Chapter 4
Examining the Case for Active Orbital Debris Removal

Introduction

For some time the problem of increasing orbital debris has been clearly understood to be a potential menace to the future sustainable use of space. Dr. Donald Kessler, the father of the concept of the so-called "Kessler Syndrome", has recently written that even with the 25 year rule for removal of debris after the end of life of spacecraft and the voluntary, non-binding rules adopted by the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) are insufficient. He believes space debris will continue to accumulate just due to collisions among existing debris. He has particularly noted the danger that comes from the potential collision of large pieces of debris. Dr. Kessler has indicated that "in the region between 700 and 1,000 km, events such as the Iridium/Cosmos collision can now be expected to occur at a rate of about once per 10 years. If the 25-year rule is not followed, then the frequency of collisions will increase more significantly over time. These collision rates can be expected to increase for hundreds of years and end only when there is a significant decrease in the number of massive debris objects within this altitude band." [Kessler] Although the low earth orbit bands, and especially the polar low earth orbits are of the most urgent concerns, there are also increased concerns about other orbits as well.

Clearly Dr. Kessler and others with expertise in this area have indicated the need to concentrate on removing large objects from low earth orbit and especially in the areas of Earth orbit that are particularly crowded. Today a great deal of attention is being devoted to considering how technical methods might be devised that could serve to remove the largest elements of space debris from low Earth Orbit and do so with technical efficiency, at low cost. Further this might be accomplished by a variety of means that might include governmental or military programs, commercial activities or projects, or perhaps by some new institutional arrangement that would still be considered consistent with international legal arrangements or accepted

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codes of conduct. This chapter examines the various possible strategies whereby active space debris might be accomplished and the relative effectiveness of these approaches in terms of a viable economic business case.

Factors Involved in Building a Business Case in Favor of Remediation

The key questions that currently surround the orbital debris issue are the following: How bad is the current situation? Will it get worse in the near future? Are there reasonable methods to address the orbital debris issue in terms of collision avoidance techniques that can be operated effectively from the ground until on-orbit systems can be developed for active removal? Are their reliable and effective means to achieve active debris removal using innovative space-based systems on the relative near term horizon? And if there are such means can they be carried out cost-effectively and reliably? And then there are the institutional, business and regulatory issues and questions.

Who should be "authorized" or "enabled" to conduct such operation? Should there be additional controls imposed on yet to be launched space missions to mitigate future debris? Should such additional controls include a separately commandable active deorbit systems and perhaps especially developed procedures involving small satellite launches? In terms of a broader concern with the sustainability of space should their also be controls related to rocket launches that relate to pollution of the stratosphere? Finally there is the question of whether those who engage in active debris removal should be governments, an authorized international entity or entities, or perhaps commercial entities working within some form of legal or regulated mechanism? The answers to these questions obviously will have a large impact on the business case for active debris removal and the cost of such operations—whether these relate to removal, prevention or the effective creation of a future sustainable space environment.

In addition to these prime questions there are also ancillary questions as well. These include such questions as: Who decides what is actually designated as space debris and whether it can be removed within the constraints of existing space regulations and practices? If some of the mechanisms that remove space debris can be considered "space weapons", would such active removal processes be considered "illegal" under the Outer Space Treaty or other space conventions and regulations? If the government that is considered the "Launching State" controls the equipment and processes associated with the removal, then does this mitigate against defining such equipment or systems as a space weapon? Would this be true regardless of whether this is a space-based instrument or a ground-based instrument? If the technology developed for space debris removal can also be used for other purposes such as on-orbit servicing does this also help bolster the business case for active debris removal in a sufficient manner so as to make such operations economically viable?

The discussion of these questions are divided into the following sections: (a) Intermediate Actions to Address Orbital Debris Collision Avoidance Using Ground-Based Systems; (b) The Business Case for Governmental Action to Exclusively Engage in Debris Removal; (c) The Business Case for a Globally Designated international Entity to Engage in Active Orbital Debris Removal; (d) The Business Case for Private Commercial Entities to Remove Orbital Debris under Some Form of International Structural Guidelines, Global Funding Mechanism or Insurance Financed Operation; (e) Business Case Based on Breakthrough Technologies. In each "case discussion" the technical, financial, operational and economic aspects will be considered, but the prime focus will be on economic viability.

(a) Intermediate Actions to Address Orbital Debris Collision Avoidance Using Ground-Based Systems

There are currently ground based laser and directed energy systems that can be used to divert the orbits of space debris elements that are projected to collide with spacecraft, the International Space Station (ISS), or other large space objects that are in low earth orbit. Alternatively it is also possible to maneuver spacecraft or space stations with thruster systems to seek to avoid collision with passive debris objects that have no control mechanisms. The use of ground initiated maneuvers to create a slight diversion to avoid an in orbit collision, however, represents only a temporary solution for a problem that could become more and more likely to occur. As noted in the introduction to this chapter the current projection is that a major collision in low earth orbit can now be expected once a decade. This type of ground-based initiated maneuver, however, can be cost effective in that no dedicated launch must be undertaken. Further the registered "launching country" could be asked to be directly involved in this type of orbital debris diversion to avoid the collision and by this direct involvement by controlling the pulsed directed energy might perhaps minimize concerns that such activity would be considered improperly undertaken without legal consent.

Such a diversionary activity, although it might be successful and relatively low cost, still poses several problems. One problem is that the diverted orbit might result in a space collision at a later date with another space object and thus the maneuver could lead to a future adverse liability claim. Secondly there could be a miscalculation and the diverted orbit for the targeted debris could actually create a space collision that might have otherwise not occurred. The participation in the orbital diversion might rather ironically lead to the very result which was being sought to avoid. Telesat maneuvers to avoid the so-called out of control Galaxy "Zombie sat" were successful, but the calculations had little tolerance for error and the Telesat officials decided to take a calculated risk that were fortunately successful.

Satellite operators have thus been able to maneuver satellites by firing jets to avoid collisions such as the elaborate maneuvers that were carried out by both SES of Luxembourg and Telesat in seeking to avoid the Galaxy satellite of the Intelsat fleet while still maintaining service. [Selding]

The use of high energy lasers or directed energy beaming systems to divert the orbit of a piece of orbital debris of irregular shape and size and to hit exactly the right spot with the exact degree of inertial force is a difficult and still largely unproven technique. Most fundamentally, such maneuvers to divert orbits are really "stop-gap" measures that do not really provide a longer term solution—just short term relief.

And if orbital diversion via laser beam energy is an unproven technique it is a step further to consider the possible use of directed energy to burn up and remove elements from orbit entirely. Currently there is research underway as to how directed energy systems could be used to destroy or divert an asteroid from hitting planet Earth, but such techniques are still in early days of experimentation. Further such a very high energy system would undoubtedly be considered a "space weapon". In this case, there are not only technical, operational and financial considerations but quite serious legal and regulatory issues to sort through as well. Clearly these issues will continue to be researched, but for the next few years, it is reasonably safe to say that ground-based directed energy systems represent a complex of issues to be solved. Only with more experimentation and some clear precedents based on viable tests will these types of ground-based methods move ahead. Currently, there is a wide-spread consensus that such ground-based solutions form only a temporary type solution and that active in-space solutions will ultimately be needed. The key, of course, will be the development of improved space-debris procedures that will assist to decrease new space debris build-up.

(b) The Case for Governmental Action to Exclusively Engage in Debris Removal

The complexity of the task associated with orbital debris removal tends to point toward either governmental space agencies or a new international intergovernmental agency being set up under a new global treaty arrangement to accomplish this daunting feat. The many challenges include:

- The huge amount of orbital debris that has now formed in low, medium and geo orbit.
- The complexity of the missions needed to remove space debris from orbit without engendering a collision and the creation of more debris.
- The high cost of such activities with no existing commercial market associated with it.

The issues here are obviously complex in that they involve financial and economic considerations, the need for governmental subsidies or underwriting, and the feasibility of a new global set of international agreements to address a concerted effort to remove orbital debris, and more. The fact that the Inter-Agency Space Debris Coordination Committee (IADC) reached agreement on procedures to minimize the creation of new debris and also has signed on to a continuing effort to address the issue of orbital debris removal is a positive sign as to the willingness of space faring nations to work for solutions in this area. The fact that the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) unanimously agreed to voluntary procedures that were closely akin to that adopted by IADC is a further positive sign. Finally, the current COPUOS Working Group on the Long-Term Sustainability of Outer Space Activities is now addressing orbital space debris and extreme solar weather as core issues in their studies.

The membership of the IADC and COPUOS are comprised entirely of governmental representatives. Any agreements reached within these bodies are by definition intergovernmental in nature. Yet despite these efforts at governmental agreement on space debris, the current situation does not seem likely to result in international agreements covering orbital space debris or providing explicit sanctions to active debris removal. No new space treaties or conventions have been reached since the five international agreements were negotiated and agreed in the late 1960s and 1970s. The expense of creating a new international agency to undertake debris removal, the potential interference that might occur with regard to missile defense and orbital tracking systems, and a number of other practical factors all argue against a new wide-spread agreement that would lead to the formation of a new international agency to address this problem. Even the most severe threats to the entire planet of extreme solar weather events and asteroid and comet strikes have only resulted in modest agreements to form a new International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG).

The history of the last 10 years thus seems to indicate that action related to active orbital space debris removal will thus end up with national governments taking action, or governments supporting, underwriting or subsidizing private aerospace enterprises to address this effort. Current activities seem to indicate a pattern of some countries looking to national space agency to undertake action for this purpose, while other countries—particularly the United States and to a lesser extent Europe—are supporting private initiatives. Perhaps the most important national governmental effort to establish a process and improved legal regime to minimize space debris has come from the French Space Operations Act (FSOA) of 2008 and 2010.

The various programs described in Chap. 2 are today essentially national governmental programs with virtually all of the funding coming from governmental space agencies. Even those commercial ventures such as the Electrodynamic Debris Eliminator (EDDE) are essentially dependent on governmental support.

The conclusion that seems most plausible and likely is that most of the initial funding for active orbital debris removal will come from governmental funds. These development programs may be derived from either national defense budgets to respond to the threat of debris impairing missile defenses and missile launch detection systems or to protect military space assets. Or they may come from national space agency programs based on a number of needs. These expenditures could be based on the need to sustain vital governmental space programs such as those conducted by the U.S. Defense Advanced Research Projects Agency (DARPA) (Fig. 4.1). Another important supplemental source of funding, however, could come from national governmental legislative mandates that impose new requirements on non-governmental programs. The requirements of the French Operations Space Act is a case in point.

This Act now requires industry to meet a number of stringent requirements in the post 2020 time frame in order not to create new debris, have the capability to de-orbit all spacecraft, and to invoke sanctions if these conditions are not met. There are even more stringent requirements that could potentially be enacted by national legislation in the future. One such proposal is that future spacecraft that are launched into orbit would have to have a separately command-able de-orbit system with an

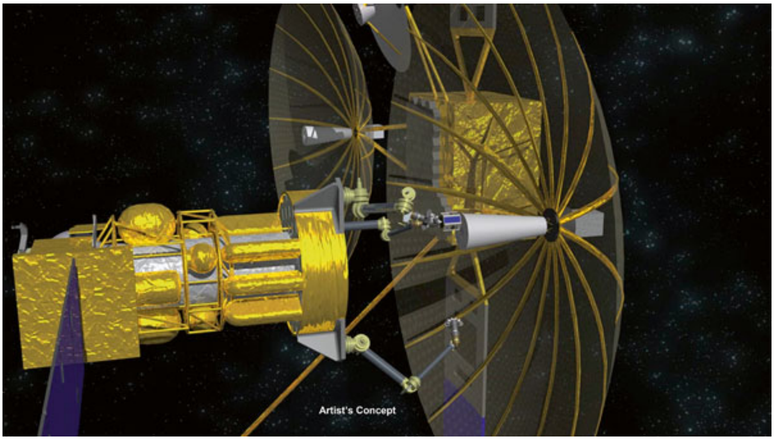

Fig. 4.1 Conceptual illustration of DARPA Phoenix on-orbit servicing vehicle (Graphic Courtesy of DARPA)

independent fuel supply to accomplish de-orbit or to place the spacecraft into a safe parking orbit.

These type "fail safe deorbit" proposals have as yet not been taken up and would likely be resisted by industry. It is important to note that these actions appear likely be undertaken as national legislation that other nations might follow but not require an intergovernmental type agreement or treaty arrangements. The important point to note here is that national legislative action could serve to "switch" the business case from an exclusive-type governmental debris removal program that would be funded by taxes to a program whereby industry would at least fund themselves as a substantial part of the debris prevention and active end-of-life debris removal programs. In short new national legislature could serve to create a new commercial market for orbital debris removal systems.

(c) The Business Case for a Globally Designated International Entity to Engage in Active Orbital Debris Removal

There have been a number of proposals with regard to how the United Nations system or other international arrangements could be made to engage in an active space debris removal program. One of the proposals championed by the Executive Director of the International Association for the Advancement of Space Safety (IAASS) is to create an organization akin to the Intelsat Organization when it was an intergovernmental organization that would be charged with active debris removal. The analysis of this proposition has indicated that before this step was taken there would need to be a preliminary demonstrated debris removal programs to verify relevant technology. The analysis has also indicated that amendment to the current Space Liability Convention might also be required since currently only designated "Launching States" are liable for any accidents involving space objects. The new international entity would be charged with the responsibility to remove debris, but without being relieved of liability if an accident should occur.

Currently there are a number of difficulties with the "business case" associated with this proposed arrangement should this approach be adopted. International organizations are difficult to create and fund and even more difficult to dismantle once formed. There are currently a wide range of space safety related issues that are pending consideration in the global space community. These issues include the regulatory and legal arrangements for the oversight of commercial space tourism travel, hypersonic travel in the so-called "protozone" or "subspace" whereby space planes might fly. In the future there could also be hypersonic space planes that follow sub-orbital arcs for intercontinental transportation, operation of high altitude platform systems and dark sky stations that would also occupy this "protozone" high altitude region, as well as robotic flights above commercial air space. All of these new "protozone" or "subspace" services will require some sort of safety regulation.

There are also concerns about radiation exposure and stratospheric pollution due to rocket launches and commercial space travel. Currently these discussions involve the possible future roles and responsibilities of the International Civil Aviation Organization (ICAO), the International Telecommunication Union (ITU), the World Health Organization (WHO), the World Meteorological Organization (WMO), and the United Nations Environmental Programme (UNEP). In light of this current set of space safety regulatory issues, it seems unlikely that yet another new international agency to address just the space debris issue could be agreed and put into place.

On top of these very pronounced policy and regulatory concerns, there is the future financial and economic set of issues to consider as well. There would be legitimate questions as to whether such a new space debris organization under the auspices of the UN or another international intergovernmental organization would be more cost efficient, have access to the key technology, research, tracking systems, and financial resources to carry out these operations in a cost-efficient manner. And if it was created and carried out its mission successfully it would be difficult to shut down if it accomplished its task, or if it was found that a totally new technology associated with a space elevator, electro-dynamic propulsion, or electric propulsion rendered a space debris organization obsolete.

The lack of any new major space treaties or significant new international agreements related to space being agreed since the 1970s—almost a half century ago—seems to suggest that such a new international agency for space debris will not be agreed any time soon. Further the business case based on either national governmental programs or commercial initiatives seem to promise more cost effective and agile programs than the creation of a new international entity charged with this responsibility. The liability issue alone might render the business case for an international entity void.

(d) The Business Case for Private Commercial Entities to Remove Orbital Debris under Some Form of International Structural Guidelines, Global Funding Mechanism or Insurance Financed Operation.

The systematic reduction of orbital debris provides potential benefits to various users of outer space. These include commercial providers of space applications services (remove sensing, mobile, fixed, and broadcasting telecommunications satellite services, space navigation, etc.) plus military and governmental satellite networks, and indeed the general public and a host of businesses that depend on space-based activities. The problem is that these various groups benefit from debris removal in widely divergent ways**.** A further issue is that different orbits (LEO, Polar Constellations, MEO and GEO) are affected to differing degrees and by different classes of users. In light of these complexities a simple formula whereby all users of space would pay into something like an insurance fund that represented a small portion of their space-related investments would not easily work out because of these various differences. The two prime areas of commercial interest, however, are low earth orbit (where the most congestion occurs and especially in high-latitude polar constellation orbits) and in GEO orbits (where upper stage rocket stages are crossing this orbit at high relative velocities). Since the GEO equatorial orbital belt is such a narrowly defined region, just one collision of this kind would have very severe consequences.

A possible solution that might address active space debris removal efforts, at least in these two most critical bands might be the creation of a space debris removal fund that operated much the same way as that used for commercial space insurance protection against launch failures. One type fund would be created for low earth orbit launches (with insurance premiums being perhaps 3.5 % of total mission value) and thus employing a metric similar to that used for launch insurance coverage. The other type fund for GEO launches would be a more modest 1.5–2 % of total mission value. The objective of the first fund would be to remove at least five large debris elements from the LEO orbit each year and the objective of the GEO fund would be to remove one to two under stage rockets or other large debris elements that cross the GEO belt at high angular velocities.

If at all possible such an economic mechanism or fund should be brought into place as soon as possible. This is simply because the problem continues to worsen. These funds could be established over time in an "organic manner" with countries forming such a fund on a national basis—or perhaps for Europe as a region. This type of national, regional—and in time ultimately universal—"space debris insurance fund" could be formed by space actors for the specific purpose of funding the systematic removal of the largest debris elements from LEO and GEO orbits (Pelton, "Possible Institutional…).

The creation of such funds could represent a pro-active "forward looking" approach to financing a solution to the problem rather than seeking a "backwards-looking" approach to addressing space debris formed in the past when no financing mechanism was in place.

The money to capitalize this type of space debris fund would be collected prior to all launches and would be capitalized through these insurance funds. These funds would be collected for a period of perhaps 25 years but would have a sunset provision on the premise that significant mitigation of orbital debris could perhaps be successfully accomplished over this length of time. A trend line that reflected less and less debris over time would be a possible objective rather than complete elimination of debris.

Such a fund (or network of funds) would be formed by means of a specific assessment paid into a designated bank account, or space insurance company, or some other designated entity or entities prior to launch. This fund would apply to all those deploying spacecraft into Earth orbit—or if on a national or regional basis—would apply to all launches from that country or region. Perhaps in time even organizations launching satellites beyond Earth orbit would also pay into the fund but at lesser rate. After each launch there could also be a small rebate assuming it was a certified as a clean "debris-free" launch as independently verified. Such a clean launch would require that the upper stage rocket would be actively de-orbited and no residual debris created (Pelton, "Possible Institutional…, 2015).

When a space craft reaches its end-of -life and is then actively de-orbited or successfully placed in a graveyard orbit there could also be a further rebate. The size of the rebate for a "clean launch" and "successful disposal" would be specified at the time the fund(s) were established. The rebate formulas could be updated over time at suitable intervals. Over half of the payments into the fund, however, would also be retained to compensate those entities involved in removing "officially designated" debris from orbit or moving defunct space objects to a graveyard orbit.

The prime purpose of the national, regional (or hopefully, in time, a universal) space debris fund(s) would be to compensate those entities "licensed under an appropriate regulatory framework" to remove debris from earth orbit. It is possible that a small fractional part of the fund could also help fund activities related to operating systems to avoid collisions, but this would not be a part of the original mandate for the insurance funds for debris removal (Pelton, "Orbital Debris…," 2012).

This licensing process for entities designated to undertake orbit debris removal or collision avoidance activities might, for example, be formally assigned to the United Nations Office of Outer Space Affairs or in time spelled out in a new international space convention after the concept had proven in practice. Clearly there would be many details to be worked out, such as perhaps initial national funding, that would kick-start the capital financing for the debris removal process. The biggest issues to be resolved would be to determine how the process of licensing entities would actually work. This would likely require for the issuance of a United Nations' designated "license" to designed entities with proven capabilities to accomplish active deorbit mission. This process might also simply be performed by national governmental space transportation agencies. The key would be to create a process where governmental enities or private commercial concerns would somehow receive an authorization to undertake the specific removal process for individually designated debris elements. There would also need to be some form of new interpretation of the "space liability convention" to allow the debris removal operation that was fully sanctioned by the designated "Launching State". This might require the creation of an international liability fund to be established to cover any liability claims that might result over the time of the 25 years or so in which the space debris removal funds were active.

Further there is the specific issue of small satellite-related debris. There is a threshold issue of whether there should be a minimum payment related for small or nano-satellites. It is hoped that in time there would be a new international agreement (or at least code of conduct) reached concerning small satellites, their registration processes, passive or active de-orbit capabilities, minimum altitudes to meet the 25 years de-orbit rule, their relationship to the overall orbital debris problem, and so on.

One might make specific arrangements for such small satellite launches by offering 3 options. Option one would be for a passive deorbit capability at end of life for launches at or below a specific altitude that would meet the 25 year rule. Option two would be an active de-orbit capability at end of life that would also meet the 25 year rule regardless of altitude. Option three would be for the small satellite to fly as a multi-mission vehicle with deorbit capabilities or on board a space station with subsequent controlled return or de-orbit. These arrangements might mitigate the need to pay into the orbital debris removal fund for LEO launches (Jakhu and Pelton 2014).

Payment into this fund would for the most part "seem and feel" to satellite operators and governmental space agencies conducting space operations very much like buying launch insurance for a spacecraft mission. Indeed the fund could possibly be administered by launch insurance companies. These payments would be different in that it would only represent perhaps about a third or less of the "net cost" associated with purchasing launch insurance, after rebates for clean launches and ultimate de-orbit. Rebates might eventually return perhaps 30–40 % of the money originally paid into the fund. Further, the projected end date for the fund would establish a very real goal for accomplishing "a largely space debris-free world" over a 25 year period (Pelton, "Possible Institutional.").

The creation of this fund and the rebate payments would reverse the current incentives that, if anything, actually "encourage" the increase of orbital debris. Under current space law the "Launching State" not only lacks an incentive to remove their space debris from orbit they actually face substantial financial penalties if the removal process somehow adversely affects another space object and create liabilities for which they are compelled to pay. The owners and operators currently have incentives to use station-keeping fuel to extend satellite lifetime, rather than to deorbit a spacecraft. In short, almost all of the incentives work the wrong way to reduce space debris (Listner 2011).

The payments into the fund are considered to be modest in comparison to the costs of postponing the removal process, since the cost of removal will only spiral upward. If the Kessler syndrome stage is ultimately reached and debris continues to cascade out of control the cost of active debris removal might truly soar into levels that might involve trillions of dollars (U.S.) ("Space Junk Problem").

If one considers this wide range of payments for launch insurance, the threat that orbital debris represents to all future space activities, and the cost of debris removal, it can be reasonably argued that a modest payment into an orbital debris fund would be modest and certainly not excessive. This seems even more reasonable when consideration is given to the process of rebates after a clean launch and a further rebate when spacecraft are deorbited. Such a fund would create all the incentives to clean up the space debris problem, eliminate the formation of new debris, and help to transfer the problem from establishing liabilities for space debris accidents to solving the space debris problem. The reasoning provided in favor of this option in this section provides the rationale for what seems to be the optimum business case for addressing the orbital debris problem at least for LEO and GEO orbits. This approach creates incentives for developing the most cost-effective debris removal processes, provides financial rewards for not contributing to new space debris, and allows nations or regions the latitude to organically develop funds that would grow in size and, in time, become a universal fund that perhaps could "break the back" of this problem over a 25 year period. Finally it would give incentives for national governments, commercial aerospace and space insurance entities and the United Nations to work together to address this problem without the explicit need to create a new intergovernmental space treaty or convention.

(e) Business Case Based on Breakthrough Technologies

The problem with attempts to create commercial, economic or regulatory solutions to problems involving outer space, or for that matter any area involving the rapid development of technology, is the mistaken assumption that the *status quo* will continue. The allocation of frequencies by the International Telecommunication Union, and even the naming of spectral bands, has never adequately anticipated the advance of new technologies. Today's Extremely High Frequency (EHF) bands range from 30,000,000,000 Hz to 300,000,000,000 Hz versus what was once thought to be the top of the frequency allocations heap and given the today's inapt name, the Ultra High Frequency (UHF) band. The UHF band at 300,000,000 Hz to 3,000,000,000 Hz covers a range of frequencies that are 100 times lower than the EHF band or 10 times lower than the so-called Super High Frequencies. In most English lexicons, the progression would most likely be "extremely", "super" and "ultra", rather than the reverse. Time and time again regulations such as speed limits, standards for pollution or safety, and so on, have been outstripped by new technology and conditions created by not anticipating the consequences of an innovation.

It is certainly hoped that technology related to space safety, orbital debris removal, planetary defense against asteroids and extreme solar weather, and so on, will make major gains in coming decades. Thus any attempt to define the solution in terms of a particular technology, or even the use of rocket technology, will likely be self-defeating. In future years the use of "electro-dynamic propulsion" or perhaps even the development of a space elevator or tether technology may provide a much more efficient and cost-effective way to address the problem of space debris and deployment of vital space infrastructure (Fig. 4.2).

In light of the dominant role that technology will likely play in space systems, the key to the orbital debris issue seems to be to allow for the maximum amount of technological flexibility and to create both positive financial incentives to minimize the formation of new debris and economic consequences for a lack of action to address this problem. In some cases there can well be serendipity that will aid the cause. The develop of new systems to provide on-orbit servicing (i.e. replacement

Fig. 4.2 Artist conception of a space elevator (Graphic Courtesy of NASA)

of batteries, refueling of propulsion tanks, and even installing new antenna systems) could also lead to improved systems for orbital debris removal. This might be particularly so in terms of having a single space mission be able to accomplish the de-orbit of many different space debris elements rather than just one. Flexible, as opposed to static institutional and financial arrangements, would seemingly be crucial to finding the most lasting and enduring solutions to space debris and perhaps space and stratospheric pollution issues as well.

Conclusions

This chapter has sought to address various approaches that might be taken to address the mounting problem of orbital space debris creating—particularly in low earth orbit as well as in the GEO orbital arc. A number of different institutional, economic, financial and regulatory approaches have been considered in terms of the overall feasibility. This type of business case analysis suggests that there could be a number of possible solutions. Some of these solutions that might involve national and regional governmental agencies, private commercial organizations and international institutions (and particularly the UN, its specialized agencies, and the Committee on the Peaceful Uses of Outer Space and the Office of Outer Space Affairs in Vienna) are not necessarily mutually exclusive. New national and regional space legislation and initiatives such as the creation of an insurance fund for active orbital debris removal might prove to be a possible way forward. But even these national initiatives, to be successful, will need international institutional support to transform from partial solutions, to a model of behavior and action that is more universally followed and thus become a coherent solution that is supported on a worldwide basis. The activities of the Inter-Agency Space Debris Coordination Committee (IADC) has provided some of the most important world leadership to address this important issue to date and perhaps the future discussions and agreements within the IADC can consider some of the options set forth in this chapter.

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