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SPACE-BASED VERIFICATION: *PAXSAT A* THEN AND DEVELOPMENTS SINCE

Developments in the 1980's leading to the *Paxsat A* Study

1. In the early 1980's the former Soviet Union was deploying newly developed intermediate-range ballistic missiles armed with nuclear weapons in Eastern Europe. The United States responded with similar deployments within Western Europe. The former Soviet Union had also long been testing land-based, co-orbital anti-satellite systems with fragmentation warheads. A US air-launched, direct ascent, kinetic kill vehicle was also undergoing development for a first test flight in 1985. Concomitant with these developments were the US and Soviet efforts to research and develop space-based versions of anti-ballistic missile defences predicated on the “other physical principles” allowances provided for under the bilateral US-USSR Anti-Ballistic Missile Treaty of 1972. It appeared to many then as though the world was about to embark on another new quantitative arms race and this time it would be in outer space.

2. Multilateral arms control agreements had also been successfully negotiated by the 1980's however to deal effectively with security challenges, including in outer space. If a comprehensive arms control agreement for outer space was going to be agreed by the Superpowers in the 1980's, it was going to have to meet several conditions. Firstly, it would need to be equitable: one State Party could not possess a developed capability, such as a tested anti-satellite system, while another State Party was prohibited from developing a similar capability. Any prospective treaty for banning weapons from outer space was also going to have to be in the national security interests of all of the State Parties of the agreement, including the two most powerful nations of the era. Consequently, the verified absence of weapons in a universally subscribed treaty would have to present a less risky

proposition for national security than national reliance upon an imperfect defence of actual weapons deployed in that domain. Lastly, any treaty of the era for outer space would have had to have been effectively verifiable. Prior to the Intermediate-Range Nuclear Forces (INF) Treaty of 1987, the former Soviet Union would not accept on-site inspections as a part of any negotiated arms control agreement. Consequently, in the 1980's, any proposed space-based weapon ban would have needed to have been verified by remote sensing systems as opposed to pre-launch inspections methods - almost perfect “choke points” - to verify an arms control agreement for outer space. Thus the need originated for the concept of a space-based verification system that would use artificial satellites to determine the function of other space objects.

3. The “*Paxsat A*” concept - a contraction for “Peace Satellite” - was developed by Canadian diplomats and industrialists to verify international agreements banning weapons from outer space. The *Paxsat A* study - A Study of the Feasibility of a Spacecraft Based System to Determine the Presence of Weapons in Space - asked a fundamental question, “Can space observations determine the role or function of an object in space?” The answer was a qualified yes. To see how this conclusion came about it is first important to understand the advantages that outer space can provide for a number of useful functions and the orbits that are used to execute these specialized missions.

On Basing Weapons in Outer Space

4. Outer Space can afford platforms operating there several advantages over their terrestrial counterparts. A satellite can provide a view of the whole Earth and it is therefore said that it has a global reach. Outer space is also a domain where the freedom of access is assured by the Outer Space Treaty of 1967. The passage of military forces on the Earth require the permission of the state exercising jurisdiction or control over the territory concerned. As outer space is not subject to national appropriation, no prior permission for the use of outer space needs to be sought from any other state, on the understanding however that outer space will be used in conformity with the rules set out in the Outer Space Treaty. A third advantage for operating in outer space occurs because a platform could present a rapid response to address time critical targets of opportunity on the Earth or in outer space. Ballistic missiles, cruise missiles, aircraft, vessels and vehicles can all require a considerable amount of time to reach an intended target on the Earth from their deployed operating stations. Finally, for many orbits, outer space can provide a degree of survivability, given that most nations do not possess indigenous space launch vehicles.

5. However attractive space flight might be to perform diverse military missions, the energy, effort and cost of placing artificial satellites into outer space is such that the satellite orbits and designs must be highly optimized in terms of their functions. The result of these physical, economic and technological constraints is that all satellites are found in specific orbits defined by their specific functions. The transparency of the atmosphere and outer space for electromagnetic observation of space objects also accords all nations the opportunity to monitor the positions of such objects and to postulate plausible functions for them based on the observation of a satellite’s Keplarian orbital elements.

6. Satellites placed into low Earth orbit have the most detailed view of the Earth's surface and are best positioned to detect weak electronic signals from sources on the ground, at sea, or in the air. In a near polar orbit, such artificial satellites can often have the opportunity to remotely sense the entire surface of the Earth at least once per day as it turns on its axis. Accordingly, meteorological, reconnaissance, ocean surveillance and electronic intelligence satellites are often located in low Earth orbits. When a military mission must continuously survey large areas at once, to communicate with large areas with mobile receivers, or to transfer vast amounts of data from one fixed point to another fixed point, a geostationary orbit is the preferred orbit to use. Consequently, meteorological, communication and early warning satellites are all found to be located in this special orbit.

7. The geosynchronous orbit, however, does not provide a clear line of sight for communications to ground stations in the high Arctic regions. Thus, service to these regions is often provided by spacecraft deployed in highly elliptic orbits with their apogees over the northern hemisphere for eight or more hours of their twelve hour periods. In addition to this communication function, navigation and early warning functions are also performed from these types of orbits. The Global Positioning Satellite (GPS) constellation, for example, uses circular semi-synchronous orbits to provide multiple satellite navigation signals to all four corners of the globe.

8. Newton's laws of motion severely constrain a satellite's ability to move without substantial effort to another orbit. It is as if each satellite is dropped into the bottom of a gravity well by its placement in one particular orbit and a great deal of effort must be spent to climb out of that well in order to manoeuvre into a different orbit. Once the satellite locates itself in that new orbit, however, it again finds itself at the bottom of yet another gravity well. Thus any anti-satellite weapons stationed in outer space would likely be found in the same general volume of space as their potential targets, given the amount of the rocket propellant that would otherwise be needed to perform rapid intercept manoeuvres in outer space from distant locales. Similarly, orbital bombardment systems and orbital ballistic missile defence systems would likely be deployed into low Earth orbits that would seek the regular coverage of regions of the Earth similar to those of many civil or military remote sensing satellites. All these orbits are the same orbits of interest for a *Paxsat A* verification mission.

Determination of the Function of an Object in Outer Space by Observation

9. At first glance one might expect that the determination of the exact function of an unknown object placed into outer space would be an exceedingly difficult challenge. But such is not the case upon further examination by persons skilled in the design and development of artificial satellites. Engineering is a reversible process when the laws of physics are equally well known to its practitioners. The high degree of optimization inherent in the physical design of all spacecraft in their specialised orbits and the further information made available by the nature of signals to and from satellites in relation to equipment on the Earth or other objects in outer space, provide highly significant data as to an unknown satellite's function.

10. In the field of architecture there is a tenet that “form follows function” and this same tenet is observed in the art of spacecraft design because there are so many constraints acting on a satellite’s design to meet the functional requirements of any given mission. The cost of launching satellites into outer space also means that every single gram of a satellite’s mass must make a contribution to an essential function. Visual images of a spacecraft are consequently highly determinative of an unknown satellite’s purpose. From high resolution optical images, particularly with regard to a satellite’s apertures, antennas and appendages, a skilled interpreter can ascertain the details of a satellite design. If the imagery is sufficiently fine, the dimensions of rocket thrusters required for attitude control and orbital change manoeuvres can be discerned. Identification of these features will assist in determining the potential for any space object to physically engage another satellite in any other orbit by the execution of orbital manoeuvres. The dimensions of radio-frequency apertures or electro-optical apertures together with measurements of a satellite’s radiated power can similarly assess the potential that any given space object may disrupt or deny a radio-frequency signal of another space object, or further damage or destroy another space object from a stand-off range.

11. The measurement of the dimensions of the size of an object’s solar panels will also enable calculating an estimate of the power a space object would have available to project at another object in space or on the Earth. If a verification satellite can also acquire images in the thermal-infrared region of the electromagnetic spectrum, then additional important information can be derived regarding the energy balance and energy utilization of the unknown spacecraft. Any space-based object that is specially designed or modified to damage or destroy another object at a significant stand-off range will possess specialised characteristics for that intended mission. Recall, for example, some of the conceptual designs that had emerged from the Strategic Defence Initiative programme of the United States and the Soviet Union’s counterpart in the mid to late 1980's.

12. All space-based objects that seek to attack other space-based objects from initial positions remote from their quarries, will also need to possess characteristic sensors and propulsion capabilities. Such interceptors, whether for use against ballistic missiles or other satellites, will all need to have homing sensors to provide sufficient guidance information necessary for on-board computers to calculate the required intercept trajectories. The configuration and size of thrusters, as well as the amount of internal volume available for storing great amounts of rocket propellant, will also likely result in observable features that will enable a skilled interpreter to assign a harm index for a space object’s potential use against other objects. In the *Paxsat A* concept, emphasis had been given to both optical and infra-red remote sensing capabilities at a range from and in close proximity to a space object under investigation.

13. The operation of almost every type of spacecraft involves a substantial amount of communication to and from the spacecraft. The characteristics of these transmissions in terms of communication protocols, the data rates, the frequency bands of operation and bandwidths, the radiated power levels and the operating cycle of the transmitters and receivers in relation to stations on the ground or objects in outer space, are all of a highly diagnostic value to a skilled interpreter of such communication signals. Military and civil communication signals are for example assigned

different portions of the electromagnetic spectrum by international agreement. Remote sensing satellite missions similarly use radio-frequencies different from fixed satellite, navigation and mobile satellite services. The presence of encryption on these signals and its grade of protection can also help to discriminate military versus civil functions. Thus, the second major payload on the *Paxsat A* spacecraft was an electronic support measures (ESM) package to determine the parameters of all radiated emissions from the spacecraft under investigation. This ESM payload also possessed sufficient sensitivity to characterise all radio-frequency signals directed towards the unknown spacecraft as well.

14. To acquire sufficient information on a compliance investigation, the *Paxsat A* concept postulated formation flying with the spacecraft under investigation and close proximity operations with it for a period of up to one year. Thus the *Paxsat A* spacecraft was to be outfitted with on-board autonomy and relative motion sensing capabilities provided by a radar similar in capability to the one on the Space Shuttle used for rendezvous and docking. The presence of a radar on-board also gave the *Paxsat A* spacecraft an additional diagnostic capability to calculate the mass of the spacecraft under inspection. Subsequent studies added gas analysers to the sensor complement to detect materials for chemically powered lasers and the type of rocket propellants used by the satellite under investigation. Radiation detectors were also to be used to ascertain the materials associated with nuclear power sources or nuclear weapons.

15. The *Paxsat A* study showed that, to a high degree of certainty, the nature and function of an unknown spacecraft with a capability to damage or destroy another object could be inferred directly by observation or through the process of elimination. Two equations were important in this regard, the rocket equation for "mass" weapons and the effective irradiated power equation for "energy" weapons. The study concluded that some uncertainty would exist in the case of systems that were predicated on interference effects rather than damage or destruction effects, but the use of such means in outer space would certainly be determined if strategic satellites were equipped with radiofrequency or laser illumination location determination and reporting payloads.

The *Paxsat A* Concept of Operations

16. The *Paxsat A* concept for space-based verification postulated the use of four satellites: two satellites would be deployed into low Earth orbits; one satellite would be deployed in a semi-synchronous orbit; and one satellite would be deployed in a geostationary orbit. The objective was to discern objects or activities that could provide a violator with a significant military advantage. The regular pre-positioning of *Paxsat A* satellites into storage orbits was the preferred deployment scenario, since it would avoid the potential of not being able to secure a timely launch when a compliance situation developed. This strategy would also avoid escalating a delicate compliance situation with the drama of a potential launch failure for a *Paxsat A* mission.

17. Because the spacecraft was limited to carrying 3,000 kilograms of fuel, or approximately 3,400 metres per second of delta-velocity, the low Earth orbit satellites could require up to ninety days to

rendezvous with the satellite in need of investigation. Later studies would add refuelling capabilities to the *Paxsat A* satellite configuration through the use of a modular design or the in-orbit refuelling concepts then under development for space station operations. This re-fuelling ability was needed to extend the number of investigations the low Earth orbit *Paxsat A* satellites could perform. When a *Paxsat A* spacecraft was not interrogating a spacecraft, it was to perform a space object tracking mission and to take advantage of fly-by observation opportunities to collect further information on existing satellites in orbit.

18. The conduct of close proximity operations with an investigated satellite was recognised in the *Paxsat A* study as a very sensitive, if not a provocative activity. Consequently, the *Paxsat A* concept was to operate as an authorised verification method for international agreements concerning the non-weaponization of outer space. Operation of the satellites by a body charged under the treaty and in accordance with agreed rules of procedure was postulated. The study further postulated that State Parties would contribute data collected by national technical means under the treaty and that the data most sought for sharing by State Parties would be space tracking data collected by terrestrial radar and electro-optic satellite tracking installations. This information would also help to queue and support the *Paxsat A* on-orbit inspections.

19. Suspected violations of an international agreement discovered through the use of the *Paxsat A* system were to be reported by any one of the States Parties to the other States Parties. On the basis of their deliberations, decisions would be made in respect to manoeuvring a *Paxsat A* satellite to perform an interrogation and to establish an acceptable time frame for reporting its findings back to the States Parties of the international agreement concerned.

Obstacles to the Development of Systems similar to *Paxsat A*

20. In many ways the *Paxsat A* concept was ahead of its time. During the course of the study it became known that the US had postulated a similar concept in the 1960's. That project was called SAINT - a contraction for “satellite interceptor”. SAINT was first to interrogate a satellite to determine whether it was a weapon or not and it was then enabled to dispose of the threat through the application of military force. That mission is not known to have ever made it off of the drawing board during the Cold War.

21. The delay until the current day in the development of proximity operation space systems for verification, however, occurred in part because of the very capable and less expensive terrestrial space monitoring systems available to the most advanced space-faring states. These types of systems also did not proceed because of the very capable reconnaissance assets the major space faring nations had already deployed into orbit. With the most recent Space Shuttle disaster it has since become public knowledge that the Space Shuttle missions could have their tiles examined by US national technical means of verification, including orbiting reconnaissance satellites. With the first launch of the Space Shuttle in the early 1980's such capabilities were the subject of much conjecture when it became known that some of the tiles had fallen off on the Shuttle’s maiden flight.

22. Also constraining the development of such proximity missions during the Cold War was the inherent danger of approaching another nation's satellite without prior notice, as such actions were likely to be considered as provocative acts. *Paxsat A* would have avoided this risk by operating as an accepted means of verification within an international agreement. If the Cold War dampened these types of activities in the past, present day dual-use microsatellite developments and some military doctrines calling for offensive counter-space operations with such close proximity operation vehicles are re-kindling new sensitivities about satellites capable of operating in close proximity to other satellites. Some of these developments could one day find themselves being applied to a space-based verification role, while yet others could one day find their application to offensive counter-space activities.

Recent Developments

23. Today's miniaturization leads to new verification challenges compared to the large weapon concepts of the 1980's, but smaller satellites must carry smaller amounts of rocket propellent. Likewise, smaller satellites will have smaller apertures and less power available to apply to their main mission. Small satellites intent on harming other satellites must therefore operate in close proximity to their intended victims. These constraints on miniature space-based weapons will consequently lead to discernable operational signatures for improved space situational awareness assets.

24. A whole host of present day satellite missions are nevertheless beginning to demonstrate close proximity operations and in-orbit refuelling capabilities. Most recent notables are the XSS-11 and Global Express missions of DARPA, the DART project of NASA and the ConeXpress mission of The Netherlands. Canada is embarked on the execution of two space-based space surveillance missions over the next few years. One of these is Project Sapphire and it will operationally support the Space Surveillance mission requirements of the North American Aerospace Defence Command (NORAD).

25. What is becoming apparent from the nature of continuing developments in the field of close proximity operations for artificial satellites is the need for all nations to improve their space situational awareness capabilities - both Earth-based and space-based - in order to ascertain the potential emergence of new threats to their national security interests in a new domain.
