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DR LEO: Debris Removal from LEO

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http://www.cranfield.ac.uk/soe/space

Overview

Some background to Cranfield and the DR LEO project

The project's objectives

DR LEO overview

Discussion: debris removal

Conclusions

Introduction to Cranfield

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- All postgraduate; ~3000 students; two campuses
- Works closely with industry
- Focus on applied science, engineering, management

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- Bioscience & technology
- **Agriculture** & food
- Water & environment
- Land management
- Manufacturing
- Advanced materials
- **Aerospace**
- Automotive
- Gas turbines
- Energy
- Offshore engineering
- **Management**

Shrivenham

- Electronics & sensors
- Mechanical, materials & civil engineering
- Computing and IT
- Applied mathematics
- **Defence** management

Cranfield Space Research Centre

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SRC is the main focus for space engineering teaching and research in the University

- 3 permanent staff, 4 visiting staff, ~50 students

Core SRC activities:

- Teaching – MSc in Astronautics and Space Engineering and European joint degrees (Erasmus Mundus)
- Research – specific topics leveraging wider University expertise
- Consultancy – ISO standards, RAeS, RSPSoc, short courses

Collaborate with other groups having specific expertise

- E.g. structures and impact, biosensors, manufacturing, Earth observation applications, radar

MSc in Astronautics and Space Engineering

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Prepares students for careers in the space industry

- International intake
- Space system engineering emphasis
  - Lecture modules on key space engineering topics (25%)
  - **Group Design Project** (30%)
  - Individual Research Project (45%)

Close industry ties

Alumni throughout the space industry

Cranfield's work related to space debris

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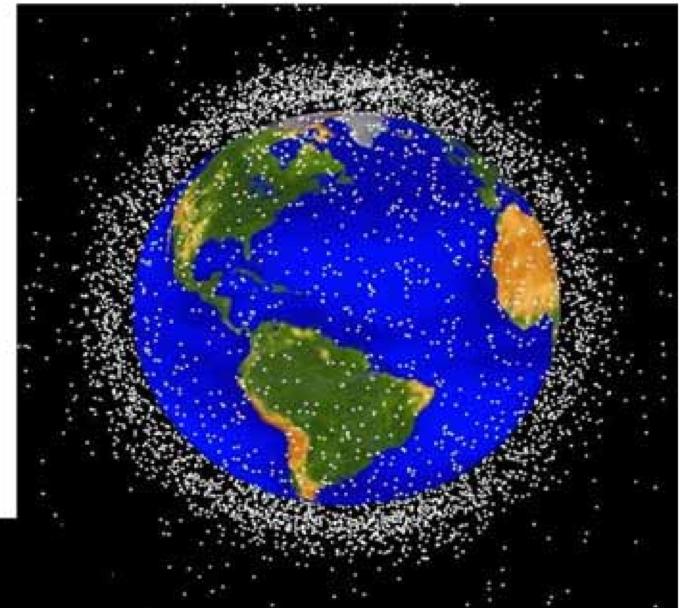
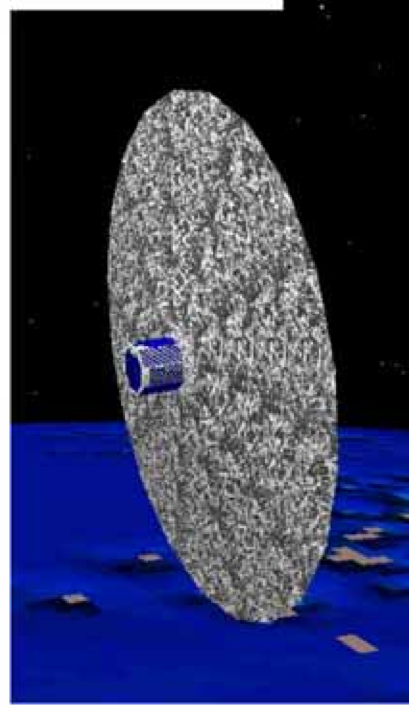
Sustainable space is the unifying theme

- End-of-life de-orbit technologies
  - E.g. drag enhancement
- ISO debris mitigation standards
  - Passivation, fuel management
- High and Hypervelocity Impact Modelling
- Spacecraft health prognostics for disposal phase and operations
- Future scenario modelling





The DR LEO project

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- Group design project of the MSc course
- Ran from October 2009 to April 2010
- Each student contributes ~600 hr (total ~4 years)
- The team:
  - James Cole, Francois Caullier, Guillaume Mathon-Marguerite, Lolan Naicker, Sandine Quevreux, Michael Demel (2nd row, L to R);
  - Rushi Ghadawala, Samuel Pin, Ruben Amengual, Vinay Grama, Andrew Ratcliffe (front row)

DR LEO requirements

- Develop a conventional debris removal mission for LEO
- Remove 5-10 large objects from orbits near 800-1000 km
- Aim for 1 yr mission lifetime
- High probability of safety and successful operation

Constraints:

- Compatible with debris mitigation guidelines
- Prefer current, European technology
- Target budget €250M

= *Remove mass from LEO as cost-effectively as possible*

Requirements analysis

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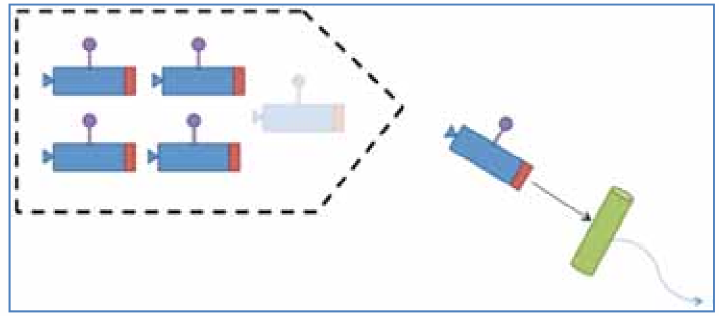
Example issues derived from the requirements:

1. The scatter of target RAAN and high ΔV for plane change mean that natural J_2 orbit precession is valuable
2. Re-entry safety risk management means a targetted re-entry over the South Pacific is needed
   - This requires a high-thrust final de-orbit manoeuvre and ruled out using only low-thrust propulsion
3. Grappling and docking: assuming targets are Ariane IV upper stages (European focus) the forces and moments needed for grappling, etc., can be estimated (~modest)

Concepts brainstorm

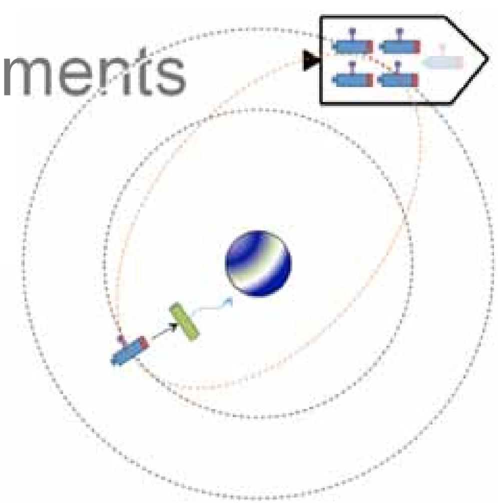


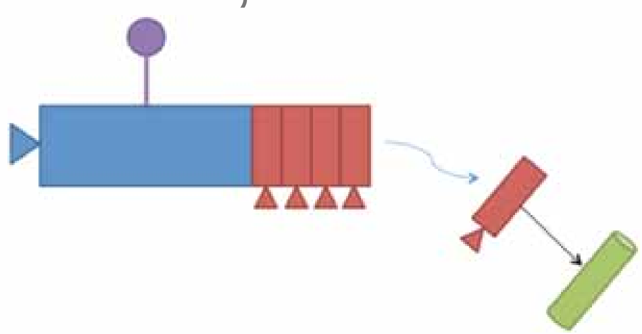
The fun part

The team proposed a wide range of mission concepts

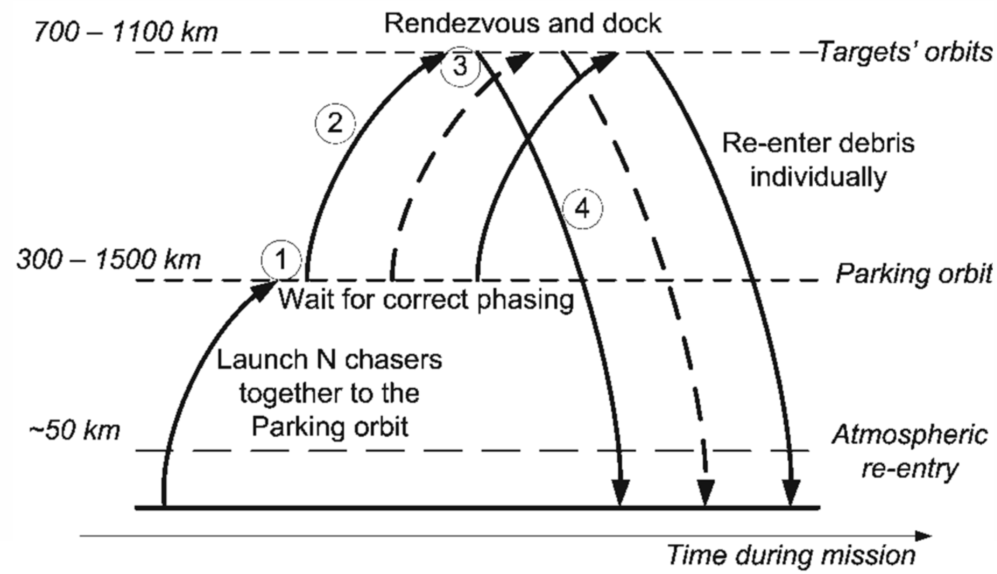
- One or several s/c, one or several grappling devices, single or multiple launch, etc.
- Then trade-off against mission requirements

Selected multiple s/c each with grappling, single launch, no “mother” craft





Parking orbit selection



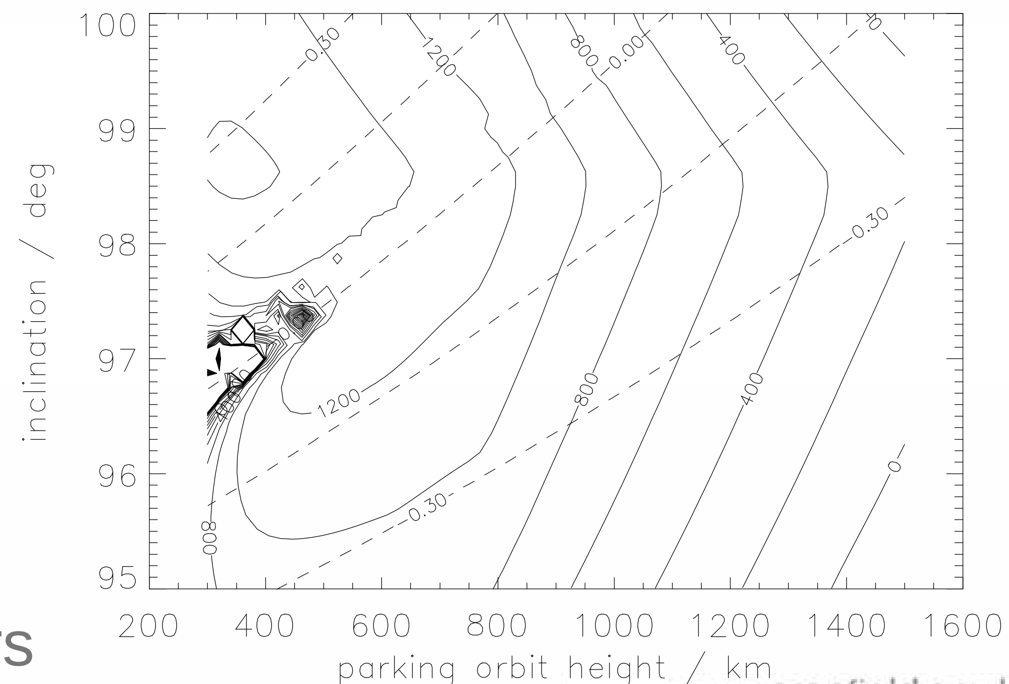
- Assume that chaser s/c are launched to a parking orbit, then wait until orbits align before rendezvous and de-orbiting a target
- For a given launcher performance (mass delivered vs orbit height, inclination), what is the best parking orbit height?
  - Too low: waste fuel overcoming drag
  - Too high: waste fuel with unnecessary orbit raising
  - Too close to targets: minimal relative orbit precession

Parking orbit optimisation

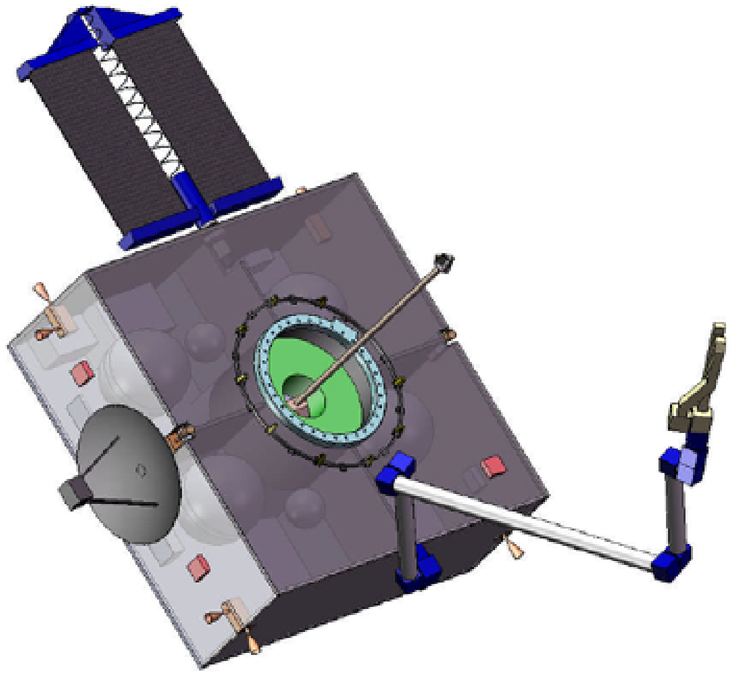
For a given set of targets (sun sync in this case) and launcher performance, calculate the mass margin as a function of parking orbit inclination and height

Results show largest margin for i = 98.6°, h ~ 350 km

- This also reduces risk if there's a failure
- Avoid parking orbits close to sun-sync
- Could launch up to 8 chasers



Final baseline



- Configuration designed for compact stacking
- Grappling and rendezvous mechanism based on DLR system
- Mass ~550 kg (inc. fuel and margin, but no technology demonstration payload)
- Cost (development, launch, and 5 chaser s/c): ~€249M
  - Thus €50M per Ariane IV upper stage (1600 kg) or €30k kg^{-1}
  - With 8 chasers, cost per Ariane IV is ~€40M or €26k kg^{-1}
  - Results are comparable with other studies (e.g. Delft)

Discussion: Mission Drivers

What were the key factors which shaped our mission?

Re-entry safety criterion

- Prevented us from using low thrust for re-entry

Propulsion system mass efficiency

- Cost would fall (by launching more chasers) if propulsion system mass were reduced

Grappling and docking mechanism

- Challenging task for un-cooperative object of unknown condition (fragile?) and state (tumbling?)
- Autonomy is assumed (but not yet proven)

Target selection

To reduce debris collision risk, the aim is to remove mass from the most collision-prone regions

- Targetting a few large objects rather than many small ones seems less risky and more cost-effective

Our mission targets objects near 780 km

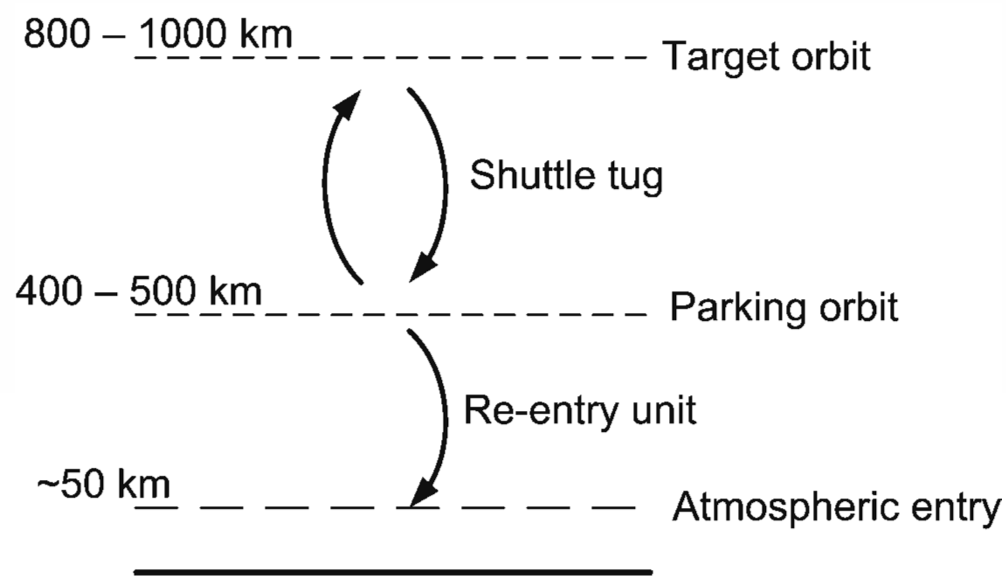
- Reduces collision risk in this region, but has little effect on other altitudes

Comprehensive programme will need to remove objects from a range of orbit heights (especially 800-1000 km), tending to increase cost

Other concepts

Reminder: Aim to establish a <u>conventional baseline</u>

- Expect other concepts to improve on this



Possible approaches:

- Relatively conventional – modify mission architecture, perhaps with improved propulsion (e.g. see figure)
- More adventurous – nets, shields, glue, lasers, …

Conclusions

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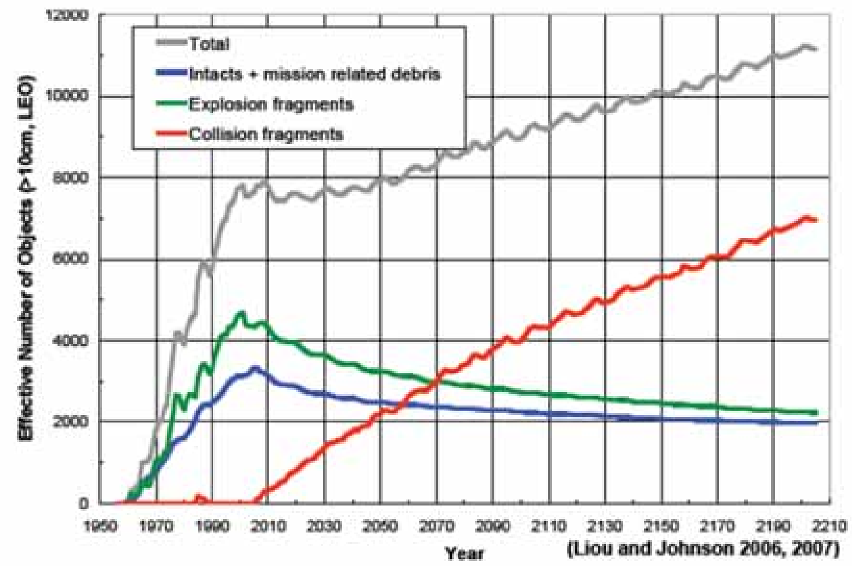
Active debris removal is feasible with ~current technology

Cost: probably more expensive than the launch

- Raises the question of how to resource ADR
- Political / policy choice: state or agency activity, or provide a framework for private enterprise?



Several areas of further work

- Within a few decades (<2050?)
- Technical and non-technical issues to be resolved

Future work - Technical

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System design iteration

- Optimize rendezvous, grappling, and re-orbiting system
- Target selection criteria

Propulsion

- More mass efficient: electric propulsion, tethers, etc.

Space robotics

- Grappling and docking for uncooperative objects

Re-entry requirements

- We need to be sure we have the right safety criteria

Future work – Non-technical

Establish international framework and trust

- Active debris removal can be benign or may be viewed as potentially aggressive
- Legal and financial agreements are needed

Risk management approach

- Balance technical, commercial, political, etc., interests

Sustainable use of space is inherently trans-disciplinary and a truly global issue demanding vision

Thank you

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I'd like to acknowledge the contributions made by many staff and students to this project:

- All the DR LEO team members
- Other staff at Cranfield
- Collaborators in industry and other research organisations
- SWF, ISU and Beihang University for hosting this meeting

Any Questions?