Institution: University of Southampton

Unit of Assessment: 15 General Engineering

Title of case study: 15-22 Space Debris in Geostationary Earth Orbit

1. Summary of the impact

The University of Southampton's research into space debris has made a vital contribution to space policy by addressing an issue identified by the United Nations (UN) as having important implications for all humanity. This research has played a key role in advising policymakers "on how best to manage the orbital environment in a sustainable manner for generations to come" (page 52, UK in Space, British National Space Centre, 2009). Challenging prevailing theories, researchers influenced Inter-Agency Space Debris Coordination Committee (IADC) Space Debris Mitigation (SDM) guidelines, resulting in the implementation of sustainable practices by satellite operators in Geostationary Earth Orbit (GEO) requiring an investment by them of an estimated £1 billion since 2008.

2. Underpinning research

Most people in the world reap the benefits of space systems, driving revenues from commercial space products and services to £70 billion in 2011 (40% of the global space economy). The biggest demand comes from Global Positioning System devices and direct-to-home (DTH) television, but space technology also plays a vital role in responding to natural disasters that affect hundreds of millions of people each year. Without space infrastructure, the ability to manage humanitarian aid and water resources; to deliver health care, telephone and internet services in remote areas, amongst other vital services, would disappear; millions of people would be adversely affected.

Within this context, the UN described space debris as one of the top-ten issues of 2008 having important implications for mankind, alongside climate change and the global food crisis (*http://www.un.org/en/events/tenstories/08/spacedebris.shtml*). The UN also released guidelines on space debris mitigation (SDM) in 2008 and established a Working Group in 2010 to address the Long-term Sustainability of Outer Space Activities (LTSSA). The LTSSA Working Group's goal is to look at measures affecting the safe use of outer space for peaceful purposes and the benefit of all nations.

Research on space debris has been conducted at the University of Southampton since 1990 and throughout the impact assessment period. The work has been supported by the Defence Evaluation and Research Agency (DERA, three studentships, 1992-2001), QinetiQ, UK Space Agency and an EPSRC post-doctoral research fellowship, held by Lewis (1999-2002 **[3.1]**, subsequently Lecturer). Arguing in 1999 that space debris models are essential in predicting the characteristics of the debris environment but that research had focused on Low Earth Orbit (LEO) **[3.2]**, Swinerd recognised a need to understand the hazards in High Earth Orbit (HEO), especially GEO, which is considered too important and unique an environment to risk degradation. Active satellites here account for most of the revenue from commercial space services. Revenues from DTH broadcasting and satellite broadband internet services from these spacecraft were £55 billion in 2011.

Understanding the GEO debris population was the subject of important preliminary research performed in collaboration with DERA **[3.3]**. This led to the development of the Debris Analysis and Monitoring Architecture for the Geosynchronous Environment (DAMAGE) by Lewis and Swinerd, a simulation model of the GEO debris environment **[3.4]**. This model includes a fast propagator, enabling studies of millions of orbits **[3.5]**. In collaboration with QinetiQ (£40,000 estimate in kind) and the UK Space Agency (value £186,000), Lewis extended DAMAGE to LEO and Medium Earth Orbit (MEO) to enable full LEO-to-GEO analyses. There remain only a handful of models worldwide with similar capability to DAMAGE, which is unique in the UK and provides the technical basis for policy development. Richard Crowther, Chief Engineer for the UK Space Agency, explains:

> *"The research conducted by the University of Southampton… has been critical in developing both national and international policy to address the long term sustainability and security of space operations. The outcome of the DAMAGE studies and access to the expertise of key individuals at the University of Southampton… enable the UK to influence policy and technical development and position UK industry and academia to win leading roles in programme opportunities emerging from the European Space Agency and the European Union."*

Serving on the IADC, the inter-governmental agency coordinating worldwide activities related to space debris, Lewis used Southampton's DAMAGE simulation tool to assist in the design of updates to the IADC SDM Guidelines. In particular, collaborative research using DAMAGE was conducted by Southampton with QinetiQ and the US Aerospace Corporation **[3.6]** to assess the importance of the initial shape, or eccentricity, of the orbits used as graveyards by retired GEO spacecraft. This work was reported to the IADC and credited in its report on IADC Action Item (AI) 22.1, GEO Disposal Orbit Eccentricity, as a key motivation for updating the IADC SDM guidelines.

3. References to the research (three key references are indicated using *)

[3.1] Swinerd, G.G., Long-term evolution of the HEO space debris environment, EPSRC, October 1999-September 2002, £144,000.

[3.2]* Walker, R., Stokes, P.H., Wilkinson, J., and Swinerd, G.G., 1999, Enhancement and validation of the IDES orbital debris environment model. Space Debris, 1 (1), 1-19.

[3.3] Martin, C.E., Lewis, H.G., and Walker, R.J., 2001. Studying the MEO and GEO space debris environments with the integrated debris evolution suite (IDES) model. Proceedings of the Third European Conference on Space Debris, Darmstadt, Germany. The European Space Agency (ESA) Special Publication 473, 351-354.

[3.4] Lewis, H.G., Swinerd, G.G., Williams, N. and Gittins, G., 2001. DAMAGE: a dedicated GEO debris model framework. Proceedings of the Third European Conference on Space Debris, Darmstadt, Germany. The European Space Agency (ESA) Special Publication 473, 373-378.

[3.5]* Williams, D.N., Swinerd, G.G., Lewis, H.G., and Gittins, G., 2004. A new fast cloud propagator for use in the GEO regime. Advances in Space Res., 34 (5), 1181-1187.

[3.6]* Lewis, H.G., Swinerd, G.G., Martin, C.E., and Campbell, W.S., 2004. The stability of disposal orbits at super-synchronous altitudes. Acta Astronautica, 55 (3-9), 299-310.

4. Details of the impact (numbers in **[ ]** refer to section 5)

To ensure the sustainability of satellite services, IADC SDM guidelines published in 2002 recommended retired GEO spacecraft should be manoeuvred to graveyard orbits above the geostationary ring. The IADC reported to the UN in 2000 that the shape of these graveyard orbits did not need to be circular because altitude variations arising from elliptical orbits would reduce the collision probability within the graveyard (*http://www.iadc-online.org/Documents/37th_UN_COPUOS_STSC.pdf*).

Lewis was able to use his research findings and capabilities of the DAMAGE simulation tool to influence the IADC SDM guideline for disposing of GEO spacecraft. In the 2006 final report on IADC Action Item (AI) 22.1, GEO Disposal Orbit Eccentricity **[5.1]**, the analysis by Lewis et al. in **[3.6]** and work by the Indian Space Research Organisation (ISRO) were credited as the key drivers for updating the IADC SDM guidelines. Both sets of researchers recommended the graveyard orbit should be nearly circular with a maximum eccentricity of 0.005. This shape ensures that retired spacecraft do not return to the geostationary ring and pose a risk to active spacecraft there.

According to Luciano Anselmo, the former Head of the Italian Space Agency Delegation to the IADC [5.2],

> *"this 'interference' situation occurs more frequently than is typically assumed, and has definite costs in terms of control centre resources and eventual avoidance manoeuvres. The critical role of the initial eccentricity was therefore confirmed, and the results obtained by Lewis and colleagues, due to their level of completeness and detail, offered the needed guidance to propose a change of the IADC Mitigation Guidelines."*

In the context of work for IADC AI 22.1, some IADC delegations expressed concern that a guideline containing a maximum eccentricity requirement was overly constraining for satellite operators and proposed manipulating the initial orientation of graveyard orbits, as an alternative. By increasing the scope of their investigation for the IADC study and analysing the evolution of many possible graveyard orbits using DAMAGE, Lewis et al. demonstrated an initial 'sun-pointing' orientation was insufficient for long-term stability of the graveyard orbits in every case. Although contradicting the analyses performed by some other space agencies, Lewis argued this was due to a selection bias. Failure to address this issue correctly could have allowed some retired spacecraft to interfere or collide with active spacecraft on the geostationary ring and pollute the region with fragmentation debris. The final report of IADC AI 22.1 [5.1] adopted Lewis et al.'s recommendation that orbit orientations should be assessed on a case-by-case basis.

Thus, a consensus was reached and the IADC SDM guidelines were updated, reflecting a more conservative, maximum orbit eccentricity requirement of 0.003. The updated guidelines were published in 2007 and have remained unchanged throughout the REF impact assessment period [5.3]. According to Holger Krag, the acting chairperson of IADC Working Group 4, which establishes and maintains the IADC SDM Guidelines [5.4],

> *"The systematic analysis by Lewis of the stability of GEO graveyard orbit altitudes constituted a major input to the working group's activities. The recent version of the guidelines and the Support Document, which recalls the theoretical background to the guidelines, build upon findings in [3.6] and make use of material gathered in that work."*

Compliance with the IADC SDM guideline ensures that valuable "real estate" in the geostationary ring is freed for future use, interference with active satellites is minimised, and collisions resulting in the degradation of the GEO environment are prevented. Holger Krag explains, *"GEO operators appreciate such guidance and apply them with increasing success rates as can be concluded from [ESA's Report on the Classification of Geosynchronous Objects].* Joanne Wheeler, Partner for Telecoms and Satellite at CMS Cameron McKenna LLP [5.5], agrees:

> *"Lewis and the team at Southampton have world-leading experience in this area and the reputation for this. A key outcome of their work has been to identify what measures can be taken by satellite operators to support the sustainable use of the geostationary region, given the challenges presented by space debris risks. This is critical for the future growth of the UK and international space sector, which rely on revenues from communications satellites in geostationary orbit."*

The IADC SDM guidelines also directly influenced ISO 24113 Space Debris Mitigation Requirements and ISO 26872 Disposal of Satellites Operating at Geosynchronous Altitude. Dr Hedley Stokes, Co-convener of the ISO Orbital Debris Coordination Working Group explains [5.6],

> *"The University of Southampton's analysis of GEO spacecraft post-mission disposal orbits has provided organisations such as IADC and ISO with extremely valuable data to assist in the formulation of international space debris mitigation guidelines and standards."*

In addition, Lewis has informed the public debate over the threats from space debris, through evidence given to the June 2013 meeting of the House of Commons Science and Technology Committee [5.7], and through a September 2011 interview on the BBC World News Today programme broadcast on BBC World News (weekly audience estimated to be 74 million: *http://www.bbc.co.uk/news/world-radio-and-tv-12957296*) **[5.8]**.

In terms of compliance with this IADC SDM Guideline, there are consequences for GEO satellite operators: the fuel used to manoeuvre a satellite to a graveyard orbit would otherwise be used to maintain satellite operations on the geostationary ring and generate revenues for around three months (roughly one-quarter of the yearly station-keeping budget). Dean Hope, Senior Manager of Flight Dynamics at Inmarsat **[5.9]** explains:

"Inmarsat and many other commercial operators now recognise the need to budget sufficient propellant onboard spacecraft in order to perform orbit raising at end of life. This is an investment that is vital to avoid the possibility of running out of fuel and drifting through the GEO arc, thereby increasing the risk of collision and polluting such a valuable resource with orbital debris. Inmarsat appreciates the work of Lewis and colleagues, which has enabled the IADC and ISO to provide much-needed, precise guidance to spacecraft operators on end of life orbit raising. Most recently, in April 2013 and after almost 23 years of operations, Inmarsat 2F1 was successfully re-orbited to an altitude of more than 400 km above GEO in accordance with IADC space debris mitigation guidelines and new ISO recommended disposal standards."

Based on the fuel requirements, re-orbiting to a graveyard orbit in compliance with the IADC SDM guideline requires an investment by satellite operators, equivalent to £16 million of earnings per satellite **[5.10]**. According to European Space Agency data, 50 of 79 GEO spacecraft reaching the end of their operational life between 2008 and 2012 were re-orbited in compliance with the IADC SDM guideline resulting in an investment of up to £800 million by the commercial space service sector. Based on current re-orbiting rates, an additional 8-18 GEO spacecraft are expected to be re-orbited by the end of 2013, increasing the investment to an estimated £1 billion during the REF assessment period.

5. Sources to corroborate the impact

[5.1] IADC AI 22.1 Final Report on GEO Disposal Orbit Eccentricity, April 2006.

[5.2] Southampton work as driver for update to IADC SDM guidelines: Istituto di Scienza e Tecnologie dell'Informazione "Alessandro Faedo", National Research Council, Italy.

[5.3] IADC Space Debris Mitigation Guidelines, IADC-020-1, Revision 1, September 2007 (http://www.iadc-online.org/Documents/IADC-2002-01,%20IADC%20Space%20Debris%20Guidelines,%20Revision%201.pdf).

[5.4] Southampton contribution to update of IADC SDM guidelines: European Space Agency Space Debris Office, Darmstadt, Germany.

[5.5] Partner,Telecoms and Satellite, CMS Cameron McKenna LLP.

[5.6] Impact of Southampton work on International Standards: Co-convener of the ISO Orbital Debris Coordination Working Group.

[5.7] http://www.parliament.uk/business/committees/committees-a-z/commons-select/science-and-technology-committee/news/130606-space-ev/

[5.8] http://www.bbc.co.uk/news/science-environment-14763668

[5.9] Impact on operators: Senior Manager, Flight Dynamics, Inmarsat.

[5.10] Estimate based on 2012 and predicted revenues from HYLAS-1 satellite: http://www.avantiplc.com/investors/financial-reports