Persistent Space Situation Awareness for the Guardians of the High Frontier

Roberta Ewart, PhD, USAF

Every moment of every day, year in and year out a watch is being kept. . . Because of the satellites, the world is a safer place. Through their constant watch, both sides know the number, location, and status of the other's weapons. And both sides know both sides know. New threats can be identified and countered. A nation can act from knowledge rather than from fear and ignorance. Surprise and bluff are no longer useful tactics. In this way, military satellites represent a stabilizing influence—acting as guardians of whatever peace exists in the world.

—Curtis Peebles Guardians: Strategic Reconnaissance Satellites

As a nation, the US will have been discussing space power, space warfare, space war fighting, or some combination of those concepts for almost 60 years, since approximately 1958. None of the recent material (2015 to the present) regarding the Space Enterprise Vision (SEV) promulgated by Air Force Space Command (AFSPC) or the at-large space control community is new. In 1994, a report was delivered to the Office of the Secretary of the Air Force Directorate for Space Programs, entitled "The Emerging Threat and the Future Necessity for Space Control," which reads eerily similar to the documents being delivered and discussed today. [1] So, to take a slightly different path for discourse, it is interesting to ask this question from a technologist's perspective: What should the nation do to better prepare, technologically, to deter aggressive action in space/cyber space—and if necessary—prevail, should deterrence fail?

To date, key pervasive technology investment approaches have been underutilized that could focus the discussion and execution of efforts to remediate perceived military space shortfalls and provide for a longer-term efficient and effective solution. This approach should be openly discussed as a foundation for stability, based on the theory of behavioral deterrence. It is not just for the benefit of the public that this more open approach should be considered. It is because within the government it will not be possible to devise a security overlay capable of bringing about the breadth of integrated change. More of the SEV effort needs to be devised in a more open way so more of the existing acquisition and operational personnel can contribute to the total solution.

To create this open-discussion approach, the following ideas, derived from existing policy and guidance, are proposed as an initial foundation for common values. These ideas are not mutually exclusive and likely not completely comprehensive:

1. Seek technologies to maintain and enhance the national security advantages afforded to the US by military space.
2. Enable military space systems to deter adversaries—and if deterrence fails—to prevail.
3. Support a more reliable, available, maintainable, and survivable military space enterprise.
4. Energize the space industrial base supporting US national security.
5. Focus space and technology innovation and facilitate its transition to military space programs of record.

From a historical perspective, but not going too far back into history, in 1995, the USAF Science Advisory Board (SAB), completed a study, "New World Vistas: Air and Space Power for the 21st Century,"[2] which laid out similar conditions, future vision, conclusions, and recommendations the military space community has been revisiting today. The technologists—in this case, the SAB—provided the framework to modify the policy, doctrine, and guidance to enable organize, train, and equip functions for the future military space environment. While the SAB technologists formulated this framework, they were adhering to the idea, "Stand on the Shoulders of Giants." This motto is for those, who have gone before and devised some of the answer, to use what they have attained, and apply it to the current situation. The entire military space community needs to do the same thing 23 years later, that is, to stand on the shoulders of its giants, and not continually reinvent what has already been devised. In doing this, all can move more quickly forward, with an emphasis on seeking the technology components for the SEV. The key foundational ideas are summarized as follows with linkages to the present-day situation.

> Space based sources and transmissions are crucial for the "information" in information-based warfare, so that US forces can respond to changing operating environments and evolving threats. A huge mass of data is available from sensor systems, and many different sources, and this data needs to be processed into information useful to the warfighter.
>
> —New World Vistas: Air and Space Power for the 21st Century
> Department of the Air Force Science Advisory Board

Currently, a space system's military value is derived from its contribution to the information dominance in the terrestrial fight. There is nothing of inherent military value to "hold" in space. There is no "ground." There is currently no resource (people, raw material, or treasure) to be taken in conflict with other nations. The value is in the spatial position the space-based system provides in relation to the information dominance for exercising terrestrial dominance.

An overwhelmingly correct prediction, applicable to this discussion, in the 1995 *New World Vistas* study, was that technology would be dispersed more widely and equally, and that vast amounts of information available commercially would change the dynamics of the information dominance equation. Dispersion of technology and access to space, which has been occurring worldwide, unsettles the previous position of supremacy the US has experienced. It was sufficiently upsetting that a third offset was called for to regain and "maintain overmatch against any potential adversary." [3] Unfortunately, the third offset has not fully manifested so it is not possible to directly link that concept to the military space doctrine/policy/guidance evolution. Yet, the third offset clearly points to the desire to find a technological underpinning sufficient to bear the weight of the enterprise vision.

So, even without a fully formed policy at the level of a third offset, military space planners can proceed as follows and begin to devise a deterrence position. From a technologist's perspective, there are sufficient technologies currently available to convert the existing space enterprise to a space war-fighting enterprise as long as the goal is information dominance. If the community can momentarily leave aside kinetic and directed energy dominance in military space, the US can proceed on a path of deterrence strategies with an underpinning of more open systems development with a larger pool of information technologists. This will bring a greater diversity of ideas and allow the cost of the effort to drop dramatically. It is well-known that developing and procuring classified systems is very expensive and lowers the number of personnel from which to draw the technology solutions. Usually, the solutions devised in a highly classified realm are not those at the cutting edge, as those reside in universities and small businesses whose personnel generally do not have US government clearances and would not want the restrictions placed on their work for that privilege. So, the core of the new idea is that by narrowing the initial scope of the SEV to its support of information dominance, and that piece of information dominance is used for a deterrence function, and that deterrence function is best devised in an open way, it is possible to create a very cost-effective partnership for many parties. What is finally needed is a requirements definition process linked to a "system of system" engineering process that allows that technology to be mated to appropriate war-fighting skills sets to take advantage of that technology.

The war-fighting skill sets are founded on principles of war. Applying the "Principles of War," the versions associated with *On War* by Clausewitz, and *The*

Art of War by Sun Tzu, to information dominance, renders two approaches.[4] The first is to use the Sun Tzu approach to avoid war altogether by a superior use of information before the engagement. This is the case where persistent space situation awareness and sufficient characterization of action in space, to attribute the parties taking actions in space, is particularly valuable. Once an engagement or conflict has begun, the second approach of applying the principles described by Clausewitz, becomes more appropriate.[5] A subset of these principles include surprise, maneuver, concentration of force, singular objective, and fog of war. While devising the space infrastructure, adhering to these principles, to support information dominance, is the key contribution to SEV. Taking each principle, it is possible to arrive at the start of a requirements generation process with the constraints from policy and guidance. For example, surprise is avoided if space-based systems can gather more and better information than the adversary's systems can. This sounds trivial, but the space situation awareness (SSA) information requirements must be broken down into the volumetric aspects of the various orbits and aspect angles under illumination, the timeliness of the reports, the precise position, and the precise time to correlate the various types of information for the SSA attribution process. This is not trivial in the analysis or design of a persistent SSA system.

Assuming the majority agree that information dominance is the appropriate initial goal for SEV, the next step is to devise the objectives for attaining the deterrence strategy. There are several forms of deterrence strategy, and one is to deter action by making the actor aware their actions and possibly intentions have been discovered. In other words, that there is no surprise to their actions and that "fog of war" is not applicable in the particular instance they seek. Those trained in Sun Tzu will agree that once the adversary is aware of the action being planned, it is unwise to continue the action and risk valuable resources. Seek better terms at a later time. So, the strategy is to cause the adversary to be deterred from acting, and instead offer another path to attain some of their goals in a continuous sequence of deferred gratification steps. This approach works well with deterrence by denial, which is when the deterrence is aimed at ensuring the adversary knows they will be denied the objective of their action.

One theory on deterrence is that by showing the capability of the systems gathering the information, such as SSA systems, it leaves no doubt in the adversary's mind that they are known and their actions are characterized. The other advantage of opening up the security classification overlays for SSA is that more of the SSA systems can be procured in the "official-use only" channels. This lowers the cost of security and increases industrial-base competition by increasing the number of vendors capable of delivering the system. Much of "synoptic" SSA needs to be an open and unclassified system, that is, the SPACE Fence, Ground-Based Electro-Optical Deep Space Surveillance System, and more recently the Geo SSA Program (GSSAP), are all examples of that type of approach. The GSSAP, once veiled, was revealed by the AFSPC commander publicly. This reveal helped both the US SSA teams and the allied, international, and commercial partners improve their collaboration efficiency. It is likely more cost-effective then, to maintain open knowledge of the synoptic systems which can in a timely fashion cue other, more capable, and more classified systems. Only a few high-fidelity, cued, and exquisite SSA characterization systems would ultimately be needed for highly -tailored responses that preserve space, not only for the US, but ultimately for the space commons. In the process, the cost efficiencies of synoptic SSA systems could buy down the cost and risk of the high-fidelity, exquisite, SSA systems. The key objective then is to obtain and maintain the highest levels of information dominance at an "affordable" price and to do that, it is crucial to have SSA at an "affordable price." It is time to consider how to make this information dominance affordable.

No nation currently has 100 percent persistent observation of the space surrounding the Earth. The most foundational space military utility is to provide a capability to constantly track objects in orbit with an emphasis on larger, maneuvering and active spacecraft. This information is the critical first step in any strategic operational or tactical process. It is necessary to accomplish this observation task for several reasons. One is that by knowing the locations of objects in space, many other activities are made possible at an affordable cost. For the national security space community, this includes protecting space operations and assets (military, civil, and commercial), supporting the underlying ability to verify international treaties and agreements, and continuing the tradition of enhancing terrestrial global military operations and freedom of movement about the globe.

Today, satellites are tracked for intervals of time. This has led to a set of SSA systems which intermittently must reacquire and retrack objects. In the intervals between observations, objects could change their orbits, deploy other objects, break up, or new satellites could be put into orbit. However, there are benefits both from an efficiency and from a characterization perspective to seek to continuously track an object, versus tracking, loosening, and reacquiring the object. The efficiency comes in the act of not having to continuously recalculate, recheck, and reacquire the object when the custody chain is broken. Constantly holding the object under surveillance lowers the cost of the additional computation, comparison, and reverification of the objects identity from its tracked behavior and eliminates errors which can occur during this process. The second benefit is that, once tracked and continuously tracked, any behavior of the object begins to indicate "its pattern of life," and this leads to a better understanding of the intent of the motion or action of the object. So, it is both more efficient with resources and provides better characterization of the behavior of an object to keep it under continuous surveillance custody.

There are numerous ways to continuously track satellites with designs that use active or passive sensors and sensors that employ different pheonomenologies throughout the energy spectrum. The strategy pursued here is to put a passive sensor far enough from the Earth so the entire volume from the low-earth orbit (LEO) to slightly beyond geosynchronous (GEO) orbits are continuously viewable. This technique of "stand-off" had been used effectively in many designs and military applications, but in all cases, pushes the state of art and the state of practice of the engineer to obtain the necessary performance at greater distance.

The additional feature of placing the sensor far from the Earth is that it will require great amounts of energy expended over time, "action" to get into this far-away position.[6] Because of the great action required, it is more difficult for any adversary to reach the system, or reach the system in a reasonable period of time to be militarily relevant, and any movement to that effect directly signals the intent of the adversary, as there is no other known reason for any system to be in the location at this great distance. So, a sensor, with this capability, at a distance which is clearly a deterrent, is itself the foundation of all deterrence functions of any space policies. Several options to realize that vision are devised below.[7]

The method chosen to constantly see any satellite is to increase the range from the observer to the satellite so that any satellite's orbit is constantly in view. Option one needs two satellites in a polar highly-elliptical orbit (HEO). Option two places one satellite in orbit about the L1 Lagrange point. Several scientific missions were or are to be conducted from versions of this orbit. Option three places a satellite in a pole-sitter orbit. From an observer on the ground, a pole-sitter orbit makes a halo over either the north or south poles. To maintain this orbit, near continuous thrusting is required.[8]

The table below compares these three options with respect to the percentage of orbit types continuously in view and the adversary action necessary to rendezvous with the satellite. The pole-sitter option offers the best continuous custody of satellites in GEO, medium-earth orbit (MEO) and HEO orbits. None of the options can constantly observe all possible satellites in LEO due to planetary obscuration. The pole-sitter option has the best resilience, necessitating about 400 times more "action" to reach than action to arrive at GEO. With current means, it would take 81 days to rendezvous with the pole-sitter.

Table. Options compared to continuity of orbit coverage and action to attack

Option	*12-day HEO*	*L1 location*	*Pole-sitter*
Percent of orbit in continuous view:			
GEO	100%	90%	100%
MEO	88%	88%	100%
HEO	80%	85%	96%
LEO	Polar 29% Equatorial 100%	29%	Polar 29% Equatorial 100%
Action needed for satellite (joulesseconds/kg)	2.6 106	2.1 108	4.4 108
Multiples of action to reach GEO	~ 2 to 3	~200	~400
Additional energy to achieve orbit (megajoules/kg)	61.7	62.4	63.5
Minimum energy time (days) to reach orbit	0.5	38	81

Note: The pole-sitter option provides the best continuous coverage of orbit types and the most resilience to adversary actions.

It is because of these advantages that the pole-sitter has been chosen as the system to further the objective of 100-percent persistent SSA that underpins deterrence, and if deterrence fails, this system will give the strategic, operational, and tactical advantage to prevail in and through space. The other two options could be used as riskreduction prototype efforts as a means to approach the capability of the polesitter.

The families of technologies comprising the pole-sitter are well-known and are already developed or in development.[9] This includes large cooled, low-noise telescopes and optics (National Aeronautics and Space Administration (NASA) James Webb Space Telescope), advanced large format infrared (IR) starring focal plane array technologies, (Space Based Infrared Systems), and solar electric propulsion systems such as NASA's Evolutionary Xenon Thruster (NEXT), which in 2010 reported the completion of a 48,000-hour (5.5 years) continuous test. Recent solar array demonstrations on the International Space Station have gathered data on large solar arrays to power the thrusters, called the Roll Out Solar Array.

The current focal plane assembly (FPA) technology readiness level (TRL) is estimated to be about 4, so it's necessary to advance this first in a laboratory setting. Solar electric propulsion (SEP), with the necessary specific impulse, are close to being demonstrated, but not with the necessary thrust. NASA reports demonstrated NEXT had achieved TRL 6.[10] Large telescopes have been placed into space, but for other wavelengths than those needed for this mission, so ground demonstration of the telescope seems prudent. Two small satellite demonstrations are suggested— one to fly a representative FPA with a representative SEP. This could be in LEO to reduce costs. Such a mission would help resolve any lingering risks associated with operation in the space environment, including jitter suppression and detectability through the SEP plume. The second space demonstration places a small satellite into the pole-sitter orbit to both characterize that environment and achieve maintaining the orbit with the necessary positional knowledge. Meanwhile the production of the full-scale telescope suitable for a space mission is accomplished and tested. While efforts are proving adequate FPA manufacture yield, a full-scale, reduced operational life system can be tested in the pole-sitter orbit using real satellite targets whose orbits are known by traditional means. This integrated technology effort was then shared with industry and industry provided improvements to the conceptual development.

Industry has deemed the technologies feasible, within the state of the art and within the planning horizon.[11] Industry advised that additional pointing and object location technologies need to be added to the list of critical technologies, due to the great distances the sensor would have to precisely identify the objects.

A scale engineering design unit (EDU) for the telescope should be constructed. This includes the mirrors or mirror panels, actuators, and control algorithms, and associated telescope structure. This EDU should undergo full environmental testing to prove that the vibration from the constant thrust component can be damped at the panel level, as well as for the entire mirror assembly. The mirrors can be cryogenically chilled and their surfaces mapped to enable the mirrors to be further polished at room temperature to achieve the appropriate shape at the designated operating temperature. Upon successful completion of scale EDU environmental testing, the telescope can be considered TRL 6. Given the complexity and effort already demonstrated on the James Webb space telescope, a great deal of the nonrecurring engineering knowledge has been gained.

To mature the solar propulsion system, put NEXT, or its equivalent, on a small satellite in LEO initially, with support from an additional payload (that is, the IR tracker) for a demonstration flight. An orbit of almost equatorial inclination is recommended, which might require additional chemical thrusters for positioning. From this orbit, the platform could start spiraling out to GEO, very slowly. Note: this will take months, if not years. Along the way, supplementary payload instruments could image satellites to calibrate optical payload capabilities and other elements of the pole-sitter SSA mission. If a hybrid solar-sail approach is pursued, a sun-synchronous orbit is preferred. This allows the spacecraft to ride the terminator and avoid eclipses so the solar arrays stay illuminated.

In summary, this article has provided a chain of thought and underlying data to illustrate that there is a key effort—persistent SSA— the nation can use to deter, and if deterrence fails, to prevail. Industry indicates they can produce a pole-sitter system at an affordable price and within the current planning horizon. This task is far less daunting than was the task facing Lt Gen Bernard A. Schriever 60 years ago. Today's Guardians of the High Frontier should consider 100-percent persistent SSA, for information dominance, as a worthy goal and consider the pole-sitter as a worthy contender to establish a pedigree of war fighting in and through space. ❑

Notes

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Roberta Ewart, PhD, USAF

Roberta Ewart is the Air Force Space Command (AFSPC) Space and Missile Systems Center (SMC) chief scientist. Her duties include serving as the principal scientific authority and technical oversight for SMC, support the SMC commander in technical reviews, program assessments, and research and development, advancing the knowledge of space concepts and technologies for Air Force capabilities, planning, conducting, evaluating, and coordinating space systems studies and demonstrations, and serving as the consultant for the AFSPC commander.