STUDY IN SPACE SECTOR COLLABORATION

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Considering the Possible Collaboration Implementation for Small Satellite and Large Satellite

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Summary

There are many players in the space sector. One of these players are satellite manufacturers and operators. Nowadays, we have become familiar with two types of satellites, large conventional satellite and the emerging small satellite. Existing perceptions view small satellite as a potential disruption to the existing satellite market, proven through several research on this topic. However, aside from playing the role of substitutes, there may also be a possibility for small satellites to become a complementary service for large satellites. We take inspiration from the drone's industry where initially they were perceived to be a disruptive technology to conventional aircrafts. Eventually the drones are able to become a very versatile complementing technology to the conventional aircraft industry. For example, structural analysis of commercial aircrafts for MRO using quadrotors and also using drones to prevent the possibility of bird-strikes in aerodromes.

Keyword : small satellite, large satellite, collaboration, innovation

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Il y a beaucoup d'acteurs dans le secteur spatial. L'un de ces acteurs sont les fabricants et les opérateurs de satellites. Nous connaissons aujourd'hui deux types de satellites, le grand satellite conventionnel et le petit satellite émergent. Les perceptions existantes considèrent le petit satellite comme une perturbation potentielle du marché des satellites existants, comme le prouvent plusieurs recherches sur ce sujet. Cependant, en plus de jouer le rôle de substituts, les petits satellites pourraient également devenir un service complémentaire des grands satellites. Nous nous inspirons de l'industrie des drones où ils étaient initialement perçus comme une technologie perturbatrice pour les avions conventionnels. Finalement, les drones sont en mesure de devenir une technologie très polyvalente complétant l'industrie aéronautique conventionnelle. Par exemple, l'analyse structurelle d'avions commerciaux effectuant des opérations de MRR utilisant des quad rotors et des drones pour prévenir la possibilité d'impacts d'oiseaux dans les aérodromes.

Mots-clés : petite satellite, grande satellite, collaboration, innovation

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Chapter I – Introduction and Definition

1. Introduction

There are many players in the space sector. One of these players are satellite manufacturers and operators. For quite a long time, well-known satellite producers such as Airbus Defence & Space, OHB SE, and Thales Alenia Space from Europe, while Boeing, Northrop Grumman, and Lockheed Martin represented the United States of America are settled with the unwritten rule of how a satellite will look like, big and expensive. The same situation applies to the satellite launchers as well, the industry became unstable when Elon Musk and SpaceX came with the idea that satellite launchers are not always expensive and unrecyclable.

Nowadays, we have become familiar with two types of satellites, large conventional satellites and the emerging small satellites. Smaller and less expensive satellites have been launched to space by new producers. Although smaller satellites mean less performance compared to the larger conventional satellites, some will argue that the cost incurred by building several smaller satellites will offset the disadvantages that may occurred by using smaller satellites.

There are also interests from big information technology companies like Google and Facebook to utilize the small satellites. They want internet to reach more customers from smaller and developing countries or countries where conventional access like fibre-optics are limited or more expensive because of the geographical situation. (dos Santos Paulino & Le Hir, 2016)

According to Facchinetti (2016) in his report, global space industry revenues have grown significantly in recent years. Between 1998 and 2015, the space sector growth accounted for three times the annual global GDP growth rate. No doubt that the future for the space industry will be amazing and part of the future success depends on small satellites. In 2008 28 nano-micro satellites (ranging 1-50 kg) were launched, the number increased to 141 in 2014. It is projected that 3000 nano-micro satellites will be launched between 2016 and 2022.

Existing perceptions view small satellites as a potential disruption to the existing satellite market, proven through several researches on this topic. However, aside from playing the role of substitutes, there may also be a possibility for small satellites to become a complementary service for large satellites.

We take inspiration from the drone industry where initially they were perceived to be a disruptive technology to conventional aircrafts. Eventually the drones are able to become a very versatile complementing technology to the conventional aircraft industry. For example, structural analysis of commercial aircrafts for Maintenance, Repair, Overhaul MRO process using quadrotors and also using drones to prevent the possibility of bird-strikes in aerodromes.

The main technological shift that these new entrants wish to exploit is the miniaturization of satellites and to reduce the cost of satellite building. This trend, which started in the early 1990s, provides a number of new opportunities in the usage of satellites.

Avgeropoulos, Sammut-Bonnici, & McGee (2015) stated that a Complementary goods typically have only limited meaning when used alone, but their overall utility increases when used with the complementary products. In their explanation, “complementary products have demand patterns that are similar to each other such that shifts in the demand of the first good will affect, positively, the demand for the other good". Therefore, the statement is in accordance with Cheng & Nahm (2007) and Chen & Nalebuff (2006) with one way complements theory, one of the products (A) has value for the consumers by itself, but the other one (B) is useless without the first one. That makes one of the complementary products "essential" and its value can be enhanced by the "non-essential" one.

We want to emphasize on the value enhancement of large satellite as "essential" product and small satellite as "non-essential" product, while small satellite usually appears as a part of a satellite constellation, as individual, small satellite has limited use. And on the other hands, although technologically advanced, large satellite is an expensive investment that has limited lifetime that and has limitation in some details for imagery.

Within this context, the research question of this research is to investigate whether small satellites can eventually become a rather complementary product to larger satellites than maintaining their position as a potential threat like the previous researches has pointed.

The research will be written in such arrangement. Initially, the paper will begin with definitions of the satellites itself, large conventional and the innovative smaller satellites, then followed by explaining the definition of cooperation, collaboration, complimentary product, and innovations. The second part of the paper will be the discussion of scenarios and possibilities of collaboration or complimentary project between larger satellites and the smaller satellites and then the paper will be closed with the conclusion.

2. Methodology

This research is a review of literatures, whether scientific articles or non-scientific articles, on satellite, cooperation, collaboration, and innovation. Therefore, in order to come out with this review, a number of journals ranging from earlier to more present journals had been analysed in the light of satellites cooperation, collaboration, and innovation perspective.

3. Theoretical Framework

3.1. Large Satellite

According to Facchinetti (2016), any artificial object intentionally placed in orbit by human action may be referred to as a satellite. It is not unusual to call them artificial satellites to distinguish them from natural satellites such as the moon. The history of Artificial Satellites dates back to the 1950s, when a world-renowned Sputnik 1 satellite launched by the Soviet Union on 4 October 1957 began the Soviet Sputnik Program and triggered the start of a space race from the United States to the Soviet Union. It was the first Artificial Satellite to be sent to space.

More than four thousand satellites have been launched successfully since 1957. Our space knowledge has been very sophisticated and will continue to develop with all the technologies created day by day as new business opportunities and development factors continue to increase.

Satellites has proven to be a vital resource for a very wide range of activities, and they have evolved by time, embracing new development as well as economic sectors, which are mainly:

- Weather information: For many activities, satellites are the first reliable way to forecast conditions in the weather, from commercial flights to farm industries.
- Climate research: The evolution of the climate as humanity confronts strong changes in atmospheric events is becoming increasingly important to understand as well as the real environmental effects of human activities. For this purpose, satellites provide hourly useful air measurements and analysis.
- Television, telephones, multimedia communication have dramatically taken advantage of satellite transmission capabilities, and they are a relevant drivers of commercial space growth.
- Data distribution: The explosive development as the new data paradigm takes place, is also the driving force behind the growth of the space industry.
- Transportation and logistics, navigation, safety security and rescue.

There are also more sectors that are specifically taking advantage of small satellites development:

- Space research
- Earth remote sensing
- Early warning and disaster management

A typical satellite consists of a number of vital subsystems, and of a payload carried for the ultimate mission purpose. A “subsystem” is a group of single components (or parts) that are organized in working units (equipment). The usual subsystems that make a satellite (and a small satellite, with no difference) working can be summarized as follows:

- Structure and mechanisms: they carry the payload and keep all the other subsystems (and equipment) together. They are often the heaviest spacecraft hardware, so they affect a number of challenges like launch loads (and costs, which can be real killers for satellite missions), material stability in vacuum and direct sunlight radiation, resistance to vibrations and shocks.
- Electric power subsystem: every satellite needs energy, so it needs a power subsystem to generate, control, store and distribute electrical current along every working component. This way, an Electric power subsystem is often divided in four smaller parts, like a power source (solar arrays), a power storage device (battery), a power control station, and a power distribution structure. Everything needs to be balanced, especially regarding overall weight as it’s been said for the outer structure. The electrical components must also be qualified for vacuum and solar radiation operations.
- Thermal control subsystem: as a satellite’s core is frequently made of integrated electronic processors, it needs to keep an adequate working temperature for all the units in some allowed ranges. Engineers have then to take into account the very different kind of solar exposition that a satellite usually faces, as all equipment is exposed to the longest direct sunlight during the day and on the other side is completely in darkness when behind Earth’s shadow.
- Attitude control subsystem: this subsystem is aimed to direct the satellite into desired directions and stabilize the satellite attitude.
- On-board data handling system: it controls the handling and the storage of satellite’s health data and all the data generated by the (eventual) payload.
- Communication subsystem: to assure the ground-satellite communication in both up- link and down-link directions. Usually it consists of one or more receivers that can be deployed and oriented. Reliability is a primary issue within

this specific subsystem, as it’s the ultimate connection between the mission control centre and the satellite in orbit.

- Payload: not always present, the payload is aimed to perform the mission objectives. For instance, a high-resolution camera constitutes the normal payload of an Earth imagery satellite.
- Propulsion subsystem: the engine of a satellite, to perform orbit manoeuvres and potentially change orbit’s altitude or trajectory. It can be used to send the satellite into a re-entering orbit or to transfer broken spacecraft into what is known as “graveyard orbits”, in order to avoid collisions with another spacecraft.

3.2. Small Satellite

Facchinetti (2016) explain CubeSat Class spacecraft are the majority of newly launched (and scheduled to launch in the near future) small satellites, together with the majority of the spacecraft in the process. The introduction of a dedicated orbital deployer, in particular the P-POD (Poly Picosat Orbital Deployer), facilitated and increased the reach of CubeSats as secondary payloads in orbit. The P-POD system can hold three 1U (standard 10cm3 factor, 1 Kg form factor), CubeSats and related combinations, and it can be considered as a good example for government, universities, and private industry technology and science collaboration, especially with NASA's CubeSat Launch Initiative (CLI) in particular.

The EELV Secondary Payload Adapter (ESPA), which can hold up to six moderate-size spacecraft in secondary payloads to a host rocket, is another major system for launching small satellites into the orbit through secondary payloads.

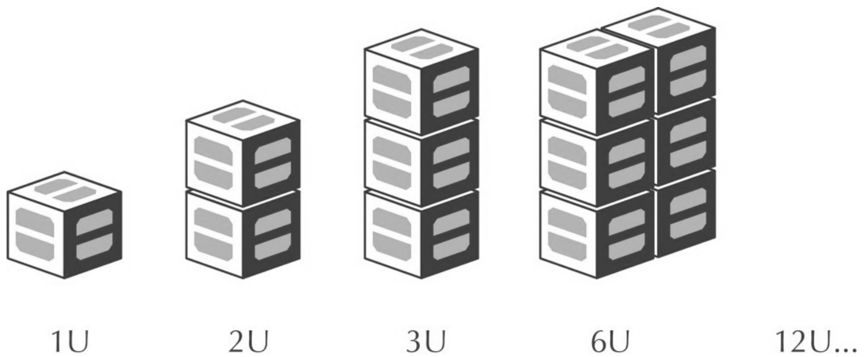

Figure 1. Configuration of P-POD

CubeSats is increasing especially as the typical CubeSat project can be launched within 18-24 months, at a cost of 1 million USD and even lesser, because of its short time-to-orbit. The CubeSat standard not only involves structural sizing of a satellite but also testing requirements and waiver processes. No less stringent development and approval processes for a Small Satellite or CubeSat are than those for traditionally large satellites: reduction of dimensions ultimately makes everything less demanding because the entire development process is tailored to that small platform.

Moreover, the CubeSat standard is relatively open with payloads and components that the satellite would carry and utilize. Most CubeSats are made of COTS (commercial off the shelf) products, helping drastically to lower costs, but it does not pose any restriction to any more sophisticated instrument to be carried, as this standard is more and more required for military and more complex civil purposes due to commercial development.

With the ever-developing technology for satellites, there comes the need to categorise these man-made space vehicles in order to project a more refined comparison of satellites. The categorisation ranges in terms of mission, orbit, but the mostly used categorisation is in terms of the size of the satellite. This classification uses a measurement unit for mass. The classifications according to Konecny (2004) are as detailed below:

- Femito-satellites (mass from 10 g to 100 g)
- Pico-satellites (mass lower than 1 kg)
- Nano-satellites (mass from 1 kg to 10 kg)
- Micro-satellites (mass from 10 kg to 100 kg)
- Mini/Small-satellites (mass from 100 kg to 500 kg)
- Medium-satellites (mass from 500 kg to 1000 kg)
- Large- satellites (mass > 1000 kg

Although there are specific names for the smaller satellites according to their mass, for this research we shall use the term "small satellites" for any satellite that is under 500 kg of mass.

The growing interest in small satellites can be brought back to:

- Increasing awareness among the public about the great potential value of on-demand access to geospatial information.
- Lowering of minimum price required to enter space.
- Lowering of cost per kilogram of hardware manufactured.
- Earth-imaging-payloads are more sophisticated and less heavy in weight.
- Technology advancements in other sectors which can be leveraged into satellite sector

All these facts are likely to show the great technology potential for a number of subjects, including:

- Education institutions, universities alike: the affordable costs and comfortable size are opening a new world of possibilities for research purposes and all STEM faculties overall.
- Business commercial opportunities for the huge amount of data that small satellites are proving to be capable to provide.
- Interest by government institutions; on the military and defence side, small satellites can achieve tactical communication, imagery for war faring and technology development while on the government-backed research side geospace and atmospheric research, earth technology and science, heliophysics, interplanetary missions.

3.3. Cooperation and Collaboration

Authors use at least one or even both words without distinguishing between them, but rather use these words as synonyms. This is problematic, since a different understanding of words may lead to a misunderstanding of project issues. Therefore, clear and unified definitions are needed for both terms, thereby allowing readers and project partners, respectively, to have the same understanding of cooperation and collaboration. Based on a literature review, Schöttle, Haghsheno, and Gehbauer (2014) in their article defines and describes cooperation and collaboration.

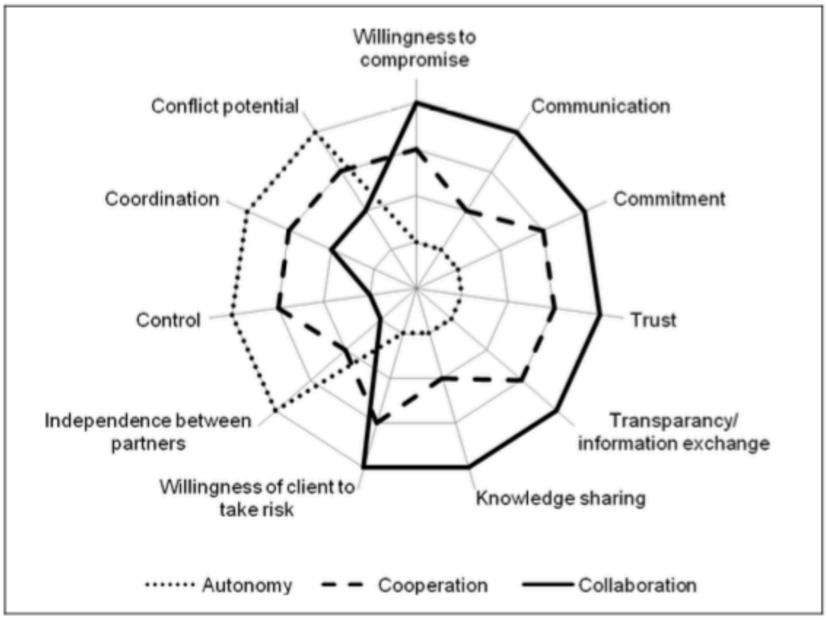

Figure 2. Compromise the Terms Cooperation and Collaboration (Schöttle, Haghsheno, & Gehbauer, 2014)

According to Schöttle, Haghsheno, & Gehbauer (2014), "collaboration is strongly correlated to the "soft" characteristics. Trust, communication, commitment, knowledge sharing, and information exchange are strong factors in collaboration. Participants of a collaboration act with high transparency. Cooperation is the middle ground between autonomy and collaboration, sometimes with a higher tendency to autonomy and sometimes to collaboration." Therefore, researcher define the terms cooperation and collaboration as follows:

- Collaboration is an interorganizational relationship with a shared vision of establishing a joint project organization with a shared, defined structure and a new project cultural culture, based on confidence and transparency, with the objective of together maximizing customers' value by solving each other's problems through interactive processes, which are planned together, and by sharing responsibilities, risk, and rewards among the key participants.
- Cooperation is a relationship between different project participants, which is usually not linked to a vision and task, leading to a distinctly organized project with an independent structure, which its culture is based on control and coordination to independently solve the problems so as to maximize its own organization's value.

Both terms require a shared understanding that participants are cannot achieve the project goals on their own. Soft factors have a strong impact on collaboration, as mentioned before. Collaboration does not exist automatically from the beginning of a project, it requires a process of development. Therefore, practitioners need to keep in mind that problems may occur, and mistakes will be made during the phase of creating.

Can be stated that the relationship between participants is more intense and stronger in collaboration than in cooperation, because a common goal and a jointly developed project culture on the basis of trust and transparency exist. According to Schrage (1995) it can be said that not all "professional situations require collaboration," but as explained in the research, calls for collaboration at least is among the key participants. For example, cooperation could be the better option for the interorganizational relationship between a sub-subcontractor and a subcontractor, whereas collaboration between the subcontractor and the general contractor could be preferred. Therefore, while developing a project team, participants and especially the client need to address the question of which kind of relationship leads to the achievement of project goals. This research supports the decision to be made by clarifying the implications of cooperation and collaboration.

According to Cheng & Sheu (2016) collaborative innovation with business partners enables firms to gain various potential profits in a number of areas, such as improved innovativeness, efficiency gains, and cost minimisation. Based on value co-creation, collaborative innovation integrates individual elements of a system through different approaches for the emergence of innovations. This highlights the importance of collaborative innovation with business partners because firms now learn from their business partners and push toward more open and collaborative forms of innovation.

The mechanisms of collaborative innovation in services have been recognised including the activation of relevant capabilities, underlying successful innovation that is a deep and broad innovation search trajectory, and leadership that is the mobilisation of diverse participants. While prior research has described the importance of organisational mechanisms in collaborative service innovation, most research emphasises the roles of systems, network structures, or leadership. A common organisational focus among collaborative partners likely influences the effectiveness of collaborative innovation.

3.4. Innovation

What is innovation? Usually, the word innovation is often being confused with the word invention. According to Lin (2006), the word innovation is originated from Latin word, Innovare which means "to make something new". Drucker (1985) defined innovation as the entrepreneurs' specific tool to exploit change for a diverse business or service. He added, this innovation can be presented as a discipline which can be learned and practiced. Meanwhile, Tidd, Bessant, Pavitt, & Wiley (1998) defined innovation as a process of transforming an opportunity into fresh ideas and being widely used in practice. Other suggested innovation is the "use of new technical and administrative knowledge to offer a new product or service to customers" (Afuah, 1998). Finally, many authors concluded that innovation is "any practices that are new to organizations, including equipments, products, services, processes, policies and projects" (Damanpour, 1991; Kimberly & Evanisko, 1981; Lin C. , 2007).

However, in order to be innovative, the management team or any responsible individuals need to have innovativeness. What is innovativeness? If we referenced to Oxford dictionary, innovativeness is a noun of the word innovative. But in the case of research, Feaster (1968) explained that innovativeness as a positive attitude toward changes and an awareness towards the need to innovate. Meanwhile, Wang & Ahmed (2004) coined the definition of innovativeness as “an organizations’ overall innovative capability of introducing new products to the market, or opening up new markets, through combining strategic orientation with innovative behaviour and process”. On the other side of the coin, innovativeness relates to the capacity of the firm to mesh together in innovation and managers use this innovativeness to solve business problems and challenges, thus resulting in providing survival and success pace for the firm, either for current or future (Hult, Hurley, & Knight, 2004). Hence, through the literature, it can be concluded that innovativeness is a key attitude in any management teams and any firms for them to be innovative, thus coming out with new ideas for the competitive advantage and durability of their firms. The last section in this research will discuss the role of innovation and innovativeness in a firm for a route to success.

Doz & Shuen (1990) have pointed out that collaborations and partnerships can be a vehicle for new organizational learning, helping firms to recognize dysfunctional routines, and preventing strategic blind spots. In dynamic environments, narcissistic organizations are likely to be impaired. The capacity to reconfigure and transform is itself a learned organizational skill. The more frequently practiced, the easier accomplished. (Teece, 1994). Change is costly and so firms must develop processes to minimize low payoff change. So, in fact, innovation not exclusively related to product, but also to business process of a company.

According to Greg Satell in his article in Harvard Business Review (Satell, 2017), there are several different kinds of innovation, depending on: a. How well the problem defined, and b. How well the domain defined. The defined innovation terms are grouped into Innovation Matrix. Satell defined 4 (four) terms, which are:

How Well the Problem Defined	Well	Breakthrough Innovation	Sustaining Innovation
	Not Well	Basic Research	Distruptive Innovation
		Not Well	Well
		How Well the Domain Defined	

Figure 3. Innovation Matrix
(Satell, 2017)

- **Sustaining Innovation**

Most innovation happens here, because most of the time we are seeking to get better at what we’re already doing. We want to improve existing capabilities in existing markets, and we have a pretty clear idea of what problems need to be solved and what skill domains are required to solve them.

For these types of problems, conventional strategies like strategic road mapping, traditional R&D labs, and using acquisitions to bring new resources and skill sets into the organization are usually effective. Design thinking methods, such as those championed by David Kelley, founder of the design firm IDEO and Stanford's d-school, can also be enormously helpful if both the problem and the skills needed to solve it are well understood.

- **Breakthrough Innovation**

Sometimes, as was the case with the example of detecting pollutants underwater, we run into a well-defined problem that's just devilishly hard to solve. In cases like these, we need to explore unconventional skill domains, such as adding a marine biologist to a team of chip designers. Open innovation strategies can be highly effective in this regard, because they help to expose the problem to diverse skill domains.

As Thomas Kuhn explained in the "The Structure of Scientific Revolutions", we advance in specific fields by creating paradigms, which sometimes can make it very difficult to solve a problem within the domain in which it arose — but the problem may be resolved fairly easily within the paradigm of an adjacent domain.

- **Disruptive innovation**

When HBS professor Clayton M. Christensen introduced the concept of disruptive innovation in his book The Innovator's Dilemma (Christensen, 2003), it was a revelation. In his study of why good firms fail, he found that what is normally considered best practice — listening to customers, investing in continuous improvement, and focusing on the bottom line — can be lethal in some situations.

In a nutshell, what he discovered is that when the basis of competition changes, because of technological shifts or other changes in the marketplace, companies can find themselves getting better and better at things people want less and less. When that happens, innovating your products won't help — you have to innovate your business model.

More recently, Steve Blank has developed lean start up methods and Alex Osterwalder has created tools like the business model canvas and value proposition canvas. These are all essential assets for anyone who finds themselves in the situation Christensen described, and they are proving to be effective in a wide variety of contexts.

- **Basic research**

Pathbreaking innovations never arrive fully formed. They always begin with the discovery of some new phenomenon. No one could guess how Einstein's discoveries would shape the world, or that Alan Turing's universal computer would someday become a real thing. As Neil deGrasse Tyson said when asked about the impact of a major discovery, "I don't know, but we'll probably tax it." To his point, Einstein's discoveries now play essential roles in technologies ranging from nuclear energy to computer technologies and GPS satellites.

Some large enterprises, like IBM and Procter & Gamble, have the resources to invest in labs to pursue basic research. Others, like Experian's DataLabs, encourage researchers and engineers to go to conferences and hold internal seminars on what they learn. Google invites about 30 top researchers to spend a sabbatical year at the company and funds 250 academic projects annually.

On the other hand David J. Teece (1986) explain the failure of innovator companies to make significant returns from innovation where as customers, imitators and other participants in the industry are often getting the benefit. They can profit more from the invention than the innovator themselves. Business strategy is proving to be an important factor, particularly as it concerns the company's decision to integrate and cooperate. His paper shows that markets do not work well when imitation is easy and the profits from innovative technology can accrue to the owners of complementary assets instead of to the developers of intellectual ownership. Since being first to market is often become a source of strategic advantage, this phenomenon may appear perplexing if not troubling to the innovator companies.

A framework is offered which identifies the factors which determine who wins from innovation: the firm which is first to market, follower firms, or firms that have related capabilities that the innovator needs. Three fundamental building blocks must first be put in place in order to develop a coherent framework: the appropriability regime, complementary assets, and the dominant design paradigm.

- Regime of appropriability
  A regime of appropriability refers to the environmental factors, excluding firm and market structure, that govern an innovator's ability to capture the profits generated by an innovation. The most important dimensions of such a regime are the nature of the technology, and the efficacy of legal mechanisms of protection.

Intellectual Property Rights		Inherent Replicability	
		Easy	Hard
	Loose	**WEAK**	**MODERATE**
	Tight	**MODERATE**	**STRONG**

Figure 4. Regime of Appropriability
Source: (Teece, 1994)

- Dominant design paradigm
  The emergence of a dominant paradigm signals scientific maturity and the acceptance of agreed upon "standards" by which what has been referred to as "normal" scientific research can proceed. These "standards" remain in force unless or until the paradigm is overturned. While new products and processes either can enhance or destroy the value of such assets (Tushman, Newman, & Romanelli, 1986)

- Complementary assets

An innovation consists of certain technical knowledge about how to do things better than the existing state of the art. Assume that the know-how in question is partly codified and partly tacit. In order for such know-how to generate profits, it must be sold or utilized in some fashion in the market. Accordingly, the nature of complementary assets are categorized in three types, which are generic, specialized, and co-specialized.

- Generic assets are general purpose assets which do not need to be tailored to the innovation in question.
- Specialized assets are those where there is unilateral dependence between the innovation and the complementary asset.
- Co-specialized assets are those for which there is a bilateral dependence.

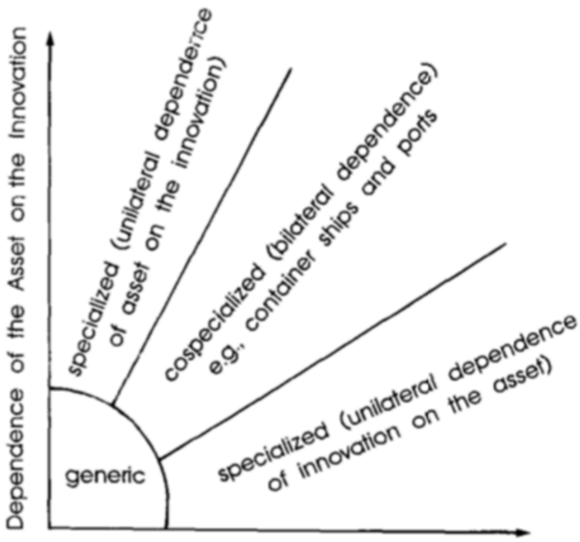

Figure 5. Dependence of Innovation on Complementary Asset
Source : (Teece, 1986)

The framework shows that the limits of the company are an important strategic variable for innovative businesses. The ownership of complementary assets helps establish who wins and who loses innovation especially if they are specialized and/or co-specialized.

Imitators can often outdo innovators if positioned better with regard to critical complementary assets. Public policies to promote innovation must therefore concentrate not only on research and development but also on complementary assets and the infrastructure underlying them.

It would seem important for the government to remove barriers to the development of complementary assets that tend to be specific or co-specialized in innovation if it were to stimulate innovation. If this is not achieved, an unnecessary large portion of innovation profits will be made available to imitators and other competitors. If these companies are located outside the national borders, there are obvious implications for the internal distribution of income.

3.5. Complementary Product

A complement refers to a complementary good or service that is used in conjunction with another good or service. Usually, the complementary good has little to no value when consumed alone, but when combined with another good or service, it adds to the overall value of the offering. A product can be considered a complement when it shares a beneficial relationship with another product offering such that a surge in demand for one product results in an increase in demand for the other.

In economics, a complementary good or complementary product is a good with a negative cross elasticity of demand, in contrast to a substitute good. This means a good's demand is increased when the price of another good is decreased. Conversely, the demand for a good is decreased when the price of another good is increased. If goods A and B are complements, an increase in the price of A will result in a leftward movement along the demand curve of A and cause the demand curve for B to shift in; less of each good will be demanded. A decrease in the price of A will result in a rightward movement along the demand curve of A and cause the demand curve B to shift outward; more of each good will be demanded.

Basically, this means that since the demand of one good is linked to the demand for another good, if a higher quantity is demanded of one good, a higher quantity will also be demanded of the other, and if a lower quantity is demanded of one good, a lower quantity will be demanded of the other. The prices of complementary goods are related in the same way: if the price of one good rises, so will the price of the other, and vice versa. With substitute goods, however, the price and quantity demanded of one good is related inversely to the price and quantity demanded of a substitute good, meaning that if the price or quantity demanded of one good rises, the price or quantity demanded of its substitute will fall.

When two goods are complements, they experience joint demand. For example, the demand for razor blades may depend upon the number of razors in use; this is why razors have sometimes been sold as loss leaders, to increase demand for the associated blades.

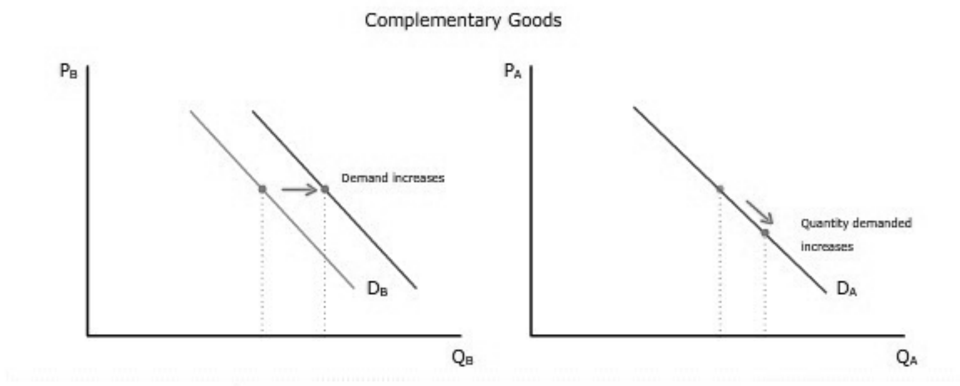

Figure 6. Supply & Demand Graph of Complementary Product

An example of this would be the demand for cars and petrol. The supply and demand of cars is represented by the figure at the right with the initial demand D1. Suppose that the initial price of cars is represented by P1 with a quantity demanded of Q1. If the price of petrol were to decrease by some amount, this would result in a higher quantity of cars demanded. This higher quantity demanded would cause the demand curve to shift rightward to a new position D2. Assuming a constant supply curve S of cars, the new increased quantity demanded will be at D2 with a new increased price P2. Other examples include automobiles and fuel, mobile phones and cellular service, printer and cartridge, among others.

A substitute good, in contrast to a complementary good, is a good with a positive cross elasticity of demand. This means a good's demand is increased when the price of another good is increased; both in the same direction. Conversely, the demand for a good is decreased when the price of another good is decreased. If goods A and B are substitutes, an increase in the price of A will result in a leftward movement along the demand curve of A and cause the demand curve for B to shift out. A decrease in the price of A will result in a rightward movement along the demand curve of A and cause the demand curve for B to shift in.

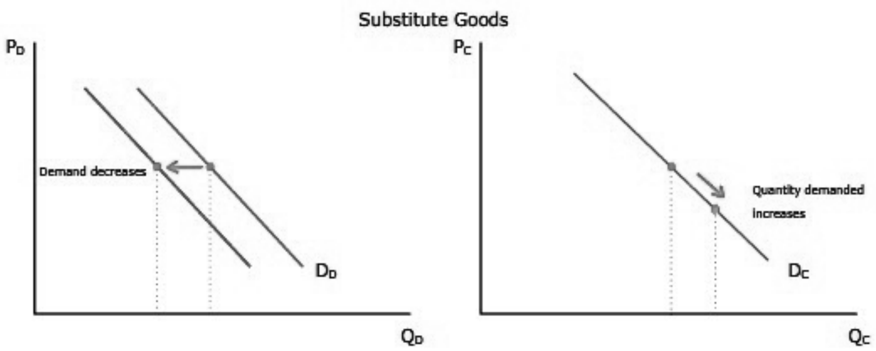

Figure 7. Supply & Demand Graph of Substitute Product

Examples of substitute goods include margarine and butter, tea and coffee, beer and wine. Substitute goods not only occur on the consumer side of the market but also the producer side. Substitutable producer goods would include: petroleum and natural gas (used for heating or electricity). The degree to which a good has a perfect substitute depends on how specifically the good is defined. Take for example, the demand for Rice Krispies cereal, which is a very narrowly defined good as compared to the demand for cereal generally. The fact that one good is substitutable for another has immediate economic consequences: insofar as one good can be substituted for another, the demands for the two kinds of good will be interrelated by the fact that customers can trade off one good for the other if it becomes advantageous to do so.

Chapter II – Discussion and Conclusion

4. Demand of satellites

The study of the demand done by dos Santos Paulino and Le Hir (2016) try to show the potential threat induced by potential disruptive innovations. They learnt from the literatures that the three types of potential disruptive innovations are: a. do not appeal to mainstream customers; b. that existing market low-end potential disruptive innovations appeal to existing customers; c. low-end potential disruptive innovations in new fringe markets and high-end potential disruptive innovations in new detached markets appeal to new customers in new markets.

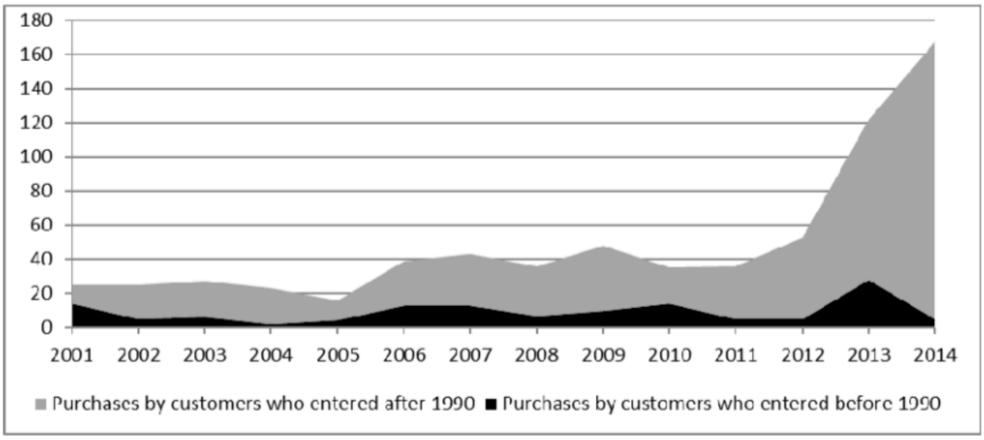

Figure 8. Evolution of Purchases of Small Satellites
(dos Santos Paulino & Le Hir, 2016)

Observation from 1990 to 2014 new customers who entered the satellite sector after 1990 purchased 3.9 times more small satellites than customers who entered before 1990. The entry of new customers in the small satellites market is noteworthy after 2012.

5. Small Satellite as Disruption

In his article, dos Santos Paulino and Le Hir (2016) stated that every new product in the same industry can be treated as a potential substitute and they use the concept of potential disruptive innovation to assess its threat. They applied analysis to the case of the satellite industry because existing firms currently face the innovator's dilemma.

According to them, small satellites are potential disruptive innovations belonging to two types and that they will induce a low threat for existing satellite manufacturers if these innovations diffuse. The initial characteristics of small satellites allow us to argue that they are an imperfect substitute for typical satellites that weigh several tons. The changes in the industry structure (performance criteria and markets) due to the introduction of small satellites are significant. The new products and the new markets are different, preventing to observe major movements of existing customers entering the new markets to adopt the new product.

As substitute means that the legacy large satellite demand is in danger of decreasing in contrast with the emerging demand of small satellite, we try to provide with some examples of small satellite utilizations that can potentially become complimentary to large satellite, which means with suitable equipment attached to the small satellite, the increasing demand of small satellite would not disturb the demand of large satellite, even increasing the confidence in large satellite, provided large satellite considered become more reliable and no longer 10-15 years of investment.

6. Discussion – Scenario of Collaboration

6.1. Disaster Relief Mission

Satellites are known to have a role in disaster relief efforts (Delmonteil & Rancourt, 2017). This is a mission that can be performed by both large conventional satellites as well as the smaller satellites. However, both of these satellite types have their own strengths and weaknesses for the particular mission.

Large satellites are mostly put into the Geostationary Orbit (GEO). This means that they are operating from a very long distance from the surface of the earth. From this orbit, the large satellites are able to provide earth imagery or telecommunications signal relay with very wide scope of coverage. However, this also limits the image resolution and also latency of signal transfer of the large satellites to the end receiver on earth.

Oppositely, small satellites operate from the Low Earth Orbit (LEO). This means they are closer to the surface of the earth compared to large satellites. From this orbit, the small satellites are able to provide better image resolution of the earth and faster telecommunications signal relay compared to the large satellites. However, the scope of coverage is more limited compared to the large satellites in an identical timeframe.

By analysing the capabilities of both types of satellites we can conclude that despite having the capability to perform the same mission, each type has a unique weakness that can be covered by the strength of the other type. This case example may also be suitable for pseudo-satellite systems due to how close to the atmosphere they operate.

As mentioned above, disaster relief missions can be performed by both large and also small satellites. The market for disaster relief missions are more less the same for both of these satellite types. That is why researchers has concluded that small satellites are substitute products to large satellites for such missions.

However, small satellites are not what we can define as perfect substitutes to large satellites. This is due to the fact that even though they can perform the same mission, the end results would be different. Combining the two satellite types service capabilities should increase the efficiency of disaster relief efforts.

In disaster relief missions, satellites play the role of both earth imagery provider as well as telecommunications signal relay device. We will discuss in detail on which satellite type is more suited for which role in the relief mission. We start from the earth observation role.

Disaster relief efforts require a detailed visual of the landscape in need of relief. Most disaster events take place in areas that are as small as a city, state, or province. Given that small satellites that perform earth observation missions are operating at LEO, they have the advantage of having the ability to provide a very detail view of a disaster-stricken area from above. Even though large satellites operating at GEO are capable of providing a wider view of the surface, such scope is not as urgent as generating more pixels of the image. Therefore, small satellites are more suited for this role. Earth observation satellites prefer sun synchronous polar orbits at orbital heights between 400 and 1000 km. If the observations are aimed at specific areas of the globe, then lower inclinations combined with elliptical orbits (150 to 500 km) can be chosen. Such orbits do not provide ideal illumination conditions, however. The choice of the orbit determines repeatability of sensing.

For telecommunications purposes, disaster relief efforts require uninterrupted long-distance back-and-forth signal relays from one point to another.

The signals relayed are for telephone, radio, television, and also internet. With large telecommunications operating at GEO, they are capable of relaying these signals to a very wide scope of coverage. The drawback of using large telecommunications satellite is that they have problems relaying signals to mountainous areas since the terrain can interfere with the signal transmissions. But this is not as troubling as losing communications signal in the middle of a telephone call due to using small satellites that travels beyond the area in need of signal relays. Hence, large satellites are more suited for this role in disaster relief efforts.

Meanwhile, sensors are required for earth imagery, along with optical sensor that is fundamental for imagery. For disaster relief mission usually, satellites will be equipped with thermal sensor (passive sensor) and sometimes active sensor like radar. but adding active sensor will add extra weight because it requires antennas for transmission of electromagnetic pulses and for reception of the backscattered reflections from the ground.

The sensor limitations for use in small satellites have been discussed in detail in the paper "High resolution mapping with small satellites" by Rainer Sandau, presented to the ISPRS 2004 Congress (1). They refer mainly to optical and thermal sensors. They are:

- Spatial resolution by the optical system, which is governed by the diffraction limitation;
- sensitivity of the detector elements requiring a minimum exposure time of about 1 m/sec;
- image motion, due to the forward motion of the satellite movement in the order of 7.4 km/sec or 7.4 m/msec.

If higher resolutions than 7 m are desired, then image motion compensation must be applied.

And also, it is important to consider the data transmission speed to ground station. The charges received at the sensor elements of the arrays need to be transmitted at appropriate readout rates to the ground stations during a ground station contact time of about 10 minutes. At a rate of 100 Mb/s up to 60 GB of data can be transmitted. If higher data rates are required data compression must be utilized for transmission.

6.2. In-Orbit Monitoring and Maintenance Mission

Satellites both large and small, have a certain lifespan. Lifespan of large conventional satellites are usually around 10-15 years and are calculated prior to launch. There are several factors determining the lifespan of satellites, mainly due to the reliability of the structure and system of the satellite itself.

Performing maintenance to satellites in orbit is still impossible at the time of writing of this research. This is due to the inefficient costs of having a secondary space unit deployment with the sole purpose of performing maintenance on an orbiting unit.

With the option of maintaining the structures of large satellites currently unavailable at the time of writing, satellite operators have focused their attentions to acquiring the capability to monitor the health of their satellites. Despite calculating the lifespan of their satellites, operators would still need to monitor the unit in order to calculate the actual lifespan with respect of the structure and system. From this condition, an efficient short-term solution would be to acquire services for visual inspection of the satellite structures.

With the limitation of size and mass, small satellites are logically only able to operate at LEO height. Currently, small satellites are capable in providing high resolution images for earth observation missions (see above explanation). Therefore, it makes sense to opens up the possibility of having their cameras assigned to monitor the structural health of large satellites that are operating at LEO, and eventually in the future, GEO, which is around 36000 km from earth, compared to LEO that only orbiting the earth at the distance of around 500 km to 2000 km.

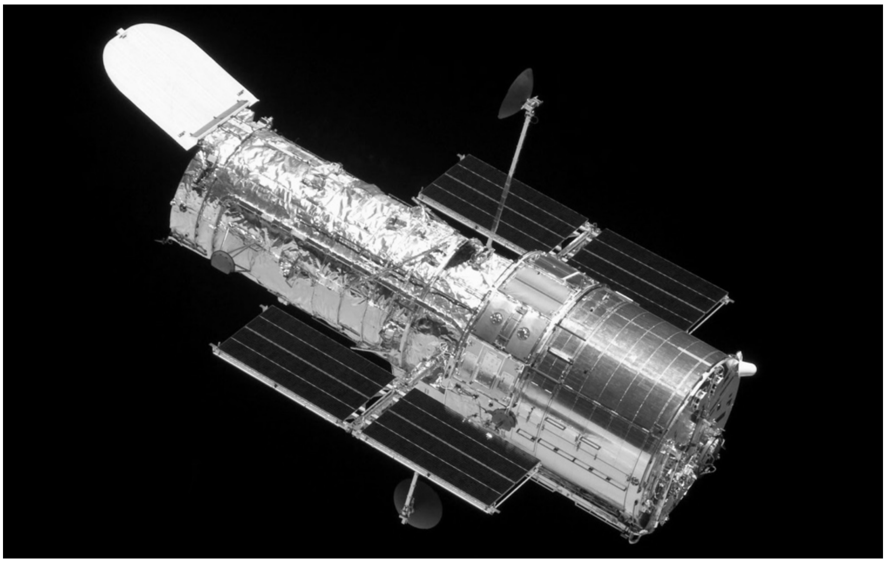

Figure 9. Hubble Space Telescope
(Credit: nasa.gov)

The operation shall involve a small satellite with mechanisms resembling the Hubble Space Telescope (HST). HST is a space telescope equipped with 2,4 m mirror with the mass of 11,110 kg that launched to LEO in 1990. With such specification and definition of satellite we have, we can consider HST as a large satellite. Scaling down the capability of HST which can provide imaging far into deep space from LEO, then we can consider in the future small satellites should be able to project visual imaging of larger satellites that are orbiting above them at 36000 km with considerable quality. By having the small satellites performing visual inspection of large satellites from a lower orbit, the large satellites become direct customers to the small satellites. The visuals would then help large satellite operators to calculate the actual remaining lifespan of their satellite unit at a given timeframe.

This method of collaboration between small satellites and large satellites resemble the existing relationship between Unmanned Aerial Vehicles (UAVs) with commercial aircrafts for maintenance purposes. Quadrotor type UAVs are utilised for damage assessments to commercial airliners to accelerate the process of engineering analysis. This not only save both the MRO company and the airline their budget, but it is also less time-consuming.

On the other hand, to make it successful, both large satellite customers and small satellite manufacturers should cooperate to provide the exact position of the satellite and to provide guarantee that the data or images provided by the smaller satellite are exclusively for the customers.

With more advancements in space bound technology, innovations are pushed by large companies and/or created by smaller companies to keep the satellites to stay longer in their orbit a little bit. Nowadays, satellite companies have begun researching to develop satellites that can provide refuelling and structural maintenance to large satellites. This is a form of potential innovation from the small satellites to increase their service capabilities to the large satellites industry. In the end, in-orbit refuelling, and structural maintenance of satellites may not be impossible.

There is a report in 2010 regarding On-Orbit Satellite Servicing Study (National Aeronautics and Space Administration, 2010) which discussed several subject, and one of the focal points is about the possibility of larger satellite can be successfully serviced. In the report it is written that “In fact, much of the servicing performed to date has been on legacy hardware never intended for on-orbit servicing. The range of applicable servicing activities includes repair, refurbishment, refuelling, and orbit modification. Servicing these legacy satellites provides an immediate customer base on which to build a future satellite-servicing infrastructure. The business case for commercial satellites is favourable if the capability is available and well understood. The first step of the proposed mission sequence is to realize this capability for satellites in Geostationary Earth Orbit (GEO).”

NASA’s Satellite Servicing Capabilities Office (SSCO) reported a successful test of Robotic Refuelling Mission (RRM) in International Space Station (ISS) in 2013, demonstrating that remotely controlled robots could work through valves and wires to successfully transfer fuel in space. And in February 2014, the SSCO announced the successful test of its Remote Robotic Oxidizer Transfer Test (RROxiTT), which involved remotely transferring toxic oxidizer fuel under the high pressures that would be experienced in space, an experiment that would be far too hazardous to perform aboard the ISS. RROxiTT successfully demonstrated the ability of the robotic transfer unit to move corrosive fuel from the tank into the satellite under these tremendous pressures. The robot sat on the ground at NASA's Kennedy Space Center, Florida, while its operator controlled its behaviour from the Goddard Space Flight Center in Maryland, further simulating the difficulties experienced by working with a unit over a distance.

Figure 10. SSCO RROxiTT, with the Oxidizer Nozzle Tool
(Credit: NASA/Chris Gunn)

This report and successful test are a pointer that in the future, equipped with suitable tools, smaller satellites will no longer be considered as a potential threat to larger satellite but rather will become a pretty useful device to prolong the usage life of larger satellite. However, this innovation would not be useful if there is no collaboration between larger satellite manufacturers and smaller satellite manufacturers. To make these innovation useful, larger satellite manufacturers should provide a standardized port for smaller satellites to attach itself and let its robotic arms to stream its payload or do maintenance to larger satellite.

6.3. Space Debris Removal Mission

Continuing on the topic of satellite structural health management. Structural health of satellites deteriorates with age, but there are also other factors that can damage the structure of satellites. These external factors are in the form of collisions with foreign objects.

The most common foreign objects that a large satellite may encounter are space debris. They can be of many shapes and sizes and in time they will grow in numbers as a result of more inactive or decommissioned artificial space objects. Collision with any form of space debris may cause considerable harm to the structure of satellites, therefore a solution must be provided for this particular problem.

Several companies are currently developing small satellites that are capable of performing space mining missions. Mechanisms such as harpoons to robotic limbs has been designed and tested by the companies to prepare them to perform the missions. These mechanisms may also be utilised to perform space debris removal in satellite operating orbits to reduce the risk of collision with in-service satellites.

The existence of space debris has been an ongoing issue for many stakeholders within the space industry. This is especially troubling for large satellite operators due to the fatal effects it may present should their units collided with any space debris of any size. That is why satellite operators has established several joint venture projects to resolve the issue.

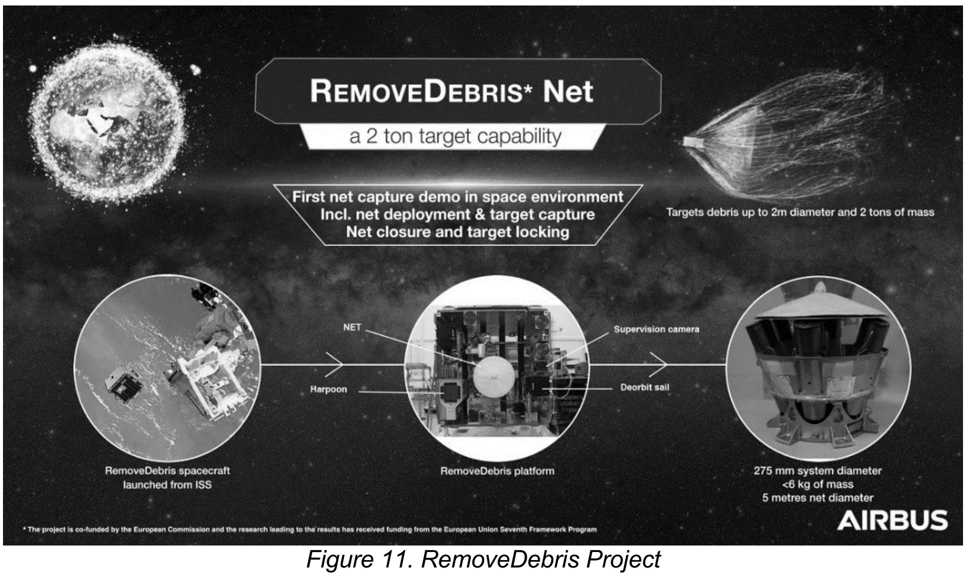

Figure 11. RemoveDebris Project
(Credit: Airbus)

The RemoveDebris experiment, designed and manufactured by a team from the University of Surrey specifically SSTL (Surrey Satellite Technology Ltd.) in the UK and the net was developed and supplied by a team of engineers at Airbus Germany as part of 15.2 million Euro, funded jointly by the European Commission and 10 partners including Airbus, Surrey Space Centre, Ariane Group, SSTL, ISIS, CSEM, Inria and Stellenbosch University. The satellite is about the size of a washing machine and weighs 100 kg (220 lbs). It carries two cubesats and three types of technologies for space-debris capturing and active deorbiting - a harpoon, a net and a drag sail. It will also test a vision-based navigation using cameras and LiDAR system for optical navigation that will help future chaser spacecraft better aim at their targets.

Should this project be successful, it will gradually decrease the threat of large satellites colliding with large space debris. There have also been discussions on a mission to remove ENVISAT (a large decommissioned earth observation satellite) from LEO. In simple terms, it is a way for small satellites to provide a solution for the space environment and indirectly supporting the operations of large satellites by protecting them from structural damages.

7. Conclusion

There are many players in the space sector. One of these players are satellite manufacturers and operators. Nowadays, we have become familiar with two types of satellites, large conventional satellite and the emerging small satellite. To make an analogy, we make a comparison between small satellite and large satellite with drones and commercial aircraft. Existing perceptions view small satellite as a potential disruption to the existing satellite market just as drones to commercial planes, which is proven through previous research on this topic. However, aside from playing the role of substitutes, there may also be a possibility for small satellites to become a complementary product for large satellites.

We come up with several examples of the possibilities of small satellite and large satellite can work together in any way or another, whether it is supported by current technologies, in development, or under research.

For small satellite to become a complementary product of large satellite, both manufacturers need to be in the same page. Larger satellite manufacturers should understand that most likely, there will be an increase of small satellite demand. It seems awful to the large satellite market and it seems to agree with the previous research that small satellite will become the substitute of large satellite. But, if we see it from the other perspective, with the increase of large satellite, there will be an increase in small satellite demand because of the capability of small satellite to support and to prolong large satellite utilization.

The main objective of this research is to point out that there is a chance, given the current situation and innovation, that in the future the relation between small satellite and large satellite can become a complementary product. Although, the possibility to materialized it eventually depends on the eagerness of each and every parties involved, small satellite manufacturers, large satellite manufacturers, government institutions, and policy maker to make it possible.

For future research, it would become a challenge and opportunity for scholars and researchers to address this matter, whether to provide another example of satellites collaboration, or to give updates on examples given in this research.

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