



**CONTINUOUS PRODUCTION AGILITY:  
FUTURE-PROOFING THE NATIONAL  
SECURITY SPACE ENTERPRISE**

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The space sector is not immune to today's dizzying pace of change and constant technological disruption. The traditional, highly customized launch-on-need approach that allowed the United States to field the world's leading space capabilities during the twentieth century is ill suited to the new era of rapidly evolving threats and emergent opportunities. To stay in the race, the United States should shift toward modular national security space architecture, interoperability standards, and a launch-on-schedule production tempo to create agility, efficiency, and predictability. This will, in turn, encourage broad industry competition and provide frequent innovation opportunities.

Our national security space architecture can avoid competitive obsolescence by "future proofing" through regular introduction of new technologies. The proposed acquisition strategy, Continuous Production Agility (CPA), introduces modularity as a key element in the architecture. Modularity enables steady production flows for foundational space system elements while providing open doors for technology insertion or agility in response to threats. It simplifies the scope of rapid prototyping efforts and reduces the barriers to adaptation. While it requires more upfront engineering, it encourages lean and focused acquisition teams. And, especially important, it fosters a thriving and motivated ecosystem of space manufacturers and innovators.

## **Background**

Today, substantial foreign, military, and commercial investments have blunted U.S. historical leadership in space and competitive edge. The number of foreign reconnaissance and remote sensing satellites has tripled (from 100 to 300) in the last 10 years. And within areas where the United States still leads, China and Russia are gaining. The National Air and Space Intelligence Center concluded that new technology deployed by these potential adversaries was unprecedented.<sup>1</sup> While striving to catch up to U.S. space capabilities in areas such as communications, reconnaissance, and positioning, China and Russia are also aggressively pursuing new electronic warfare, directed energy, kinetic weapons, and cyberattack capabilities that threaten U.S. space capabilities. Space is now an actively contested domain.

In March 2018, then Deputy Secretary of Defense Patrick Shanahan asked The Aerospace Corporation (Aerospace) to look at how U.S. space systems can outpace the emerging threat. Three months later (July 2018), Aerospace responded with a briefing titled, "Creating an Agile Space Enterprise." To continue to outpace our adversaries, Aerospace recommended a

strategy called *Continuous Production Agility* (CPA), which is designed to realign space acquisition for speed, adaptability, and resilience. The keys of CPA are increased production, a modular open systems architecture design and contracting approach, and enhanced competition.<sup>2</sup> By shifting to a continuous production approach and opening the space system architecture, the DOD can more readily field new capabilities or respond to counter-space efforts while combining the energy and ingenuity of the new entrants to the U.S. space industry with the deep expertise of the traditional defense space players.

Since proposing this new strategy, considerable progress has been made to support the overall CPA vision across various classes of spacecraft and the United States Space Force's (USSF's) alternate acquisition strategies:

- ◆ **Small spacecraft.** The National Security Space (NSS) community has reimagined several of its constellations, looking at synergies with low Earth orbit (LEO) spacecraft constellations that already reflect varying degrees of modularity and/or high-volume production (e.g., Starlink and OneWeb). Additionally, new nano-satellite form factors for rapid prototyping (e.g., the Air Force Research Lab's Mycroft and Aerospace's HIVE) have also received innovation, research, and development funds.
- ◆ **Hosted payload opportunities.** The Space and Missile Systems Center (SMC) has revived its payload hosting strategy to take advantage of excess power and weight capabilities of large commercial vehicles. A modular and standardized payload interface specification would accelerate these hosted payload opportunities.
- ◆ **Medium size “combat capable” spacecraft.** Studies of future space systems routinely find that some NSS user requirements can only be met effectively by mid-sized spacecraft in orbits above LEO. Industry responders to the March 2019 “SMC Modular Enterprise Spacecraft Bus Procurement” request for information validated Aerospace's assessment that these needs could be met by modular/scalable spacecraft designs to accommodate NSS strategic missions.<sup>3</sup> This enterprise spacecraft bus would fall within a “sweet spot” or range of mass and power values that currently includes medium Earth orbit (MEO), geostationary Earth orbit (GEO), polar and high Earth orbit (HEO) satellites. To generate CPA opportunities for these systems, SMC encouraged the formation of a working group in September 2019, bringing together vehicle and payload manufacturers to develop open bus (platform) to payload interface descriptions.
- ◆ **USSF acquisition authorities.** Aerospace provided recommendations to the Air Force to help inform a May 2020 report to Congress on USSF alternate acquisition authorities. While the USSF continues to take shape, its largest acquisition organization reorganized into SMC 2.0 before the end of 2019. The new structure emphasizes an enterprise approach and encourages partnerships, innovation, and cultural shifts to respond to the new space environment with speed.

## What Is CPA and Why Use It?

**Dynamic Space System Acquisitions.** CPA shifts the architecture of space systems into elements that can be dynamically integrated into the broader NSS architecture and coevolved. Some of these elements can be commercial off-the-shelf (COTS), some can require specialization for National Security Space, and some elements can be purchased as services (e.g., ground station as a service). This modularity opens the doors for innovation and multisided platform network benefits (see sidebar). It also creates opportunities for production efficiencies through reuse of platform elements and/or proliferation of modules across systems.

Establishing modular platforms and breaking down engineering and manufacturing silos makes sense in today's fast-paced and budget-constrained world. From automobiles to personal computers to telecommunications, the commercial sector has already discovered that modular platforms with interoperable interfaces minimize development costs and provide advantages to the consumer. For the defense community, modular architecture is written into law, with 10 U.S.C. 2446a

requiring that all major defense acquisition programs be designed and developed using modular open standards architecture (MOSA). Applying MOSA principles, the DOD space enterprise can break out of the high value asset procurement model that has yielded expensive and sometimes vulnerable systems. Instead, an agile, higher volume space production concept will deliver modular buses and payloads that can rapidly evolve. (see Figure 1).

Ultimately, CPA’s virtuous cycle of lower incremental costs and more frequent launches further reduces unit costs and feeds the cycle again. Moreover, CPA’s shorter acquisition cycles allow for frequent prototyping and testing. And, as opportunities emerge, successful prototypes are inserted into the architecture.

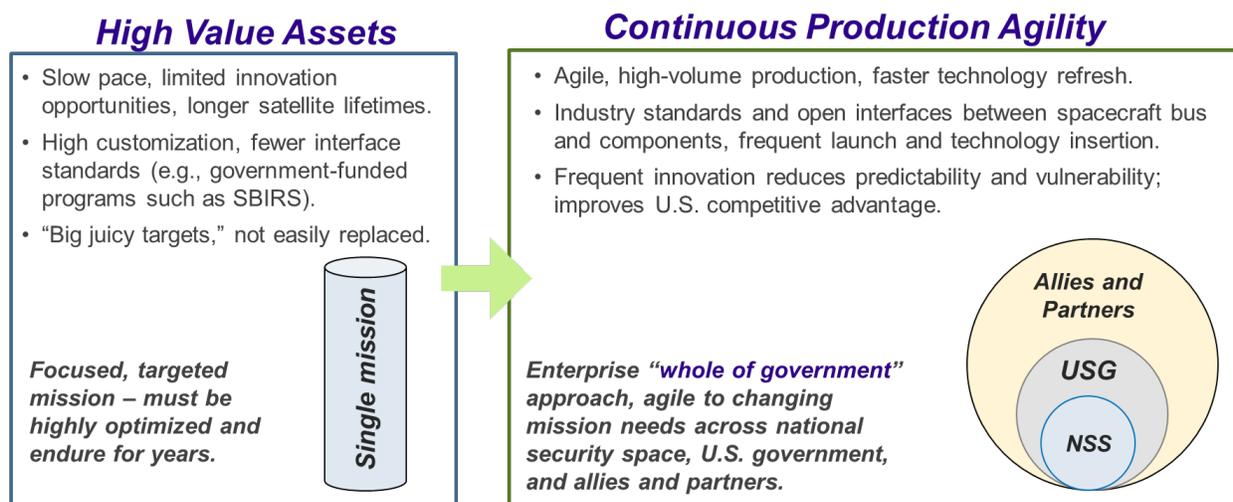
**CPA Introduces Multisided Platform Benefits**

Multisided platforms refer to technologies or products that create “network effects” or value primarily by facilitating interactions between two or more participant groups. A widely cited 2009 study, “Platforms, Markets and Innovations,” refers to these participants as “core components,” which are primarily stable, and “complementors,” which are encouraged to vary. CPA’s multisided platform is a good example of an “industry platform” where the core components (space bus providers) and complementors (payload innovators) combine to “create novelty without developing a whole new system from scratch.”<sup>4</sup>

**Whole of Government.** The term whole of government is popular these days. It refers to working under a shared mission toward a joint goal to maximize appropriate resources in a collaborative effort. This term is applicable to the space sector and is referenced in the July 2020 White House report, “A New Era for Deep Space Exploration and Development,” wherein the National Space Council calls for a cooperative approach within the U.S. government (USG) and with other spacefaring nations:

The important supporting roles of the Departments of State, Defense, Commerce, Transportation, Energy, and Homeland Security in space exploration and development are among the major reasons the United States takes a whole-of-government approach to its space activities....

The challenge in this new era is not simply to achieve what others cannot but to provide opportunities for others to partner with us.<sup>5</sup>



**Figure 1: Operational Paradigms.** CPA addresses a rapidly evolving and changing threat environment. CPA’s modular approach allows each generation of satellite to remain relevant for a longer time period by allowing frequent technology insertion from an ecosystem of payload providers. The same frequency of insertion opportunities can also invite broader participation for shared missions across the NSS government agencies, civil government agencies, and multinational partners.

Whole-of-government wider interests can translate into multiple customers on the same production line or even on the same satellite. CPA embraces this concept, allowing a wider range of customers and missions by replacing stovepiped space systems with a modular architecture and an ecosystem of developers. While whole of government is a laudable goal, specific acquisition strategies will continue within the NSS community that will not rely on a CPA approach. Still, the trend is for greater use of modular open systems for sharing architectures and inviting a larger group of participants.

Beyond defense-related missions, a modular and scalable platform with a range of payload options could meet various USG missions or could support shared missions with allies and partners. For instance, SMC satellites that are in GEO are well known for short production runs, and some experts still do not believe that they are suitable for mass production.<sup>6</sup> Extensibility across orbits has been validated by industry request-for-information responses, and an open architecture can likewise support partners such as the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and other USG stakeholders. A modular bus with a range of compatible payloads serving wider interests improves economies of scale. Such an approach is consistent with CPA's whole-of-government approach to maximize the government's buying power.

Finally, a whole-of-government approach must also stretch across acquisition strategies. The CPA strategy should fit and complement the larger acquisition framework, including balancing capital expenditures (CapEx) and operating expenditures (OpEx):

Lower CapEx



Higher CapEx

1. **Services-Oriented Architecture (SOA)** – Leveraging the full suite of commercially available and appropriate on-demand satellite services, and the growing trend toward infrastructure as a service (IaaS) for ground stations, launch sites, network operation centers, and cloud services and analytics. This approach offers the ability to rapidly access existing services and infrastructure while minimizing CapEx. Over time, SOA will increase OpEx as USG becomes a subscriber for more services.
2. **Commercial Off-the-Shelf (COTS)** – Acquiring existing commercial hardware offerings that can perform the mission, potentially augmented with limited government-unique technology. Advantages are rapid access and use of heritage systems. With time, more of these COTS space systems are also developing modularity for both LEO and GEO. This will allow for increased technology insertion and customized missions within certain constraints.
3. **Continuous Production Agility (CPA)** – Creates a foundation for an ecosystem of payload innovators and bus providers. By executing a high-volume, launch-on-schedule plan, lower unit costs can be achieved. While the cumulative CapEx could exceed that of a locally optimized program of record, the incremental nature of CPA ideally allows reduced capital exposure for any one design. This allows more frequent evolution to incorporate emerging capability or respond to threats. Also, both SOA and COTS solutions can be compatible with CPA and can serve to further lower CapEx and improve time to market. Modular open interoperability standards result in reduced costs when looking across the whole of government.
4. **High Value Assets / Programs of Record** – Focused, targeted missions requiring highly optimized designs that must endure for longer periods. Allows for highly customized, high-performance missions.

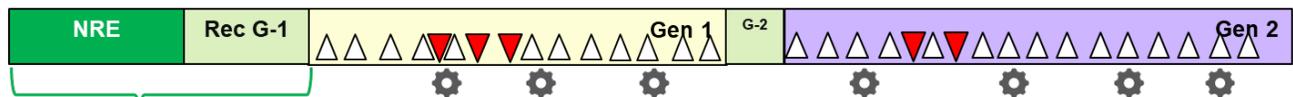
**Prioritization of Incremental Delivery over Launch-on-Need.** CPA proposes a high-tempo, launch-on-schedule strategy to deliver an entire operational constellation over a short period (targeting five years for most constellations) and to replenish the constellation on a schedule-certain basis. The additional quantity of satellites drives steady demand and incentivizes industry to make capital investments in manufacturing capability for efficiency and speed. This is a significant change from the more traditional, customized, and lower volume launch-on-need approach. CPA requires more upfront capital investment in terms of nonrecurring engineering costs for high-volume production design. The idea is that over time, this investment pays off in terms of reaching lower unit costs and increased generational extensibility. Extensibility is essential, as modular elements are more readily changed, and more frequent technology insertion allows each fielded system to stay relevant to evolving needs. Figure 2 compares the two operational paradigms, launch-on-need versus launch-on-schedule, and the advantages of each.

**The CPA is a suitable strategy for those missions that require agility, speed, and technology relevance, where a modular platform can be introduced.**

**A: Current Approach – Launch-on-Need:** Less frequent technology insertion. Launches are based on replacing failures or expiring satellites. New technologies are typically introduced with new satellite generations. Satellites are often designed as long life “Class A” satellites and experience fewer failures. They also require more time to manufacture.



**B: CPA Approach – Launch-on-Schedule:** A modular open systems architecture allows for continuous production improvement and frequent technology insertion. Higher upfront NRE costs and reduced recurring costs associated with later generations are due to greater investment in modular architecture and capital infrastructure needed to produce high satellite volumes. High degree of modularity also allows for rapid production.



Initial costs are higher compared to launch-on-need because launch-on-schedule strategy must initially invest in modular architecture and high production capital infrastructure. Recurring costs are less for future generations.

This modular open system approach allows for architecture extensibility whereby each generation can extend its relevance.

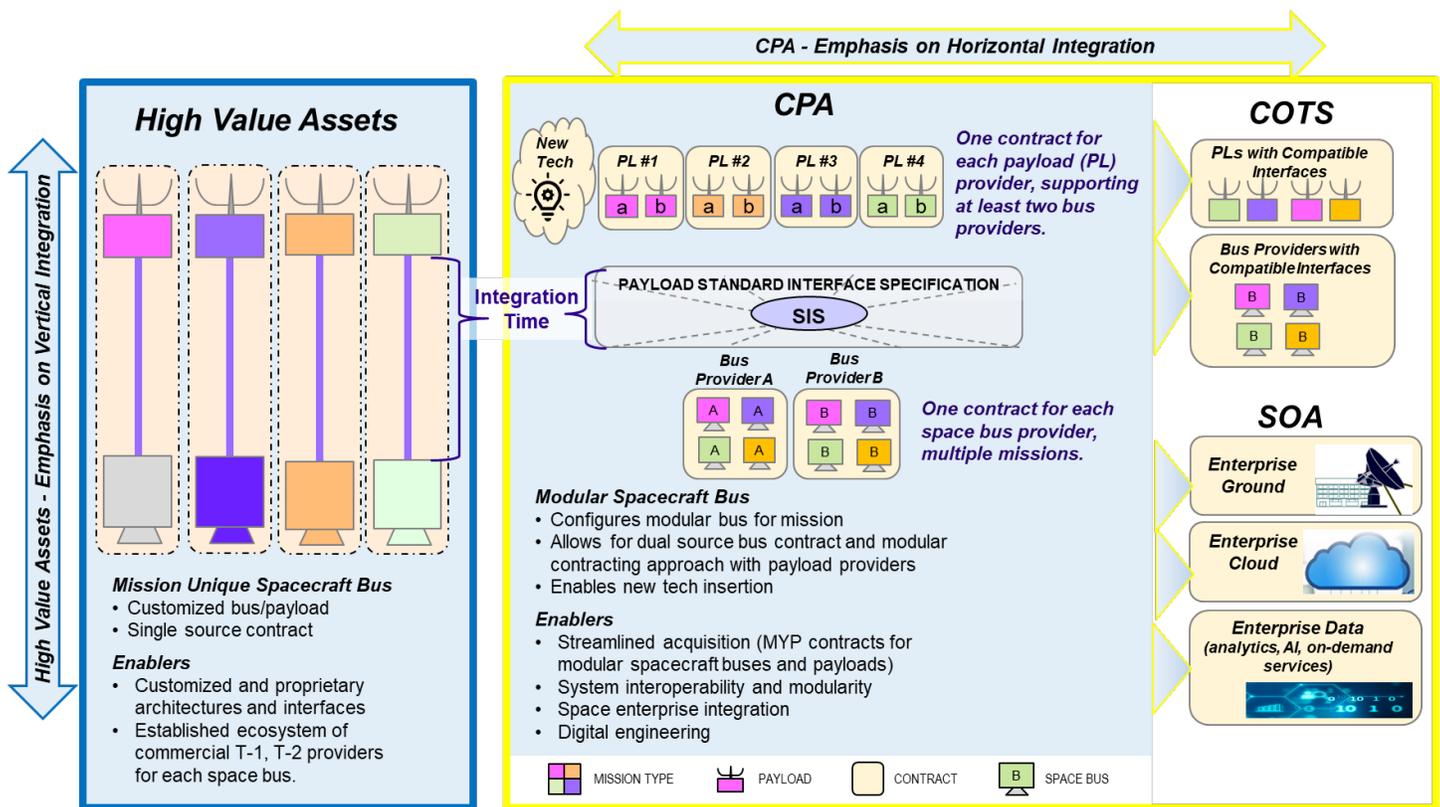
- Nonrecurring engineering (NRE) costs
- Recurring engineering costs (Rec G-1, G-2, G-3, G-4)
- Satellite launch
- Technology insertion
- Satellite failure

**Figure 2: Comparing Launch Tempo Alternatives for Fixed Performance.** Provides a comparison of the traditional (Figure 2A) launch-on-need versus and (Figure 2B) launch-on-schedule. Both approaches can meet similar mission performance requirements. However, launch-on-schedule results in increased technology insertions and development cycles and requires greater upfront capital investment. Longer term, the payback is greater agility and decreased recurring costs due to modular architecture design benefits. Under the CPA approach, each generation of satellite can stay relevant for longer due to a more open architecture which allows new payloads to be introduced.<sup>7</sup>

**A Modular and Scalable Platform for Multiple Missions and Adversarial Threats.** The satellite industry is ripe for reinvention. Instead of focusing on building a highly customized satellite from the ground up, the CPA strategy calls for configuring mission-specific payloads to a modular space bus platform. Figure 3 describes how the space enterprise can compress integration time by opting for a modular architecture. Just as the Evolved Expendable Launch Vehicle (EELV) standard interface specification (SIS) decoupled the launch vehicle design from its payloads, a SIS separates evolution of payloads from their spacecraft “buses.” This provides for agile pairing of payloads to buses and for innovative solutions for either to smoothly bridge the development gap into operational systems.

This strategy is consistent with USSF efforts to leverage DOD’s MOSA policy and move toward rapid prototyping and agile acquisition. Figure 3 also shows that CPA can work well with both COTS and SOA acquisition approaches by allowing those commercial payload and bus providers with compatible interfaces to become part of the ecosystem of potential solutions. Compatible COTS approaches may work particularly well with CPA for the smallsat class of satellites characterized best by proliferated LEO spacecraft such as in the Starlink and OneWeb constellations.

CPA will also shift NSS test and operations practices. Space testbed platforms, such as X-37 and the Long Duration Propulsive ESPA (EELV Secondary Payload Adapter) ring, have already created regular opportunities for on-orbit test. An open and modular vehicle architecture will allow advanced payloads (or platform) solutions to be developed at their natural



**Figure 3: High Value Assets vs. CPA.** CPA initiates a sweeping change from the traditional “High Value Assets” model by breaking down stovepipes and separating spacecraft bus designs from payload designs to achieve efficiencies through higher volume production. The higher production quantity lowers the per-unit platform production cost, even when including non-recurring engineering (NRE). In addition, standard and open government-facilitated spacecraft bus-to-payload interfaces will yield a greater variety of bus-payload pairings (e.g., the multi-sided platform architecture increases potential connections and attracts new participants, or “positive network effects”) and enable regular technology insertion opportunities to outpace the threat. Also, standard interfaces enable the government to own the technical baseline and minimize the potential for technology or vendor lock-in.<sup>8</sup>

pace, tested in place, and then inserted into operational constellations. Extensible platforms, supplemented by digital twins\* and model-based systems engineering (MBSE) capabilities provide operators with training assets for tactics, techniques, and procedures development. The digital twin frees the payload innovators, spacecraft bus providers, and various integrators and program managers from the physical realm, allowing common visualization, including conceptualization, comparison, and creative collaboration capabilities.<sup>9</sup>

## Industry Reinvention

**Enhancing the Speed to Market: Responding to Competitive Threats.** The automotive industry has successfully applied the use of platforms to produce product families since the 1960s. Sometimes these single platforms, the core automobile framework and its underbody, can extend beyond one car manufacturer.<sup>10</sup> For instance, in July 2020, Fisker Automotive announced a platform-sharing arrangement with Volkswagen (VW) to use VW’s modular electric vehicle platform, known as Modular Electric Drive Matrix (MEB). According to the July 2020 investor presentation, the MEB platform will allow Fisker to “enter the market in approximately half of the time and with costs substantially reduced relative to a vertically integrated business model.” The MEB presentation also notes that “multiple vehicles can be produced on the same platform, which will enhance the speed to market and meaningfully reduce the cost and risk of future product offerings.”<sup>11</sup>

By leveraging the existing VW modular vehicle platform, car designer Henrik Fisker avoided the non-recurring engineering costs in producing his own electric vehicle platform. Fisker and other automotive manufacturers are now adopting a horizontal integration business model to avoid the huge capital investments in chassis platform manufacturing and expensive production delays that have haunted Tesla.<sup>12</sup> The space sector can adopt this type of strategy for responding to ever-changing adversary threats, saving time to orbit and reducing costs. Shifting from a vertically integrated and “High Value Asset” architecture to an open and modular CPA strategy can help the space enterprise realize greater economies of scale with a greater diversity of system designs (see Figure 3).

**Extensibility of the CPA Standard Interface Specification (SIS).** Already disruptive new space startups are embracing modular architectures. Examples include:

- ◆ NanoAvionics (Lithuania) – Standardized flight-proven 6U (six-unit) CubeSat modular satellite bus, scalable to 12U and 16U form factors.<sup>13</sup>
- ◆ Maxar (Canada) – Legion Class satellite platform built with a modular architecture that can scale to meet a variety of mission requirements.<sup>14</sup> Maxar has year 2021 launch plans for Earth imaging satellite constellation WorldView Legion and for Swedish mobile broadband provider Ovzon.
- ◆ NovaWurks (Los Alamitos, California) – Developer of the Hyper Integrated Satlet (HISat), a GEO-qualified flight-proven satellite platform that is modular and scalable to various payload missions.<sup>15</sup>

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\*A digital twin is a dynamic digital representation of a physical system. The twin is continually updated as the physical system undergoes various changes throughout its testing, operations, and maintenance lifecycle. The concept of digital twin was introduced during a 2003 Product Lifecycle Management course by Michael Grieves.

Much like VW’s scalable MEB platform, which can provide the underlying electric vehicle platform for a compact sports car or larger utility truck, modular spacecraft can contribute to a range of space mission areas and will have scalability built into their design. The end vision of the modular bus is an open architecture for space vehicles to support a variety of payload modules and missions.

## Future-Proofing Space: Opportunities for Decisionmakers

For those situations where national security space requires increased agility and technology relevance, CPA provides key benefits, including frequent technology insertion, production efficiency, mission flexibility, and support for key industrial base capabilities. Most high-tech commercial companies face the same strategic imperative: to introduce new technologies effectively and often or face competitive obsolescence. The space sector faces a similar challenge. The DOD and national security space enterprise can prepare for adversarial and competitive threats by leveraging modularity and frequent launch rates to support space asset adaptability and space industrial base sustainability.

Opportunities exist for decisionmakers within the context of CPA.

### Recommendations

- ◆ **Embrace a whole-of-government approach.**
  - ▶ **Fit across NSS – Enterprise Integration.** Space responsibilities for the NSS enterprise are spread across multiple organizations. For those missions that require agility, speed, and increased technology relevance, the NSS should adopt a strong CPA enterprise integration approach based on an open architecture.
  - ▶ **Fit with partners.** CPA could extend well beyond NSS to USG civil space. In a world where the ability of a single nation or a small group of nations to drive a global agenda has faded significantly, CPA can provide opportunities for allies and international partners to maximize resources to meet joint goals.
  - ▶ **Fit within the full spectrum of acquisition options.** Decisionmakers should consider a range of levers to provide stability to the space industrial base and to ensure best value for mission budget. CPA can support a range of acquisition strategy options, including use of COTS solutions and service-oriented architecture elements.
- ◆ **Ride the operational and cultural paradigm shift by breaking down a previously monolithic, requirements-driven system into manageable phases.**
  - ▶ **Development ecosystem.** Accept the reality that government is no longer the driver for all space system innovations. Increasingly, government’s role is shifting to a focus on fostering a healthy market and adding limited government-unique capabilities. Use collaborative design spaces/testbeds (e.g., emulating Silicon Valley garage or modern “plug fests”). Nurture an ecosystem of payload innovators. Ensure regular, rapid prototyping of all elements. Emphasize industry consensus standards, and a modular, open framework to lower both the risks of technology transition and barriers to entry.

### What Do We Mean by Modularity and Scalability?

**Modularity** is the grouping of components, logically or physically, with well-defined interfaces to simplify integration, upgrades, and/or changing out elements. CPA argues for modularity within space vehicles, especially between payloads and a bus platform (e.g., attitude determination and control, command and data handling, structure, and thermal), between space and launch vehicles, and at space-to-ground links.

**Scalability** is the ability to change, add, or remove components within an architecture, such that it can be tailored to address a wide range of capabilities and missions. For example, adding propellant tanks for missions where propellant capacity needs to be scaled up. Or swapping a low accuracy sensor for a high accuracy one.<sup>16</sup>

- ▶ **Steady Procurement.** Create a virtuous cycle by placing space vehicles on a production footing using extensible bus platforms, with a regular rhythm for payload flights and technology upgrades.
- ▶ **Deployment.** Continue to emphasize open, modular architecture to allow for smooth technology insertion into operational systems and responsiveness to evolving needs.
- ◆ **Align USSF acquisition authorities for MOSA and CPA.**
  - ▶ **Long-term planning and flexibility across missions and NSS enterprise.** The NSS organizational structure should be complemented by funding and authority that allows for confident long-term planning. This could be enabled by reallocation of budget dollars within the USSF to fund extensible/modular architecture elements supporting multiple missions and to ensure integration across the NSS, with the goal to move toward a flexible architecture for the NSS space enterprise.

Recently, the Air Force’s Report to congressional defense committees on space acquisition identified several opportunities which are worthy of serious consideration, though their viability will depend on shared trust between DOD and Congress.<sup>17</sup> These opportunities include:

- ◆ **Efficient Space Procurement.** Take “an evolutionary block-upgrade approach to production satellites, sometimes referred to as *Efficient Space Procurement*.” The combination of block buys and incremental funding help smooth out budget spikes in procurement<sup>18</sup> and provide a steady, more efficient demand signal to industry.
- ◆ **Define “useable end items” to encourage open architecture and innovation.** Authorize USSF to determine that key components of a modular space vehicle architecture, like a modular satellite bus or various peripherals that could be attached to it, constitute “usable end items” for federal budgetary purposes. This would encourage the “pursuit of open architectures, innovation, robust supply chains, and greater commercial and international partnering opportunities.”<sup>19,†</sup>

## Conclusion: “What got us here, won’t get us there”

What earned the U.S. dominance in space in the twentieth century won’t keep the U.S. ahead in the twenty-first century. By shifting from highly integrated and locally optimized space system designs to a modular and open space architecture, USG buyers can harness domestic production capability and American ingenuity to stay ahead. A modular architecture allows acquisition centers to shift the expensive platform capabilities into production contracts and to focus development dollars for technology maturation and rapidly evolving payloads. This decoupling provides for agility in response to threats and opportunities. The combination of a steady production demand signal and agile design, termed *Continuous Production Agility*, creates a virtuous cycle of industrial capacity, ingenuity, flexible fielding, and new opportunities to seed the next generation of advanced space capability.

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<sup>†</sup>DoD Financial Management Regulation (DOD 7000.14R) “requires the total estimated cost of a complete, military useable end item or construction project [be] funded in the year in which the item is procured.” Exceptions to this policy require Secretary of Defense approval in order to avoid incremental funding or budgeting an item in one fiscal year that would depend on a future year’s funding to complete procurement. For MOSA applications in space, the challenge is that many modular elements may not have military utility by themselves.

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