ACTIVE DEBRIS REMOVAL:
CURRENT STATUS OF ACTIVITIES IN CNES

Christophe BONNAL

CNES – Paris - Launcher Directorate

christophe.bonnal@cnes.fr

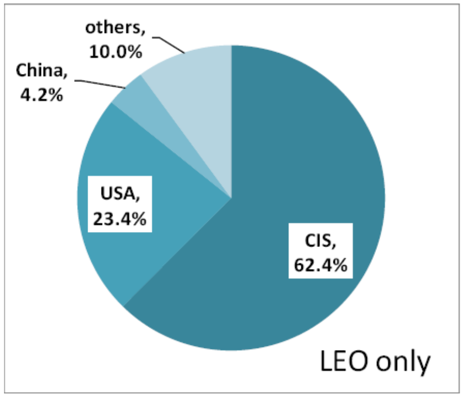
Content

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 [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



[1] *D.J. Kessler, B.G. Cour-Palais, Collision frequency of artificial satellites: the creation of a debris belt, JGR 83 (A6) (1978) pp. 2637–2646.*

■ 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 [1]**
    - **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**

[1] *J.-C. Liou, N.L.Johnson, N.M.Hill, Controlling the growth of future LEO debris populations with active debris removal, Acta Astronautica 66 (2010) pp. 648 - 653*

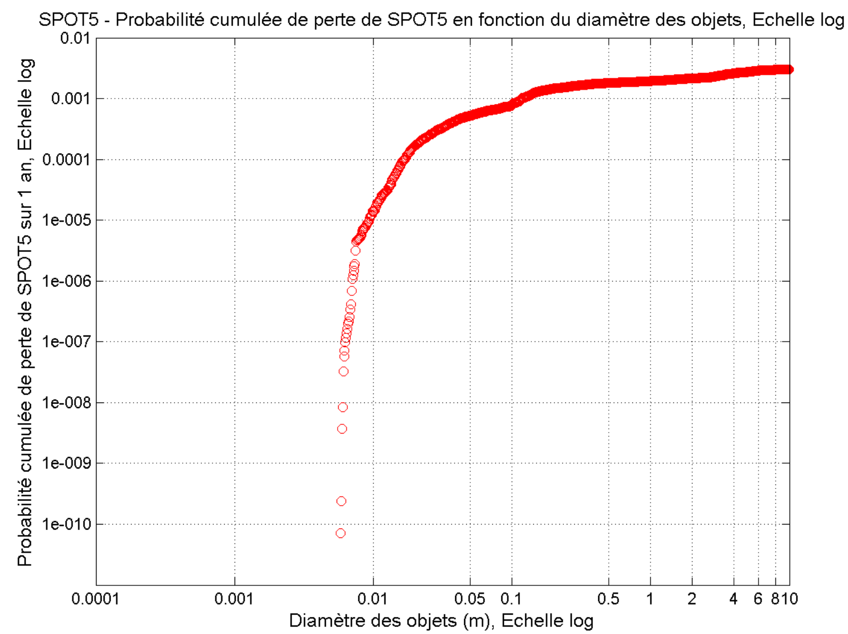
1. High Level Requirements

■ 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*

[2] *R. Destefanis, L. Grassi, Space Debris Vulnerability Assessment of the Sentinel 1LEO S/C, PROTECT Workshop, Mar. 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 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 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 [2]**

[1] JC. Liou, The top 10 Questions for Active Debris Removal, #S1.3, 1st European Workshop on ADR, Paris, June 2010
[2] P. Couzin, X. Rozer, L. Stripolli, Comparison of Active Debris Removal Mission Architecture, IAC-12-A6.5.5, Naples 2012

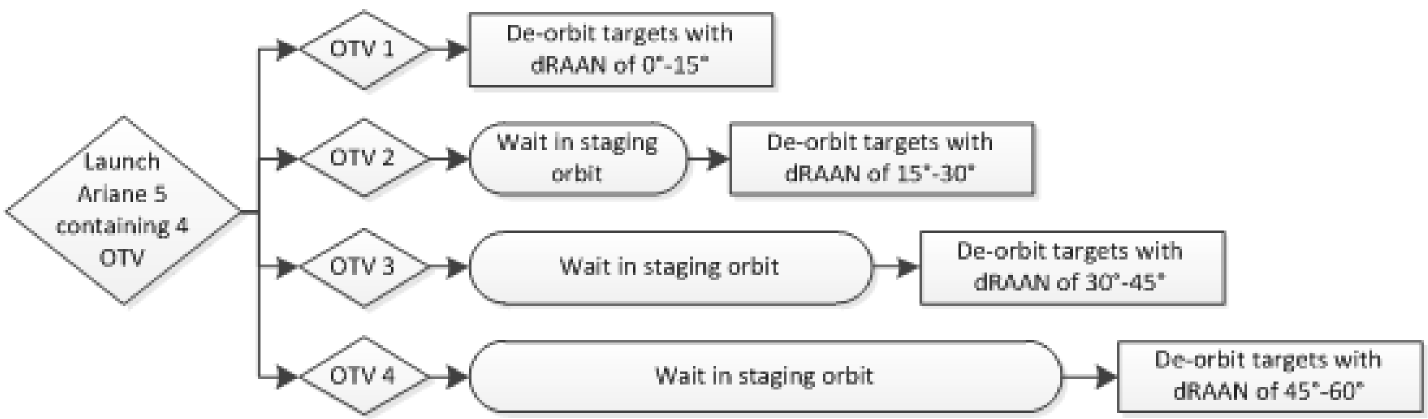
Strategy for successive debris removal

- 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** [1]

- **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



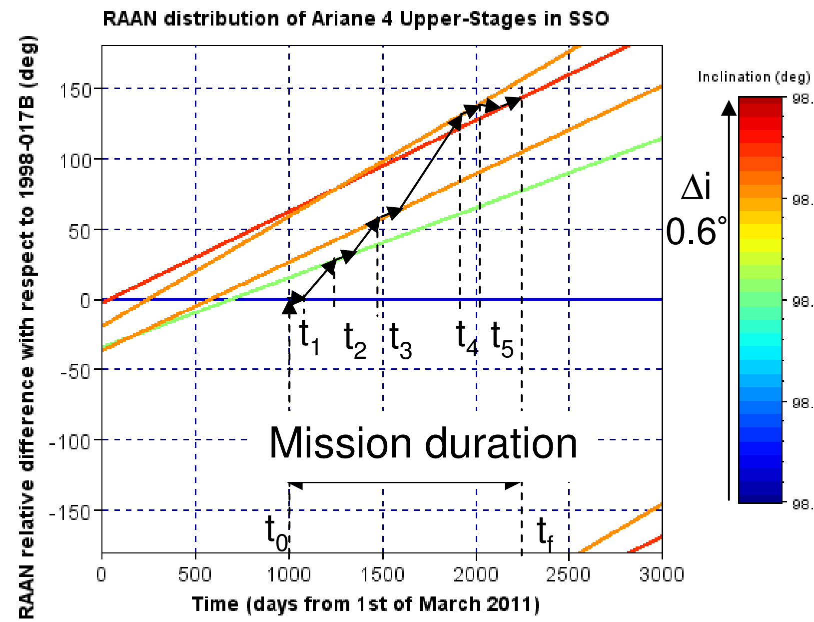
[1] *P. Couzin, X. Rozer, L. Stripolli, Comparison of Active Debris Removal Mission Architecture, IAC-12-A6.5.5, Naples 2012*

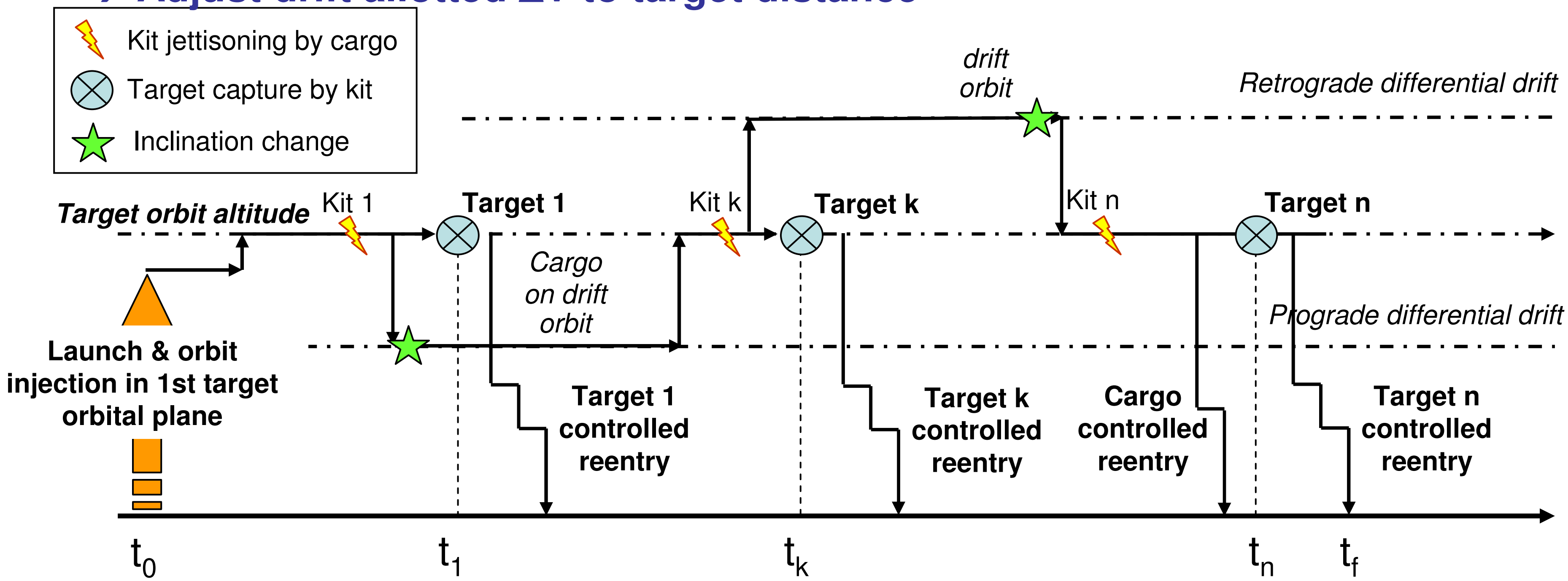
2. System architecture options

- **From CNES Internal Study OTV [1]**
  - 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**



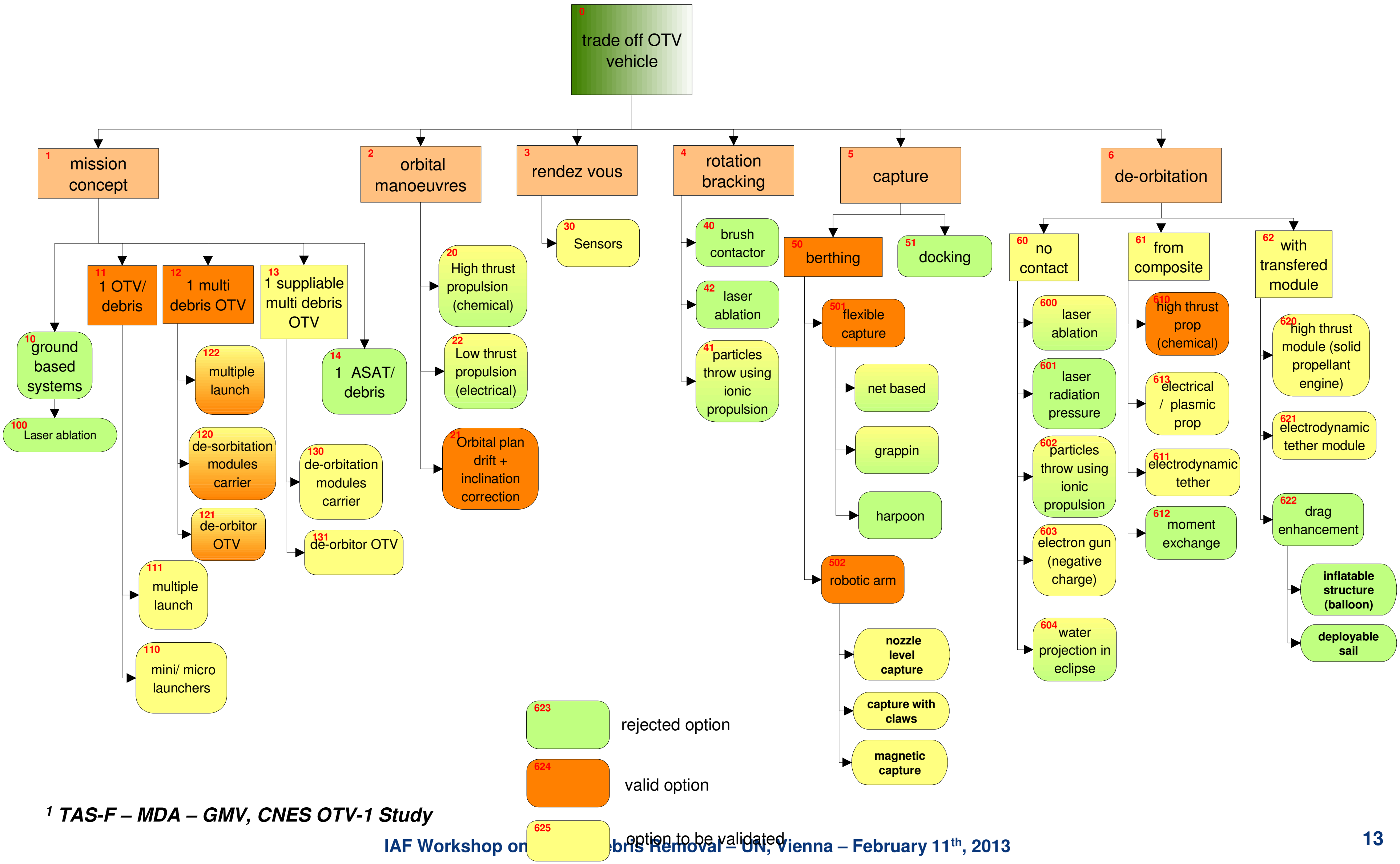


[1] *E. Pérot, Active Debris Removal Mission Design for LEO, #479, 4th EUCASS, St Petersbourg July 2011*

- **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]):



[1] ***TAS-F – MDA – GMV, CNES OTV-1 Study***

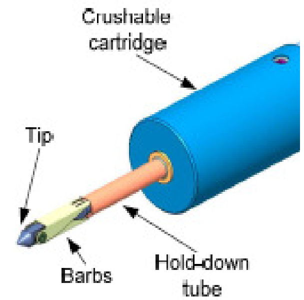
F2: Short Range rendezvous, up to contact

- **Numerous sensors can be considered**
  - Optical, Mono or Binocular, Lidar / Radar…
  - Example from MDA-TASF [1]
- **No single technology can cover the complete function**

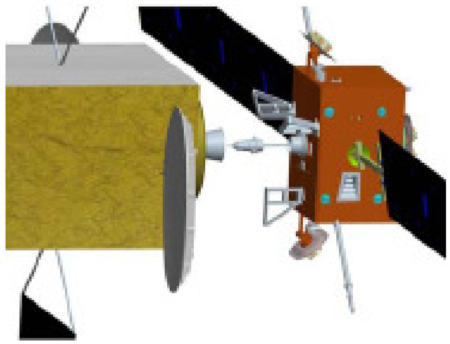
[1] TAS-F – MDA – GMV, CNES OTV-1 Study

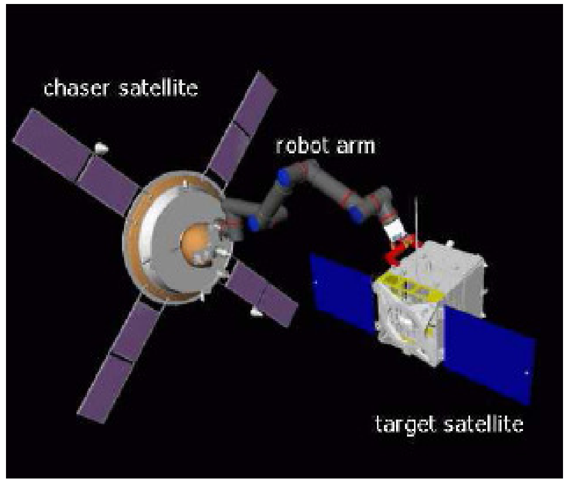
3. ADR High Level Functions

■ F3: Mechanical interfacing, some examples:

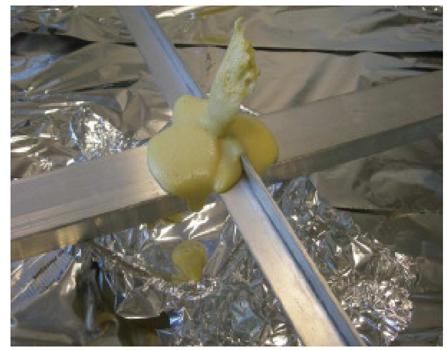


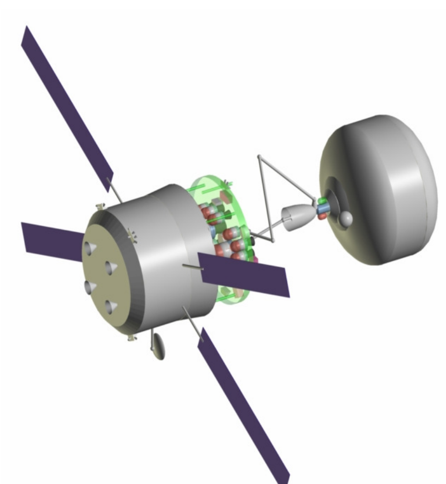
Astrium UK: harpoon

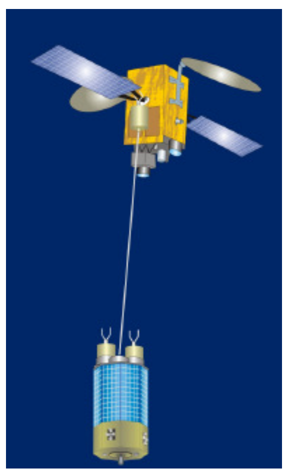

OSS: clamp inside the target nozzle

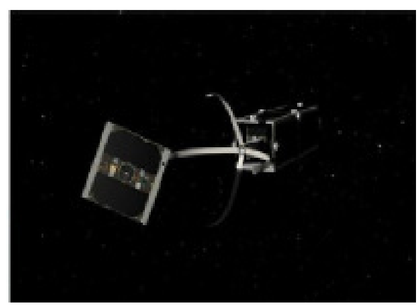


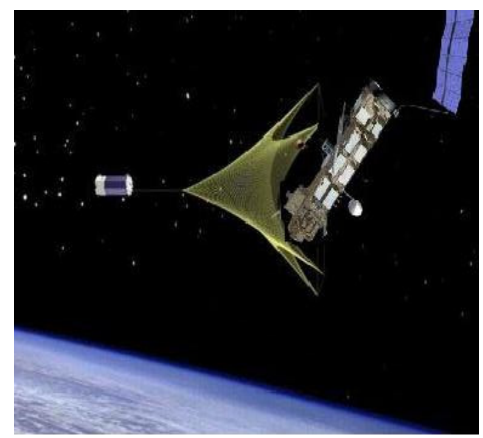
DLR: robotic arm DEOS


Uni. Roma: foam gluing


CNES: deorbiting kit with robotic operations


ESA-Astrium: hook ROGER


EPFL: claw

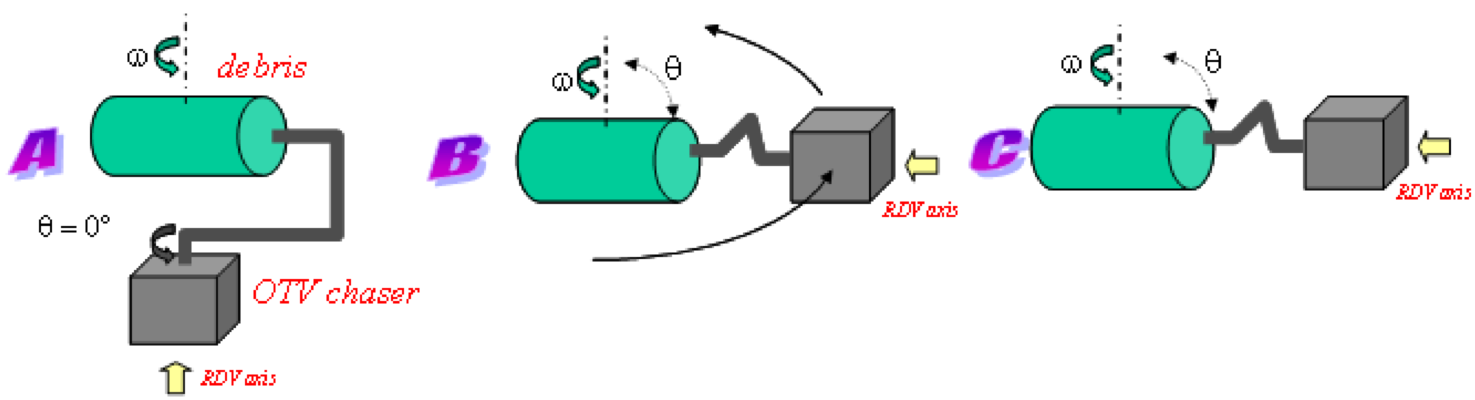

Astrium: net capture

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)

F4: Control-Detumbling of the debris:

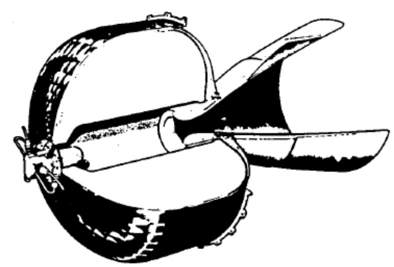
- Example from MDA [1]
- Rendezvous analyses demonstrate:
  - A dramatic dependency of the rendezvous sizing to the tumbling rate
  - The importance of the rendezvous axis
- Results suggest to assess different rendezvous scenarios, associated to different robotic solutions:
  - A – RDV along the debris tumbling axis
  - B – RDV along the robotic capture axis
  - C – Approach perpendicular to the tumbling axis

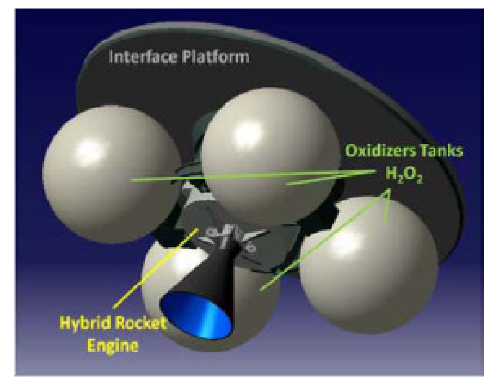


[1] *TAS-F – MDA – GMV, CNES OTV-1 Study*

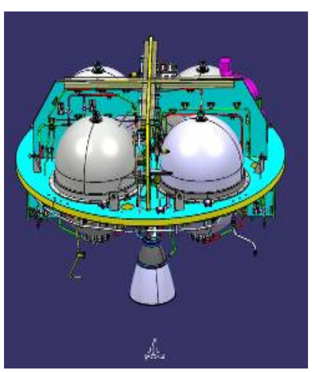
F5: Deorbitation:

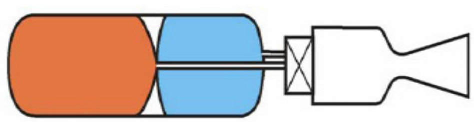
- **High thrust deorbitation, Controlled reentry**
- **Rendezvous analyses demonstrate:**
  - **Conventional chemical propulsion**
    - Solid, Hybrid, Monopropellant, Bi propellant
    - Each have drawbacks and advantages
  - **Potentially most promising: Hybrid propulsion**

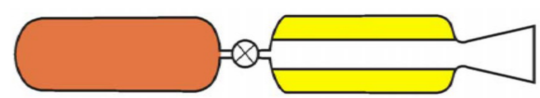




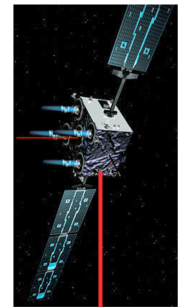
DeLuca et al. IAC-12-A6.5.8







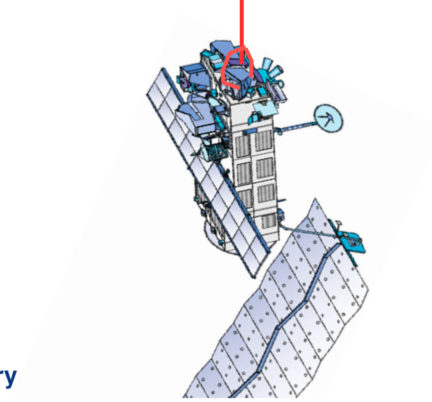
4. Support studies



Velocity vector

- **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]**

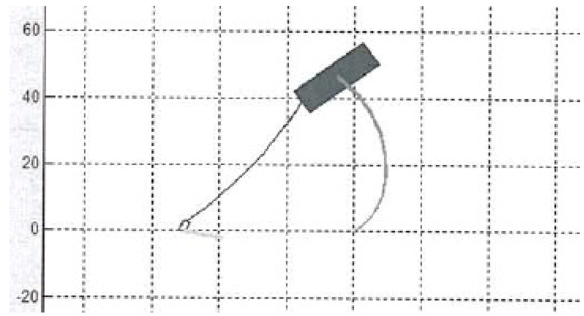
Earth center



[1] *C. Bonnal, C. Koppel, 2nd European workshop on ADR, Paris, June 2012*

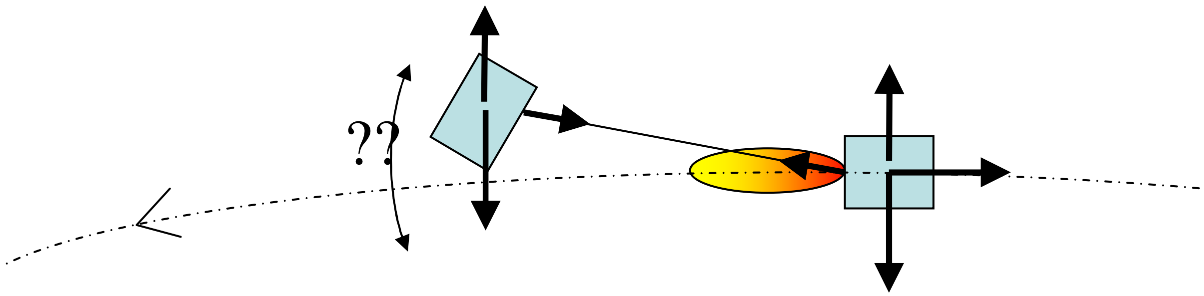
4. Support studies

- **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**



- 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