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When Quantity Matters…

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ABSTRACT

Quality and performance are very often the design drivers of engineers working on Space Projects. Reliability and availability of space systems are requirements on a single unit. In case the unit fails or underperforms, the mission is not accomplished or seriously compromised. The Quality Assurance has the task of making sure that the satellite complies with the specifications and operates flawless for the entire life. In mass production, the role of Quality Assurance is to minimize, not to eliminate, the number of defects. A certain number of defective units are acceptable. They are repaired or replaced during the guarantee period.

How far are satellites from the point where the production cost is so low that replacing a defective unit is cheaper than ensuring it is defective free? Once the satellite market has reached that point, we can say that quantity matters more than quality. In recent years, space projects have seen the deployment of recurrent units for constellations, as GPS, Iridium, Globalstar, and others. Still the number of recurrent units is too small to make a difference.

We still need to reach the point where satellites can be built and launched for a fraction of the present cost. Do technologies and methodologies of small satellites play a role to reach the turning point where quantity makes the difference? Is there any market requiring enough recurrent units to push down the development cost per unit to a negligible level?

The paper analyzes the technology maturity of small satellites and shows how far small satellites are from the point where the quantity matters more than quality. The work analyses market dynamics and how non-space technologies may play a new role in deploying new space assets. The paper shows the pace at which space technologies are approaching the turning point where quantity matters more than quality.

INTRODUCTION

A large bibliography[1,2] can be found on approaches to build, design, test, and operate low cost satellites. The challenges to built low cost satellites within a tight budget and schedule a have taught the aerospace community many lessons. Large Satellite Integrators (LSI) and Institutions as NASA, US-DoD, France DGA, and ESA, were initially sceptical about practical applications of small satellites. In the early days of small satellites they were seen as underperforming, not yet proved, and of questionable reliability, good only at keeping busy small communities of very green rocket scientist. In those times small satellites were a territory mainly occupied by Universities, small National initiatives. The work done on small satellites were a combination of training and best effort *"to make it work".*

Along the path of continuous growth of small satellites, many communities came on board. In-flight proof that "*it does work, even better of what we expected*" and the shrinking budget for aerospace missions, make LSI and Institutions looking at the Small Satellites as an opportunity to make more with less.

What's the present situation?

1. Very green rocket scientists are still busy with small satellites;

2. Large Satellites Integrators have complemented their portfolio with a number of low cost small platforms;

3. Institutions have now stable small satellites programs for complementing large missions or dedicated to specific low cost missions;

4. A few companies are now on the market delivering small satellites or services using constellations of small satellites.

5. The Small Satellite approach is cost effective and quick way to verify concepts or to fill operational gap.

Points 1, 2 and 3 are sharing the same market of the early days: Institutional funds. Points 4 and 5 are the sign that new markets are opening for small satellites.

Miniaturization, technology development and the better knowledge on how to build and operate a low cost satellite, made a larger number of applications possible, extending the share of the small satellite market. Surveys [paper presented USU 2008, session dedicated at the last Berlin conference] confirm the trend of small satellites enlarging the possible applications.

Knowledge on how to built small satellites improves continuously, reducing cost and improving reliability of the whole process. What will happen when we will be able to build and deliver a satellite for a fraction of the present cost? Is there any market [ref to the book "seeing what's next"] that will suddenly materialize when the performance to cost ratio will overcome a certain threshold?

How this will change the way of designing, building, launching and operating satellites?

Predicting what will happen for high technology markets is not very easy; sometimes it is even questionable to place a too large effort to predict a too far future. Some Hi-Tec companies organize themselves to follow the paradigm "don't be smart, be fast". But even if our capability to envisage is limited by the rapid and unpredictable evolution of the technology, we still shall observe trends that may provide some clues on how to do be ready to quickly adapt to the forces of new markets.

Among all possible applications of small satellites we focused on Earth Observation satellites, seen by the Authors as one of the most dynamic market of small satellites, both in term of market grow and technology evolution.

THE MOTIVATION/ABILITY FRAMEWORK

Aspects as the disruptive role of small satellites, their technology evolution or breakthrough has been well addressed in the past years in this conference, but we still have limited capabilities to forecast markets evolution and to identify what it's the next opportunity.

The Motivation/Ability Framework[3] is a two-by-two matrix (figure 1). The Motivation are the opportunities seen by the industrial players in a market, the Ability is defined as the capability to offer products and services that fulfill customer needs.

Figure 1 - Motivation / Ability Framework

Motivation	Ability: Low	Ability: High
High	*Target out of reach* Companies need to acquire the technology to develop their capability. ***Market driven by technology innovation***	*The Hotbed* Companies well established in a profitable market. ***Market driven by technology evolution.***
Low	*Hic Sunt Leones* Companies are unable to create and exploit innovation in this market. ***Non-market, can only be occupied by synergic technologies***	*Looking for opportunities* Companies struggling to enter a low end market. ***Market occupied by disruptive technologies***

The most interesting part of the market, for the scope of this paper, is area with low motivation and low ability. We called this area "Hic Sunt Leones", an expression in old maps for undiscovered territories. Hic Sunt Leones on a map indicated an unknown and dangerous land. We found this term very appropriate for the markets requiring high technology but offering very low profitability business. Those markets will be difficult to enter and difficult to navigate, but may offer interesting new opportunities. These markets will not exist if synergies cannot be established among different types of technologies and market. We would like to use an examples somewhat related to space to explain the use of the Motivation/Ability matrix.

GPS Navigation through the traffic

The Global Positioning System is a large infrastructure developed the US DoD to guide USAF aircrafts over territories not covered by Loran or other ground based naviation systems.

GPS navigators are now a very common electrical device. A large number of companies are present in the market selling GPS navigator at a price affordable for the mass market. None of the companies selling GPS would have had the resources to develop the complex GSP space infrastructure, and consequently sell handheld devices for the consumer market. The GPS case is an example how a Government driven technology has generated market opportunities in an area that is unaffordable to private investors.

One more interesting evolution of GPS is the guidance through the traffic. This service, recently offered by Tom-Tom for a modest 10€ /month, gives the users very accurate traffic information and suggestions on possible detour. The information is obtained by mobile telephone companies that retrieve traffic information by monitoring the average speed at which the telephone of their subscribers switch between cells along highways.

This example shows how the navigation systems can deliver a service at a very affordable cost by sinergically use a different technology and a Government supported development. Tom-Tom exploits a market that will not generate enough revenue to pay back the investment for the whole infrastructure of GPS and traffic monitoring. The traffic information service on the Tom-Tom occupies the low motivation, low ability part of figure 1.

A similar case is the "Personalized Weather Forecast". A number of companies offer personalized weather forecast for a modest subscription fee. This service is very useful to user that systematically need timely and accurate weather forecast. Also in this case, this service use government sponsored infrastructures, the weather forecast service, in synergy with a different technology: internet broadband. The use of mobile telephone connected to a laptop make this service available also to users located in remote areas.

In the above two examples we have seen as Government driven technologies and infrastructures and opportunities to make synergic use of technologies can open markets out of reach to private enterprises or simply beyond our imagination. (*We wonder who could have imagined 30 years ago that today we could have been able to find our way through the traffic by using somebody else telephone).*

THE STUDY CASE: EARTH OBSERVATION SATELLITES

Can we use the same template to forecasts if non-markets for the small satellites for Earth Observation will materialize? What type of technologies will be needed to deliver new services and products?

Making this type of forecast goes well beyond the capability (and the imagination) of the Authors, but we can still observe what trends and forces are moving Earth Observation satellites in the Motivation/Ability matrix. Figure 2 reports the Motivation/Ability matrix for Earth Observation (EO) satellites.

Figure 2

Motivation/Ability Matrix for EO Satellites

Motivation	Ability: Low	Ability: High
High	*Target out of reach* New HiRes Earth Observation Systems for defense and Environment ***Market driven by technology innovation***	*The Hotbed* Earth Observation Satellites for Institutional Market ***Market driven by technology evolution.***
Low	*Hic Sunt Leones* Example: One meter, one day revisit on your PDA. ***Non-market, can only be occupied by synergic technologies***	*Looking for opportunities* EO for customers other than Institutions (DMC, HiRes Images) ***Market occupied by disruptive technologies***

The Hotbed

Institutional Market is still one of the most important markets of LSI of EO satellites. Applications as weather forecast, defense, and environment monitoring are demanding always increasing performance and functionalities. Multibillion contracts are awarded by governments for the procurement of space segments for these applications. It is interesting to observe what is the trend of the cost of EO satellites. As example we would like to refer to Sentinel-2A. This satellite is a multispectral high resolution satellite developed in the frame of GMES. The cost of Sentinel-2A is 200 M€, less than half of ERS-1, the 1st European remote sensing satellite, launched in 1991, whose cost was 500M€. Remarkably, Sentinel 2B, a recurrent unit of Sentinel-2A, is expected to cost 100M€, close to 1/10 of ERS-1, if costs are compared on current economic conditions.

The trend of EO satellites becomes more evident when comparing the evolution of the resolution. Landsat-1 in launched in 1972 had a resolution of 100 meter, the resolution of SPOT-1, launched in 1985 was 10 meters, and Ikonos-2 launched in 1999 reached 1 meter. The resolution of EO satellites improved a factor 10 every 12 years. The evolution of resolution and the reduction of the cost of the space asset is decreasing the cost of satellite data at an exponential rate.

The multibillion Institutional contracts to built Earth Observation satellites resulted in developing the capability to produce remote sensing data in a much more cost effective way.

Moving Down from the Hotbed

<u>The role of Governments: the ORS case</u>

The ORS requires fast response. USA DoD through DARPA, and ARFL have supported a number of R&D initiatives in order to shrink the development and the AIV time of satellites. Small satellites have been the natural test bench to understand what can be done to minimize the "time to orbit". The work done in the last few years aimed at the development of standards that will streamline the design, assembly, and verification of satellites. Inevitably, this will translate in a cost reduction and in more competitive products. How far the performance of low cost EO satellite can go and how cheap the satellite can be has been recently demonstrated by TacSat-2[4]:"*…the Operationally Responsive Space (ORS) program is building and launching a set of small, relatively inexpensive, and technically innovative satellites that could change the way the military, if not the intelligence community, does business. TacSat-2 was launched with an experimental one meter resolution imager and a fairly basic signals intelligence payload.*"

<u>The Role of Institutional Missions: LSI and the Complementary Missions</u>

One of the driving forces of European Space Agency (ESA) is geo-return: all ESA member states shall receive contracts in proportion to the participation of their Countries. With the vertical integration of LSI one single company could build most of a satellite, making more difficult to comply within a single mission to the geo-return rule. A number of small satellites recently developed within ESA as Smart-1, Proba helped to balance the geo-return. Small missions are now seen by the Agency as an opportunity to balance geo-return, to give smaller companies a fair business opportunity, and at the same time to complement large missions. This opens a Government supported market of Small satellites and push forward the know-how to develop low cost satellites.

Looking for Opportunities

Both ORS and ESA supported mission are governmental forces helping industries building small satellite. At the same time, National space programmes traditionally in favour of small satellites, keep a role in maintaining active lines of small satellites. Those companies, presently supported by National programmes, are looking for opportunities outside of their counties and are learning how to thrive in the lower part of the motivation.

Entering the Land of Lions

TacSat-3 is one example on how Government sponsored developments are preparing small satellites to enter "*the Land of Lions*": "*- Four ideas with the same name. - The first idea is the best known, to give the combatant commanders direct access to, and tasking authority over, a set of space assets. The second goal is to change the economics of military space and to get away from the extremely expensive—though highly capable—intelligence satellites and replace them with smaller specialized spacecraft, such as TacSat-3. The third element is the drive to reduce the costs of getting spacecraft into orbit. This is why the ORS program has been so supportive of Elon Musk's SpaceX and their Falcon launchers, although they also are using Orbital Sciences Corporation's Minotaur that* *recycles old elements of Minuteman ICBMs. The fourth and final idea is to push forward new technologies that will allow the Defense Department to "surge and replenish" satellite constellations and to do so quickly and at a reasonable cost.*[3]

The access to a non-market may result from a mix of technology developments supported by Government and disruption innovations in other fields. By combining products and services that were out of reach because their complexity and development cost can offer the opportunity to enter a low end market.

Cost reduction of few orders of magnitude of technology and the proper mix of available services have in recent past created totally new markets, from home computers, to mobile phones. How far the cost of small satellite shall go down before we will see the generation of a new market?

The TacSat program in the USA is just one example. A number of initiatives in Europe both coordinated by ESA (Proba series of small satellites) and at National level (Miriades sponsored by CNES, and similar initiative started by DLR) will produce a similar effect: to reduce the barriers to enter the low Motivation/ low Availability part of the plot by reducing the cost of space asset.

One of the cost drivers in satellites is the development that usually accounts for 50% of the overall cost. In case of recurrent units, even if built only a few years after the first satellite, the development cost is still a large percentage, because the obsolescence of EEE components and upgrade of the design will re-inject non recurrent costs. The cost of development of more and more complex SW is another cost driver that is becoming more important in recent EO mission. In some missions, the development of the SW to handle the amount of data produced by the increasing capability of the satellites accounts for approximately 25%. Handling of data, from on-board data compression to the ground analysis, archiving, and retrieving facility is becoming a larger percentage of the overall cost.

Both of the above cost drivers can be reduced to a fraction of the overall percentage when satellites are produced in series, but the real breakthrough will happen when it will be cheaper to replace a satellite instead to ensuring it will work for its entire lifetime. This will decrease the level of quality assurance on a single unit, and therefore the cost of the satellite. The major obstacle in replacing quantity with quality is related to the current procurement process: the Customer-Supplier relations are governed by procurement contracts where performance, availability and reliability of the service play an important role. In this situation nobody is willing to trade on quality.

In a low motivation market that accepts a degraded service provided that the cost of the information is affordable, the Customer/Supplier relation will follow a different scheme. One example is an in-orbit delivery contract. The customer will only pay for the data once he receives it, and if the service is "good value for the money". The development of an in-orbit delivery suffers of the same problem of Tom-Tom traffic navigation information. The cost of the infrastructure is too high and the market motivation too undefined to justify the risk of the investment. Digital Globe (www.digitalglobe.com) and DMC (www.dmcii.com) have already entered the market of delivering EO images addressing two different market segments: Digital Globe focuses on high quality high resolution, while DMC is addressing a lower end of the market. Both companies have invested in a constellation of a few satellites. The users of data delivered by both companies are institutions or companies.

We examined a possible evolution of the technology and of the market: to broadcast in near real time high resolution satellite images on a digital handheld device. The reason for selecting this example is to apply the model we described above and to verify if it is possible to draw some conclusions. The motivation of the final user to pay a high price is very low, and the cost of the infrastructure (space segment + ground processing and distribution) does not justify the investment. This example is in the low Motivation low Ability section of the Matrix. This is a non-market than may become available only when forces external to the market will play an important role. Again looking into the mix Government supported activities and technology evolution we can observe:

1. The bandwidth of personal communication as internet connection and wireless access to internet (as mobile phone based internet connection) is growing at a surprising pace.

2. SW for image compression / decompression and automatic feature recognition is evolving under both government sponsored development and for commercial uses.

3. Defense related needs (situation awareness) and fast response to natural disasters requires near real time broadcast of HiRes Images. The timeliness to process satellites image from acquisition to availability to the user is constantly decreasing. The cost of developing the technology and to build the necessary on-ground infrastructures is supported by Government funded projects.

The elements to make possible to enter the "Hic Sunt Leones" area are already present and are evolving at fast pace. The event that may unlock the door to open the non-market is the relation between the "in orbit delivery" approach of mass market, and still the high cost of the final infrastructure, in which the ground segment plays a very important role. When it will be possible to fulfill the request of "in-orbit" delivery of remote sensing data the gap will be closed, the market will reward by asking for a large quantity of information more than their quality. In that moment it will be possible to break the vicious circle[1] high reliability → high cost → lower n. of satellite → higher reliability.

The technology areas to be monitored to early understand when the non-market of EO direct broadcast of High Resolution images are:

1. Disruptive technologies for manufacturing low cost high resolution Optics;
2. Disruptive Technologies in Detectors (large areas CMOS);
3. Use of commercial grade detectors in Space and/or large integration EEE components;
4. Development of image processing and data compression dedicated hardware.

Another aspect to be monitored to understand to potentialities of these products is to whom high resolution images are sold. We have observed that the market of high resolution images has followed the evolution: Defence as first application, Government institutions, now large companies are routinely purchasing high-resolution EO satellites, when the cost high resolution images will further decrease, a larger amount of small companies will soon capable to afford procurement of high resolution images. At that point, we are one step from the mass market, where the user will only see the cost per square kilometer of an image. At that point quantity will matter more than quality. If the application of the technology of direct image broadcast developed by TacSat will have followed the same market evolution, we will be very close to have broken all the barriers of the non-market for near real time high resolution on your PDA.

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