Rationale for Need of In-Orbit Servicing Capabilities for GEO Spacecraft

Prepared by Intelsat General Corporation

At both NASA and DARPA, robotic programs are being executed which will serve as catalysts for changing how the commercial world thinks about satellites and satellite life. Technology is being developed today by both governments and private companies which will allow towing, servicing and lifetime extension of spacecraft already in orbit. These same technologies can be leveraged to come to the rescue of future satellite missions which suffer launch performance shortfalls or deployment anomalies. The capability of these robotic vehicles could even include the potential to collect orbital debris.

While the apparent advantages seem many, it has been a challenge to socialize these capabilities with both commercial operators and with the United States Government. This paper will discuss some of the history of in-orbit servicers, current program status, benefits which could be realized by on-orbit servicing (for both recently-launched as well as heritage / end-of-propellant-life spacecraft) as well as discuss the reasons why potential users have been hesitant to embrace this technology.

Nomenclature

ASTRO	=	Autonomous Space Transport Robotic Orbiter
ATK	=	Alliant Techsystems Inc.
BOL	=	Beginning of Life
COF	=	Cost of Funds
CONOPS	=	Concept of Operations
DARPA	=	Defense Advanced Research Projects Agency
DART	=	Demonstration of Autonomous Rendezvous Technology
EOL	=	End of Life
GEO	=	Geostationary Earth Orbit
GOES	=	Geostationary Orbiting Environmental Satellite
ASAT	=	Anti Satellite
ISR	=	Intelligence, Surveillance & Reconnaissance
ISS	=	International Space Station
LEO	=	Low Earth Orbit
MDA	=	MacDonald, Dettwiler and Associates
MEV	=	Mission Extension Vehicle
NASA	=	National Aeronautics and Space Administration
OE	=	Orbital Express
OLEV	=	Orbital Life Extension Vehicle
ROI	=	Return of Investment
RPO	=	Rendezvous and Proximity Operations
RRM	=	Robotic Refueling Mission
SIS	=	Satellite In-orbit Servicer
SMART	=	Small Missions for Advanced Research and Technology
SSCO	=	Satellite Servicing Capability Office
TCL	=	Total Constructive Loss
TTO	=	Tactical Technology Office
USG	=	United States Government

Intelsat General Corporation, AIAA Member.

I. Introduction

AT both NASA and DARPA, robotic programs are being executed which will serve as catalysts for changing how the commercial world thinks about satellites and satellite life. Technology is being developed today by both governments and private companies which will allow towing, servicing and lifetime extension of spacecraft already in orbit. These same technologies can be leveraged to come to the rescue of future satellite missions which suffer launch performance shortfalls or deployment anomalies. The capability of these robotic vehicles could even include the potential to collect orbital debris.

While the apparent advantages seem many, it has been a challenge to socialize these capabilities with both commercial operators and with some agencies of the United States Government. This paper will discuss some of the history of in-orbit servicers, current program status, benefits which could be realized by on-orbit servicing (for both recently-launched as well as heritage / end-of-propellant-life spacecraft) as well as discuss the reasons why potential users have been hesitant to embrace this technology.

The term "in-orbit servicing" refers to operations conducted on in-orbit spacecraft intended to accomplish some value-added task. While most may think that this implies use of robotics to mechanically assist a satellite in need, it also refers to activities such as providing "life extension" or performing visual inspections.

<u>In-orbit Servicing Examples</u>

- Robotic Manipulations
  - Assisting release of stuck solar arrays or antennas
  - Adjusting out-of-place thermal blankets
  - Placing mechanism coordination cables back into tracks
  - Addition / removal of externally accessible hardware
  - Collection of orbital debris

- Life Extension
  - Using attached stationkeeping / momentum dumping modules to allow continued operations
  - Delivering consumables (fuel, oxidizers, pressurants, coolants, ion-drive fluids)

- Towing
  - Moving non-operational spacecraft out of GEO (dealing with "ZombieSat")
  - Assisting with orbit raising of spacecraft receiving substandard launch service drop-off
  - Tugging end of life spacecraft to graveyard orbit for decommissioning
  - Inclination lowering, orbital node rotation,

- Inspections
  - Examination of damage caused by launch events
  - Imaging of possible damage caused by orbital debris
  - Analysis of partially-deployed hardware anomalies

II. Development of In-Orbit Servicing Technology Facilitated by the United States Government

Two agencies of the U.S. Government (NASA and DARPA) have recently been in the spotlight due to their on-going servicing program initiatives. Specifically NASA Goddard's Satellite Servicing Capability Office (SSCO) has been developing technology for refueling of GEO spacecraft for quite a number of years. The DARPA Phoenix program sponsored by the Tactical Technology Office (TTO) has been developing hardware to "harvest" antennas from retired spacecraft and demonstrate their reuse. The goal of both NASA and DARPA is not to compete with a possible commercial servicing venture in the U.S., but rather to assist with socialization and development of a U.S.-based commercial space robotic business so that the country retains a leadership position.

NASA Robotic Refueling and Restore Mission

Goddard's current efforts for their RESTORE mission[1] (see Figure 1) focuses on teaming with a commercial entity who will provide program financial assistance by potentially providing a bus (hosting NASA's refueling robotics) and by providing launch services for the refueling spacecraft. Their recent Robotic Refueling Mission[2] (RRF) demonstration hosted on the International Space Station (ISS) has served to reduce risk by working out possible kinks in the robotic hardware and operational procedures (see Figure 2). To the commercial world, the pace of RRF schedule execution appears overly drawn out – but NASA is likely being driven to move very slowly to avoid making any mistakes (as operational errors will result in excessive public scrutiny). Goddard was recently budgeted $125M in FY 2014 to continue this work. A significant increase over last year, Goddard should have budget sufficient to continue to build flight hardware.

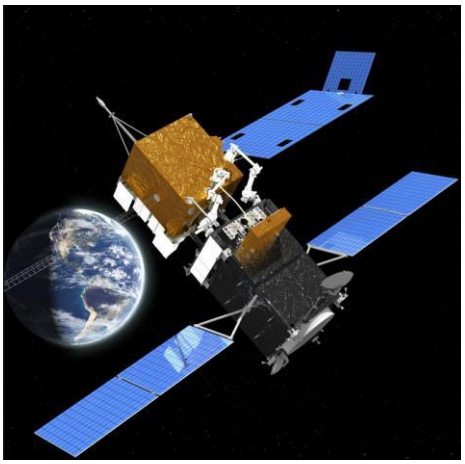

Figure 1: RESTORE Robotic Spacecraft (right) Tending GOES (left) [NASA]

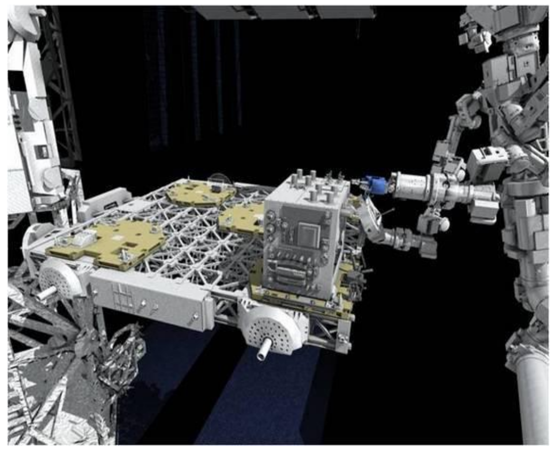

Figure 2: Dextre Two-armed Robot Carrying out RRM Demonstration on ISS [NASA]

Phoenix

The DARPA Phoenix antenna harvesting / reuse program[3] (See Figure 3) is organized into three phases. Phase 1 of the program, where design trades are evaluated and leveraging of new technologies is assessed, is nearing completion. Phase 2 of the program should begin later this year with building of flight hardware and refinement of mission CONOPS. A challenge for Phoenix is a mass-limited launch which will not permit demonstrations using highly inclined antenna donors (where most retired spacecraft reside) and budget which may require scale-back for some of the program objectives. More than two dozen companies (including some out of the United States) have been contracted to conduct Phase 1 activities. While some of these companies at first glance appear to have solutions looking for a purpose –DARPA has demonstrated insight which seems to leverage each of these technologies to their fullest extent. While DARPA has gone to great lengths to provide world-wide visibility into the Phoenix program, there will likely be those who nevertheless claim that this technology is being developed for ASAT applications. If the Phoenix program objectives end up being overly ambitious, partial execution of the program may only demonstrate that robotics can be used to disable on-orbit satellites.

Figure 3: Phoenix Servicer Tender Docked to Aperture Donor Spacecraft [DARPA]

Orbital Express

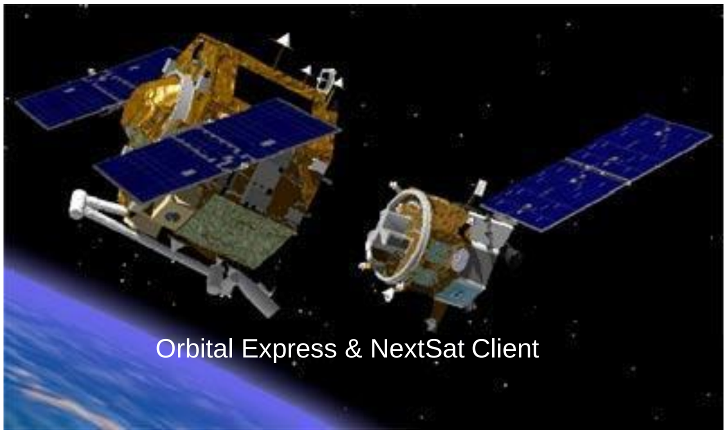

Figure 4: Orbital Express Spacecraft [Boeing]

In 2007 DARPA's Orbital Express (OE) program (see Figure 4) demonstrated "the technical feasibility of robotic, autonomous, on-orbit refueling and reconfiguration of satellites during a three-month mission"[4,5] in Low Earth Orbit (LEO). During this mission a serviceable "client" satellite (NextSat) was serviced by the Autonomous Space Transport Robotic Orbiter (ASTRO) servicing vehicle. During the OE mission, several Rendezvous & Proximity Operations (RPOs) and docking demonstrations were conducted. Liquid propellant, a battery and a flight computer were successfully transferred from ASTRO to NextSat. Unfortunately, while the mission was highly successful, both vehicles were decommissioned and left to begin orbital decay immediately after the DARPA mission objectives were completed – eliminating a possible opportunity to provide inexpensive leave-behind capability using either space vehicle. Either spacecraft could have served as a host platform for LEO-based experiments for many years to come.

DART

Figure 5: DART Ranging MUBLCOM [NASA]

The success of OE in 2007 attenuated waning confidence in in-orbit servicing following NASA's Demonstration of Autonomous Rendezvous Technology (DART) incident a couple of years earlier[6]. The goal of the 2005 DART program was to demonstrate completely autonomous in-orbit rendezvous between DART and the MUltiple paths Beyond-Line-of-sight COMmunications (MUBLCOM) satellite (see Figure 5). Unfortunately, as a result of inaccurate navigational data DART actually collided with MUBLCOM. This was compounded by premature estimation of propellant exhaustion which initiated an autonomous retirement by DART. While partially successful in meeting its goals, the program mishap could likely have been avoided had sufficient systems engineering been conducted during the design and test phase of the program.

III. Development of In-Orbit Servicing Offerings by Commercial Entities

In-orbit servicing is not a new concept and several companies have been pursuing potential customers for some time. The early European offerings (Orbital Recovery Corporation & Orbital Satellite Services Limited) included vehicles whose purpose was to attach to the aft end of a satellite and provide propulsion, navigation and guidance if the spacecraft did not have the capability or did not want to use its on-board propellant resources. Currently in the United States, ViviSat/ATK is advertising a similar capability to:

- place or maintain satellite's position in their designated orbital slot
- move satellites into a different orbital slot, inclination or rotate orbital nodes
- tow dead GEO satellites into graveyard / supersync retirement orbit

Long considered the "Holy Grail" of in-orbit servicing[7], refueling of on-orbit satellites is being pursued by Canada's MacDonald, Dettwiler and Associates (MDA). Refueling provides life extension services for spacecraft whose attitude control system is intact but just suffers from a lack of propellant. The MDA refueler is designed to move from one spacecraft to another and does not require hardware to be left behind. It would seem that the best offering might be from a company that could offer to a client robotic servicing and life-extension services (whether it be via tug or refueling). As the on-orbit market for clients is limited, a consolidation of capabilities from a single entity may be in the future.

OLEV

European Orbital Life Extension Vehicles (OLEVs) have been offered by two companies[8,9]. The first used Orbital Recovery group's ConeXpress-OLEV (CX-OLEV) vehicle (see Figure 6). This was essentially a tug mounted on the aft end of the client to prolong the operating lifetimes of by supplying propulsion, navigation and guidance. In 2005, Orbital Recovery announced they had entered into a Memorandum of Agreement (commercial client signed for a reservation) to provide services to a commercial customer with a launch date in 2008. Two deployments were planned for 2009, followed by three annually from 2010. It appears that Orbital Recovery missions did not move to completion as very little has been heard from them for quite a few years.

Figure 6: ConeXpress-OLEV and Client Spacecraft [Orbital Recovery]

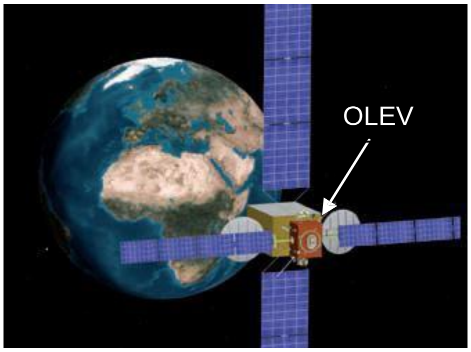

Figure 7: SMART-OLEV in its Mated configuration [Orbital Satellite Services]

Several key players pulled out of Orbital Recovery in 2007 to form a new venture called Orbital Satellite Service Limited (OSSL)[10]. They offered an Orbital Life Extension Vehicle (OLEV) based upon ESA's Small Missions for Advanced Research and Technology (SMART) platform developed by Swedish Space Corporation (see Figure 7). The SMART-OLEV service was originally planned to launch at the end of 2010 - with the first docking in space slated for 2011. After announced delays, the go-forward schedule appeared to have been indefinitely put off.

DEOS

The German Space Agency, DLR (Deutsches Zentrum für Luft und Raumfahrt), has been developing the Deutsche Orbitale Servicing mission (DEOS) robotic spacecraft for over a decade (see Figure 8) and contracting with various European companies to work on various technical elements.[11] One DEOS mission consists of a capture of a non-cooperative and tumbling defective satellite (orbital debris) which is then pulled into a destructive re-entry into the Earth's atmosphere.

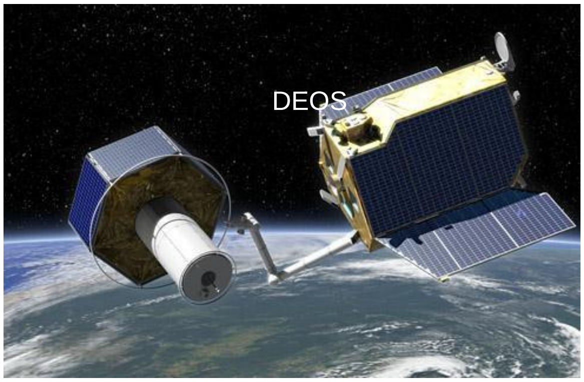

Figure 8: DEOS Robotic Spacecraft Attending Client [DLR]

Refueling applications are also being considered. “But to date, nobody has been willing to invest in such a system, in part out of concerns about liability in the event that a planned in-orbit rendezvous damages the satellite selected for servicing.” [12]

MDA - SIS

Figure 9: Satellite In-orbit Servicer (SIS) docked to Client Satellite [MDA]

In March of 2011, MacDonald, Dettwiler and Associates (MDA-Canada) and Intelsat announced they had signed a major contract ($280M) for delivery of propellants to Intelsat’s fleet spacecraft using MDA’s Satellite In-orbit Servicer (SIS)[13,14,15,16,17]. This was a game-changing innovation as previous commercially-offered solutions for life extension required use of attached tugs.

The initial year of operation was slated to be ~2015 – however, in January of 2012 the companies announced they “would be canceling their collaborative agreement”. MDA indicated they had placed their SIS initiative on hold pending finding a second client, beyond Intelsat. MDA also had a lot of uncertainty over whether they would be able to bid on USG contracts – especially since NASA Goddard indicated they would be building and launching a robotic servicer to refuel USG satellites - possibly in advance of MDA’s current schedule. According to MDA, the NASA-backed satellite servicing venture would pose “very challenging competition” to service USG spacecraft. Intelsat indicated they would “remain very interested in refueling and SIS, and will continue to explore potential solutions to refueling.”

ATK – MEV

Meanwhile in the United States, ViviSat and ATK (Alliant Techsystems Inc.) have been developing a tug technology to provide supplemental attitude and propulsive capabilities[18]. Named the Mission Extension Vehicle (MEV) it provides life extension and other services very similar to the European OLEV (see Figure 10). The “all US” ViviSat solution may initially have an advantage over MDA in serving the USG marketplace. It is noteworthy that ViviSat recently opened the ATK RPO facility to clients – demonstrating the MEV system one step closer to operational capability.

Figure 10: ViviSat Mission Extension Vehicle About to Dock with Client [ViviSat]

It is interesting to note that MDA, ATK, and Intelsat were all awarded DARPA contracts for elements of the Phoenix program. This clearly indicates significant interest in orbital robotics from not only satellite / technology builders, but also from the user community. This begs the question, why is no satellite owner/operator currently under contract with a satellite service provider?

IV. Financial Benefits of In-Orbit Servicing

Clearly robotic servicing can offer potential solutions to address on-orbit anomalies and propellant shortfalls for both commercial and government spacecraft. In the case of a commercial communication satellite at GEO the owner's investment could be $200M - $400M (taking into account build of the spacecraft, the launch and insurance). USG satellite programs (usually uninsured) could easily cost twice to ten times this amount, consequently the "benefit" of a robotically-assisted recovery provides even greater value. A fair evaluation of the benefits for in-orbit servicing really needs to take into account two different types of owners (commercial versus government) and two different type of spacecraft (new versus older "heritage" satellites).

The "value" of a new satellite initially seems pretty easy to determine – perhaps just the sum of the cost of manufacture, launch and insurance? This is actually an over-simplistic picture because the executed mission of the spacecraft always provides a greater value than its replacement cost (which is the value insured). A positive Return on Investment (ROI) is always required for commercial programs. The ROI needs to include many factors, including the Cost of Funds (COF) since alternatives exist regarding whether available cash should be invested or used to buy down existing debt. A programs' ROI must significantly exceed COF – especially if mission hazard exists which puts satellite revenues at risk. The breakeven for recouping this investment takes many years and failure early in life has a very detrimental impact on a company's projected revenues and valuation.

If a new, insured commercial spacecraft suffers a launch service shortfall, a deployment anomaly, or other type of problem which results in a diminished capability to provide services, the terms of the insurance policy generally specify some point at which a "pro-rated" payout is replaced by a Total Constructive Loss (TCL) payout. This TCL may be based upon a loss of life (i.e. propellant) or loss in capability of the payload itself (hardware failures). If a servicer could increase the lifetime above the TCL threshold, then a considerable ROI may be realized (by the insurance company). However, if the on-orbit service is not "almost immediately" available, the insurance company may be obligated to pay the claim in a timely fashion (well in advance of the ability of a servicer to "come to the rescue"). Robotic-assisted freeing a stuck antenna or solar array would provide considerable value to the satellite owner operator, the spacecraft manufacturer, and the insurance company.

ROI for USG spacecraft is much more difficult to assess for several reasons. First of all the "program" delivered capability cost is made up of many things besides the "per item" space asset – it also includes considerable NRE, ground infrastructure, hardware designed/built specifically for the space asset, a lot of labor and oversight,.. Especially difficult to assess is the loss in earned-value when a space asset is NOT available when needed. How is the cost of a delayed or botched USG military mission assessed – especially when international relations may have been affected or lives may have been put in jeopardy (or lost) due to impairment of mission-dependent Intelligence, Surveillance, and Reconnaissance (ISR) capability? Commercial operators have a pretty good idea of the amount of lost revenue because amount charged for service is contractually well-understood (as are financial penalties when the service is not available). Regardless, just considering the replacement cost for the USG space asset will be sufficient for this sort of discussion.

Performing life extension on an older spacecraft has met with considerable skepticism - often heard is that the "business case cannot close". Let us examine this claim in more detail.

If the older satellite runs out of propellant prematurely (due to excessive propellant burn following an anomaly or poor propellant bookkeeping) the owner operator may have limited options. If sufficient propellant exists, the owner operator may opt to cease North/South Station Keeping (NSSK) which consumed the majority of propellant but continue to provide inclined orbit services (remaining propellant used just for East/West Stationkeeping and possible momentum dumping). Annual inclination growth of ~0.8 degrees may be acceptable for some customers who have antennas capable of tracking the spacecraft. The owner operator may opt instead to move customers to a backup spacecraft and (if possible) attempt to move the spacecraft to graveyard orbit for decommissioning. If service cannot be maintained for the customers, the owner operators lose both the revenue, expose themselves to possible penalties, and damage their reputation for providing dependable service. In this case, the availability of a servicer to provide life extension (either by refueling or through a tug service) provides great value. If a satellite has 24 transponders (small satellite) earning $2M / year (average), continuation of a $48M revenue stream might be enabled by using a servicer. Larger spacecraft may have 48 to over 100 transponders – yielding considerably higher ROI with just a slightly higher annual life-extension cost.

It is possible that the life of an operational satellite can be extended just to delay the cost of building and launching its replacement. In this case the “benefit” comes from that delay in spending capital. Assuming a COF of 6% on a $300M investment, it would seem that delaying the replacement satellite would save $18M annually – this is where the business case becomes challenging. It is possible that the annual cost of providing life extension services may be close to this number – hence there appears to be little incentive to delay manufacture of the new spacecraft, especially if the new spacecraft includes additional capabilities which may increase total revenues possible from its assigned orbital slot. However in a time when capital is tight or customers are unable to commit themselves to contracting for service from the new spacecraft (possibly at a higher cost per transponder), life extension remains a viable short-term option. Note that new “all electric” satellites might not be propellant constrained in the future, but since there are already hundreds of spacecraft on orbit depending on liquid propellant to maintain orbital control, a “life extension” business window of 12 to 15 years is likely to presently exist.

USG spacecraft missions (satellite and launch) frequently cost $500M - $2B, but the savings from delaying expenditure of tax dollars to fund these missions is a little more difficult to calculate. Given the interest paid on 10-year Treasury Bills (currently around 3%) the annual cost of funding a $1B program would seem to be ~ $30M, so it is likely that life extension could be value added for the USG. However, even with greater financial incentive the USG will likely be one of the last to leverage the advantages for the reasons noted in Section 6.

V. Industry Need for In-Orbit Services

It seems that the principal benefits of an on-orbit servicing capability are realized only to deal with surprises such as a Beginning of Life (BOL) anomaly or unexpected End of Life (EOL) propellant depletion. Resolving BOL anomalies provides a “windfall” opportunity with huge ROI. However, both of these situations are unplanned and consequently difficult to put into a business plan. The only service which can reliably be put into a business plan is Life Extension for prolonging the life of EOL spacecraft – and there the commercial business case is “marginal”.

Can BOL anomalies on GEO spacecraft be predicted? If so, investment in an in-orbit servicing capability might be justified based upon a statistical ROI. In September of 2011 The Aerospace Corporation conducted an interesting study of all spacecraft launched to GEO in the past 20 years[19]. As can be seen from Figure 11, excluding catastrophic launch failures, approximately 10% of satellites launched experience premature EOL (termination of services prior to the end of their design lifetime). Additionally approximately 1/3 of satellites launched 15-20 years ago were still operational today – well past their initial design lifetimes. Contrary to popular belief, old satellites do not just fall apart at the end of their design life – many functional spacecraft are decommissioned due to lack of stationkeeping propellant. In fact, it is probably more likely that a new satellite will suffer from a launch failure than a “heritage” spacecraft will suddenly fail during several years of life extension.

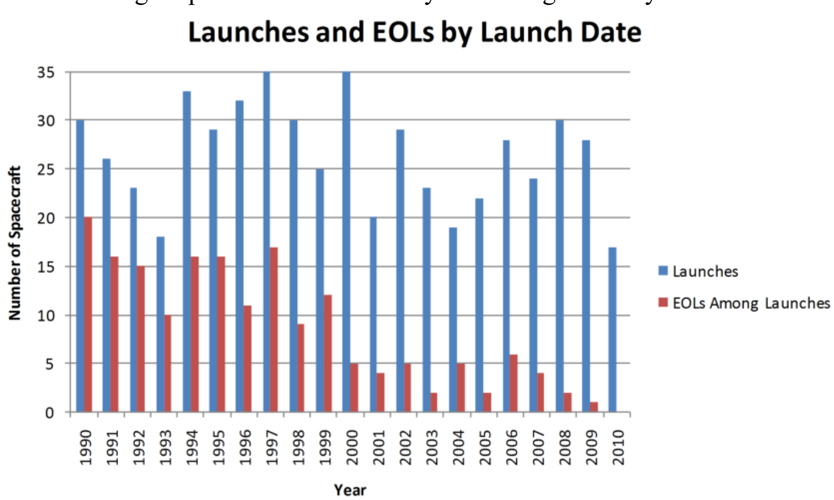

Figure 11: GEO Satellites Still Operational Over Past Twenty Years [Aerospace Corp.]

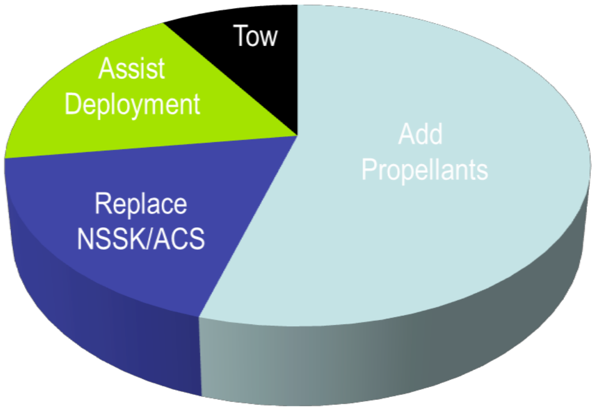

Figure 12: Serviceable GEO Satellite Anomalies over Past 10 Years [Intelsat General Corporation]

A literature study of published satellites anomalies over the past 10 years indicated about one-half of these failures could have benefited from some sort of in-orbit servicing. As shown in Figure 12, over 1/2 of these spacecraft would have benefited just by the addition of liquid propellants, about 1/3 would have benefited from a tug (which also would have been a solution for propellant shortfall), and aboue 1/6 of the spacecraft would have benefited by robotic assistance for a deployment.

Statistically, a company such as Intelsat with over 50 satellites in GEO and launching an average of ~3 satellites per year to replenish the fleet (15 year design life) could be expected windfall benefits by BOL servicing at a fairly predictable rate:

3 spacecraft / yr x 10% premature end of life x ½ serviceable now = 0.15 windfall serviceable anomlies / yr

This means that just for Intelsat, approximately 1 anomaly will occur every 7 years where simple in-orbit servicing could "save the day" and provide a windfall ROI based upon current technology. While this number is not surprising (in fact might even seem too low) we need to also take into account that there are currently over 400 non-classified satellites in GEO – thus Intelsat's contribution is about 1/8 of the total. Multiplying by 8 we find that statsistically there will be at least one GEO satellite in need of simpleBOL servicing every year. [20]

The rate of BOL satellite failures where in-orbit servicing could provide a windfall gain (~1/ year across the industry) suggests that closure of a business plan to provide servicing will require "endorsement" by several owner operators. The business case for extending the life of heritage commercial spacecraft is marginal but predictable. The best combination seems to be contracting for EOL life-extension services sufficiently to "just close" a business plan, and then depend upon the windfall gain of a BOL rescue to fully make the case. This is reminiscent of an insurance policy where coverage for small ticket items (life extension) enables coverage for catastrophic loss (BOL rescue).

VI. Reluctance by the GEO Community to Embrace In-orbit Servicing

Having established the statistical need and the finanical ROI, what are the reasons that most owner operators still not embraced in-orbit servicing?

1) owner operators and the USG would rather build new satellites with the latest technology and additional capabilities than depend on extending the life of older spacecraft
2) in today's world of shrinking budgets with funding for expensive satellite programs in the crosshairs for cancellation, the arrival of an option (life extension) which could provide justification for space asset budget reduction or delay is seen as a threat, not as a benefit
3) owner/operators think servicing places space assets into "harm's way" and creates risk of accidental collision and creation of orbital debris
4) owner/operators are not confident that servicing can be conducted without causing attitude transients or other problems which would cause satellite services to be disrupted

Additionally, while robotic servicers could provide a path for capture of orbital debris, there is currently little financial incentive or controlling government regulation motivating investment in a pricy venture to collect yesterday's space trash.

VII. Conclusion

The high-confidence business case (life extension for EOL spacecraft) provides a positive but not overwhelming return on investment. If interest rates increase (as is likely with the devaluation of the U.S. dollar on the world market) the business case for life extension of EOL satellites will improve. Building a business case for servicing problems that have not yet occurred (BOL anomalies) is a challenge, but waiting until the anomaly has already occurred will not yield sufficient responsiveness to be practical.

Satellite owner operators are a conservative community and unwilling to take any chances with space assets. They will sit on the sidelines watching to see what happens and jump in only after in-orbit servicing at GEO has been proven by somebody else. Both NASA and DARPA have recognized this reluctance and have established programs to help develop space robotic capability. Once the technology has been sufficiently socialized and proven on-orbit, it is expected that commercial industry will be swift to fully leverage the possibilities.

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