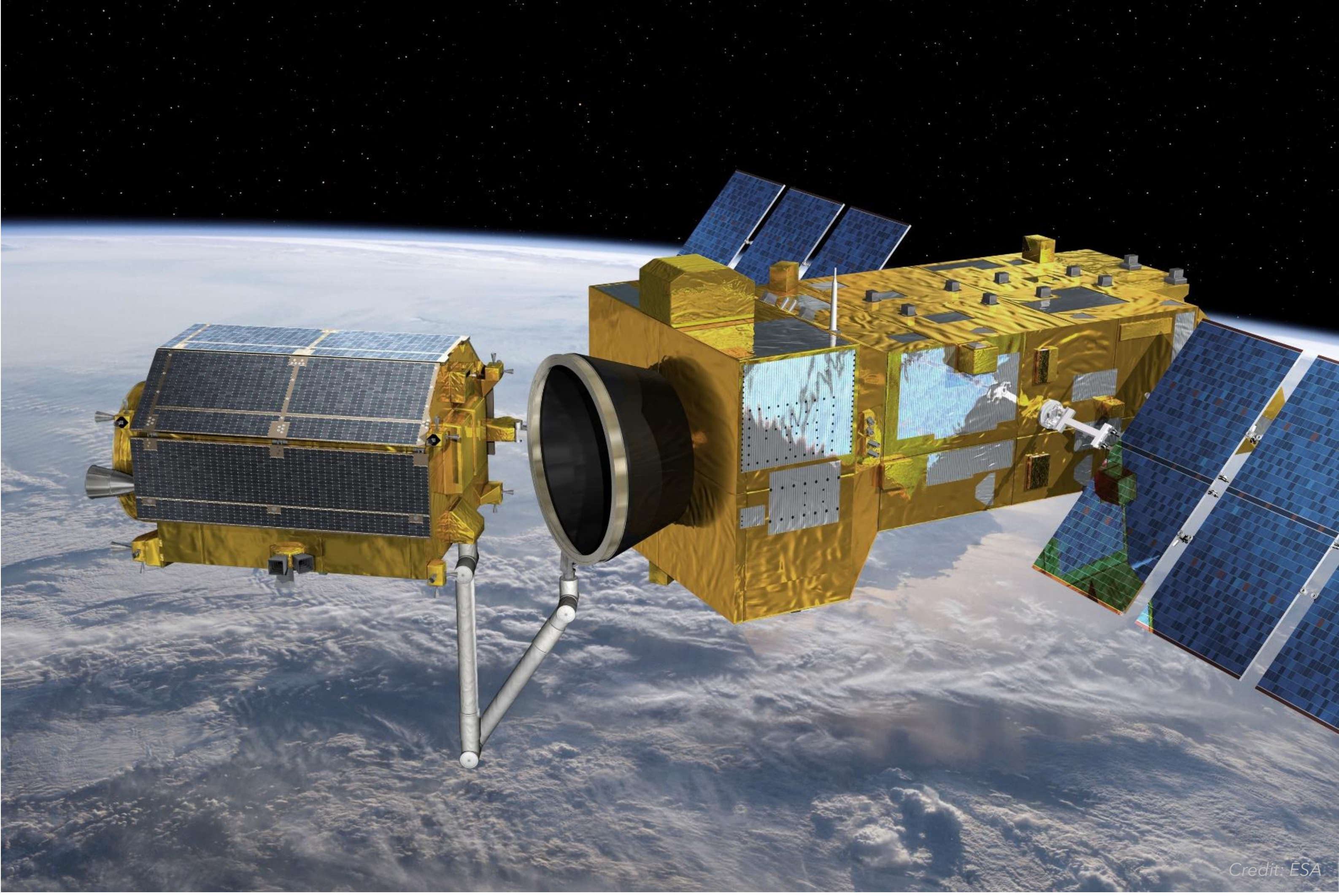
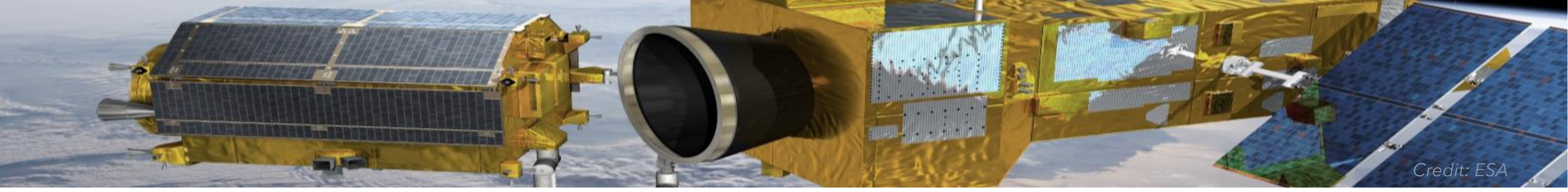


In-Orbit Servicing: Dependencies with Space Surveillance and Tracking

Full report for the UK SPACE AGENCY

know.space

18th March 2020


Credit: ESA

Contents

About us

know.space[1] is a new specialist space economics consultancy, based in London and Dublin. Founded by the leading sector experts, Greg Sadlier and Will Lecky, it is motivated by a single mission: to be the source of **authoritative economic knowledge for the space sector**.

www.know.space hello@know.space

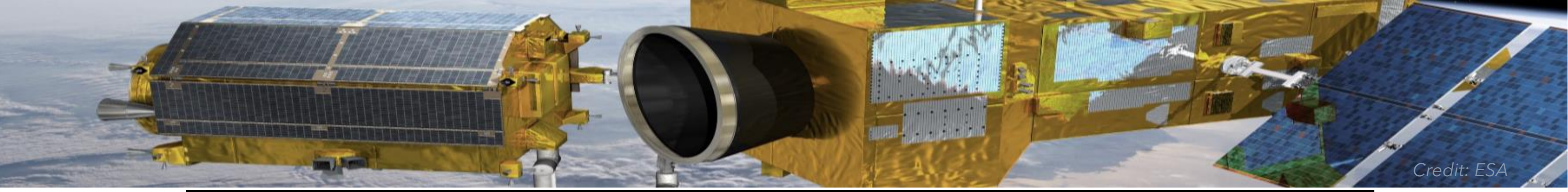
know. /nəʊ/v.

to understand clearly and with certainty

Acknowledgements

We would like to thank all the individuals and organisations consulted, whose thoughts and input were invaluable in the production of this research. We would also like to acknowledge the useful guidance and feedback provided by the UK Space Agency over the course of the project. Responsibility for the content of this report remains with **know.**space.

[1] **know.**consulting ltd. (CRN: 12152408; VAT: 333424820), trading as **know.**space



1 Introduction

With space debris posing a growing threat to the satellites that underpin modern life, planned mega-constellations adding to congestion in Low Earth Orbit (LEO), and over 200 geostationary satellites reaching the end of their operational lifetime within 10 years, **the need for active management of space assets continues to grow**.

While currently in its infancy, the **In-orbit Servicing (IoS)** market is expected to grow significantly in coming years – one recent forecast estimated that cumulative revenues over the 2019-2028 period from IoS services will reach $4.5 billion.[2] IoS has the potential to open up new opportunities through satellite life extension, robotics and salvage, while also offering sustainability benefits through debris removal and material recycling over the longer term.

How the IoS market will develop depends on a range of factors, including how **Space Surveillance & Tracking (SST)** capabilities will evolve. In turn, the direction and growth of the SST market will be influenced by demand from emerging IoS architectures and applications. Understanding these **inter-dependencies** is essential if the UK is to support its burgeoning IoS industry, design effective policies to mitigate risks to UK-licenced spacecraft, and to position itself to benefit from potentially lucrative growth opportunities in this market.

Against this backdrop, **know.**space were commissioned by the **UK Space Agency** to strengthen the understanding of the IoS market dependencies on these wider capabilities, specifically SST. This report outlines our detailed findings.

1.1 Methodology

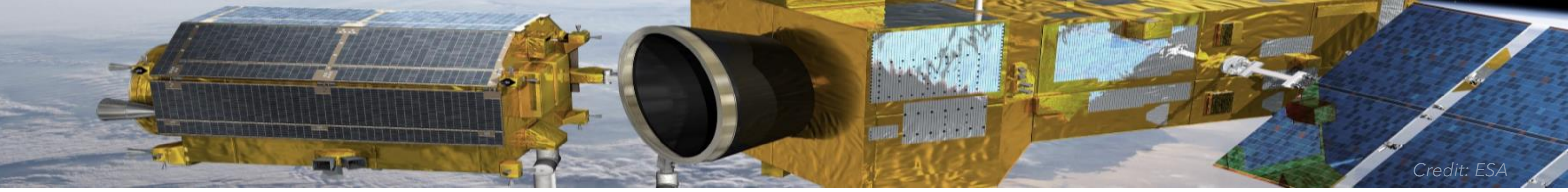
We followed a dual research approach combining a **desk-based literature review** and a programme of **stakeholder consultations**, seeking a wide range of views from:

- Operators of:
  - In-orbit servicing, refuelling and inspection;
  - Debris removal (active and passive); and
  - In-space manufacturing and assembly.
- Civil, military and commercial SST providers;
- The legal community;
- The insurance community;
- The regulatory, licencing and policy communities; and
- Academia.

A total of **25 practitioners and subject area experts** have been consulted (organisations consulted are listed in the **Annex**).

Following stakeholder consultations, we conducted **supplemental desk-based research**, to follow-up on suggested avenues for further reading, and to compare interview findings to those contained in published reports and other sources of information.

[2] Northern Sky Research, *In-Orbit Servicing Markets (second edition)*, March 2019.



Caveats

Terminology

Reflecting the embryonic nature of IoS markets and the lack of international norms and consensus on SST-related issues, there is often a **lack of agreed definitions** and **terminology**, compounded by geographic variation in use of terms.

The interpretation of '**In-orbit Servicing**' (IoS) used in this study is **relatively broad**, covering everything from in-orbit assembly through to active debris removal, though we recognise – and tried to reflect in our interview discussions – that different actors use narrower definitions. IoS is sometimes referred to as On-Orbit Servicing (OOS) – with no distinction drawn – but **IoS is the chosen acronym** for our study.

Similarly, there are overlaps and differences in how different SST-related terms are used and interpreted. We do not attempt to set out an agreed framework here, but recognise that **Space Surveillance and Tracking (SST)**, **Space Situational Awareness (SSA)**, **Space Traffic Management (STM)** and **Space Domain Awareness (SDA)** are all separate but inter-related terms, with varying degrees of agreement on their coverage. To address this, we kept our discussions **broad** and focused on the key issues at stake and have tried to make appropriate distinctions in our reporting where relevant.[3] Space Surveillance and Tracking (SST) and Space Situational Awareness (SSA) are often used interchangeably, but **SST is the chosen acronym** for our study.

Coverage

This was a relatively short study conducted between December 2019 and March 2020, with a broad – but limited – range of stakeholders consulted. It **cannot therefore be seen to be a comprehensive synthesis of all stakeholder views** but is intended to serve as a broad summary to help inform the direction of future work in this sector.

Nascent markets

There is not yet any fully commercial **IoS service** in operation and many demonstrator missions are still in the **planning phase**. Similarly, **SST capabilities are evolving**, both in the public and private spheres, and it is not clear which technologies will 'win out'. It will be many years until full market potential is understood and this uncertainty dissipates.

Many of the research questions posed in this study are also relatively technical, and consultees often felt that while the questions posed are clearly important, they are often impossible to answer fully at the current time. In the words of one consultee, "*no one has answered them yet*". While we have tried to reflect this in our summary, there is **intrinsic uncertainty in many of the answers** which should be borne in mind.

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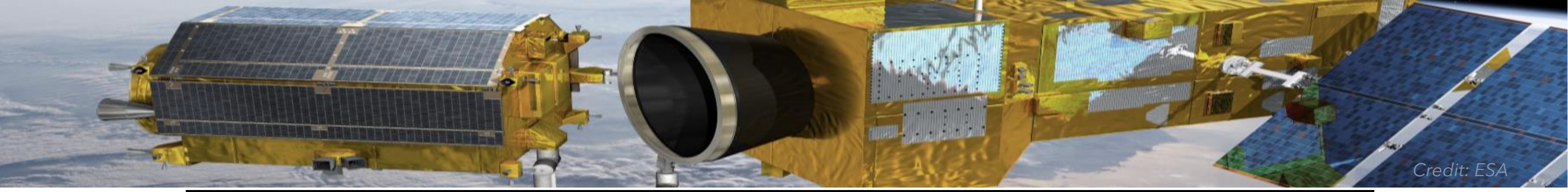
[3] For a more detailed discussion of definitional issues, see: IDA Science & Technology Policy Institute, *Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)*, April 2018.



2 Research findings

In this section we provide answers to the specific research questions posed for this study. We also include relevant (anonymous) interviewee quotes, to give a flavour of the different views expressed.

2.1 Sources of spacecraft position data

"We don't know yet how we'll use SSA and SST data"

"The current system is long past obsolete"

"Space-Track is slow, but usually right"

"We use the database to get us into the right ballpark"

"Current commercial solutions are niche, sometimes overblown"

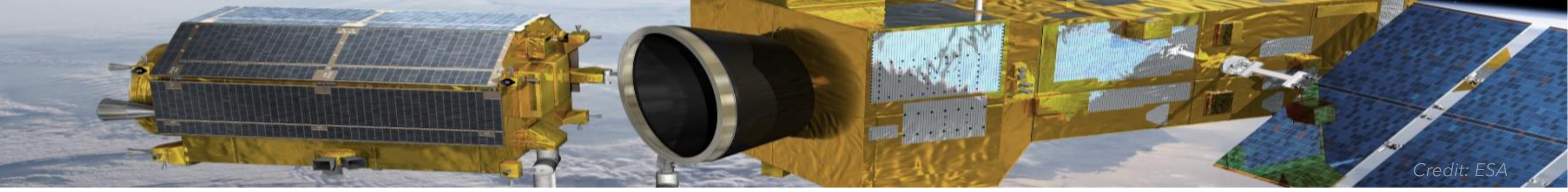
With most missions still in the pipeline and only a few current/imminent demonstrator missions (e.g. ELSA-d, ClearSpace-1, DARPA RSGS, NASA Restore-L profiled in §2.4), many respondents suggested **it's generally too early to say with any certainty how SST/SSA data will be used**. Several operators we spoke to do not yet have any active IoS missions but stated that this is an area they are looking at with increasing seriousness.

Operators suggested they typically *"work with what we have"* and as such 'standard sources' of data are expected to be important for IoS missions – with an important distinction to be drawn:

- For objects under control (e.g. chaser/servicer vehicle, active satellites targeted for life extension): the best source of position data was frequently cited as **data from satellites/spacecraft themselves** based on: **telemetry** (Attitude Orbit Control Systems (AOCS), Data Collection System (DCS), ranging signals), **GPS/GNSS** (if equipped with a receiver), **star tracker** (most accurate, but expensive), and **sun sensors** (senses the light intensity and position of the sun). Concerning positioning for **proximity operations**, **on-board sensors** can confirm identification and give accurate relative positioning using: thermal **infra-red** (IR cameras are good for identifying thermal objects against a cold background), **radar** (radio waves), **LIDAR** (Light Detection And Ranging), **optical and machine vision** (on-board cameras/telescopes, though illumination is not guaranteed and the objects are moving very fast). However, if data is not available from the satellite/spacecraft directly (e.g. client satellite in advance of service mission), **SST** can also be useful to identify, position and track (e.g. to validate correct target).

- For objects not under control (e.g. space debris, defunct satellite): the main source of positioning data (for now and the near future) is **SST** (at least until the object is within detection range of on-board sensors of a servicer or chaser spacecraft).

The primary source of SST data is **Space-Track.org** provided from the **U.S. Space Surveillance Network (SSN)** operated by the U.S. Air Force's 18th Space Control Squadron (18 SPCS) – which is also the primary source of Conjunction Data Messages (CDMs), or collision warnings. This is perceived to have numerous gaps and limitations, though developments such as the U.S. Air Force / Space Force '**Space Fence**' S-band



modern surveillance radar expected to imminently (at the time of writing in early 2020) be in initial operational capability will boost capabilities. It is, however, for the time being just one radar in one location, so has corresponding limitations. There is an option for construction of a second site in Western Australia, which *"would significantly increase the accuracy and timeliness"* of unusual orbital activity by allowing the radar to observe objects more frequently.[4]

As it continues to develop, the SST segment of the **ESA SSA programme**, which brings together a wide range of data from various national/private/research sensors (radar, optical and laser), will over time provide increasingly useful and complementary capabilities to the U.S. Space Surveillance Network.

In general, the development of new capabilities such as the **EU Space Surveillance and Tracking system** was welcomed and were thought to be useful future sources of data, though understandably, some operators are more focused on what is available today.

However, several consultees stressed that SST doesn't have to be limited to Earth-based sensors. The addition of (potentially dynamic) **space-based tracking assets** (e.g. GNSS space service volume, inter-satellite links) could help to establish a real SST system – enabling **persistence** and **small object tracking** (<10cm).

Commercial SST providers, such as *LEOLABS* in LEO (radar), *ExoAnalytic Solutions* and *Numerica* in GEO (optical telescope), *GMV* (LEO and GEO), and *Deimos Sky Survey* from LEO out to Near-Earth Objects (NEO), could be useful for specific mission types, though this will be decided by weighing up costs and benefits on a case-by-case basis for specific missions. Furthermore, **willingness to pay** is yet to be fully determined.

It was also suggested that IoS services may go beyond life extension – to **service enhancement,** by providing additional capabilities to the client satellite (e.g. star tracker, GNSS receiver).

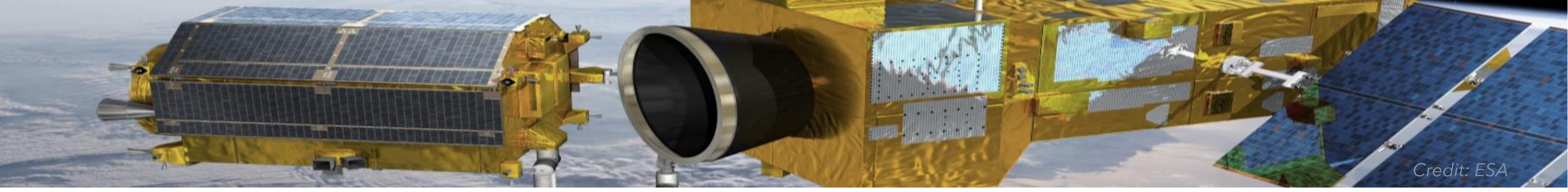
2.2 Key moments in IoS for positioning, and role of SST

"Current missions will teach us a lot about what we need and can do"
"Fundamentally, SSA is data to make decisions"
"A key question is whether the client is cooperative or non-cooperative"
"Only ever do close-proximity operations with on-board sensors"
"SST is used for verification, but it won't be part of the control loop, as it is not trustable enough for metres of accuracy"

SST data will be used for a variety of functions **before**, **during** and **after** IoS missions:

1. Planning and pre-launch: Naturally, the planning phase for any IoS mission begins a long time ahead of launch. SST data can help identify the **at-risk periods** (e.g. orbital congestion), as well as playing a core **diagnostic** function (e.g. identity tumble rate of debris/defunct satellite from the ground – if too aggressive then servicing / removal may not be possible – better to scrub plans pre-launch rather than abort at rendezvous). It also helps in understanding the attitude and operational status of a satellite, and not just its location. SST data plays a critical

[4] SpaceNews, *Indian anti-satellite test proves early test for Space Fence*, April 2019. https://spacenews.com/indian-anti-satellite-test-proves-early-test-for-space-fence/

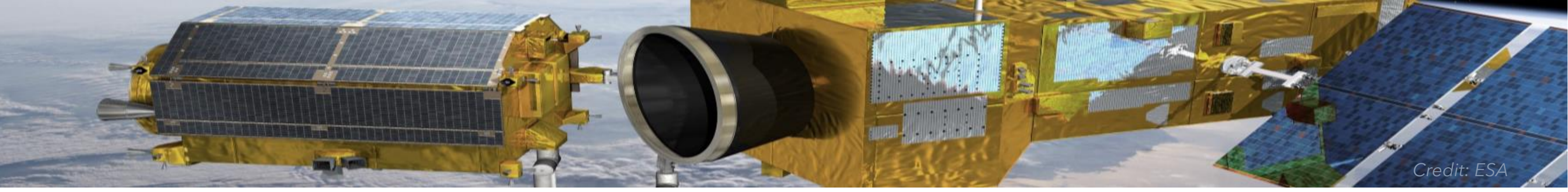


role in **forecasting**, helping mission planners understand the safest time to complete an operation, with short-, medium- and long-run elements to these decisions. One operator suggested that many in-orbit services (especially **in-space assembly**) would only be carried out in 'clean' orbits due to long mission duration to minimise collision risk. In the planning phase here, SST data would help identify optimal, clean orbits.

2. Launch: SST has an essential use in **launch collision avoidance (COLA)**, where launch mission plans/trajectories are scanned against the Space-Track catalogue. This is also done for **orbit-raising operations**. During the latter phases of launch, SST is used to **check separation**, and **verify correct deployment and orbital insertion**.
3. Collision avoidance: Throughout an IoS mission (as any mission) SST is essential to **identify collision risks, provide warnings and to plan safe collision avoidance manoeuvres (CAMs)**. Regardless of mission, the IoS servicer craft will act like any other licensed object in the instance of getting collision warning (CDM) and will manoeuvre to avoid (currently all involve a manual instruction, but in future might be autonomous – depends on the quality of SST data). Once a servicer starts a deliberate approach to a client satellite, it is not considered a 3rd party anymore. In both independent and joint-stack cases, the servicer needs to comply with any alerts/evasion manoeuvres, and **the IoS operator is responsible for the joint-stack manoeuvres**.
4. Initial approach and contact observation: During IoS missions, SST is used in the initial phase to **identify, localise and verify** the target. However, even commercially-available Earth-based SST can only bring the servicer to **within 2-3km proximity of a target**, at which point the servicer will **switch to on-board sensors** (see 2.1) which are now in range. Cameras on the servicer could help inspect to identify problems and permit preventative maintenance.
5. Undocking & retreat: In the case of satellite servicing (as opposed to debris removal) SST is also used for the undocking and retreat process – **to ensure a clear retreat path** away. Once beyond ~2km proximity (depends on policy specifics), the careful coordination of the proximity operation ends, as does the joint mission insurance.
6. Verification: SST data plays an important **verification** role after the servicing element of the mission is complete – though this verification can in some cases be provided solely by on-board systems on the services satellites themselves. **If a mission does not go to plan, SST data is arguably more important** as it is essential for understanding consequences (new debris, trajectory for tumbling satellites, etc.).

The **cooperative** (active, transmittable, manoeuvrable) and **non-cooperative** (not under full control, etc.) distinction is important. Where both client and servicer satellites are transmitting accurate position data, the need for SST is more limited, especially in GEO. For non-cooperative satellites, the need is much greater, as they cannot provide their own data. There is also a '**seriously uncooperative**' distinction, reflecting the dual civil-military applications of certain IoS capabilities.

Where missions involve **de-orbiting**, the 350km orbit was suggested by one consultee as the most important time for them to know exactly where they are, i.e. when orbital decay begins to 'bite' in earnest.



At all stages, SST data can play a critical role in **persistent** and **accurate** data provision on all active assets, non-active assets and other sources of space debris, used to ensure the safety of all missions, both IoS and otherwise.

Again, though, the **requirements and role of SST data will vary by mission type** and characteristics. For example, in one in-space manufacturing case, the consultee stated that all they need to know for the time being is that they are maintaining their orbit, i.e. relatively simple – and cheap – requirements. However, for other IoS missions, requirements will typically be much greater.

2.3 Key moments for independent monitoring, and role of SST

"To honour a contract, you need to understand what's around you"

"The patient doesn't typically need to watch the operation, but is obviously interested in how it went"

"SST is not just used to prevent collisions, but also for licencing, response, etc."

IoS missions are considered **dual-use** (civil and military applications), so **transparency** is very important – IoS operators need to be able to **independently demonstrate** (e.g. by a commercial SST provider) that they are a civil peaceful mission.

SST is also used by a range of **3rd parties** to monitor the IoS mission (the customer, the regulator of the IoS operator, the regulator of the target/client satellite … and potentially – in future – insurers).

Customers will want to understand mission details beforehand and following the operation to validate whether it was successful. Their need during the mission will depend on mission type – substantially higher for life extension of an active satellite than for de-orbit of a defunct satellite. At the critical point of a life extension mission, the customer would have to (based on the SST, camera data, etc.) give a 'Go/No-go' decision to go ahead with the operation.

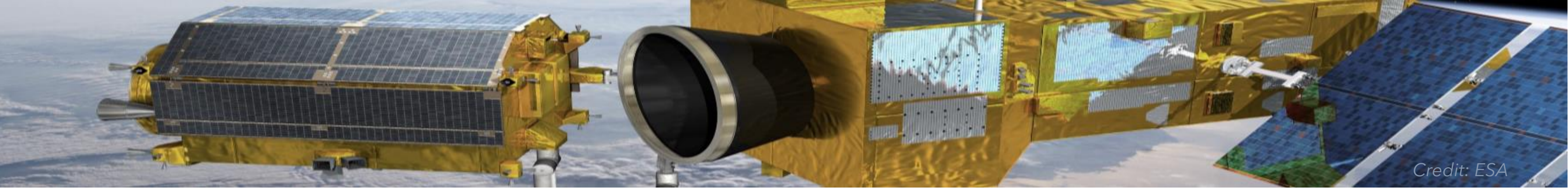
Throughout the whole mission it is very important for **regulators** and licencing authorities to have transparency with what IoS operators are doing. For the first few missions, it is likely that the regulator will pay a bit more attention, but less so if/when IoS becomes a routine service. The UK government will need to do this for any launches licenced by, or launched from, the UK.

For **insurers**, the current use is very limited. Typically, contracts do not prescribe that SST data must be used, but do include higher-level requirements for appropriate due diligence. Generally, there is an 'act as if you are uninsured' clause to manage the moral hazard risk, i.e. stipulating that they should take reasonable precautions, which may implicitly involve the use of SST. Establishment of liability for any collision damage would be a **legal** issue, but could, in future, utilise SST data.

2.4 SST role in IoS missions, and performance requirements

"It's simply too early to answer the questions of: what is the technology, what is the market"

Many respondents thought it was **too early to tell**, as missions are typically still on the drawing board.



One respondent stated that **SST as it is currently provided is not fit-for-purpose for IoS**; SST databases comprise spot-checks of millions of active assets and pieces of debris, but what IoS operators need is **persistent, reliable and accurate positioning data for just two spacecraft:** the **servicer/chaser** and the **client/target** – and this is not currently provided.

Current and planned IoS demonstrator missions are expected to teach us a great deal about SST needs and capabilities for IoS missions. These missions include the following:

- **MEV-Intelsat 901** and **Phantom Echoes:** Northrop Grumman successfully completed the historic first docking of Mission Extension Vehicle (MEV) with Intelsat 901 satellite on February 25, 2020. As part of this mission, the Defence Science and Technology Laboratory (Dstl) and representatives from the Five-Eyes nations (UK, US, Canada, Australia and New Zealand) are collaborating on an experiment to demonstrate how allied SST sensors and processing capabilities can be integrated to enhance the performance over individual systems working independently to improve space safety for UK and allied satellites in and near Geostationary Orbit. See box in §2.8 below.
- **ClearSpace-1:** This ESA mission will be the first space mission to remove an item of debris from orbit, planned for launch in 2025. The mission is being procured as a service contract with a startup-led commercial consortium (led by Swiss startup ClearSpace), to help establish a new market for in-orbit servicing, as well as debris removal.
- **DARPA RSGS:** The Robotic Servicing of Geosynchronous Satellites (RSGS) mission will develop technologies that would enable cooperative inspection and servicing in GEO and demonstrate those technologies on orbit within the next five years.
- **ELSA-d:** The End-of-Life Service by Astroscale (ELSA) program is a spacecraft retrieval service for satellite operators. ELSA-d (demonstration) is the first mission to demonstrate the core technologies necessary for debris docking and removal. It is scheduled to launch in 2020.
- **NASA Restore-L:** A robotic spacecraft that is equipped with the tools, technologies and techniques needed to extend satellites' lifespans, even if they were not designed to be serviced on orbit.

Typically, **all IoS missions will use some form of SST, but it's impossible to do close proximity operations without on-board sensors**. Again, SST specifications will vary significantly by mission type, reflecting the use of IoS as an umbrella term.

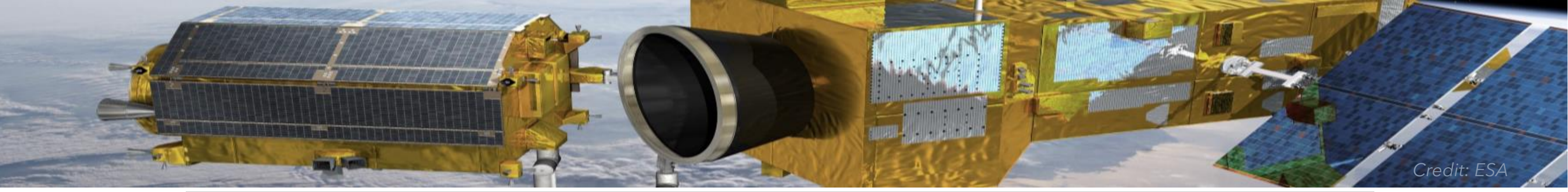
Several operators suggested (tongue-in-cheek) that they would ideally like perfect real-time data, that's free, accurate and with comprehensive coverage. In practice, they **will work with what's available** – ultimately how SST capabilities are built into future IoS missions will depend on a balance between the costs and the benefits of different technologies and their availability and interoperability. This will vary by mission type.

2.5 Costs, benefits and drawbacks of using SST to support IoS

"The rise of private commercial SSA providers may drive prices down for the services provision aspects of an SSA architecture"[5]

"Even if SST data is free, interpretation of that data is still an important overhead cost"

[5] Institute for Defense Analyses (IDA), Science & Technology Policy Institute, *Evaluating Options for Civil SSA*, August 2016.



"SST is mandatory (not optional) in New Space era where space sector is driven by commercialization and resource utilization"

The consensus view on costs, benefits and drawbacks was that it is again **too early to tell.**

SST data is typically seen as being **essential** for the operation of IoS missions, and different sources of data have different **pros and cons**, and levels of suitability to different mission types.

To the extent that some form of SST is a **prerequisite** for IoS missions, then **cost-benefit analysis is arguably irrelevant**.

Future prices and capabilities are not yet known, and as such it is hard for operators to comment on any future cost/quality trade-off. Again, it varies by mission type – for example tracking in LEO was noted by one consultee to cost them just 10p a message. In practice, it will be a **case-by-case assessment** of what SST capabilities are required and how the benefits compare to the costs, with all the above factors (mission type, orbit, client status, etc.) affecting decisions. Ultimately the mission specifics and what is being 'serviced' will drive what is needed need and how often.

There are no drawbacks currently, but **any additional future requirements** might create drawbacks and add cost.

2.6 IoS technical, commercial & regulatory viability without SST

"Not possible – forget about it."

"Without SST? Good luck."

"The risks are still low – sometimes people get carried away"

"It's very important but not essential - engineers would find another solution"

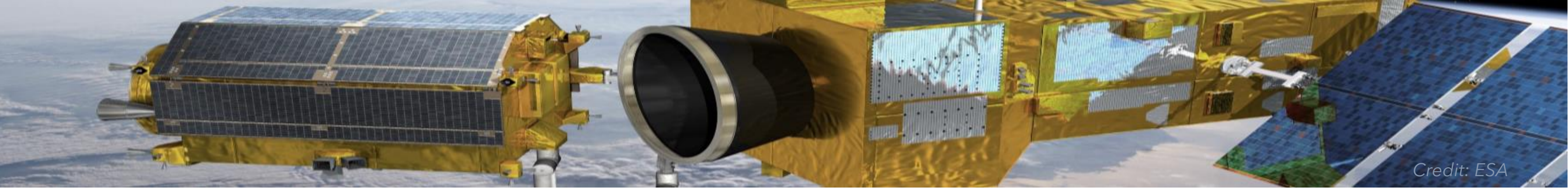
"Impossible to know where the [debris] target is without SST"

"Not viable or not sustainable (to be precise)."

While **an IoS mission could in theory be technically viable without SST**, if all sensing was done by on-board systems, consultees tended to suggest that **it would not be sensible** and would certainly carry a large degree of risk. Several consultees pointed out that risk can never be eliminated, just managed, and that SST data plays a core role in this risk management process. Over time, better SST data will provide greater clarity on collision likelihood and enable more effective operations, **reducing risk**.

Commercially, it was thought that without SST, operators would find it **impossible to get insurance** for their IoS mission. Unless they choose to self-insure, this would likely make missions non-viable for operators. Insurers pay close attention to how the operator ensures that they do not crash into a target, naturally, but the close proximity navigation technology used is considered on a case-by-case rather than prescriptive basis.

For regulatory viability, linked to the risk management point above, respondents generally thought that without SST the mission would **fail threat assessments**, would fail to get a licence for launch, and so would not be viable.



2.7 Improvements needed for SST data to be more useful

"SST could be better renamed 'Space Surveillance and Forecasting'"

"It's essential to have as accurate data as you can for regulation, insurance and licencing"

"The system today isn't how you'd do it if building from scratch, but here we are"

"The technology exists today – nothing new needs to be invented; it's about rollout"

"The UK should invest in complementary capabilities [to U.S.], and not try to do ourselves"

There is a strong consensus that **both technical and performance improvements are needed** – **low computation**, **reliable** and **high-accuracy** positioning as it would allow reduction of on-board sensors, redundancies and costs.

Consultees sought the following improvements in SST data as:

- **Low latency** towards **real-time** or near-real-time data (in LEO operators have only about 90 mins to make a decision);
- **Comprehensive coverage** (currently only spot checks) **increasing temporal resolution** towards **persistence**;
- **More infrastructure**, including space-based SST in future, to provide multiple space/ground-based observations for tracking orbits;
- Higher **spatial resolution** to track smaller objects (e.g. picosatellites, <10cm debris);
- **Mixed sensor technology** (e.g. radar and phased array antennae can 'see' through clouds);
- **Better prediction & forecasting**, with increased accuracy from SST models;
- **Better interoperability** between different SST data sources;
- **Ability to handle more data** (e.g. better application of AI / machine learning);
- **Cheaper commercial SST data.**

A **full live catalogue of all orbital items** – active, inactive, debris, natural, man-made, etc. – was seen to be a particularly useful target to aim for, though all agreed that we are a long way from this being a reality at present.

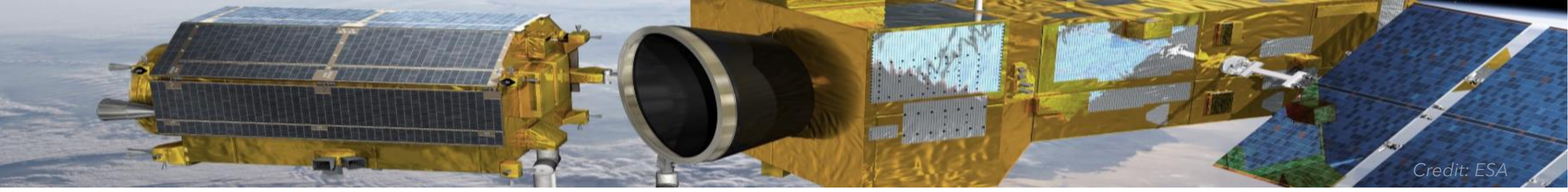
It was noted that **having different capabilities and sources of data** that can provide **backup** as well as playing **different roles** (e.g. radar being used when there is cloud cover affecting optical telescope capabilities).

Ultimately, more accurate, timely data allows better decisions. If, for example, this leads to fewer collision avoidance manoeuvres, this saves fuel and increases lifetime and/or saves cost.

Some consultees highlighted the **role that government should play** in moving SST forward, for example as an 'anchor customer'.

The issue of **interoperability** and **fusion of data** from different systems is expected to be a significant issue in future that could affect the development of IoS markets. Some work has been carried out here, for example by ESA using different systems to look at the Envisat satellite and examine the potential for data fusion using the IOTA tool.[6] This

[6] Šilha, J., *et al.*, *Debris Attitude Motion Measurements and Modelling by Combining Different Observation Techniques*, 7th European Conference on Space Debris, Darmstadt, Germany, 18–21 April 2017, published by the ESA Space Debris Office. https://conference.sdo.esoc.esa.int/proceedings/sdc7/paper/1060



provides a useful base, though further research here will undoubtedly be needed as the range of data sources and technologies used to provide these increases.

Autonomy in Space: AI and autonomy and the development of IoS markets

A common theme in our research and discussions was that AI and autonomy are expected to play a key role in the development of IoS markets, particularly with regards to on-board self-awareness to understand risks and reducing operator workload. Many useful discussions around these topics were held at the *Towards Greater Autonomy in Space* workshop[7], held on 21 January 2020 and co-organised by the Satellite Applications Catapult, University of Liverpool, UK Space Agency and the Fair-Space Hub.

The first commercial debris removal demonstrator - ELSA-d, launching this year - will be 'level 3' autonomy under the 4-level European Cooperation for Space Standardization (ECSS) autonomy framework, i.e. with break points in operation to make sure humans on the ground can give a 'go' decision.[8]

Different techniques are at different TRLs, but for autonomous orbital rendezvous experts suggested we are typically at TRL 4-5 (with in orbit validation on-board a D-Orbit mission launch towards end of 2020 providing the opportunity to test capabilities), and at TRL 4 for autonomous orbital manipulation and grasping (i.e. validated in digital and physical orbital testbeds). In general, the trends may be away from vision-based navigation and robot vision towards more deep learning and mixed AI.

Several challenges to market development have been identified. In the short-to-medium term, these include 3D mapping and perception with lower computational power and higher accuracy, energy optimised locomotion mechanisms and control, resource-aware computation and data assimilation for parameter tuning, and hardware/software reconfiguration and self-verification in real time.[9] In the longer-term, the challenge is to achieve long-lived, robust mobility and autonomy for next-generation spacecraft. There is still much to learn, with fully autonomous constellation operations not yet proven operationally. In the words of one expert *"the concepts are often there, but the business case is not – at least yet"*.

There are many open questions here, which are evolving not static. For example, whether there should always be a human 'in the loop', how to ensure interoperability with multiple actors in the supply chain, and whether it will be possible (or desirable) to move towards an open architecture and away from traditional business models.

2.8 SST best practice guidelines, standards and regulations

"By far the most important consideration is the need for international cooperation"

"You could write books on this stuff"

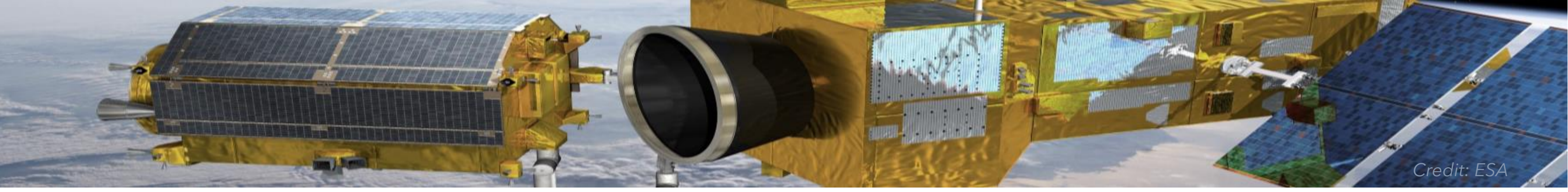
"Without regulations in place, we won't see a proper IoS marketplace develop"

"If UK space activities are to develop, the regulation/safety demanded needs to be light-handed, but effective."

"Prevention is better than cure… we can easily lose control"

"It's tricky to see where things will go"

[7] More information: https://sa.catapult.org.uk/events/towards-greater-autonomy-in-space/
[8] A helpful summary is provided by the European Robotic Goal-Oriented autonomous controller (ERGO) consortium: https://www.h2020-ergo.eu/project/background-on-autonomy-software-frameworks/autonomy-in-space-systems/
[9] This point builds in particular off a presentation given by Professor Yang Gao from the University of Surrey at the *Towards Greater Autonomy in Space* workshop, and useful follow-on discussions.



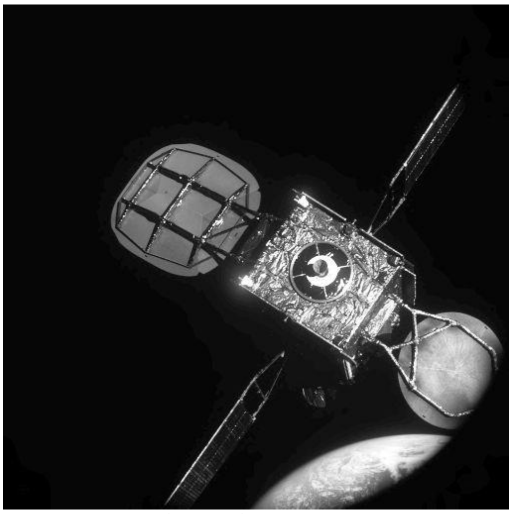
Norms of behaviour will continue to drive action, but **few norms have yet been established in space** (even though we have been launching satellites since the 1950's). In the opinion of several consultees, this is blocking IoS market growth. However, as discussed above, progress is expected to come slowly, through incremental steps, rather than in sudden jumps. This view has also been echoed in *SpaceNews*.[10]

A common theme in our research and consultations is **the importance of working together internationally to ensure availability of SSA/SST data through dedicated or shared assets**, together with the ability to exploit this ever-increasing data more effectively. This, for example, is a core part of the ESA Space Safety Programme, which has been adopted as a new basic pillar of ESA's activities. Clearly, for the UK, continued working through international organisations including but not limited to UN-COPUOS, IADC, ITU and ISO, and with EU Member States and other organisations such as the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS), the Space Data Association and the Global Network On Sustainability In Space (GNOSIS) will be important for helping to shape future guidelines and standards in a direction that will not disadvantage UK companies.

Watch this space: UK's Defence Science and Technology Laboratory participates in Five Eyes SSA experiment[11]

On February 25th 2020, Northrop Grumman's subsidiary SpaceLogistics successfully completed the **historic first docking of a servicer** (Mission Extension Vehicle-1, MEV-1) **with a satellite** (Intelsat 901) to provide life-extension services.

As part of this mission, the Defence Science and Technology Laboratory (Dstl) and representatives from the Five-Eyes nations (UK, US, Canada, Australia and New Zealand) are collaborating on a unique experiment. Known as **Phantom Echoes**, the experiment aims to demonstrate how allied SSA sensors and processing capabilities can be integrated to enhance the performance over individual systems working independently to improve space safety for UK and allied satellites in and near Geostationary Orbit.



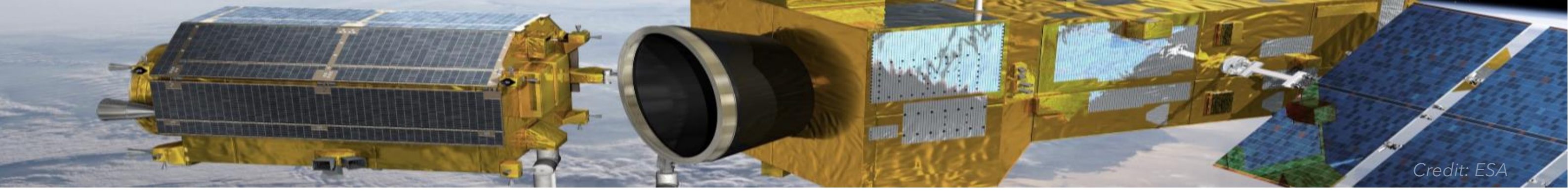
Credit: Northrop Grumman

A combination of simulation and real-world events will be used to understand the strengths and constraints of each system that will advise the development of operational SSA architectures within the Coalition Space Operations (CSPO) initiative.

A cooperative observation campaign will be conducted using allied ground-based telescopes and space-based sensors to observe MEV-1 that was launched into Geostationary Transfer Orbit (at 36,000km altitude above Earth's surface) on 9 October 2019 from Kazakhstan.

The Phantom Echoes team are using this historic event to understand the challenges posed in observing this unique mission as the two satellites manoeuvre towards each other and perform docking operations.

[10] SpaceNews, *Muddling through space traffic management*, September 2017. https://spacenews.com/muddling-through-space-traffic-management/
[11] This box combines news updates with a DSTL press release: https://www.gov.uk/government/news/dstl-in-unique-five-eyes-space-situational-awareness-experiment



Credit: ESA

As noted by the European Space Policy Institute (ESPI), **providing timely, accurate and actionable data and services supporting safe operations in a congested space environment is a serious technical challenge** that will require greater transparency and information sharing among operators and space surveillance systems which will, in turn, raise new **interoperability issues** to ensure data quality, integrity, availability and confidentiality.[12]

The interlinkages between the IoS market and more general space debris considerations were frequently highlighted. Some consultees suggested that **without better dialogue on who needs to keep space clean, the investor story may fail**. The need to take a holistic view was highlighted, factoring in launch, spectrum and end-of-life process among other factors.

Some consultees were worried that regulation would continue to be too voluntary, highlighting the importance of discussions continuing to focus on how to enforce emerging and future norms.

For working internationally, a common view in both our desk-based research and consultations was around **the importance of including industry – including legal professionals and insurers - in seeking out solutions and developing future standards**. For example, one report noted that: *"New uses of space assets (rendezvous and proximity operations, active debris removal, and on-orbit servicing, to name a few)…test the boundaries of both the existing legal regime and established practices for activities on orbit"*.[13] From a different perspective, if IoS missions extend the lifetime of satellites, this could cause upsets to the existing space insurance market.

In practice, the current Space-Track system is around and widely used essentially because the U.S. wants it to be. However, if the US Congress will not be able to introduce new laws till 2021, this will have knock-on effects for the UK and other countries. Several interviewees noted that the U.S. (and Russia) will not accept new regulations put on them.

Finally, a common theme in both the consultations and desk-based research is that change is undoubtedly incoming, but **the bottom line is that understanding the locations of satellites and their operational status will only grow in importance**. This presents both a **challenge and an opportunity**.

2.9 Role of SST in cultivating trust for IoS operations

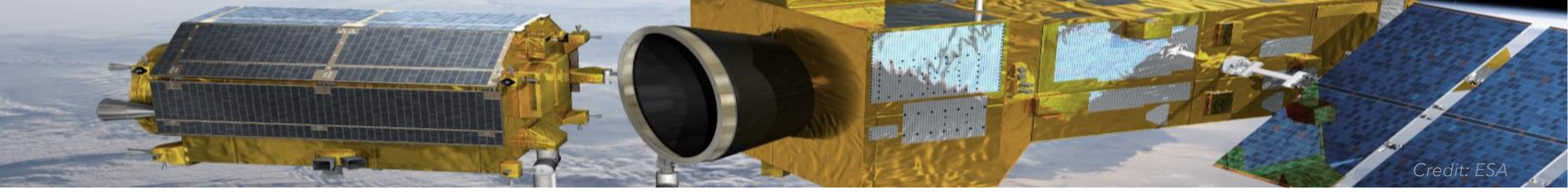
"Ultimately it's all about trust"

"Mandatory for long term and sustainable in-orbit operations"

Nearly all respondents to this question agreed that SST plays and essential role in cultivating trust in IoS missions, particularly from a third-party validation perspective. **This trust in turn opens new markets** – whether trust in accuracy, continuity or other factors. Without SST, it is hard to get an independent assessment, so it provides accountability.

But, as discussed above, there are **limits**. In close proximity, ground-based SST generally is not able to provide the accuracy that is required for some of these purposes. The

[12] ESPI, *Towards a European Approach to Space Traffic Management*, January 2020.
[13] Samson, Wolny & Christensen, *Can the Space Insurance Industry Help Incentivize the Responsible Use of Space?* (paper for IAC), October 2018.



development of future capabilities will enable greater accuracy, greater trust, and so potentially faster market development.

Furthermore, as one respondent highlighted: **trust is built in many ways**, not only ongoing independent observation. A company that engages with and delivers civil operations in a routine way will be seen to be trustworthy and not engaged in nefarious applications.

3 Next steps

The **IoS market is at a nascent stage of development**, and much is expected to be learned from current demonstrator missions. Similarly, **SST capabilities are evolving**, with commercial providers providing new capabilities, and publicly funded programmes driving the deployment of new solutions.

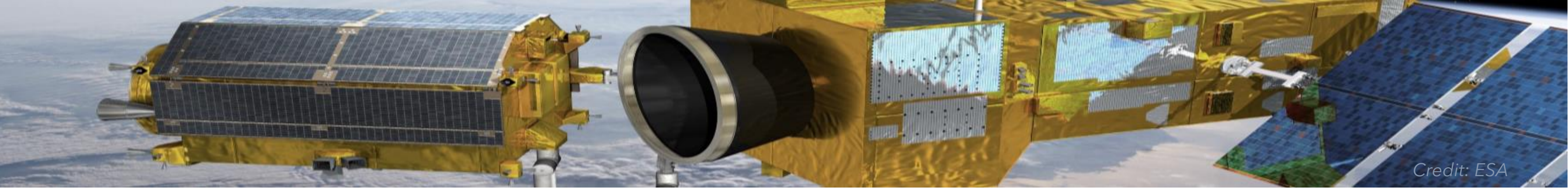
Against this backdrop of change, there is much still to discover and there is only a limited ability to comprehensively answer the research questions posed by this study accurately and with confidence. It will be important to see how these markets develop together, but one consistent message is that improvements to **SST capabilities will be needed if the IoS markets are to see the growth** that some commentators claim.

There are reasons for a positive outlook for the UK. For example, respondents (from the private sector) noted that ***"the UK is at the leading edge of industry and capability"*** (albeit IoS rather than SST capability provision), and the business and regulatory environment is generally seen to be efficient and effective but not heavy-handed (*"we're broadly confident in the UK's ability to have safe, entrepreneur-friendly regulations"*).

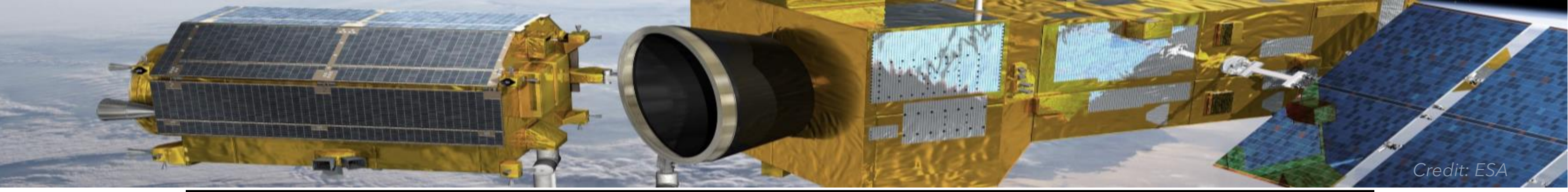
Still, the UK is one of many global players and another of the key themes is around the **importance of international collaboration**. The **future is uncertain**, but the UK's interests can best be advanced by sustained collaboration with international partners in the US, Europe and beyond to advance best practice and encourage new actors to adopt this to 'level the playing field'.

Several **potential policy questions** arose as a result of our research and discussions with experts in the community. There is clearly great enthusiasm to engage with these questions, and the prospect for further, more detailed analysis of these issues. These policy questions include the following:

- What is the role of (the UK) government in:
    - Developing its own SST capabilities?
    - Driving IoS-relevant SST capabilities forward?
    - 'Owning' SST as a public good?
    - Pursuing integration and interoperability of different data sources, including public and private sources?
        - How to recognise issues of national security and proprietary information within this?
        - What mechanisms / platforms could be used to enable this?
    - Convening and securing buy-in from different stakeholder groups (e.g. civil, military, international, commercial, regulatory, insurance, legal)?



        - How to minimise the risk of divergence of interest among stakeholders, duplication of effort, and/or reduced cost-effectiveness if different countries try to 'go it alone'
    - Promoting innovation in SST and IoS markets?
    - Balancing commercial growth with effective risk management, while securing flexibility
    - Ensuring that UK firms do not end up at commercial disadvantage due to U.S. ambitions to lead the development of standards and best practice?
- To what extent should the development of SST capabilities for IoS missions be left to the market? How can government best enable this market growth?
- Should we seek more 'teeth' in guidelines? How best to pursue?
- What is the respective split of roles and responsibilities between private IoS operators and public agencies (both civil and military) in maintaining and using SST data?
- What is the role of improved SST data for regulatory compliance, monitoring and enforcement for IoS missions?
- What lessons are there from other sectors and technologies (e.g. nuclear, maritime, cyber, GPS, autonomous vehicles)?
- Can future missions be 'futureproofed', and what is the role of government here, for example in setting out 'soft rules'?
- For IoS missions, what objects should be licenced, under what conditions, when should they be licenced differently, and should there be 'by type' approval?
- Should LEO constellations have IoS as a licence condition, and should there be more stringent requirements? If so, how can this be enforced?
- What should contracts for missions – constellations or otherwise – say with respect to IoS, what is the role of government in ensuring this is included, and should government be asking to see contracts for liability reasons?
- If the issue is one of policy rather than technology, should government be funding less R&D and more rollout-focused activity?
- What is the role of governments – and indeed people – in future autonomous systems on board spacecraft and the decision-making that entails?



Annex

Organisations consulted

As part of this project, we spoke to a range of organisations, listed below. All views provided by individuals are their own, and they do not necessarily represent the views of their parent organisations.

- Airbus Defence & Space
- Alden Legal
- Astroscale
- Atrium Space Insurance Consortium (ASIC)
- Chilbolton Observatory (STFC/UKRI)
- D-Orbit
- Defence Science and Technology Laboratory (DSTL)
- Defense Advanced Research Projects Agency (DARPA)
- Effective Space
- ExoAnalytic Solutions
- Global Aerospace Underwriting Managers
- GMV
- MadeInSpace (Europe)
- MDA (UK)
- Northern Space and Security (NORSS)
- Satellite Applications Catapult
- Secure World Foundation
- Spaceforge
- Surrey Space Centre, University of Surrey
- UK Department for International Trade
- UK Space Agency
- University of Southampton
- Willis Towers Watson

... now you **know.**