Feasibility Study of Active Debris Mitigation for Mega Constellations
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- ADR Operational concept
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Study logic
Study

ITT ESA 8815 Managed by Robin Biesbroek

GSP funded contract

Thales in France and Thales in Italy team

- Carole Billot, Raphael Hache, Isabel Moore, Andrea Sita
- Mauro Pasquinelli, Maria Valeria Catullo, Simona Ferraris

- 12 months study
- KO end April 2017
Logic

Phase 1: Constellations identification
- Constellations defined by ESA
- TAS marketing inputs
- Task 1A: Market analysis
- 4 Constellations representative of the future

Phase 2: Constellations/ADR trade-off
- 4 Phase 1 Constellations
- ADR studies background
- Operators business plan
- Task 1B(C/D): Reliability / Collision analysis; scenarios identification; Preliminary cost analysis for each scenario Market assessment
- 2 Constellations where ADR is a promising SDM solution

Phase 3: Consolidation of ADR business plan
- 2 Constellations defined with ESA
- Preliminary ADR constraints
- D4R studies background
- ADR conceptual Design
- Constellation design impact
- Task 2(A/B): Mission profile; service module definition; technologies trade-off Assess programmatic and cost

Phase 4: Recommendations
- Operators feedback
- SDM identified solutions
- Task 2C: Prepare recommendations for updates of SDM standards
- Recommendations for updates on Debris Mitigation applicable policies

Creativity sessions
Reference constellations

Goal to have a portfolio with significant differences on the following key parameters:

- Number of satellites
- Altitude
- Type of propulsion

Others parameters deducted from the knowledge of the existing projects

MEGA 1000
- 1080 sat of 200 kg – Elec
- 20 planes 54 sat – 85°/1100 km
- 20 Launch/year - 18sat/LV

MEGA 200
- 200 sat of 1000 kg - Chemical
- 10 planes 20 sat – 85°/1100 km
- 5 Launch/year – 10 sat/LV

TAS 3200
- 3200 sat of 380 kg - Chemical
- 2*32 planes 50 sat – 53°/820 km
- 26 Launch/year – 25 sat/LV

TAS 100
- 108 sat of 1200 kg – Elec
- 6 planes 18 sat – 90°/1400 km
- 6 Launch/year – 8 sat/LV
Mitigation methods

• Problematic & ADR functional
Problematic of megaconstellation operational lifetime
Solution

- **Reliability increase**
  - Design
  - Redundancy
  - In-space maintenance
  - EOL kit on-board

- **Deorbitation and natural re-entry**
  - 25 years
  - 5 years

- **Reorbitation**

- **Deorbitation and controlled re-entry**

- **Deorbit kit plugged by chaser/remover**
ADR to reduce collision risk and debris generation

Satellites May Experience Collisions ➔ Collision Risk Analysis

Satellites May Experience Internal Failures ➔ Input: 10% of Probability of Loss of Disposal/CAM functions

Large numbers of satellites, Long Infrastructure Time ➔ Higher Risk

Dynamic issue
Any collision or critical failure modifies the environment, increasing the risk.
**ADR reference operational activities**

\[ \text{cost}_{\text{ADR}} = N_{\text{removers}} \cdot \text{cost}_{\text{remover}} + N_{\text{launchers}} \cdot \text{cost}_{\text{launcher}} + \text{cost}_{\text{GS}} + \Delta \text{cost}_{\text{constellation}} \]

Cost of ADR is the cost of keeping clean the operational orbit

Different strategies w.r.t. Strategies, Technologies and allocation to:
- Constellation system
- ADR system
Collision Risk

• With Debris
• Among constellation
Risk Evaluation: ESA MASTER 2009 Environment

Evaluation of the risk of losing satellites of constellation caused by impact with untrackable and trackable debris

Untracked debris:
Risk of losing the satellites caused by an impact with untrackable debris (diameter <10cm):
- failure of internal items
- failure of external items

Tracked debris:
- Risk of losing the satellites caused by an impact above the catastrophic threshold (40 J/g)

Debris environment vs Altitude (ESA MASTER 2009)

<table>
<thead>
<tr>
<th>Debris environment</th>
<th>MEGA-1000</th>
<th>MEGA-200</th>
<th>TAS-3200 (780km)</th>
<th>TAS-100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-catastrophic (operational)</td>
<td>7.94E-04</td>
<td>3.18E-03</td>
<td>2.96E-03</td>
<td>2.4E-03</td>
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<tr>
<td>Catastrophic – Operational</td>
<td>3.57E-06</td>
<td>1.35E-05</td>
<td>5.42E-05</td>
<td>5.39E-06</td>
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<tr>
<td>Catastrophic - Deorbiting</td>
<td>3.36E-06</td>
<td>3.48E-05</td>
<td>9.46E-06</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Evaluation of Collisions

Non-catastrophic (first set)

Such number can be mitigated by providing adequate MMOD protection and physical configuration

Note: Using 2009 MMOD Environment → Very optimistic

Catastrophic collisions
– They depend on the amount of defunct or decaying satellites → influenced by ADR and time for decay

TAS3200 – amount of defunct satellites on operational orbit

TAS3200 – amount of decaying satellites, comparison of decay strategies

Probability of catastrophic collision between 2 satellites among the constellation not included

(90% of satellites decaying)
Mission Overview

- Mission analysis of the 4 constellation cases
- Launcher selection
- Removers selection
# ADR Space and Launch Segment Strategies and Options

## Space Segment configurations & number of services

<table>
<thead>
<tr>
<th>Specific Characteristics</th>
<th>Chemical One-shot</th>
<th>Chemical Multi mission</th>
<th>Electrical Multi-mission</th>
<th>Electrical with DOK</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Net or simplified capture system</td>
<td>Robotic Arm</td>
<td>Robotic Arm</td>
<td>Robotic Arm DOK installation (higher complexity)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of services, Soyuz</th>
<th>EP Deorbit without DOK</th>
<th>EP Deorbit with DOK</th>
<th>EP Graveyard</th>
<th>CP Deorbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mega 1000</td>
<td>25</td>
<td>17</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>Mega 200</td>
<td>N/A (1)</td>
<td>(Controlled re-entry with DOK) 9</td>
<td>13</td>
<td>(Controlled re-entry) 1</td>
</tr>
<tr>
<td>TAS3200</td>
<td>(uncontrolled) 35</td>
<td>22</td>
<td>N/A (11)</td>
<td>(uncontrolled) 14</td>
</tr>
<tr>
<td>TAS 100</td>
<td>N/A (1)</td>
<td>(Controlled re-entry with DOK) 9</td>
<td>16</td>
<td>(Controlled re-entry) 1</td>
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</table>

## Launch strategy options:

- **One remover per launcher**
  - Launch when needed

- **Batch of Removers**
  - Stacked launch of removers, moving in different planes with RAAN drift

- **Shared Launch with constellation**
  - The remover is sent together with constellation satellites in predisposed planes. Favourable for size of spacecraft comparable with constellation sats

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**Thales Alenia Space Internal**
Trade-off Mitigation solution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Passive debris mitigation</th>
<th>Active debris mitigation</th>
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<tbody>
<tr>
<td>Number of additional launches</td>
<td>Constellation design modification</td>
<td>ADR single shot</td>
</tr>
<tr>
<td>Additional mission control functions complexity index</td>
<td>Constellation increase of reliability</td>
<td>ADR multi removal</td>
</tr>
<tr>
<td>Number of additional Ground Stations &amp; Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Servicer complexity index</td>
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<td>Added cost for Constellation Satellites</td>
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<td>Increase of single satellite lifetime because of increase of available propellant (no self-disposal)</td>
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<td></td>
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<tr>
<td>Potential Compliance with future regulations</td>
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<td>Additional Services</td>
<td></td>
<td></td>
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<td>Reduction of constellation size (Reduction of constellation sat. needed)</td>
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<td></td>
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<tr>
<td>Long term sustainability of the orbit and decrease of CAMs because of failed satellites in the operational orbit which cannot be removed.</td>
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<td></td>
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<tr>
<td>Added cost for removers (as % of the constellation cost)</td>
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MEGA 1000

TAS 3200

ESTEC Industrial days
19/06/2018
ADR Mega 1000
Operational concept
ADR Trade-off
ADR MEGA 1000 Configuration

Operations

ADR launch within the population of the constellations
- Verification IOT
- Waiting phase on optimal orbit before rescue
MEGA1000: Collision Risk Mitigation Effects

Effects for the space environment:
- 20% more satellites (incl. ADR) decaying at lower orbit
- Drastic reduction of long-term pollution

Effects for the constellation:
- 10% more operational satellites
- No failed satellites close to operational orbit (reduction of risk of constellation loss and of CAM needs)

With ADR + Less Decay Time
(25y→5y)

With ADR

No ADR
MEGA1000: Evaluation with the 2009 MMOD environment

Preliminary calculations show that one catastrophic collision could be prevented (with ESA MASTER 2009 env.).
**ADR MEGA 1000**

*Overall Architecture*

**Wet Mass under 200 kg**

- Compatible with rest of constellation

<table>
<thead>
<tr>
<th>SVM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Propulsion</strong></td>
<td>Electric - ARDE 6.2 - 2 * 13mN = 39mN</td>
</tr>
<tr>
<td><strong>Architecture</strong></td>
<td>Derived from OneWeb</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>2 * SA wing</td>
</tr>
<tr>
<td><strong>Avionics</strong></td>
<td>SMU with LEON2/3 FT Processor</td>
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<tr>
<td><strong>Payload</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Capture</strong></td>
<td>2 Net Capture Systems</td>
</tr>
<tr>
<td><strong>RDV sensors</strong></td>
<td>2 * 2D camera</td>
</tr>
</tbody>
</table>
ADR TAS 3200
Operational concept
Collision Risk Mitigation Effects for TAS3200

**No ADR**

- ~10% more satellites decaying at lower orbit
- Drastic reduction of long-term pollution

**With ADR**

- Additional ADR system
- Limited number of failed satellites close to operational orbit (reduction of risk of constellation loss and of CAM needs)

**With ADR + Less Decay Time (5y→1y)**

Effects for the space environment:
- Increased number of satellites decaying at lower orbit
- Reduction of long-term pollution

Effects for the constellation:
- Additional ADR system
- Limited number of failed satellites close to operational orbit (reduction of risk of constellation loss and of CAM needs)
Effect on catastrophic collisions (with 2009 MMOD environment)

From > 10 collisions to ~0.3 collisions in 50 years (with ESA MASTER 2009 env.)
ADR TAS 3200 Trade-off

Soyuz Launch

Evaluation of number of services per launch

- Launcher performance
- Relative cost of the ADR
- Electric versus Chemical propulsion
- Reliability
- Accommodation under Soyuz fairing
- Number of services per ADR
- ADR lifetime

1500 kg ADR Main electric propulsion

Sensitivity analysis supports selection of:
- Thrusters -> QT6
- Reliability -> 0.95
- Re-entry -> non-controlled
- Accommodation -> stack

ADR TAS 3200 Trade-off

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# ADR TAS 3200

## Overall Architecture

| SVM | Propulsion | Hybrid  
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<tr>
<td></td>
<td>Electric</td>
<td>MT-Aerospace L-XTA 3001 - 2 * QTB thruster</td>
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<tr>
<td></td>
<td>Chemical</td>
<td>MT Aerospace PTD-222I - 18 * 1N</td>
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<tr>
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Conclusion
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For the 4 cases of mega-constellations considered in this study, the ADR solutions which give the best positive impact vs the initial baseline are:

- ADR one shot based on constellation platform for MEGA 1000
- ADR EP multi-mission with Soyuz for TAS 3200
- ADR impacts the operators business plan up to 30%
- For very large constellation, it is mandatory
- At one step, the revenue will stop because of catastrophic collision

- Constellation reliability increase is a favorable trend
- Analogies can be found with on-ground situation for Electrical and Electronic Equipment
  - Subjected to individual handling and management
  - Regulatory requirements exist for Waste EEE
  - For those requiring individual operations, end-of-life logistic cost is in the range from 20 to 30%.
Recommendations

Current regulations are not relevant with the emergence of mega-constellations

- Sustainable low earth orbit cannot be maintained with the 25 years decay orbit rule
- Recommendation to change Standards and Policies to prevent orbits becoming overpopulated with debris and to drive the constellation operators to use space responsibly and sustainably
- Solutions have to be considered at constellation level

Use of ADR for EOL constellation management

- Is necessary when the number of failed satellites in the operational orbit becomes unmanageable
- Is necessary to keep long-term business without endangering space activities
- Needs Operators/Industry to anticipate and « prepare » satellite
- Needs ADR technology ready with sufficient TRL
Thanks