Investing in Satellite Life Extension – Fleet Planning Options for Spacecraft Owner/Operators

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As satellite owner operators are challenged to provide enhanced services to their customers at lower cost per bit, a creative approach is required to meet economic realities. Business plans include significant investments to finance the satellite build, procure launch services and purchase insurance. As prices for these items escalate and bandwidth becomes scarce, satellite owner operators can meet the challenge in one of two ways – they can either invest in new high-throughput satellites (expensive) or extend lifetimes of existing space assets (inexpensive). With the end goal of minimizing the cost / bit paid by their clients, some owner operators are choosing to do both.

This paper will explore the economics of life extension, the technical options available, and the challenges faced by those investing in providing these services to the world community. Additionally, as security of owner/operators' producing space assets is considered paramount; this paper will discuss how commercial industry is addressing this concern. Also presented will be the spin-off benefits to the world space community generated by development of life extension technology.

Nomenclature

ATK	=	Alliant Techsystems Inc.
ASAT	=	Anti-Satellite Technology
BOL	=	Beginning of Life
COF	=	Cost of Funds
CTL	=	Constructive Total Loss
EOL	=	End of Life
GEO	=	Geostationary Earth Orbit
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
ROI	=	Return of Investment
SIS	=	Satellite In-orbit Servicer
USG	=	United States Government

I. Introduction

As satellite owner operators are challenged to provide enhanced services to their customers at highly competitive rates, a creative approach is required to meet new economic realities. Business plans include significant investments to finance the satellite build, procure launch services and purchase insurance. As prices for these items escalate and bandwidth becomes scarce, satellite owner operators can meet the challenge in one of two ways – they can either invest in new high-throughput satellites (expensive) or extend lifetimes of existing space assets (inexpensive). With the end goal of minimizing the cost / bit paid by their clients, some owner operators are choosing to do both.

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concern. Also presented will be the spin-off benefits to the world space community generated by development of life extension technology.

"Life Extension" refers to the process of lengthening the period of time that an on-orbit asset can be operated in a manner consistent with its intended purpose while staying within its licensed orbital and operational boundaries. Indeed, the intended purpose of the space asset may change over its lifetime and a life-extended satellite may not provide the same revenue opportunities as originally envisioned, however an attractive return of investment is still possible – especially at the end of life when the asset has been fully depreciated the only investment "costs" consist of satellite operations and the expense associated with life extension services.

A previous paper presented at Space 2014[1] by this same author provided an overview of "in-orbit servicing" and described in some detail the technical progress made by various commercial companies and USG agencies along that path. The intent of this paper is not to provide an update on that initial overview, but rather to focus on the financial benefits provided one of these services – specifically "life extension". After several years of hearing satellite manufacturers and some in the USG claim that "there is no business case for" and "no interest in" life extension, perhaps it is time for a commercial company to provide an alternative viewpoint and back it up with some representative numbers.

II. Commercial Options Offered to Provide Lifetime Extension Services

Two fundamentally different technologies are being offered to provide life extension services to on-orbit spacecraft. One of the services involves use of an attached tug that replaces the station keeping (orbital control) and momentum dumping function of the host spacecraft. The other service consists of robotic refueling - transfer of liquid propellants from the servicer to the client allowing the satellite to continue use of its own propulsion and attitude control subsystems. Both of these solutions involve similar orbital rendezvous and docking procedures, however that is where the similarity ends.

A) Tug Services

Tug services are being currently being offered by ViviSat (working with Orbital/ATK) using a platform they have christened the Mission Extension Vehicle (MEV)[2] – see Figure 1. The MEV remains attached to the client satellite for as long as the service is required and replaces the ACS (Attitude Control System) functions of the client. Orbital drifts, station keeping functions, momentum dumping become the responsibility of the tug.

The business case is challenging as the MEV must remain attached as a "mass tax" for the life of the contract. Additionally, the business case must cover not only the propellant used to station keep the client, but also the propellant to station keep the mass of the MEV. If a tug service is contracted to remove inclination, the business case must cover the cost of increasing inclination of the MEV to dock with the client, then return of the combined mass to lower inclination. An overwhelmingly-better financial decision would be to attach the MEV before client inclination was allowed to grow.

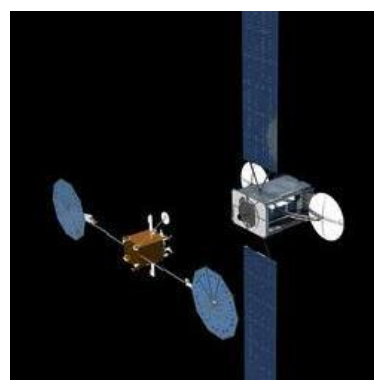

Figure 1: ViviSat Mission Extension Vehicle About to Dock with Client [ViviSat]

At the end of the MEV service contract, the MEV can just be detached and drifted to its next opportunity. Residual propellant in the client can then be used to supersynch the spacecraft into graveyard orbit. If the client does not have sufficient propellant or its propulsion subsystem is disabled, the MEV can be used to supersynch the spacecraft - but this also involves the propellant cost of the MEV's round trip.

Satellites which become stranded on orbit, either due to malfunction of the spacecraft or poor management of propellant reserves, might have no alternatives to graveyard except use of a tug. It is highly likely that when tug services are readily available at GEO, satellite operators will be legally "obliged" to remove their derelict spacecraft to prevent possible collision with other objects. Good stewardship of the space environment could easily be enforced by changes in space law which might prohibit space "littering" on a go-forward basis. A company's decision to NOT purchase an available tug service to removing their debris could be viewed by a court as negligent, and result in significant financial liability when other space assets are placed in harm's way.[3]

ViviSat recently reported that they had "bookings" for the first three MEVs[4]. Launched in pairs, it is hoped that the 4th booking will provide sufficient confidence in the financial community to get production in high gear.

Tugs will likely utilize both ion and chemical propulsion systems. Ion systems will be used for delta-V maneuvers when sufficient time is available to fully leverage its efficiencies. However, if the tug must be drifted in orbit quickly or while in the vicinity of other spacecraft, the higher thrust afforded by chemical thrusters is likely required. This begs the question whether the tugs should be built to be easily refueled themselves, and might they just buy that propellant from the competing life extension solution – namely robotic refuelers.

B) Refueling Services

Considered the "Holy Grail" of in-orbit servicing[5], refueling of on-orbit satellites has been the aspiration of USG agencies such as NASA and DARPA for some time. Refueling provides a viable life extension solution when the client spacecraft's propulsion and attitude control subsystems remain intact. It is likely the most efficient way to extend lifetime, as the only "mass tax" left with the client is that of the propellant itself.

Figure 2: Satellite In-orbit Servicer (SIS) docked to Client Satellite [MDA]

Canada's MacDonald, Dettwiler and Associates' (MDA) Satellite In-orbit Servicer (SIS) robotic refueling venture was looking very promising when they signed a $280M contract in mid-2011 to provide refueling services to Intelsat's fleet of over 50 GEO satellites[6] (see Figure 2). However, the inability to get commitments from other commercial GEO customers stalled MDA's forward progress. MDA's technical experience with space robotics had already been well established – building both the Space Shuttle's "Canada Arm" (see Figure 3) and the Dexter[7] robot currently being used on ISS. Nevertheless, possible competition from NASA to refuel USG satellites using their own robotic refueling spacecraft being developed under the RESTORE program appears to have been an issue[8]. In subsequent months MDA elected to "cancel their collaborative agreement" with Intelsat and divert investment elsewhere[9]. In late 2012 MDA completed the purchase of Space Systems Loral[10] – establishing a significant US presence for sales of future services to the USG and mitigating some of the previous ITAR/non-U.S. concerns.

III. Benefit of Life Extension

A) Several More Years.

Frequently heard in discussions about life extension is that it is too difficult, too expensive, or of little interest because the technology on the older satellites is obsolete or the hardware is at the end of its design life. Satellite manufacturers should not feel threatened by life extension. The goal of life extension is NOT to add another 10 years of operations to a heritage 15-year spacecraft – rather to add a few years of life to allow flexibility in fleet planning. Satellite owner operators will make their decisions based upon business plans, and if the business plans indicate that the latest technology will provide the greatest return, that is the path they will take. Owner operators will purchase the new satellites with the latest technology when it makes "dollar and cents" for them to do so.


Figure 3: Leasat 5 satellite being released from the payload bay of Space Shuttle Columbia on STS-32 in 1990 [NASA]

B) Proven Reliability

As described in a report done by the Aerospace Corporation, about 1/3 of GEO satellites are operated well past their 15-year design life[11]. If the heritage technology was obsolete and not able to produce valuable services, this certainly would not be the case. As an example, Intelsat's Leasat 5 satellite, launched in 1990, is still being operated after 24 years of on orbit (see Figure 3).

C) Cash Flow Stabilization

Companies such as Intelsat procure block buys of satellites and launch services to obtain preferred pricing. These series of spacecraft are built, launched, and thus come to end-of-fuel life over a small time period. Replacement of these assets involves considerable outlay of investment. The ability to "smooth" out the procurement expenditures over more years yields a preferred cash flow situation for the company finances. This means, i.e. if replacing a block buy of 6 satellites, 2 might not be life extended, 2 might be extended by 1-2 years, and 2 might be extended by 3-4 years.

D) Spin-off Benefits

Tugs and robotic refuelers can perform value-added services for new satellites as well as the propellant-challenged older variety. For example, a new satellite getting a marginal drop-off from its launch service might need to make up the delta-V shortfall by using its own on-board propellant reserves. This could leave the satellite with little remaining station keeping life upon reaching GEO[12]. The ability to replace the propellants could bring SIGNIFICANT value to both the owner/operator as well as the insurance company potentially responsible to pay a claim. The same robotics used to conduct refueling operations could be used to assist the deployment of a stuck antenna,[23] solar array[13], or even adjust a loose thermal blanket. Robotic servicers could provide a capability for capture of orbital debris, however, today there is little financial incentive or government regulation motivating investment in a pricy venture to collect yesterday's space trash (see next section).

IV. Risks and Security Concerns

The space community is justifiably a very conservative group – investments in space assets are huge and on-orbit problems are almost impossible to fix. Spacecraft are frequently designed to survive "worst case" scenarios and environments. Flight heritage is precious and an entire Test Readiness Level (TRL) scale[14] has been developed as a measure of "flightworthiness". The future of on-orbit servicing is bright but the industry is full of doubters – they will buy into servicing only AFTER it has been proven SEVERAL times on SOMEBODY ELSE'S spacecraft. Disruption of services is a near-sacrilegious event with stiff financial consequences.

Orbital debris has been a rising concern over the years and a couple of highly destructive events at LEO[15 16] have fueled the fire. While the "vastness" of space once rivaled the perspective of the vastness of the oceans, decades of launches left thousands of objects in orbit – mostly in at lower altitudes. We would like to believe that understanding of the uniqueness of geosynchronous orbit would be sufficient justification for every space-faring nation to keep the neighborhood free of litter – but this has not been the case. In fact, well over half the ~1400 items tracked at GEO[17] altitude are uncontrolled objects (see Figure 4). These uncontrolled objects scream North/South through the equatorial plane twice a day, picking up 100 mph closing speed every year. Eventually there will be a collision at GEO that releases many thousands of additional fragments. What is the space community doing about THAT worst-case scenario? Answer is… not enough.

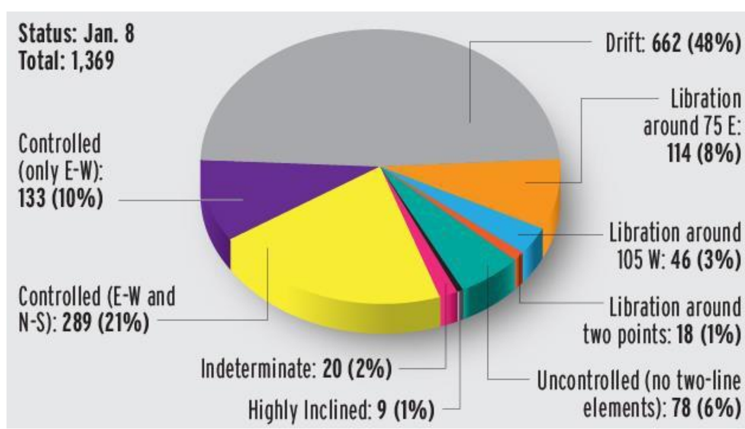

Figure 4: 80% of Objects at GEO Altitude Consist of Uncontrolled Orbital Debris [ESA/SpaceNews]

Spacecraft are designed to be somewhat resistant to "micrometeoroids"[18] – but the debris created by a collision at GEO would dwarf the impact from those micrometeoroids. The Space Data Association[19] works with commercial operators to track debris (and each other's satellites) and provides conjunction warnings to the applicable parties when "resident space objects" (RSOs) are predicted get within some predefined distance of an active spacecraft. The controlled spacecraft might be maneuvered to increase the conjunction distance beyond the range of position uncertainty. However, there is a good chance that both objects might be uncontrolled and the collision unavoidable. Could a robotic servicer "prevent" such a collision by capturing one of these objects prior to the predicted collision? It would be an expensive undertaking but likely less expensive and more practical than capturing asteroids.

What would be the consequence of a robotic servicer (tug or refueler) colliding rather than docking with an active satellite? Would one or both of the spacecraft become disabled? Would the two become entangled? Would a debris field be created? A previous NASA rendezvous mission resulted in a low speed collision and both spacecraft survived[20]. The closing rates between a servicer and a GEO satellite during the docking procedure are extremely slow. Autonomous procedures kick in automatically to increase the separation in the unlikely event that a command link is lost or the vehicles' closing rate is too rapid.

Maintaining attitude control sufficient to sustain pointing of the client communications antennas is another matter. It is likely that initially there will be a lot to learn regarding optimizing the attitude control alogrithms of the docked servicer/client composite and that initial missions will not be able to maintain the original "pointing budget" of the client. Is that a risk? - only if it was unexpected.

Risk exists that the client's propellant valves might not function (or fully reseal) following 15 years on on-orbit dormancy. Those requirements were never part of the original spec for those valves – they were not "designed" to be opened/closed after 15 years exposure to corrosive propellants. Will they function properly? There are a lot of on-orbit systems available for a demonstration prior to servicing a high-value spacecraft. It is expected (and likely required) that an on-orbit demonstration on a nearly-identically designed satellite will be required before attempting those same operations on a high-value asset.

Does the presence of on-orbit robotic spacecraft represent an anti-satellite (ASAT) threat?[21] Could the robotic spacecraft be used to intentionally disable somebody else's satellite? The answer is "yes" – and likely the DoD has put a lot of thought into that possiblity. But then, any controlled satellite could be intentionally flown "into" somebody else's spacecraft today – might miss the first few times but eventually contact could be achieved. At high enough speeds it would likely result in mutual destruction. An intentional collision could be executed – just as it could with airplanes, cars, tanks – even submarines.

Could a tug be used to "capture" and relocate somebody else's spacecraft against their will? Probably so – but the presence of tow trucks on our roads has not resulted in a rash of car thefts. Future satellites will likely include some sort of localized situational awareness sensors – might not prevent the tampering problem but certainly could provide attribution. Intentionally approaching another nation's military satellite is already the equivelnt of violating terrirorial waters, and intentionally harming that nation's satellite could be construed as an overtly hostile act. This makes robotic capability in space a very sensitive international issue.[22]

V. The Financials

Using a servicer to "save" the mission of a new satellite (i.e. fixing an antenna deployment anomaly[23]) clearly could provide a windfall return of investment. However, the business case for development of life-extension services cannot depend upon revenue collected while coming to the rescue of satellites that haven't even been launched yet. Furthermore, until the procedures have been proven, neither owner/operators nor insurance companies will put a service provider "on retainer" to provide future rescue services. Securing financing for a life extension venture will require some level of pre-commitment from clients. The business case (for both service provider and serviced client) needs to stand on its own just extending the lifetimes of "heritage" satellites. This is the business case that many in the industry claim just doesn't close – they are wrong because they are likely using the wrong set of initial assumptions.

A) From the Perspective of the Client

To determine the return of investment (ROI) for purchasing a year of life extension on a heritage satellite, one need to estimate both the associated costs and resulting revenues. Assuming a mid-size satellite with 48 transponders at 50% utilization, revenues from sale of bandwidth (assuming a modest $2000 / MHz – month) would result in revenues of:

48 transponders x 50% utilization x 36 MHz/transponder x $2K/MHz-mo. x 12 mos. = $21M / year

A mid-sized satellite at fully-depreciated EOL might use 40 kg propellant per year for station keeping and momentum management. MDA was able to make a business case delivering 1000 kg of on-orbit propellant to Intelsat for $280M. The annual cost of life extension is thus:

$280M / 1000 Kg x 40 kg / year = $11M / year (propellant is ~$280K / Kg)

Adding in $1M / year for cost of operations & sales and another $1M / year for cost of capital results in:

Client Return / Investment = $21M / $(11M + 2M) = 1.6 → a whopping 60% ROI

One could make the case that a more realistic way to calculate the value of life extension to a commercial operator would be based just upon the advantages provided by delaying to cost for procuring the follow-on spacecraft. Let us examine this case. Assuming a COF of 8%[24] on a $350M investment, it would seem that delaying the replacement satellite would save $28M annually. This suggests an excellent ROI for refueling, but a marginal ROI for life extension using a tug (see below). If the replacement spacecraft includes additional capabilities which may increase total revenues possible from its assigned orbital slot, the owner/operator may elect to retire (or move) the asset anyway. 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), even life extension using a tug 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, a "life extension" business window of 12 to 15 years is likely to currently exist.

B) From the Perspective of the Service Provider - <u>Refueler</u>

Is it reasonable that a life extension service provide could charge "just" $11M / year and still make a return? Their return is based upon selling a lot of propellant – likely all of the propellant reserves on the original servicer plus a 2000 Kg "refill" from a tanker (or two) – after all, the servicer better be able to be refueled itself.

Spacecraft, robotics, I&T	$250M	Tanker, I&T	$200M
Launch	$100M	Launch	$100M
Insurance	$ 35M	Insurance	$ 30M
Operations	$ 30M	Operations	$ 5M
Cost of funds	$ 60M	Cost of funds	$ 50M
TOTAL COST Load 1	**$475M**	**TOTAL Cost Load 2**	**$385M**

Servicer Only:	**Return / Investment = $ 560M / $ 475M**	**= 1.18 → 18% ROI**
Servicer and 1st Tanker:	**Return / Investment = $1120M / $ 860M**	**= 1.3 → 30% ROI**
Servicer and 2nd Tanker:	**Return / Investment = $1680M / $1245M**	**= 1.35 → 35% ROI**

While the life extension ROI for the service provider is about half of that of the client, it should be noted that the windfall profits for conducting a rescue mission will go entirely to the service provider. Also note that propellant used getting to/from the ~zero inclination client is not part of the 2000 Kg load – that propellant is booked separately as part of the initial servicer cost. If the client is not easily accessible (i.e. inclined) propellant burn getting to/from the client would be billed to the client.

C) From the Perspective of the Service Provider - <u>Tug</u>

Assuming a dual launch, a cost of $150M for a tug, and a 16 year design life[2] the following estimate could apply:

Two Tugs	$300M
Dual Launch	$150M
Insurance	$ 50M
Operations (15 yrs x 2)	$ 30M
Cost of funds	$ 70M
TOTAL COST 2 Tugs	**$600M**

In order to obtain a 20% ROI, what might a tug service provider need to charge the client?

$600M x 120% ROI / 32 years = $23M/year

Clearly (and no surprise) the business case for a tug service is more challenging than refueling. Since the value to the client (assuming 50% transponder fill rate) was about $21M/year, the benefit is almost a break even. Assuming a higher transponder loading (i.e. 75%) the annual satellite revenues would be closer to $31M and the ROI respectable:

Client Return / Investment = $31M / $(23M + 2M) = 1.2 → 20% ROI

The tug could provide other shorter-duration value-added services providing higher returns:

1) Inclination reduction
2) Tow to new operational orbital location
3) Tow to supersynch (graveyard retirement)
4) Hosting of payloads
5) Bringing spacecraft to GEO from substandard launch drop-off
6) Towing an inclined spacecraft to a robotic refueler

An interesting concept is the idea of tugs and refuelers working together to provide on optimal service offering to their mutual client. For example, let us assume that a client has been operating their spacecraft in an inclined orbit for a number of years because their propellant reserves were low. Reserving sufficient propellant for the trip to graveyard, they discontinued North/South station keeping and just used remaining propellant just for East/West Station keeping and momentum dumping. The strong market suggested opportunity, but the inclination was becoming a problem with their customers. A tug could be used to bring the spacecraft back to lower (or even slightly negative) inclination and then released to continue service. Alternatively the tug could bring the spacecraft to zero inclination where a refueler could add whatever propellant might be required. The tug itself might just carry enough liquid propellant for the round trip (plus some margin), then get a "refill" from the refueler. In this manner, excess propellant mass tax is not carried to and fro for each servicing opportunity. If the refueling process was not successful (i.e. damaged propulsion subsystem), the tug would already be on hand to continue operations.

D) Servicing USG Satellites

If a USG satellite was being serviced (or life-extended) the "value" to the USG could greatly exceed for price being charged to commercial clients. In a market where few alternatives exist, the first capability to orbit will likely contract a number of high-value (possibly classified) missions which have been waiting for "rescue".

Operational ROI for USG spacecraft is 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, and a lot of labor and procurement 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 communications or Intelligence, Surveillance, and Reconnaissance (ISR)?

USG spacecraft missions (satellite and launch) frequently cost $800M to $2B. Assuming a 15 year life (many USG satellites are less) the “replacement cost”/year could be $1B/15 years = $65M (assuming the Congress releases the funds). Hence either tug or refueling services seems to provide an excellent ROI to the USG.

E) Insurance Company Perspective

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 Constructive Total Loss[25] (CTL) payout. This CTL 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 CTL 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 of a stuck antenna or solar array would provide considerable value to the satellite owner operator, the spacecraft manufacturer, and the insurance company. Consider it likely that future policies will allow insurance companies following an anomaly some time to pursue independent recovery strategies to minimize CTL claims.

VI. Conclusion

The business cases described in this paper for life extension on EOL spacecraft provide a substantial ROI for refueling services, and a positive (but marginal) ROI for tug services. 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 only 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 before launching a solution will not provide 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. 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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