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Operationally Responsive Space:
Past, Present and Future

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The Past

Where did the idea of Operationally Responsive Space originate? You might imagine that the idea was born during the First Gulf War, (sometimes called the First Space War), where use was made of strategic space systems to support operations. It was apparent, though, that strategic systems with very small fields of view and long revisit times were not well suited to operational reconnaissance. Other limitations of these strategic systems included a tasking system not suited for tactical timelines; significant data downlink requirements, making it difficult to deliver data into the theatre; a large in-theatre "footprint" for intelligence analysts; and lack of "command assurance" that the requested collection would not be pre-empted by higher national priorities, for which reason field commanders were unwilling to place reliance on them for critical operations. It is tempting to think that these limitations inspired system designers to conceive of constellations of smaller, more affordable satellites with wider fields of view.

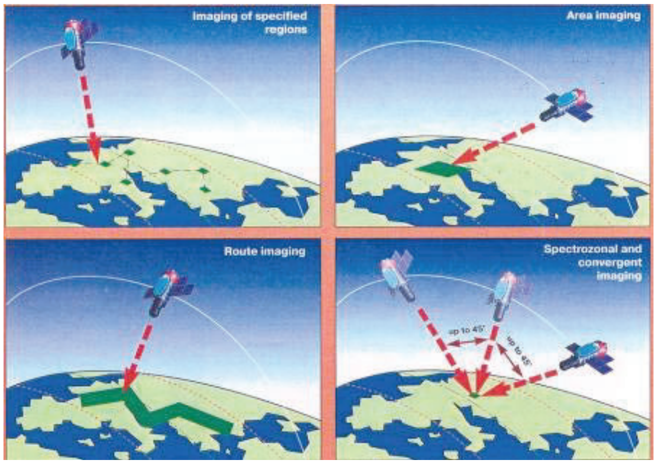
But in 1991, while the West was struggling to adapt the operations of its satellites to meet the demands of the conflict situation, the Russians were launching optical and RF surveillance satellites at an impressive rate. If the ORS programme does ever succeed in launching 18 low Earth orbit surveillance satellites in a four-month period like the Desert Shield operation, it will simply be emulating what the Russians achieved 20 years ago. In the same period in 1991, the West launched just one military mission, and had Russia chosen to engage in that conflict, it is clear which side would have possessed the "information edge". Analysts in the West quietly doffed their caps to the "operationally responsive" space programme in Moscow, who had comprehensively demonstrated a "Tier-2" launch-on-demand capability long before the concept was formally articulated in the West

And the Russians didn't stop there. In the mid-1990's they fielded a system called Arkon, which had an astonishing level of tactical capability. Placed in a high-altitude LEO, (with an apogee of 2750 km and a perigee of 1500 km), this large mission, (which would be considered a "Tier-1" asset in today's responsive space terminology), was able to deliver imagery with a resolution of better than five meters over enormous fields of regard. In the summer months, when the lighting in the Northern hemisphere was at its best, this single satellite could have provided between 8 and 10 images of a given point on the Earth's surface per day, and its high-altitude orbit would also have provided frequent opportunities for commanding and data dissemination.

The Russian Arkon Satellite

The Arkon satellite had a repeating ground trace, allowing it provide repeat coverage from the same point in space when required. This capability allowed the imagery from two consecutive days to be compared very easily, highlighting changes which would focus the attention of the analysts on areas of interest within the very large imagery scenes.

The Arkon satellite was large – it required a Proton launch vehicle to place it in orbit – but it was also agile. Illustrations released by the production organization in Russia showed at least four different modes of operation, including imaging of point targets, of areas, of lines of communication, and a mode in which the satellite could be trained on a specific location for tens of minutes if required.

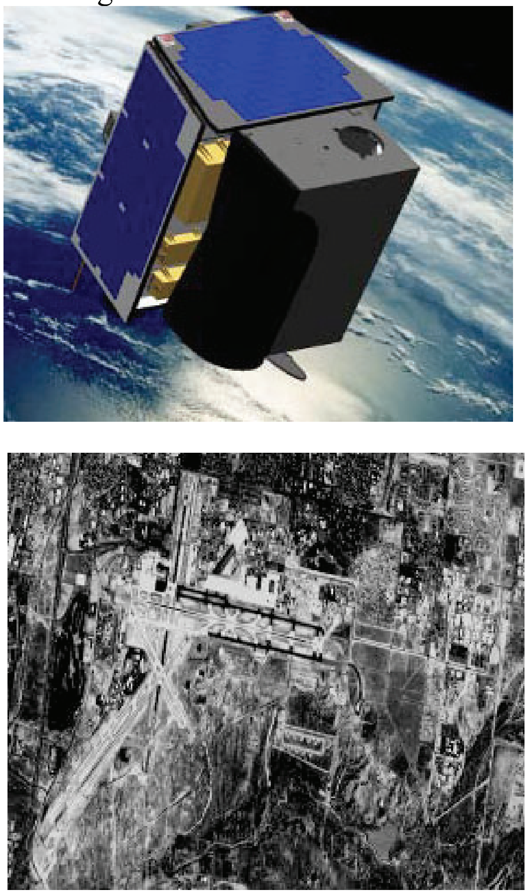


The Arkon Satellite's Operational Modes

Once again, analysts in the West doffed their caps!!

The Present

Tactically oriented satellites in the West have taken a different path, based on much smaller hardware, but it was not the United States who took the lead. Built in the United Kingdom, the TopSat satellite set a world record for "resolution per mass of satellite" by delivering better than three meter resolution imagery from a satellite platform weighing just 120 kg. For a satellite that cost less than $20m to build and launch, this mission set a new performance threshold. By the time TopSat was launched in 2005, the U.S. tactical space programme had commenced, and had assigned the designators TacSat-1, TacSat-2, TacSat-3, etc. Since TopSat preceded these US missions into orbit, collaborative experiments were conducted with U.S. researchers and TopSat was designated TacSat-0.



The TopSat satellite and one of its images of Kirtland AFB, NM

The specific technical trick that TopSat employed was to pitch backwards quite deliberately as it passed over its targets. This pitching motion slowed the effective ground rate of its sensor, allowing more light into the camera system, thereby getting close to the diffraction-limited performance of its 20 cm aperture telescope. This level of agility is only possible with small, rigid satellites. Large platforms are seldom capable of achieving the angular rates required; and generally initiate vibrational modes that demand significant "settling time" before acceptable quality imagery can be collected.

But TopSat's pitching trick permits two other advantages that are key to ORS. One is that, if deployed into a sun-synchronous orbit, the satellite is no longer constrained to a local time of ascending node close to noon. It is able to extend the range of local times of day when imagery can be collected by pitching through a larger angle; compensating for the comparative lack of reflected sunlight near the terminator by slowing the ground rate of its sensor still further. The other key advantage is that a satellite like TopSat is no longer constrained to operate in a sun-synchronous orbit. If a satellite is deployed into a lower inclination orbit, (to provide more frequent revisits over operational regions, for instance), it is inevitable due to the laws of orbital dynamics that it will pass over its targets at different local times of day. For a larger satellite, this might be a problem, but for TopSat it simply means selecting an appropriate pitch rate for the local time of day and the prevailing lighting conditions.

The low cost of the TopSat mission demonstrated the potential affordability of constellations of small satellites to provide significantly greater timeliness, but to date it is Germany which has exploited the constellation concept most effectively for military purposes. Germany now has two 5-satellite constellations at its disposal; the military SAR system, SAR-Lupe, and the commercial RapidEye optical imaging system. SAR-Lupe and RapidEye are specifically designed to operate as constellations with much better revisit characteristics. The RapidEye constellation is comprised of small agile satellites which can roll off-nadir, meaning that the constellation can provide imaging opportunities over the entire globe at least once per day. And the SAR-Lupe satellites are equipped with an intersatellite link system which enables the satellites to transfer commanding information when they come within view of one-another and thereby enhance the response time of the system.

In an ORS context, both these systems would be regarded as "Tier-1" capabilities, in that they are already "on-orbit". However, they differ from the assets that have traditionally been assumed to comprise Tier-1 because they are not strategically oriented, single satellites being pressed into service as inefficient tactical surrogates.

These systems differ philosophically from the missions in the TacSat and ORS programmes in at least three key respects:-

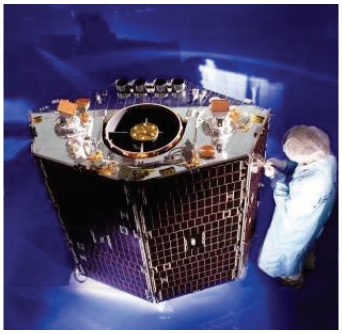
- Firstly, they are clearly designed to operate as part of a constellation, (which affects all aspects of the satellite design, including both the payload and the platform). By contrast, the U.S. systems have yet to clearly indicate the "objective systems" that might result if the TacSat and ORS experiments are deemed successful.

- Secondly, they are being used to support commercial and strategic applications whilst in orbit. It is arguable that one reason why the ORS programme in the US has not gained more momentum is that it is seeking to find funding for missions which, if only used over operational zones, are only going to be exploited for 1% or 2% of the time. Clearly the value for money from a satellite is greatly enhanced if it can also be used to support other missions, such as homeland defense; commercial collection; operational training; and the requirements of allies elsewhere on the globe.

- Thirdly, they are expected to be launched once constructed, rather than being held on the ground as a series of sub-systems. For a commercial system like RapidEye, there is clearly a significant "opportunity cost" involved in having valuable hardware on the ground rather than in orbit, and even in the case of a military system such as SAR-Lupe, the pace of change in small satellite design means that hardware can rapidly become technically obsolescent if kept in storage for too long, (which some might suggest was the fate of the original TacSat-1 payload)

Now it might be argued that it is very difficult to design a satellite that can be used to support all these differing requirements, and this may once have been true. However, sensor and payload technology has advanced to the point where the agility of small satellites can support a number of different modes of operation. The SSTL-300, which is due for its first launch in May 2011, is a prime example.

Some of these modes presume detailed advanced knowledge of the target regions, and so are more suited to strategic surveillance, whereas others cover larger regions and can provide support to operational and tactical missions. Moreover, the satellite is equipped with both wide area cameras and a high resolution camera on the same platform. This is analogous to the way that the human eye operates, with the lower resolution, wide-area "peripheral vision" cameras providing detection and cueing data for the higher resolution, small area camera that provides the high fidelity imaging.



The SSTL-300 imaging satellite

So where have the major successes of the ORS programme occurred to date? One of the principal achievements was the inclusion of both imagery and Radio Frequency (RF) surveillance sensors on the TacSat-2 mission. To extend the analogy with the human sensing system, this satellite had ears as well as eyes, and was therefore potentially capable of greater "self-cueing". (In practice, accommodation constraints and power budget limitations meant that TacSat-2 was not able to operate its eyes and ears simultaneously over the same region of the ground, but it certainly points towards the future.)

Another clue to the future is provided by the feedback from the TacSat-3 mission. Equipped with a small-footprint hyper-spectral sensor the satellite demonstrated the potential value of spectral imagery, if not the area coverage rate and timeliness required to support the warfighter.

The Future

As technologies continue to improve, the contribution that operationally responsive space systems can make to military operations will continue to increase. Charge Coupled Device (CCD) detectors now allow the imaging of far greater areas than was possible previously.

The image below shows the image footprint of a modern small satellite over Australia. The much smaller brown stripes across the continent are the footprints generated by the Landsat satellites at a comparable resolution.

A comparison of current and historical coverage rates

Clearly, the increased volumes of data generated by such sensors demand greater on-board storage capacities, and higher data downlink rates, but again the rapid pace of development in terrestrial computing technologies is providing a solution to these problems. In the case of the SSTL-300, the demand for greater downlink capacity is being addressed via the development of a steerable data downlink antenna system which can track a specific ground station with a narrow beam-width antenna, enabling the available satellite power to be concentrated into a smaller region and so deliver a higher capacity link budget.

And as the power of on-board computing increases, it will become increasingly common to process the imagery data on board the satellite, and downlink a much smaller image file, rather than transfer the raw collection to the ground – although the raw data could be downloaded if necessary.

And the nature of the connections available to transfer this data will also change. At present, the number of ground stations available to an ORS system is usually quite limited. This constrains both the speed with which the imagery data can be returned, and the overall capacity of the system, (since the number of times that the satellite's on-board memory can be filled and emptied on a given day will also be dependent on its access to ground station facilities).

Those downlink requirements are becoming more impressive all the time. An example is SSTL's Earthmappper system, where a constellation of 5 satellites, each weighing just 100 kg, now has the capability to image the entire landmass of the globe on a daily basis.

Essentially the satellites are "always on", and collect imagery whenever the mission is over the Earth's surface. The challenge is clearly to ensure that this valuable imagery is down-linked to the ground, and not trapped on orbit.

In the next generation, it is expected that the use of inter-satellite links will become increasingly common on ORS assets. Currently, such links are generally reserved for grand strategic systems, but the success of UAV's using satellite communication systems suggests that this will also become routine for satellites in the future. They are, after all, the ultimate high-flying UAV's, and some, (e.g. ORS-1) are even based on modified airborne sensor technology!

Another obvious solution to the downlink issue is to internationalize the ORS programme, providing the opportunity to access ground station facilities in multiple nations at different longitudes around the globe. A thirteen-nation MOU is currently in the process of negotiation, and this has the potential to start the process of creating the "Coalition ORS" concept which has been proposed previously.

Moreover, international collaboration between the United States and other nations already exists elsewhere in the space arena. One example is the use by the U.S. Government of leased capacity on Paradigm's Skynet 5 satellites, which were launched to provide secure communications for the UK MOD under an innovative procurement process which transferred significant risk to the contractor in exchange for a long duration contract. This arrangement establishes a precedent which could also be exploited in the surveillance domain if the UK elects to invest in a sovereign surveillance system. . The recently released U.S. National Space Policy and the DoD National Security Space Strategy both direct the use of coalitions where appropriate for both operational and geopolitical reasons.

As satellites have become essential to war-winning, they have increasingly become the target for anti-satellite capabilities – both in space and on the ground. Expect to see increasing efforts to protect satellites from such measures by the application of stealth technologies to the space vehicles and continuing efforts to harden the terrestrial networks and infrastructure against all forms of hostile interference. Augmenting existing satellite constellations with small satellites makes intentional or unintentional interference or denial of the overall capability more difficult. Additionally, integrating space and terrestrial capabilities can further enhance the overall resilience of the system, and although breaking down "stovepipes" is difficult, this is another possible medium-term development.

Conclusion

Finally and perhaps most importantly, small satellites can radically change the calculus concerning satellite lifetimes. Smaller, cheaper satellites simply do not have to last as long as large satellites in order to deliver the same value for money. As a consequence, it is logical to consider deploying them in lower, shorter-lived orbits, and this could modify the overall approach to ORS enormously. Satellites closer to the Earth require smaller apertures and less power, with the result that the missions can be scaled down to the point where they become candidates for air-launch.

These new technologies and new capabilities offer tremendous flexibility that will make the next generation of satellite constellations truly operationally responsive.