What's next after industry disruption by Cubesats? – Industry disruption by Open Source

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ABSTRACT

A decade ago, CubeSats featured almost exclusively in the academic domain only. The same can be said today for Open Source satellites.

In the same way that CubeSats and the associated development mindset started in the academic community and are now embraced by commercial, civil and defence communities, the goal of the Open Source Satellite Programme is to initiate a similar outcome for open source satellite mission architectures by developing a design that is freely available for all to use.

KISPE's goal is to build a community of open-source contributors, collaborators and beneficiaries, including those from CubeSat and SmallSat teams who are at the forefront of adopting and championing non-traditional approaches to delivering space missions.

A key characteristic of open-source projects is stakeholder engagement: to collaborate, iterate and improve elements of the architecture and design - and ultimately, to leverage and benefit from the design outputs.

KISPE's Open Source Satellite Programme is developing a robust, flexible satellite platform which addresses future market, mission and programmatic demands, leverages emerging technologies and is scalable for Nanosat to Microsatellite systems, enabling teams to utilise the platform as a low-cost "commodity" or infrastructure item on which to develop their specific mission.

INTRODUCTION TO KISPE

KISPE Limited.**1** ("KISPE"), established in 2016, is a programme and systems engineering company working in the Electronics, Telecommunications and Space sectors, and draws on significant industry knowledge and experience acquired over thirty years in engineering, programme, strategic, management and leadership roles in a number of different organisations.

KISPE works with customers around the world in the commercial, institutional and government sectors on the execution or implementation of their business ideas, from early inception and business planning activities, through the design, manufacture, integration, test and operations. KISPE also creates and delivers specialist training and development and provides consultancy services.

KISPE has two further operating entities: Applied Space Solutions Limited.**2** ("Applied Space"), which was established in 2017 to provide space related analytics, applications and services, specifically in the areas of astrodynamics and space domain, and KISPE Space Systems Limited.**3** ("KISPE Space"), which was established after an investment round in 2018, to address the Company's space-systems activities, including the development of an open-source microsatellite platform.

THE VISION AND MISSION OF THE OPEN SOURCE SATELITE PROGRAMME VISION

The Vision

The vision of the Open Source Satellite Programme is to make space more accessible through the development of an open source microsatellite platform and community. Allowing all to freely access the design of a performant microsatellite platform will stimulate the responsible and sustainable use and utilisation of space and will enhance the capabilities of small satellite solutions to address an ever-increasing range of applications and services.

The Open Source Satellite Programme Manifesto.**4** describes KISPE's approach for the development of a flexible, robust, low-cost microsatellite platform, making the design freely available for anyone to utilise and benefit from, and for realising this vision in a sustainable, enduring way.

Whilst the recent, rapid growth in the use of small satellites has been encouraging, most small satellites are beyond the direct reach of many who could benefit from their commercial value because of their initial unaffordability, the challenges in being able to maximise the full system capabilities and the difficulty in sustaining long-term financial sustainability throughout mission life.**5**

The Mission

The mission and goal of the Open Source Satellite Programme is to develop a solution that addresses those challenges. The Open Source Satellite Platform will be an accessible, highly capable, cost-effective, modular, microsatellite platform; a basis upon which teams can readily develop future space-based systems.

Rather than starting with an existing design, based on legacy approaches, the aim is to harness the cross-cutting potential of technological advances and processes from diverse industries to develop a next-generation, low-cost small satellite platform to achieve a price:performance point that truly makes space more *affordable*, and adopting an open source approach to make space more *accessible*.

COMBINING OPEN SOURCE AND SPACE

The intersection of small satellites and open-source thinking is creating a springboard for the development of a community-based approach to delivering space and space-enabled systems that are more affordable and accessible.

The open source approach has been very effective in the software domain for increasing accessibility, improving quality, allowing customisations, increasing freedom and flexibility, promoting interoperability, providing support and allowing stakeholder contributions to influence the direction of development according to emerging needs. Above all, it allows these benefits to be delivered at a lower cost than alternative options. The aim of the Open Source Satellite Programme is to apply the open source philosophy and generate similar user and stakeholder benefits for space projects.

The Birth of the Open Source Space Ecosystem

Having witnessed the impact the opensource approach has made in the software and hardware industry, numerous teams are embracing the open source philosophy to implement systems throughout all segments of the space industry and adjacent sectors.
For example, the complementary mindsets of the Cubesat and Maker communities led to the first spaceflights of Android phones, Arduinos and RaspberryPis in space, these early demonstrations of opensource systems in space paving the way for the development of the open source space ecosystem.

The first annual Open Source Cubesat Workshop took place in 2017 for 80 attendees, with the support of the European Space Agency. 200 people registered for the 2019 conference.[6], signalling the growing interest in the philosophy of open source space. Teams with diverse areas of expertise are continuing the academic tradition of experimenting, demonstrating and learning quickly, and then sharing and leveraging their knowledge and experience to create better systems in the future.

Replicating the Cubesat Growth Curve with Open Source Space

There are only a few companies developing open-source spacecraft, the most prominent activities being led by the teams listed in Figure 1~~Figure 1~~.

Organisation Name	Organisation Logo	Organisation Website	Primary areas of activity
AALTO Satellites	A? Aalto University	https://www.aalto.fi/en/spacecraft	Cubesat Subsystems, Missions, Ground segment designs and tools
Aristotle Space and Aeronautics Team		https://asat.gr/	Cubesat Subsystems, Missions, Science Payloads
Fossasystems	FOSSA	http://fossa.systems/	Cubesat Subsystems, Missions, Ground receivers
LibreSpace		www.libre.space	Cubesat Subsystems, Spacecraft, Missions
LibreCube	LIBRE CUBE	https://librecube.org/	Open Source Earth and Space Exploration
Open Source Satellite Programme	OPEN SOURCE SATELLITE	www.opensourcesatellite.org	Microsatellite components, subsystems, Platforms and Missions

Figure 1: Organisations developing open source spacecraft

The spacecraft itself is only a small part of the solution; a thriving ecosystem comprising the necessary end-to-end capabilities such as tools, technologies, subsystems, ground systems, mission operations and data analysis, needs to exist to underpin the space architecture and deliver useful services to end users.

From components and subsystems through to operations, small teams working on high altitude missions through to global collectives with a vision of interplanetary settlement, training and education platforms through to commercial systems, delivering applications as diverse as biological experiments through to space situational awareness; there are a multitude of teams working to create open systems and applications that all can contribute to and benefit from.

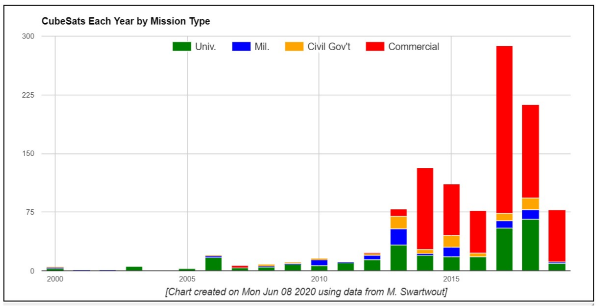

Figure 2: The transition of cubesats from the academic to the commercial domain.[7]

The open source spacecraft developed to date have been focussed on the cubesat sector. No teams have yet successfully implemented an open source philosophy for larger microsatellite-class spacecraft that can be used to develop sustainable businesses.

A key aim of the Open Source Satellite Programme is to support the development of the capabilities and opportunities that will transition open source satellites from the predominantly academic and cubesat sphere towards larger, more robust systems that can underpin sustainable business success in a similar way to the growth cycle witnessed in the cubesat domain as illustrated in Figure 2~~Figure 2~~.

THE GAP IN THE SATELLITE MARKET

One of the catalysts for the Open Source Satellite Programme was our experience of working with a wide range of customer and stakeholder groups, who are seeking to use satellites and space-enabled systems at the heart of their businesses to deliver sustainable value and capability to their own end customers. Many of these teams are unable to close their business cases because of high total mission costs driven by several factors, including:

- High cost to get to orbit
- Long development cycles
- Short mission duration
- High in-orbit operational costs

Figure 3~~Figure 3~~ classifies the price:performance characteristics of the three main classes of Legacy Spacecraft: Traditional Spacecraft, Small Satellites and Cubesats. This figure illustrates that the price:performance metric has remained a constant, irrespective of the size/mass class of the spacecraft.

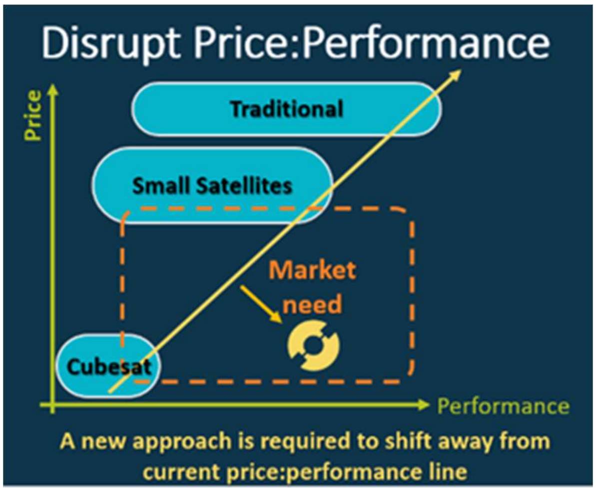

Figure 3: Satellite price:performance has typically remained constant, irrespective of mass class

Traditional Satellites

Traditional Satellites – in which the "traditional" descriptor refers to the classical programmatic approach adopted for such (generally institutional) missions – span a wide mass range but are typically in excess of 300kg. Such satellites occupy a well-established position in the industry for the provision of exquisite, highly optimised systems for, typically, "one-off" flagship missions with a low tolerance for perceived and actual risk. This is reflected in the processes that are applied throughout the project.

Mission assurance rather than mission cost is the primary driver for programmes with these characteristics. A low appetite for introducing risk by doing things differently means that there is little incentive to make significant changes to the price:performance point of Traditional Satellites.

Small Satellites

Small Satellites in the 100kg to 300kg mass class offer reasonable mission capability in terms of payload accommodation and mission support, but typically have relatively small payload mass fractions and can be costly to develop due to a range of organisational factors in established satellite companies.

It is difficult to scale down (in terms of physical size mass, complexity, processes, customer expectations) these systems to support smaller missions, meaning that there is little scope to reduce spacecraft costs or launch costs.

The majority of megaconstellation spacecraft designs fall into the Small Satellite mass class. Megaconstellation developers rely on amortizing the NRE (non-recurrent engineering costs) of developing the production line and operational architecture over hundreds, even thousands, of satellites, to arrive at an affordable unit price per satellite. Current indications are that the projected spacecraft unit prices are much higher than the desired price targets and that the ground segment architectures are impacting the overall economic viability of several. LEO communications constellations

In addition to limited accessibility to such platforms, should teams want to use one of the highly-optimised, highly-integrated platforms as the basis for a different mission, there will be a significant amount of NRE incurred to modify the system to meet different mission requirements.

Cubesats

Cubesats stimulated the market, changed longstanding industry paradigms and resulted in an upsurge in new missions. Cubesats' low absolute cost and launch mass lowered the barriers to entry and their inherent physical constraints created opportunities for a multitude of innovations. Rapid implementation cycles and lessons learned have resulted in cubesats successfully making the transition from academic projects to useful operational tools.

The limitation is that Cubesats are typically less than 10kg in mass and, in the case of university cubesats, are typically estimated to fail within the first six months (excluding infant mortality).**8**, which does not provide value for institutions' scarce funds, effort and resources; and which also reduces opportunities for utilising and developing the all-important applications and services that are necessary to transition ideas from the research and demonstration sphere to commercially-viable solution.

Furthermore, there has not been sufficient evidence to indicate that cubesat designs can be affordably scaled up in size, capability and system robustness to deliver larger, longer lifetime satellites that can support larger, more demanding payloads and missions.

An Alternative to Legacy Satellite Systems

Evaluation of existing spacecraft capabilities, as discussed in the previous section, led to the conclusion that a gap exists in the market for an affordable, robust and flexible microsatellite platform design that does not need to be changed from mission to mission. The affordability and capability shortfalls need to be tackled in order to create sustainable space-enabled applications and services, otherwise we risk seeing industry stagnation and business failure, which will in turn restrict funding and deter new entrants to the industry.

A novel approach is required in order to yield a price:performance point that is an order of magnitude better than the metric that the majority of legacy spacecraft possess, irrespective of size. These are the factors that led to the initiation of the Open Source Satellite Programme.

NGMP TOP LEVEL ROADMAP

The end goal for The Programme is to develop a single multi-mission, multi-orbit microsatellite platform that performs well in harsh environments – MEO, GEO, lunar and interplanetary, as well as delivering cost-effective missions in LEO.

The roadmap can be broken down into three top-level phases of development as described in Figure 4~~Figure 4~~.

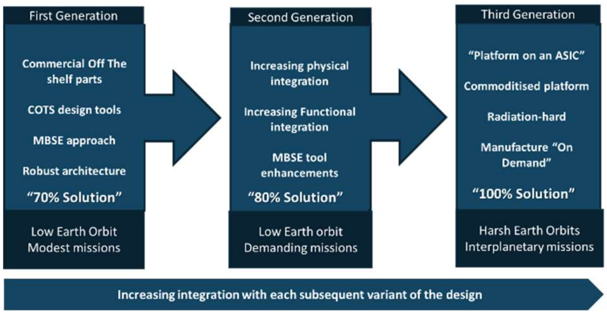

Figure 4: The Open Source Satellite Programme roadmap

The initial target is to achieve 70% of the technical, programmatic, commercial and community objectives; the next variant will satisfy more demanding missions in LEO as well as increasing the level of platform integration; and the final 20% of our objectives will be realised in the interplanetary-capable solution.

A key element of the approach is to reduce labour costs, which typically account for in excess of 60% of mission costs. This will be achieved by increasing the level of integration and leveraging a greater degree of Industry 4.0.**9** approaches such as Model-Based System Engineering (MBSE).**10** and increasing design digitisation with each subsequent variant of the design:

The First Generation "70% solution" will maximise the use of COTS (commercial off the shelf) parts, COTS design tools, and a MBSE approach to enable the development of a robust baseline architecture.

The interim Second Generation "80% Solution" will build on the work of the first variant, increasing the degree of physical and functional integration, enhancing the application of the MBSE approach to the full system, and improving the applicability of COTS tools. Increasing the degree of physical integration allows a reduction in the size, weight and power of the platform, increasing the fraction of resources that are available for payloads and mission-specific systems. Increasing the functional integration allows the practical elements which do not change from mission to mission to be "baked into" the baseline architecture; reducing the NRE to just the payload and mission-specific adaptations only.

The Third Generation will include iterations and developments that will lead to the development of a "Platform on an ASIC", at which point we will have a truly commoditized platform for all mission types. This is a good illustration of one of the technology/cost challenges: it is not currently possible to develop ASICS that are affordable in the relatively-low volumes that will be required to sustain missions based on the Open Source Satellite platform design. Identifying and being aware of such challenges from the start permits the team to leverage the power of the “hive mind” and collective knowledge and intelligence of the open-source community to consider how such challenges can be addressed.

Top-Down and Bottom-Up Roadmap Consistency

The development roadmap represents a pragmatic approach, acknowledging that the end goal cannot be achieved from the outset; there are many design, technology, programmatic, commercial and community challenges that need to be addressed with a logical, stepwise approach.

It is important that regular checkpoints are held to ensure that there is consistency and coherency between the first-generation and final-generation systems and design goals and system. The “top-down” evaluation ensures that the requirements of the final solution are considered from the outset, and the “bottom-up” assessment ensures that the earliest design and technology decisions create the appropriate building blocks to allow progression towards the final version. At this early stage the convergence checking is being done at a high level; detailed roadmapping consistency reviews will be introduced as the programme progresses in the coming months.

First Generation Platform Technical Specifications

The target performance specifications for the first-generation Open Source Microsatellite Platform were defined as a result of inputs from stakeholders with a range of mission requirements and priorities. The baseline capabilities defined in Table 1 will support the implementation of diverse missions, including a range Earth observation, communications, science and technology demonstration.

Table 1:First Generation Technical Specifications

First Generation Platform Performance Specification
25kg-250kg Spacecraft mass
70% Payload mass fraction
Flexible payload accommodation
10W-1kW Payload power, scalable to suit mission power needs
3-Axis stabilised - increasingly important for communications payloads as well as sensor payloads
400km to 850km altitude
<14 month recurrent delivery schedule
5 to 7-year lifetime
Recurrent price of $1m for 50kg, £1m for 100kg
A cost-effective modular, scalable, flexible, robust, reliable microsatellite platform for LEO missions

THE CLEAN SHEET DESIGN APPROACH

Developing the Open Thinking Required to Develop an Open Source Satellite

The Open Source Satellite Programme is developing a microsatellite platform by starting with a clean sheet of paper and actively challenging the mindset of “we've always done it this way”. This requires the team to be mindful of not becoming become constrained by the mental models moulded from each team members’ prior experiences.

Despite possessing similar and complementary backgrounds, team members’ differing individual experiences result in the use of different terminology and understanding of the environment within which the Open Source Satellite platform will sit. Therefore, in order to achieve better alignment, the first undertaking has been the construction and iteration of a shared ontology.

The Purpose of the Ontology

The purpose of the ontology is to capture the concepts that are specific to the domain within which the Open Source Satellite exists and the relationships between these concepts. This forms the basis of a shared language that is being used within the team, helping to ensure that the artefacts that are generated are consistent and can be understood by anyone with knowledge of the ontology.

The decisions that go into defining the ontology and what the Open Source Satellite Programme consists of is an effective way of sharing the individual mental models to develop a collective mental model that is shared by the team. This approach stimulates the systems thinking around the needs of the different stakeholders and how this translates into the resultant Open Source Satellite.

In order to prevent inadvertent biasing or constraining the way in which the Open Source Satellite problem is analysed, the ‘whole’ needs to be considered which means taking a holistic approach. This involves looking at the system within the context it is to be used, the interactions between the various aspects of the system (internally and within its environment) and the impact of any changes.

Developing the Ontology

An extract of the ongoing ontology definition work is shown in Figure 5. It has been captured using Systems Modelling Language (SysML) notation.[11] It provides a common language for the team and the community to communicate and understand each other.

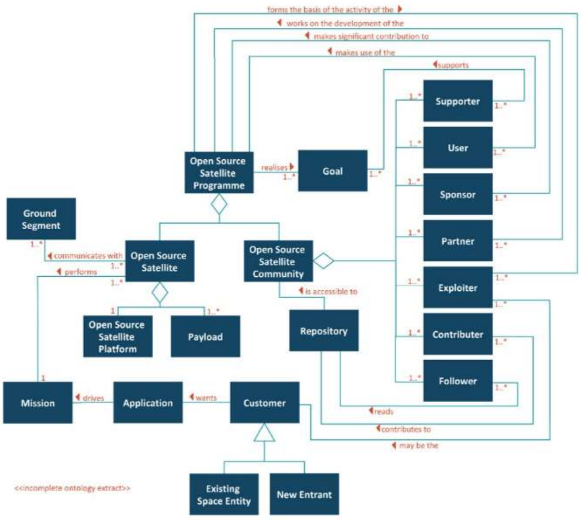

Figure 5: Open Source Satellite ontology (incomplete)

The ontology is envisaged to be a live artefact, which will be updated as additional terms, concepts and relationships are uncovered. It will provide a sanity check as to whether new items that are introduced into the Open Source Satellite Programme fit within the concepts that are collectively understood, and if not, will trigger discussions as to why not, for example if it is something that is already captured masquerading under a different name or if is it something that has truly been missed.

SHARING THE DESIGN

The aim is to make available the entire Open Source Satellite platform design, 12 months after launch. Information will be released as the project progresses, including design drawings, schematics, parts lists, board layouts, software source code and manufacturing information. The open source approach will allow engagement with a much more diverse range of people and capabilities than is possible in any single organisation; helping to ensure a better end product because of the variety of perspectives and competencies involved in defining requirements and in identifying, articulating and solving problems.

The team is starting to build a community of sponsors and supporters and has opportunities for individuals, teams and organisations to be involved in the development and exploitation of the satellite platform as well as the growing ecosystem and bringing the benefits of space to many more people.

There are many ways in which people are able to embrace the potential of and participate in the success of the Open Source Satellite Programme. For example, a number of groups are interested in gaining access to the design data in advance, before general release to the public, to help them accelerate their own internal developments, as part of a sponsorship or strategic partnership arrangement. These arrangements are being crafted to suit the specific interests and capabilities of each team, ranging from pure financial sponsorship, to in-kind contributions in the form of equipment, software, services and domain expertise.

Creating an Environment for Sharing and Collaboration

A key element of the Open Source Satellite Programme is the creation of an environment for sharing knowledge and ideas. The intention is to stimulate wider interest and extend access to knowledge that will catalyse the next generation of mission developers and end users, who can utilise the Open Source Satellite platform as the tool for achieving the next step in affordable, high-capability satellite missions.

A library of Resources is being created that will be made available to everyone. These Resources will address the full end-to-end mission lifecycle and provide the small satellite community with design information that will enable teams to develop their own open-source satellite missions.

The Open Source Satellite Programme website (Figure 6~~Figure 6~~) is intended to become a community hub, where information and designs for the Programme activities can be found, alongside resources relevant to open source and other open source space initiatives.

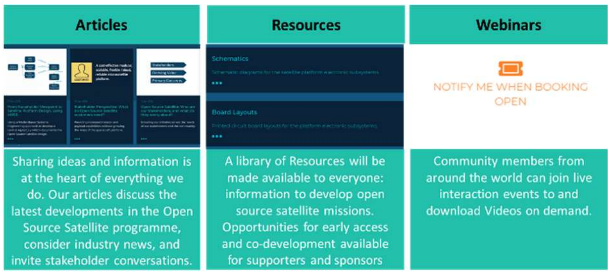

Figure 6: The Open Source Satellite Programme website will be a hub for the open source community

GROWING THE COMMUNITY

The Programme is seeking the participation of individuals, teams and organisations that are interested in collaborating to and benefitting from the results of the Open Source Satellite Programme.

Interested parties have been registering their interest to collaborate via The Programme website (https://www.opensourcesatellite.org/register/). Once Collaborators' skills and interests are understood they are accepted into the programme and have access to view and contribute to planned activities via the Collaborator Workspace (Figure 7) .

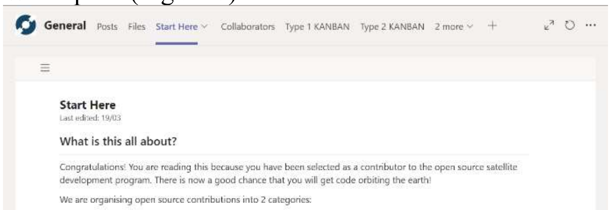

Figure 7: Collaborator workspace area (snapshot)

Seeking Diverse Skills, Experiences and Backgrounds

The Programme is seeking collaborations with individuals and teams with a diversity of backgrounds, to maximise stakeholder involvement and to better-represent the communities that could make use of the design.

Involvement is welcomed at all phases of the project, including:

- Concept definition
- Designing
- Reviewing
- Testing and verification
- Mission operations

Examples of specific disciplines and areas of expertise include the following:

- Attitude and orbit control
- Autonomy
- Communications
- Configuration management
- Customer mission scenarios and use cases
- Ground segment architecture
- In-orbit operations
- On-board data handling and spacecraft management
- Power
- Production
- Programmatics
- Redundancy and FDIR
- Regulatory
- Software development
- Space environment
- Space legal, licensing, policy, regulations
- Space segment architecture
- Structure and mechanical
- Systems engineering
- Testing
- Thermal

There is a continuous open call for participation on the Open Source Satellite Programme website, where all interested parties can register their interests.**12**

CONCLUSION

The Open Source Space movement is very much still in its infancy; however, the conditions that led to the development of open source software and the Cubesat revolution exist today in the space industry.

The twin drivers of affordability and accessibility are creating the demand for a next-generation microsatellite platform that is performant, robust, reliable and which can be developed for a similar price to cubesats.

Seeing the platform as a stable "commodity" product, with a design that can be used unchanged from mission to mission represents a major paradigm shift. It will take time for industry and organisational inertia and paradigms to change for this approach to become accepted as the mainstream.

The initial elements of an open-source ecosystem are starting to develop; the goal of the Open Source Satellite Programme is to work with like-minded teams and individuals to create a design and a community that will stimulate the next wave of innovative and affordable missions, applications and services.

Acknowledgments

The Open Source Satellite Programme acknowledges the support of KISPE Limited, KISPE Space Systems Limited and Teaching Science and Technology Inc.**13**

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