The Case for a Commercial/Civil Space Traffic Management Capability

The future space environment is driving change on how to manage the Space domain

Given the rate of technology change and the current Space 2.0 hype, it's difficult to predict what space will look like in 10 years' time, and therefore it's difficult to accurately predict what kind of regulation and controls will be needed. But when we look at what we do know, we can draw some relatively straight forward goals and objectives. What we do know is as follows:

- We will have more objects in space in 2026 than we have now, including mega-constellations of CubeSat's in LEO.
- There will be an increase in launch frequency.
- A number of new services are being proposed including, refurbishment, replacement, and repair & refuelling of satellites, asteroid mining, tourism, etc.
- Many of these new services will increase the frequency of on-orbit manoeuvres.
- This increase in manoeuvring and increasing launch frequency will require a fundamental redesign of the space domain awareness capability to ensure the safety of flight and environment.
- The Joint Space Operations Center (JSpOC) is the organization responsible for performing all of the orbit determination activity necessary to maintain the US space catalogue and providing collision avoidance warnings.
- US congress are currently considering if another commercial or civil entity, such as the FAA, should be conducting, space catalogue, tracking and collision avoidance whist the Military concentrate on protecting and defending their valuable assets.

If we can agree on the need to establish a commercial/civil space traffic management entity, we need to explore what that capability may look like, what they will do, and how they would do it. This paper explore some the issues inherent in developing this capability including technology, policy, insurance and economics.

It also presents a potential launch scenario that examines how a commercial/civil space traffic management entity may operate and what information is already available to support their mission.

> *"We will go from needing help for computers to needing help with their satellites … even primary school students are launching."*

The current space environment is transitioning from military dominance to commercial dominance

Access to space is becoming cheaper and this is resulting in more commercial actors become involved and more activity results in more resident space objects around earth.

The space domain is not as mature as other domains such as maritime, land and aerospace. This is due to the dominance of two actors, US and Russia, and also the relative low use of space, meaning that the need for regulation has not evolved due to the limited interactions between actors in space. This is changing as other countries gain access to space and commercial companies create new missions such as space tourism, mining, satellite repair etc. This increased mission set will require technology and policy to catch-up. We are currently in a unique situation where we have access to advanced technology whereby we can learn from other domains such as Air Traffic Control, to create a STM system.

These changes result in space transitioning away from military dominance, and it is expected that commercial dominance will occur soon. This leads to increasing visibility of what is in space and what is happening in space. Although this is challenging to traditional actors who could operate in space with relative secrecy, this is changing quickly. Governments are realising that sharing data makes it cheaper for everyone; and now that anyone can peer up into space and see what is there and what is happening the argument that governments must maintain secrecy quickly evaporates. An example of this type of data is in radio astronomy. Whilst their primary mission is deep space they have archived data that shows streaks across their instruments which are resident space objects. They have discarded this data in the past, but could easily reach into their archives and reconstruct space domain awareness.

The current question is what would this arrangement look like? How would a commercial STM capability operate? Who would pay for this service?

Military will still function as Military STM, but needs another entity to deliver commercial/civil STM

The Joint Functional Component Command for SPACE (JFCC SPACE) is responsible for identifying, cataloguing and tracking over 23,000 man---made objects achieving orbit. JFCC SPACE executes this mission using data collected by the U.S. Space Surveillance Network (SSN) and through the expertise of its personnel at the Joint Space Operations Center (JSpOC), located at Vandenberg Air Force Base, in California.

During the period of military dominance it's sensible that the JSpOC is tasked to catalogue and track objects for all space. However as space transitions to commercial dominance, JSpOC's mission becomes more difficult. A 20% increase in the number of satellites is still achievable for JSpOC using the current technology, but if the number of manoeuvres increase, which is expected, then we need to rethink how best to achieve this mission. The JSpOC would still protect military satellites but the commercial RSOs would be better managed by a civil entity such as the FAA, which is currently under investigation.

Significant investment in Space Domain Awareness will be required as space becomes increasingly crowded. One of the issues facing any new entity that wants to conduct Space Traffic Management is where does the funding come from? The general public is adept at using space technology, but do not understand the costs, nor the issues, of providing these services. As this growth is fuelled by commercial assets and services is it feasible that these same commercial companies should be paying for this investment? The questions are who pays? how much?

What would a commercial/civil STM capability need to look like?

Historical Aspects

Space Situational Awareness (SSA) was initially developed in response to the cold war missile threat, in a space domain that was dominated by two actors, the USA and Russia. As such current SSA mission has been created with the mindset of detecting missiles passing through space, there are several issues with this:

1. The phenomenology of Missile Defence is relatively simple compared to identifying and cataloguing space debris

2. The certification costs of developing and maintaining nuclear componentry is rigorous, for a reason, however the same safety critical assurance is not required for space debris tracking.
3. The length of time to re-accredit equipment under nuclear certification makes efficient design and development difficult
4. Due the cost to develop and build, many sensor systems are dual purpose for missile defence and space debris tracking, this adds unnecessary complexity and cost to the space debris tracking mission.

Therefore to make commercial space traffic management affordable a different mindset is required.

Analogous business models

When considering what type of business models to use for Space Traffic Management it is useful to consider similar models. Although you will unlikely be able to adopt a model completely, analogous models do have many lessons learned that can be used in determining the future STM model.

Air Traffic Control

How is it similar?

Systems don't talk to each other, data is in different format

Airspace is big, but there are areas where concentration of aircraft are higher

Orbital space / airspace (ATC will tell plans 24 hrs in advance)

Different phases of flight launch versus aircraft flight plan

What are the differences?

No flight plans in space

ATC must be cooperative with aircraft

ATC can issue instruction to aircraft

No handovers in space (ATC have control areas)

ATC monitor weather and make changes based on that i.e. windtracer and separation of landing

ATC simulate conditions i.e. what if you make changes, what happens does it cause other issues

Aircraft have systems on it that identify and locate them

What are the lessons learned?

ATC, pilots report air turbulence and it increases awareness. Satelitte do not report weather and other events and do not have systems to be able to detect the issues, the assets that can detect are not able to due to military sensitivities

Space Weather data

Weather data is currently gathered, shared and used internationally, via the use of standard formats. Similarly space weather data can be gathered internationally if we have a standard format, therefore we need to define those fundamentals before going forward.

Drones

The use of drones in civil airspace have similar issues with space traffic management i.e. its difficult to detect identify and track drones. As an example, legitimate drone operators have shown a willingness to invest in tracking devices so their business is uninterrupted. This leaves authorities to focus on rogue drones.

Issues to address

Mega constellations

Several mega constellations of cube sats have recently been proposed in LEO. This will significantly increase traffic in LEO and raises the question of how this needs to be managed?

Economic

In other industries it has been the civil costs that have driven investment simply because there is more money involved. This is possible also in space as the number of launches increases, and the number of manoeuvres increase and the number of activities done in space increase. These will all drive the need for greater surveillance and demand decision support tools.

Currently the burden for space situational awareness is worn by the ground infrastructure that needs to be in place to conduct it, this is perpetuated by JSpOC who provide conjunction reports, and access to the space catalogue to commercial operators for free. A commercial operation would require shifting the burden from ground sensors to space segment.

However if the general public do not understand the costs, nor the issues, of providing these services how do you incentivise people to behave in a certain way? What is required is to:

- Quantify the utility/value of downstream based systems, applications and services;
- Extrapolate the economic model;
- Identify the economic drivers; and
- Educate the general public of the issues and costs of space based services.

Militarisation of Space

Most space faring nations are signatories to the outer space treaty, which promotes the peaceful use of space and prohibits the use of weapons of mass destruction in space. However, Space is a dual civilian and military environment and therefore it is arguable that space is already militarised. Many of the proposed technologies/services being proposed are either dual use, or could be dual use i.e. if you are servicing a satellite you could just as easily disable one. Therefore the policy/treaty issues that need to be considered include

- What are the allowable dual use systems?
- Do we need guidelines on weapons testing in space?
- Civilian versus military control of space – who takes control when? Can you declare a space zone as military?
- Acknowledgement of capability
- Definition of weapon

Dual use

Many RSOs are, or can be perceived to be, dual use i.e. can be used for military or commercial purposes. The question remains do we need to distinguish and how could we distinguish dual use.

Do we define RSOs via their;

- Mission;
- Capability; and/or
- Architecture?

Can we determine a framework that looks at;

- Application or intended use? How would you prove intended use?
- Not-for-profit versus for profit?
- Military versus peace?

Does space tourism have an impact?

Is there a continuum to define i.e. pure military ←→pure civilian ←→pure science

Object ownership

The ownership of RSO is fairly clearly whoever launched it, with additional responsibilities for the nation that owns the launch. However there are instances where ownership can become less clear.

- When a RSO disintegrates, who owns the constituent parts? This is particularly relevant for hosted payloads and if you didn't see the object that hit the RSO it would be difficult to determine which pieces of debris belong to which original RSO.
- What happens to abandoned assets? What if the company that launched the asset no longer exists? Do/should salvage rights apply in space? Can you charge a RSO owner to remove debris on their behalf?
- If a piece of space debris is on a conjunction course with another RSO, who has responsibility to move? If another entity moves space debris to prevent a conjunction, under current rules whoever moves the debris is responsible for any subsequent impacts. If a satellite operator moves out of the way of debris can they seek compensation from the debris owner?
- Registration

Space Law

Policing

Enforcement

Resolution

Litigation/Arbitration

Unintended consequences

Interference

Regulatory Environment

Some nations believe that the space based actions of universities in their countries are not their responsibility, but the UN law is clear that nations are responsible for things launched from their country

The current pervading mindset is that if I can get to space, my responsibilities to the space treaty is met. Now that space is becoming crowded, should we now have additional regulations for responsible use of that object i.e. RSO owners must know where it is, where it is going and be able to control it.

Because of the services provided globally by JSpOC, satellite owner operators have never accepted full responsibility for their actions in space. They expect to be able to manoeuvre on orbit without needing to notify or gain concurrence from anybody else, and the industry needs to realise that it may not be sustainable.

Liability/Insurance

Liability and insurance for RSOs has not been practically assessed. Questions remain of who has liability if they hit? Currently if two objects are on a collision course, JSPOC advises of a potential collision but JSPOC does not ask people to move. Therefore, if no one moves and they collide there is no liability (act of god), if one manoeuvres and they hit, the maneuverer has liability.

In the Iridium Cosmos collision the probability of collision was low and within the risk profile of Iridium and nobody claimed anything from anybody subsequent to the collision. Therefore, what is the economic incentive on satellite operators? Certainly Insurance for their satellite and also third party to pay for damage inflicted by the object

Does it change if space travel is implemented? Does insurance equation become more prevalent? When the first insurance claim comes in do we expect the other actors to respond?

How to track

Cubesats are proliferating due to their cost and utility. However they are difficult to track, and are generally similar in size and shape, making it difficult to discriminate. Therefore what is the best way to regulate cubesats? Bigger ground sensors are not the answer due to the expense, but it could be possible to track them via an ADSB, wireless, or RFID type solution. The solution would need to be inexpensive and low weight due to volume of cubesats being planned, to keep the costs low and to ensure the cubesats don't grow in size incommensurate with the utility of the proposed regulated systems. The ability to range in quickly, determine an orbit, and then discover salient details about the cubesat reduces the STM problem remarkably. A legitimate operator may be willing to invest in tracking devices so their business is uninterrupted, leaving authorities to focus on rogue RSOs.

On-orbit manoeuvres

On-orbit manoeuvres currently occur without the need to consult widely with other space actors, some of the issues to consider include:

- How much will imposing standards affect what we do in space operations?
- How can we spot a problem early enough for small corrections to be made before there is an issue?
- We don't care if a cubesat hits debris, we care if cubesat hits a big satellite and causes damage
- In maritime the smaller vehicle needs to move out of the way, but in space the larger vessel only has the ability to manoeuvre
- We need to be able to assess trajectory to ensure on-orbit manoeuvres will not create harm
- Satellite operators need to have flight plans and share flight plans to be able to handle

Future model principles

It was generally agreed that the new model must:

1. Avoid collisions between RSOs
    a. Continuity of ops service
        i. reduce collisions as collisions produce debris,
        ii. make additional launches possible
    b. Economical – know when you must move
    c. Actionable
2. Optimises use of space
3. Share workload and benefit – not one actor can do it all, must have trust
4. Preserve access to space

5. Be a complete STM capability
    a. It enables environmental awareness
    b. Catalogue is info core – catalogue is technical and can be improved easily
    c. Management is where you will run into issues, i.e how to use the catalogue ⍰ need agreement on outcomes and rules to achieve those outcomes
    d. Need an agreed framework (similar to ICAO) in place. Need fundamental cross party alignment?
    e. Decision support tools versus surveillance
6. Maximum use of existing systems and coordination of agencies

Technical areas for development

Space environment and Astrodynamics

To determine the effect on RSOs the following environmental factors need to be measured and predicted

- Space Weather
- Ionospheric conditions
- Gravitational forces
- Atmospheric density
- Micro-meteorite flux

To assist in gathering and distributing space environment data the following items should be considered

- Hosted space environment payloads
- Shared telemetry between satellites
- 'crowd sourcing' of data

Once the data is gathered it needs to be analysed and algorithms develop to assist with orbit determination and propagation.

Space Operations

To enable more effective space operations, we need to better understand what's currently up in space via the following research areas:

- Debris/not debris classification
- Cooperative and non-cooperative
- Cooperative model for self-classification
- Completeness of catalogue

We then need to know where it is headed, and understand if that is normal or abnormal using the following research areas:

- Orbit propagation and forecasting
- Space behaviours and patterns of life
- Cooperative planning and monitoring
- Non-cooperative determination by data
- Object resolution and discrimination

Then consider what the best way to solve the problem is?

- Space vehicle autonomy versus STM automation
- Many-on-many conjunctions
- Rendezvous and proximity operations (RPO) with respect to debris removal and satellite servicing

Finally we need to explore further how this works in practice i.e.:

- Authority to 'instruct' to move or 'advise'
- How does that affect liability?
- Will accuracy be an issue? Can you develop statistical models of probability
- Burden of proof: "beyond reasonable doubt, "balance of probability" "best effort"

Debris Remediation

Explore the different methods of debris remediation including

- Active debris remediation - development and testing of removal techniques
- Just-in-time conjunction avoidance
- "hardened" satellites
- Constellations – such that there could be, multiple satellite failures due to debris that don't affect the performance of the overall constellation
- End of life protocols
    - Alternate orbits
    - De-orbit systems
        - Post mission satellite removal – i.e. balloons, tethers
        - Standardised attachment to link to de-orbit system
        - Common standardised de-orbit systems i.e. solar sails
- New materials for reduced debris generation over time
- On-orbit servicing
    - Mission life extension
    - Ability to meet post-mission disposal requirements

Sensing Modularity's & Sensor Systems

- Thermal IR for SSA characterisation and daytime work
- Multi-wavelength data fusion – hyperspectral identification and polarimetry
- Detecting smaller an dimmer objects
- Sensor hand off, cueing, cross-cue
    - Mixed sensor modularity
    - How do you optimise for performance, cost and risk
- On-board ID, cooperative position reporting
- Data models to report/store details
- In-orbit sensor i.e. for small debris population and evolution
- Low cost LEO

Information management

- Probabilistic reasoning
- Data driven ontologies/taxonomies
- Data provenance, standardisation
- Protocols (policy, tech) for sharing
- Catalogue(s) and alternatives

- Info- theoretic sensor networks/tasking
- Info fusion models – hard and soft inputs
- Data reduction via creation of information
- Archiving at what level? Are there legacy issues? Who?
- Visualisation – what are we showing to who?
- Who owns the data? How does trust and verification work?