ACTIVE DEBRIS REMOVAL:
CURRENT STATUS OF ACTIVITIES IN CNES

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Kessler syndrome

- Identified theoretically by Don Kessler and Burt Cour-Palais in 1978.\(^1\)
- 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

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

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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 $\equiv$ 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 ΔV
    - 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 robustness…)
  - 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 ²

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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 $\Delta a \rightarrow +/-36^\circ$/yr drift capacity
  - Targets visited in increasing order of inclination $\rightarrow$ cumulated $0.6^\circ \Delta i$

$\Rightarrow$ Mission duration depends on launch date

$\Rightarrow$ Adjust drift allotted $\Delta V$ to target distance

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

IAF Workshop on Space Debris Removal – UN, Vienna – February 11th, 2013
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 OTV/duress
- 1 multi debris OTV
- 1 suppliant multi debris OTV
- 1 multi launch
- 120 de-sorbtion modules carrier
- 130 de-orbit OTV
- 111 multiple launch
- 100 mini/ micro launchers

- 1 mission concept
- 2 orbital manoeuvres
- 3 rendez vous
- 4 rotation bracking
- 5 capture
- 6 de-orbitation

- 20 High thrust propulsion (chemical)
- 21 Low thrust propulsion (electrical)
- 22 particles throw using ionic propulsion
- 23 orbital plan drift + inclination correction
- 30 Sensors
- 40 brush contactor
- 41 laser ablation
- 50 berthing
- 60 no contact

- 51 docking
- 52 flexible capture
- 53 robotic arm
- 54 nozzle level capture
- 55 capture with claws
- 56 magnetic capture

- 57 net based
- 58 grappin
- 59 harpoon

- 60 laser ablation
- 61 laser radiation pressure
- 62 particles throw using ionic propulsion
- 63 electron gun (negative charge)
- 64 water projection in eclipse

- 65 from composite
- 66 with transferred module

- 67 high thrust module (solid propellant engine)
- 68 electrodynamic tether module
- 69 drag enhancement
- 70 inflatable structure (balloon)
- 71 deployable sail

1 TAS-F – MDA – GMV, CNES OTV-1 Study

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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

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<thead>
<tr>
<th>Technology</th>
<th>Operation Phase</th>
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<tbody>
<tr>
<td></td>
<td>Debris Detection</td>
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<tr>
<td></td>
<td>-8.5km</td>
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<td>Passive Camera (monocular)</td>
<td>Bearing</td>
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<td>Feature Inspection/Imaging</td>
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<tr>
<td>Stereo Camera</td>
<td>Bearing &amp; Range</td>
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<td>Satellite Pose &amp; Pose Rate</td>
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<td>Mounting Ring Pose &amp; Pose Rate</td>
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<td>Feature Inspection/Imaging</td>
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<td>Laser Range Finder</td>
<td>Ranging</td>
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<td>Scanning LIDAR</td>
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<td>Pose &amp; Pose Rate</td>
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<td>Flash LIDAR</td>
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<td>Feature Inspection/Imaging</td>
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<td>Pose &amp; Pose Rate</td>
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<td>Tracking</td>
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1 TAS-F – MDA – GMV, CNES OTV-1 Study

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3. ADR High Level Functions

- **F3: Mechanical interfacing, some examples:**
  - **OSS:** clamp inside the target nozzle
  - **DLR:** robotic arm DEOS
  - **Uni. Roma:** foam gluing
  - **ESA-Astrium:** hook ROGER
  - **CNES:** deorbiting kit with robotic operations
  - **Astrium UK:** harpoon
  - **Astrium:** net capture
  - **EPFL:** claw

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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 ¹
  - 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 ≅ 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

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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