ACTIVE DEBRIS REMOVAL:
CURRENT STATUS OF ACTIVITIES IN CNES

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Content

Introduction
1. High Level Requirements
2. System Architectures Options
3. ADR High Level Functions
4. Support studies
5. Conclusions
Kessler syndrome

- Identified theoretically by Don Kessler and Burt Cour-Palais in 1978

- Four sources of space debris:
  - Mission Related Objects, Break-up, Aging, Collisions
  - When the “collision” source becomes larger than the “atmospheric cleaning”, natural increase of orbital population
  - Critical density varies strongly with the orbit altitudes:
    - Most critical zones in LEO, between 700 and 1100 km, highly inclined (including SSO)

- Potential need for Active Debris Removal (ADR)

- International problem
  - Sources of debris from every space-faring nations
  - No nation shall nor can solve the problem alone

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Introduction

- Logic of the activities

  - Consolidate the need, if any, to perform ADR in addition to the proper application of mitigation rules,
  
  - Identify the corresponding system solutions,
  
  - Identify the required technologies and clarify the corresponding development constraints,
  
  - Identify some reference scenarios, with solutions precise enough to evaluate the programmatic consequences,
  
  - Propose a scheme at international level to initiate such operations if, once again, they appear compulsory.
1. High Level Requirements

- **Number of debris to remove**
  - Studied at worldwide level since more than a decade
  - Reference studies from NASA Orbital Debris Office
    - Need to remove 5 large debris per year to stabilize the environment
    - Numerous robustness and sensitivity studies
  - Cross-check led by 6 other IADC delegations
    - Same hypotheses, model and mitigation
      - 100% explosion suppression
      - 90% success of end of life measures
    - Different tools
    - IADC Action Item 27.1
    - Coherent results, and confirmation of the need to remove 5 large objects, at least, per year
    - “new mitigation measures, such as Active Debris Removal, should be considered”.

- **Highest level priority for CNES:**
  - Development by Toulouse Space Center of a predictive tool, with different modeling, enabling robustness studies
  - Tool MEDEE is now available and will be presented in Darmstadt

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1. High Level Requirements

■ Size of Debris

♦ Removing large debris enables a long term stabilization of orbital environment

♦ Operators’ main concern is short term risk induced by small debris

♦ Examples:
  • Risk on Spot 5 (CNES) ¹
    - Mission loss 0.3% per year
    - Main influence of < 5 cm
  • Risk on Sentinel 1 (TAS-I draft) ²
    - Mission loss 3.2% over lifetime

❖ Large integer objects may not be the only ones to remove:
  • Different concerns
  • Very different solutions

¹ P. Brudieu, B. Lazare, French Policy for Space Sustainability and Perspectives, 16th ISU Symposium, Feb. 21st, 2012
1. High Level Requirements

- **Stabilization of environment**
  - Current recommendations aim at stabilizing the orbital environment
  - But do we really want a stabilization?
    - Is the current risk considered acceptable by operators?
    - Could it be increased? To which level?
    - Should it be decreased?
    - When should we act? Now? In 20 years time?

- **Acceptability of random reentry**
  - Can ADR operations lead to random reentry of large dangerous objects?
    - Casualty threshold = $10^{-4}$ per operation
    - By definition, ADR shall be done on large objects = Dangerous
  - Random reentry would be illegal according to French Law on Space Operations
  - However, it improves both debris situation and casualty risk
  - Action on-going at CNES Inspector General level
  - Action to be led within IADC WG4
2. System architecture options

- **Debris playground**
  - **Definition of an “interesting target”:**
    - Function of size – mass – orbit density
    - Function of the debris population in one given zone in case of multiple debris chasing
      - Minimization of the mission \( \Delta V \)
      - Minimization of global mission duration
    - **Could be function of criticality of random reentry:**
      - Random reentry not acceptable if casualty > \( 10^{-4} \)
      - To be confirmed at national level, then at IADC level
      - Typical threshold in size: 500 to 1000 kg
      - Could be antagonist with finality of ADR
      - Only solution with Direct Controlled Reentry are studied today
    - **Could be function of nature of debris**
      - Launcher stages pose potentially less problems than Satellites (definition of a debris, confidentiality, mechanical robusteness…)
  - **Not function of country**
    - Deliberate choice to consider for the operational phase all debris
      - International problem, tackled at international level
  - **Identification of the most interesting zones:**
    - Initial sorting identified 10 critical zones
    - Refined subdivision into coherent sub-regions

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1. JC. Liou, *The top 10 Questions for Active Debris Removal*, #S1.3, 1st European Workshop on ADR, Paris, June 2010
2. System architecture options

Strategy for successive debris removal

- Numerous possible schemes:
  - Single shot: one chaser, one debris
  - Multiple debris: one chaser, several debris
  - Multiple debris: one carrier + multiple deorbiting kits, one debris per kit
  - Multiple debris: multiple chasers in one launch, several debris each

- No obvious solution:
  - Cost of the launch → Dedicated or Piggy-back
  - Size of the launcher
  - Cost of the chaser “functions” → Effect of mission rate
  - Sizing of the multiple debris chasers → Global mission ΔV

- Analyses performed by Astrium, TAS-F and Bertin under CNES contract
  - Results are still differing!
2. System architecture options

Among the most promising solutions:

- Considered for the Operational phase
  - First Generation may show different optimum
- Large launcher with multiple chasers, each delivering multiple kits

- Big launcher (e.g. Ariane 5) launching N different multi-debris OTV's
  - Group is divided into N RAAN regions
  - Each OTV targets a certain part of the group
  - Lower launch staging orbit generates a shorter wait

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1 P. Couzin, X. Rozer, L. Stripolli, Comparison of Active Debris Removal Mission Architecture, IAC-12-A6.5.5, Naples 2012
2. System architecture options

- From CNES Internal Study OTV
  - Removal of 5 Ariane upper stages
  - Autonomous kit achieves capture
  - Similar targets
  - +/-200 km Δa → +/-36° /yr drift capacity
  - Targets visited in increasing order of inclination → cumulated 0.6° Δi

→ Mission duration depends on launch date
→ Adjust drift allotted ΔV to target distance

1. E. Pérot, Active Debris Removal Mission Design for LEO, #479, 4th EUCASS, St Petersburg July 2011
3. ADR High Level Functions

Active De-orbiting of a debris requires 5 functions:

- **F1**: Far Range rendezvous between Chaser and Debris:
  - Up to 10 to 1 km from target
  - Can be done through absolute navigation
  - Already demonstrated and space qualified

- **F2**: Short Range rendezvous, up to contact
  - Never demonstrated (published) yet for objects which are:
    - Non cooperative
    - Non prepared
    - Potentially tumbling
    - Potentially physically and optically different from expected

- **F3**: Mechanical Interfacing between Chaser and Debris
  - Never demonstrated (published) yet for a non prepared object

- **F4**: Control, De-tumbling and Orientation of the debris
  - Partially demonstrated in orbit, but Human operations

- **F5**: De-orbitation
3. ADR High Level Functions

General approach and trade-off (example from TAS-F):

1. Mission concept
   - OTV/debris
   - Multi debris OTV
   - Suppliable multi debris OTV

2. Orbital manoeuvres
   - Orbital plan drift + inclination correction

3. Rendez-vous
   - High thrust propulsion (chemical)
   - Low thrust propulsion (electrical)

4. Rotation braking
   - Berthing
   - Flexible capture
   - No contact

5. Capture
   - Docking
   - Net based
   - Grappin
   - Harpoon

6. De-orbitation
   - Laser ablation
   - Laser radiation pressure
   - Electrodynamics tether module
   - Electrobearing
   - Drag enhancement
   - Inflatable structure

Options:
- Rejected option
- Valid option
- Option to be validated

Footnote: TAS-F – MDA – GMV, CNES OTV-1 Study
3. ADR High Level Functions

- **F2: Short Range rendezvous, up to contact**
  - Numerous sensors can be considered
  - Optical, Mono or Binocular, Lidar / Radar…
  - Example from MDA-TASF
  - No single technology can cover the complete function

<table>
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<tr>
<th>Technology</th>
<th>Debris Detection</th>
<th>Relative Navigation</th>
<th>Debris State Monitoring</th>
<th>Mounting Ring Tracking</th>
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<td></td>
<td>~8.5km</td>
<td>5km</td>
<td>2km</td>
<td>50m</td>
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<td>Bearing</td>
<td>Feature Inspection/Imaging</td>
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<td>Satellite</td>
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<td>Pose &amp; Pose Rate</td>
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<td>Tracking</td>
</tr>
</tbody>
</table>

1 TASF – MDA – GMV, CNES OTV-1 Study
F3: Mechanical interfacing, some examples:

- OSS: clamp inside the target nozzle
- DLR: robotic arm DEOS
- CNES: deorbiting kit with robotic operations
- ESA-Astrium: hook ROGER
- Uni. Roma: foam gluing
- EPFL: claw
- Astrium: net capture
- Astrium UK: harpoon

ADR High Level Functions
3. ADR High Level Functions

- **F3: Capture – Mechanical Interfacing**
  - No reference solution yet
  - Solutions without mechanical interface are discarded here:
    - Electrical engine beam pressure
    - Electrostatic tractor
    - Lead to uncontrolled reentry
  - Solutions may impose different modes of deorbiting
    - Net, hook… will impose “pulling” the debris
    - Some allow the control of the debris, other don’t
  - Among the preferred:
    - Net capture
    - Harpoon or hook
    - Robotic arms
    - Trade-off ongoing during the OTV-2 study (AST and TAS)
3. ADR High Level Functions

■ F4: Control-Detumbling of the debris:

■ Example from MDA

■ Rendezvous analyses demonstrate:
  • A dramatic dependency of the rendezvous sizing to the tumbling rate
  • The importance of the rendezvous axis

■ Results suggest to assess different rendezvous scenarios, associated to different robotic solutions:
  • A – RDV along the debris tumbling axis
  • B – RDV along the robotic capture axis
  • C – Approach perpendicular to the tumbling axis

¹ TAS-F – MDA – GMV, CNES OTV-1 Study
3. ADR High Level Functions

- **F5: Deorbitation:**
  - High thrust deorbitation, Controlled reentry
  - Rendezvous analyses demonstrate:
    - Conventional chemical propulsion
      - Solid, Hybrid, Monopropellant, Bi propellant
      - Each have drawbacks and advantages
    - Potentially most promising: Hybrid propulsion

*DeLuca et al. IAC-12-A6.5.8*
4. Support studies

Envisat:

- One of the highest priorities debris
- Proposal to reorbit above 2000 km:
  - First generation
    - Would allow a full scale demonstration of most of the functions
    - Need to find the cheapest solution possible
  - Electrical propulsion
    - Derived from Smart 1 (x 4)
    - Compatible with a Vega launch
    - Long tether (500 to 1000 m)
  - Mechanical interfacing with hook on one of the “zenit” instruments
  - Global mass budget $\approx 820$ kg
- Presented in Ref $^1$

$^1$ C. Bonnal, C. Koppel, 2nd European workshop on ADR, Paris, June 2012
4. Support studies

- Stability of the Chaser-Tether-Debris assembly:
  - Towing = Preferred solution today, but very low TRL
  - Control laws of the chaser during de-orbiting boost:
    - Parameters of tether: length, elasticity, damping
    - Initial conditions of Debris: 6 DOF = orientation = angular motion
    - Parameters of Chaser: MOI, thrust and variation, initial orientation
    - Parameters of tether-debris interface: unbalance
    - Acceptance criteria: ΔV amplitude, orientation, dispersions
    - Control laws

- Three teams working on the topic in France
  - Mines Paris-Tech
  - Supelec
  - Thales Alenia Space

- Numerous other teams worldwide (ESA, Russia, USA…)
- Results not yet available
  - Dedicated session during upcoming EUCASS in July 2013
5. Conclusions

- **First priority is to consolidate high level requirements:**
  - Question today is not yet How, but What and When
  - Study of technical solutions:
    - Necessary for programmatic evaluations
    - Necessary for R&T programs for TRL increase
  - Numerous questions have very high priority:
    - Legal and insurance framework, ownership, launching state
    - Political hurdles: Parallel with military activities
    - Financing schemes
    - International cooperation framework

- **Recommendation to work on a reference test case**
  - Cosmos 3M upper stage could be a good example
  - Benchmarking of solutions over same hypotheses
  - Initial steps of international cooperation