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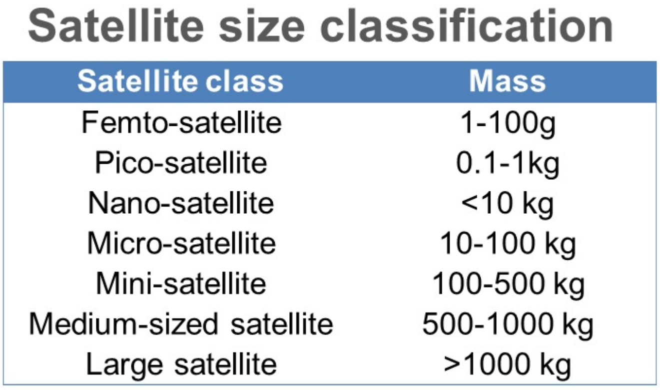
Nanosatellites: Enabling Technologies For Novel Mission Architectures

Dr Katharine Smith, University of Manchester

The subject was a topic in which most, and possibly all, attendees had no personal experience, so it was appropriate that the presentation began with an explanation of what constitutes a Nano-satellite. A tabulation of satellite classification revealed that the aerospace community has already accommodated satellites that range from what seemed to be little more than a postage-stamp with an antenna, to the International Space Station (ISS). To this commentator's surprise the latter (not as launched, but the part assembled in many stages) is a 420,000 kg (930,000 lb) mass leviathan. Even so, it has had a part to play regarding the launch of some nano-satellites – less than 10kg overall mass.

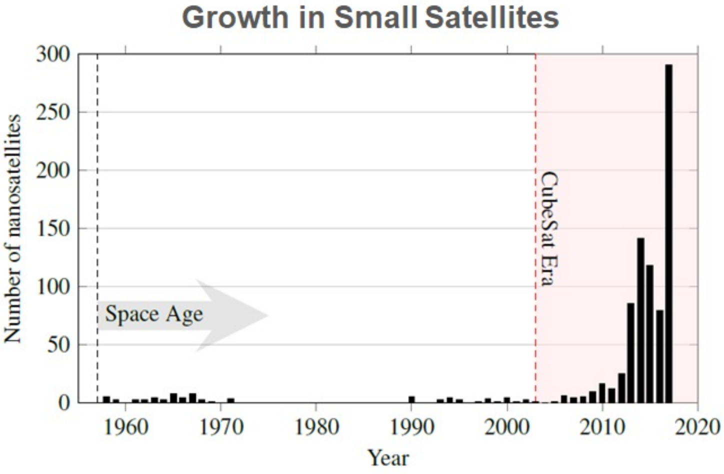

Satellite size classification

Satellite class	Mass
Femto-satellite	1-100g
Pico-satellite	0.1-1kg
Nano-satellite	<10 kg
Micro-satellite	10-100 kg
Mini-satellite	100-500 kg
Medium-sized satellite	500-1000 kg
Large satellite	>1000 kg

The adjacent tabulation lists the mass values applicable to different satellite classifications. Nanosatellites are likely to be stowed on a launcher dedicated to a large-satellite project, and carried in otherwise unused space around the primary payload. There is a payload launch cost, and orbital parameters must be compatible with the main payload.

A time-line graph reveals that 'small' satellites have been commonplace since the earliest days, with most early satellites (e.g.: Sputnik 1) having been only a few kilograms. In the most recent 15 years or so the 'piggy-back' technique has provided opportunity for small satellites. In addition to using otherwise wasted payload volume, these small satellites can be designed to fulfil scientific roles with sensors and transmitter antennae, be relatively cheap to manufacture, and thus useful for fundamental research programmes.

Nanosatellites are so small that they account for only a fraction of the overall payload mass put into orbit. The speaker has specific involvement in the development of components and systems that are unique to the genre, and provided a comprehensive overview of nanosatellite anatomy, technology and applications, both current and in prospect.



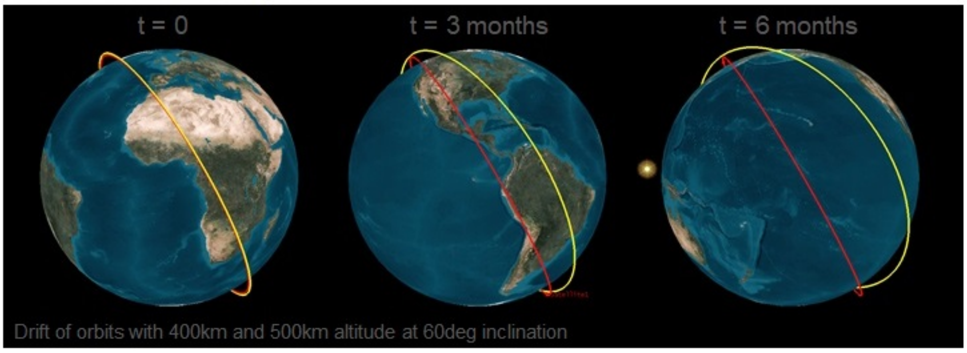
A 'nanosatellite' can be as small as a microchip and a simple antenna. However, most are larger and configured to have items essential to mission capabilities. Solar panels, in some cases extendable from the core unit, are often used, and sensors can take on numerous guises. Details are role-dependent, although most will have a data-transmission capability in order to convey satellite 'images' and/or specific sensor data.

Launch providers are willing to carry these 'small' payloads 'piggy-back' to the primary payload, provided they use designated volumes and can be launched with a simple ejection mechanism. Associated to this was the introduction, around 2017, of a common physical 'frame' for nanosatellites, and now referred to as the 'cubesat.' The baseline component is a rectangular module that is 10 cm × 10 cm × 11.35 cm (4 in × 4 in × 4.5 in). Within this systems must be accommodated, and antennae or solar panels can be extended after it has been deployed from the launcher. A 10kg mass satellite might use three modules combined to form a linear unit, 10cm square and 34.5cm long. There may be several on one launch provided they can be accommodated in the otherwise 'unused' payload bay space.

At the current time there are about 2,000 nanosatellites in orbit , of which 27% used cubesat modules. The proportion will increase over time. As each satellite is released a spring mechanism ejects it with a velocity relative to the main payload so that it will not interfere with the host's orbital path. An alternative launch platform is the International Space Station, and nanosatellites have been ejected from an attachment to an existing extendable manipulator, once again offering low-cost launch option. Again, a spring-based mechanism ensures each nanosatellite's orbit in dissimilar to that of the ISS.

Nanosatellites are being used largely in low-earth orbits (below 600km), a region where there is still some atmosphere. Although it is a very rarefied atmosphere the air density is sufficient to create a small 'drag' force. This causes the un-propelled device to dissipate energy and to lower its orbit. The time from insertion into orbit to when it will have slowed so much that it re-enters the earth's atmosphere (and is destroyed) can be as long as 25 years. However, it is considerably less in a lower orbit; below 500km its lifetime might be a year or less. The size and shape will also influence drag. There is no simple correlation with the drag estimation processes used to estimate aircraft performance, but researchers are gathering information from observed nanosatellite orbital decay rates and are developing a capability to predict individual nanosatellite life-times.

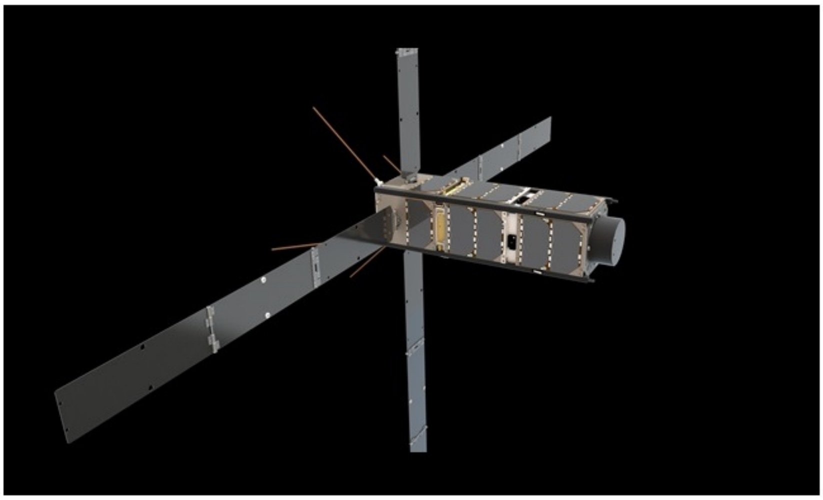
Distance above the Earth's surface determines the orbital velocity and orbital period, and there are other parameters that have a large influence on what can be achieved in various applications. These were described and illustrated using animations (pictures worth a thousand words) They cannot be incorporated here, so a simple summary must suffice.



Orbital drift due to nodal precession

An orbit will be at an angle relative to the earth's equator. The extreme cases are equatorial (0°) and polar (90°), but the majority of launches will be at an intermediate angle. This is the orbital **inclination** – e.g: 60°. Keeping to a low-earth orbit, the time taken to complete one-orbit is about 90mins. As the Earth's rotates the satellite does not return over the same place as it completes each orbit. An asset for all satellites is that, at some time, all of the earth's surface, between limits set by the inclination, are overflown (at 60° inclination that would be 60°N and 60°S latitudes). However, because the Earth is not a perfect sphere there is a dynamic consequence: an orbital drift referred to as **nodal precession**. The above diagram shows a typical outcome, the orbit shifting gradually over time: the diagram shows orbit location at insertion (left) and 3 months and 6 months later.

Animations were also used to illustrate how numerous satellites (up to 50 is typical) with common orbital parameters can be spaced to create 'halo', 'space-ball' and 'figure 8' configurations. This is all related to the physics of orbital dynamics and is achievable without complex manoeuvring or flight controls. The actual location of any satellite can be tracked, and its future position predicted with considerable confidence, and the orbital configuration chosen in any application will be determined by mission criteria.

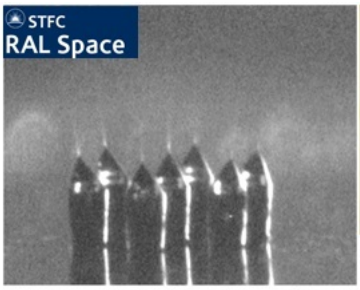


SOAR – Satellite for Orbital Aerodynamic Research (University of Manchester)

The University of Manchester plans to launch a nanosatellite – named 'Satellite for Orbital Aerodynamic Research' (SOAR) – in the last quarter of this year (2020).

Based on three 'cubesat' units, it has solar panels, deployable fins which will be used to test aerodynamic control of satellites in very low earth orbit (VLEO), and numerous sensors. It will be in a low earth orbit for several years. The launch date, and definitive orbital parameters, will be dependent on the requirements of the host payload.

Current Nanosatellites cannot manoeuvre as their size does not provide space sufficient to install even the simplest conventional propellant-based powerplant. However the speaker described research into the electrospray (ES) process from her studies, when interest centred on terrestrial roles, mainly associated to precision engineering. As the name suggests, electric charges are used to create a 'spray' of atomic-scale ionised particles. The spray can be generated from a very small space, and the process generates a minute force.



7-Array electrospray [1]

Breadboard MEMS ES thruster [2]

ES is potentially relevant to nanosatellites as a candidate to meet the mass, space and dynamic requirements of a simple nanosatellite propulsion system. Studies have suggested that the electrical power needed to create a thrust sufficient to influence a nanosatellite's trajectory may be compatible with the energy supplied by solar panels.

If it is able to oppose, partially or wholly, the minute drag force that a nanosatellite experiences it would improve our understanding of the drag forces in such a tenuous region of the atmosphere, and could contribute to extending mission durations. Dr Smith was clearly aware of the need to progress with caution, but with ES technology research in her portfolio any opportunity to research ES and nanosatellite compatibility seems assured to be a leading component of forthcoming studies.

The presentation attracted about 100 attendees and revealed examples of technology in the making. It delivered a strong message that there are no limits for those with a pioneering spirit. In the future, those of us that attended may be less astonished than many others if the heralded concept, described to us on this day, that space ships of the future will be propelled without chemical fuels, comes to be. The enthusiasm and novel thinking revealed is appreciated, and long may such visionary research be supported and prosper.

Lecture notes by Mike Hirst