ABSTRACT

For decades, clever people in and around the space industry have been dreaming up ways of using space for commercial or scientific gain. However, in many cases the ideas, though valid, were not economically or technologically feasible. Arthur C. Clarke dreamt up the concept for geostationary satellites long before there was even a means to get satellites into space, and many more ideas have come and went in the period in between never to manifest themselves as real missions.

This paper will explore proposed mission concepts that were before their time and will assess their relevance to today’s technology and capability. In addition, it will assess the suitability of today’s technology to enable old problems to be solved. In particular, the paper will use the CubeSat platform as an example of a very low-cost means of launching multiple spacecraft into orbit to meet specific application needs. The paper will also assess the use of today’s small satellite technology to service the gap in the long existing need for data for the purposes of science, communication and prediction/warning of natural disasters. Finally, conclusions will be drawn as to the impact that small and miniature spacecraft can have on the future commercial, science and data driven space mission of the next 10 years and what the author considers to be the most relevant barriers and opportunities to the growth of small satellite success in these areas.

INTRODUCTION

The great thing about the human race is that we are never quite content with what we have; we are always striving to improve. From a space industry perspective, we are seeing vast leaps in technology developments in all areas; in particular, small satellites are achieving quite amazing performance levels with sub 1m resolution satellites imminent, if not already launched, on spacecraft of less than 200kg.

With the rapid advancement of technology in the small satellite industry it is important for research and commercial organisations to revisit the ideas that were not viable previously and to see whether they fit with today’s technology.

In many cases, today’s technology has the ability to enable old problems to be solved. In particular, the CubeSat platform provides an example of a very low-cost means of launching multiple spacecraft into orbit to meet specific application needs.

Excellent examples of good ideas that never materialised in the last 10-20 years include; GANDER, a constellation of nanosatellites utilising reflected GPS signals to help ships navigate around rough seas, and ESAT, a constellation of small satellites that would read gas and electricity meters. Both of these missions are assessed in this paper to evaluate the potential for them to become more viable by using today’s technology and extremely low-cost platforms.

Additionally, science missions are traditionally the most expensive satellites launched, but their data is limited to specific times of the day and it is not economically viable to deploy a number of these large, expensive spacecraft to address this problem; small satellites with today’s technology can fill this gap in data by offering increased temporal resolution through the use of multiple spacecraft.

Similarly, the need for a space based early warning systems, such as for forest fires, is not achievable with traditional spacecraft for reasons of economics and the large number of spacecraft that would need to be used. However, CubeSats may offer a means to provide a relatively low cost space segment that can identify the early signs of bush and forest fires, potentially saving homes, lives and billions of dollars in insurance claims.

This paper aims to show that the viability of unfulfilled ideas of the past must be continually challenged with each
advance in technologies and techniques in spacecraft and mission design. This is important not just from a business perspective, but enabling these missions can have significant impact on quality of life and other aspects such as the understanding and knowledge of our environment.

SOME '90S SMALL SATELLITE CONSTELLATIONS THAT DIDN’T HAPPEN

In the 1990s there were a number of constellation proposals that almost achieved the transition from paper to hardware projects. The ideas behind the projects were sound, but either the market wasn’t ready or the economics of the project just didn’t justify the implementation.

There are also examples of constellations that did become hardware projects, but that failed spectacularly for reasons of economics and timing. For instance, although now a going concern, Orbcomm went bankrupt due to the slow up take of the service; this was also compounded by the investment needed to develop and deploy the space segment [3]. Following bankruptcy, the new company acquired many of its communication assets from the bankrupt company, enabling it to continue as a viable service company. Orbcomm may cite this as a barrier to entry for any future competitors as bankruptcy is not a typical business plan.

For the purposes of this paper I have selected two ideas from the 1990s to be evaluated in terms of today’s capabilities: GANDER and ESAT.

GANDER

The original idea of GANDER was to have a constellation of 10 microsatellites, in complimentary orbits, using backscattered signals from Global Position System (GPS) and other Global Navigation Satellite System (GNSS) satellites to monitor global sea conditions via altimetric measurements. This system offered an alternative to using active altimetry which typically requires a high power radar system, resulting in the need for much larger spacecraft.

It is reported that the marine insurance industry pays out over US$2 billion in claims for weather-related accidents every year. In addition, bad weather causes one ship in over 500 to sink somewhere on the globe every week. From this it is clear that there is a need for some system to help to reduce these figures.

However, the level of investment required to launch a sufficient number of active altimeters to provide this service is prohibitive, and it would be unlikely. In addition, a government funded system would require the cooperation of a large number of countries around the world, which would probably be politically impossible.

The alternative to this would be to use the GANDER model, where the altimeter is passive. The business case for this system implementation is still very valid but the expense of the system is still prohibitive. The cost of the spacecraft and launch service would result in an investment need of around $100m or more.

A Nanosatellite Approach

More recently, a proposal to provide passive altimetry using a 10kg nanosatellite platform has been tabled and is under study in the UK by a Surrey Satellite Technology Ltd led consortium [6]. This concept is based on the SNAP platform and is shown in Figure 4. This system
has more chance of being viable due to the potential for lower launch costs due to the smaller size and mass of the spacecraft. However, this spacecraft is still a bespoke design, with bespoke launcher interfaces and will typically have non-standard interfaces (i.e. only standard to the company building the satellite). In 2002, the estimated price of a spacecraft of this type was US$1.2m [8]; combined with the payload and launch costs, you could expect a passive altimeter constellation with 10 spacecraft of this type to cost in the region of US$15m - US$20m.

From a technical perspective, the main challenge in meeting the performance goals of the mission is the ability for the platform to generate enough power. Using a 3U CubeSat platform with the Clyde Space solar arrays, Electrical Power System (EPS) and lithium polymer battery, it is possible to achieve in the region of 10-20W orbit average power (OAP) [7] which, based on the performance requirements from the nanosatellite concept, is more than sufficient for the payload and data downlink requirements. (N.B. the OAP of the SNAP is approximately 6W [9])

The CubeSat Solution?

Over the last 5 years, the nanosatellite community has been focussing on the use of the global ‘CubeSat’ standard, first developed by Prof Bob Twiggs of the University of Stanford. There are many benefits of having an industry standard spacecraft in the context of this mission. The main ones are

- Shorter, less expensive launch campaigns (due to use of standard and understood launch interfaces)
- More launch opportunities.
- Lower cost, proven bus systems.
- Higher performance (through the availability of subsystems from a number of competing companies).
- Lower mass.
- Shorter programmes (further reducing cost).

The average cost of a 3U, 5kg Cubesat with deployed solar panels and a payload mass of 3kg, is in the region of US$200k to US$300k [1]. Using this technology, and assuming the same payload costs, it is estimated that a 10 satellite passive altimeter constellation would cost in the region of US$5m to US$8m. It is clear that this offers a more attractive business proposition, with greater Return on Investment (ROI), and therefore is more likely to succeed in raising the required funds.
The fact that such a system has the potential to save the insurance industry hundreds of millions in insurance claims makes the implementation of a system such as this very attractive. The use of today’s spacecraft engineering approaches in cost reduction makes the viability of such a mission possible.

**ESAT**

ESAT was a similar concept to the Orbcomm model; a constellation of SIX small satellites using narrowband communications to retrieve data from ground assets, specifically the global gas and electricity metering industry.

10 years on, it is clearly more cost effective to use the state of the art solar cells than lower efficiency equivalents. The reason being is that, the cost per watt in comparison with single junction cells is competitive, if not better. Also, it takes less effort to prepare a solar panel of equivalent power levels as it has fewer cells and hence less processes. In addition, due to the higher efficiency cells being used, the solar panels can be much smaller, helping greatly to reduce the size of the spacecraft.

Lithium ion batteries have almost completely replaced both Nickel Cadmium and Nickel Hydrogen batteries for use in all mission types in the last ten years. Again, the use of this technology has enabled the platform to shrink considerably, especially for LEO missions where there is a need for a relatively large battery (i.e. due to frequent eclipse periods and the shallow depth of discharge required to ensure the battery last for 5 years). Nickel cadmium batteries provide approximately 20-30Whrs/kg. Compared to the 150Whr/kg provided by the Clyde Space lithium polymer battery, there is a significant saving in mass and volume to be gained through the change to this technology.

**Figure 6 Pumpkin MISC2 CubeSat platform with Clyde Space solar panels [1].**

**Figure 7 ESAT Constellation launch (image from [10])**

SMART metering in homes and business is now a huge international market and there is a very clear need for a competitive data collection system that can be used to retrieve data from these meters. ESAT is a prime example of an idea that attempted to reach a market that was not yet mature enough. Even as recent as the late 1990s, low-cost implementation of this type of spacecraft still involved the need for larger spacecraft buses, inevitably pushing the price of the mission up to unfeasible costs for materials, assembly and launch. The reasons for the need for a larger platform were mostly from a power perspective. In the late 1990s, triple junction and tandem solar cells were in their early development stages, efficiencies weren’t much better than single junction equivalents and costs were very high. Also, spacecraft designers were still using nickel cadmium batteries for the most part. Combined, this resulted in the need for much larger solar panels to generate the same power levels.
Furthermore, advances in digital technologies in the last 10 years have been significant. This is not just for terrestrial technology, but also for space, offering lower power consumptions and significantly higher performance. A good example of the types of technology available for space is the Virtex-4 FPGA family from Xilinx; Virtex 4 was introduced as a new FPGA range in 2004, offering higher performance at a lower power, superseding the previous ranges. In 2009, Virtex 4 is the range used for radiation tolerant design up to 300kRads. These types of technology are further enabling the reduction of the size of spacecraft, whilst at the same time enabling higher system performance.

In April 1999, it was reported that ESAT had contracted two launches with a value of US$30m and six spacecraft, each weighing 130kg, with a value of US$17m. A further US$90m was agreed with a prime contractor for the mission and payload supply.

The CubeSat Solution?

With today’s CubeSat technologies, it is certainly possible to provide all of the necessary bus systems. The ESA funded joint development between Clyde Space and Mars Space (Southampton, UK) of a micro-Pulsed Plasma Thruster for CubeSats will enable CubeSat to perform orbit maintenance manoeuvres in order to maintain the correct constellation distribution. It is expected that this system will be available from mid-2010.

Given the typical cost of a CubeSat platform, the estimated cost of a SIX spacecraft constellation would be in the region of US$4m for the space segment (excluding payload non-recurring engineering NRE costs), and about US$1.5m for the launch. It is clear to see that, again, today’s technology offers solutions that make more compelling cases economically and from an ROI perspective.

FILLING THE DATA GAPS WITH CUBESATS.

Most science and remote sensing missions are limited to one or a handful of spacecraft. The reasons for this are economical; the spacecraft are large, the payloads are extremely expensive and the cost to launch is very significant. This often results in gaps in data that scientists receive.

Example Case: NASA Orbiting Carbon Observatory

The Orbiting Carbon Observatory (OCO) was a NASA mission to study CO2 concentration from the surface of the Earth to the top of the atmosphere. Its high-resolution measurements were to provide a more complete picture of human and natural sources of CO2 at the local and regional scale. With hundreds of scientists around the world eagerly waiting the launch (and perhaps a few politicians and oil companies dreading it), it was a catastrophe when the launch failed on February 24, 2009.

At a cost of US$280m, this was also a big loss financially. In addition, the number of years in waiting for the mission to be designed, built and launched is not insignificant. The time taken to design and deploy the mission, in
addition to the failure of the launch vehicle, means that there is now a huge gap in the data that this mission was designed to gather.

At roughly the same time as the launch of the OCO, the Space Flight Laboratory at the University of Toronto Institute for Aerospace Studies also launched a satellite called CAN-X 2. It was a CubeSat and one of the experiments on board was a miniature atmospheric spectrometer to detect greenhouse gases. The measurement principle of this experiment was almost the same as the OCO, although not close enough for the data to be as valuable to the scientist awaiting the data from the OCO.

Figure 11 SFL/UTIAS CAN-X2 mission [12]

This however, raises an interesting question. For missions of this type, where there is a clear need for data, could there be two missions? For example, if, as part of the OCO mission, a CubeSat carrying a dumbed down version of the main experiment was introduced, this could result in the following advantages:

- Quicker deployment to orbit of a useful part of the mission.
- Data can be gathered quicker, enabling useful trend analyses and comparison once the main mission is launched.
- Scientists can ‘cut their teeth’ on the low cost CubeSat version of the mission.
- The mission can be de-risked through the use of two spacecraft.

Bush/Forest Fire Early Warning System

Bush and forest fires are a major problem world-wide. Space is the most obvious method of monitoring for fires in order to attempt to catch and extinguish them when they are small enough to manage, or to evacuate quickly the affected area.

The main problem, however, is the cost of the constellation required to monitor fires within a sufficient repeat period. It has been determined that the preferred repeat period for this type of monitoring system is 20 minutes. With conventional satellites, the cost of such a system is extremely prohibitive. However, CubeSats may offer a solution.

An initial study at Clyde Space with the UK Astronomy Technology Centre has shown that it is feasible to accommodate an imager with a 30m ground resolution and a swath width of 122km (600km) on a 3U CubeSat. In addition, Clyde Space have been developing a miniaturised Attitude Determination and Control System (ADCS) based on the pointing and stability requirements of the imager, as this was determined as one of the key performance constraints of CubeSats.

In order to achieve the ground coverage and repeat time required, taking Australia as an example case, there would be a need for between 30 and 50 satellites in order to have a repeat time of 20 minutes over the complete area. With mass manufacturing of CubeSats already successfully practiced, it would be possible to dramatically reduce the cost of each platform to below US$150k. The most expensive item on the spacecraft would be the imager, mainly due to the sensor technology required, but again this would be in the region of about US$300k. In total, each spacecraft would cost less than US$500k.

Figure 12 Coverage providing 20minute repeat period requires 30 to 50 spacecraft.

Therefore, with 50 spacecraft, the space segment cost would be around US$25m. There would, of course, be a need for NRE costs, for 3 to 5 dedicated launches and the ground segment, but the fact that the total cost of the system would be in the region of US$50-60m, makes the concept of such a system being deployed attractive from a commercial and government perspective.

CONCLUSION

This paper has attempted to evaluate today’s technologies and approaches to satellite engineering in the context of unfulfilled ideas for missions from the past 10-20 years,
in order to see if their objectives could now be more feasible using today’s spacecraft engineering approaches and technologies. In order to assess this, two missions, one in global communications and another in Earth observation, were selected. In both cases it was shown that there was not only a compelling technical case to the missions with today’s techniques, but also that the cost of implementing the missions could be significantly reduced, making the realisation of raising the funding for the mission more likely.

In addition, two cases where today’s technology could fill a need in data deficit, both for science and disaster warning systems, were evaluated and a case made for the use of this technology to fill the gap:

- The concept of flying a dumbed down version of science instruments ahead of the launch of the main spacecraft, by using small satellites, was tabled. The objective of this was to de-risk the mission objectives by having two instruments launched separately and also to start gathering data for the purposes of performing trend analysis earlier in the mission.
- The use of miniature spacecraft for constellations to monitor for bush fires (as an example) where a 20 minute revisit is required in order to provide sufficient warning to emergency services to allow them to successfully tackle and eliminate the threat to homes and lives in the affected area.

A compelling argument was made in both cases, at the very least for further investigation to be made into the implementation of today’s spacecraft engineering techniques in order to solve this issues.

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REFERENCES

[7] Clyde Space internal technical note on power budget analysis of 3U CubeSat with Deployed solar arrays.