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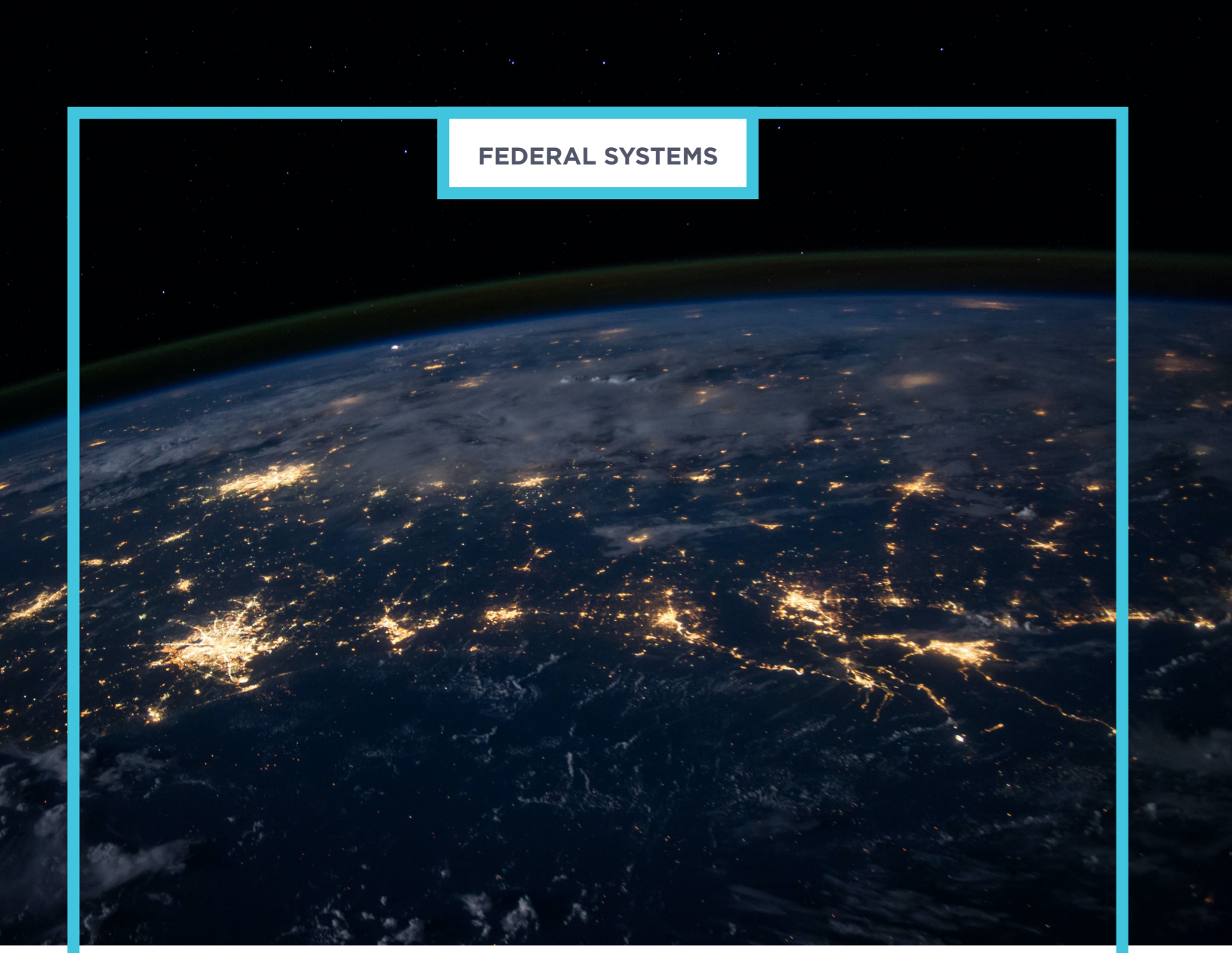

ADDRESSING ASSURED PNT NEEDS THROUGH OPEN STANDARDS

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Executive Summary

With all military services actively focused on modernizing system capabilities and bringing the latest enhanced capabilities to the warfighter, Orolia continues to align our capabilities to include the integration of Military Code (M-Code) and advanced sensors to maintain trusted and assured PNT data even in a GPS denied and/or threatened environment. The benefits of assured PNT can be realized and addressed through the adoption of open standards.

Section 1 of this document describes the need for assured PNT in any modernized system. Section 2 describes the adoption of open system architectures and its impact on process and business rules. Section 3 describes the adoption of SOSA and FACE and the impacts on competition generation. Section 4 covers the ability of the Air Force to rapidly innovate and plan.

This document is intended to guide engineering staff, integrators, and decision makers in recognizing the need for assured PNT in modernized systems. The adoption of open standard elements leads to improvements in technical performance and sustainment of systems through the use of assured PNT in modernized systems.

Section 1
Assured PNT backbone

Assured PNT is more than just beneficial. It is an integral part to any system as the basis of assured position, navigation and timing needed to maintain system operability.

Position and navigation are required to update the warfighter with critical, real-time accurate location that can be used to act and react as necessary. Timing, arguably the most critical piece, ensures that the combination of system components operate at the highest capacity possible. Maintaining high operational performance is paramount to warfighter safety and success.

Achieving and maintaining high operational performance is not an easy task. With each new mission, the environment will have an impact on the PNT solution used to drive system performance. Maintaining the integrity and trust of the PNT solution is of the utmost importance. For example, a simple delay in time of 1 millisecond or more can cause the navigation solution derived from an inertial navigation solution to diverge and provide incorrect position and velocity information. Likewise, the same millisecond (or even microsecond) inaccuracy in time can and will impact the integrity of a radar, EW, or SIGINT system.

The need for resiliency is there. The need for a system that the warfighter can reliably trust is there. Through SOSA and FACE, Orolia provides a means for an Assured PNT that can protect, detect, and mitigate the impacts of emerging threats.

With all military services actively focused on modernizing PNT and bringing the latest enhanced capabilities to the warfighter, vendors and government continue to align capabilities to include the integration of new technologies such as Military Code (M-Code) and advanced sensors to maintain trusted and Assured PNT data even in a GPS denied and/or threatened environment.

The A-PNT solution must be layered. These PNT capabilities can be incorporated into an open standard architecture that allows for modular upgrades to any fielded platform. Alignment with an open standard makes this possible. Remaining agnostic to the platform allows for streamlined integration based on mission requirements.

Resiliency, Reliability, and Protection with **Integrity and Trust**

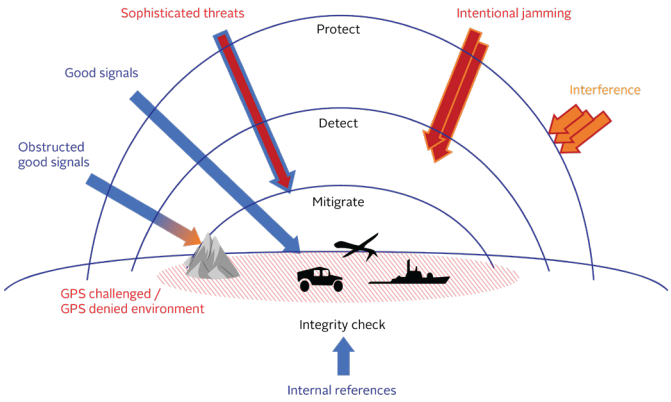
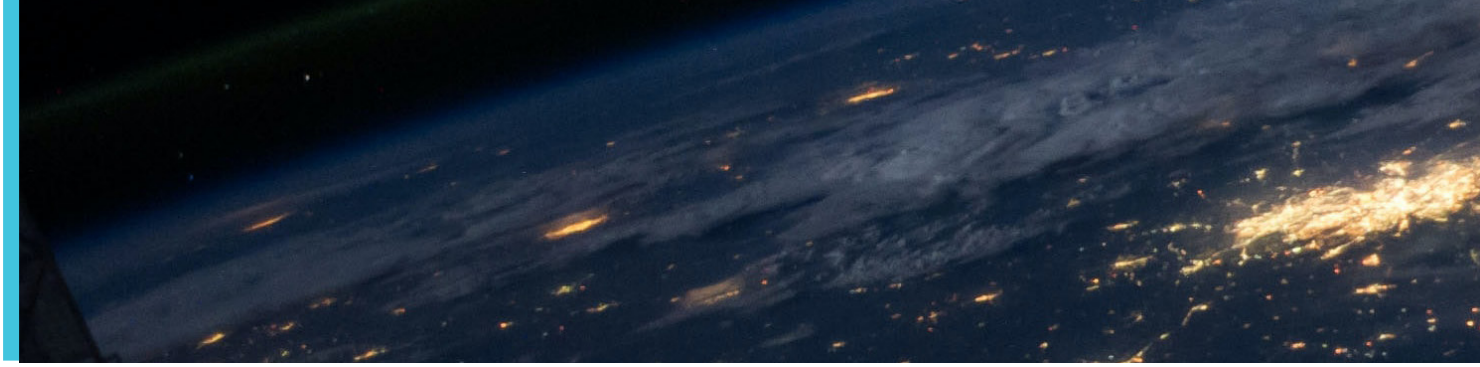


Figure 1: The importance of integrity in Assured PNT



The most versatile assured PNT card utilizes a layered approach.

- A timing reference with performance characteristics tailored to the system.
- A GPS or GNSS reference that can be hardened, easily updated, secure, and encrypted.
- An integrated sensor fusion platform capable of quick, seamless integration of new sensor and technologies to address emerging needs.
- An inertial measurement unit (IMU) that can provide high fidelity measurements in at least 6 degrees of freedom.
- Alternate assured PNT sources, such as odometry and RF signals, that are available and can be coupled and IMU and timing reference to provide reliable data even through GPS degraded and denied environments.
- A jamming and spoofing detection and mitigation platform, such as Broadshield, that provides integrity monitoring and statistical information both used in the sensor fusion platform as well as provided to other systems through a standard distribution interface.
- PNT distribution over a standardized data interface allowing for assured PNT distribution across cards.

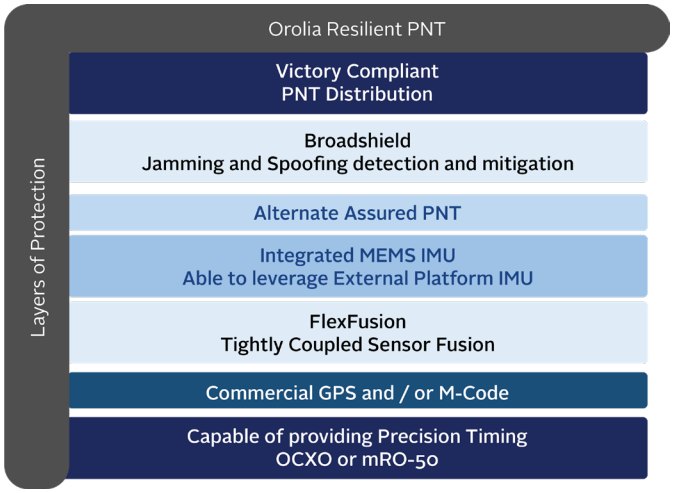


Figure 2: The layers of protection in a Resilient PNT solution

An A-PNT solution is backed by a solid foundation of sensors that play a large role in the performance of the navigation and timing solution. This solid foundation is built around two core competencies - timing and position.

For timing, this can be an Oven Controlled Crystal Oscillator (OCXO) up to miniaturized rubidium oscillators (mRO) and chip scale atomic clocks (CSAC). There are trade-offs that should be considered by a system designer which will determine which timing reference to use. Two of these items, phase noise and stability, are important for different reasons.

Phase Noise – Phase noise is the noise generated from the rapid, short-term fluctuations in the phase (frequency) of the timing reference. These fluctuations spread the power of the signal to adjacent frequencies, causing noise and interference. In systems where the frequency reference is used to send and receive signals, the impacts may be viewed as amplitude variations of received signals, channel interference, and random rotations of received signals. Phase noise is unavoidable, but the impacts of phase noise can be mitigated by choosing low phase noise timing references.

Stability – Stability can be ability for the timing reference to transmit at the designated frequency for the entire life of the device without any deviation. Short-term stability, frequency accuracy, and aging are important for signal integrity and co-channel interference. In systems that require very accurate frequencies with little drift or accurate phase coherence may look for stable timing references.

Phase Noise and stability are important criteria to take into consideration but not all timing references support both low phase noise and stability. To complicate matters, vibration and system dynamics will have a large impact on the performance specifications for both phase noise and stability. Each system design has different requirements and using a modular approach, the requirements can be met through a signal A-PNT form factor. Through using an open standard, the difficulties behind integrating different timing references are mitigated by common architectures and platforms that facilitate rapid development, testing, and deployment.

For position and navigation, the absolute reference typically used is an IMU. These devices can be described as commercial (automotive), tactical, navigation, and strategic grade.

The errors and specifications will have an impact on the drift of the IMU, the lower the bias and noise, the less the IMU will drift. However, there is a trade-off in size, weight and power and cost when using higher grade parts. Not all systems require higher grade, larger IMUs when the smaller IMUs are adequate for the mission.

Figure 3: IMU grade comparison (leveraging Petovello)

Sensor error	IMU grade			
	Commercial	Tactical	Navigation	Strategic
Gyro bias [deg/h]	100+	0.1-10	0.005 - 0.010	<0.005
Gyro noise [deg/h/vHz]	N/A	0.2-0.5	0.002 - 0.005	<0.002
Accel bias [mm/s2]	12+	2-4	0.050 - 0.100	<0.050
Accel bias [mm/s2/vHz]	N/A	2-4	0.050 - 0.100	<0.050

Figure 4: IMU grade comparison (leveraging Petovello)

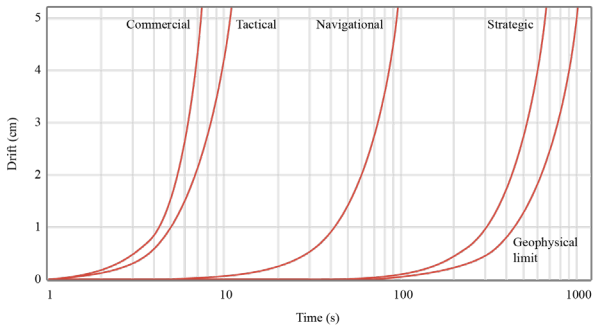
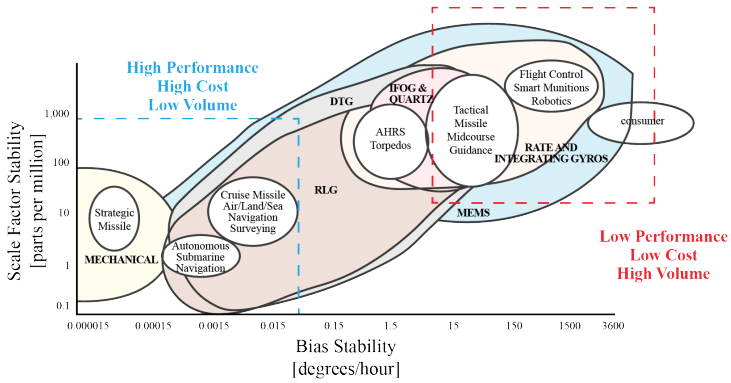
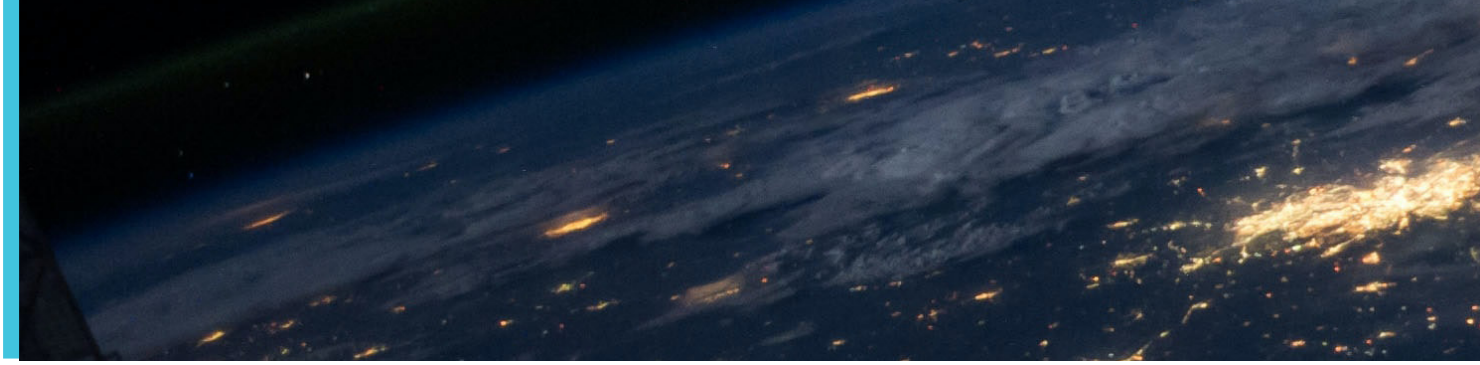


Figure 5: Comparison of IMU technologies and grades (Passaro)





An IMU will impact navigation performance in GPS degraded and denied environments when the only sensor to rely on is an IMU. Thus, incorporating other sensors like barometers, alternative signals, and location references can provide high fidelity estimations of position, velocity, heading and orientation. Not all these sensors are available in different platforms, so ensuring a modular approach to the A-PNT solution allows for swapping out different sensors, fusion algorithms, and capabilities to meet the system needs. As technology advances, IMUs capabilities will increase. Systems will soon be able to utilize high performance gyroscope in a small form factor meant for modular form factors. A modular A-PNT solution is the difference between operating over seconds to minutes without GPS versus operating for hours without GPS.

Inside the A-PNT solution lies an integrity checking and monitoring solution. Through tests in the lab and during other test event opportunities, interference detection and mitigation (IDM) software must be thoroughly updated to address the ever-present threats. Using updated IDM software, the A-PNT solution introduces dual purpose situationally aware sensor fusion platform and protected system driver for the important PNT data.

At a top level, PNT distribution over the VICTORY Data Bus allows for accessibility and information distribution that is agnostic to any system. Taking advantage of an open system architecture allows for system integrators to design systems around performance specifications and mission requirements without the need to also modify system components outside of the PNT card.

A multi-layered A-PNT approach is needed to (1) maintain and improve situational awareness, (2) enable GPS denied mission operations, and (3) keep our warfighters safe through threatened environments. A-PNT solutions address these challenges by providing encrypted GPS M-Code signals, multiple layers of protection, and unprecedented capability to defeat and function in the presence of Electronic Warfare (EW) threats.

An A-PNT sensor card that adheres to an open standard tackles very important criteria for any system used by warfighters today:

- **Military Off-The-Shelf components** – Procurement and sustainability are addressed through use of off-the-shelf components.
- **Flexibility, Scalability and Upgradability** – The system is flexible, scalable, and upgradable to newer sensors and technologies with developer support.
- **Ease of Use and Ease of Integration** – Easy for the integrator and user to operate with familiarity.
- **PNT subject matter expertise** – Allows for integrity and trust of the technology as a system designed around an integrated PNT sensor core. Position and navigation are required

Not all systems are the same. As emerging missions evolve, so must the technology that is relied on by the warfighter. Historically, this has not been an easy task. Modular Open System Architecture (MOSA) has provided a means to address the need for rapid development, test, and integration of new technologies for emerging missions. The benefit of this should not be understated. Rapid development and test leads to simplifying the procurement challenges that confront acquisition efforts. Leveraging the open standards in SOSA and FACE alongside simulation technologies allows the Air Force to be ready when needed.

Section 2

The impacts on culture and practices

Organizational structure is very delicate detail. Bureaucracy exists in all large organizations. The most successful organizations are methodical in their approach towards achieving success. These approaches are typically unique to the business or organization as there is not a "one size-fit-all" solution. The impacts of the differences in cultures and practices between organizations can and does impact the timeliness and effectiveness of decisions being made. Altering culture and practices that prevent timely and effective decisions is difficult, but it starts by making open systems available to the Air Staff.

In the ecosystem that provides warfighters with the latest and greatest technology, intellectual property is owned by the vendor. This is problematic when trying to develop, test, and field systems for the warfighter. Adopting open standards like SOSA and FACE reduce the restrictions that impact information flow between governing bodies and vendors. Intellectual property is owned by vendors. This makes it difficult for the same information to be shared between vendors, between governing bodies, and between vendors and governing bodies. The goal of SOSA and FACE is to not own the intellectual property of the vendor but to make the interfaces and modules, used by the proposed solution, widely available.

In removing the intellectual property barrier and making the interfaces and modules widely available reduces another pain point in the development of products. With known requirements for interfaces and modules, time is not spent on making the design decisions but rather on the development, test, and integration of the solution. This allows for the air fighter to improve speed, quality of decision support, and achieve greater alignment among Air Staff.

Orolia had the opportunity to participate in an Open Innovation Lab (OIL) Plugfest. A Plugfest is typically an event, based on a technical standard or system, where the designers of some technology (electrical equipment or software capabilities) test the interoperability of their products or designs with those of other manufacturers. The technical goal is twofold: check compliance to the standard and test the effectiveness of the standard. Besides helping the vendors improve their interoperability, Plugfests help create awareness about the standard and can improve transparency on compliance. These Plugfests can be formal, providing public test scores or informal and private.

SOSA and FACE provide opportunities through Plugfests and technical exchange meetings for vendors and government to not only stay informed of compliance and alignment success but also collaborate and innovate. Such opportunities are only made possible through the application of open standards and modular frameworks.

During the OIL Plugfest, multiple vendors were asked to provide CMOSS, and SOSA aligned products to integrate alongside other cards and chassis. Years ago, such an event could not exist due to vendor restrictions. Open standards reduced the overhead requirements of designing the electrical and mechanical interface, understanding the software modules, and deciding on the form factor that would be implemented. In as little as 6 weeks, Orolia adapted a boxed based A-PNT solution to a card based A-PNT solution that was plug-in compatible with the system. Systems that adopt the Modular Open System Architecture (MOSA) provided by SOSA, CMOSS and FACE have proven to be modular, easily accessible, and easy to integrate.

The end goal of any business or organization may not change, but the methods that may be employed must often adapt. Adaptation does not come easy but is necessary for constant improvement.

Section 3

Addressing long-term strategic competition

MOSA is meant to enhance the department's ability to modify weapon systems effectively.

Modularization simplifies system design by making complexity manageable, enables programs to conduct parallel development efforts, and accommodates future uncertainty by allowing incremental changes to a system.

A STATEMENT FROM THE SUMMARY OF THE 2018 NATIONAL DEFENSE STRATEGY:

"A long-term strategic competition requires the seamless integration of multiple elements of national power – diplomacy, information, economics, finance, intelligence, law enforcement, and military. More than any other nation, America can expand the competitive space, seizing the initiative to challenge our competitors where we possess advantages, and they lack strength. A more lethal force, strong alliances and partnerships, American technological innovation, and a culture of performance will generate decisive and sustained U.S. military advantages."

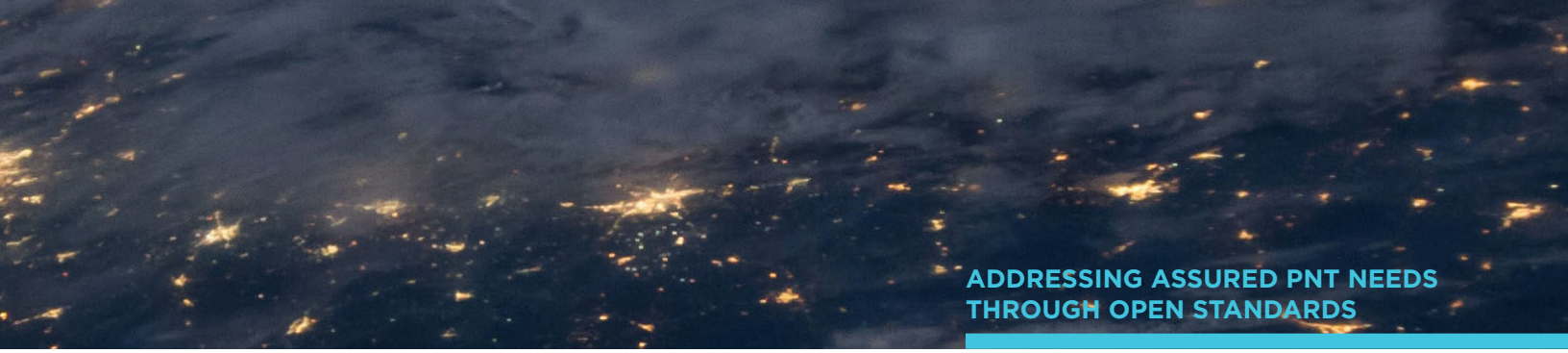
Key edicts from the national defense strategy that can prove paramount to warfighter success. Open standards are a key differentiating factor that benefit both industry and government. As the needs of the warfighter continues to expand, technological capabilities employed by the warfighter must also continue to expand.

Be strategically predictable, but operationally unpredictable. Adopting an open standard in SOSA and FACE provides the means to innovate and bring about new technologies. These technologies, either being improvements upon existing technologies or completely new technologies, will allow the warfighter to address this mission critical piece to competitiveness.

Frustrating their efforts. Assured PNT is the backbone of any mission critical system. Knowledge of position and time will impact the functionality of any system. As such, position and time are very critical, and very susceptible components to a system designer or integrator. Competitors are aware of such a bottle neck and will try to disrupt these capabilities through this point of weakness. The need to protect, detect, and mitigate against such threats emerges every day. The need to rapidly address, innovate, and deploy the new technologies should not be slowed by proprietary interfaces, communication protocols, and process. Open System Architectures provide a means to counteract and even accelerate development and procurement to ensure success.

Integrate with U.S. interagency. This edict expands to all aspects of U.S. interagency, including applying internally as well. The need to identify and build partnerships amongst military entities is an absolute requirement to address areas of economic, technological, and informational vulnerabilities. Such a task must not be hindered by the development or acquisition of systems caused by lack of information sharing and lack of common architectures. The deployment of common platforms, supported by MOSA, facilitates this agenda.

Foster a competitive mindset. To succeed, new technologies must be robust and resilient. The key is to out-think, out-maneuver, and out-innovate the competitors. The use of resources to verify compliance and credibility is paramount to ensure any newly developed technology is deployable. New technologies can be developed using simulated environments without the overhead of working through proprietary methods which inevitably delays the development process and loses the competitive advantage.



Using internal testing and hardware-in-the-loop capabilities that can emulate real world threats, developers and integrators can take that next step to developing resilient and assured capabilities. GPS simulators, either used on mobile test platforms or coupled with hardware-in-the-loop capabilities to simulate inertial movement, can shorten the development and testing that would be required for final integration.

An evolving technological capability is an absolute requirement. Minimal impact to system interoperability is a key goal to ensuring that the edicts mentioned above are achieved. By allowing for modular open system architectures, rapid improvements can be made to A-PNT cards that include:

Encryption: Layering and improving encryption methodologies (such as upgrading receivers in the field), it would be possible to harden GPS. A robust PNT ecosystem allows for a unified effort to improve encryption through affordable solutions.

Threat Detection and Mitigation: Various algorithms can drive and improve filtering and help operators detect potentially malicious interference in navigation and timing systems. Through modular software components and hardware architectures, updating threat detection and mitigation capabilities using algorithms and layered PNT remains seamless. As new threats emerge, protecting the A-PNT through on-board interference detection and mitigation algorithms is a need.

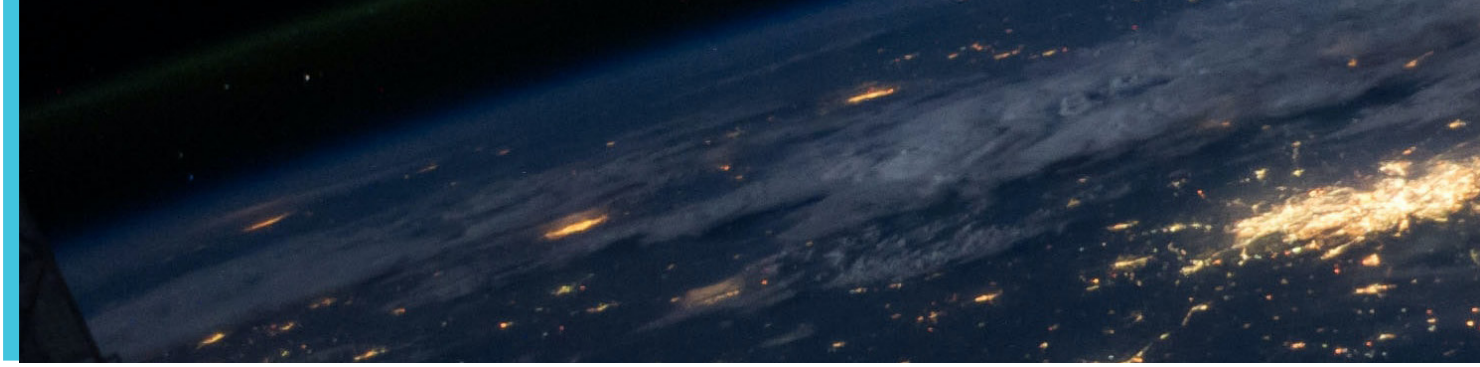
Improved signal processing: Emerging tools on the consumer side have improved the ability to process radio frequency signals. The NATO Research and Technology Organization points to improved signal processing as one of several key measures needed "to boost the resistance of GPS to [adversarial] jamming technologies." High-end simulators can help the military to test such capabilities and get them into the field more quickly.

Improved signal processing could also support more robust uses of PNT data leading to more effective systems. Higher receiver bandwidth, more accurate position and navigation, and phase coherent timing solutions are all results of the improved signal processing.

Using analytics and modeling and simulation analyses, continuous testing can be performed to challenge the current systems and the potential to create new requirements to provide the correct PNT information.

Advanced antennas: An advanced antenna creates focused beams and antenna patterns, focusing on where the satellites are and avoiding any potential interference. Strategically predictable yet unpredictable with the ability to adapt quickly.

A high-level view of this approach and the different PNT information opportunities can be found in Figure 6 (next page).



Each individual item adds a unique solution that is incorporated into the PNT solution provided by an A-PNT card. With opportunities to use these sensors, the ability to adapt, foster competition, and frustrate the competition is easier to achieve. While not all sensors may be available all the time, having choices allows for an adaptable solution that remains unpredictable and fosters interagency communication.

Finally, the use of GPS simulators and other various test events drive collaboration among government and vendors alike. The Air Force must take advantage of operational tests that exercise the new technologies. With modular technologies and open, available standards that vendors have access to, the Air Force can quickly test these new technologies, fostering not only an atmosphere of collaboration but competitiveness as well.

Figure 6: Available assured sensors for more robust solutions

Section 4

Preparing for the future starts now

The goal is for any leveraged system to be the state of the art.

Integration of the newest sensor and system technology, the highest operational performance, and the advancement of software design and implementation are of the utmost importance. These goals are shared both by vendors and government alike. Despite the common goal set, the approach has been different. As each approach is different, systems today result in tightly coupled integration without portability and flexibility. State of the art at the cost of flexibility decelerates the transition from the force that exists today to the Air Force the nation needs. To achieve technological preparedness, the groundwork must be laid now. Adopting a common framework through open standards is a means to do so.

Utilizing a standard reference architecture helps remove the barriers prohibiting modularity, portability, and interoperability.

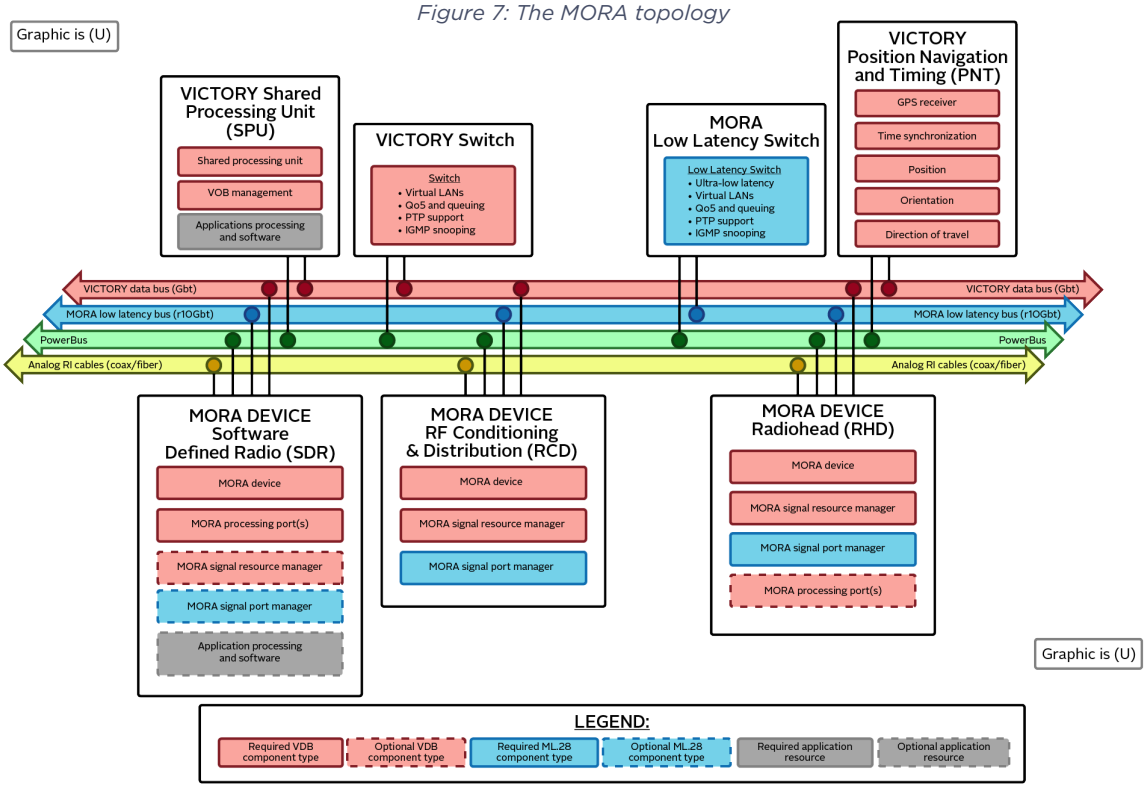
Modularity. Software and sensor components drive the capability of the system. Vendor specific software leads to tightly coupled integration which prohibits the modularity of the software and system. The hardware modules must be decoupled from the software components such that software components and hardware modules can be developed and tested independently. This independence cuts down on development time and promotes the development of test tools that can be further leveraged to verify compliance and compatibility. VICTORY, as an example, promotes a standardized software interface. Along with a test tool and standards body, conformance and capability can be tested and verified without the need for specific hardware implementations. This allows developers to continue addressing near term implementation goals without relying on supply chain management or other roadblocks.

Portability. Sensor components found in fielded systems are the backbone of the system functionality. These items must be easily replaced and updated to sustain and increase system performance. The same is applied to software components developed for systems and solutions. The need to port existing software solutions to newer processors or platforms will assist in reducing the impacts of supply chain or procurement initiatives. The adoption and implementation of open standards leads to portability between platforms. Ease of portability allows for integrators and decision makers to address emerging needs with resilient, tested, and trusted solutions. As an example, the Orolia C-PNT solution has been ported to multiple different platforms and iterations. The software is built to remain agnostic to sensors such that the inclusion of VICTORY, SOSA, CMOSS and FACE allow for easy portability to more available processors.

Interoperability. Communication between components and modules is important for any functioning system. Plugfest opportunities help test the compliance, the interoperability, and performance of newly designed systems. Such events may only exist due in part to the adoption of MOSA and standards that are managed and agreed upon. As open standards bodies, SOSA and FACE host opportunities for vendors and government to test this interoperability. A key importance of interoperability is found in the ease of replacing technologies as well as updating technologies. For example, if the need arises to swap out an inoperable sensor or the need to update a sensor itself with a newer version, the interoperability of the sensor card is important to reduce integration and development time.

Take, for example, the Modular Open RF Architecture established through SOSA (Figure 7, next page).

Figure 7: The MORA topology



The VICTORY Position Navigation and Timing (PNT) is abstracted from the system software component types such that an end user can address and update components through a common standard data bus. The only limitation for an A-PNT solution to be updated or upgraded is the adherence to an established standard in VICTORY. With the communication and component level standardized, the three key aspects of modularity, portability and interoperability can easily be addressed with no impact on other devices or components of the system.

The importance of removing these barriers allows for the Air Force to transition to the next level and take advantage of the state-of-the-art technologies. Removing the focus on integration and development and spending more time focusing on the strategic targets allows for success and safety of the warfighter.

Giving the Air Force more time to address the areas of need allow for greater attention to be paid to the near term and long-term strategic mission. Evaluating acceptable levels of risk to mission, force and security is paramount to the success of any organization. Leveraging open system architectures and standards remains beneficial to this end goal.

Conclusion

Modernized systems require modernized technology. As the emerging needs grow and evolve, the technology needs to advance with it. As a mission critical piece to any modernized system, assured position, navigation, and timing technology cannot be hindered by tightly locked solutions that do not allow for modularity and growth. The capabilities must rapidly and effectively evolve.

The adoption of open standards is a unified approach to addressing the needs of the air fighter today and for the future. To rapidly evolve, designers should not be burdened by lack of modularity, interoperability, or information flow. To effectively evolve, decision makers should not be burdened by information flow and process which detracts from more focus on planning and strategy. Promoting the collaboration between industry, academia and government will allow the Air Force to overcome any technical challenge.

Such a change in culture and process can be facilitated through the adoption of open standards. They allow us to go fast, be effective, and most importantly, be successful.

References

(Please note that the links below are good at the time of writing but cannot be guaranteed for the future.)

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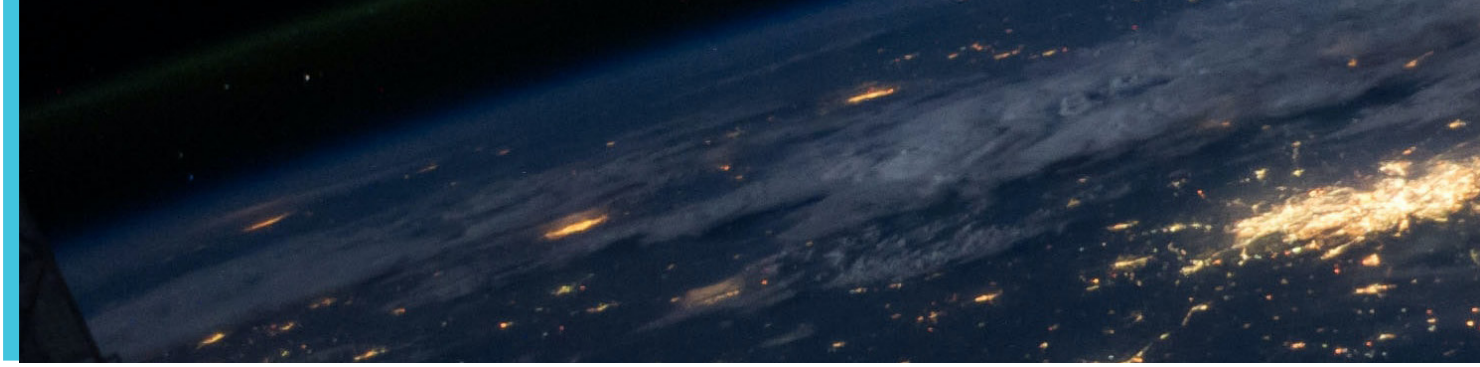
About the Author

Brent Abbott is an R&D technical lead and manager for Orolia Defense & Security, a leader in Assured Position, Navigation, and Timing products. He has a Bachelor's and Master's in Signal Processing and has worked in the DoD space for more than 13 years. He constantly seeks to promote the advancement of technology as seen through several PNT related patents, publications, and presentations.



About The Open Group FACE™ Consortium

The Open Group Future Airborne Capability Environment™ (FACE) Consortium, was formed as a government and industry partnership to define an open avionics environment for all military airborne platform types. Today, it is an aviation-focused professional group made up of industry suppliers, customers, academia, and users. The FACE Consortium provides a vendor-neutral forum for industry and government to work together to develop and consolidate the open standards, best practices, guidance documents, and business strategy necessary for acquisition of affordable software systems that promote innovation and rapid integration of portable capabilities across global defense programs.

Further information on the FACE Consortium is available at www.opengroup.org/face.

About The Open Group SOSA™ Consortium

The Open Group SOSA™ Consortium enables government and industry to collaboratively develop open standards and best practices to enable, enhance, and accelerate the deployment of affordable, capable, interoperable sensor systems. The SOSA Consortium is creating open system reference architectures applicable to military and commercial sensor systems and a business model that balances stakeholder interests. The architectures employ modular design and use widely supported, consensus-based, nonproprietary standards for key interfaces.

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