

SpaceOps-2023, ID # 509

Spacecraft Operations: Working in an Unsecure World

Mark Loveday^{a*}, Stephen Jones^a, Lina Cirtautaitė^a, Paul Collins^a, Lorenzo Arona^b

^a *Spacecraft Operations Centre, Avanti Communications, Goonhilly Satellite Earth Station, Goonhilly Downs, Cornwall, TR12 6LQ*

^b *Spacecraft Operations Centre, Avanti Communications, One Ariel Way, White City, London, W12 7SL*

* Corresponding Author

mailto: <name>.<surname>@avanti.space

Abstract

Avanti Communications is a leading provider of Ka-band satellite data services in Europe, the Middle East and Africa, controlling a fleet of geostationary communications satellites from our Satellite Operations Centre (SOC) (Fogg et al. [1]). Avanti has grown from a small start-up to a fleet controller capable of performing routine and non-routine operations safely (Arona et al. [2]). This paper discusses the challenges we faced and overcame maintaining safe and secure satellite operations during the COVID-19 pandemic of 2020/21.

Avanti's recent experience in adapting our concept of operations is directly relevant to new and growing satellite service providers. Avanti has built a flexible, scalable operations infrastructure for its fleet of Ka-band spacecraft along with a new concept of operations that requires a core number of operational staff to be working on-site and socially distanced from each other. Our experience of enabling operational support functions – Spacecraft Engineering, Ground Systems, Payload Management and Flight Dynamics – to move rapidly from on-site to remote working means that we understand the kind of issues that are inherent in operating a profitable, efficient satellite service with 90% of the staff working remotely.

Avanti's concept of operations originally focused on all staff being on-site, working in secure areas to meet our requirement for safe and secure satellite operations. Whether this was “business as usual” activities – execution of flight operations procedures, software, and database upgrades - or non-routine operations – spacecraft relocations and disaster recovery.

Avanti followed best practice, as defined in the 2010s, during the design and build of the ground control system infrastructure with strict remote access controls for administrators. This infrastructure was found not to be ideal in early March 2020, as Avanti was required to move more operational support staff to working from home while maintaining the customer services availability service level agreements (SLA).

The rapid migration of ground control system infrastructure to a design that can support more remote than local staff, whilst not increasing the threat and vulnerability of the system, required a solid vision and determination to achieve, with many challenges encountered along the way. This paper will examine the issues faced and how Avanti overcame them, with a focus on satellite operations. The priorities this paper will look at are:

- Maintaining the Confidentiality, Integrity, and Availability triad of the ground control system infrastructure to ensure safety of flight for all spacecraft in the Avanti fleet and adjacent operators.
- Development of the Avanti's new concept of operations.
- Managed handover between socially distance on-site staff.
- Maintaining effectiveness and moral of teams working remotely.

The paper will also examine the future path for Avanti, as remote working is now the normal rather than the exception. The path towards this involves an increase in the understanding of the threats to satellite operations and the vulnerabilities in the system during the requirements and design phase of the satellite control software and network infrastructure. Along with automated trending and machine learning to improve the monitoring of system behaviour.

Keywords: (Satellite Operations, Remote Working, Cyber security, Cyber compliance)

Acronyms/Abbreviations

CAB	Change Advisory Board
CDR	Critical Design Review
CIA	Confidentiality, Integrity, Availability
COC	Customer Operations Centre
EBITDA	Earnings before Interest, Taxes, Depreciation, and Amortization
ECSS	European Committee for Space Standardization
FD	Flight Dynamics
GS	Ground Systems
HYLAS	Highly Adaptable Satellite
IDS	Intrusion Detection System
ITAR	International Traffic in Arms Regulations
KPI	Key Performance Indicator
LEOP	Launch and Early Orbit Phase
NOC	Network Operations Centre
PDR	Preliminary Design Review
SCR	Satellite Control Room
SCT	Spacecraft Control Team
SLA	Service Level Agreement
SOC	Spacecraft Operations Centre
SOE	Spacecraft Operations Engineering
SOM	Satellite Operations Module
T&V	Test and Validation
TRL	Technology Readiness Level
VPN	Virtual Private Network

1. Introduction

In recent years, Avanti has undergone a significant change to the infrastructure that supports spacecraft operations by the Satellite Operations Centre (SOC). Avanti's first steps into spacecraft operation was the transfer of the control of Avanti's first two High Throughput Satellites (HYLAS 1 & 2) from a third-party operator to "in-house" operations. This was followed a year later by the launch of HYLAS 4, when control was passed from the manufacturer's LEOP team to the SOC once the HYLAS 4 spacecraft was on station.

To control our fleet from the Satellite Control Room (SCR), Avanti procured a capable Mission Control and Automation system based on ESA's SCOS-2000. A Mission Control System with high TRL and flight proven on European and US spacecraft platforms. Thus, the legacy of the evolution of the software products and operating system used by SCOS-2000 had an influence on the operational architecture design of Satellite Operations Module (SOM) during the Preliminary Design Review (PDR) and Critical Design Review (CDR). As is often the case, during the development of any software product there is always a trade-off being made between user functionality and security. Often cost, ideas and beliefs about threats and vulnerabilities at the time of development is the driving factor behind the balance of Confidentiality, Integrity, and Availability (CIA) of any system.

Unfortunately, these systems, as a necessity, have a heavy focus on functionality and cybersecurity consideration is often a by-product of attempts at safeguarding the space system from failure and not any malicious intent (Oakley [3]). For the Avanti Ground System, the balance between functionality and security tipped towards the boundary of the SOM having the greater security focus over functionality. Whereas, inside the SOM it was functionality over security. At the time of the procurement and integration of the Ground System, the idea and belief that it needed to support members of the operational teams working from home for any length of time would have been fanciful.

The COVID-19 pandemic in 2020/21 changed that belief over-night and Avanti had to create a digital transformation roadmap for the SOM to ensure that it could deliver on its business commitments in this "new normal" of remote working. Our experience in adapting our concept of operations and SOM infrastructure to survive and thrive in the "new normal" is directly relevant to legacy and new space operators. Avanti has taken a flexible, scalable operations centre, born on the legacy of the Space Age in the 1960s towards one that can support the remote and hybrid working model of the future.

2. Ground Segment

2.1 *Managing the Change*

The need to implement government provided social distancing guidelines meant that the Satellite Operations Module (SOM) now had to support all spacecraft operations teams activities from their homes. As the changes to the Satellite Mission Control System would have to be undertaken in as short a time as possible, Avanti was not able to directly follow standard software change methodologies defined by the ECSS Software Engineering Standard but to adapt them to a more agile approach.

Early on in this change process, Avanti made the choice to exploit the existing design of the SOM network rather than deploying new technologies. This meant that Avanti has able to lean heavily on the knowledge that had been accumulated by members of the Ground Systems and Network teams, and the information collected in the ITIL compliant ticketing system.

Since the transfer of satellite operations to Avanti, in March 2016 (Fogg et al [1]), the SOC managers have generated a weekly KPI report. The data that feeds into this report has been extracted from the ITIL compliant ticketing system and each manager is responsible for supplying the data related to their own team. The KPI report itself is a set of charts showing change of the selected data over the previous 52 weeks and is not onerous to generate, if the manager's team has created and updated the tickets as they work. To ensure this, the process to deliver the KPI report to senior management has been kept as a manual task – save as pdf file and email - shared between the SOC managers. But rather than a rota, a game of 'Last One Standing' has been initiated. Whereby the manager who supplies their data last, takes responsibility for the delivery of the KPI report. This kept the data contain in the tickets up to date and relevant, and thus was an important source of information for this critical change.

Avanti's Change Advisory Board (CAB) process is used to communicate and record all changes that are applied to the Ground Control Systems, a forum where an engineer reports a planned change to representatives of the other SOC operational teams. The purpose being to eradicate unplanned service impacting changes on the production environment. An engineer proposing a change is required to demonstrate that it is planned and communicated to all affect parties, that the risks are understood and where appropriate have been mitigated, and that the technical resources and skills required to perform the change are available.

When the CAB process was initially rolled out, the focus was on availability of a service and how a change would affect that availability. The thought process by the engineers – presenter and attendee – was on whether a change would result in a penalty on a SLA for a given service. Engineers would probe and question the planning and mitigation proposed in the change to ensure that the risk to the service was as low as possible and fully understood. There was little time or thought given to the threat and vulnerability of the system and to how these would be affected during the change or after the change had been applied.

In October 2015, the chief executive of Talk Talk (K Ahem [4]) received a ransom demand associated with a cyber-attack that the company had suffered. The outcome of this news story brought the issue of cyber-attacks to the attention of many. With this new awareness of cyber threats to Avanti's digital infrastructure, the CAB process was updated to include an assessment of threat and vulnerability for any proposed change.

With up-to-date information in the ticketing system and a CAB process that has threat and vulnerability analysis ingrained, Avanti's SOC had the foundations on which to implement a significant change to the existing design of the SOM network.

2.2 *Implementing the Change*

The key to understanding how the Ground Control System could be adapted to meet the requirements of four teams within the SOC, was to consider what access controls already existed for each team.

2.2.1 *Spacecraft Controllers Team (SCT)*

The role of the SCT is providing 24/7 satellite control and monitoring, Access control for members of the SCT is primarily a physical control, where each member of the team has a smart card that allows individual access into the SCR. Once in the room, the SCT has full access to the operational workstations. These workstations are configured to support Avanti's fleet of spacecraft by a single operator working on a 12-hour shift for nominal operations (Fogg et al [1]) and for non-nominal operations the number of operators required may be increased to two (Arona et al [2]). At the end of each shift, monitoring and control of Avanti's fleet is handed over to the next member of staff on the SCT shift rota.

2.2.2 *Flight Dynamics (FD) Team*

The role of the FD team is providing orbit determination and propagation and manoeuvre planning. They primary work office hours, with additional out of hours support for non-nominal operations. Access control for members of the FD team is physical control, where each member of the team has a smart card that allows individual access into Avanti's office space and password-based authentication on their individual workstation located in that office space is then applied.

2.2.3 Spacecraft Operations Engineering (SOE) Team

The role of the SOE team is providing engineering support, including planning and analysis of operations and long-term trending. This team works office hours (same as FD team) and covers the out-of-hours on call service. Access control for SOE team is the same as the FD and SCT teams because their role requires monitoring of spacecraft operations alongside the SCT during periods of non-nominal operations and access to workstations connected to the Training and Validation (T&V) chain. This chain is an identical copy of the operation chains and is used as a reference engineering model for the verification of software and procedure changes.

The T&V workstations are in a separate room that is essentially a copy of the SCR, but with the additional capability to access the Dynamic Satellite Simulators (DSS) provided for all spacecraft within the Avanti fleet.

2.2.3 Ground Systems (GS) Team

Remote access control via SSL VPN tunnels was already available to GS team, as their role requires administration of equipment located in data centres that are not in the same geographical location as the member of this team.

Given the access control and operational requirements, it was clear that the SCT could not work away from Avanti's office space. To replicate their system at home would be nearly impossible, given the amount of infrastructure that would be needed at each member of the SCT's home. Furthermore, to support the availability requirements using a home broadband setup would require two operators to be on-shift 24/7 rather than the nominal single operator. Thus, Avanti needed to remove all face-to face interaction between members of the SCT at shift handover and periods where the SOE team needed to support non-nominal operations.

For the FD and SOE teams, their physical access control needed to be replaced with a solution like the GS remote access control in order to allow the remaining members of the SOC to perform their roles from home.

2.2 Mitigating Threats

These changes to a space ecosystem will lead to changes in the threat actors trying to attack a space system (Bradbury et al [5]). Thus, Avanti deployed a set of systems for intrusion detection and prevention within the SOM network rather than at the boundary, thereby changing the cyber defence strategy of the SOM network to state akin to a concentric castle rather than that of a single high defence wall.

Avanti's approach to the intrusion detection and prevention is foremost to prevent access to the SOM network and then to detect non-nominal behaviour in the network.

2.2.1 Prevention

The process of prevention is to deter and block access to unauthorised users, which for the SOM was the remote access SSL VPN.

The URL of the SSL VPN into the SOM network is the outer wall of Avanti's SOC cyber defence. A member of the SOC is informed of the URL and requested to initiate a connection via the home broadband service rather than from inside the corporate network. Thus, requiring the Network team to move the DNS record from inside the enterprise onto the public internet, a change which would make it visible to internet-based search tools. To make it that our URL did not stand out from the crowd, all references to the term 'vpn' and/or 'remote' were removed from the URL and replaced with an arbitrary noun. Those that are authorized access to the SOM, would be informed of the noun to use as a prefix on the base URL for remote access into the SOM. A threat actor searching for a remote access point to exploit would be less likely to be stumble across the correct URL and would be required to apply a "war dialling" attack on all of Avanti's DNS records.

The next wall is the authorisation policy on the SSL VPN device, where a valid user is required to supply a username, password, and one-time password to gain access. All valid users of the SOM SSL VPN would authenticate themselves on a corporate laptop. Avanti's IT policy is that only laptop supplied by our IT department are allowed to access the corporate LAN whether in the office or from a remote location. When a laptop is issued, the IT department record several metadata parameters about the laptop against an asset number. This is a valuable source of information, that can be queried by an SSL VPN device when any machine connects. Thus, Avanti was able to use

this information to block access to laptops that are unknown. Displaying the SSL VPN login page only to those machines issued by the IT department.

Once a valid user had gained access to the SOM, their role within the SOC would determine how and what they could access. Thus, if an engineer required access to a specific workstation using a remote desktop application, that is what would be granted.

2.2.2 Detection

The process of detection is to be alerted to non-nominal behaviour within the SOM network or action by an authorised user.

Avanti already possessed expertise in a cyber AI detection system within the corporate IT department, This cyber AI service could map a system and build a database of normal behaviour. Thus, Avanti deployed this AI system in the SOM network to build up a picture of normal behaviour as the system was used by SOC teams. When these AI systems start that will inevitably raise several alarms, which when investigated are flagged as false positives. By using the T&V chain to perform standard operation activities, this can help to build a picture of normal behaviour and thus reduce those false positive alarms.

To detect non-nominal behaviour by an authorised user the GS team deployed decoy user accounts and a host IDS on all servers in the SOM. Syslog messages were then flowed to a centralised log server, which then analysed the messages in real-time for non-nominal user behaviour and alerting when detected.

3. Concept of Operations

By March 2020 the UK government had triggered it's stay at home policy, due to the COVID-19 pandemic, but Avanti had anticipated this possible outcome by the splitting of all operational teams into two groups – A and B – a month earlier in order to minimise the possible transfer of the virus between all members of the teams with the same functional role. The loss of all members of a team, would create a significant non-cyber threat to the integrity and availability of that team's function, which in turn would lead to further integrity and availability problems for the other operational teams. As all manual tasks and the monitoring of automated tasks by the loss of an operational team would stop until such time as a member of the team was able to return to the office. During this period, it would have created additional overhead on the remaining staff to pick up these tasks which can easily lead to incidents caused by human-error. A situation that is known to be exploited by cyber criminals.

When the 'stay at home' policy was announced, Avanti was not able to immediately move all spacecraft operational staff to a 'work from home' scenario. However, it was able to do this with the COC, NOC, and support staff (IT, HR, Finance, Legal), because 6 months previously Avanti had rolled out a high throughput and bandwidth corporate VPN solution and replaced its PBX solution with a VoIP solution. Thus, over a 48-hour period, staff working in these functional areas could just take their assigned IT equipment home and set up there with little disruption to business continuity,

With the number of staff required to attend the office space reduced, it allowed staff to spread out across the desk space available and thus comply with the social distance criteria. The decision to locate our primary Satellite Operations Centre at the Goonhilly Satellite Earth Station in Cornwall, UK (partly because of its remote location (Fogg et al. [1])) also helped to minimise personal contact. In addition, the Avanti staff assigned to satellite operations were travelling to and home the office by their own personal vehicles rather than public transport, thereby avoiding a high-risk environment for spreading any contagious illness.

Fairly soon after the announcement by the UK government, Avanti was able to procure an electronic office booking application and COVID-19 testing kits for its primary and backup operational centres. With these assets, Avanti implemented a new procedure for staff whose functional role required them to access the office space. At all operational centres, a room close to the entrance was assigned as a COVID-19 testing interlock ("Mantrap") and a new access procedure was implemented which required that every member of staff scheduled to be in the office was certified as 'well enough to work', by:

- Checking that no one in their group was already in the office.
- Booking in on the office booking application.
- Taking a COVID-19 test in the assigned testing area.

For a negative test, the member of staff was then able to go about their business following socially distancing guidelines. If the member of staff had a positive test, they could then escalate to their line manager and HR and then vacate the building, along with signing out of the office booking application. In such a scenario, Avanti would then be able to check the booking application to see if the positive member of staff could have infected other members of

staff if they had attended the same office in the previous 5 days. Subsequently, notifying them of the possibility of contact with someone that has tested positive for COVID-19.

With these process and procedures in place, the cleaning team could be notified immediately that additional cleaning is required, and the satellite operation managers could adjust shift plans to minimise further possible exposure to other members of staff.

There were a few teams, mainly the 24x7 functions, that were unable to work remotely. Partly due to security risk and integrity of the control system used, but also down to the risk of loss of connectivity during critical commanding activities. Consequently, Avanti had to devise a safe system of working that protected staff from coming into direct contact with each other. A remote handover process was also introduced whereby the oncoming shift member would ring into the office from a second clean office for the verbal handover. Additionally, not only would the off going worker carry out their normal clean down of all workspaces & consoles, but this would then be repeated by the incoming worker. The expectation being that should an area be missed during the clean it would be covered by the second clean. However, it was later noted that it was not possible to power down the consoles meaning that the keyboards/mice could not be satisfactorily cleaned. Avanti subsequently procured individually issued keyboard covers sufficient for all workstations per person to mitigate further against infection transmission.

4. Remote Working

Avanti Executive Committee was very conscious that remote working could leave staff feeling isolated, so to combat this they set up several initiatives to get as many employees together on as regular a basis as possible. These included fortnightly all hands meetings where the CEO would brief all personnel on Covid updates around the Avanti areas of operations and comparing how different governments chose to protect its populations against the spread of the virus. These would also be used for discussions and interviews with inspirational personalities, including both individual and team sportspersons, injured veterans, TV personalities and other company CEOs to name but a few. These interviews would be used to give staff an insight into coping mechanisms that could be used to improve wellness during the periods of isolation etc. Other inclusive activities were inter-department quizzes, which introduced the requirement of dispersed departments having to get together in various online meeting rooms, thereby encouraging interaction and ultimately ‘teambuilding’.

Avanti took a very high interest in the welfare of remote staff and in addition to the Executive Committee led activities, Avanti also provided staff with the opportunity to take part in professionally led wellness sessions and/ or active challenges, including daily squat challenges, weekly and monthly individual exercise challenges or very early on before flour became scarce even the ‘Great Avanti Bake Off’.

In addition to the staff welfare and Executive Committee led activities, Avanti focused on staff professional and personal development, by providing an online learning platform to all staff. This web portal could be accessed in and out of hours for self-studying or for arranging a team training session.

Avanti did not put in place any system to monitor how many hours each employee would be actively working at the computer, also because the challenges associated to COVID-19 – like childcare – often caused employees to work less during nominal working hours, then continue working during the evenings and weekends.

While the company allowed for considerable flexibility, it also requested to diligently follow a pre-existing process of objective settings, monitoring, and review – usually in one-to-one meetings between manager and employee to be performed on video conference tools on a regular basis. This essentially allowed the company to run fair performance reviews of all employees, regardless of how much or how long they had worked as a remote worker.

The more challenging part associated with remote working was employee onboarding. While equipping a new employee with a corporate laptop and phone could be done in remote by shipping the items to the new employee home address, team building on a completely remote basis was a challenge.

In the case of spacecraft operations, all new employees must undergo a long, thorough, detailed and meticulous training before they are allowed to take full responsibility of the in-orbit assets of the company. Throughout lockdown, this proved to be a blessing in disguise, as the training would provide an excuse for daily interaction between new employees and more senior team members. The actual training sessions would consist of:

- Discussions about the physics of the space environment (on PowerPoint).
- Reviews of the satellite architecture and subsystems (on material provided by the manufacturer).
- Review of Avanti own’s policies, processes, and procedures, developed in-house (usually Word documents).
- Programming tutorials and familiarization with the many scripts and tools used to run analyses or post-process some output (usually Python or Excel).
- Actual operational duties (on the actual operational software), divided into:

- An operation run by the most senior team members on the operational platform, which the new employee would observe during a screen-sharing session.
- Or a rehearsal that the new employee would run on a Test and Validation platform, with the more senior team member observing in screen-sharing.

In Avanti's case, the duration of this training is usually four-to-six months in the best circumstances. When performed remotely, the duration tended to be a few weeks longer, mainly because new employees often felt they would prefer to repeat a few of the most challenging operations before feeling comfortable running them unsupervised.

The last part of this training would consist of operations shadowing, in which the new employee and a senior team member run the same operations independently and without interaction. Once all outputs are generated by both, these are compared by the two, and each difference is reviewed and justified. When the new employee can run all the fleet operations and generate output that are of equal quality of those generated by more senior team members, the new employee is included in the operational rota and takes shared responsibility of the fleet.

Throughout lockdown, this set of activities, often regarded as painstaking, provided the new employees with several opportunities to talk, interact, or even chat with other team members, easing the onboarding process.

Spacecraft operations management also started to search for more ways for team members to interact in constructive ways.

For example, whenever a team member would generate an output – coding a script, writing a procedure or technical report, running an analysis – the team leader would assign another team member to review it and 'play Devil's Advocate' before the output would be presented to management for final review and approval. This process created positive reasons for team members to discuss a topic, favoured knowledge sharing, and resulted in the overall quality of the deliverables to improve.

Another way the SOC fostered communication and collaboration among members has been to introduce objectives shared by more than one team member, ensuring that two or more members would have to work together to meet them. For example, team members would attend the same (online) training or webinar and would work together on illustrating the lessons learnt to the team and updating the team processes and procedures accordingly.

In the case of spacecraft operations, most duties can be performed by logging into a dedicated machine. The one notable exception is the actual spacecraft commanding, which needs to be performed in a restricted access facility because of ITAR requirements.

Because of this, once the SOM network had been configured and the role-based permissions had been granted to the SOC personnel, performing duties like operations planning and scheduling, operations monitoring and evaluation, anomaly investigation and reporting, change and problem management could all be performed as a remote worker.

It is worth noting that, at the end of the financial year, there was no evidence of remote working negatively affecting the EBITDA value reported by Avanti.

5. Conclusions

From our inception in 2002, Avanti has maintained its position as a leading provider of High Throughput Satellite data services across Europe, the Middle East and Africa. Whilst maintaining engineering rigor and following industry best practices the SOC has also adopted an agile and innovative approach to satellite operations, which has been embedded across all the teams. Our nimbleness and willingness to learn from others outside of the space industry is part of Avanti's success story. In this paper, Avanti has presented how the SOC adapted the satellite concept of operations and access control during and beyond the COVID-19 pandemic. This experience has highlighted the importance of collaboration between information security and operational teams throughout the Systems Development Life Cycle. By fostering a strong relationship between all subject matter experts, Avanti has been able to mitigate risks associated with an unimaginable situation at the time of the initial system design.

Avanti is committed to maintaining an agile and innovative approach to satellite operations and systems engineering to ensure safe and secure operations by our staff and of our fleet of spacecraft.

References

List of references

Reference to a journal publication:

- [1] M.Fogg, L.Arona and M. Loveday, “Spacecraft Operations: Defining the Avanti Way”, <https://doi.org/10.2514/6.2018-2444>
- [2] L.Arona, M. Fogg, M. Loveday, B.Wengemayr and I.Ituen, “Regulatory Constraints and Operational Best Practices to Ensure the Safety of Non-routine Space Operations”, https://doi.org/10.1007/978-3-030-94628-9_2
- [3] Oakley, J.G. (2020). Space Systems. In: Cybersecurity for Space. Apress, Berkeley, CA. <https://doi.org/10.1007/978-1-4842-5732-6>
- [4] Kamal Ahem, TalkTalk chief received email demanding money from cyber attackers, 23 October 2015, TalkTalk chief received email demanding money from cyber attackers - BBC News
- [5] M. Bradbury, C. Maple, H. Yuan, U. I. Atmaca and S. Cannizzaro, "Identifying Attack Surfaces in the Evolving Space Industry Using Reference Architectures," 2020 IEEE Aerospace Conference, Big Sky, MT, USA, 2020, pp. 1-20, doi: 10.1109/AERO47225.2020.9172785