe to assess their compliance with the recommendations contained in that document.”

**ARES**
Assessment of Risk Event Statistics:
Analyze requirements for collision avoidance manoeuvres expected for a mission.

**MIDAS**
MASTER (-based) Impact Flux and Damage Assessment Software:
Modeling of the collision flux and damage statistics for a mission.

**OSCAR**
Orbital Spacecraft Active Removal:
Analyze disposal manoeuvres of spacecraft and compliance with ESA’s mitigation requirements.

**CROC**
Compute projected cross-sectional areas of complex bodies

**SARA**
*Spacecraft Entry Survival Analysis Module (SESAM):*
Modeling the re-entry of a spacecraft.

*Spacecraft Entry Risk Analysis Module (SERAM):*
Assessing the on-ground risks of objects surviving re-entry.
DRAMA/ARES

- Providing statistics related to the collision risks for a mission.
- Determines required CAM fuel mass
- Flux based on MASTER-2009
- Results **statistical**, based on “average encounters”
- Four functionalities:
  - Annual collision probability
  - Manoeuvre rate, false alarm rates, risks as a function of accepted collision probability level (ACPL)
  - Estimate DV to perform CAMs
  - Estimate propellant mass for CAMs

**Risk reduction**: risk actually removed by manoeuvres

**Residual risk**: risk not intended to be reduced (although it would be possible)

**Remaining risk**: risk which cannot be reduced (caused by undetectable objects) + Residual risk
ARES example

Envisat-like: 780 km altitude polar, 26 m diameter, chaser limit size 10 cm

Catalogue covariance as per CDM

Catalogue covariance as per TLE

Higher risk reduction for same ACPL, in particular for $10^{-4}$ almost all risk reduced with CDM accuracy, only half the risk with TLE accuracy
ARES example - manoeuvres

With TLE accuracies: Much higher number of manoeuvres for same ACPL. Risk reduction 50% at ACPL of $10^{-4}$ at cost of approx. 30 manoeuvres!