



Changing the economics of space

Service Oriented Approach To The Procurement/Development Of An Active Debris Removal Mission

Executive Summary



2 EXECUTIVE SUMMARY

2.1 Purpose and Objectives of the Study

The purpose of the study was threefold [AD-1]:

- **Objective 1:** To address the technical feasibility of an Active Debris Removal (ADR) mission, targeting a 'heavy' (>4000kg) object in Sun Synchronous Orbit (SSO).
- **Objective 2:** To define a business model for the implementation of the mission defined as the output of objective 1.
- **Objective 3:** To define a business plan for future ADR missions, and to define the technology roadmaps needed to achieve sustainable ADR activities.

The overall rationale for such a study has been driven by two factors. Firstly the unexpected on-orbit failure of the Envisat mission in 2012, has now created a specific and immediate 'debris problem' for ESA. Secondly, the number of and density of damaging space debris in Low Earth Orbit (LEO) is predicted to rise in the future, which has the potential to negatively constrain future space operations for all operators and users. This later point is the so-called Kessler Syndrome, a phenomenon predicted to occur in LEO, whereby self sustaining collisional cascading will occur, leading to a runaway growth in the debris population.

Such collisional cascading is ultimately driven by the presence of large uncontrolled debris such as rocket bodies (R/B) and satellites that are no longer controlled. These act as 'mass reservoirs' holding the potential to release thousands of dangerous new fragments if they are involved in a catastrophic collision with another object. These fragments can then go on and become progenitors for further collisions, leading to even more fragment production.

Studies have shown that if a sufficient number of such large objects are removed from orbit, then the future debris population can be stabilised at, or near to, present day values. Current internationally accepted predictions are that 5-10 objects need to be removed from LEO each year over periods of at least several decades to be effective. Given the difficulty and expense of launching a satellite safely into space, it is not a surprise that safely disposing of the same object is also expected to be technologically challenging. However, there are many non-technical challenges to ADR missions, including the legal and regulatory framework within which they will exist, the financing of such missions over the long-term, the liabilities and responsibilities for other space users and the dual-use nature of some technologies. It is for this reason that ADR has been described by J.C.Liou of NASA as '*A Grand Challenge for the 21st Century*'.

Furthermore, ADR brings no immediate value to the operator. Instead it is delaying the possible increase in collision risk, and operational implications that might occur in the future. In an era of highly constrained budgets, space agencies and operators must find cost-effective and Value-for-Money (VFM) ways to conduct space debris mitigation activities such as ADR. Because of this, the possibility of conducting ADR as a service rather than a more traditional institutional procurement should be explored. Public Private Partnerships (PPP) and service models have been successfully applied to other space domains, e.g. launch vehicle services in the United States, and geostationary communications programmes in Europe (Skynet 5, Alphabus etc.). Therefore the investigation of the use of such schemes in the context of ADR is a key objective for the study.

2.2 Study Team and Structure

The study team (shown at Figure 1) was led by SSTL, with Aviospace, Elecnor Deimos, and the University of Surrey as sub-contractors. Consultancy on legal, financial and insurance matters was provided by Atrium Space Insurance Agency, CGI and Holman Fenwick Willan.


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Figure 1: Study Team

The study was built around four main Work Packages (WP):

- **WP 1: Preliminary System Concept:** This covered the high-level technical feasibility analysis of an ADR mission against a large uncontrolled debris object in LEO. As well as the technical analysis, a cost-estimate for the development and flight model production of the proposed concept has been generated.
- **WP2: Definition of Business Model:** This covered the analysis of different financial and implementation models for delivering the mission defined in WP1, considering funding options, legal and insurance requirements and risk sharing.
- **WP3: Future ADR Business Plan:** This covered the investigation of delivering ADR services beyond the first mission characterised in WP1 and WP2. This analysis covered two points:
 - **1)** The consideration of different architectures and system options for ADR (Market Study)
 - **2)** The development of a hypothetical business model for an ADR service provider.
- **WP4: Roadmaps and Implementation:** This covered the key technical developments needed to reduce technical risk in the mission profile defined in WP1 and WP3, as well as roadmaps for the overall ADR business implementation.

At a high-level, the main focus of the study has not been a detailed technical assessment of ADR missions, as this is being covered by other studies and contracts with ESA. Instead, the motivation for the study has been the assessment of the business possibilities for ADR and the possibility of providing ADR as a commercial service rather than as an Agency managed mission. Nevertheless, in order to provide a realistic assessment of the business opportunities, a technical feasibility assessment has to be performed in order to generate a realistic initial baseline.

2.3 Main Study Results

2.3.1 Objective 1

A limited technical study was performed on removing Envisat from orbit (this being the only ESA owned object meeting the study requirements), and a development plan and cost estimate were created. The main results are:

- It will be technically challenging to perform a mission to remove Envisat from orbit, but it appears feasible on the basis of the study performed.
- A thorough trade-off on possible capture systems has identified a thrown net, similar to that proposed for the ROGER study, as the best option. Some heritage also exists from the ESA YES-2 tether mission.
- A GNC sensor suite of wide and narrow angle cameras (flight proven) as well a LIDAR (under development) is proposed for relative guidance and navigation.
- The spacecraft - the 'Chaser' - design is based on a mixture of flight proven heritage LEO avionics and sub-system technologies, coupled with the structure and propulsion systems from geostationary satellite designs.
- The design employs 4 side mounted 400N bi-propellant thrusters (2 pairs in cold redundancy) to provide the necessary thrust to de-orbit Envisat.
- With a 20% system margin, the wet mass at launch is 1480kg. This is close to the maximum Vega lift capability into the currently defined injection orbit (1.2% margin), and a risk exists that a larger and more expensive launcher will be required. It should be noted that future enhancements to Vega capability, may reduce this risk by the time the mission is ready to fly.
- Critical areas needing further in-depth investigation are the dynamics and control of the tethered pair of objects (both under thrust and in a passive configuration, and including the behaviour of the net with respect Envisat), and the interactions between the tether, the spacecraft structure and the thruster plumes.
- Assuming a proto flight model approach for the system development, a total design, development and verification schedule of 4.75 years has been defined.
- Technology developments will be needed for the capture mechanism, including development and engineering models, as well as tests on parabolic flights and potentially sounding rockets. Full scale testing in ground-level gravity will not be representative.
- Complementary ADR In-Orbit Demonstration missions are also planned to be flown in the coming years (e.g. European Union FP7 programmes) and a certain degree of technology de-risking can be expected, although these programmes will not be representative of the scale or mass of the Envisat target.
- The selected GNC sensors are either flight proven or already at a high TRL level. Nevertheless a development effort will be required in order to build a GNC system including the necessary software and processing algorithms. This will require the development of mission simulators and hardware in the loop testing.
- For the Chaser, in addition to the proto-flight model, structural qualification and thermal models of the spacecraft will also be needed, especially to validate the assumed thermal interactions.

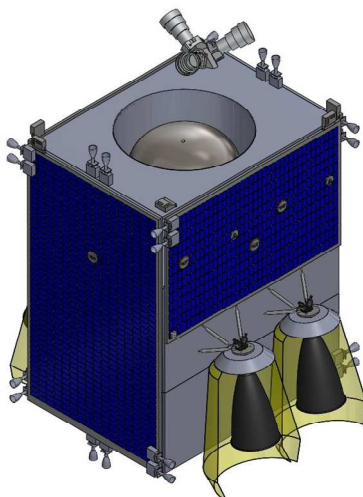


Figure 2: SSTL Chaser Concept

2.3.2 Objective 2

The possibility of providing the Envisat ADR mission as a service has been analysed, considering different financial, legal, and programmatic approaches. The main results are:

- It does not appear possible at the present time to conceive of a true PPP service model for a single Envisat mission.
- The market for ADR is as yet undefined, and the lack of a firm customer base makes large scale commercial investment for a single mission unfeasible.
- If a true service model is adopted, then this is likely to result in a price increase to ESA, a more risk-adverse approach from the viewpoint of spacecraft manufacturer, and a longer and more protracted development schedule.
- The mission will be legally complex, with several serious potential liability exposures. Commercial insurance products can be used to cover these to the maximum market limit, but state level indemnification may still be required.
- Under current international legal conventions, ESA – as the launching state – will retain legal responsibility for Envisat even if a service model was adopted.
- Agreement will be needed from the ESA member states who contributed to the Envisat programme, as they ultimately hold liability for Envisat (shared in a pro-rata arrangement).
- It is still not clear how liabilities would be shared once Envisat is captured and the two spacecraft are connected. Under current law, both ESA and the UK (if SSTL is the service provider) would retain legal responsibility for each other's 'part' of the composite pair of objects.
- Hold harmless agreements would be needed between ESA and SSTL in the event of a service approach.
- A hybrid staged payment model, in which ESA procure the spacecraft from SSTL under a defined and agreed programmatic approach, seems to be the best option.
- This kind of approach allows ESA to gain a quicker and lower cost development route, whilst also ensuring that the operational liability risk (which would be unmanageable in a commercial setting) is retained at state level.
- The proposed programmatic implementation foresees a collaborative approach between SSTL and ESA (as used on the GIOVE-A mission), in which a mutually agreed set of SSTL processes and development approaches are used in conjunction with a defined review and project milestone structure.

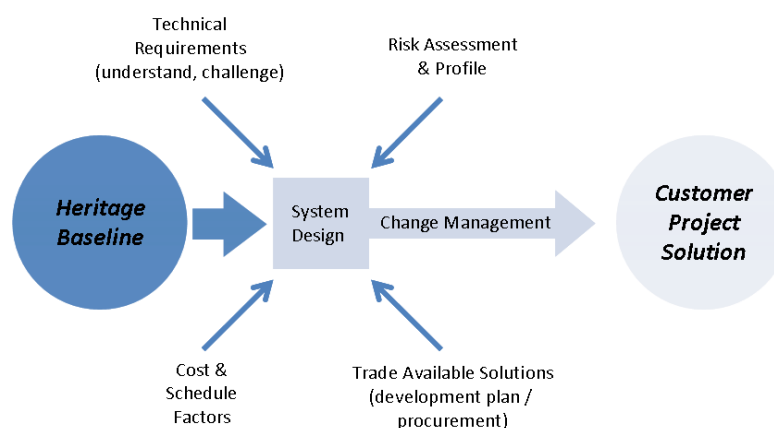



Figure 3: General approach taken by SSTL in developing a specific new mission based on existing heritage

2.3.3 Objective 3

The expected evolution of the LEO debris environment has been investigated, and the cost impact to operators estimated. The existing debris objects in orbit have been ranked in order of risk criticality, and the physical and political implications of the targets have been considered. A number of different architectures and concepts for ADR have been modelled. A hypothetical business plan for a future ADR service business has been produced, and preliminary financial predictions obtained. The main results are:

- An analysis of the commercial implications of space debris in the short to medium term shows that the financial implications for operators should be relatively small.
- The most significant increases in debris population numbers is predicted to occur in 100 years or more into the future, which again makes large scale short term investment unrealistic.
- Large scale commercial investment in ADR services in the short term seems unlikely, but there may be a moral and societal basis for undertaking ADR that could be politically driven rather than financially.
- A relative ranking of the highest risk posing debris objects (based on the product of their mass and collision probability) shows that total risk in LEO is dominated by several specific clusters of objects in altitude-inclination clusters.
- The primary risk source is a collection of Russian SL-16 (Zenit) rocket bodies and old Tselina-2 electronic intelligence satellites at 850km altitude and 71° inclination. There are 18 SL-16 rocket bodies in this grouping, each having a mass in excess of that of Envisat.
- Overall, the highest ranking risk debris in LEO is dominated by Russian objects, which account for ~2/3 of the highest priority objects.
- Many of the objects that could be considered as priority targets are associated with military missions and this could influence the ability of a commercial service provider to obtain permission to remove the object.
- In addition, some nation states may see ADR technologies and capabilities as national strategic assets, and not suitable for a service provision model.
- Out of a number of different architecture concepts for an ADR business that were analysed, the re-use of the Chaser concept developed for Envisat, coupled with an evolution using Electric Propulsion (known as a 'Shuttle') seem most attractive.
- The Shuttle concept removes multiple objects (e.g. 3 SL-8 rocket bodies from 975km altitude) to a LEO graveyard orbit at ≥2000km altitude, whilst the Chaser removes debris from lower orbits via a controlled atmospheric re-entry.
- Some modifications, particularly to the capture mechanism, may be needed for multi-target missions such as the Shuttle, which may require the accommodation of many capture systems. Concepts have been proposed including a moveable net dispenser, based on a rack and pinion mechanism.
- On the basis of a cost-based trade-off the Shuttle provides a much lower cost per object removed, but only at the expense of a smaller reduction in global LEO risk (mass and collision probability) compared to the Chaser missions.
- An ADR business concept has been developed based on a hypothetical SSTL subsidiary company called 'Surrey Removal Services' (SRS).
- A key element of the business model is that ADR missions will be coordinated by a new Intergovernmental Organisation (IGO) dedicated to space debris mitigation.
- The IGO will coordinate mitigation activities and ultimately contract for ADR missions (funded from an international pool), part financed by direct subscriptions from member states, and partly from launch deposits collected by national licensing authorities which would only be returned to operators that correctly comply with debris mitigation requirements.
- The creation of an IGO may be diplomatically and politically difficult and time consuming. However if ESA is seen to be taking active steps to remove Envisat from orbit, this could give it some 'leverage' in terms of providing momentum for the IGO creation.
- On the basis that the IGO will be funded from a mix of different sources from different countries, then it seems likely that some form of geographical return would be present, and it thus also seems unlikely that any one service provider would be allowed to capture 100% of the global ADR market.
- It is postulated that 'orbital sectors' could be defined, which would only be open for ADR services by certain suppliers (e.g. 'European' sector, 'American' sector etc.). Such sectors would comprise of a defined set of objects in a particular altitude and inclination range.
- The IGO will contract with a service provider such as SRS for a 10 year period, with the service for the removal of a certain number of debris in this time.
- The assumed SRS market share is predicted to initially be 2 objects per year for the first 10 years, rising to 5 objects per year for the next 10 years.
- The business is assumed to be setup in 2016, with the IGO created in 2019. The first service contract will be let in 2021 and the first missions are assumed in 2023.
- A small initial company equity investment is assumed, supplemented after 3 years by a second investment from a private investor, which would ideally be from a launch services provider (such a partnership could be advantageous for both sides in the long term, given the duration of the IGO contracts).

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- A commercial bank loan will be needed to finance the initial spacecraft manufacturing and launches. This is estimated to be €135M, which is modelled with an assumed 7% interest rate and is re-paid over 7 years.
- The SRS model assumes the re-use of the Envisat Chaser concept for the first 10 years of operation, with a mix of Chaser and Shuttle missions subsequently.
- A discounted cash flow model of the SRS concept shows that prices around €65M per debris removed with a Chaser, and €30M per debris removed via a Shuttle, are required to sustain the business.
- Such prices can only be achieved with adaption of non-European launch vehicles, and in particular postulated partially reusable concepts such as Falcon 9R, or completely reusable single stage to orbit vehicles such as Skylon from 2030 onwards.
- The model predicts a time-to-profit of approximately 11 years from formation in 2016, with a profit margin of ~25% by the end of the second set of IGO contracts.
- Over the time frame simulated (2 sets of IGO contracts), the total paid to SRS by the IGO will have a present value of ~€800M (discounted at 7%). Over this time SRS will have removed 70 objects from orbit, equating to an average present value cost of ~€11.4M per object.
- If considering constant value Euros, the total paid is ~€3400M, equal to €43.3M per debris.
- If the prices and debris removals carried out by SRS are extrapolated to an estimated global total, then over the 20 years of missions, the total spent on ADR is equal to ~0.46% of the global spending on all space activities (at current budgetary levels).
- Of this, the payments to SRS will account for 0.11% of the global spending on space.
- Considering the general societal and long-term economic benefits of ADR, it is argued that this level of financial commitment represents good value for money.

An overall roadmap for ADR, considering the development of an Envisat mission through to the first service contracts for SRS is shown overleaf at Figure 4.

On the basis of the preceding conclusions, the following high-level recommendations can be made:

- Continued study of ADR system concepts should continue, not only the Chaser design developed in this study, but also of other different or potentially complementary concepts in case other interesting solutions can be found. The knowledge base for ADR is still limited, and it is possible that new ideas may be generated in the coming years that could offer a better, lower risk, or lower cost solution.
- A dedicated and detailed study on the legal implications of a service approach could be considered, as the potential for liabilities and risk exposure is one of the largest blocking points to a commercial model.
- SSTL and ESA should work together to better understand each others expectations and requirements in terms of a mutually acceptable programmatic approach.
- ESA should work internationally with its space agency partners to promote the concept of the IGO.

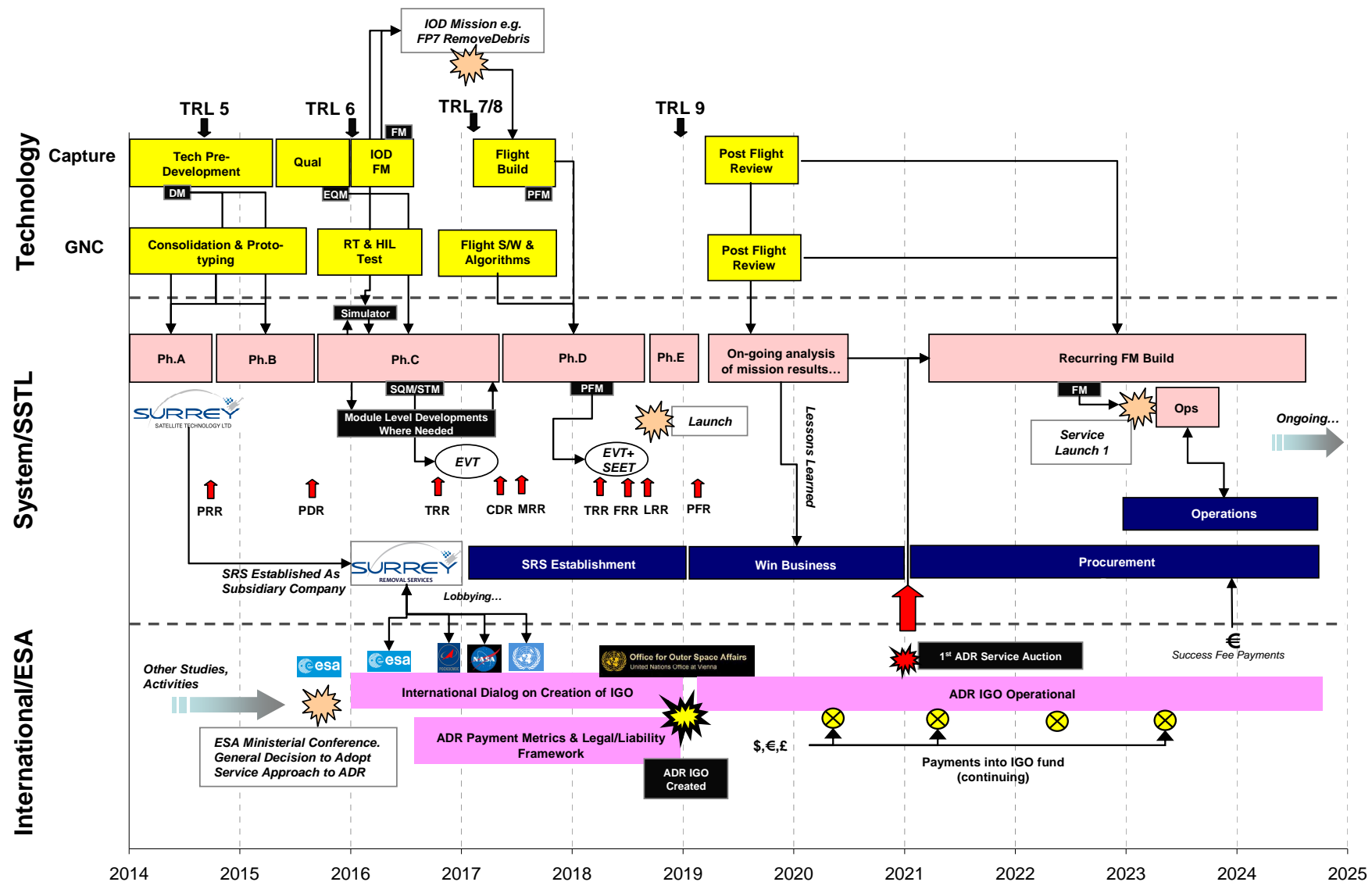


Figure 4: Roadmap for ADR, from development of Envisat mission through to first service contracts