US ACTIVE DEBRIS REMOVAL (ADR) EFFORTS

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This presentation solely represents the opinions of the author and should not be construed as being endorsed or validated by the US Government.

- This information reflects efforts that have been conducted and does not address planned future US investments.
USG National Space Policy (June 2010) called for NASA and DoD to pursue R&D on ADR, reducing hazards, and increasing understanding of debris environment.

**NASA**
- Centralized funding and policy implementation through NASA/HQ.
- Johnson Space Center is center of excellence for orbital debris mitigation.
  - Several other centers and Office of Chief Technologist have unique contributions.
- Space Technology Program applying resources for concept exploration and technology development.

**DoD**
- ADR activities performed largely in labs (NRL, APL, AFRL, etc.) and the Defense Advanced Research Programs Agency (DARPA).

Regular (at least annual) NASA/DoD OD Working Group meetings cover a full range of OD efforts to include ADR.
US ADR EFFORTS BY LIFE CYCLE

<table>
<thead>
<tr>
<th>General Concept</th>
<th>Analytic Modeling</th>
<th>Policy Formulation</th>
<th>System Solutions Development</th>
<th>Technology Demos</th>
<th>System Acquisition</th>
<th>Legal/Policy/Insurance Adjudication</th>
<th>Operational Use</th>
</tr>
</thead>
</table>

Next Three Charts

- PALAPA-B2, WESTAR-6, LDEF, and HST
- ?
- ?
- ?

Foundational research papers by Johnson and Liou on ADR, 2009 and 2011

Rendezvous, grappling, and retrieval/servicing missions
### Evaluation of Possible ADR Methods

2009 Conference in US - Catalyst to Discussions

<table>
<thead>
<tr>
<th>Debris object class</th>
<th>Removal method</th>
<th>Orbit</th>
<th>Feasible physics</th>
<th>Encounter velocity</th>
<th>Anti-collision maneuver?</th>
<th>Units needed</th>
<th>Acceptable</th>
<th>Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td>Propulsive tug</td>
<td>Any</td>
<td>Yes</td>
<td>Near 0</td>
<td>Yes</td>
<td>&lt; 10</td>
<td>Yes</td>
<td>Large amounts of delta-v, object capture, rotating objects</td>
</tr>
<tr>
<td>Large</td>
<td>Inflatable drag device</td>
<td>LEO</td>
<td>Yes</td>
<td>NA</td>
<td>No</td>
<td>10s per year</td>
<td>No</td>
<td>Collision with active or other large debris</td>
</tr>
<tr>
<td>Large</td>
<td>Solar sail</td>
<td>GEO</td>
<td>Maybe</td>
<td>NA</td>
<td>No</td>
<td>10s per year</td>
<td>No</td>
<td>Low mass object capture mechanism</td>
</tr>
<tr>
<td>Large</td>
<td>Electrodyanmic tether</td>
<td>LEO</td>
<td>Maybe</td>
<td>TBD</td>
<td>Maybe</td>
<td>&lt; 10</td>
<td>No</td>
<td>Complex control, dynamic stability, debris object capture method</td>
</tr>
<tr>
<td>Large</td>
<td>Momentum tether</td>
<td>Any</td>
<td>Maybe</td>
<td>TBD</td>
<td>Maybe</td>
<td>&lt; 10</td>
<td>No</td>
<td>Complex control, dynamic stability, debris object capture method</td>
</tr>
<tr>
<td>Large, Medium</td>
<td>Ground based laser</td>
<td>LEO</td>
<td>No</td>
<td>NA</td>
<td>No</td>
<td>NA</td>
<td>No</td>
<td>Engagement geometry, laser physics, detection &amp; tracking</td>
</tr>
<tr>
<td>Large, Medium</td>
<td>Space based laser</td>
<td>LEO</td>
<td>No</td>
<td>NA</td>
<td>&lt; 10</td>
<td>No</td>
<td>No</td>
<td>Engagement geometry, laser physics, detection &amp; tracking</td>
</tr>
<tr>
<td>Medium</td>
<td>Passive sweeper</td>
<td>LEO</td>
<td>Yes</td>
<td>Up to 11 km/s</td>
<td>No</td>
<td>45,000</td>
<td>No</td>
<td>Infrequent debris encounters, collision with active or other large debris</td>
</tr>
<tr>
<td>Medium</td>
<td>Active sweeper</td>
<td>LEO</td>
<td>Yes</td>
<td>Up to 11 km/s</td>
<td>Yes</td>
<td>100</td>
<td>No</td>
<td>Need large numbers, large delta-v, advanced sensors</td>
</tr>
<tr>
<td>Medium</td>
<td>Liquid, Gas, Particulate cloud</td>
<td>LEO</td>
<td>Yes</td>
<td>Up to 11 km/s</td>
<td>No</td>
<td>10,000s</td>
<td>No</td>
<td>Need large numbers, effect on operational spacecraft</td>
</tr>
<tr>
<td>Medium</td>
<td>Electromagnetic</td>
<td>Any</td>
<td>Maybe</td>
<td>Up to 11 km/s</td>
<td>Yes</td>
<td>100s to 1,000s</td>
<td>No</td>
<td>Massive device, complex encounter geometry, detection &amp; tracking, object composition</td>
</tr>
</tbody>
</table>

**Scores and metrics are outdated**
FOUR “MAINSTREAM” AREAS

- **EDDE (ElectroDynamic Debris Eliminator)**
  - E-tether uses Earth’s magnetic field to create propulsive force
  - Use force to both rendezvous for grappling and to move derelict
  - Some partially successful testing in the past

- **GOLD (Gossamer Orbit Lowering Device)**
  - Inflatable
  - Simple, effective
  - Better long-term collision risk than any ADR system except for propulsive tug

- **Solar Sail**
  - Uses solar photon pressure to move derelicts
  - Similar systems deployed previously but not for operational ADR applications
  - Fragile and slow process

- **Propulsive Tug**
  - Traditional propulsion system still the most mature capability
  - High impulse and controllability for reentry risk mitigation
  - Exemplar for several satellite servicing initiatives
THREE “NICHE” EFFORTS

- **Laser Removal from ground or space**
  - No need to detumble or even go to space for groundbased version
  - Physics of dwell time and laser interaction are unproven
  - Feasibility for ADR unclear

- **Geosynchronous Large Debris Reorbiter (GLiDeR)**
  - Contactless-coupling plus ion thrusters in GEO only
  - No need to detumble
  - Unproven, limited applications
  - Deposit in GEO graveyard, not deorbit

- **Tungsten Dust**
  - Remove derelicts by depositing tons of dust in space to “wash out” medium-large debris
  - Significant effects on operational spacecraft
  - Feasible only for “start over” mode
ORGANIZING ADR OPTIONS

- **Orbital** solution creates potential risk to create more orbital debris via **ballistic** (i.e. sub-orbital) system
- Options viable for certain **orbital regions**: LEO, GTO, and/or GEO
- Needing **propellant to rendezvous** adds cost/weight
- Needing **propellant to remove** adds cost/weight
- It is important to be able to **control deorbiting** to minimize risk to people on the ground
- Technology readiness level (TRL) provides measure of programmatic risk and potential investment needed to make operational
- **Cost per object removed** determines financial efficacy of approach
- **Cost per collision prevented** is a broader metric that may motivate examination of “other” approaches... such as just-in-time collision avoidance (JCA)
ADR-RELATED OBSERVATIONS

PERSONAL THOUGHTS

• 1. Need to examine **metric for success for ADR** for large derelict objects
  • Environmental stability is the common factor discussed but reduction in satellite operational lifetimes from collisions with nontrackable/lethal debris fragments might be more relevant

• 2. **Detumbling** of derelicts is often overlooked
  • May be significant component of solution

• 3. Include Just-in-Time Collision Avoidance (JCA) with ADR for “**derelict collision prevention**” mission space
1. **Identify**: Ground and orbital systems detect imminent collision.
2. **React**: Air-launch system is mobilized with JCA system on board.
3. **Deflect**: JCA system is deployed to induce a slight change in the orbit of one of the objects involved by deploying cloud of high density gas.
4. **Prevent**: If the object’s orbit is changed enough the collision will be prevented.
PREVENTING DERELICT COLLISIONS
ADR AND JCA

Removal

Active Debris Removal (ADR)
- Requires many launches
- Requires grapple/detumble
- Execute over decades
- Manage reentry risk

STRATEGIC - Statistical

Avoidance

Just-In-Time CA (JCA)
- Want low false alarms
- Need enhanced el set accuracy
- Hourly/daily response
- No reentry risk

TACTICAL - Deterministic
# ADR AND JCA

**BOTH ARE DIFFICULT AND EXPENSIVE**

<table>
<thead>
<tr>
<th></th>
<th>ADR</th>
<th>JCA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of objects</strong>&lt;br&gt;moved/removed per collision prevented</td>
<td>~30-50</td>
<td>~5-3,000</td>
</tr>
<tr>
<td><strong>Costs per collision prevented</strong></td>
<td>~$100M's-$B's</td>
<td>~$10M's-$10B's</td>
</tr>
<tr>
<td><strong>Game Changer(s)</strong>&lt;br&gt;Needed</td>
<td>10s-100s of derelicts removed per launch</td>
<td>Improve el set accuracy by 25x (250m→10m) and ballistic launch less than $1M</td>
</tr>
</tbody>
</table>
PARTING THOUGHT
“PAY ME NOW OR PAY ME MORE LATER”

• Timing for ADR...
  1) research and development;
  2) demonstrations;
  3) industry scale-up;
  4) legal/policy evolution and codification;
  5) operations and maintenance; and
  6) accrued benefits

are uncertain.

• Tradeoff between acting too soon or acting too late needs to be examined.