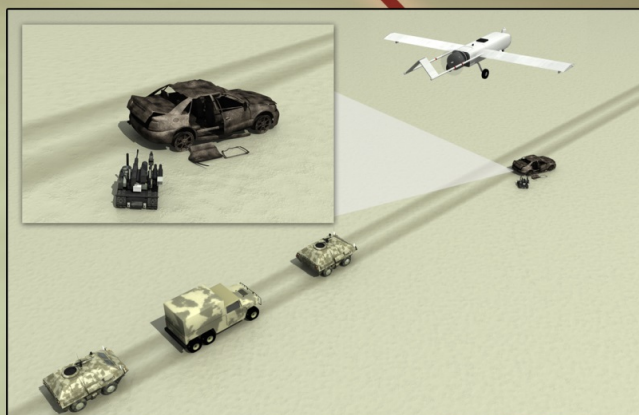
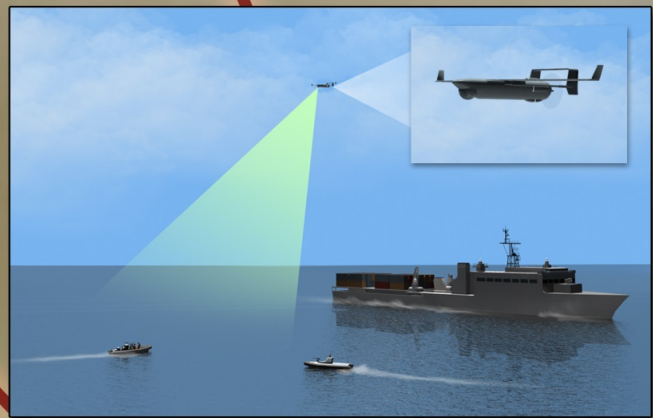
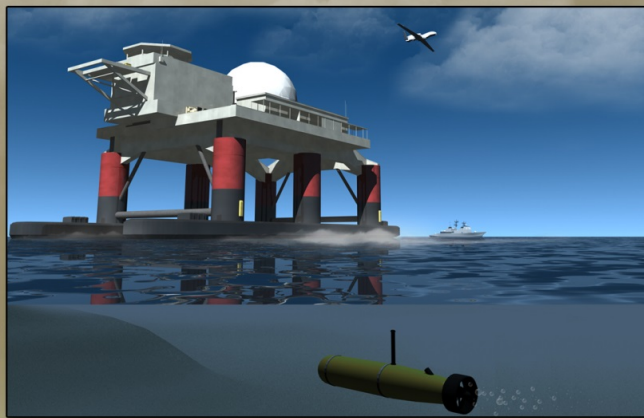
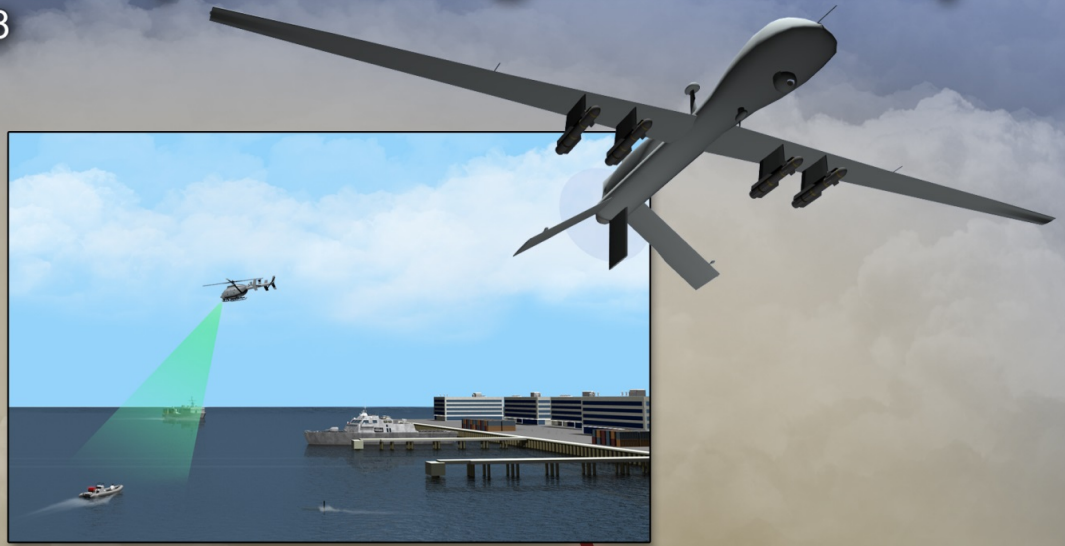


# Unmanned Systems Integrated Roadmap

FY2013-2038



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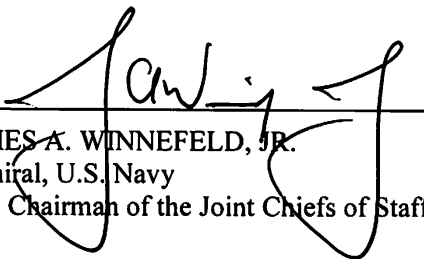
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*UNMANNED SYSTEMS INTEGRATED ROADMAP*

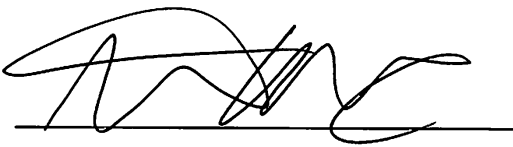
*FY2013-2038*

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# Executive Summary

Unmanned systems continue to deliver new and enhanced battlefield capabilities to the warfighter. While the demand for unmanned systems continues unabated today, a number of factors will influence unmanned program development in the future. Three primary forces are driving the Department of Defense's (DoD) approach in planning for and developing unmanned systems.

1. Combat operations in Southwest Asia have demonstrated the military utility of unmanned systems on today's battlefields and have resulted in the expeditious integration of unmanned technologies into the joint force structure. However, the systems and technologies currently fielded to fulfill today's urgent operational needs must be further expanded (as described in this Roadmap) and appropriately integrated into Military Department programs of record (POR) to achieve the levels of effectiveness, efficiency, affordability, commonality, interoperability, integration, and other key parameters needed to meet future operational requirements.
2. Downward economic forces will continue to constrain Military Department budgets for the foreseeable future. Achieving affordable and cost-effective technical solutions is imperative in this fiscally constrained environment.
3. The changing national security environment poses unique challenges. A strategic shift in national security to the Asia-Pacific Theater presents different operational considerations based on environment and potential adversary capabilities that may require unmanned systems to operate in anti-access/area denial (A2/AD) areas where freedom to operate is contested. Similarly, any reallocation of unmanned assets to support other combatant commanders (CCDRs) entails its own set of unique challenges, which will likely require unmanned systems to operate in more complex environments involving weather, terrain, distance, and airspace while necessitating extensive coordination with allies and host nations.

The combination of these primary forces requires further innovative technical solutions that are effective yet affordable for program development.

The purpose of this Roadmap is to articulate a vision and strategy for the continued development, production, test, training, operation, and sustainment of unmanned systems technology across DoD. This "Unmanned Systems Integrated Roadmap" establishes a technological vision for the next 25 years and outlines actions and technologies for DoD and industry to pursue to intelligently and affordably align with this vision. The Roadmap articulates this vision and strategy in eight chapters:

***Chapter 1: Introduction*** — This chapter explains the Roadmap's purpose and scope. It examines the current unmanned environment from an inventory and budget perspective while also surveying the potential future environment. The chapter includes an operational vignette to show potential future capabilities using some of the technologies described later in this Roadmap. Also, the chapter explains the reduction in budget over the next five years beginning with the President's Budget request for \$5.6 billion in unmanned systems in Fiscal Year 2013. In fact, the unmanned air domain as described in the 2014 President's Budget released to the U.S.

Congress shows a 33.4% reduction in research, development, test, and evaluation and procurement funding from the previous year.

**Chapter 2: Strategic Planning and Policy** — This chapter expounds on the structure, direction, and established guidance from DoD leadership toward planning and developing unmanned systems. It briefly discusses some of the prevailing unmanned issues of the day and expresses departmental direction in their resolution.

**Chapter 3: CCDR Mission and Capability Needs** — A joint perspective emerges in this chapter through a discussion of mission capabilities unique to unmanned systems and an explanation of the requirements process used to deliberately develop those capabilities to achieve improved efficiency, effectiveness, and survivability and to reduce the burden on manpower at lower costs while still meeting future operational requirements. The perspective establishes that future unmanned systems must

- Provide capabilities more efficiently through such attributes as modularity, interoperability, integration with manned systems, and use of advanced technologies.
- Be more effective through features such as greater automation, improved performance, and flexible use of capabilities.
- Be more survivable in contested environments through improved and resilient communications, increased security from tampering, and system design.
- Reduce manpower requirements to operate and support unmanned systems.

**Chapter 4: Technologies for Unmanned Systems** — Certain key areas of interest for improving technology reflect DoD's shift in strategic priorities and address the requirement to continue to reduce lifecycle costs across all systems, including unmanned systems. The six areas of interest highlighted in this chapter are interoperability and modularity; communication systems, spectrum, and resilience; security (research and intelligence/technology protection (RITP)); persistent resilience; autonomy and cognitive behavior; and weaponry. This chapter also describes how limited science and technology funding will potentially impact such emerging technology solutions.

**Chapter 5: Operating Environment** — This chapter describes the operating environments of unmanned systems, which are critical in determining system performance flexibilities (e.g., appropriate levels of automation, maneuverability, communication options) needed to accomplish the mission. The chapter emphasizes that every aspect of the operating environment, including the physical and regulatory, should be incorporated in all acquisition lifecycle stages. Guidance is currently available from each Military Department although requirements and standards must still be developed to support new capabilities.

**Chapter 6: Logistics and Sustainment** — The rapid development and fielding of large numbers and types of unmanned systems present DoD with a significant sustainment challenge. This chapter discusses the necessary transition from supporting immediate warfighter capability requirements to creating an affordable, long-term sustainment environment utilizing a flexible blend of original equipment manufacturers (OEM), other contractors, and organic support to meet logistics support objectives.

*Chapter 7: Training* — The current state and forces shaping the training environment are similar to those that have shaped the logistics environment. As DoD transitions to a peacetime environment, the proper mix among the live, virtual, and constructive domains must be put into place to ensure that the asymmetric advantages offered by unmanned systems can be employed in future operations and at a reduced cost. This chapter describes the current state of training for unmanned systems, related challenges, and the way ahead.

*Chapter 8: International Cooperation* — This chapter reflects DoD's efforts to include cooperative research, development, test and evaluation, and regulatory/standard agreements of defense technologies and systems with foreign partners as well as the procurement of defense articles, systems, and services from foreign partners. DoD objectives and methods are explained.

While DoD unmanned systems development funding will likely be constrained over the early part of this decade, unmanned systems (air, maritime, and ground) continue to hold much promise for the warfighting tasks ahead. If the technical, logistics and sustainment, training, and cooperation challenges are addressed by accomplishing the projects and tasks described in this Roadmap, advances in capability and affordability can readily address the needs dictated by the plans, policies, and operating environments. These advances will achieve well beyond what is attainable today.



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## Unmanned Systems Integrated Roadmap FY2013-2038

### 1 Introduction

The purpose of this Roadmap is to articulate a vision and strategy for the continued development, production, test, training, operation, and sustainment of unmanned systems technology across the Department of Defense (DoD). Recent combat operations in Southwest Asia have demonstrated the military utility of unmanned systems in today's combat environment and have resulted in the rapid integration of unmanned technologies into the joint force structure. This Roadmap establishes a vision for the next 25 years and outlines actions and technologies for DoD, industry, universities, and others to pursue to achieve the sustained, affordable, rapid integration and application of unmanned systems.

This Roadmap is required by goals within the Unmanned Aircraft Systems (UAS) Task Force charter. Specifically, Goal 5 of the charter refers to the roadmap task:<sup>1</sup>

*Goal 5. Serve as the Department's lead activity for the development and promulgation of the Unmanned Systems Roadmap.*

#### 1.1 DoD Vision

DoD will develop and field affordable, flexible, interoperable, integrated, and technologically advanced unmanned capabilities that will

- Prevail in the full range of contingencies and in all operating domains, including cyberspace (Defense Strategic Guidance 2012);<sup>2</sup>
- Enable decisive force effectiveness in Joint and coalition operations;
- Be critical to future success;
- Emphasize missions according to strategic guidance from intelligence, surveillance, and reconnaissance (ISR); counterterrorism; counter-weapons of mass destruction (WMD); and operations required to operate across all environments, including anti-access and area denial (A2/AD);
- Protect the homeland; and
- Be able to surge and regenerate forces and capabilities.

#### 1.2 Scope

This Roadmap continues the path outlined in the 2011 edition of the Roadmap and addresses three unmanned operating domains: air, ground, and maritime. It leverages the existing roadmaps produced by the individual military departments and agencies and focuses on the common technical, training, and policy challenges that each Armed Service faces in achieving the full potential of unmanned systems technology. A list of the applicable Service documents that form the foundation of these conclusions can be found in Appendix A.

<sup>1</sup> The full charter is available on the Unmanned Warfare Information Repository (Figure 1).

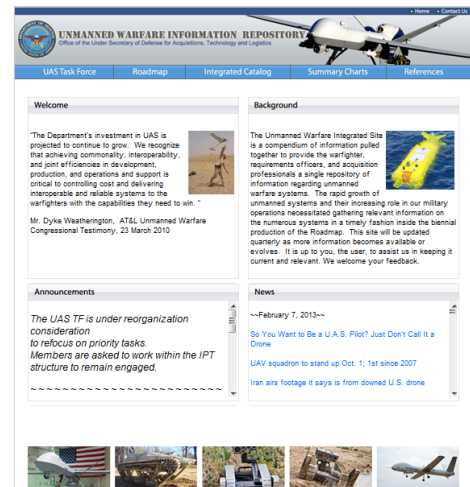
<sup>2</sup> "Sustaining U.S. Global Leadership: Priorities for 21st Century Leadership," Defense Strategic Guidance, January 2012.



## Unmanned Systems Integrated Roadmap FY2013-2038

This document serves a diverse stakeholder community with one of the primary target audiences being DoD. By providing a common vision toward overcoming unmanned challenges, this Roadmap can shape military department investments in unmanned innovations. The plans outlined in this document also shape the efforts of Service requirements developers, budget planners, program managers, laboratories, warfighters, and other key DoD stakeholders. In addition, this document serves the defense industry by providing insight into DoD priorities and helping to shape industry investments, particularly for independent research and development investment strategies. Finally, this Roadmap informs key stakeholders outside DoD, including Congressional staffs, the Government Accountability Office, advocacy groups, and academic institutions.

The traditional unmanned catalog, historically contained in this document, now resides in a separate, online tool. This tool has been in place since 2010 and provides greater functionality than a hard-copy document. The online approach also facilitates more frequent updates to the catalog than the biennial publication of this Roadmap. Readers can find the common access card-protected catalog on the Unmanned Warfare Information Repository (Figure 1) at <https://extranet.acq.osd.mil/uwir/>.<sup>3</sup>



**Figure 1. Unmanned Warfare Information Repository**

### 1.3 Current Environment

Urgency resulting from the swiftly changing international environment is deeply felt within DoD's acquisition programs. Specifically, three forces are driving this sense of urgency: department budgetary challenges, evolving security requirements, and a changing military environment. Budgets for unmanned systems are discussed in this section while the other two forces are addressed in the future environment section (see Section 1.4).

*As we turn the page on more than a decade of grinding conflict, we must broaden our attention to future threats and challenges. That means continuing to increase our focus on the Asia-Pacific region, reinvigorating historic alliances like NATO, and making new investments in critical capabilities like cyber.*

*In order to accomplish our mission, we also must make wise budget decisions prioritizing our interests and requirements.*

*— Chuck Hagel, Secretary of Defense<sup>4</sup>*

<sup>3</sup> Common access card protection is required on the OUSD(AT&L) network infrastructure. Inquiries can be made to OUSD(AT&L)S&TS-UW&ISR. See page 149 of Appendix G for contact information.

<sup>4</sup> Source: <http://www.defense.gov/Speeches/Speech.aspx?SpeechID=1754>.

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The 2013 Presidential Budget (PB13) reduced the overall DoD budget by \$259 billion over the next Future Years Defense Plan (FYDP), with a total reduction of \$487 billion over the next 10 years. The 2014 Presidential Budget, with the potential effects of sequestration, further reduces the budget by about \$55 billion across the FYDP.<sup>5</sup> Some defense programs were bolstered with additional funds while others required adjustments downward. The budget focuses on developing A2/AD technologies to ensure dominance in A2/AD scenarios and will fund the next-generation bomber and other modernizations. Table 1 explains the unmanned systems portion of PB14.

**Table 1. DoD Unmanned Systems Funding (\$ mil/PB14)**

FYDP		2014	2015	2016	2017	2018	Total
Air	RDTE	1189.4	1674.0	1521.4	1189.4	1087.9	6662.2
	Proc	1505.5	2010.2	1843.5	1870.7	2152.8	9382.7
	OM	1080.9	1135.2	1102.7	1156.9	1178.5	5654.1
Domain Total		3775.9	4819.4	4467.6	4217.0	4419.3	21699.1
FYDP		2014	2015	2016	2017	2018	Total
Ground	RDTE	6.5	19.1	13.6	11.1	10.6	60.9
	Proc	6.5	27.9	30.7	42.6	55.4	163.1
	OM	0.0	0.0	0.0	0.0	0.0	0.0
Domain Total		13.0	47.0	44.3	53.7	66.0	223.9
FYDP		2014	2015	2016	2017	2018	Total
Maritime	RDTE	62.8	54.8	66.1	81.0	87.2	351.9
	Proc	104.0	184.8	160.1	158.1	101.1	708.2
	OM	163.4	170.3	182.4	190.5	193.6	900.2
Domain Total		330.2	409.8	408.6	429.7	381.8	1960.2
FYDP		2014	2015	2016	2017	2018	Total
All Unmanned Systems	RDTE	1,258.7	1,747.9	1,601.1	1,281.5	1,185.7	7,075.0
	Proc	1,616.0	2,222.9	2,034.3	2,071.4	2,309.3	10,253.9
	OM	1,244.3	1,305.4	1,285.1	1,347.4	1,372.1	6,554.3
Domain Total		4,119.1	5,276.2	4,920.5	4,700.4	4,867.1	23,883.2

Note: Ground operations and maintenance (OM) is funded with overseas contingency operations funding.

Over the past decade, the quantities and types of unmanned systems acquired by the Military Departments have grown, and their capabilities have become integral to warfighter operations. The size, sophistication, and cost of the unmanned systems portfolio have grown to rival traditional manned systems. Unmanned systems now include both major acquisition programs to provide long-term capability and short-duration projects to meet urgent needs.

For this Roadmap, unmanned systems operating in the air domain are referred to as unmanned aircraft systems (UAS); in the ground domain, unmanned ground systems (UGS); and in the maritime domain, unmanned maritime systems (UMS). Each operating domain brings a unique set of environmental attributes affecting the warfighter. In complex mission

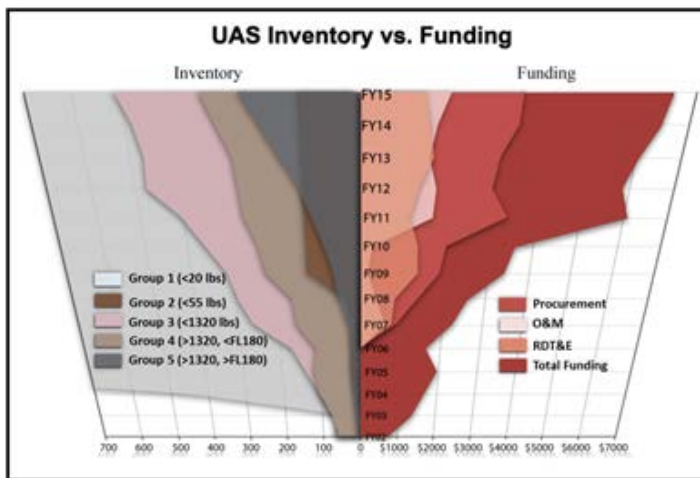
<sup>5</sup> Source: <http://www.defense.gov/speeches/speech.aspx?speechid=1643>.

## Unmanned Systems Integrated Roadmap FY2013-2038

environments, multiple systems across several domains must cooperate and interoperate to effectively perform mission tasks.

### 1.3.1 Unmanned Aircraft Systems

An unmanned aircraft system (UAS) is a “system whose components include the necessary equipment, network, and personnel to control an unmanned aircraft.”<sup>6</sup> In some cases, the UAS includes a launching element. DoD inventories and funding of UAS are expected to continue a gradual upward trend through 2015 (see Figure 2) and then trend downward in 2016 and beyond, although UAS experienced a full \$1.3 billion (33.4%) reduction from fiscal year (FY) 2013 to PB2014 in combined research, development, test, and evaluation (RDT&E) and procurement funding. Outside DoD, UAS sector growth is predicted to continue to rise and was described as “the most dynamic growth sector of the world aerospace industry this decade.”<sup>7</sup>



**Figure 2. UAS Inventory vs. Funding**

comparison of DoD funding plans versus industry predictions indicates DoD will not be the bulk user within that market. However, DoD does intend to be the most innovative user. From a strategic planning perspective, UAS have grown to a sizable fleet providing a variety of capabilities that DoD will need to maintain over the near term. See Figure 3.

Within DoD, RDT&E funding is planned to taper off over the next five years; and depot maintenance consolidation efforts underway are expected to reduce operation and maintenance costs (O&M).

However, considering current inventory levels, overall funding demonstrates a continued commitment to invest in UAS performing predominately ISR missions. Thus, while one industry analysis and forecasting group estimates worldwide UAS spending will almost double over the next 10 years to a total of \$89 billion,<sup>8</sup> a

<sup>6</sup> Joint Publication (JP) 3-52, Joint Airspace Control, 20 May 2010.

<sup>7</sup> “Teal Group Predicts Worldwide UAV Market Will Total \$89 Billion in Its 2012 UAV Market Profile and Forecast,” *Press Release Newswire*, United Business Media, 11 April 2012.

<sup>8</sup> Ibid.

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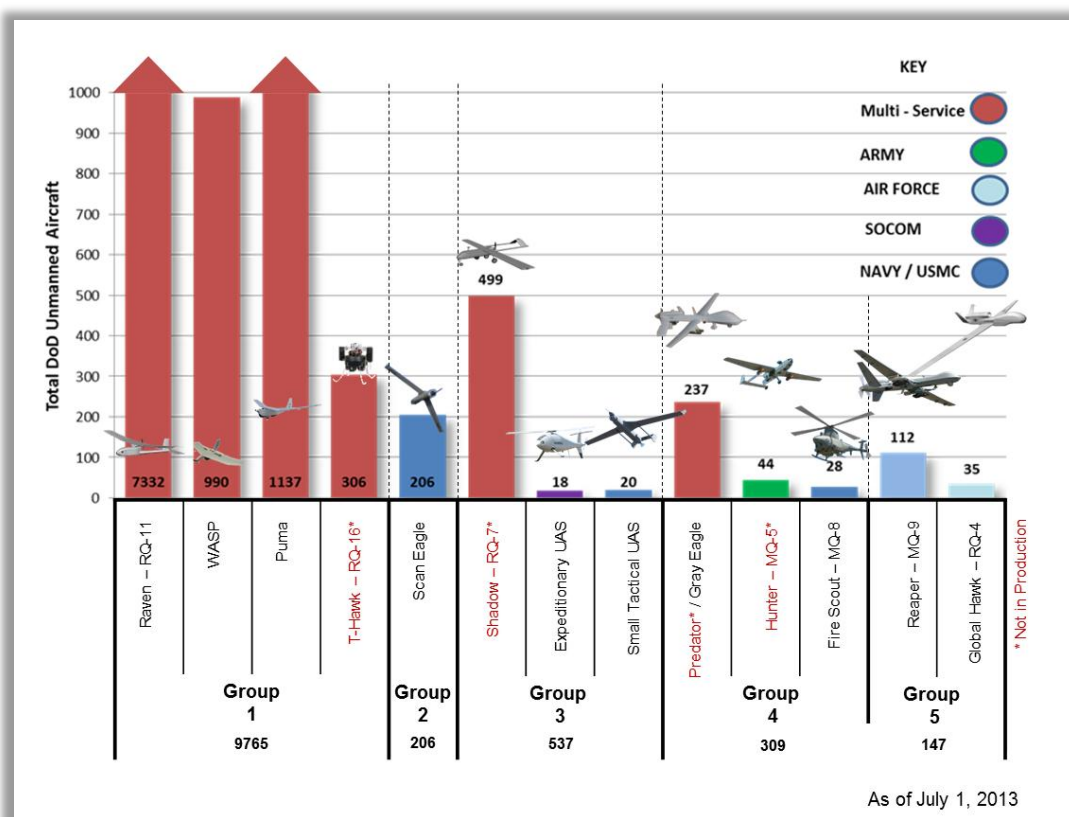


Figure 3. Inventory of DoD UAS

Looking toward the future, modernization of current capabilities will dominate, and limited development of new capabilities will likely focus on smaller numbers of higher end platforms capable of operating in more contested air environments. With fewer new systems in development and many future projects being deferred, the planning outlook toward future systems is much more conservative. See Figure 4.

Additionally, DoD seeks to improve overall interoperability over time. The latest Joint Concept of Operations (CONOPS) for UAS (approved by the Joint Requirements Oversight Council (JROC) builds on all applicable joint guidance for manned aircraft operations while describing the capabilities and complexities of employing UAS.<sup>9</sup> Similarly, the latest Unmanned Aircraft Systems Interoperability Initiative (UI2) Capability Based Assessment (CBA) provides an operational assessment of UAS interoperability tasks needs.<sup>10</sup> The CBA identifies and prioritizes DoD's ability to satisfy those needs and suggests doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy (DOTMLPF-P) solutions to close each gap.

<sup>9</sup> Joint CONOPS for UAS, Third Edition, November 2011:

[https://extranet.acq.osd.mil/uwir/docs/Joint\\_Concept\\_of\\_Operations\\_for\\_Unmanned\\_Aircraft\\_Systems\\_Third\\_Edition\\_Final\\_November\\_2011.pdf](https://extranet.acq.osd.mil/uwir/docs/Joint_Concept_of_Operations_for_Unmanned_Aircraft_Systems_Third_Edition_Final_November_2011.pdf)

<sup>10</sup> Unmanned Aircraft Systems Interoperability Initiative (UI2) Capability Based Assessment, 14 May 2012:

<https://extranet.acq.osd.mil/uwir/docs/UI2%20CBA%20Report%20Final%20Signed.pdf>

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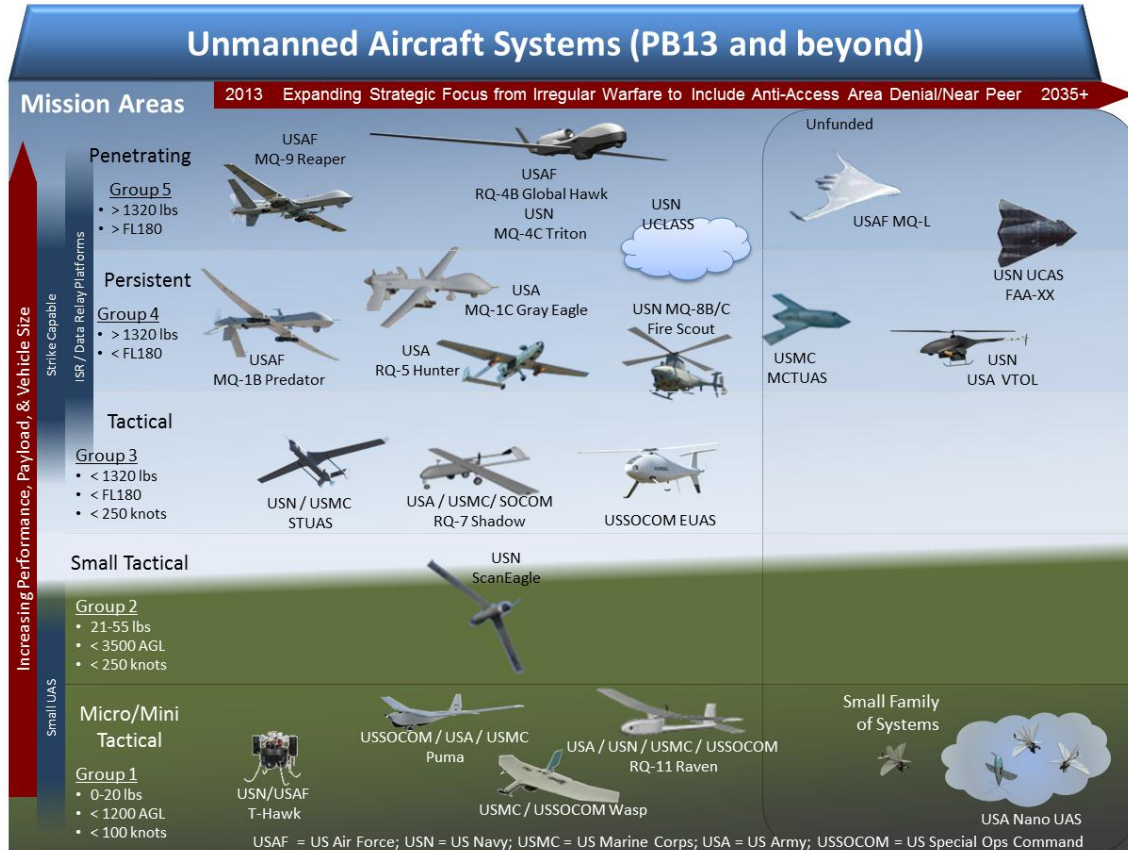


Figure 4. UAS (PB13 and Beyond)

## 1.3.2 Unmanned Ground Systems

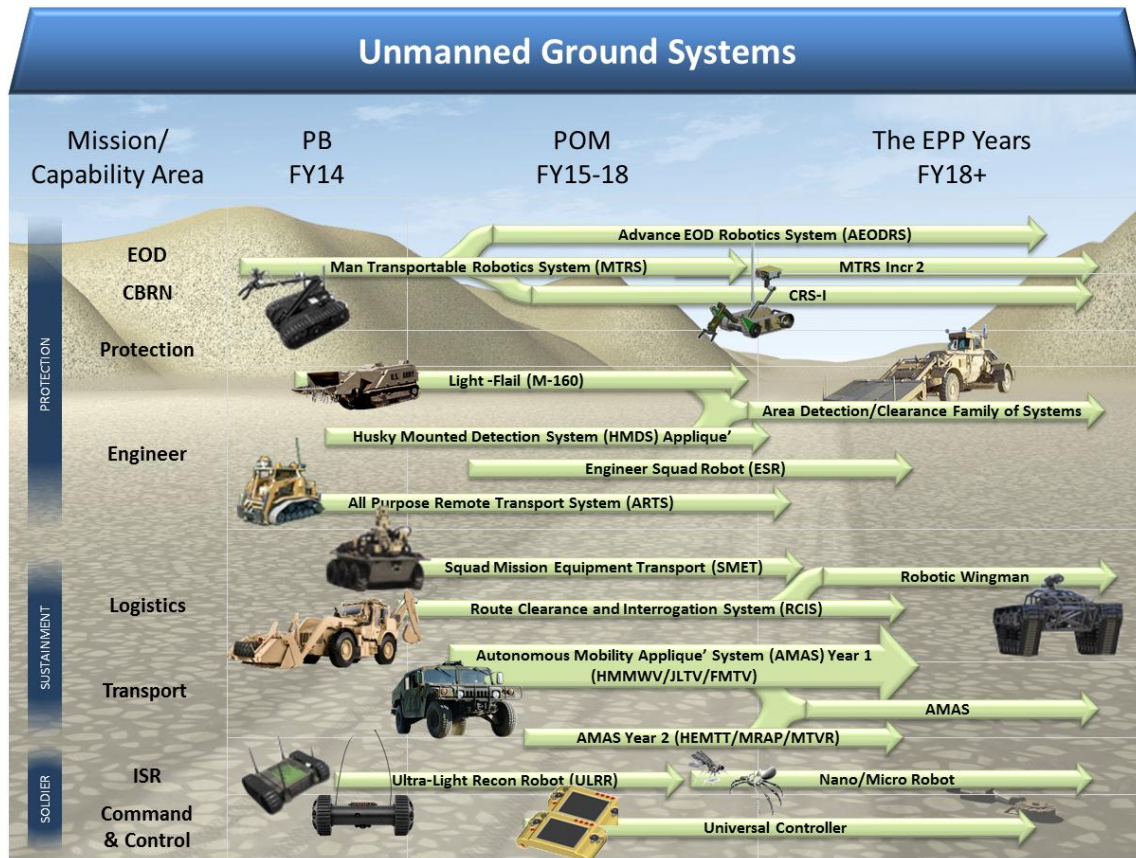
UGS are a powered physical system with (optionally) no human operator aboard the principal platform, which can act remotely to accomplish assigned tasks. UGS may be mobile or stationary, can be smart learning and self-adaptive, and include all associated supporting components such as operator control units (OCU). Integration of UGS enabled by add-on mission module payloads to the other military domains is an essential part of future DoD operations, not only from a system perspective, but also from a joint-service and coalition perspective. This vision continues to be strengthened as ground-based robots have proven their worth in Iraq and Afghanistan across a spectrum of mission areas as shown in Figure 5.

As the Nation's 10 years of war wind down, DoD inventories and funding of UGS are expected to decrease in 2014, followed by a gradual upward trend in 2016 and beyond with the fielding of new programs of record (PORs) to meet expanding mission requirements. The first wave of UGS fielding resulted from rapid acquisition programs driven by urgent warfighter needs in support of Operation Iraqi Freedom. Recognizing the need to maintain the UGS capability beyond today's fight, but lacking fielded PORs, the Deputy Chief of Staff of the Army approved a directed requirement for continued support and sustainment of selected contingency systems. This directive authorizes the sustainment of specific capabilities beyond today's



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worldwide engagements to bridge the capability gap until enduring capabilities are developed and acquired using traditional Armed Service programming.



**Figure 5. UGS by Mission/Capability Area**

DoD has maintained an enterprise approach to UGS capability since the early 1990s. The Joint Ground Robotics Enterprise (JGRE) construct has enhanced joint-service capabilities and coordination and provided a means for focusing DoD efforts in UGS. The JGRE focus has evolved over time in response to technology advancements and warfighter needs. Today's enterprise focus is on synchronizing UGS programs across the Services to eliminate redundancy and maximize investments to ensure that future systems are affordable, mission flexible, and supportable while eliminating duplication across DoD.

In response to Congressional concerns, the U.S. Army has developed a 30-year UGS campaign plan. This campaign plan was developed as a broad avenue of approach to coordinate and synchronize UGS RDT&E efforts with Army force modernization requirements. The purpose of the resulting UGS execution order is to provide a modernized force of manned-unmanned teams with improved persistence, protection, and endurance. Realization of this goal will decrease physical and cognitive workloads on our warfighters, while increasing their combat capabilities. The end state is an affordable, modernized force as a manned-unmanned team with improved movement and maneuver, protection, intelligence, and sustainment.

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### 1.3.3 Unmanned Maritime Systems

UMS comprise unmanned maritime vehicles (UMVs), which include both unmanned surface vehicles (USVs) and unmanned undersea vehicles (UUVs), all necessary support components, and the fully integrated sensors and payloads necessary to accomplish the required missions. While funding for UMS is falling 45% across the FYDP, future UMS inventories continue to rise. Indeed, as new littoral combat ships arrive in service, support UMS will rise in number. Refer to Figure 6 for an overview of UMS.

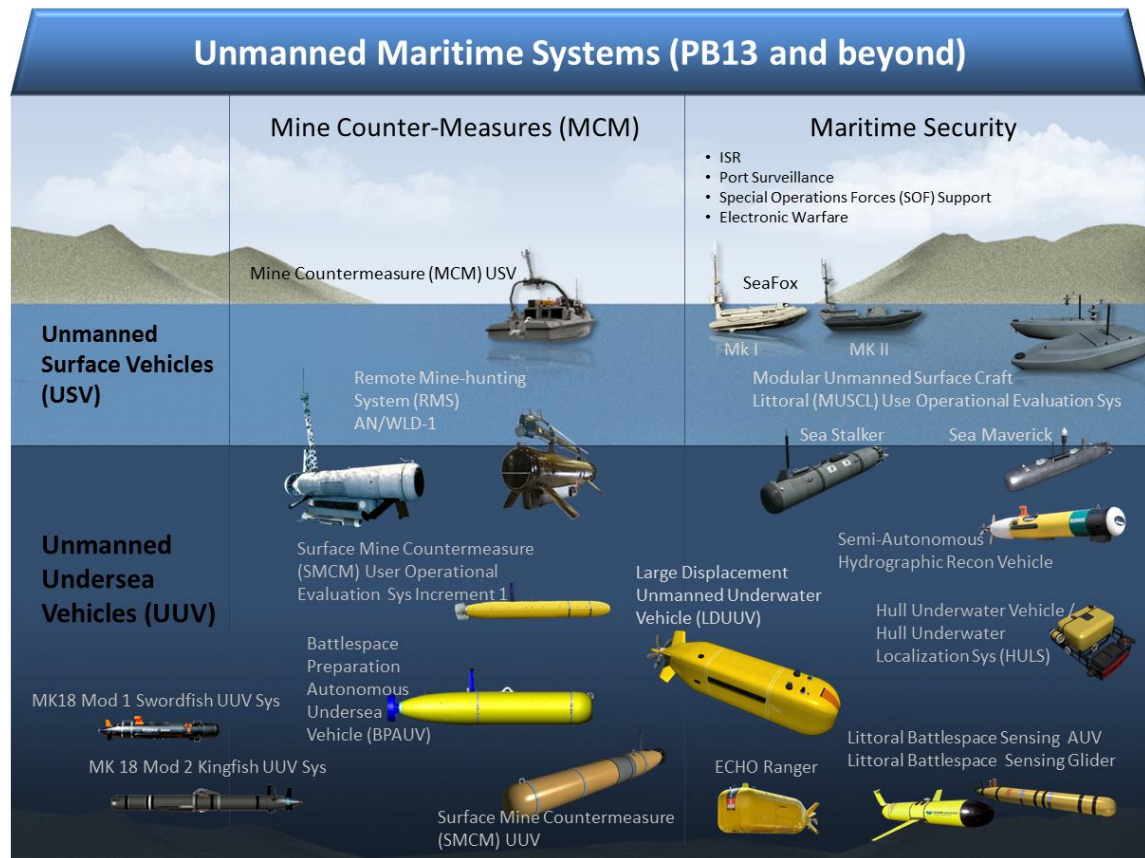


Figure 6. UMS by Mission Area

### 1.4 Future Environment

As stated in 1.3, the swiftly changing strategic environment is causing a sense of urgency primarily driven by three forces: department budgetary challenges, evolving security requirements, and a changed military environment. Sections 1.3.1, 1.3.2, and 1.3.3 addressed budget challenges, and 1.4.1, 1.4.2, and 1.4.3 address the security requirements and military environment and describe the future operating environments as foreseen in U.S. strategic documents.



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### 1.4.1 Objectives

The 2010 Quadrennial Defense Review identified two clear objectives<sup>11</sup> for DoD:

- Rebalance the capabilities of America's Armed Forces to prevail in today's wars while building the capabilities needed to deal with future threats.
- Continue strong support for DoD processes to better support the urgent needs of the warfighter; buy weapons that are usable, affordable, and truly needed; and ensure that taxpayer dollars are spent wisely and responsibly.

In today's conservative fiscal environment, austere military budgets must be focused on purchasing improved capabilities that responsibly support the nation's strategies while maintaining a leading edge in appropriate technology innovations. These strategies are based on potential conflicts around the world. Two strategy and budget documents that guide joint priorities, "Sustaining U.S. Global Leadership: Priorities for 21<sup>st</sup> Century Leadership" and "Defense Budget Priorities," both released in January 2012, state that U.S. military strategy will place renewed emphasis on the Asia-Pacific region.<sup>12,13</sup>

*Indeed, as we end today's wars, we will focus on a broader range of challenges and opportunities, including the security and prosperity of the Asia Pacific.*

*— Barack Obama, President of the United States<sup>14</sup>*

Consequently, air, land, and naval forces in the DoD planning cycle will be focused on improving operational capabilities to address current and future threats plus A2/AD security challenges analogous to the strategic state of the Asia-Pacific region as described in the "Joint Operational Access Concept."<sup>15</sup>

Today's problems and their solutions may not solve the problems arising 20 years from now. What possible strategic world situations should the United States prepare for to prevail militarily in conflicts 25 years in the future? What will the operational environment be like? Who are potential rivals? How should the United States invest in cutting-edge, critical unmanned capabilities to ensure success of the joint strategy while using networked cross-domain solutions?

<sup>11</sup> "Quadrennial Defense Review," February 2010.

<sup>12</sup> "Sustaining U.S. Global Leadership: Priorities for 21st Century Leadership," Defense Strategic Guidance, January 2012.

<sup>13</sup> "Defense Budget Priorities," January 2012.

<sup>14</sup> "Quadrennial Defense Review Report," February 2010.

<sup>15</sup> "Joint Operational Access Concept," 17 January 2012.

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### 1.4.2 Trends and Characteristics

Consider these environmental trends and characteristics and how they will affect DoD's operational unmanned systems:



- *Pressure for reductions in federal budgets* (and thus reduced military department budgets) will continue to increase; therefore, DoD cannot afford to acquire capabilities exceeding military needs. This increased pressure will further drive the need to be interoperable and better share information across the joint force.<sup>16</sup>
- *Operational issues will be more complex* as the pace of technological change accelerates.<sup>17</sup> Designing systems to easily accept technological improvement capabilities and support multiple mission needs will be increasingly important.
- *U.S. military forces will be rebalanced.*
  - Tension and change will contribute to uncertainty in the Middle East.
  - Unable to compete force-on-force or globally, determined adversaries will adapt their strategies toward attempting to prevent access to certain regions or airspace and will target critical, less protected nodes (e.g., South Asia, Africa, and the Middle East). Such strategies will likely include attempts at the proliferation of nuclear weapons.
- *Violent extremism* will continue to threaten U.S. interests at home and around the globe.
- *Unmanned technologies will continue to improve* in many different capability areas.
  - Competitors are catching up in unmanned technology.
  - Increasingly data-intensive multisensor/multi-mission capabilities are evolving.
  - Unmanned technology innovations are rapidly increasing.
- *Cyber domain will be a conflict environment* as readily as land, sea, or air and space.<sup>18</sup>
- *Enemy unmanned systems will complicate* air, ground, and maritime operations by adding new low-altitude, ground, and amphibious threats to the force that must be countered. This concern will require the development of friendly countermeasures, including tactics, techniques, procedures, and training that enable the force to operate in the emerging environment.

### 1.4.3 Operational Vignette

The following futuristic storyline gives insight into the capabilities that could come about with today's emerging technologies applied on future unmanned systems.

<sup>16</sup> "Sustaining U.S. Global Leadership: Priorities for 21st Century Leadership," Defense Strategic Guidance, January 2012.

<sup>17</sup> Ibid.

<sup>18</sup> "Joint Operational Access Concept," 17 January 2012.

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### 1.4.3.1 The Setting

In the year 2020, a nuclear inspection team from the United Nations (U.N.) International Atomic Energy Agency is expelled from the (notional) country of Norachi while on its second visit in three weeks. The agency team was denied access to nuclear sites and, therefore, could not verify any “military dimension” within the country’s nuclear program. A government spokesperson for Norachi insists its nuclear program does not have military applications. Meanwhile, Norachi’s leader declares on state-owned TV that the country has weapons grade nuclear enrichment capability and announces new military exercises “to prevent aggressions” by Western powers. Western concern centers on a new uranium enrichment plant, which is buried deep underground and, therefore, much harder to monitor or, if necessary, attack. Additionally, the potential transport and/or selling of WMDs materiel or technology increases the threat to the Western powers.

Western officials are divided over whether Norachi is shifting toward a defensive posture or is just playing for time to pursue its nuclear program, which it says is for strictly peaceful purposes. The U.N. has responded by enacting a ban on the sale of goods to Norachi, including an embargo on oil sales. Neighboring nations that are friendly to Norachi do not share this view.

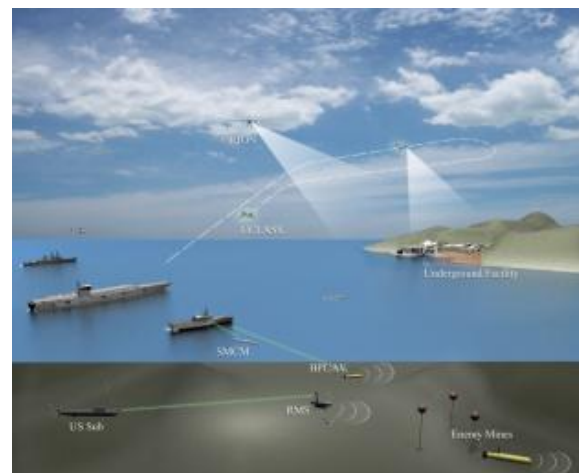
The U.N. is requesting the support of the United States and allied powers in surveillance and enforcement of the export bans to Norachi. Norachi is situated on the coast with mountainous areas inland. See Figure 7. Many ports have active commercial shipping enterprises in addition to their military facilities and berths. Additionally, Norachi has a modern road network and mature air transportation network for transport of goods to and from the country.

### 1.4.3.2 U.S. Forces

- Traditional manned air, sea, and land forces
- Land-based unmanned aircraft
- Sea-based unmanned aircraft operated from aircraft carriers and support ships
- Unmanned ground systems
- Vertical lift unmanned systems
- UUVs
- Small tactical UAS and UGS

### 1.4.3.3 Norachi Forces

- Homeland Defense ground forces
- Surface ships (patrol boats and frigates)
- Kilo-class submarines
- Integrated air defenses with anti-aircraft artillery and surface-to-air missile systems
- Late-model fourth-generation fighters
- Sophisticated jammers
- Sensor intelligence



**Figure 7. Operational Battlespace**

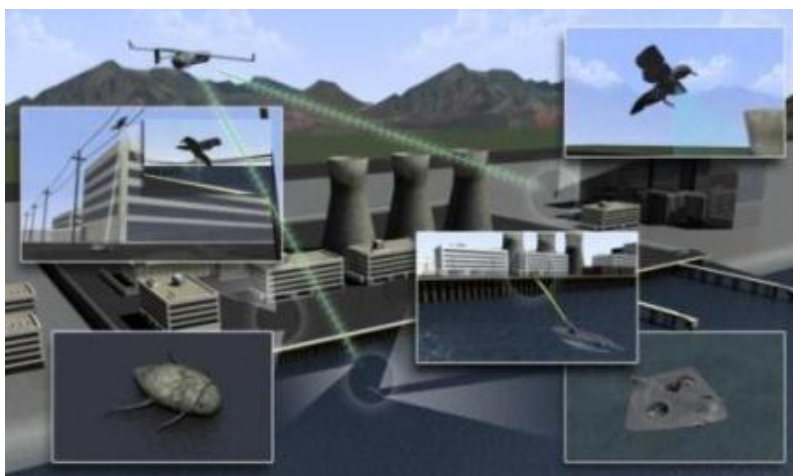
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### 1.4.3.4 Air, Maritime, and Ground Intelligence

The National Command Authority (NCA) tasks the Combatant Commander (CCDR) to support the U.N. resolution and assist in enforcing the ban on Norachi. NCA also requests increased surveillance and reconnaissance efforts on Norachi for indications and warnings of potential escalation of threats.

To enforce the ban, the CCDR employs a variety of land-based and sea-based systems to conduct ISR and interdiction. Unmanned systems provide a critical enabler to this mission. To survey the land and sea approaches to the country, the Air Force's and Navy's unmanned systems, including the high-altitude long-endurance (HALE) UAS with its multiday ISR and communication relays, provide extended persistence with a wide variety of sensors. Also, the aircraft carrier *USS Abraham Lincoln* and its supporting carrier strike group ships are tasked to help enforce the maritime portion of the ban on exports to Norachi. Using the Unmanned Carrier Launched Airborne Surveillance and Strike System (UCLASS), persistent ISR and strike capabilities are available to the CCDR. Using ship-based and land-based UAS and UMS with sophisticated sensor suites, maritime movement to and from Norachi is effectively tracked and identified. UUVs provide an effective network that detect underwater traffic and track identified submersibles in detail. Some of these underwater systems have extreme endurance and can patrol enemy coastlines.

After a few days, unmanned reconnaissance flights and UMS intelligence establish pattern of life in the region and at the WMD facilities, including maritime traffic in the region. Activity-based algorithms exploit the incoming intelligence data and conclude anomalies exist in the Norachi nuclear facility network. Additional unmanned assets are employed to further investigate these anomalies. Special Operations Forces deploy inexpensive, small, low-power unmanned sensor systems. One bird-like vehicle is deployed to conduct an overwatch of one noted facility. It perches on an electrical power line where it derives its power to gather and transmit images. Rugged UGS are deployed; they navigate over difficult terrain autonomously and provide closer video surveillance. These electrically powered vehicles accept power from solar/moon panel converters and a low-power laser light received from overhead assets in the



**Figure 8. Array of Future Unmanned Systems (Notional)**

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vicinity, such as the perched bird-like vehicle. See Figure 8. When these unmanned assets are applied and the resulting intelligence data are analyzed, U.S. leadership concludes Norachi has reached a critical stage in development at the nuclear site. Human intelligence correlates and confirms this conclusion.

### *1.4.3.5 Escalation of Tension*

Norachi determines the international community is aware of the maturity of its nuclear program. To garner support, Norachi reaches out to another like-minded nation and negotiates a sale of WMD material. Through human intelligence, the international community becomes aware of the sale, yet does not know how or when the WMD will be moved. The threat of WMD proliferation, plus the potential of interception and stealing by non-state actors, escalates the tension with Norachi.

The United States maintains a heightened level of surveillance to detect any shipments from the WMD facilities. The integrated network of air and ground sensors, with automated processing and exploitation algorithms, monitors activity and cues sensors based on activities. The sensors detect abnormal movements of vehicles from a key WMD storage site. The U.N. authorizes interception of the WMD because proliferation and potential terrorist use of the WMD are greater risks than a likely response from Norachi. Penetrating, high-altitude airborne systems track the vehicle and provide cueing information to incoming strike aircraft. Launched from the off-shore aircraft carrier, the strike package comprises of manned tactical aircraft with numerous combat support UAS providing tactical intelligence communication relay, jamming support, and strike support. The joint strike fighter operates as a command ship and works in concert with its supporting unmanned systems as a seamless network of strike and jamming aircraft. The strike package penetrates Norachi airspace and intercepts, strikes, and stops the convoy. An extraction team follows shortly behind, secures the area, and locates the WMD. The extraction team loads the cargo on unmanned vertical-lift transports and departs the area. The operation stands down while maintaining a continuing presence of air, sea, and land systems to maintain situational awareness as the Norachi situation evolves.

As illustrated by this vignette, many new capabilities might be possible utilizing today's emerging technologies and applying those technologies on unmanned systems.

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## 2 Strategic Planning and Policy

### 2.1 Strategic Guidance

DoD uses a vast array of unmanned systems to complete its mission, from ground and undersea to aircraft flying in the upper regions of the atmosphere. In the past, those systems were such an enhancement to ongoing operations that some systems were fielded before they were completely ready for production and without adequate training plans while others were being rapidly developed in limited numbers to satisfy an immediate warfighter need.

Unmanned systems continue to prove their value in combat operations in Afghanistan, where military operations are planned and executed in extremely challenging environments. Indeed, adversaries are fighting using increasingly unconventional means, taking cover in the surrounding populations, and employing asymmetric tactics to achieve their objectives. In future conflicts, we must be prepared for these tactics as well as for a range of other novel methods of opposition, including so-called “hybrid” and A2/AD approaches to blunting U.S. power projection. Unmanned systems will be critical to U.S. operations in all domains across a range of conflicts, both because of their capability and performance advantages and because of their ability to take greater risk than manned systems.

As unmanned systems have proven their worth on the battlefield, DoD has allocated an increasing percentage of its budget to developing and acquiring these systems. With the transition from a handful of innovative experimental systems to normalized program developments, unmanned systems have received their share of inclusion in Congressional direction and are influenced by many acquisition initiatives and departmental policies.

### 2.2 Congressional Direction

Legislation requiring

- Creation of an executive committee (ExCom) for UAS airspace integration
- Federal Aviation Administration (FAA) plan integration of UAS into the National Airspace System (NAS) by 2015



### 2.3 Acquisition Initiatives

- Should Cost/Would Cost<sup>19</sup>
- Affordability<sup>20</sup>
- Better Buying Power<sup>21</sup>
- Roadmap Guidance — Mandate Affordability as a Requirement<sup>22</sup>



<sup>19</sup> Carter, Ashton B., Under Secretary of Defense, Acquisition, Technology, and Logistics, “Should-cost and Affordability Memorandum”: <http://www.acq.osd.mil/docs/Should-cost%20and%20Affordability.pdf>.

<sup>20</sup> Ibid.

<sup>21</sup> Better Buying Power (Public Site): <https://acc.dau.mil/bbp>.

<sup>22</sup> Carter, Ashton B., Under Secretary of Defense, Acquisition, Technology, and Logistics, “Implementation Directive for Better Buying Power — Obtaining Greater Efficiency and Productivity in Defense Spending”: [http://www.acq.osd.mil/docs/USD\(AT&L\)\\_Implementation\\_Directive\\_Better\\_Buying\\_Power\\_110310.pdf](http://www.acq.osd.mil/docs/USD(AT&L)_Implementation_Directive_Better_Buying_Power_110310.pdf).



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### 2.4 Departmental Policy Consideration

Of the many issues arising over the use of unmanned systems in today's world environment, several have become questions of departmental policy and required active direction from leadership. Five of the many unmanned issues that required departmental consideration over the past two years include autonomy, data protection, data exploitation, selective innovation, and Manned-Unmanned System Teaming (MUM-T).

#### 2.4.1 Autonomy

DoD defines unmanned aircraft as “an aircraft or balloon that does not carry a human operator and is capable of flight under remote control or autonomous programming.”<sup>23</sup> Therefore, when the aircraft is under remote control, it is not autonomous. And when it is autonomous, it is not under remote control. While these two conditions could exist (controlled and uncontrolled), current DoD UAS are remotely operated and capitalize on automation in extreme circumstances, such as a lost link condition, to automatically perform a preprogrammed set of instructions. This distinction is important because our community vernacular often uses the term “autonomy” to incorrectly describe automated operations. Chapter 4 contains a detailed discussion on autonomy and cognitive behavior and notes that research and development in automation are advancing from a state of automatic systems requiring human control toward a state of autonomous systems able to make decisions and react without human interaction. DoD will continue to carefully consider the implications of these advancements.



The potential for improving capability and reducing cost through the use of technology to decrease or eliminate specific human activities, otherwise known as automation, presents great promise for a variety of DoD improvements. However, it also raises challenging questions when applying automation to specific actions or functions. The question, “When will systems be fielded with capabilities that will enable them to operate without the man in the loop?” is often followed by questions that extend quickly beyond mere engineering challenges into legal, policy, or ethical issues. How will systems that autonomously perform tasks without direct human involvement be designed to ensure that they function within their intended parameters? More broadly, autonomous capabilities give rise to questions about what overarching guiding principles should be used to help discern where more oversight and direct human control should be retained.

The relevant question is, “Which activities or functions are appropriate for what level of automation?” DoD carefully considers how systems that automatically perform tasks with limited direct human involvement are designed to ensure they function within their intended parameters. Most of the current inventory of DoD unmanned aircraft land themselves with very

<sup>23</sup> JP 1-02, *Department of Defense Dictionary of Military and Associated Terms*, 8 November 2010 (as amended through 15 April 2013): [http://www.dtic.mil/doctrine/new\\_pubs/jp1\\_02.pdf](http://www.dtic.mil/doctrine/new_pubs/jp1_02.pdf).



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limited human interaction while still operating under the control of a human and perform this function with greater accuracy, fewer accidents, and less training than a human-intensive process; as a result, both a capability improvement and reduced costs are realized. This specific automatic process still retains human oversight to cancel the action or initial a go-around, but substantially reduces the direct human input to one of supervision. Human-systems engineering is being rigorously applied to decompose, identify, and implement effective interfaces to support responsive command and control (C2) for safe and effective operations.

Systems are designed and tested so that they perform their tasks in a safe and reliable manner, and their automated operation must be seamless to human operators controlling the system. This automation does not mean operators are not monitoring the control of the system. Currently, automated functions in unmanned systems include critical flight operations, navigation, takeoff and landing of unmanned aircraft, and recognition of lost communications requiring implementation of return-to-base procedures. As technology matures and additional automated features are thoughtfully introduced, DoD will continue to carefully consider the implications of autonomy. For armed platforms, DoD Directive (DoDD) 3000.09 establishes policy for the development and use of autonomous capabilities.<sup>24</sup>

### 2.4.2 Data Protection – Near, Middle, and Long Terms

**Near Term (0–4 years).** Encryption of UAS C2 and data links is critical for protecting UAS operations, ISR, and other communicated information. Presently, DoD specifies encryption and key management for UAS C2 communications and both still and motion imagery. Type 1 validated encryption is required for processing classified communications, and FIPS 140-2 validated encryption at a minimum must be used for processing unclassified communications.<sup>25</sup> DoD Instruction (DoDI) S-4660.04 also specifies further encryption and key management methods, such as the use of encryption keys provided by the National Security Agency (NSA), to enable interoperability.



**Middle Term (4–8 years).** Future encryption solutions will contain products that have a quicker time to market, greater coalition interoperability, and improved key management. The use of software Suite B<sup>26</sup> cryptography, which enables the protection of classified information,<sup>27</sup> is the primary driver behind faster product certification, which allows faster approval for coalition partner use. The development of UAS noncontrolled cryptographic products in the near term is expected to aid in coalition interoperability and lower lifecycle and logistics costs. Key management improvements will provide greater scalability, efficiency, and standardization for dynamic group keying techniques in UAS airborne networking with dynamic joining and leaving.

<sup>24</sup> DoDD 3000.09, Autonomy in Weapons Systems, November 2012.

<sup>25</sup> Details of these requirements, which apply to groups 2 through 5 UAS, can be found in DoDI S-4660.04, Encryption of Imagery Transmitted by Airborne Systems and Unmanned Aircraft Control Communications (U), 27 July 2011.

<sup>26</sup> Suite B cryptography is defined by NSA: [http://www.nsa.gov/ia/programs/suiteb\\_cryptography/index.shtml](http://www.nsa.gov/ia/programs/suiteb_cryptography/index.shtml).

<sup>27</sup> For additional information, see Committee on National Security Systems (CNSS) Policy (CNSSP) 15.

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**Long Term (more than 8 years).** In the longer term, advancements in component consolidation, higher data rate cryptography, and open standards will enhance UAS encryption. Hardware consolidation yielding single chip and coprocessor encryption modules will make routine cryptography both faster and feasible for smaller, group 1 UAS.<sup>28</sup> Improvements in hardware will also lead to higher data rate cryptography. Further standardization in common radio and cryptographic interfaces will enable improved remote UAS management and lower lifecycle costs.

### 2.4.3 Data Exploitation

Data are increasing in volume and availability as is the number of sensors with increased resolution and time-dominant requirements that present significant challenges and opportunities for DoD. As more and more sensors arrive on the battlefield and those sensors' capabilities increase, more data are delivered to warfighters, but the warfighters' ability to process and exploit such a large volume of data in a timely fashion is increasingly challenged. The problem is also exacerbated on both ends of the transmission link. Either huge volumes of data must be downsized before their transmission, or the data highway on which they travel must be increased in size and speed. Many gaps identified and prioritized in the UI2 CBA describe this in detail.

Further, after reception, the data must be used by analysts to draw conclusions for the decision makers. If the data are already formatted and arrive prioritized, fewer analysts are required to take advantage of the intelligence. Similarly, if the various databases are archived in a standard way, the various warfighter intelligence cells will use far fewer analysts to exploit databases and draw conclusions. Data must be immediately accessible by both anticipated analysts/consumers and unanticipated analysts/consumers.

Automated exploitation techniques are improving in ground-based intelligence production systems in the distributed common ground station (DCGS) families, the attack and Joint Architecture for Unmanned Systems (JAUS) programs, and other elements of the unmanned systems family. Current sensor resource management commands must be extended to include preset data resolution and reporting criteria. These current capabilities must be addressed for use as a requirements base and prototyping for UAS onboard applications. Onboard exploitation is further discussed in Section 4.6.4.

*Strategic Studies Quarterly*<sup>29</sup> recognized that DoD improvements to the warfighters' situational awareness are necessary and a metamorphosis is needed to develop into a tightly organized and dynamic ISR force. The Air Force report makes the following recommendations:

1. Overhead capabilities must be planned and executed in coordination with the National Reconnaissance Office because surveillance is increasingly becoming a standoff capability.

<sup>28</sup> In commercial industry, Intel implemented instructions, named Advanced Encryption Standard (AES) New Instructions (AES-NI), for Core processors in 2010 that can conduct several steps of AES encryption and decryption into a single instruction.

<sup>29</sup> "Air Force Strategic Vision for 2020–2030," *Strategic Studies Quarterly*, Spring 2011.

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2. Planning for a postwar (Afghanistan and Iraq) transition surveillance and reconnaissance structure must address the DCGS (a prime user of raw, unmanned-system-derived intelligence) and shift focus to processing and disseminating national and allied intelligence products.

3. Automated technologies must be exploited to improve data analysis so that human analysts are employed in the highest order tasks. Accelerated development of translation software, artificial intelligence, and electronic means to process raw data — signals and electronic intelligence — is the most practical approach to managing this glut of data and should become an Air Force funding priority. Additionally, collaborative tools could transform traditional data exploitation, including addressing high-value target intelligence mission exploitation. This activity traditionally

consumes large amounts of human resources; therefore, a tool for this priority would reduce analyst requirements.

### 2.4.4 Selective Innovation

Both national military strategy and joint concept documents describe a vision of utilizing technical innovation for future capability improvements. Given the aforementioned budgets constraints, future mission needs will have to be met by funding capability improvements that exploit existing systems with innovative improvements to their indigenous technologies. This approach might be as simple as modifying a sensor to improve data flow or applying standard message set architectures to improve interoperability.

*...even at a time of increasing budget constraints, the Army has been good about finding money for UAS improvements.... Advances in technology have taken sensors, cameras and other gear from the analog to the digital age, making them ever smaller, lighter, more energy-efficient and useful.*

*— COL. Tim Baxter, Army UAS Project Manager  
in the Program Executive Office for Aviation<sup>30</sup>*

Innovation must continue, especially under the current fiscal environment, and must include not only improvements to existing CONOPS but also the development of entirely new CONOPS. More emphasis on innovative approaches must be given to all future unmanned systems development. Unmanned systems open up new avenues for pursuing systems that are smaller, lighter, faster, and more maneuverable and that take more risk than equivalent manned platforms. In particular, the ability of unmanned assets to take risks that would not be taken with manned assets opens up new CONOPS, such as low-cost, expendable systems that trade armor and stealth for quantity. In other words, a fleet of low-cost, disposable platforms could survive through attrition rather than through expensive, exquisite capabilities.

<sup>30</sup> Source: [http://blog.al.com/huntsville-times-business/2012/04/armysunmanned\\_aircraft\\_systems.html](http://blog.al.com/huntsville-times-business/2012/04/armysunmanned_aircraft_systems.html).

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### 2.4.5 Manned-Unmanned System Teaming (MUM-T)

Technological advances and military adaptation will result in merging unmanned systems from air, ground, and sea domains into teams of unmanned and manned systems. MUM-T will be essential as DoD makes a shift in geographical priorities toward the Asia-Pacific region while retaining emphasis on the Middle East. A force of the smaller, more agile manned-unmanned systems of the near future will enable DoD to mobilize quickly to deter and defeat aggression by projecting power despite A2/AD challenges. MUM-T will provide the following key capabilities:

- Defeating explosive ground surface, sub-surface (tunnel), and sea hazards from greater standoff distances.
- Assuring mobility to support multiple points of entry.
- Enabling movement and maneuver for projecting offensive operations.
- Establishing and sustaining the shore lines of communications required to follow forces and logistics.
- Protecting austere combat outposts.
- Providing persistent surveillance to detect and neutralize threats and hazards within single- to triple-canopy and urban terrain.

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### 3 Combatant Commander Mission and Capability Needs

#### 3.1 Why Unmanned?

The prevalence and uses of unmanned systems continue to grow at a dramatic pace. The past decade of conflict has seen the greatest increase in unmanned aircraft systems, primarily performing ISR missions. Use of unmanned systems in the other domains is growing as well. The growth of unmanned systems use is expected to continue across most domains. Unmanned systems have proven they can enhance situational awareness, reduce human workload, improve mission performance, and minimize overall risk to both civilian and military personnel, and all at a reduce cost.

The capabilities of unmanned systems are not unique over manned systems. Weapon systems produce effects in nearly all domains, independent of being manned or unmanned. It is important to highlight that there are no requirements for unmanned systems within the Joint force, but some capabilities are better fulfilled by unmanned systems. Unmanned systems provide persistence, versatility, survivability, and reduced risk to human life, and *in many cases are the preferred alternatives especially for missions that are characterized as dull, dirty, or dangerous*. With that mindset, unmanned systems are being optimized for these dull, dirty, or dangerous missions:

- Dull missions are ideal for unmanned systems because they involve long-duration undertakings with mundane tasks that are ill suited for manned systems. Good examples are surveillance missions that involve prolonged observation. Unmanned systems currently fulfill a wide variety of “dull” mission sets, and the number will increase in all domains as unmanned systems capabilities improve.
- Dirty missions have the potential to unnecessarily expose personnel to hazardous conditions. A primary example is chemical, biological, and nuclear detection missions. Unmanned systems can perform these dirty missions with less risk exposure to the operators.
- Dangerous missions involve high risk. With advances in capabilities in performance and automation, unmanned systems will reduce the risk exposure to personnel by increasingly fulfilling capabilities that are inherently dangerous.

#### 3.2 Requirements Processes

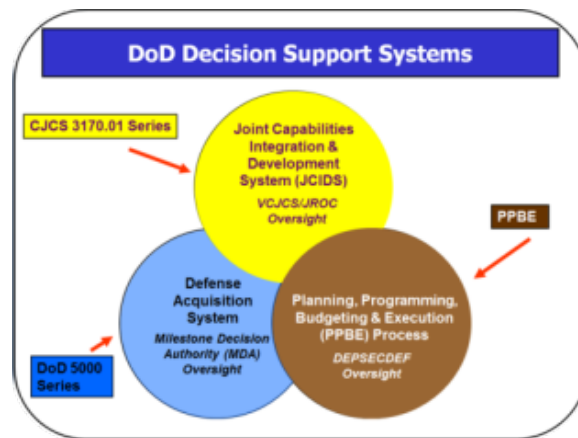
Growth in unmanned platforms of all sizes and shapes has been substantial, with a corresponding increase in payload numbers and capability. Several of these systems were developed using the deliberative requirements and acquisitions processes. Policies have reflected a shift to support the integration of unmanned systems into the joint force and use across the battlefield when the capability is required by the CCDR. Many systems were rapidly acquired and immediately fielded using the Joint Urgent Operational Needs (JUONs) process. JUONs have successfully added significant capability to joint warfighting. While those unmanned systems were rapidly developed to meet the immediate needs of the warfighter in the near term, they have not undergone rigorous requirements review and joint coordination through the normal Joint Capabilities Integration and Development System (JCIDS) process, including, for example, review for systems interdependencies and interoperability. Further, their long-term enterprise-wide capability portfolios have not been fully considered. Consequently, they have not received

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due consideration in the context of broader joint capability areas (JCAs), which provide structure and organization to requirements development. In the future, consideration of such factors as the recently required JCIDS Training Key Performance Parameter (KPP) will more fully allow operators, maintainers, and leaders to realize full design capability sooner in the requirements process.

A formal review and approval process has been implemented for delineating which programs should transition to enduring programs (and eventually PORs) and/or which program sensors or other components need to be maintained via other programs. During this process, the JUONs and CCDR's integrated priority list (IPL) requirements were considered as well as the capabilities adjudicated against the Joint Direct Support Aerial ISR JROC-approved initial capabilities document that outlines the tactical commander's needs.

DoD recently revised the JCIDS requirements process to streamline urgent and deliberate capability development and enable requisite timeliness in meeting warfighter needs while giving important consideration to long-term affordability and sustainability. JCIDS is a key supporting process for DoD acquisition and Planning, Programming, Budgeting, and Execution (PPBE) processes. It ensures the capabilities required by the warfighter are identified with their associated operational performance criteria to successfully execute the assigned missions. This coordination ensures a better understanding of the warfighting needs early in capability development and provides a more comprehensive set of valid, prioritized requirements. DoD's acquisition arm can then focus on choosing options to meet well-defined requirement capabilities. Figure 9 shows the linked and streamlined process.



**Figure 9. Linked JCIDS Process**

The key decision body in the JCIDS process is the JROC, chaired by the Vice Chairman, Joint Chiefs of Staff. JROC has the responsibilities under Title 10 of the United States Code to consider input from CCDRs on joint requirements as well as to consider cost, schedule, and performance tradeoffs in establishing requirements. Currently, JROC is shaping the force with a more robust requirements review process. The Council is addressing the complex issues earlier and iteratively, using better upfront fidelity on cost, schedule, and performance tradeoffs and more analytic rigor in risk analysis. JROC constantly assesses joint capabilities by comparing risk and affordability against current defense strategies. Unmanned systems must provide capabilities with superior cost, schedule, and performance metrics to compete against other systems within JROC or other DoD forums.

Given today's highly constrained fiscal environment, it is imperative that DoD look at areas where efficiencies can be gained to create unmanned systems that are both effective and affordable. DoD will look at capitalizing on commonality, standardization, and joint acquisition strategies, among other strategies. Unmanned systems must become more efficient in addressing



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capability gaps, including increases in interoperability, autonomy, modularity, effectiveness, and teaming with manned systems. In addition, DoD demands these unmanned systems be affordable at the outset, experience little or no cost growth in their development and production evolution, and control lifecycle costs. To achieve these objectives, the full range of DOTMLPF-P options must be considered in the earliest development activities.

Capability requirements, validated by the JCIDS process, inform prioritization activities in the competition for funding during the PPBE process. The objective of the PPBE process is to provide the best mix of forces, equipment, training and support attainable within fiscal constraints according to DoDD 7045.14.<sup>31</sup> To meet this objective, the PPBE process aims to meet goals established by the President and the Secretary of Defense (SECDEF) in the Strategic Planning and Joint Planning Guidance. In the PPBE process, the Military Departments match available resources (e.g., fiscal, manpower, material) against validated requirements to achieve the strategic plan. A key task is to develop a balanced, affordable capabilities-based Service Program Objective Memorandum (POM). The POM position for the capability to meet a given requirement is assessed and revised when necessary to fit with Joint and coalition capabilities, and the final position becomes part of the President's budget.

An important input to the POM position is each CCDR's IPLs. These lists are communicated annually by the CCDRs to SECDEF, the U.S. Congress, and the Joint Staff. IPLs can be specific or cross-cut capability gaps. The Joint Staff develops recommended solutions to the gaps. These gaps can span from programmatic changes of current programs, initiation of a new capability documents via JCIDS, and investment in science and technology (S&T) solutions to the initiation of new studies and experiments. JROC decides which gaps are most important to mitigate based on risk assessments and the adequacy of DoD's ongoing efforts. This prioritization of gaps is part of the capability gap analysis (CGA) process and results in a key input to the PPBE process. While specific capability gaps are classified, they typically include a range of needed capabilities. Within the CGA process, the Joint Staff determines whether any system could best satisfy the capability gap. Unmanned systems do not get special consideration. Systems must demonstrate a superior ability to satisfy the capability to garner support.

Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 6212.01F provides another JCIDS consideration.<sup>32</sup> It further defines responsibilities and establishes policy and procedures to develop the Net Ready Key Performance Parameter (NR KPP) and its certification requirement for all information technology (IT) and national security systems (NSS) that contain joint interfaces or joint information exchanges. The DoD Chief Information Officer (CIO) is also in the final stages of issuing DoDI 8330 to address IT and NSS.<sup>33</sup> This issuance will supersede DoDD 4630 issuances and the DoD CIO's Interim Guidance Memorandum. DoDI 8330 employs a new concept of "tiered accountability" to meet interoperability requirements internal to DoD and external mission partners.

<sup>31</sup> DoDD 7045.14, Planning, Programming, Budgeting System (PPBS).

<sup>32</sup> CJCSI 6212.01F, Net Ready Key Performance Parameter (NR KPP), March 2012.

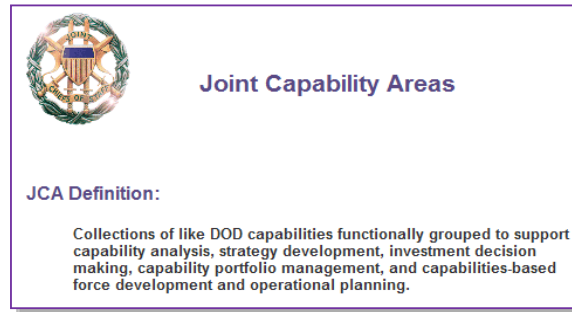
<sup>33</sup> DoDI 8330 (DRAFT), Interoperability of Information Technology (IT), including National Security Systems (NSS).



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### 3.3 Joint Capability Areas (JCAs)

The JCAs<sup>34</sup> are currently the preferred method DoD uses for reviewing and managing capabilities. The JCA framework provides the structure around which capabilities and capability gaps can be aligned across DoD and across the various portfolios to correlate similar needs, leverage effective solutions, and synchronize related activities. Also, various frameworks, such as the Universal Joint Task List, are readily available to aid in identifying and organizing the tasks, conditions, and required capabilities.



Mapping current and projected unmanned systems against the JCAs provides a sense of what the product line portfolio is for unmanned systems and how it currently contributes, and could contribute in the future, to the missions of DoD. Each JCA represents a collection of related missions and tasks that are typically conducted to bring about the desired effects associated with that capability. Nine Tier One JCAs are defined, and unmanned systems are key contributors in the Battlespace Awareness, Force Application, Protection, and Logistics JCAs. Each area is assigned to a Functional Capability Board (FCB) on the Joint Staff (JS). FCB contact information is available on Intellipedia through the Secure Internet Protocol Router Network (SIPRNet).<sup>35</sup>

Current technology and future advancements can and will enable single platforms to perform a variety of missions across multiple capability areas. This versatility represents an opportunity for DoD to achieve a greater return on investment. Furthermore, the projections show that there will be opportunities for joint systems to conduct missions for each Service, just as there will be situations in which domain conditions or Service missions will dictate unique solutions.

#### 3.3.1 Battlespace Awareness JCA – JS/J-28, BA FCB

Battlespace Awareness is a capability area where unmanned systems in all domains have the ability to contribute significantly into the future to conduct ISR and environment collection-related tasks. Applications in this JCA include aerial, ground, surface sea, and undersea surveillance and reconnaissance. Today, these functions are performed by several systems across all domains and mission sets. In the future, technology will enable mission endurance to extend from hours to days and allow for long-endurance persistent reconnaissance and surveillance in all domains. Unmanned systems are expected to integrate a greater range of C2 options from soldier-to-platform direct control to increased CONOPS options for operations that can be independent of C2. Therefore, onboard sensors that provide the systems with their own organic perception will contribute to Battlespace Awareness regardless of their intended primary mission. To achieve this goal, unmanned systems development and fielding must include the tasking, collection, processing, exploitation, and dissemination (TCPED) processes required to translate vast quantities of sensor data into a shared understanding of the environment. Many ongoing efforts are streamlining these

<sup>34</sup> Source: <http://www.dtic.mil/futurejointwarfare>.

<sup>35</sup> Source: <http://www.intelink.sgov.gov/wiki/jroc>.

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processes. This capability area lends itself to tasks and missions being conducted collaboratively across domains as well as teaming within a single domain.

### 3.3.2 Force Application JCA – JS/J-8, FA FCB

Force Application is another JCA that includes a proliferation of unmanned systems contributing to maneuver and engagement. Today, Predator, Reaper, and Gray Eagle UAS are weaponized to conduct offensive operations, irregular warfare, and high-value target and high-value individual prosecution; this trend will likely continue in all domains. In the air domain, projected mission areas for UAS include air-to-air combat, electronic warfare (EW), and suppression and defeat of enemy air defense. On the ground, UGS are projected to conduct missions such as remotely conducted, nonlethal crowd control; dismounted offensive operations; and armed reconnaissance and assault operations. In the maritime domain, both UUVs and USVs are projected to be particularly suited for mine laying and mine neutralization missions.

DoD personnel must comply with the law of war, including when using autonomous or unmanned weapon systems. For example, paragraph 4.1 of DoDD 2311.01E requires that “[m]embers of the DoD Components comply with the law of war during all armed conflicts, however such conflicts are characterized, and in all other military operations.”<sup>36</sup>

Current armed unmanned systems deploy lethal force only in a fully human-operated context for engagement decisions. For these systems, the decisions both to employ force and to choose which specific target to engage are made by a human. The United States operates defensive systems for manned ships and installations that have human-supervised autonomous modes and has operated these systems for decades. As technology advances and more automatic features are introduced, DoD will continue to carefully consider the implications of autonomy in weapon systems to ensure safe and reliable operations and minimize the probability and consequences of failures that could lead to unintended engagements. For this reason, DoDD 3000.09, Autonomy in Weapon Systems, mandates a policy review before entering formal development for proposed weapon systems that would use autonomous capabilities in a novel manner.

### 3.3.3 Protection JCA – JS/J-8, Protection FCB

Protection has particular applicability for unmanned systems to assist in attack prevention or effects mitigation. Unmanned systems are ideally suited for many protection tasks that are deemed dull, dirty, or dangerous. As the future enables greater automation with respect to both navigation and manipulation, unmanned systems will be able to perform tasks such as firefighting, decontamination, contingency base and base camp security, installation security, obstacle construction and breaching, vehicle and personnel search and inspection, mine clearance and neutralization, sophisticated explosive ordnance disposal (EOD), casualty extraction and evacuation, and maritime interdiction. In the Protection JCA, teaming within domains and collaboration across domains will likely prevail.

### 3.3.4 Logistics JCA – JS/J-4, Logistics FCB

Logistics is ideally suited for employing unmanned systems in all domains to deploy, distribute, and supply joint forces. Unmanned systems will perform logistics tasks at home and

<sup>36</sup> DoDD 2311.01E, DoD Law of War Program, 9 May 2006.

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with the forward deployed. The purpose of the capability is to enable unmanned cargo systems in full-spectrum operations to perform the dull, dirty, and dangerous missions by capitalizing on the persistence of unmanned systems to free up manned assets for more difficult missions within an area of operation. The following tasks are particularly well suited for unmanned systems:

- Transportation of routine supplies (e.g., food, water, ammunition, and medical supplies) to the forward units in all types of ground terrain.
- The resupply from sea-based assets located offshore.
- Support for special operations forces.
- An alternative delivery option to widely dispersed operating forces for routine (around the clock) and immediate (time-sensitive) logistics support.
- Routine maintenance-related tasks such as inspections, decontamination, and refueling.
- Material handling and combat engineering.

Although currently prohibited by policy, future capabilities by unmanned systems could include casualty evacuation and care, human remains evacuation, and urban rescue. The unmanned vehicles are intended to mitigate risk to the maximum extent by reducing the requirement to operate manned vehicles when the weather, terrain, availability, and enemy pose an unsuitable level of risk.

### 3.4 A Look to the Future

This Roadmap provides a DoD vision for the continuing development, fielding, and employment of unmanned systems. Chapter 4 discusses the investments in technology to enhance capability and reduce cost. Warfighters value the inherent benefits of unmanned systems, especially their persistence, versatility, and reduced risk to human life. The Joint Staff will continue to support unmanned systems when they fulfill joint requirements and are effective and affordable. Unmanned systems must

- Provide capabilities more efficiently through modularity and interoperability.
- Be more effective through greater automation and greater performance.
- Be more survivable with improved and resilient communications, development for antipermissive environments, and more security from tampering.
- Take the “man” out of unmanned. Currently personnel costs are the greatest single cost in DoD, and unmanned systems must strive to reduce the number of personnel required to operate and maintain the systems. Great strides in autonomy, teaming, multi-platform control, tipping, and cueing have reduced the number of personnel required, but much more work needs to occur.

JROC supports a Joint Doctrine and Planning Conference review of the approved November 2011 Joint CONOPS for UAS to determine whether it has matured enough to transition to joint doctrine and become integrated into existing Joint Publications.

## 4 Technologies for Unmanned Systems

### 4.1 Introduction

The pace of technological advances across the broad spectrum of unmanned systems applications has allowed what were once rather cumbersome vehicles and systems outside the “circle of warfare trust” (systems trusted by the warfighter) to shoulder burdens in warfare mission areas unforeseen only a few years ago. With dramatic increases in battery life and computer processing; reduction in size and complexity of sensors; and improvements in reliability, maintainability, automation, and operator interfaces, unmanned systems are now vital components of an operational commander’s tool kit.

While commanders have become more accustomed to the capabilities (and limitations) of unmanned systems from operations during the first decade of the 21<sup>st</sup> century, the next decades are already presenting a two-sided challenge that represents stark differences from recent operations. First, a strategic shift in national security to the Asia-Pacific Theater presents different operational considerations based on environment and potential adversary capabilities. Second, a shrinking fiscal environment (without overseas contingency operations (OCO) funding) and base budget levels that are likely to be flat at best will challenge both unmanned systems operators and suppliers to seek efficiencies in total cost of unmanned systems ownership, from cost of manufacture, avionics, and deployment to manpower savings and logistics. This challenge is two-sided because one side cannot be considered without the other: meeting operational demands must be accomplished in the context of budgetary constraints — in the near, middle, and long term. See Figure 10 for an example of the President’s 2012 S&T budget request for DoD.<sup>37</sup>

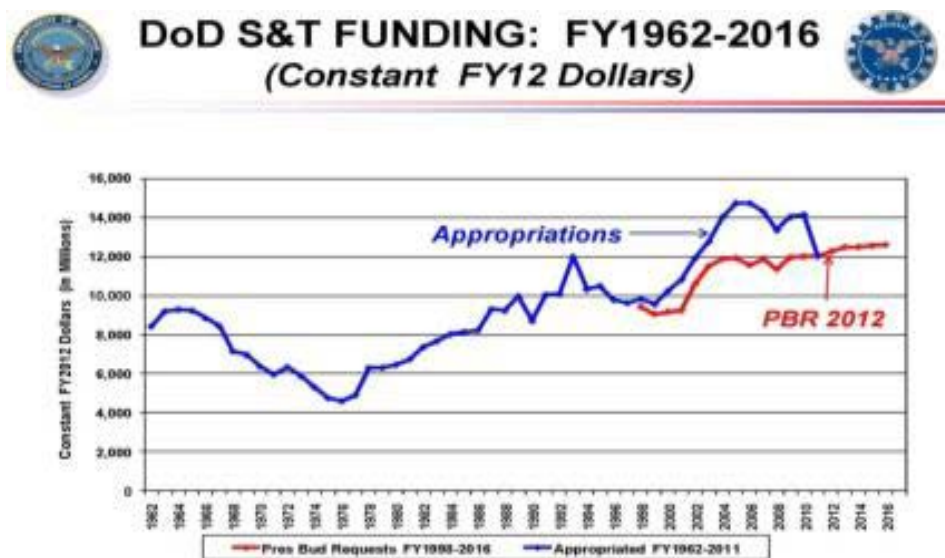


Figure 10. DoD S&T Funding: FY1962–2016

<sup>37</sup> Slide #15 extract from Mr. Bob Baker, Deputy Director, Plans & Programs, Assistant Secretary of Defense & Engineering, FY2012 President’s Budget Request (PBR) for the DoD S&T Program Briefing, 21 June 2011.

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*When I announced the new guidance, I highlighted five key elements of the strategy and five key elements of the vision that we have for a military force of the future. And let me just summarize each of those...First, the military will be smaller and leaner, but it will be agile, flexible, rapidly deployable and technologically advanced. It will be a cutting-edge force...[F]ifth, we will protect and prioritize some very important and key investments in technology and new capabilities as well as our capacity to grow, adapt, to mobilize, to surge as needed.*

*— Leon E. Panetta, Former Secretary of Defense<sup>38</sup>*

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As a result of DoD's new warfighting strategy and in recognition of new budgetary constraints, the Under Secretary of Defense (USD) for Acquisition, Technology, and Logistics (USD(AT&L)) is sponsoring a Defense Science Board study with the following charter:

"The Defense Science Board (DSB) is requested to conduct a study of emerging technologies that will enable the next generation of dominant military capabilities to be in development or fielded by 2030. Some of the products of the study will be:

1. A set of recommendations intended to guide the DoD research and development investments in applied technology and technology demonstrations over the period of 2014 to 2020;
2. Mapping of the identified technologies to applications and capabilities that may be enabled; and
3. For a select set of promising technologies, recommended experiments or concept demonstrations that foster innovation and provide entry ramps to enhance operational capabilities via block upgrades to existing systems or as entry ramps to new systems and operational concepts."

The study is guided in part by the January 2012 military strategy guidance, "Sustaining U.S. Global Leadership: Priorities for 21<sup>st</sup> Century Defense."<sup>39</sup>

The study will include surveying and assessing the potential for significant advances in technology outside DoD that could contribute to future military capabilities. These advances could augment DoD investments in areas such as quantum computing, microelectronics, robotics, nanomaterials, genetics, "big data," alternative energy sources, advanced materials, and modeling and simulation. Technologies that have the potential to significantly enhance or transform the nature of warfare in the sea, land, air and space, and cyber regimes will be the focus of this study.

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<sup>38</sup> Source: <http://www.defense.gov/transcripts/transcript.aspx?transcriptid=4962>.

<sup>39</sup> USD(AT&L) Memorandum, "Terms of Reference-Defense Science Board Study on Technology and Innovation Enablers for Superiority in 2030," 15 March 2012.

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This chapter highlights six areas of interest for the technological advancement of unmanned systems. The areas are reflective of DoD's shift in strategic priorities and also address the requirement to continue to reduce lifecycle costs across all systems, including unmanned systems. In each section, near-, middle-, and long-term goals, as defined in Figure 11, are discussed.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2030+
Desired Capability	<b>Near Term:</b> Capabilities and advancements which should be operational within the next five years. These items principally require industry investment to mature and/or operationally demonstrate to ensure rapid fielding and/or budgetary prioritization with discrete and operationally representative data. Investment in advanced technology initiatives via S&T 6.3 funding, also apply here to an extent.					<b>Mid-Term:</b> Capabilities and advancements which could be (or are currently) in discrete project stages at laboratories and S&T directorates such as DARPA, IARPA, ONR/NRL, AFRL, ARL, JHU-APL, MIT-LL amongst others. These items principally require investment via both S&T 6.3 initiatives and Applied Research initiatives via S&T 6.2 funding. The timeframe for Mid-Term objective is five to ten years.					<b>Long Term:</b> Capabilities and advancements which are in the basic research stage, such as (but not limited to) materials development or new & novel processes or approaches. These items principally require investment in Basic Research initiatives via S&T 6.1 funding. Time frame for long term objectives is ten years and out.	

**Figure 11. Near-, Middle-, and Long-Term Goals**

The six areas of technology key for DoD to enhance capability and reduce cost are interoperability and modularity; communication systems, spectrum, and resilience; security (research and intelligence/technology protection (RITP)); persistent resilience; autonomy and cognitive behavior; and weaponry. Other important areas include sensor air drop, weather sensing, and high-performance computing (HPC).

### 4.1.1 Interoperability and Modularity

Sensor and weapon technology is rapidly maturing, as is processing and algorithm development, often outpacing DoD's ability to transition upgraded capability and material improvements to fielded platforms. The current myriad of sensors, communications, and weapons systems is continually evolving due to leveraged commercial processes and electronic standards technology. Coupled with DoD's major systems inventory designed to last several years, technology refresh presents both an intra-platform challenge (modularity) and an inter-platform challenge (interoperability). Interoperable interfaces for enhanced modularity and cross-domain data sharing present an opportunity to minimize future lifecycle costs, reduced force structure requirements, and adapt rapidly to changing threats or new available technologies. See 4.2 for more details.

### 4.1.2 Communication Systems, Spectrum, and Resilience

The challenges that all unmanned systems face include the availability of communication links, the amount of data that the communication links support, certification of the communication spectrum, and the resilience of all radio frequency (RF) subsystems against interference (e.g., electromagnetic). See 4.3 for more details.



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### 4.1.3 Security: Research and Intelligence/Technology Protection (RITP)

Unmanned systems are often employed with critical program information and sensitive, classified data to complete the assigned mission and, therefore, require RITP. Unmanned systems must include appropriate security measures not only to prevent unauthorized access/control, unauthorized or unintentional disclosure of data, and preservation of technological superiority, but also to enable more rapid adaptation of new sensors, weapons, and processing software. See 4.4 for more details.

### 4.1.4 Persistent Resilience

While unmanned systems are inherently more persistent based on significantly better fuel/weight ratios, unmanned systems' design schema can be better optimized to provide overall, more effective on-station time. Additionally, further miniaturization of avionics, power and propulsion, and stores management enables smaller systems, which, when combined with more persistence, can minimize investment. Increased persistence calls for improvements in reliability, maintainability, and survivability. Therefore, while further size, weight, power, and cooling (SWaP-C) improvements are hallmarks of all systems, including unmanned, they must be accomplished while enhancing reliability, maintainability, and survivability to ensure broad-spectrum warfighting effectiveness. See 4.5 for more details.

### 4.1.5 Autonomy and Cognitive Behavior

Nearly all unmanned systems require active control of basic vehicle operations and behavior that affects communications, manpower, and system effectiveness. One of the largest cost drivers in the budget of DoD is manpower. A significant amount of that manpower, when it comes to operations, is spent directing unmanned systems during mission performance, data collection and analysis, and planning and replanning. Therefore, of utmost importance for DoD is increased system, sensor, and analytical automation that can not only capture significant information and events, but can also develop, record, playback, project, and parse out those data and then actually deliver "actionable" intelligence instead of just raw information. As with other facets of unmanned systems, the need for greater autonomy is subject to fiscal pressures, i.e., operating within budget constraints while reducing manpower needs and U.S. exposure to dangerous risks and increasing operational effectiveness. See 4.6 for more details.

### 4.1.6 Weaponry

Expanding options for weapons delivery from unmanned systems includes new munition options where some capability is now integrated and adding additional weaponized platforms to the unmanned force structure. To fully integrate the use of weapons and unmanned systems, it will be critical to leverage the key technology areas in the preceding paragraphs (4.1.1 to 4.1.5) as well as in specific, weapons-related areas. See 4.7 for more details.

### 4.1.7 Sensor Air Drop

Unattended sensors were used extensively during the Vietnam War and were influential in reducing the rate of arrival of personnel and equipment into the south. Emplacement of multiple types of unattended ground sensors can provide indications and warning, communications relay, weather reports, activity identification, high-value individual/target



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detections, kinetic weapon cueing, and near-real-time alarms and can support predictive movements via array lay-downs. Using UMS for placing sensors provides a method for increasing persistence and determining/identifying activity and targets without dedicating personnel or multiple high-demand sorties to provide both area and/or point coverage.

Many unmanned platforms are already equipped to externally carry equipment, and all have mission plans that provide their controlled, overwatch and/or autonomous covert movement. Unattended ground sensor technologies are increasing and are able to collect and report unique information and to use coordinates-seeking location capabilities for accurate covert emplacements. The unmanned family of vehicles typically has complementary sensors that can provide exact emplacement location along with imagery information and that can support mission planning and route following. However, the need to improve persistence and situational awareness continues to increase beyond the expected numbers and capabilities of unmanned assets. In the future, UAS platforms and profiles may be ideal for penetrating denied battlespace to accurately dispense sensors and nonkinetic capabilities, etc. Future capabilities may also include deploying “attach bots” that would allow tracking/identification of personnel who pass through an area.

### 4.1.8 Weather Sensing

UAS platforms fly throughout areas of operations on a near-all-weather 24/7 basis at multiple altitudes. These missions require accurate and timely weather forecasts to improve sensors planning and data collection in support of the CDR and to avoid potential weather-related accidents. Accurate weather reporting also supports complementary ground and flight planning synchronization. Future weather reporting will be ingested in near real time in the DCGS weather application and CONUS weather central and will be correlated with other weather information to improve accurate predictions for the tactical commander. Weather sensing information will be automatically formatted and reported via multiplexing on the platform’s data link with automated routing to the DCGS and other appropriate weather prediction and reporting positions. As UAS endurance dramatically increases, weather predictions will be more imperative to ensure launch, recovery, and ranging limitations are accurate so that potential weather-related incidents can be avoided and coordinated flight and ground operations can be improved.

### 4.1.9 High-Performance Computing (HPC)

Very high capacity and high-definition sensors are causing bandwidth issues. Each sensor and communications have independent components to process disparate information. This individualism creates a wide breadth of nonstandard airframe kits, component interfaces, and SWaP-C configurations. Future technologies will provide the capability for a standard HPC (family) for most unmanned systems. HPC allows a common hardware-defined architecture to correspond with a common software-defined architecture to form a consolidated plug-and-play standard performance and applications architecture that would host the processing in one miniaturized chassis. The common architecture would be available to UAS vendors for compliance to make integration less costly. Using a member of the HPC family and/or use of a common hardware would also support technology insertions as one of several possible component interchanges within processor boards, memory, or other electronics. It would also further enable improved software downloads. HPC can be applied in multiple subsystems within

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unmanned systems to address challenges in cloud computing and multilayer security, communications, open standards, data storage, cost, ease of technology insertion, SWaP-C, etc.

## 4.2 Interoperability and Modularity

### 4.2.1 Background

Warfare has become increasingly complex, and U.S. military operations often require cost-effective integration of disparate assets from across the Services and other joint, interagency, intergovernmental, and multinational (JIIM) partners. Furthermore, unmanned systems are playing an increasingly vital role in these operations. For this reason, it is imperative for DoD, in cooperation with JIIM partners, to not just develop standard information exchange requirements (IERs), but also to stabilize them. Stable IERs that address joint and Service needs, interoperability profiles (IOPs), middleware (which can translate multiple system inputs and outputs), and other areas are needed to reach the necessary level of interoperability across manned and unmanned systems.

It is DoD policy<sup>40</sup> (based on federal laws) that IT and NSS employed by DoD components shall, where required, be interoperable with existing and planned systems and equipment of joint, combined, and coalition forces, other U.S. Government departments and agencies, and nongovernmental organizations, as appropriate. DoDD 5000.01 requires that “Systems, units, and forces shall be able to provide and accept data, information, materiel, and services to and from other systems, units, and forces and shall effectively interoperate with other U.S. Forces and coalition partners.”<sup>41</sup> CJCSI 6212.01F requires DoD components to develop, acquire, test, deploy, and maintain ITs that are interoperable and supportable with existing, developing, and proposed (pre-Milestone A) ITs through architecture, standards, defined interfaces, modular design, and reuse of existing IT solutions and are interoperable with host nation, multinational coalition, and federal, state, local, and tribal agency partners.

DoD unmanned systems have historically been developed for Service-specific needs driven by the rapid fielding timelines in support of immediate operational requirements. While fielding these systems rapidly has been valuable, fully stable IERs have often been, of necessity, sacrificed to battlefield urgency, and fielded systems can generally demonstrate only limited interoperability with other manned and unmanned platforms across Services. As more and more unmanned systems are fielded, open architectures (OAs), nonproprietary interfaces, government-owned data rights, and standard IOPs will be required to further enable a broader net-centric environment that is truly interoperable, open, and scalable.

As a result, DoD is adopting and exploiting open system design principles and architectures to increase competition, foster reuse across systems, and increase interoperability. This new acquisition model requires access to multivendor solutions to enable rapid insertion of new technologies to counter emerging threats, avoid technology obsolescence, and decrease time to field new capabilities. For example, DoD is adopting an open business model to support the implementation of an OA for UAS ground control stations (GCSs) to drive greater acquisition

<sup>40</sup> CJCSI 6212.01F, Net Ready Key Performance Parameter (NR KPP), 21 March 2012.

<sup>41</sup> DoDD 5000.01, The Defense Acquisition System, 12 May 2003.

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efficiencies and reduce the total ownership costs. This effort will also include application of a common UAS Control Segment (UCS) architecture as described in 4.2.4.3.

### 4.2.2 Interoperability Functional Description

The USD's vision for interoperability spans the JIIM domains. Successful definition and implementation of proper interoperability will enable the warfighter to add capability, encourage innovation, and support program cost control.

*The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to make use of the services, units, or forces; and to use the services so exchanged to enable them to operate effectively together. An example for the use of this policy would be the condition achieved among communications-electronics systems or items of communications electronics equipment when information or services can be exchanged directly and satisfactorily between them and/or their users.<sup>42</sup>*

Interoperability is integral to the continued success of missions using unmanned systems and represents a long-term objective of the Services and their stakeholders. The urgent needs in theater and corresponding rapid acquisition approach during recent years have resulted in the current fleet of unmanned systems that generally do not interoperate with each other or with external systems. The combat development community is calling for interoperability as a critical element to the future unmanned systems fleet. The ability for manned and unmanned systems to share information will increase combat capability, enhance situational awareness, and improve flexibility of resources. Interoperability will improve the ability for unmanned systems to operate in synergy in the execution of assigned tasks.<sup>43</sup> Properly stabilized, implemented, and maintained, interoperability can serve as a force multiplier, improve warfighter capabilities, decrease integration timelines, simplify logistics, and reduce total ownership costs.

New rules in acquisition establish the requirement to acquire systems and families of systems (FoSS) that are interoperable.<sup>44</sup> Once mature and stable IERs and other key interoperability areas are defined in support of this overall objective, DoD's unmanned systems must demonstrate interoperability in a number of realms that will challenge current systems:

- Among different systems of the same domain, i.e., using a common GCS or OCU for multiple, heterogeneous unmanned vehicles.
- Among systems of different domains, i.e., allowing ground, aircraft, and maritime vehicles to work cooperatively.
- Among systems operated by different military departments under various CONOPS and tactics, techniques, and procedures (TTPs), i.e., allowing joint Service systems to work in concert to execute a common task or mission.

<sup>42</sup> Unmanned Interoperability Initiative (UI2) Capability Based Assessment, 1 March 2012.

<sup>43</sup> JP 1-02, Department of Defense Dictionary of Military and Associated Terms, 12 April 2001 (as amended through 17 March 2009).

<sup>44</sup> DoDD 5000.1, Enclosure 1, paragraph E1.10.

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- Among systems operated and employed by coalition and allied militaries under the governance of various Concepts of Employment (CONEMPs) and TTPs in multinational combined operations or North Atlantic Treaty Organization (NATO) standardization agreements, i.e., allowing coalition and allied systems to work in concert to execute a common task or mission based on predefined roles and responsibilities.
- Among military systems and systems operated by other entities in a common environment, i.e., allowing military UAS to share the NAS and international airspace with commercial airliners and general aviation or allowing military UGS to operate safely in the civilian roadway environment.

### 4.2.3 Modularity Functional Description

Concurrently, subsystem modularity and interoperability of components are essential to affordable improvements, maintenance and sustainment, and increased capability. As payloads, sensors, software, and computing algorithms and devices are anticipated to evolve much faster than the vehicle platforms, creating interoperable component/subsystem interfaces for enhanced modularity represents an opportunity to minimize future lifecycle costs and adapt rapidly to changing threats or new available technologies. Upgrading existing proprietary components may be both expensive and logistically unfeasible because whole platforms may need to be taken out of service and/or replaced. Such a closed development approach has resulted in a number of unfavorable characteristics that impede applications of technical progress and the adoption of new capabilities. In addition to the interoperability characteristics mentioned in 4.2.2, unmanned systems must be modular so the same or at least similar components can be used in the same or different types of systems, e.g., plug-and-play use of different sensors on unmanned systems (the vehicle and its supporting systems).

### 4.2.4 DoD Initiatives to Increase Interoperability and Modularity

The following subsections summarize the DoD initiatives that will require technological advances and cooperation among DoD, governmental agencies, and industry. Each initiative is also described in more detail in Appendix C.

#### 4.2.4.1 *Unmanned Interoperability Initiative (UI2) Capability Based Assessment (CBA)*

This CBA is the culmination of a joint working group (WG) effort to conduct an operational assessment of unmanned systems interoperability task needs, identify and prioritize gaps in the ability to satisfy these needs, and identify potential DOTMLPF-P priorities to mitigate the identified capability gaps. Appendix G of the CBA provides the prioritized listing and description for each of the 29 joint interoperability gaps. Each military department and agency will find aspects of the CBA relevant to its mission responsibilities. The Interoperability Integrated Product Team (I-IPT) under the UAS Task Force will continue to work with the military departments and agencies to close gaps identified within the CBA to ultimately improve capability to the warfighter.

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### 4.2.4.2 *Standards and Governance Efforts*

DoD is working to accomplish unmanned systems interoperability by standardizing critical interfaces within the overall UAS architecture by implementing standard IOPs. Since “standards are ever evolving,” key enablers in this effort will be to clearly and consistently define the communication protocols, message formats, and implementation methods across these interfaces for new start efforts and system upgrades. In addition, development of middleware that can translate the multiple system inputs and outputs will be a key enabler. This effort will facilitate the mandated acquisition, technology, and logistics lifecycle management efficiencies across current and future unmanned programs.

### 4.2.4.3 *UAS Control Segment (UCS) Architecture*

The UCS Architecture is a framework representing the software-intensive capabilities of current and emerging UAS programs in the Army, Navy, and Air Force inventories. The goal is to develop an architecture based on Service-oriented architecture (SOA) principles, which will be adopted by each Service as a common business model for acquiring, integrating, and extending the capabilities of the control systems for UAS.<sup>45</sup>

### 4.2.4.4 *Unmanned Systems Interoperability Profiles (USIPs)*

USIPs are the implementation of the mandate by the Deputy Secretary of Defense’s “Unmanned Aircraft System (UAS) Memorandum 14667-07” (13 September 2007) to develop standard IOPs linked to JCIDS documents. They help drive the implementation of approved DoD and/or joint interoperability priorities at the Service level and may even require a new Service IOP or revision to an existing IOP.

USIPs also support the CJCSI interoperability requirement by creating specific points of “capability-based interoperability.” The purpose of a USIP is to define profiles of standards sufficient to guarantee interoperability in support of a specific mission capability. A USIP may reference DoD standards, Intelligence Community standards, Service-specific IOPs, and commercial standards to achieve capability-based interoperability. All approved USIP standards can be found on the DoD IT Standards and Profile Registry (DISR).

### 4.2.4.5 *Service Interface Control Working Groups (ICWGs)*

The intent of a Service-level ICWG is to ensure UAS program/product managers, developers, Services, and end users actively participate in the development and implementation of Service-specific interoperability solutions. This collaborative organization (Government-industry partnerships) serves as the standards recommendation body chartered within each Service to promote interoperability across various product lines.

### 4.2.4.6 *Service IOPs*

Historically, unmanned systems have used very deterministic point-to-point interfaces; however, provisions of network-centric warfare require UAS programs to implement common standards in support of a FoS type of architecture. Widely accepted or approved standards are

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<sup>45</sup> Source: <https://ucsarchitecture.org/>.

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often too broadly defined with varying options and inadvertently allow compliance but not necessarily interoperability (e.g., common data link (CDL) standards and Motion Imagery Standards Board (MISB) standards). Interface “standards” vary and allow for diverse implementation strategies and interpretations. To be truly interoperable, a FoS requires the Service-level development of IOPs, and eventually those IOPs must be interoperable with IOPs of the other Services.

### ***4.2.4.7 DoD CIO Interoperability Steering Group***

Due to the SECDEF’s efficiency initiatives, the DoD CIO and Director for Force Structure, Resources, and Assessment of the Joint Staff (J-8) formally agreed to transfer all Interoperability Certification Panel (ICP) responsibilities to the DoD CIO in a memorandum of understanding (MOU) dated 26 August 2011. The DoD CIO subsequently renamed the ICP to the Interoperability Steering Group. The DoD CIO will designate the chairperson of the Interoperability WG and direct its associated activities to review interoperability policy, program, testing, and certification matters in coordination with the Defense Information Systems Agency (DISA) and Joint Interoperability Test Command (JITC).

### ***4.2.4.8 Joint Interoperability Test Command (JITC)***

JITC is an organizational element of the DISA Test & Evaluation Directorate and has responsibility (per DoDI 4630) for certifying joint and combined interoperability of all DoD IT and NSS. It works closely with the Services, Joint Staff, Office of the Secretary of Defense (OSD), and DoD CIO to provide recommendations to the Interoperability Steering Group for waivers, extensions, and ultimately full interoperability certification and compliance status reporting to defense acquisition executives (DAEs) and service acquisition executives (SAEs).

### ***4.2.4.9 Joint Technology Center/Systems Integration Laboratory (JSIL)***

JSIL supports the assessment of system integration readiness during the product development process, prior to actual flight testing. JSIL provides for distributed hardware-in-the-loop testing of payloads, air vehicles, ground system components, and joint interfaces using the Multiple Unified Simulation Environment (MUSE) in globally distributed command exercises and experiments. The purpose of JSIL is to provide simulation, integration, and a full range of test support to the joint unmanned systems family.

### ***4.2.4.10 DoD IT Standards and Profile Registry (DISR)***

DISR is an online repository of DoD IT and NSS standards and related information, formerly captured in the Joint Technical Architecture (JTA), version 6.0. DISR replaces JTA. All approved USIPs are submitted to DISR. The Navy intends to use the DISR to formalize its approved Service IOPs.<sup>46</sup>

### ***4.2.4.11 Future Airborne Capability Environment (FACE)***

The Army common operating environment (COE) is an approved set of computing technologies and standards that enable secure and interoperable applications to be rapidly

<sup>46</sup> Source: <https://gtg.csd.disa.mil/uam/homepage.html?timestamp=>.



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developed and executed across a variety of computing environments. Within the COE initiative, FACE is Army Aviation's implementation. The objective of FACE is to establish a standard COE to support portable, capability-based applications across DoD avionics systems.

### ***4.2.4.12 Sensor/Platform Interface & Engineering Standardization (SPIES) Initiative***

The goal of the SPIES initiative is to develop electro-optical/infrared (EO/IR) sensor-platform interface standards that reduce acquisition, integration, and lifecycle costs; improve agility; promote OA and interoperability objectives via Navy/DoD standardization; and maintain system performance, reliability, maintenance, and availability.

### ***4.2.4.13 IOPs Defined for UGS***

As payloads, sensors, software, and computing devices are anticipated to evolve much faster than base platforms, creating interoperable interfaces for enhanced modularity represents an opportunity to minimize future lifecycle costs and adapt rapidly to changing threats or new available technologies. The Robotic Systems Joint Project Office (RS-JPO) I-IPT, formed in 2009, is working to establish, adopt, and apply interoperability standards for UGS by working with the combat developers, the S&T community, and private industry. The effort is focused around utilization of the Society of Automotive Engineers (SAE) AS-4 standard for Joint Architecture for Unmanned Systems (JAUS) with implementation guidance defined by the UGS IOPs.

### ***4.2.4.14 Advanced Explosive Ordnance Disposal Robotic Systems (AEODRS) Common Architecture***

Currently, fielded EOD robotic systems are modified commercial products with different OCUs, limited autonomy, different architectures and designs, and company proprietary software. AEODRS is being executed by the Naval Explosive Ordnance Disposal Technology Division via the Navy Program Office for Explosive Ordnance Disposal (PMS 408) to provide joint forces with an improved and modular EOD capability to respond to unexploded ordnance, counter-improvised explosive devices, and WMD missions. AEODRS comprises three system variants, utilizing Government-owned common system architecture and interfaces, which will be fielded in an incremental approach. The common architecture is present at the physical, electrical, and logical interface levels for the UGS FoS to enable modular plug-and-play components and interoperability.

### ***4.2.4.15 Test & Evaluation – Architecture and Bench Testing***

The AEODRS program utilizes an architecture test bed and simulation environment to verify logical interfaces that are defined by architecture definition documents and interface control documents. Capability module evaluation is accomplished by utilizing a test bed to verify compliance with AEODRS common architecture. Each capability module is plugged into the test bed separately to ensure individual capability modules adhere to architecture and performance requirements.

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### 4.2.4.16 *GEOINT Functional Manager Seal of Approval (GFMSA)*

The Director of the National Geospatial-Intelligence Agency (NGA), serving in the dual roles of the DoD Geospatial Intelligence (GEOINT) Manager and the Intelligence Community GEOINT Functional Manager, has established a GEOINT Functional Manager Seal of Approval (GFMSA) endorsement process. The GFMSA is recognition that an IT component has been tested and/or evaluated by a credible independent party and has been found to meet the standards conformance and interoperability qualification criteria set by the National System for Geospatial-Intelligence (NSG) community. GFMSA addresses NGA's responsibility to develop interoperability test and evaluation (T&E) criteria, measures, and requirements related to GEOINT per CJCSI 6212.01F. GFMSA increases visibility of GEOINT test criteria, measures, and requirements by offering recognition for entities that follow existing statutory and regulatory T&E processes while giving due diligence to GEOINT.

The GFMSA objective is to promote a standards-based interoperable working environment throughout the NSG enterprise. The GFMSA process enables program and project managers to confirm that the required GEOINT capability is delivered. One of the greatest challenges for a program/project manager is to extend high-level capability requirements sufficiently into manageable functional, operational, and technical components to accommodate acquisition development. The key questions are 1) "What do I want to have happen as a result of my program activities?" and 2) "How will I know it when it happens?" For the GEOINT functional aspect of a program/project, the GFMSA recognition program adds significant fidelity to answer these questions and minimizes the research needed to understand the application of GEOINT standards and the interoperability objectives and operational capabilities that must be realized across the NSG enterprise.

A group within NGA, the NSG Interoperability Action Team (NIAT), is an assistance and outreach body composed of subject matter experts in the field of GEOINT (and associated metadata) standardization and architecture deployment. The GFMSA is tightly connected with the NIAT functions to promote GEOINT interoperability across the NSG enterprise. The NIAT aids program offices with expertise in the area of GEOINT implementations for a given sensor/platform pairing in support of the system's capability. The NIAT supports acquisition category (ACAT) programs throughout the requirements and acquisition processes, joint capability technology demonstrations, and quick reaction capabilities. GFMSA ensures the adequacy of those implementations within the system in support of its data and metadata interoperability across the enterprise. This effort also encompasses the appropriate provisions of the standards needed to meet regulatory, architectural, operational, and functional requirements for integration of GEOINT functions and capabilities across the NSG enterprise.

### 4.2.5 *Interoperability and Modularity Key Technologies*

IER performance today is driven by a number of factors, including proprietary interfaces, data, bandwidths, communication waveforms, frequencies and settings, the type of data being shared (e.g., imagery, detections, voice), and the metadata tagging required (which varies widely depending primarily on end users, their processing needs/capabilities, and types of data). The ability of platforms to share data among a variety of users depends primarily on the characteristics described above, and in most instances, system engineering tradeoffs must be

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made in each of those characteristics so that a system's development, production, maintenance, and performance are optimized.

Two primary challenges related to improving and maintaining IER performance go hand in hand: 1) the ability to modify platforms for different IERs rapidly while avoiding broken IERs and safety degradation (particularly airborne platforms) and 2) the ability to rapidly modify platforms for different sensor capabilities while concurrently ensuring new sensing capabilities are distributed via the appropriate IERs.

Attempting to keep pace with these evolving needs with "core" platform systems is likely unattainable; however, maturation of a few key technologies could address these evolving needs while minimizing platform impact:

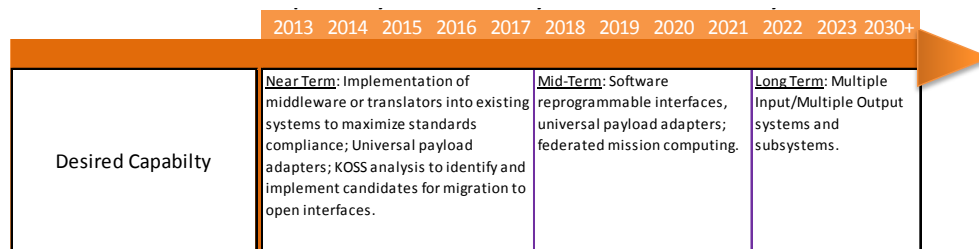
- **Middleware.** The ability to easily adjust data tagging and formatting to keep pace with evolving analytical and processing needs. If "raw" sensor data can be retagged or formatted without affecting core platform sensors or computers, IER performance could be more easily maintained while realizing the benefits of technology advances and minimizing platform impacts.
- **Multiformat discovery and processing.** The ability to ingest and process different data types simultaneously. This key enabler for continued performance can minimize platform impact. If data formats, tags, and content are known for fielded systems and if processing and analytical algorithms and computing can interact with different data formats and types at the same time, then analyst workload can be reduced in discovery and reallocated to analysis while platforms can more synergistically update their products via middleware and in concert with other improvements possibly driven by obsolescence issues or related emerging performance needs.
- **Federated mission computing.** The ability to plug and play payloads while needing only to address SWaP-C constraints. Adding new payloads to older platforms, which do not rely on centralized mission computers, is typically much easier to do than adding new payloads to newer platforms with their centralized computing. The move about 20 years ago to centralized mission computing meant that while payloads could physically be added, the cost and time to recertify the mission computing made those modifications more lengthy and difficult. Either changing mission computing philosophy or federating mission computing down to the payload (or possibly GCS) level could greatly improve rapid integration of new technologies.
- **Universal payload adapters.** The ability to install and uninstall different payloads given a platform's allocated SWaP-C. When combined with federated mission computing and defined platform SWaP-C, a standard hardware and interface installation point is critical to rapidly reconfiguring platforms for emerging needs. Today, platform weapons stations are typically used for this function because their SWaP-C and data interfaces are defined and controlled by the weapons that must be carried. A similar approach for sensing payloads would be a key enabler.

### 4.2.6 Summary

While the initiatives summarized in 4.2.4.1 to 4.2.4.16 are by no means all inclusive, they serve to illustrate the vast amount and diversity of effort and attention being given to

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interoperability and modularity concerns and the pursuit of mature and stable IERs. The battle lines in the maneuver space of the battlefield are blurring, and the need to share information, sensors, payloads, and platforms is real. The fiscal battlespace is also blurring, and vendors must shift strategies to adhere to open standards to the maximum extent practical by utilizing tools such as universal payload adapters, different mission computing philosophy, and key open subsystems (KOSS); developing middleware solutions to manage the input and output from legacy systems and manned systems; migrating toward OAs; reusing software; and developing robust repositories. As unmanned systems are relied on more and more heavily, their ability to communicate data with Service and joint systems along with their ability to adapt internally and externally will be critical to maintaining warfighting effectiveness against emerging threats while taking advantage of more capable technology. Figure 12 summarizes the goals for interoperability and modularity for unmanned systems.



**Figure 12. Interoperability and Modularity Goals for Unmanned Systems**

## 4.3 Communication Systems, Spectrum, and Resilience

### 4.3.1 Introduction

Key challenges all unmanned systems (other than pure autonomous systems) face are the availability of communication links, the amount of data that the communication links support, the assignment of spectrum allocations, and the resilience of all RF subsystems against interference (e.g., electromagnetic). There is a continued need for the Services and agencies to match and improve interoperability requirements to meet mission needs for CCDRs. DoD unmanned systems need a process for operational control and mission data distribution, especially for nonautonomous systems. For some UGS and UMS, these types of information exchanges can use a cable for the transmission path, but for highly mobile unmanned operations, the exchange is more likely to use signals sent across the electromagnetic spectrum (EMS) or by other means (e.g., acoustical or optical).

Figure 13 illustrates the communication network operational architecture (OV-1) required to support unmanned systems. Manned systems are included in this architecture to illustrate the need for a common communication support infrastructure between manned and unmanned sensor and other C2 systems — the supporting command, control, communications, and computers (C4) infrastructure should be platform agnostic (manned or unmanned). The operational architecture employs various EMS frequency bands, communication gateways and relay sites, data centers and data dissemination nodes, and terrestrial radio and network services. The communication links within this architecture support the C2 of unmanned platforms and their respective payloads and support the backhaul of information from those payloads to tactical, operational, and strategic consumers. Wherever possible, payload mission data should

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instantly reside on globally accessible data centers that enable users worldwide to find, obtain, and consume real-time and non-real-time ISR and other mission data quickly and easily. Sections 4.3.2 through 4.3.17 address needed and planned developments within the unmanned communication systems architecture and identify applicable standards and system guidance for each area.

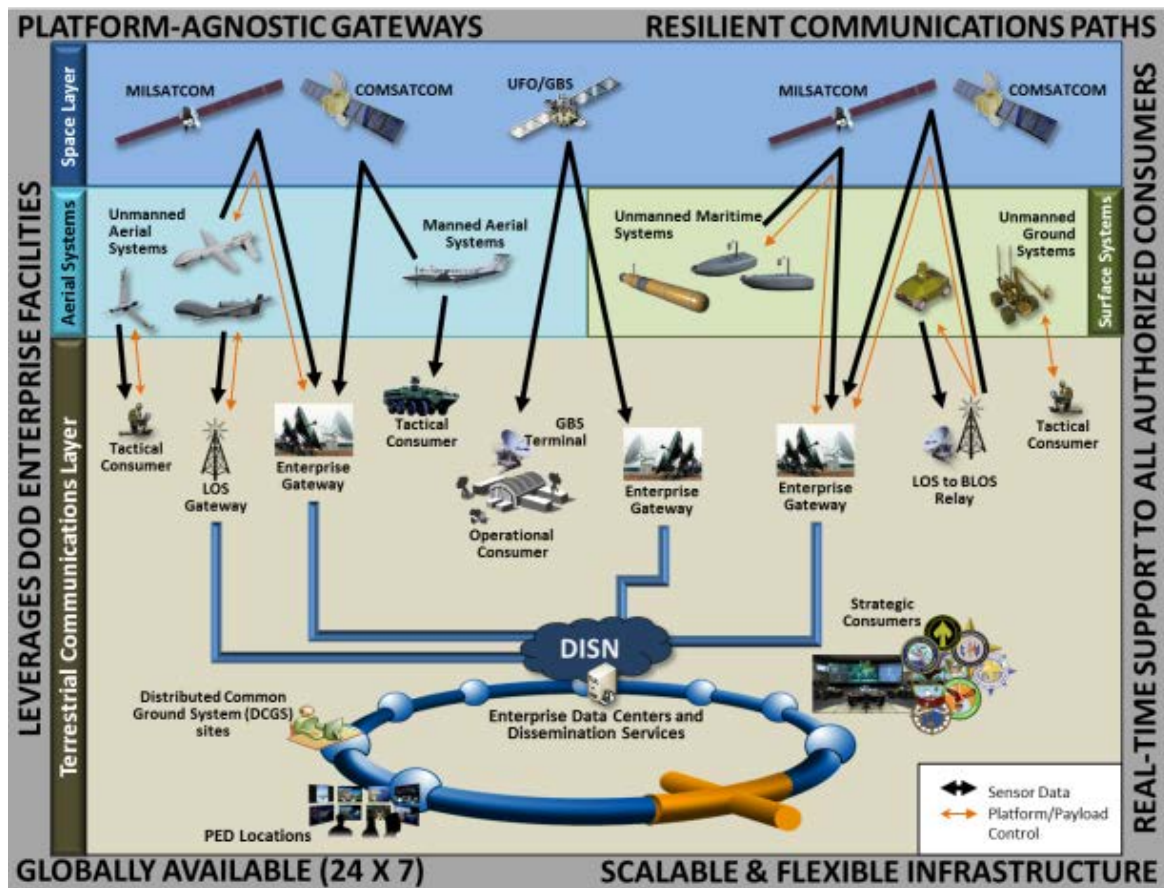


Figure 13. High-Level C4 Infrastructure Operational Concept Graphic (OV-1)

### 4.3.2 Issues with Current Unmanned Systems Communication Infrastructure

Operational lessons learned, detailed analytical studies, after action reviews, JUONs, and combat mission need statements over the past 10 years of global combat operations have repeatedly shown C4 infrastructure shortfalls in our ability to support unmanned platforms. Specific issues include

- Poor Global Connectivity.** Insufficient ability and capacity to globally distribute high-bandwidth data from unmanned platforms (e.g., full-motion video (FMV)) to strategic, operational, and tactical users. A majority of the current unmanned infrastructure is focused on the Middle East and unable to support operations in other parts of the globe.



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- **Costly Satellite/Network Contracts.** Much of our satellite communication bandwidth for each system is procured separately through commercial leases, often at a premium over the traditional DISA commercial satellite communications (SATCOM) portfolio. Many systems also rely on separate platform-centric terrestrial network infrastructures to provide connectivity with tactical, operational, and strategic consumers. Because this connectivity is often provided by leased commercial networks, the overhead cost of each system is further increased.
- **Stovepipe Infrastructures.** Many unmanned systems programs established vendor proprietary communication solutions, including gateways for beyond-line-of-site (BLOS) communication and access to terrestrial network infrastructures. This approach prevents the sharing of resources across platforms, significantly increases infrastructure overhead costs (e.g., facilities, program management), and inhibits system interoperability.
- **Poor Information Sharing.** Many systems employ dedicated processing, exploitation, and dissemination (PED) and mission data infrastructures that prevent effective data sharing among systems, services, and organizations.

In short, the current unmanned systems communication infrastructure is prone to wasteful redundancy of efforts, lacks interoperability, and inhibits the distribution of system data to potential consumers.

To better understand the best ways of addressing the challenges facing future unmanned systems operations, it is helpful to make several key assumptions:

- **Programmed Resources Will Be Limited.** OCO funding has been sustaining most unmanned systems operations in recent years. This funding will disappear in the coming years as troops draw down. Without program resources, the limited leased C4 infrastructure in place today will atrophy.
- **C4 Infrastructure Demand Is Growing.** Unmanned systems capacity requirements will grow with improvements in sensor technology and greater global distribution and will require a robust and flexible communication infrastructure, which in turn will require growth in the transport of multiplexed and multilevel classified disparate information. UAS data link capacities are expected to be capable of consolidating several high-bandwidth ingests and be network capable. Advanced airborne routers should be able to sort single-data-link disparate data and route to the appropriate consumer with assured classification transport. Onboard processing should also provide applications to provide appropriate bandwidth, compression, imagery frames per second, and resolutions in accordance with user capabilities.
- **Operating Environment Will Be Challenged.** Future unmanned missions are expected to occur in both benign and contested C4 operating environments. The C4 infrastructure must be resilient and able to perform the mission even in hostile electromagnetic and cyber environments.
- **Open Standards Improve Interoperability.** Future development of unmanned system platforms and their associated communication infrastructure must be guided by open standards and interfaces to enable interoperability and efficiently utilize limited resources.



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- ***Enterprise Capabilities Improve Efficiency.*** Establishing a sensor-agnostic communication infrastructure that is shared by multiple unmanned programs will provide cost reductions and improve information sharing and interoperability.

### 4.3.3 Communication Gateways and Relay Sites

DoD and commercial gateways provide access to military and nonmilitary satellites and to the Defense Information Systems Network (DISN) transport and Internet Protocol (IP) net-centric services, which in turn provide global distribution of mission data and enable long-range C2 of unmanned systems. Likewise, relay sites connect line-of-sight (LOS) communications with BLOS radio systems for mission data and C2 connection to DISN.

Numerous platform-centric and proprietary gateways are provided today to support operations in the Middle East. To reduce long-term expenditures on gateways and to more efficiently and effectively process information from unmanned systems, DoD will transition to platform-agnostic gateways utilizing existing global enterprise SATCOM gateway facilities (e.g., teleport standard tactical entry point (STEP) sites). Existing enterprise gateways can provide common, secure facilities; operators and maintainers; and rack space. They can also provide centralized management of floor space; power; and heating, ventilation, and air conditioning (HVAC). As a result, they can reduce the duplication of efforts among the various unmanned system program offices. Leveraging these Government assets greatly improves the affordability over a communication infrastructure based on dedicated, proprietary gateways currently used for some unmanned systems. Near-term efforts are already underway to establish manned and unmanned ISR connectivity at the Lago Patria Gateway, Italy, and Pope Air Force Base (AFB), North Carolina, STEP sites. These facilities will be configured to support a wide variety of airborne platforms utilizing commercial Ku band SATCOM.

Each gateway site will host multiple IP SATCOM systems including frequency division multiple access (FDMA) (e.g., enhanced bandwidth efficient modem) and multiple frequency time division multiple access (MF-TDMA) (e.g., Joint IP Modem, iDirect, Linkway, Linkstar, and Advantech) modems. The gateways provide intermediate frequency (IF) routing of signals between modems and earth terminals. All IP-enabled modems are connected to the converged IP transport and routing network to provide dynamic routing of IP packets and access to DISN services. Each gateway site will provide cooperative technologies to enable and/or support automated bandwidth leveling, di-plexing and further IP dissemination (routing) of multilevel security information, alternate routing, and recovery and data backup.

SATCOM gateways alone will not satisfy all deployed warfighter requirements for satellite coverage. Certain operating environments will fall outside the coverage area of these gateways and their associated SATCOM assets or may require service from satellites with which the SATCOM gateways are currently unable to communicate. In such scenarios, a dedicated BLOS gateway will still be required to support unmanned systems. DISA is developing cooperative research and development agreements (CRADAs) with industry to look at expanding the SATCOM gateway enterprise to include commercial satellite gateways. DISA's SATCOM gateway vision includes leveraging commercial satellite gateways as black (encrypted) packet entry points into DISN. This capability could provide a lower cost alternative to coverage shortfalls and preclude the need to hire dedicated vendors to establish all new entry facilities, baseband and encryption equipment, and associated terrestrial connectivity to DoD networks. To

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support this CRADA effort, DISA is also exploring improvements in gateway transport technology, in particular, the development of digital IF technology for interfacility transport of a modem IF output. This capability would facilitate connectivity from any modem to any antenna in the world, through the DISN fiber core. Digital IF will enable collapse of modem assets into centralized enterprise sites and transform SATCOM gateways into simplified radio access facilities. Additionally, digital IF would also allow the option of using commercial gateways as radio access facilities to provide black packet transport in areas where DoD SATCOM gateways do not provide sufficient coverage.

Unmanned systems require standard relay system architectures to facilitate connection of LOS systems to potential global consumers. To support operations in Afghanistan, a JUON drove the development of relay systems to support delivery of high-volume sensor traffic. The corresponding C4 infrastructure took more than a year to build and deploy. To provide support for operations outside the Afghanistan area of operation and to ensure this capability is available at the start of a contingency operation, DoD might consider a designated lead agent to manage and develop future relay systems. The lead agent could leverage existing radio systems wherever possible. For example, linking state-of-the-art transceivers used for LOS transmission of FMV and C2 data with two-way Global Broadcast Service (GBS) systems can provide a standard relay component for the unmanned systems architecture.

### 4.3.4 Enterprise Data Centers and Distribution Nodes

The Intelligence Community and Under Secretary of Defense for Intelligence (USD(I)) are responsible for ensuring that data are accessible, and they have made great strides in increasing accessibility to the warfighter. Ultimately, NGA and NSA are the functional combat support agencies for imagery and signals intelligence and maintain the authority and responsibility for data storage and dissemination. The stovepipe nature inherent in current unmanned systems extends to the data storage, handling, and dissemination functions of these systems. To reduce overhead costs, optimize manpower requirements, and improve data sharing among various services, organizations, and allied partners, unmanned systems data should be consolidated into cloud-enabled enterprise data centers with a standard infrastructure established to distribute the data to all authorized consumers. This approach falls in line with overall federal and DoD mandates to consolidate and reduce data centers and establish a select number of facilities to support all platforms and joint consumers. Recent efforts to accomplish this goal include the Intelligence Community's "big data" cloud computing efforts and DISA's Unified Video Dissemination Service (UVDS) established to support real-time distribution of FMV data to consumers around the globe. See Figure 14.

DISA's UVDS provides DoD-wide FMV consolidation, enterprise-wide FMV situational awareness, metadata transformation and dissemination services, and a robust routing capability for worldwide dissemination of FMV. Installed in DISA's Defense Enterprise Computing Centers, UVDS supports various FMV sources and user communities by providing for the dissemination of black (encrypted) and red (unencrypted) FMV streams via multicast streaming and near-real-time web-based streaming. UVDS implements DoD and industry standards, protocols, and profiles (e.g., SD, HD, H.264, MPEG-2, FLASH) to ensure the greatest level of interoperability among existing systems while taking advantage of existing computing infrastructures associated with DoD's Global Information Grid (GIG) terrestrial connectivity. The robust routing architecture connects CONUS and OCONUS locations and takes advantage

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of DoD gateways for efficient and real-time dissemination of FMV across SATCOM networks (e.g., GBS, Joint IP Modem, and USCENTCOM Digital Video Broadcast with Return Channel via Satellite). UVDS replaces the need for dedicated point-to-point communication circuits supporting Predator and Reaper operations. See Figure 15.

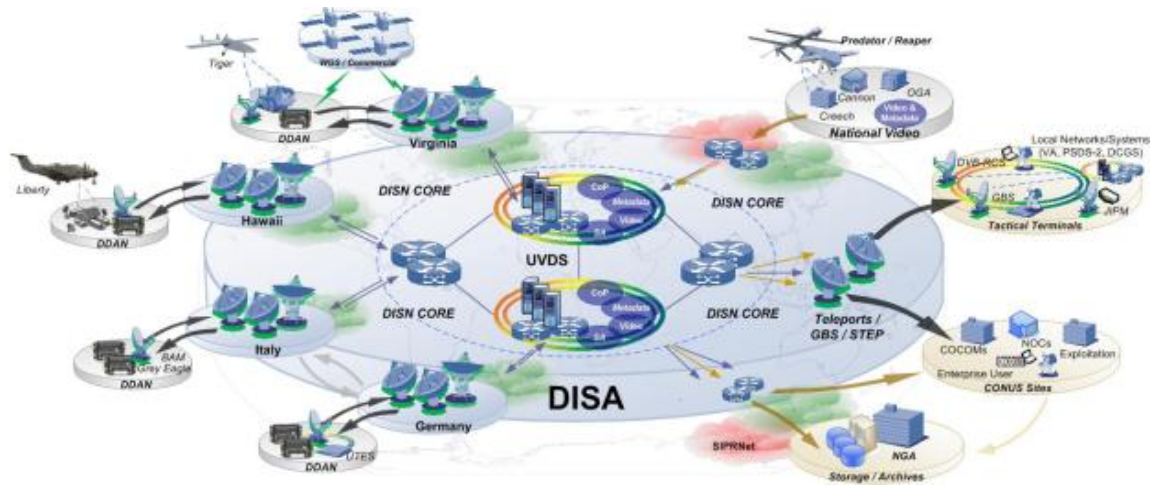


Figure 14. DISA Proposed UVDS Functional Architecture

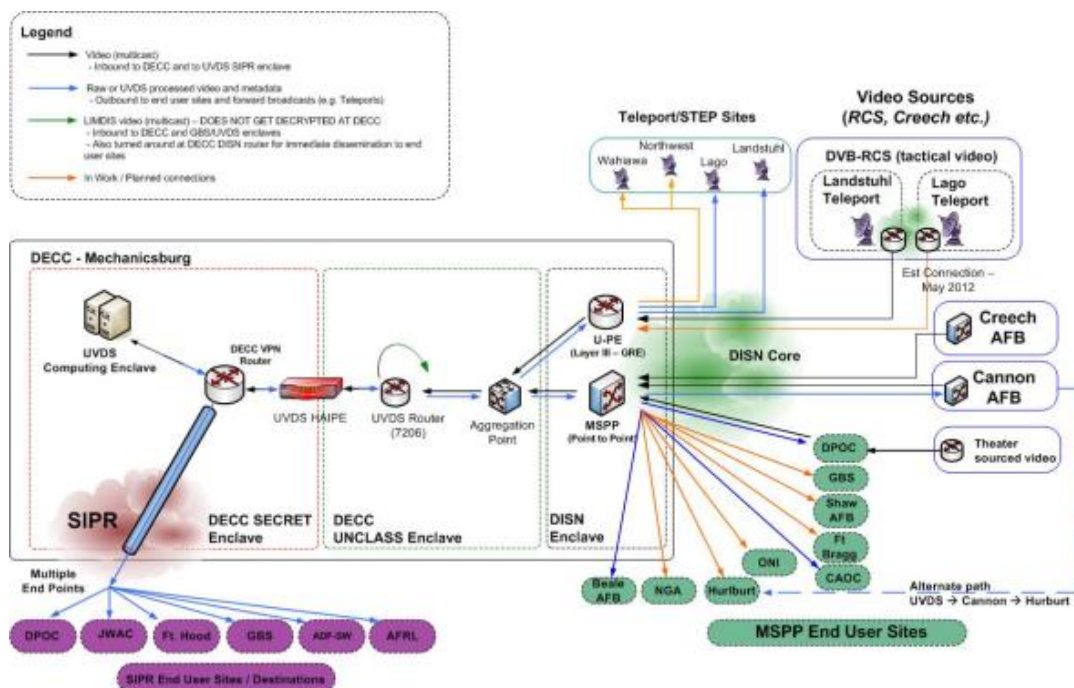


Figure 15. Current UVDS Operational Architecture (February 2012)

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### 4.3.5 Satellite Communications

A significant cost of current unmanned systems architectures is the procurement of satellite bandwidth through commercial leases. Most bandwidth used in support of deployed unmanned systems missions was procured individually, under unfavorable terms. By aggregating commercial SATCOM leases across multiple unmanned systems, DoD could significantly reduce costs in the future. To do so, future lease arrangements should be investigated through the DISA commercial SATCOM portfolio, utilizing the Future COMSATCOM Services Acquisition (FCSA) contract structure. Additionally, DoD should pursue innovative, alternative contractual opportunities and arrangements with industry that minimize the necessity for annual or multi-year leasing. These approaches allow more competitive pricing and increased buying power for Government customers. Using a common infrastructure, including compatible waveforms, will make possible the sharing of satellite bandwidth and potentially reduce the aggregate demand below the sum of the individual requirements of each system. Furthermore, the FCSA contract structure will provide the flexibility for “surges” in capabilities in response to changing mission environments.

In addition to more efficient commercial leases, the overall cost of satellite bandwidth can be further reduced by leveraging more DoD SATCOM assets. Wideband global satellite (WGS) can be used in conjunction with DoD enterprise gateways to offload unmanned systems data traffic from commercial transponders. However, this strategy is not feasible today due to a lack of installed Ka band terminals on unmanned platforms. All unmanned systems programs requiring BLOS connectivity must develop plans to establish Ka band capability to leverage military SATCOM resources and avoid costly annual commercial leases. Wherever possible, unmanned systems BLOS transceivers should consider support of both commercial and military satellite bands to provide operational flexibility and use available DoD resources.

These benefits should be carefully weighed against the potential operational risks if military units use commercial SATCOM services. UAS programs must consider a strategy and/or provisions to manage the potential risks of using the non-U.S. military SATCOM services. The major components of an implementation strategy should include need, potential operational risks identified in all related operational scenarios, and the optimal balance between cost effectiveness (benefits) and operational risks.

### 4.3.6 Networking Infrastructure and Systems

Wherever possible, unmanned systems programs should leverage the DISN core as their baseline terrestrial networking infrastructure for global connectivity. Connection points to the DISN core are already available at DoD gateway sites. Additionally, DISA is further developing its DISN core and enterprise wide area network IP service offering to complement the unmanned systems relay solution set.

The IP networking component of enterprise gateways provides routing and encryption/decryption to multiple security enclaves for access to DISN. Encrypted unmanned systems traffic would be routed through the DoD gateway net-centric convergence router, which provides connectivity between IP modem hubs and DISN. The convergence router is currently connected to both the Layer 3 unclassified provider edge and Layer 2 multiservice provisioning platform and supports multiple traffic types, virtual private network tunnels, and circuit connections.

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Unmanned system design configurations and DISN must ensure that proper IP address and ports and services assignments are planned into the design before the systems are fielded and that the systems' network configurations are modifiable in the field to quickly respond to network intrusion events.

However, unmanned systems design configurations and DISN will need to provide technology that rectifies jitter and latency inherent within an all-IP-based system for the most sensitive type sensors or other critically high reliability mission functions. Buffering issues discovered on legacy unmanned systems can cause loss of sensitive data due to dropped packets if transferring on an all-IP-based environment. In the past, deterministic technologies, such as asynchronous transfer mode, would provide the precise timing and buffer resilient capability to ensure complete data transfers with effectively no jitter or latency. Unmanned systems and DISN will need to develop and provide a similar network that ensures no packets are lost end to end between the most sensitive sensors from the unmanned vehicle, through the respective unmanned controlling segment, to various networking, to end user mission partners.

DISN core connectivity will not be readily available in all potential operating environments. Networking of multiple deployed unmanned systems may be necessary to better ensure connectivity of the systems in non-line-of-sight (NLOS), urban, hostile, and/or noisy EMS environments to relay or transfer the collected information onto GIG. Currently, envisioned network concepts include employing topology control algorithms for sparsely connected directional networks in response to jamming detection; developing cognitive algorithms for jammer detection; utilizing resilient topology control for directional networks, using IP-based, autonomous, self-organizing, nonhomogeneous networks; and providing LOS control to UAS from within an isolated network (i.e., no reach back). In 2012, the Air Force demonstrated a network with UAS and several ground nodes under the Net-T demonstration. Another concept is within the Defense Advanced Research Projects Agency's (DARPA's) LANdroids program,<sup>47</sup> which calls for the deployment of small, inexpensive, smart robotic radio network relay nodes that can leverage their mobility to coordinate and move autonomously. The program seeks to demonstrate the capabilities of self-configuration, self-optimization, self-healing, tethering, and power management. There is interest in the application of SOA approaches to future network configurations and the use of multicast communication technologies to allow semiautonomous and autonomous collaborations.

### 4.3.7 Antennas

Communication with highly mobile systems requires high-gain, rugged, and lower cost multidirectional antennas. The larger UAS may also use highly focused beams to achieve connectivity with more distant systems.<sup>48</sup> Developments in phased array antennas and "smart" antennas (including combining signals from multiple antennas) could offer an alternative to traditional dish antennas; however, they require tradeoffs among SWaP-C. DoD and industry must also continue developing such techniques as multifocused and supercooled antenna systems.

<sup>47</sup> Source: <http://www.darpa.mil/ipto/programs/ld/ld.asp>.

<sup>48</sup> Global positioning system (GPS) could be used to aid in this connectivity.



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Future antenna systems must be able to receive signals over a broad range of frequencies, but they also must be frequency selective (see 4.3.13). Therefore, phased arrays are a viable approach. Dynamically controlled (e.g., null jammers) element ( $\sim 9$  elements) arrays are available now, but significantly larger numbers of elements that are conformal (e.g., using metamaterial) and that are molded within the vehicle surfaces are in development (2020). SWaP-C and low-profile aspects are major developmental areas. The utilization of common apertures has called for the development of new interference mitigation methodologies that minimize co-site interference effects and improve the potential for achieving simultaneous transmit/receive operations within adjacent frequency bands.

### 4.3.8 Transmitter/Receiver Systems

Future transmitter/receiver systems require improved interoperability, resiliency, efficiency, and operational flexibility. Wherever possible, future BLOS transceivers should support both commercial Ku band and military Ka band connectivity. Programs such as the Navy's Triton and Army's Gray Eagle efforts are already moving in this direction. Such hardware will allow maximum flexibility across operating environments and improve resiliency of the systems in contested environments. The challenge of using multiband terminals on unmanned sensor platforms is often not caused by technological limitations, but rather by budgetary constraints. Significant upfront cost is involved with upgrading or installing new multiband terminals on unmanned platforms. However, the lifecycle costs of such systems are lower than the lifecycle costs of a Ku band-only platform, which continues to rely on leased, costly commercial SATCOM bandwidth to support operations. Further, all platforms should consider employing multiband LOS transceivers. This strategy will provide an alternate means of connectivity to potentially contested satellite resources, improve link diversity/resiliency, and link to future ground and airborne (e.g., Joint Aerial Layer Network (JALN)) relay nodes. In addition to this broad guidance on transmitter/receiver systems, the following technical recommendations are provided:

- Transmitters.** Current transmitter solid-state power amplifiers (SSPAs) are typically made with gallium arsenide (GaAs) substrate. Gallium nitride (GaN) SSPAs, currently in development, provide significant advantages over GaAs SSPAs. GaN SSPAs offer more than double the efficiency of GaAs amplifiers; they increase the amplifier operational bandwidth; and they may provide for a wider range of frequency of operation. The high transmit efficiency of GaN systems will also reduce the cooling requirements. To achieve some of these benefits, the amplifier designs are being enhanced with adaptive operating point controls that adjust to the instantaneous power being demanded from the amplifier. This enhancement significantly reduces the average prime power required by the transmitter's high-power amplifier (HPA) by allowing it to effectively turn itself off when not in use, yet adjusting to maintain proper conditions to ensure minimal distortion at higher instantaneous powers. The GaN technologies are currently available for selected frequency bands and will soon be available for fielding (2014). The HPAs may also utilize signal-processing-based signal predistortion techniques to compensate for the basic nonlinearity of the amplifier's transfer characteristics. To help in anti-jam and RF interference risks, developments in frequency-hopping characteristics should continue.



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- Receivers.** Instantaneous bandwidth performance and analog-to-digital converter sampling speeds have continued to improve year after year.<sup>49</sup> In addition, improvements in integrated chip fabrication methods have allowed for significant miniaturization and reductions in part counts and for various transmit/receive and antenna functions and components to be integrated on a single chip (2013). These receivers must incorporate higher system selectivity, high spur-free dynamic range (greater than 80 dB to 90 dB from adverse adjacent and off-channel electromagnetic environmental effects (E3)), and resistance to adverse E3. Fiber optics has been used to speed up the data and signal transfers from and to the antenna and the signal processing hardware (2012).<sup>50</sup> Microelectromechanical systems (MEMS) developments should provide smaller size, more flexibility, and greater performance (by a factor of 100 or better) in receiver designs (2015). However, these receivers must be able to operate in the presence of adjacent high-power transmitters that can drastically desensitize their RF front end, and tunable analog preselector filtering (using innovative low-SWAP-C technology) may reduce such desensitization. Future developments are expected to provide improved reliability and fabrication yields, reduced thermal characteristics, reduced integration complexity, and lower production costs.
- Transmit/Receive Systems.** Such systems will emphasize new technologies like spatial, combining, high-power, solid-state amplifiers using monolithic microwave integrated circuits (MMICs). A MMIC (sometimes pronounced “mimic”) is a type of integrated circuit device that operates at microwave frequencies (300 MHz to 300 GHz) and typically performs functions such as microwave mixing, power amplification, low-noise amplification, and high-frequency switching. MMICs are smaller and cheaper than conventional integrated circuits.

Recent developments, including software-defined radios, have produced a diversity of technologies, but no formal standards have been developed yet for this technology. Recently, the VITA 49 Radio Transport (VRT) standard<sup>51</sup> has been proposed as a solution to the interoperability dilemma. This standard provides an interoperability framework that can be used for analysis of RF spectrum and localization of RF emissions. The framework is based on a transport protocol to convey time-stamped signal data in IF data packets and metadata in context packets. The protocol abstracts the receiver data from specific hardware implementations and thus enables a common software suite to be developed independent of the receiver architectures, manufacturers, and physical links.

### 4.3.9 UMS Communications

Ocean dynamics challenge underwater and surface communications and are unique to UUVs and USVs. However, there is a significant difference between UUV and USV communication requirements. An UUV is very autonomous and requires less bandwidth than an USV acting on the surface. Due to collision regulations and safety, the USV must send to a

<sup>49</sup> Lundberg, Kent H., *High-Speed Analog-to-Digital Converter Survey*, MIT Press, 2002.

<sup>50</sup> See the DARPA Optical RF Communications Adjunct and the Office of Naval Research’s Enabling Capability programs. This application is more for ground-based systems than for airborne systems. This use also significantly minimizes the signal loss and allows more advantageous placement of selected components.

<sup>51</sup> Reference work by Robert Normoyle, DRS-Signal Solutions.

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watchstander live feedback that requires significant bandwidth. Once autonomy becomes more reliable, perhaps the bandwidth could decrease, but a USV is expected to always have a requirement for higher bandwidth due to its mission types. For example, the USV will be used generally for engagement of surface targets requiring active oversight by an operator/weapons person.

UUVs will gain efficiency and effectiveness with the development of improved real-time, two-way communications that do not undermine mission accomplishment. The Navy's *Undersea Dominance Roadmap* (published in 2012) identified current and future architectures to link UUVs, distributed netted systems, and tactical platforms. The Navy has begun initial production of a planned 150 littoral battlespace sensing UUVs, which are capable of completing up to six-month-long autonomous sensing missions. Advanced UUV sensors and clandestine and low-latency communication and networking capabilities are viewed<sup>52</sup> as key game changers. Future developments will come through the Office of Naval Research S&T research and development efforts.

### 4.3.10 Spectrum Considerations

The EMS is highly regulated at the national<sup>53</sup> and international<sup>54</sup> levels. Federal Acquisition Regulations and Office of Management and Budget policies require U.S. national spectrum approval before funds are expended on spectrum-dependent systems (SDS). DoD policy and military department regulations require submission of technical parameters to the national spectrum approval process as well as to host nation's approval processes for prior approval before spectrum operations can commence within the United States or other nations. While numerous over-the-air communication systems and active sensors, such as radar, have been designed, built, and fielded so they comply with national and host nation spectrum regulations and technical standards and have performed reasonably well, others have been fielded in a noncompliant status and have often not met final operational constraints.

U.S. military operations are now occurring in many parts of the world where adequate spectrum is not available for C2, sensor, and data link systems. There is a significant increase in the number of SDS the United States, our partners, and our coalition forces deploy to address current, and may want to deploy to address expected future, mission areas. In addition, these SDS collect more information, and missions often require greater bandwidths to send their information directly to warfighters. Also, mission areas are becoming more spectrally "noisy" because of increasingly cluttered and hostile spectrum environments. As such, a continual demand for improved spectrum efficiency and effectiveness is being placed on all DoD SDS.<sup>55</sup> All unmanned systems must complete, during their development process, a spectrum supportability and risk assessment (SSRA) in accordance with DoDI 4650.01. The SSRA is to identify and mitigate regulatory, technical, and operational spectrum supportability. Because

<sup>52</sup> Navy's updated UUV Roadmap.

<sup>53</sup> For the U.S. Government, see the National Telecommunications and Information Administration's *Manual of Regulations and Procedures for Federal Radio Frequency Management*. Washington, DC, January 2008 edition, September 2009 revision (incorporated by reference under 47 CFR 300.1).

<sup>54</sup> International Telecommunication Union (ITU), *Radio Regulations*, Geneva, Switzerland. 2007 Edition.

<sup>55</sup> All new and modified SDS programs now must conduct an SSRA prior to Milestone B (source: DoDI 4650.01).

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national and international spectrum rules and policies can rapidly change,<sup>56</sup> developers should maintain a close liaison with appropriate DoD spectrum offices before finalizing communication system designs.

There is particular interest in expanding DoD UAS operations in nonsegregated portions of the NAS; this expansion may require the use of specific types of spectrum allocations to perform C2 and sense and avoid (SAA) functions due to safety and regularity of flight requirements. The preferred allocations are those set aside for, and carefully controlled by, civil aviation authorities. Where necessary, alternative allocations may be used by Government users provided an equivalent level of protection can be demonstrated. That equivalent level may include higher performance specifications, e.g., those for reliability and data latency.

The teleoperation of UGS from a remote location requires negotiation between LOS and NLOS conditions to provide situational awareness and reconnaissance to the warfighter. Wide frequency bandwidths are needed to support the near-real-time imaging required to negotiate confined areas, doors, etc. The availability of the right spectrum is critical for the operation of UGS to support various missions. This availability is determined by a number of factors, including a host nation's allocation and assignments of spectrum within its borders, congestion, and operational requirements of the SDS. Based on the results of appropriate SSRAs, the SDS may need to be planned and designed for multiband operation and/or provide significant tuning flexibility to maximize global use.

The DARPA's Next Generation project and its follow-on Wireless Network after Next (WNaN) program demonstrated the feasibility of dynamic spectrum access (DSA). DSA offers the ability to change frequency band use based on the actual use or nonuse of certain bands by other adjacent SDS. The Army is also considering having WNaN become part of an Army POR. However, a recent Air Force Scientific Advisory Board study said that DSA is far from being proven technology. Developmental challenges include susceptibility to countermeasures, costs of integrating with existing systems, developing standards (including regulatory aspects), and co-site interference (2015).

### 4.3.11 Waveforms

In accordance with DoD policy, CDL is the DoD standard waveform for all airborne manned and unmanned platforms with ISR sensors. All ISR wideband terminal variants, including tactical CDL equipment, must comply with Specification 7681990 and the overarching Specification 60038365.<sup>57</sup> Furthermore, wideband terminal variants must comply with the latest revision of Specification 60038368.<sup>58</sup> Legacy ISR programs upgrading communication

<sup>56</sup> Relatively near-term spectrum usage changes came from ITU and its 2012 Worldwide Radiocommunication Conference (WRC); UAS spectrum use was a conference agenda item. Changes in frequency band usage for UAS may also come from the FAA and the International Civil Aeronautics Organization (ICAO) as part of the UAS operations in the NAS airspace and in other nation-states' airspace during preparations for the WRC to be held in 2015.

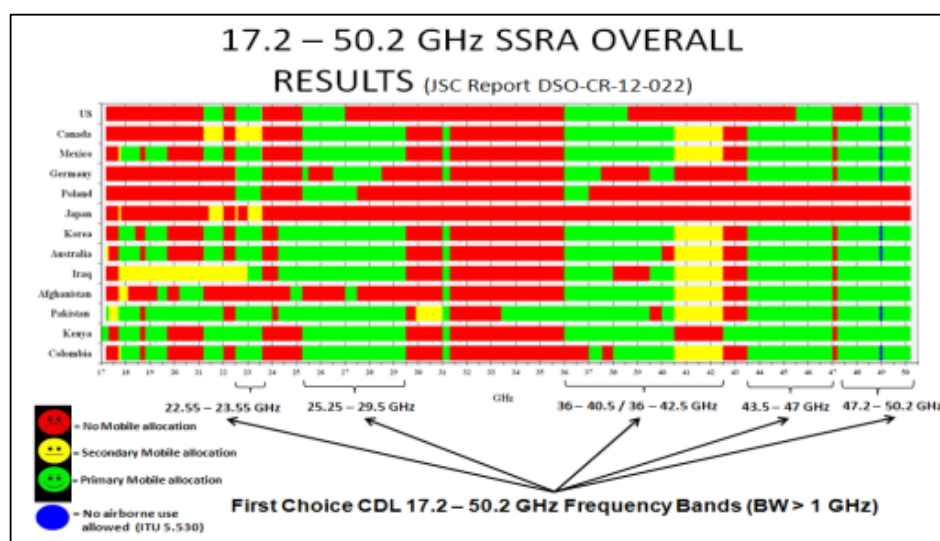
<sup>57</sup> Specification Number 7681990, Performance Specification for the Standard Common Data Link (Std-CDL) Waveform, November 2009, and Specification Number 60038365, Capstone Specification for the Network-Centric Common Data Link (CAPSTONE), November 2007.

<sup>58</sup> Specification Number 60038368, Performance Specification for the Bandwidth Efficient-Common Data Link (BE-CDL) Waveform, May 2011.

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capabilities must comply with the latest revision of the appropriate CDL specification, and any systems not implementing a current interoperable version of CDL must develop a migration plan for review by the DoD CIO and USD(I). Any waivers from these requirements must be approved by the USD(AT&L).

The CDL family (currently five variations) of waveform specifications permits terminals to operate in S, C, X, Ku, and Ka bands. Other bands are under consideration (see Figure 16), and they are employed in multiple aerial and ground ISR platforms. Current plans call for CDL to evolve from a point-to-point capability. Near-term added capability plans include modernized cryptographic solutions (including agile and dynamic key distribution methods to support mission retasking at the strategic and tactical level), dynamically adaptive waveform parameters and A2/AD requirements [anti-jam, and low probability of intercept/low probability of detection (LPI/LPD)]. Middle-term (2019) plans include new networking capabilities (e.g., self-healing and self-forming, ad-hoc networking, disruption-tolerant networking, and dynamic and multiple-access network management). Long-term (2020+) plans include autonomous policy-based network management and cognitive CDL. CDL waveform changes must comply with DoDI 4630.09.<sup>59</sup>



**Figure 16. Possibilities of Obtaining Spectrum Support in Various Host Nations for Wider Frequency Range**

Due to size, weight, and power considerations, small unmanned aircraft systems (SUAS), which require data link terminals smaller than available miniature CDL technology, may be exempted from this policy after waiver review by the OUSD(AT&L). Moreover, to ensure SUAS transition to achieve DoD net-centric policies and to support efficient spectrum use, incorporation of encryption, and interoperability requirements, the DoD CIO and USD(I) will review and approve any SUAS data link solutions prior to acquisition. The miniature CDL terminal has low enough size, weight, and power that it could be used on vehicles down to

<sup>59</sup> DoDI 4630.09, Wireless Communications Waveform Development and Management, 3 November 2008.

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roughly 30 lb. All CDL terminals require an approved encryption capability (DoDI S-4660.04). Any CDL terminals not compliant with encryption policy require a review by the DoD CIO and USD(I) with support of NSA.

The CDL program will promote interoperability, standardize interface implementations, promote compliance with industry-accepted standards (including USIP and other commercial development/maintenance standards), and maximize use of open standards. Future CDL technologies will promote reuse of waveforms, software, and hardware so that the amount of new development (i.e., items created from scratch) is reduced. The Services are encouraged to use competitive acquisition for procurement of CDL systems, and any new CDL developments shall include unlimited rights for technical data and software.

### 4.3.12 Multiple-Input, Multiple-Output (MIMO) Systems

MIMO is a proven technology and is currently being used in commercial fourth generation (4G) wireless systems moving at less than 30 knots. It has been tested at data rates up to 300 Mbps.<sup>60</sup> MIMO combines information theory, forward error correction coding, signal processing, and propagation theory; therefore, the mathematics behind MIMO and space-time coding is complicated. MIMO would use multiple paths (although they are not necessarily independent) with lower data rates on each path; apply space-time coding and capacity optimization to achieve a total high data rate mission; apply power saving to jammer margin; and evaluate performance in benign and stress conditions.

With further improvements in electronic discovery, interface design, and adaptive protocols, self-forming and self-healing mesh networks may enable unmanned systems to operate in multiplatform, multisensor networks.

### 4.3.13 Electromagnetic Environmental Effects (E3)

Electronic systems may be susceptible to damaging E3 that can arise from a variety of natural or manmade (including enemy EW and friendly counter-EW) environmental sources.<sup>61</sup> E3 applications include full vehicle susceptibility analysis; enclosure shielding effectiveness calculation; test rig design, assessment, and normalization to free space environments (e.g., lightning return conductor systems); cable design and shield transfer impedance extraction; prediction of induced currents and voltages in complex cable systems; and performance of electromagnetic interference (EMI) filters, ferrites, or nonlinear transient protection circuits. The DoD E3 handbook<sup>62</sup> describes the tasks that should be accomplished to ensure E3 control and EMC measures are incorporated into the development and operational procedures of an item to achieve the desired level of EMC during its life cycle. The joint E3 control strategy recognizes that electromagnetically interfering and susceptible equipment designs should be eliminated or avoided (via proper budgeting support) during development and in acquisition and proposes use

<sup>60</sup> The conditions in UAS applications are much different than those for commercial cell phones.

<sup>61</sup> These sources may include electromagnetic pulse (EMP), radio frequency interference, high-intensity radiated fields (HIRF), electromagnetic interference (EMI), electrostatic discharge (ESD), lightning strikes, and precipitation static (P-STATIC). Other concerns include the hazards of electromagnetic radiation to personnel, ordnance, and volatile materials (RADHAZ).

<sup>62</sup> MIL-STD-464, MIL-STD 461F, and MIL-HDBK-237B, Guidance for Controlling Electromagnetic Environmental Effects on Platforms, Systems, and Equipment.

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of a positive control methodology called “gating” in conjunction with established “exit criteria” to monitor the planning and application of E3 control measures.

A critical challenge is that while communication needs continue to increase, degradation from interference also tends to increase at a comparable, if not more accelerated, rate. While it is not an easy task to design a highly sensitive radio receiver that also has a wide dynamic range, communication systems transmission advances without comparable E3 resilience advances will not ensure continuous operations of unmanned systems.

### 4.3.14 Optical Communications

The application of lasers in unmanned systems communications could provide increased target detection capabilities, improved anti-jam performance, robust LPI/LPD, and decreased EMI within the communication subsystem. Optical routers will be more practical when we employ unmanned high-flying vehicles like the Global Hawk, Boeing’s Phantom Eye, and the X-37B. Optical communication systems are hampered by atmospheric absorption challenges, yet they offer far greater bandwidth (measured in gigabits per second) capabilities. LOS optical links have successfully been demonstrated at link ranges in excess of 50 km. Applications could apply to fixed locations and in air-to-air and ship-to-ship scenarios. Theoretical estimates indicate that air-to-ground links are feasible at rates up to 100 Mbit/s for link slant ranges up to 100 km, depending on atmospheric conditions. Due to the extreme narrow beamwidth of such systems, maintaining pointing accuracy to and from a moving unmanned system will be a major challenge (>2020). A recently completed DARPA program, Free Space Optical Experimental Network Experiment, employed a hybrid optical/RF communication technology and demonstrated air-to-air (>200 km range; data rates of 3 Gb/sec to 6 Gb/sec) and air-to-ground (>130 km slant range; 3 Gb/sec to 9 Gb/sec) point-to-point communications.

### 4.3.15 Advanced Navigation Developments

DARPA<sup>63</sup> is working on two advanced navigation strategies that are kinematic (i.e., there is no force rebalance) and should offer significant improvements in effectiveness.

The Precision Inertial Navigation Systems (PINS) program seeks to use ultra-cold atom interferometers as an alternative to GPS updates. Advancements in atomic physics in the past two decades have given scientists much better control over the external quantum states of atoms, including deliberate production of matter waves from ultra-cold atoms. This advancement has allowed development of matter wave interferometry techniques to measure forces acting on matter, including high-precision atomic accelerometers and gyroscopes. Using this technology, this program seeks to develop an inertial navigation system, which should have low unprecedented drift rates yet address many scientific and technical challenges. The program is on schedule to demonstrate a high-precision atom interferometer inertial navigation system on an aircraft during 2013, with a total system volume less than 20 liters. Since this innovation is an entirely inertial system, it will require no transmissions to or from the platform, thus enabling a jam-proof, nonemanating inertial navigation system with near-GPS accuracies for future military submarines, aircraft, and missiles.

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<sup>63</sup> The point of contact is Dr. Stefanie Tompkins.



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The program has developed improved gravity gradiometers, accelerometers, and gyroscopes where the atoms are in a nearly perfect inertial frame of reference (no sensor case) and the laser/atomic physics interactions determine the relative motion between the inertial frame and the sensor case. The sensor accuracy derives from the use of optical wave fronts to determine relative motion.

The High Dynamic Range Atom (sensors) (HiDRA) program seeks to develop the compact sensor operation used on dynamic platforms where the inertial measurement unit (IMU) would offer accuracies of a 20 m/h, 10 g, 100 °/s, <4 L sensor, <20 L system. Relative to conventional sensors, it would offer a common technology for accelerometers and gyroscopes, a high sensitivity and linearity for high-g environments, and cost-effective fabrication and maintenance. Relative to PINS II sensors, it would offer use in multiple axes, high-g operation, compact sensor heads, integrated laser system/sensor heads, field-programmable gate array timing system for high repetition rate operations, atom recapture, scattered light suppression for short modulation period, and multipulse beamsplitters (optional).

### 4.3.16 Improved GPS Operations

The NGA has developed the Estimation and Prediction of Orbits and Clocks to High Accuracy (EPOCHA) real-time software for GPS orbit/clock estimates, which enables the capability for potentially higher accuracy GPS positioning for many platforms. Using the NGA EPOCHA products could provide more current, higher rate information to improve position estimates. The concept has been demonstrated in post-processing, and the results confirm the improved accuracy; decisions regarding incorporating it within existing or future systems have yet to be made. Initial Operational Capability (IOC) for EPOCHA real-time support to military platforms is FY2014 (October 2013), with a 5-minute message update rate. Full Operational Capability (FOC) is scheduled by FY2016 (October 2015), with a 30-second message update rate.

Many UAS conduct Positioning, Navigation, and Timing (PNT) using GPS. Currently, DoD requires Selective Availability Anti-Spoofing Module (SAASM) GPS<sup>64</sup> as SAASM decreases GPS vulnerabilities by offering encrypted GPS data and satellite authentication. In the near future, a military GPS upgrade known as M-code GPS will be made available. M-code GPS is required for all new acquisitions starting in FY2017.<sup>65</sup> The M-code signal provides better jamming resistance and has enhanced features for authentication, confidentiality, and key distribution. Unlike prior systems that may rely on GPS for positioning, M-code GPS can calculate PNT independently using only the M-code signal.

### 4.3.17 Cost Effectiveness Considerations

DoD's desire is to operate unmanned systems in theaters or within the United States and its possessions so that constraints on communications and active sensor systems do not adversely affect successful mission execution. Specifically, DoD must significantly improve communication transmission efficiencies; attain better bandwidth efficiencies; increase transmitter/receiver efficiencies; acquire communication systems that are of less size and weight,

<sup>64</sup> Relevant SAASM GPS policies include DoD GPS Security Policy, 4 April 2006, and Chairman of the Joint Chiefs of Staff Master Positioning, Navigation and Timing Plan, 13 April 2007.

<sup>65</sup> The M-code GPS mandate is stated in Public Law 111-383, Sec 913.

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require less power, and need less cooling to operate satisfactorily; and acquire higher gain antennas that are able to receive signals over a broader range of frequencies while retaining frequency selectivity. Unmanned systems programs must also leverage existing DoD enterprise facilities wherever possible and avoid building separate platform-centric communication infrastructures. Current and future operational employment of unmanned systems will also require access to a range of SATCOM capabilities. Planning and budgeting for such unmanned systems operations must take into account realistic assessments of projected SATCOM bandwidth (both military and commercial) in a range of operational scenarios. Investments in unmanned systems must be matched with appropriate investments in the military and commercial SATCOM capabilities that are required to support unmanned systems operations.

### 4.3.18 Future Trends

Based on the force multiplier that unmanned systems have provided to our combat troops, it is expected that there will be a continued and increasing demand for capabilities to be supported by their communication systems. Those demands will include such capabilities as having a single operator conduct more real-time analysis of multiple situations, while the unmanned system performs many of its assigned functions autonomously. Future communication equipment must be simple plug-and-play payloads that are easily, quickly, and cost-effectively modified, updated and/or upgraded, and linked to globally available enterprise capabilities (e.g., gateways, data centers) to ensure rapid discovery and exploitation of mission information from any authorized DoD consumer.

### 4.3.19 Mobile Technologies

The mobile technologies initiative is pursuing rapid Government off-the-shelf application development; transition to tablets and smartphones for computing platforms; and a 4G cellular infrastructure to disseminate intelligence, data, and voice transmissions. By leveraging the devices developed and supported by commercial industry, significant cost advantages and infrastructure can be used to accomplish missions without requiring taxpayer investment in a large and bureaucratic network or capability.

### 4.3.20 Summary

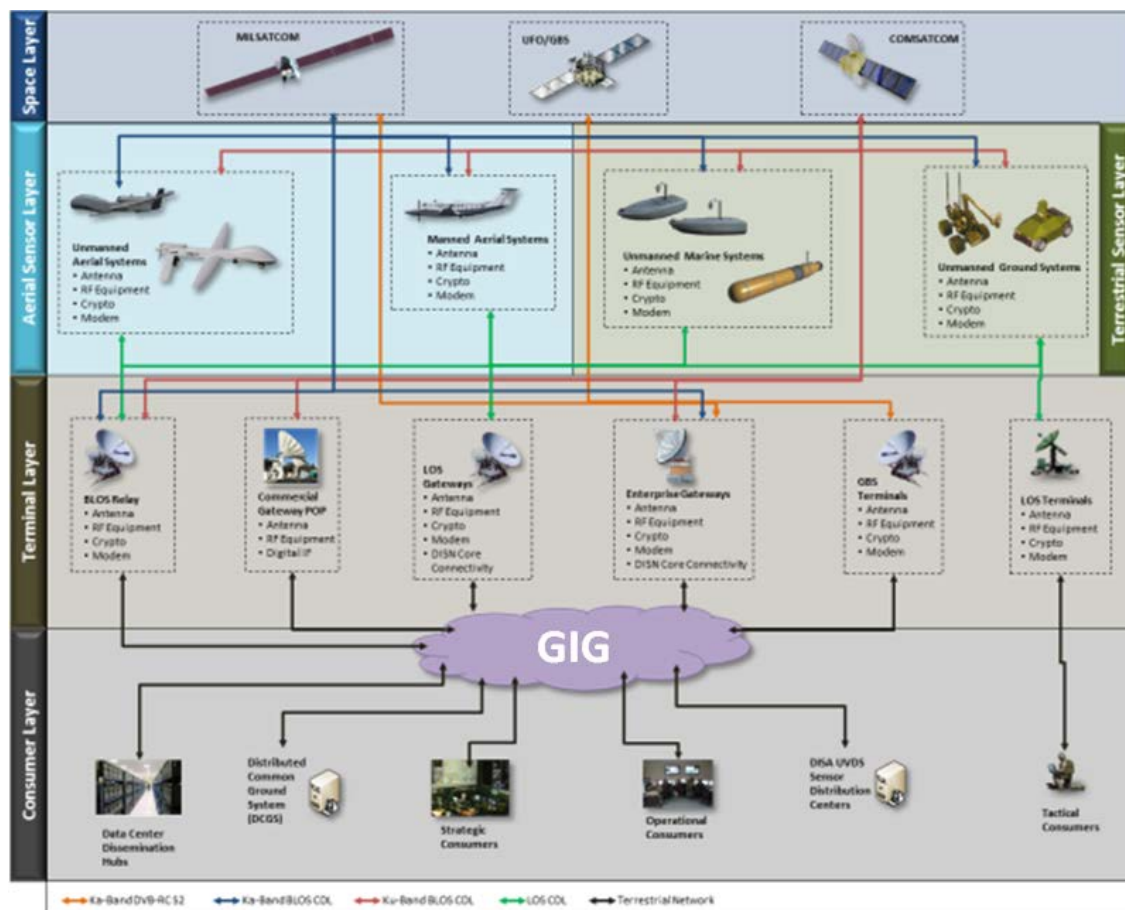
Several steps can be taken to solve the challenges faced by the future unmanned systems communication infrastructure. Affordability may be improved by centralizing unmanned systems enterprise management. Centralized management of C4 transport and network infrastructures can greatly improve system availability and efficiently use scarce system resources. Common management of multiple system assets will result in network redundancy, resilience, and path diversity for sensor platforms. It will also allow flexible frequency usage for launch and recovery. Interoperability should be the key factor in considering affordability of future architecture solutions. The architecture should transition away from redundant stovepipe solutions to leveraging existing enterprise SATCOM, gateway, and terrestrial network assets. Common IP modems (e.g., JIPM) should become the standard for providing net-centric system capabilities. Future commercial services should be procured through more innovative strategies (e.g., FSCA leases, point-of-presence access to commercial gateways). Additionally, the pool of communication resources can be deepened by expanding operating spectrum usage to military

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Ka band and leveraging aerial networking capabilities such as JALN, including its GIG injection points.

Open standards and interface definitions are key to mitigating the challenge of interoperability of unmanned systems communication infrastructures. Enforced open standards and Government-owned data rights will promote the leveraging of common components and facilitate reuse among heterogeneous unmanned system platforms. Using Government-owned enterprise assets (e.g., WGS, DoD enterprise gateways, DISN core) will help unify the communication infrastructure.

Figure 17 summarizes the target unmanned systems communication architecture with the proposed solutions in place, and the new infrastructure exhibits greater interoperability among various unmanned system platforms through the use of common control and data dissemination systems. Resiliency is improved through use of multiband terminals and common interfaces, and this improved resiliency allows access to DoD and commercial SATCOM resources as well as to enterprise gateways and small points of presence at commercial radio facilities. The increased utilization of DoD assets in this architecture offsets commercial resource requirements, improves efficiency, and reduces the operating costs.



**Figure 17. Unmanned Systems Target Architecture**

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Figure 18 summarizes the goals for communications systems, spectrum, and resilience for unmanned systems.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2030+
Desired Capability	<b>Near Term:</b> Unmanned System connectivity to Teleport sites supporting Africa and Pacific, Global UVDS capabilities, Secure Micro Digital Datalink, DSA, WNaN, Chip Count reduction, Ka-band terminals, Single Chip T/R, GaN technology, Eff. FEC, "Dial-a-rate" CDL, Adv. MIMO, consolidated gateway sites under common communications architecture, aggregate COMSATCOM leasing under FCSA.			<b>Mid-Term:</b> Multi-focused, Super-cooled Antennas, Conformal phased array antennas, standard multi-band transceivers, cloud-enabled enterprise data centers, transition BLOS gateway capabilities to enterprise gateway sites supplemented with dedicated gateways outside coverage areas, tech refresh terminal upgrades to Ka-Band or multi-band hardware.			<b>Long Term:</b> Adv. Error Control, Further Adv. MIMO configurations, Network Path Diversity, Optical Communications, commercial gateway points-of-presence with Digital IF inter-facility transport.					

**Figure 18. Communication Systems, Spectrum, and Resilience Goals for Unmanned Systems**

### 4.4 Security: Research and Intelligence/Technology Protection (RITP)

While the challenge of incorporating security measures on unmanned systems mirrors that of manned systems, additional C2 requirements are unique to unmanned systems and expand the overall requirement for system security. This section addresses those overall requirements.

The evolution of integrated sensors across multiple systems drives the need for a modified approach to program protection. The emphasis has shifted from protecting system-organic technologies and information to a more comprehensive methodology: a platform-agnostic, sensor-specific approach to address program protection across multiple systems and platforms. This methodology seeks to ensure protection of not only the technology on which the sensors are based, but also the intelligence information collected by these sensors.

RITP includes the layered application of protective principles, techniques, and solutions to prevent compromise of critical information and/or technology to an adversary or otherwise unintended entity. This concept was developed to address the range of security elements required to carry out policies described in DoDI 5200.39.<sup>66</sup> RITP incorporates DoD and Navy directives, instructions, policies, and guidance concerning program protection and/or countermeasures, including anti-tamper. RITP is accomplished through the rigorous evaluation of subsystems to identify critical program information (CPI) and assessment of resulting CPI to determine which elements require additional protective measures. RITP bridges systems security engineering and other overarching security operations to ensure protection of intelligence sensors and products.

System vulnerabilities and threats are examined, as well as risk of exposure and consequence of system compromise, to proactively establish the foundation of security disciplines as early as reasonable in the developmental life cycle. Impact to the program in terms of cost, schedule, and performance is also factored into the determination of appropriate protective measures. When applicable, protective measures selected for implementation are

<sup>66</sup> DoDI 5200.39, Critical Program Information (CPI) within the Department of Defense.

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validated and verified as part of program systems engineering, T&E, and systems security engineering processes. With the integration of emerging technologies with critical information, it is more important than ever to evaluate appropriate layered protective measures through an integrated approach that includes complementary disciplines such as information assurance, operational security, anti-tamper, and counterintelligence and intelligence analysis. Anti-tamper is more cost effective when implemented at program onset.

### 4.4.1 Data at Rest (DAR) Encryption

To date, no NSA-approved, type 1–certified DAR encryption devices are suitable for U.S. military operational and/or tactical airborne platforms storing data labeled top secret and secret compartmented information (TS/SCI) and below. The manned systems community often relies on an emergency destruct plan to ensure physical destruction of classified media, including DAR stored on hard drives, should an operator believe the classified media are at risk of compromise.

As spinning hard drives are replaced by solid state drives and other media storage devices, the need for other methods of destruction becomes more critical. Other manned platforms face similar data destruction challenges. While NSA-approved data sanitization techniques are available, these techniques are either too time consuming for emergency scenarios or not approved for the sanitization of TS/SCI data. These limitations drive programs to seek other protective measures, including encryption.

For UAS, destruction of data becomes an even more challenging endeavor because aircrews are not available to carry out procedures such as an emergency destruct plan. Unmanned programs must rely on autonomous protective measures. Unmanned platforms are required to have an emergency location transmitter that transmits its GPS location to support rapid recovery and/or for coordinates-seeking NLOS weapon targeting for data/vehicle destruction.

### 4.4.2 Cost Effectiveness

Since the DAR encryption capability for data labeled TS/SCI and below is extremely limited, several programs have collaborated to devise a solution that can be implemented across systems in the very near term, such as within 24 months. Although some development work is still required, the cost involved with the acquisition, development, and production is relatively minimal when the overall payoff is considered. The end product would cost less than most Type 1–certified network encryptors and would help to ensure that, with a push of a button (or even with an autonomous command), DAR would be rendered unobtainable by the adversary. The overall cost savings in terms of prevention of technology or information/intelligence loss would far exceed the initial development cost.

### 4.4.3 Near-Term Goals

Representatives from the Navy and Air Force have identified the need to integrate more robust methods for protecting classified DAR. The proposed solution includes the identification of resources for concept development of an NSA-approved Type 1–certified DAR encryptor that will be integrated on airborne (manned and unmanned) platforms and their associated ground support and processing stations. Unmanned systems must have the ability to remotely and

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autonomously render DAR unrecoverable by the adversary through a reliable and immediate encryptor key zeroization process. The proposed solution also allows the DAR to be recovered when appropriate key recovery protocols are executed.

The proposed next-generation DAR encryptor must be installed in a manner that is as transparent to platform subsystem functionality as possible to minimize subsystem redesign requirements. Performance must not be degraded due to encryptor latency. The use of inline media encryptors (versus software-based and/or embedded encryption methods designed into each platform subsystem) may minimize the integration impact on legacy platform subsystems requiring DAR encryption. Inline media encryptors will also allow for flexibility to upgrade to media with greater storage capacity. Mission and ground support and processing CONOPS have proven to be a primary driver for DAR encryptor functional specifications. Key management processes must be conducive to interoperability across systems and GCSs. Multiple encryptor keys may be loaded through a single key fill port. The single encryptor may support multiple inputs and multiple target storage media locations, at multiple classification levels. Technical concepts for a next-generation DAR encryptor have been identified and evaluated for compatibility with the intended CONOPS. Several platforms have provided input for encryptor functionality with a focus on platform-agnostic, sensor-specific integration.

### 4.4.4 Middle- and Long-Term Goals

Evolving technologies for storage media will drive the need for faster, more specified encryption devices that support data in various states and blur the line between DAR and data in transit. Similarly, storage media requirements will increase, along with the need to move those media at a more efficient speed. As more data are processed and stored off the system, the need for adaptive technologies for data encryption becomes more critical. As these adaptive technologies emerge to support encryption, program protection requirements will also evolve. The complementary approach of integrating layered protective measures will likely yield the most cost-effective and robust means to prevent compromise of the data and/or technologies.

### 4.4.5 Unified Security Classification Guidance

As sensors are integrated across multiple platforms with similar mission requirements, the need for unified security classification guidance becomes more evident. Systems will integrate sensors from multiple classification levels and comply with guidance from various classification authorities. As conveyed by the Office of the Director of National Intelligence, Associate Director of National Intelligence, and the DoD CIO in the “Intelligence Community Classification Guidance Findings and Recommendations Report”:

*A critical component of effective intelligence collaboration and information sharing is a common understanding of information classification standards and policies. Inconsistent interpretation and application of the classification levels defined by Executive Order 12958, as amended, often results in uneven guidance, misunderstanding, and a lack of trust between Intelligence Community agencies and mission partners concerning the proper handling and protection of information. Agency-unique or contradictory classification guidance can slow or prevent information sharing across agency, Government, and partner lines. Therefore, we must*



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*create classification guidelines that transcend organizational cultures. True information sharing and intelligence collaboration cannot occur until all participants trust that when they provide information it will be appropriately protected. A capstone Intelligence Community classification guide governing intelligence information is necessary to enable that trust.*

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### 4.4.6 Cloud Computing and Multilayer Security

With the progression of unmanned ISR platforms and the resulting surge of data, the need to disseminate this information to a broad area of users in a timely manner becomes painfully evident. On a similar note, as DoD continues to feel budgetary pressure, programs are urged to find ways to more effectively conduct their operations — the Intelligence Community is no exception. There is a tremendous push to consolidate IT systems, eliminate redundancy, and focus on a cloud solution instead of traditional desktop or network architectures. It is not surprising that the Intelligence Community embarks on this endeavor with a great deal of caution.

*There is going to be a cultural shift in addition to a technology shift in the way we do business, and in the agencies recognizing that some of their individualities and their equalities are not going to be given up, but they're going to interface with them in a different way.*

*Cloud computing initiatives are being developed as the Intelligence Community works to transform its use of IT to a model that incorporates shared services and requires less duplicative resources.*

*Grant Schneider,  
Deputy Director, Information Management and  
CIO, Defense Intelligence Agency*

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Some of the driving concerns about cloud computing within the Intelligence Community involve confidentiality, integrity, and availability. Stringent requirements are set to prevent unauthorized disclosure of classified data. It is critical to ensure that the implementation of a cloud computing architecture in the Intelligence Community enables the user to distribute and receive information, while maintaining the required level of security controls to protect that information. Integrity of that information must be preserved to ensure that the data are not unintentionally (or maliciously) modified or degraded. Availability to users is a primary concern. The expansive operational (and often mobile) user environment dictates the need for a robust cloud computing capability. The increasing requirement for larger volumes of data presents bandwidth, latency, and storage challenges. As the user base becomes broader and multiple classification domains are introduced, these challenges become even more difficult to manage.

Incorporating a multiple-security-level network (and the associated requirement for data tagging) presents its own inherent challenges: combining these networks into a well-defined, interoperable architecture requires extensive consideration. As agencies move to a centralized architecture, security processes, policies, and standards must be integrated into a unified,

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enforceable structure. This transition is not simple because agencies are already operating under well-established processes and governances. Initiatives are in place to incorporate cloud computing in the Intelligence Community. The residual challenges reside in how the operational platforms will be able to incorporate their mission CONOPS and platform architectures into the cloud to enable more effective information dissemination.

### 4.5 Persistent Resilience

By working with Service sponsors and their respective laboratories in aligning the S&T portfolios to the warfighters' needs, the Services must take a synergistic approach to provide linkages and insight to upcoming technology initiatives across the unmanned systems portfolio.

To that end, persistent resilience is a key component to all unmanned systems, regardless of whether the system is being used in air, ground, or maritime domains. The Navy is currently developing a Broad Area Maritime Surveillance (BAMS) UAS under the Persistent Maritime Unmanned Aircraft Systems program office (PMA-262). BAMS UAS, now called Triton, is being developed to provide persistent ISR, which to successfully execute will not be possible without the resilient subsystems that make up the overall UAS. In simplistic terms of a system or subsystem, without resilience, persistence is not possible. *Resilience* is the ability for an application, system, or subsystem to react to problems in one of its components and still provide the best possible service. *Persistence* is the continuance of an effect.

The areas where emerging technology enablers should focus for persistent resilience are

- Size, weight, power, and cooling (SWaP-C) (see 4.5.1)
- Reliability, availability, and maintainability (RAM) (see 4.5.2)
- Survivability (see 4.5.3)
- Structures and material degradation (see 4.5.4)
- Propulsion (see 4.5.5)

#### 4.5.1 Size, Weight, Power, and Cooling (SWaP-C)

DoD wants to reduce the size, weight, and power consumption of military platforms, as does the consumer electronics business, because large SWaP-C impedes mobility and raises maneuvering costs. Day-to-day operations may require tradeoffs in available time on task when a payload must be added at the expense of less fuel. If the payload is too large to add into existing internal space, it may have to be added externally. External placement can add drag to a UAS and reduce time on task. Additionally, some program offices are currently being constrained by the power consumption of payloads. These programs must look at upgrading to larger, more powerful generators, which add more weight, take up space, increase heat, and cause cooling concerns.

Miniaturization generally enables smaller systems and, when combined with more persistence, often minimizes investment. Miniaturization also generally reduces weight and power consumption. Therefore, SWaP-C issues can be addressed by focusing on compact sensor operation on dynamic platforms. In development under DARPA's PINS/HiDRA programs is a six-degrees-of-freedom cold atom IMU, which is an example of a miniaturized three-axis gyro-accelerometer currently being developed to address package size, weight, and power

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consumption while still providing precision navigation. Additionally, focus is turning toward modularity of payloads, which allows plug-and-play capabilities in joint and combined architectures. Plug-and-play attachments are capable of rapid integration into existing systems, including joint systems that integrate into an OA in which the interfaces comprise open standards. As DoD envisions cost savings by reducing stovepipe development and shifting toward standardized architectures to further enable interoperability, modularity will also play a key role to ensure interoperability, ease of upgrades to systems, and synergized DOTMLPF-P. Miniaturized systems that allow multirole, multi-mission capabilities will further reduce costs by allowing Services and program offices to leverage modular systems that have already been developed. Ultimately, less continual investment is required when a smaller volume can continually accomplish the same missions. Figure 19 summarizes the goals for SWaP-C for unmanned systems.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2030+
Desired Capability	<u>Near Term:</u> Miniaturized Position, Navigation, Time (PNT) solutions; Miniaturized Warning and Self-Protection Systems; Adaptive Power Generators; Improved / Smaller Batteries and Lithium-Chemistry Batteries; Overall Power Improvements without Additional Volume, Weight and Heat.			<u>Mid-Term:</u> Improvements in Micro and Nano Technology; Improved Power and Energy Density.				<u>Long Term:</u> Improvements in Energy Storage and Energy Harvesting; Extreme Environmental Conditions Battery Technology.				

**Figure 19. SWaP-C Goals for Unmanned Systems**

### 4.5.2 Reliability, Availability, and Maintainability (RAM)

Reliability and maintainability are critical performance attributes for unmanned systems to accomplish their missions and to achieve required operational availability. With many unmanned systems being required to provide persistent support, such as ISR for periods of 24 to 30 hours (and potentially more in the future) by one vehicle, it is inherent that the systems are reliable with low failure rates. Use of failure rate will be consistent with any reliability parameter such as mean time between failure (MTBF). Systems must meet or exceed mission reliability goals to ensure that unmanned systems can reliably accomplish their missions once they have been deployed. Furthermore, when a system becomes degraded, it must be simple enough to maintain and replace, especially in the austere expeditionary environments with little infrastructure support in which these systems are being operated. These systems must remain simple and supportable by the operators and maintainers in the field. Built-in tests may be sufficient at a weapons-replaceable-assembly (WRA) level, but at a system or subsystem level, the lack of integration causes RAM issues.

The more reliable the systems, the more cost effective they become over the life cycle. As well, the simpler a system is to maintain and repair, the more cost savings it provides. However, one of the largest challenges to maximizing system RAM is the potential impact to development and production cost. Another hurdle to achieving RAM in systems is the continued pursuit of new capabilities, which often consumes program resources at the expense of RAM. To overcome this hurdle, it is important for strong RAM requirements to be developed concurrently with the system CONOPS and capability requirements. Satellite systems are designed to last without repair for years and sometimes decades by necessity, but that also comes at a significant

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development and production cost. To achieve total ownership cost effectiveness in RAM, higher reliability materials and parts must be used to reduce sparing levels, improve maintainability (including enhanced integrated diagnostics), and reduce levels of corrective/direct maintenance, etc. Figure 20 summarizes the goals for RAM for unmanned systems.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2030+
Desired Capability	<p><b>Near Term:</b> Low cost/high reliability materials and components; Prognostics Health Monitoring (PHM) Algorithms for Existing Systems; Composite Repair Improvements; Corrosion Control; Software Maturity Prediction and Growth Methodologies (including a better understanding of the integration of software and the computational environment and the required testing); Composite Manufacturing Technologies for Repair Parts Fabrication (out of autoclave); Wireless Data Transmission (elimination of signal wires).</p> <p>Standardized RAM-Cost (RAM-C) modeling and analysis (including Life Cycle Cost and CONOPS optimization)</p>											
	<p><b>Mid-Term:</b> Low cost/high reliability materials and components; Integration of Health Monitoring Design/Coding with Prognostics Design/Coding; Composites Flaw Detection/Resolution Technology; Methods for Predicting Hardware Reliability Based on HALT Tests; Sensor Fusion for Diagnostics and Prognostics; Composite Manufacturing Technologies for Repair Parts Fabrication (additive manufacturing for structural components); Direct Writing Technology (elimination of signal wires).</p>											
	<p><b>Long Term:</b> Low cost/high reliability materials and components; Material Behavior Prediction and Integration with Structural Prognosis; Advanced Troubleshooting to Component Level; Reduce Scheduled and Unscheduled Maintenance; Robust Life-prediction in Automated Logistics Environments. Collection and Long-term Storage of all PHM Data.</p>											

Figure 20. RAM Goals for Unmanned Systems

#### 4.5.3 Survivability

Survivability is a function of five key elements:

- **Detectability** is the probability of being discovered by an enemy force.
- **Susceptibility** is the probability of being hit or jammed in a particular environment.
- **Vulnerability** is the probability of surviving if hit or jammed in a particular environment.
- **Stability** is the probability the vehicle will reliably operate in the manner that was intended after it has been hit or jammed in a particular environment.
- **Crashworthiness** is the probability the vehicle and its load will survive an impact without serious damage.

An important characteristic of unmanned systems is that to some extent their loss is acceptable if it prevents the loss of warfighters or innocent civilians. Areas of survivability that are always a challenge, particularly for UAS, are susceptibility and vulnerability. Many of the warning and self-protection systems that are found on manned platforms may seem applicable to unmanned platforms because they face the same threats. However, the vehicles typically have not been designed with the SWaP-C or, in some cases, the maneuverability of the manned platforms, which would more easily support the warning and self-protection systems currently used on manned platforms. The warning and self-protection systems found on manned platforms require high electrical power, which causes high temperatures, or heat, in the avionics compartments; because UAS (and unmanned systems in general) have smaller compartments, heat dissipation is a constant issue. Adding to the heat issues, due to bandwidth limitations in uplinks and downlinks, more and more processing is being done aboard the platforms to reduce

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the high amounts of raw data being transmitted via the C2 links. With the need for more processing power aboard the platforms come increases in temperature on the small computer chips and boards of the survivability systems. Another challenge area in susceptibility and vulnerability is jamming or spoofing. Miniaturized solutions for anti-jam antennas or SAASMs to counter threats such as GPS-denied environments are needed. Again, unmanned systems are typically smaller than manned systems; however, some unmanned systems still have large radar cross sections, IR, and acoustic signatures that make them detectable and, therefore, susceptible.

Cost effectiveness in the area of survivability is going to be achieved much the same way that it will be achieved in SWaP-C. Survivability systems require a lot of power and put out a lot of heat, which, in the smaller compartments of unmanned systems, can cause RAM issues. By miniaturizing the survivability systems and improving power consumption and heat dissipation with more reliable and durable components, cost savings can be realized. This approach will also translate into systems that can be used by both manned and unmanned platforms and thereby provide a way to leverage common systems across similar and dissimilar platforms. Additionally, improvements or new technologies, e.g., IR signature reduction or low IR paints, must be cost neutral to standard paints and equipment currently being used. These products must also remain as maintenance and cost recurring friendly as possible. Figure 21 summarizes the goals for survivability for unmanned systems.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2030+
Desired Capability	Near Term: Miniaturizing Warnings and Self-Protection Systems (Anti-Jam, SAASM, etc); Antenna Improvements; SWaP-C Improvements / Power Efficiencies; Increased Onboard Processing Capability for Warning and Self-Protection Systems; RF/IR Countermeasures / Use for Slow Movers; Cooling/Heat Dissipation for Warning/Self-Protection Systems; Multi-Spectral DIRCM (LASER); Signature/RCS Reduction / Low Infra-Red (IR) Paint; Crashworthiness; Stellar Navigators (GPS Independent Navigation)					Mid-Term: Light Weight Towed Decoys; Smaller/Lighter Radar Warning /Missile Warning Receiver Sets for Countermeasures; Electro-Magnetic Pulse Protection.					Long Term: Improved Electronics; Nitride-Transistor Technology; Alternatives to Silicon-Based Electronics; 3-D Integrated Circuits.	

**Figure 21. Survivability Goals for Unmanned Systems**

### 4.5.4 Structures and Material Degradation

Today's unmanned systems operate in extreme environments ranging from sandy and hot climates to humid or freezing climates and from high altitudes to fathoms beneath the oceans. Unmanned systems need optimized material properties that can endure these conditions in addition to withstanding stress, corrosion, and other structural effects of the operating environments. Today's unmanned systems are relying more and more on composite materials that provide lightweight, flexible, strong structures. While these new composites are currently difficult and expensive to repair, industry and DoD are making great strides in the design and production of advanced composite materials.

The tradeoff for a lighter yet strong material is its high cost. Cost effectiveness for structural and material durability must now be achieved by focusing on the strength and durability of materials and structures to reduce or avoid repair costs. DARPA's Defense Sciences

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Office has multiple programs with objectives to improve materials in the areas of novel materials and material processes, multifunctional materials and material systems, and biologically inspired materials. However, more industry focus must be on the near term for structures and material degradation. Figure 22 summarizes the goals for structures and material degradation for unmanned systems.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2030+
Desired Capability	<p><b>Near Term:</b> Corrosion Protection, Detection, and Mitigation; Structural Mode Characterization; High-Loading; Lightweight Structural Materials; Advanced Structural Concepts; Materials Degradation/Corrosion; Structural Protection /Maintenance; Advanced Joining Methods for CMC subcomponents; Durable Thermal/Environmental Barrier Coatings; Manufacturing/Fabrication Processes for Affordable CMCs in Hot Section Applications. Use of nano tube technology for EMI hardening, anti-icing</p> <p><b>Mid-Term:</b> High-Fidelity Residual Strength and Life Prediction Tool for Adhesively Bonded Composite Structures; Innovative Approaches for Enhancing Interlaminar Shear Strength of Two-Dimensional Composite Reinforced Flex Beams and Yokes; Composites Flaw Detection/Resolution Technology.</p> <p><b>Long Term:</b> Advance material science. This area is currently one of the focus areas for DARPA and its Defense Sciences Office (DSO). For more background on the DARPA DSO programs in these material areas, visit the following link: <a href="http://www.darpa.mil/Our_Work/DSO/Focus_Areas/Materials.aspx">http://www.darpa.mil/Our_Work/DSO/Focus_Areas/Materials.aspx</a>.</p>											

**Figure 22. Structures and Material Degradation Goals for Unmanned Systems**

### 4.5.5 Propulsion

As mentioned in 4.5.4, today's unmanned systems operate in many different and extreme environments. With these external factors, fuel-efficient propulsion and power output is needed for the many systems aboard unmanned systems. Persistence in conducting missions such as ISR is not possible without adequate propulsion and power. Unmanned systems must maintain their health, currency, and technical superiority with innovative approaches for increasing power and thermal management and improving power output and thermal loads. Many of today's persistent systems rely on efficient forms of propulsion that are sustainable for long-endurance missions. Other systems require propulsion that can be optimized for long range and endurance or optimized for high speed. Additionally, systems such as UUVs face challenges to extend endurance into months with energy technologies that are air independent. Regardless of providing propulsion for an air system or a surface system, a propulsion system must be not only efficient, but also adaptive to faults by continuing to operate in a degraded state or by stabilizing itself and returning to a normal state.

As technology for propulsion systems continues to evolve and improve, the areas of maintenance, sustainment, and lifecycle cost reduction will always remain key to achieving cost effectiveness. Smarter systems (via software and computers) should allow for diagnostics or logic-based tools to perform "virtual inspections" and thereby reduce the time to troubleshoot the system or its components. Likewise, validated propulsion health monitoring systems will allow for just-in-time maintenance. Also, biofuels that are renewable and that meet or exceed military or jet fuel performances metrics will help reduce the dependence on fossil fuels. Additionally, as mentioned above in RAM, the more resilient propulsion systems become, the more cost effective they will be, and the more cost savings they will provide. Figure 23 summarizes the goals for propulsion for unmanned systems.



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	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2030+
Desired Capability	<b>Near Term:</b> More Efficient Electrical Power Generation, Thermal Management; Air Independent Energy Systems (UUV); Quick Recharge/Refueling (UUV); Jet Noise Reduction; Component Technologies Accommodating Increasing Power/Thermal Loads; Hot-Section Materials and Coatings, Maintenance, Sustainment, Life-Cycle Cost Reduction; High Capacity & Power Battery Technology.			<b>Mid-Term:</b> Introducing Geared Turbofan Developments into Smaller Systems; Future Vertical Lift; Turbo-machinery and Drive Systems; Variable Cycle Engine Technologies; Hybrid turbine-electric power.			<b>Long Term:</b> Fuel Cell/Non Hydrocarbon Fuels (same propulsive qualities and similar or lower cost); Bio-Fuels, Alternative Fuels, New Energy Sources.					

**Figure 23. Propulsion Goals for Unmanned Systems**

### 4.5.6 Summary

As stated in 4.5, the areas of focus for emerging technology enablers in persistent resilience are

- Size, weight, power, and cooling (SWaP-C)
- Reliability, availability, and maintainability (RAM)
- Survivability
- Structures and material degradation
- Propulsion

For unmanned systems in future middle- to high-intensity combat against more capable adversaries, persistent resilience must not be limited to traditional analysis of just the unmanned vehicle(s), but must also investigate the ground, communication, tactics, and manning aspects that collectively provide the unmanned systems capability. The ultimate benefit from this activity is the avoidance of significant loss of unmanned systems capability and resulting adverse combat outcomes for the total force. The objective of early analysis of persistent surveillance is to achieve early identification of system weaknesses in the context of known and projected threats; subsequent identification, analysis, and exploration of alternatives to mitigate significant weaknesses; and the development of material solutions and/or training and tactics solutions to institute before encountering such conflicts in the future.

### 4.6 Autonomy and Cognitive Behavior

Unmanned systems that have the option to operate autonomously today are typically fully preprogrammed to perform defined actions repeatedly and independently of external influence or control; that is not to say these systems are unmonitored. These systems can be described as self-steering or self-regulating and can follow an externally given path while compensating for small deviations caused by external disturbances. However, the automatic system is not able to initially define the path according to some given goal or to choose the goal that is dictating its path.

The future of autonomous systems is characterized as a movement beyond autonomous mission *execution* to autonomous mission *performance*. The difference between execution and performance is that the former simply executes a preprogrammed plan whereas performance is associated with mission outcomes that can vary even during a mission and require deviation from

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preprogrammed tasks. Autonomous mission performance may demand the ability to integrate sensing, perceiving, analyzing, communicating, planning, decision making, and executing to achieve mission goals versus system functions. Preprogramming is still a key part and enabler of this kind of operation, but the preprogramming goes beyond system operation and into laws and strategies that allow the system to self-decide how to operate itself. Initially, these control algorithms are created and tested by teams of human operators and software developers. However, if machine learning is employed, autonomous systems can develop modified strategies for themselves by which they select their behavior. An autonomous system is self-directed by choosing the behavior it follows to reach a human-directed goal. Various levels of autonomy, in any system, guide how much and how often humans must interact or intervene with the autonomous systems. In addition, autonomous systems may even optimize behavior in a goal-directed manner in unforeseen situations (i.e., in a given situation, the autonomous system finds the optimal solution).

It is important to note here that automation is only as good as the software writer and developer because the control algorithms are created and tested by teams of humans. In these algorithms, the “patterns of life” are critical to automation and must be observed and captured properly to ensure accuracy and correctness of a decision-making process within the software. Ensuring accuracy and correctness requires a continual process in which the observe – orient – decide – act (OODA) loops in the software are continually updated via manual analysis, training, and operator understanding of algorithm inputs and outputs. The human brain can function in dynamic environments and adapt to changes as well as predict what will happen next. In simplistic terms, the algorithms must act as the human brain does.

To take on increased autonomy in unmanned systems, the systems will require additional sensors that can provide a more accurate perspective of their surroundings as well as the capacity to interpret those inputs so that they can respond appropriately to the situation. Additionally, they will require the ability to be untethered from human interaction. A key enabler in unmanned systems autonomy will be navigation. Given the dependence UAS have on PNT, the platform will execute only as well as the accuracy of the PNT in the system. Inaccurate PNT introduces error to air vehicle navigation and sensor cueing. Mission computers are continuously updated with position, air speed, ground speed, and drifts so the UAS can intelligently pick the best route to take while maneuvering away from restricted areas or boundaries. Navigation alternatives must be researched and evaluated to overcome dependency on systems such as GPS.

Autonomy in unmanned systems will be critical to future conflicts that will be fought and won with technology. The near-term area for Air Force and Navy capability development is implementing land and carrier-based UAS to provide ISR and strike from the land and sea. Middle- and long-term naval capability will focus on A2/AD. The Air Force and Navy are investing research and development efforts and procurement programs to overcome these access threats and assure the ability of the joint force to project power in support of our allies and partners and to protect U.S. interests.

An important element of overcoming access threats and maximizing the fleet’s capacity is unmanned systems. As a result, autonomy in unmanned systems has been identified by Navy and DoD leadership as a high priority. However, specific pathways for the introduction of technologies that enable greater levels of autonomy have not been identified. The special feature of an autonomous system is its ability to be goal-directed in unpredictable situations. This ability

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is a significant improvement in capability compared to the capabilities of automatic systems. An autonomous system is able to make a decision based on a set of rules and/or limitations.

To aid in the ongoing solutions for autonomy on unmanned systems, the Naval Research Advisory Committee is conducting a study to clarify the potential of autonomy to transform naval operations and eventually the operations of other Services. The study will explore the current and anticipated potential of technology to achieve various levels of autonomous operations. The study will also consider potential naval uses of autonomy, with emphasis on maritime systems, and the challenges associated with realization of these applications. The study will consider autonomy as a capability that is enabled by a set of technologies, such as sensing, intelligence, reliability, and endurance. Advances in these technologies are key to permitting an autonomous system to make decisions in the framework of an operational mission. The study will assess state-of-the-art autonomy and identify technical shortfalls or opportunities to significantly advance the capability. The goal is to identify where autonomy has high potential to enable naval missions; however, implementation of autonomous systems also introduces operational challenges, such as affordability, policy, and doctrine.

Additionally, S&T development programs are underway in the Air Force, Army, and Navy as well as at DARPA. While applications of autonomy among the Services tend to be applied to a specific domain of interest, in many cases the underlying technology is applicable across domains. For example, the Air Force is developing teaming technologies for air platforms, while the Navy and Marine Corps are applying similar technologies to ground vehicles and the Army is applying similar technology to robots. The following subsections detail efforts by the Department and show similarities where appropriate.

As the level of autonomy increases, manpower savings can be achieved and/or human resources can be redirected to other tasks. As examples, Army tactical robots could ultimately augment manning in small units, Marine Corps intelligent UGS may also conduct logistics missions, and Air Force/Army systems are envisioned to be designed so a single operator can control multiple UAS. All these systems offer the opportunity for significant manpower savings or the opportunity to use the saved manpower in other critical tasks.

As DoD advances the state of the art in autonomy, industry and academic partnerships will be critical. Investment to produce affordable systems will allow unmanned systems to become ubiquitous on the battlefield.

### 4.6.1 Today's State (2013–2017)

In general, research and development in automation is advancing from a state of automatic systems requiring human control toward a state of autonomous systems able to make decisions and react without human interaction.

Related to UAS, the Navy is partnering with the Air Force in advancing airborne sense and avoid (ABSAA) technologies. The Army is leading the ground-based sense and avoid (GBSAA) common requirements development coordination for the Airspace Integration IPT. In addition to technologies for airborne operation, the Navy is investing in development of autonomous deck operations. In the near term, autonomous deck operations research and

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development includes technologies to support high operating tempo (OPTEMPO) launch and recovery of small UAS and precision on-deck UAS locating and tracking.

A major goal of naval developments for Marine Corps applications is to make systems smarter and cheaper. The Navy is developing low-cost, ubiquitous, intelligent, tactical UGS that will operate as a force multiplier integrated with manned, unmanned, and optionally manned systems. The current state of autonomy for most tactical UGS requires human decision makers and LOS communications. Systems that are autonomous require highly structured and predictable environments. In the near term, Navy research focuses on transitioning from teleoperated UGS to autonomous logistics connector UGS with independent path planning functionality and doctrinally appropriate maneuvers and behaviors. Further, the Navy is developing technologies to navigate trafficable on- and off-road terrain at tactically appropriate speed. Affordability is a key requirement for all these developments, and effective operation in day, night, and GPS-denied environments is critical. In the near term, the Office of Naval Research is developing technologies that will enable a 2016 limited military utility assessment of the logistics connector Unmanned Ground Vehicle (UGV), which includes multimode perception, day and night operation, and complex terrain traversability.

*We can't support small teams of Marines using robotic platforms whose sensors cost hundreds of thousands of dollars, and whose software cost millions or in some cases billions of dollars to develop.*

*— George Solhan, Director,  
Office of Naval Research Code 30*

The Army S&T vision is one where manned and unmanned systems work together with greatly enhanced capabilities in the following five problem domains: adaptive tactical reasoning; focused situational awareness; safe, secure, and adaptive movement; efficient proactive interaction with humans; and interaction with the physical world. The Robotic Collaborative Technology Alliance (RCTA) uses the following anthropomorphic shorthand to describe these five problem domains: think – look – move – talk – work.<sup>67</sup> Figure 24 summarizes the Army's vision for these five problem domains, barriers to achieving its vision, and work to be done to advance toward the vision.

In the near term, the RCTA plans a Capstone Experiment in FY2014. See Figure 25. The Capstone Experiment is centered around a notional cordon-and-search operation: during urban transit by a small unit (i.e., four to five soldiers), a fugitive is reported to have entered a building the unit is approaching. A man-transportable robot is instructed to “cover the back door” of the building by the unit commander because he cannot safely split up his limited resources. The robot must understand and acknowledge the order, associate the order with its perceived environment, move safely and securely to an appropriate vantage point, observe activity behind the building, and report any salient events to the unit commander. As needed, it enters the building and negotiates stairs or other mobility obstacles. It then returns to its unit, maintaining situational awareness, and is ready for another assignment. While this narrative occurs in the context of a cordon-and-search operation, its underlying capabilities support a broad range of

<sup>67</sup> Robotic Collaborative Technology Alliance (RCTA) FY2012 Annual Program Plan.

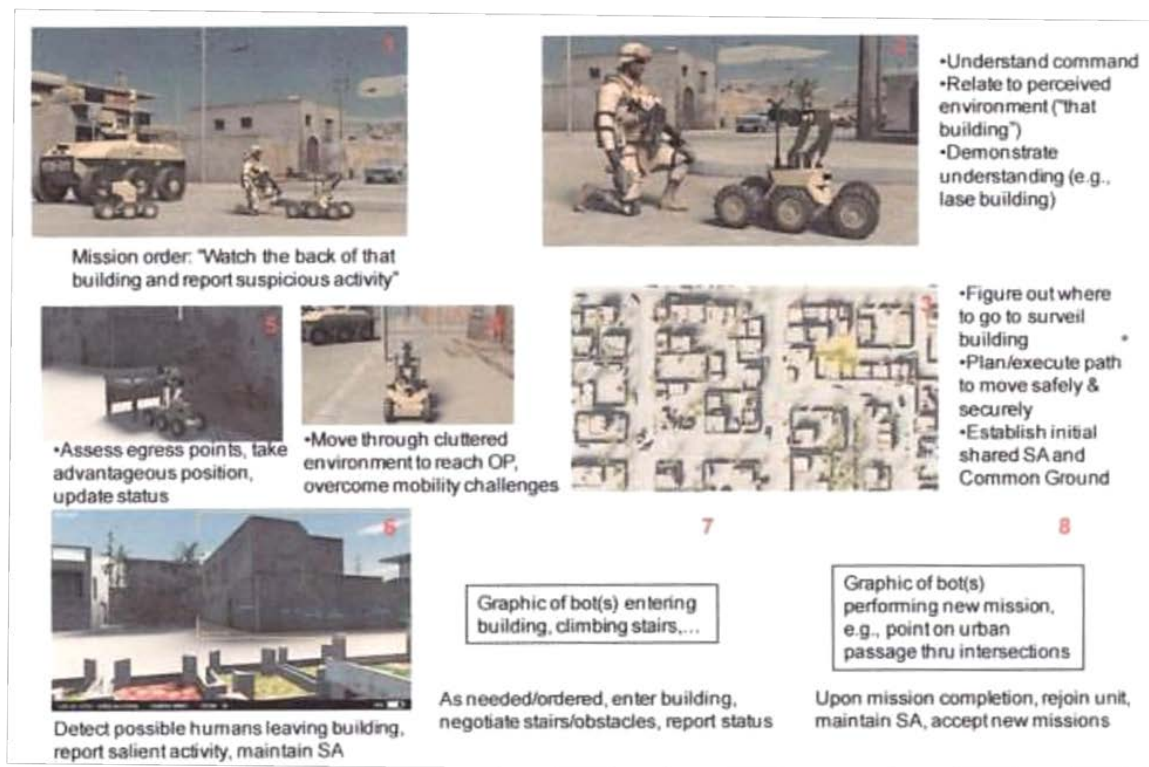
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potential operational missions. Similar to the other Services, middle- and long-term work by the RCTA will continue to evolve and improve capabilities to increase the level of autonomy in systems from the current, remotely operated systems to autonomous systems and system-of-systems (SoS) approaches.

	Barriers to Achieving our Vision ---->	Simplistic and Shallow World Model	Mobility-Focused Perception	Tele-operated or (at best) Scripted Planning	No Shared Understanding of Missions and Roles	Missing or Shallow Learning Capabilities
		World Model is either at only a metric level precluding reasoning, or at only a cognitive level without physical grounding	Objects in the world are perceived primarily only as mobility regions not as discrete objects of semantic and cognitive importance	Bots are almost always tele-operated or at best only perform sample scripted behaviors - and scripting all needed behaviors is not tractable	Bots are opaque and distributed, and cannot explain what they are doing - primarily because they don't know	Bots must be explicitly programmed to do tasks, so it is intractable to produce the needed scope of behavior. Any learning capability is shallow and lacks generalization
<b>"Think"</b>	<b>Adaptive Tactical Reasoning</b>					
	Understand tasks, missions (METT-TC)	World model needs to represent concepts such as missions, tasks, and generally METT-TC.		Robots need to generate behaviors pertinent to achieving the mission, adapt to changing situation.	Robots need to be able to follow instructions given at a semantic or cognitive level, not just "goto (x,y)."	
	Follow semantic instructions					
	Generate behaviors to achieve mission, adapting to changing situation					
	Understand teammates and what they need to know					
<b>"Look"</b>	<b>Focused Situational Awareness</b>					
	Maintain SA relevant to current task/mission	World model needs to represent, maintain, monitor, and correct all info needed for SA.	Robot needs to contribute to the general SA of the unit, noting salient observations.		Robot needs to report on salient observations as needed to other elements of its unit.	Robot should learn by comparing its observations and actions to those of its human counterparts.
	Contribute to general SA of unit					
	Look for salient unforeseen events					
	Observe and report on salient activity					
<b>"Move"</b>	<b>Safe, Secure and Adaptive Movement</b>					
	Move cognitively in reaction to safest route in the world (as people do) with GPS or other metric crutches	World model needs to store and operate upon all entities needed to relate movement to tactical constraints.	Robot must perceive all entities in its environment relevant to safe, secure, and adaptive movement.	Robots must move in a tactically correct manner and react to changes in mission or circumstances.		Robot needs to learn from its movement experience whether from mobility challenges or tactical behavior.
	Move in tactically and continually relevant manner					
	Adjust to mobility challenges such as terrain, weather, barriers					
<b>"Talk"</b>	<b>Efficient Interactive Communication</b>					
	Receive and acknowledge semantics instructions	World model needs to have shared mental models as a basis for human-robot interaction.	Robot needs to send and information relevant based on a shared perception (common ground).		Robot needs to receive and acknowledge cognitive-level instructions and similarly explain its own behavior.	Robot needs to be able to learn through cognitive-level interaction with human teammates.
	Explain own behavior					
	Report information relevant to mission					
	Seek guidance as needed					
<b>"Work"</b>	<b>Interaction With Physical World</b>					
	Inspect and manipulate objects	World model needs to represent wide variety of objects to be manipulated.	Robot needs to perceive well enough to interact effectively with objects in a 3D world.	Robot needs to figure out how and when to manipulate or transport objects as needed.		Robot needs to learn from interaction with the physical world, e.g. when door is locked.
	Transport objects as needed					
	Open doors, windows, hoods, trunks, etc.					
	Use tools as needed					

**Figure 24. Army's Vision for Five Problem Domains  
(Think – Look – Move – Talk – Work)**

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**Figure 25. RCTA's Capstone Experiment in FY2014**

### 4.6.2 Middle-Term Future State (2017–2022)

The middle-term future state in the 2017–2022 time frame will consist largely of a further maturation of near-term capabilities. Middle- and long-term goals primarily increase capability, scale technologies, move from ground-based to platform-based technologies, and move the capability further along the scale from automatic to autonomous behavior. As an example, the Air Force's multiple-aircraft manager could be matured to include management of transit operations involving multiple UAS, which could reduce crew requirements and optimize the allocation and use of crews.

The Navy's middle-term technology developments will evolve near-term technologies to greater levels of autonomy and team-oriented behaviors. In the middle term, naval autonomous deck operations research includes technologies for autonomous flight deck awareness and movement, decision aids for interactive manned/unmanned operations, and robust intelligent autonomous flight deck operations. Middle-term plans for Marine Corps UGS include transition from autonomous logistic connector to integrated operations with dismounts with follow-me/come-to/go-to capability; autonomous "wingman" capable of human-like tactical behaviors; in-stride support of Marine Corps rifle squads, including tactical decision making while in enemy contact; advanced perception of individual humans, urban environments, and effective operations



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in challenging weather conditions; and enhanced human-robot interaction that enables teaming and trust.

### 4.6.3 Long-Term Future State (Beyond 2020)

The long-term state for unmanned systems will bring further maturation of the middle-term capabilities. It will also bring higher levels of automation. It will allow concepts like smart teams of unmanned systems operating autonomously to conduct operations in contested environments. It will also allow concepts like “loyal wingmen,” i.e., unmanned systems that operate in conjunction with manned platforms to conduct operations.

Similarly, naval research and development for both shipboard systems and marine UGS in the long term are focused on greater automation and SoS. The desired long-term capabilities for UGS include fully autonomous, multirole platforms with independent and cooperative decision making. Additionally, the Marine Corps desires self-sustaining, integrated warfighter-machine SoS approaches in the long term.

### 4.6.4 Key Enablers and Concerns

To fully realize the operational benefits of autonomy, certain key enablers must be available. Included among these are mission planning that is dynamically modifiable; precise navigation and timing; cross-cueing sensors; handoff capabilities and information transport to other onboard systems; and data dissemination to GCS operators, controllers, and edge warfighters. Autonomous controls are required to develop and disseminate requisite information tailored to bandwidth and user profiles. Precise PNT is critical for autonomous systems operation. PNT allows for freedom of movement, understanding of the operational area, collision avoidance, and sensor and weapons cueing. Precise PNT must be maintained even in harsh and GPS-denied environments. Ultra-high precision inertial navigation systems and other non-GPS navigation systems will be key enablers for autonomous system operations.

Additionally, cross-cueing and/or dynamically retasking of multi-intelligence sensors/modes and/or weapons capabilities are required to support onboard processing that provides aided target recognition, identification, and tracking. Filtered target information must be passed to onboard weapons systems as the onboard cueing and/or tasking of onboard sensor target information is confirmed. Change and status notification must be given to UAS operators and operations intelligence staffs so they can monitor, and override if necessary, the autonomous payload and/or weapons systems information and controls. The system must be able to operate in a continuous OODA loop. This ability will depend on well-written and tested software, coupled with sensors that allow the system to autonomously observe and react to patterns of behavior. To achieve autonomy, this OODA loop interaction must occur continuously and must not be based on a single point in time.

As autonomous systems become ubiquitous, efficient utilization of bandwidth will be a key enabler. As more autonomous systems occupy the battlefield, MIMO communication networks could be one of the crucial technologies. Further, bandwidth must be used efficiently and effectively to prevent denial of service.

Finally, several concerns are associated with full-scale operation of autonomous systems, many of which are related to the key enablers. As examples, maintaining accuracy and

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availability of PNT is a key concern. Proper training and timeline to develop the operational experience that enables the continuous OODA loop are additional concerns. Development of the ability for operators to turn processing on and off and conserving bandwidth via metadata standards are additional concerns. Lastly, development of appropriate rules of engagement for utilizing processed information and for lost links is a developmental concern. As autonomy development continues to proceed from automatic to autonomous systems, developers must address these concerns.

### 4.7 Weaponry

The increased use of unmanned systems as weapons delivery platforms has been a significant step in the integration of unmanned systems in the battlespace. Unmanned systems can be used in significantly different operating and threat conditions than manned platforms, come in a much wider range of classes and sizes than manned systems, can exhibit greater persistence and endurance than manned systems, and have the potential to support a large range of mission sets.

The introduction of remote video links, enabling operators to monitor the unmanned systems payload view in real time, enables users to employ weaponized unmanned systems with more flexibility and with improved confidence. Network-enabled systems employing distributed C2 elements with ISR and armed airborne assets (either separate platforms or integrated into a single unit) benefit from progress made with unmanned systems and precision-guided weapons.

Typical weapons that could be adapted for UAS use include the Laser Homing Attack or Anti-Tank Missile (LAHAT) (Figure 26). As early as 2004, this weapon was proposed for testing with U.S. Hunter UAS. LAHAT utilizes the semi-active laser homing guidance method to accurately home in on targets from a distance beyond 10 km. Fitted with a shaped charge multipurpose warhead, LAHAT can engage targets marked by a laser designator mounted on the launching platform or by an indirect designation from another unit located closer to the target. Each missile weighs about 13 kg, and a complete launcher with the four missiles weighs only 75 kg, significantly less than any alternative weapon.



**Figure 26. Laser Homing Attack or Anti-Tank Missile (LAHAT)**

The laser-guided SPIKE (Figure 27) was developed by the Weapons Division of the Naval Air Warfare Center with assistance of DRS Technologies. Originally designed as a man-portable weapon for the Marines and the Navy's special operations force, SPIKE fills a critical niche for a low-cost, lightweight guided weapon for U.S. ground forces. It is also considered for tactical UAS and a force-protection weapon to defend surface ships from small-boat swarms or light aircraft. The missile uses a semi-active laser seeker to engage laser-designated targets from

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a distance of two miles. Each SPIKE missile weighs 5.3 lb (2.5 kg) and is 25 inches (63.5 cm) long. The missile performed its first controlled flights in 2005. The Spike missile is designed to be used on medium-weight and lightweight UAS. The missile has already been tested with the DRS Sentry HP drone at Eglin AFB, Florida, as part of Air Force UAS Battlelab evaluation.



**Figure 27. Laser-Guided SPIKE**

Another type of lightweight weapon considered for UAS is the 2.75-inch Hydra-70 rocket. In 2005, four 2.75-inch rockets were fired from Vigilante UAS test bed and demonstrated the weaponization potential of rotary-wing UAS. The tests evaluated the stability and flight control adjustments necessary to compensate for excessive loads during the weapon's firing. On these tests, the Vigilante was controlled from a nearby UH-1 manned helicopter. Such tests will provide important data for the integration of Advanced Precision Kill Weapon System (APKWS II) with future rotary-wing UAS.

APKWS II is intended to fill an aviation systems weapons gap between the Hellfire missile and unguided Hydra-70 2.75-inch rocket and introduce an affordable, lightweight, precision aerial guided rocket. APKWS II weighs about 13 kg and integrates a strap-down laser seeker (fixed in the wing roots) and guidance section onto the Hydra-70 rocket. It will be effective against soft and lightly armored targets as well as urban operations. A new design uses existing or new production rockets, fitted with a middle-body guidance approach that employs a distributed aperture semi-active laser seeker; the same element is also used in the Army's Precision-Guided Mortar Munitions program.

APKWS II will use the Hydra Universal Rail Launcher (HURL), a lightweight four-rail launcher originally developed for the Comanche attack helicopter but modified for use with UAS. Designed as a "smart rocket launcher," HURL can be linked to onboard avionics through MIL-STD-1760 and MIL-STD-1553 interfaces.

A version of a 2.75-inch laser-guided rocket called Direct Attack Guided Rocket (DAGR) is designed to be fully compatible with the Hellfire II system and 229 smart launcher system and, therefore, to increase the launcher load out by up to four times.

Switchblade (Figure 28) is a weapon designed for hand, tube, or aerial launch that could provide the warfighter with a rapid delivery to gather ISR information on BLOS targets. Designed as an expendable system, Switchblade will also have an option to carry a small explosive charge to enable rapid prosecution of selected targets with minimal collateral damage.

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The miniature, remotely piloted or automated platform can either glide or propel itself via quiet, electric propulsion and provide real-time video for information gathering, targeting, or feature or object recognition.



**Figure 28. Switchblade Munition**

Adapting proven weapons technology with new concepts to take advantage of unmanned systems persistence and emerging net-centric capability, manned and unmanned teaming will be critical to improving the sensor-to-shooter equation and further decreasing in the kill chain timeline. However, certain technological issues must be addressed to further enhance unmanned systems as weapons delivery platforms in the near, middle, and long term.

### 4.7.1 Interoperability

No current weapons system employed from unmanned systems was designed specifically for unmanned vehicles. As discussed in other sections of this chapter, the capability need to rapidly deploy weapons on unmanned systems drove design compromises in interoperability. The same rigor now being applied to systems interoperability must be used to address current concerns and design of future weapons systems for unmanned systems:

- Cross-Service, cross-platform interoperability and capability. Manned platform have settled on common armament interface units, bomb racks, and logistics. Unmanned systems should follow this lead, especially with shipboard storage and employment concerns, logistics, training, and flight certification.
- Interchangeability within classes of unmanned systems where practicable as well as with manned systems where practicable.
- CONEMPs and TTPs standardized across the services.

The OSD USIP WG initiated a Weapons USIP (USIP 5.0) based on a recommendation from the I-IPT and Services. This effort was a truly joint approach to enable efficient UAS weapon integration to significantly reduce risk with mature, standardized interfaces. USIP 5.0 helps to define the mandatory implementation of standards and specifications to achieve an interoperable mode of operation for internal and external exchanges for all weaponized UAS and applicable manned platforms. The USIP also includes an IOP to address cooperative engagement and the Joint Digitally Aided CAS (DACAS) project. Once approved by OSD(AT&L), USIP 5.0

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will be maintained on the DISR as a mandated standard and shared with the appropriate NATO Standardization Agreement (STANAG) bodies for incorporation into international standards.

### 4.7.2 Unmanned System-Specific Weapons

To take advantage of all classes of unmanned systems, especially UAS, technological advances in specific areas must be addressed in weaponry to arm multiple classes of unmanned systems:

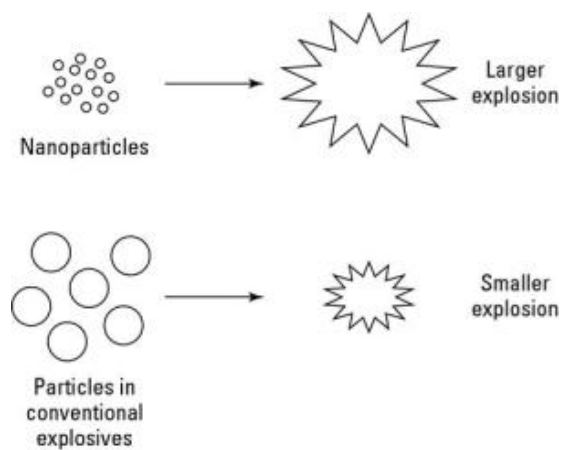
- ***Weapons designed for multiple missions.*** The ability to select the yield of the weapon in advance of employment is often referred to as a “scalable effects” warhead. The ability to vary the explosive power of a warhead has clear implications for reducing risk to friendly forces and civilians and also for reducing unnecessary damage to infrastructure other than the intended target. Historically, the notion of varying the explosive power of a warhead has been primarily linked with nuclear weapons, where the term “dial-a-yield” is generally used. In this case, the amount of material that can “boost” the yield (for example, tritium) can be varied, as can the performance of “initiators,” which allow a chain reaction to propagate. Achieving this scalability with conventional (i.e., chemical) explosives presents different challenges. A plausible explanation of how this may be achieved would be varying the manner in which the explosive material contained in the warhead is detonated.
- ***Weapons designed with multiple modes.*** Current multimode requirements are derived from current and future mission environments, such as frequent bad weather. In current operations for both manned and unmanned aircraft, a mix of weapons is carried to ensure the proper weapon is available for the weather and threat at the target area. Depending on the environment, often only half of the bomb load is employed. For certain classes of unmanned systems, this approach is simply not an option. A true multimode weapon will be an essential aspect of arming unmanned systems. However, multimode weapons are only part of the solution. The ability to integrate unmanned systems within the manned weapons construct, while taking advantage of the unmanned systems’ inherent traits of endurance, survivability, etc., will be key. They must be able to target and track moving threats reliably and precisely and identify the target and acceptable collateral damage in bad weather and with many targets in a cluttered environment. This goal will require a common network between human observers, the unmanned system, and other delivery platforms and weapons.
- ***Weapons design for use within the unmanned systems environment.*** The potential weapons operating environment for unmanned systems will be significantly different from comparable manned platform performance envelopes and weapons engagement envelopes.
- ***Standardized weapons designs*** including modular designs, interchangeable within similar unmanned systems from different services and designed for shipboard storage and employment.

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### 4.7.3 Advanced Weapons Technology Areas

#### 4.7.3.1 Nanoenergetics

Energetic materials contain chemical energy that, when released, can burn rapidly, such as in fireworks or rocket fuel, or explode, such as in a grenade or bomb. Energetic materials at the nanoscale show promise for military applications. Nanoparticles have more surface area and, therefore, have increased contact with the other chemicals that make up a propellant or explosive. After a reaction is initiated (that is, the explosion is set off), this greater surface area causes a faster reaction rate, which makes for a more powerful explosion. This work could be useful in weapons systems that would utilize greater amounts of energy, making them more lethal. By working at the nanoscale, weapons designers can also control the rate at which energy is released by changing the size of the nanoparticles; in other words, the designers could customize the explosive for each application. For example, a weapon designed to penetrate into the ground to destroy a bunker may need an explosive with a different reaction rate than a weapon designed to explode and project shrapnel above ground troops. See Figure 29.



**Figure 29. Nanoparticles and Explosions**

An example of this technology is the use of aluminum nanoparticles in explosives that the Air Force is developing. When nano-aluminum powder is added to explosives, weapons can be made smaller and more powerful. These weapons are useful in aircraft with limited space, such as remote control drones. Researchers are developing techniques that allow weapons manufacturers to add a greater amount of nano-aluminum powder to an explosive using a solvent.

#### 4.7.3.2 Advanced Weapons Materials

Significant research is ongoing at Service and national laboratories in areas such as polymers, metals, ceramics, composites, and bio-inspired materials. Unmanned systems are looking for opportunities to transition to these advancements to reduce SWAP-C and enhance safety and survivability, where applicable.



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### 4.7.3.3 Unmanned Systems as a Weapon

The theory of aerial dominating weapons is not new, but to date its implementation has remained limited by current technology to few, specific contingencies, such as the suppression of enemy air defense (SEAD), where targets could be clearly identified and pursued with radar homing weapons.

Israel pioneered this field with the Harpy loitering SEAD weapon, developed by Israel Aerospace Industries. The system has been acquired by several countries including China, Turkey, South Korea, and India. Israeli Military Industries is demonstrating a similar multipurpose warhead for its Delilah air-launched missile, yet this weapon is quite large for conventional UAS. A follow-on to Harpy, known as Cutlass, was developed under U.S.-Israeli cooperation. While the program has not been officially concluded, Israel is known to have offered advanced Harpy systems to several customers, including the United Kingdom, where it was proposed as “White Hawk,” for the British Loitering Munition Capability Demonstration under cooperation with Missiles, Bombs, and Deadly Ammunitions (MBDA). Another Israeli company, RAFAEL, competed for the same program, offering the BLADE (Battlefield Loitering Artillery Direct Effect), based on a modified Sparrow M UAS designed and produced by EMIT.



A different concept developed for the Army, pursued area domination by a combination of several types of loitering NLOS missiles. The original concept included “smart” loitering weapons, which would provide area surveillance, target acquisition, and pursuit of time-critical attack, while other targets would be engaged by precision attack missiles (PAMs), fitted with imaging IR seekers. However, this concept proved too costly and complex. The Army eliminated the loitering missile-sensor element and deployed the NLOS launch system with the PAM, as a weapon repository ready to support combat units, targeted by assets available to the unit over the network.

Various types of air domination systems are being considered by the Air Force to enable a military force to dominate an area from the air for extended periods and deny enemy movements and maneuvering. Current systems under consideration are standard weaponized UAS or small expendable loitering weapons, fitted with imaging sensors, such as the Low-Cost Autonomous Attack System (LOCAAS). Operating in swarms of “intelligent munitions” weapons, the LOCAAS can autonomously search for and destroy critical mobile targets while aiming over a wide combat area. Recent enhancements of the LOCAAS concept introduced man-in-the-loop functionality to enable retargeting and the ability to abort attack by a human controller when required. Further enhancements could integrate the LOCAAS into a “Surveilling Miniature Attack Cruise Missile” (SMACM) “mothership” carrying four LOCAAS units. The mothership will be able to support the units with targeting, surveillance, and communication support and extend the range and persistence of the basic version beyond 250 nautical miles. LOCAAS and SMACM are designed to operate in open area and pursue stationary and mobile targets of opportunities as soon as they are exposed in the open.

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A tremendous amount of work has yet to be done in the area of autonomous systems as a weapon. Current systems have less than optimal loiter times and are not readily adaptable to the shipboard environment and the strike fighter mission. As well, advances in interoperability, materials technology, and fusing have not been incorporated across the unmanned systems spectrum.

Figure 30 summarizes the goals for weaponry for unmanned systems.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2030+
Desired Capability	Near Term: Integration and interoperability of current weapons employed for unmanned system.					Mid-Term: Unmanned specific weapons development.					Long Term: Long Term Nano energetics.	

**Figure 30. Weaponry Goals for Unmanned Systems**

## 5 Operating Environment

### 5.1 Introduction

The world's markets, technologies, and regulatory environments for unmanned systems are evolving rapidly and creating opportunities in platforms, payloads, leasing, operations, and maintenance. DoD is looking beyond Iraq and Afghanistan towards a world of rapid deployments to trouble spots where airfields may not be available. After U.S. forces begin withdrawal from Afghanistan in 2014 in accordance with presidential planning, commanders expect to focus on contingency missions where the United States may have no established presence. UAS must then operate from ships or beaches rather than from fixed bases. Airborne launch of unmanned platforms is another approach.

Unmanned systems are better suited than manned platforms in some circumstances. In anticipation of such use, every segment of unmanned systems — the deployed platform, control station(s), and control link(s) — must all be considered from the earliest stages of program development. The environment must encompass all influences on this extended system, not just focus on the platform itself. System technology program requirements must be outlined in a CONOPS that details how the system is to be used in the intended physical operating environment and provides a baseline for all system requirements.

In addition to operating unmanned systems in strenuous physical environments, programs must also account for the ability to operate within existing regulations and within socially acceptable means. There will always be regulatory uncertainty when a revolutionary technology is introduced, as is the case with unmanned systems. A prime example is the consideration of UAS flights in the NAS, where UAS must operate within the FAA Federal Aviation Regulations (FARs). Even in cases where UAS do meet all applicable FARs, users of the UAS must consider the safety of the general public and abide by applicable privacy laws. Similarly, UGS intending to operate on U.S. public roads must at a minimum comply with Department of Transportation (DoT) regulations and federal, state, and local motor vehicle laws, but should additionally show safety and traffic efficiency enhancements to gain acceptance from the general public.

The unmanned systems safety guide for DoD acquisition references DoDI 5000.1, which instructs program managers to prevent environment, safety, and occupational health (ESOH) hazards, where possible, and manage ESOH hazards where they cannot be avoided. The unmanned systems must also comply to the Army equipment spectrum certification (ESC), which allows program management offices and others to apply for new equipment frequency allocations (i.e., spectrum certifications), request changes to existing spectrum certifications, request host nation coordination, and submit questions. The system tracks these “requests” and provides real-time status updates and mechanisms to collaborate with the Spectrum Management Office, which processes the request. Currently, the ESC process manager supports only Army requests while Navy and Air Force versions of this system are under development. Also, unmanned systems must meet information assurance requirements for their complex software systems as these systems must interact with other systems and humans through networked C2 systems to share information and control these systems. The Navy and Air Force have differing versions of this same process.

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### 5.2 Problem Statement

The operating environment of the unmanned system is a critical factor in determining the appropriate level of autonomy and the capability to maneuver as needed to accomplish the mission.

The intended physical operating environment provided in a CONOPS and other program requirement documents will help determine the level of technology that must be applied to the unmanned system. More stressing physical environments will most notably affect the level of autonomy required, along with the capability to act on the situation at hand.

Similarly, in the regulatory environment, program plans must account for the regulatory hurdles that are typical with revolutionary technologies. Individual technologies must be carefully examined at every level in the system until the appropriate levels of technological advances are defined to be capable of overcoming such hurdles.

These concerns are especially important and apply to A2/AD scenario planning factors. These factors include technologies supporting survivability, anti-jam, all weather, and persistence capabilities as described in Chapter 4.

### 5.3 Physical Environment

The physical operating environment provides the basis for the unmanned systems capabilities. Ideally, unmanned systems should be able to adapt to any environment but, to constrain the problem, many state-of-the-art unmanned systems are currently designed from the ground up to operate within an assumed environment.

The UAS physical operating environment may vary greatly. Generally, UAS will operate in similar conditions as manned aircraft, i.e., in all weather, from low to high altitude, and in airspace that is congested and possibly contested. Some UAS, such as Triton, are intended to fly in maritime environments at both very high and low altitudes. Flights at lower altitudes must consider saltwater and humidity in both design and operation, while high-altitude operations must consider extreme temperatures and the lack of air pressure. Also, the altitude transitions through weather and additional stresses will require additional capability considerations.

The physical operating environment determines the basis for UGS capabilities. Operations for future UGS will vary from occurring in structured and semi-structured environments to occurring outside a defined perimeter on semi-structured to unstructured terrain in support of force protection or physical security missions in more hostile environments. UGS maneuvering must account for environmental conditions (e.g., obstacles, threats, road conditions) in addition to the system performance. Further environmental classifications, such as urban/rural, forest/open, road/non-road, indoor/outdoor, must be addressed with regard to UGS.

DARPA and the auto industry continue to pursue automated technologies that could allow UGS to operate in a variety of conditions. Current efforts allow vehicles to operate within pavement lines, operate in sequence, stop when objects are ahead, and take caution when foreign objects are near (such as deer). Many of these efforts are intended to enhance vehicular safety, but also assist unmanned systems technology through increasing automation.

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The intended physical operating environments for UMS are in and around harbors, strategically placed within major shipping routes such as the Strait of Hormuz, or possibly out in the open ocean. Although maneuvering with no roads and no “water traffic controller,” USVs must be capable of avoiding ships, docks, floating debris, and navigation aids and must stay within proper navigable waters (i.e., not run aground). In addition, USVs must operate in accordance with collision regulations (COLREGS).<sup>68</sup> Because not all maritime traffic (including military and commercial) always follows the COLREGS, however, autonomous behavior is more difficult to develop for USVs.

On the other hand, although UUVs have the risk of running into underwater obstructions, they do not typically have to worry about other vehicles. Furthermore, there are also no navigation rules for underwater operation. For UUVs operating in a stressing environment such as open ocean, the technology must be capable of providing enough power to last long durations of time while autonomously performing their missions even when communication links are limited.

### 5.4 Policy and Regulatory Environment

Unmanned systems programs must consider all the policies and regulations of the appropriate authorities as program planning begins. UGS may need to operate on public roads where DoT is the regulatory authority within the United States, while UGS on foreign lands must remain within the policies of the host nations. Projects conducted by the National Highway Traffic Safety Administration will provide valuable data to develop safety standards and performance requirements, which will help ensure the safe testing and subsequent operation of autonomous vehicles on public roads. New technologies for UGS must be tested for safety and verified by the appropriate regulatory authority.

The primary regulations controlling the safe navigation of U.S. vessels are the navigation rules published by the U.S. Coast Guard.<sup>69</sup> These rules are applicable to international and inland waters. The international waters rules are based on the 1972 International Regulations for Prevention of Collision at Sea (72 COLREGS), as amended, a treaty that the United States adopted in 1977.

The Navigation Safety Advisory Council (NAVSAC) was established by the U.S. Congress to advise the Secretary of Transportation, via the Commandant, U.S. Coast Guard, on matters relating to the prevention of collisions, ramblings, and groundings. In May 2011, NAVSAC recommended to the Coast Guard that UMS be required to comply with the navigation rules, including some amendments deemed necessary for UMS compliance.

In addition to safe navigation rules, UMS must comply with other rules and regulations, such as for RF communication equipment operation and for environmental restrictions covering the operation of sonars and underwater acoustic instruments.

Safe operation of aircraft within domestic national airspace is governed by the FARs maintained and published by the FAA. Compliance with the FARs requires a pilot in the cockpit of the aircraft to “see and avoid” other aviation traffic. Therefore, UAS by nature cannot comply

<sup>68</sup> International Regulations for Prevention of Collision at Sea (COLREGS), 1972.

<sup>69</sup> COMDTINST M16672.2D, Navigation Rules, International – Inland, 23 November 2011.

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with the FARs. DoD UAS operations outside of restricted or warning areas within the NAS are currently required to obtain a Certificate of Waiver or Authorization (COA) from the FAA in accordance with FAA Order 7610.4, Chapter 12, Section 9.<sup>70</sup> The order identifies information that should be included in the COA request, including a description of the intended flight operations, UAS characteristics, and lost link procedures.

Outside U.S. sovereign national airspace, foreign nations have designated civil aviation authorities (similar to the FAA) that regulate and exercise governance over their sovereign national airspace. Furthermore, when operating in international airspace (i.e., over the high seas) DoD UAS observe International Civil Aviation Organization (ICAO) flight procedures when practical and compatible with their mission. However, in accordance with DoD policy (and consistent with international law) when operational situations do not lend themselves to ICAO flight procedures, such operations may be conducted under due regard.<sup>71</sup> In designated combat airspace, DoD UAS operate in accordance with instructions provided by the designated airspace control authority.<sup>72</sup>

### 5.4.1 Testing and Certification

Testing of UMS is required for the Military Departments to be able to certify compliance with regulations and demonstrate safe operations.

USVs must meet the same requirements of a manned craft or boat that is intended to be put into service. Testing unmanned systems in general is a significant challenge and can be very costly. For example, if it is impossible to put a man aboard a USV, the amount of time and expense increases significantly to verify that the propulsion system is working correctly. The Navy has developed a guide for testing USVs and drafted an approach to certifying USVs. The guide and draft certification method are available from the Naval Surface Warfare Center Carderock, Detachment Norfolk.<sup>73</sup>

To be able to fly in any airspace, DoD UAS are required to be certified as airworthy. Airworthiness certification is a core acquisition and engineering process conducted for system safety and takes into account material, service life, and mission requirements within the intended airspace.

Level of certification depends on the mission requirements of the system. A certification allowing unlimited NAS access may be cost prohibitive and unnecessary. For systems that do not require full airspace access or are constrained by cost or other technical hurdles, military departments may impose operational restrictions when issuing airworthiness statements for UAS. Examples include flights within a shipboard environment, only in uncongested airspace, or under other certain conditions with specific safety precautions. UAS may be allowed very limited access to the NAS, such as flights limited only within restricted or warning areas or only over unpopulated areas with other restrictions if little is known about the system or the operational risks are deemed too high to permit operations within the NAS.

<sup>70</sup> FAA Order 7610.4P, Chapter 12, Section 9.

<sup>71</sup> DoDI 4540.01, Use of International Airspace by U.S. Military Aircraft and for Missile/Projectile Firings, 28 March 2007.

<sup>72</sup> JP 3-52, Joint Airspace Control, 20 May 2010.

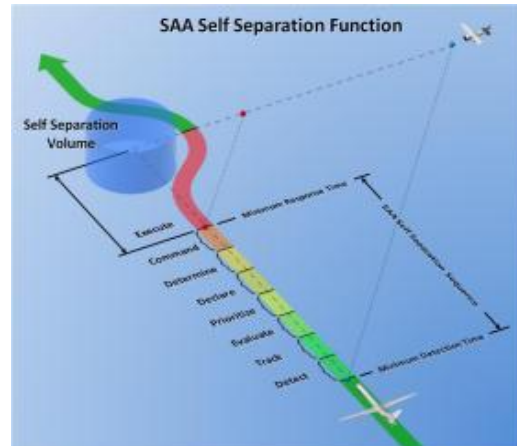
<sup>73</sup> Scott Sampson, Naval Surface Warfare Center Carderock, Detachment Norfolk.



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### 5.4.2 Sense and Avoid (SAA) Capability

SAA is a technical approach that has been proposed to bridge the gap between the FAR requirement for a pilot in the cockpit to “see and avoid” and the “unmanned” nature of UAS. In general, an SAA system should include the ability to perform the eight functions listed in Figure 31. It should be noted that for DoD UAS, expanded access to the NAS based on SAA technology will require continued use of COAs until current FAA policy, guidance, or regulations can be changed.



### 5.4.3 UAS Executive Committee (ExCom)

**Figure 31. SAA Self-Separation Functions**

The UAS ExCom was developed from a recommendation on conflict and dispute resolution from the 2009 National Defense Authorization Act. It is a focal point for senior leaders from DoD, FAA, the National Aeronautics and Space Administration, and the Department of Homeland Security to resolve any policy and procedural disputes and to identify solutions to enable the integration of DoD and other federal agency UAS into the NAS.

The UAS ExCom approved the UAS NAS Access Plan in October 2010, which addresses the milestones, policy recommendations, flight standards, and operating procedures necessary to provide a path for UAS integration into the NAS. The ExCom continues to work on many of the issues and recommendations identified in the plan, including continued improvements to the COA process as well as policy and procedural updates to enable significant improvement in UAS NAS access. In addition, the ExCom extended the COA expiration interval from 12 to 24 months and formalized an agreement on allowing transition from Class D airspace to adjacent Restricted or Warning areas. The ExCom is actively working to improve several other policy-related UAS issues, including

- Developing processes and procedures to allow multiple unmanned and manned operations in Class D airspace
- Simplifying the process for UAS to operate in Class D airspace from military airfields
- Simplifying the process for, and expanding the access of, SUAS to operate in Class G airspace
- Allowing UAS flights in remote operating areas with limited restrictions

### 5.5 Technology Application

An unmanned system may include a SoS. For example, a USV may host a UAS and UUS, or a UAS can provide inflight refueling to another UAS, or a UAS may be deployed as a communication relay station for UGS. Unmanned systems may be part of a greater system including manned elements as well. Technology developments must assess the impact each has across the rest of the system components or other systems.

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*Technology will improve the performance of our systems and allow them to last longer, to use fewer people, to cost less, and to provide more relevant information, where it's needed and when it's needed.*

### 5.5.1 Unmanned Aircraft Systems

One of the key capabilities UAS currently provide to the warfighter is persistence, for example, persistent ISR. Technology improvements can expand persistence much further, but programs must consider the operating environment while incorporating the technology. As an example, one technology application is onboard data processing. This automation technology can help minimize critical bandwidth necessary to transmit ISR data to the warfighter and may also be suitable for reducing the intelligence officer workload and decreasing the time in the kill chain.

Key technology enablers that UAS will encounter in operational environments include C2 links, SAA systems, sensors and displays, separation algorithms, and interoperability.

#### 5.5.1.1 C2 Links

As an essential component of UAS by definition, solutions to problems associated with link spectrum availability, latency, and reliability must be developed in all operating environments. Spectrum considerations should be fully understood for UAS to operate at any given location for C2 and also for SAA (where radar is employed). For C2 within LOS, the United States and other countries have an approved spectrum allocation to globally use the Aeronautical Mobile (Route) Service 5030–5091 MHz band. For BLOS, the World Radiocommunications Conference (WRC) was unable to reach agreement at the WRC-12, but will continue studies for decision at WRC-15. The WRC-12 decided that no additional spectrum allocation was required for SAA purposes.

#### 5.5.1.2 SAA Systems

An SAA system, whether ground, air, other, or integrated, will result from the effective use of many technologies. The SAA system will be a SoS, including sensors to detect and track, C2 subsystems to transmit information to a display providing situational awareness to a qualified pilot/operator, and algorithms to recommend or implement maneuvers depending on varying degrees of autonomy. Complex SAA systems may allow for formation flights or multiple shipboard operations in both SUAS and large UAS environments, all while preserving or enhancing flight safety.

##### 5.5.1.2.1 Ground-Based SAA (GBSAA) Systems

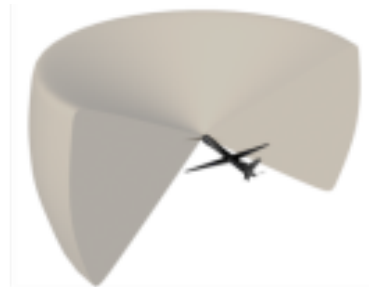
A GBSAA system is designed to provide safe separation for UAS operations within a prescribed volume of airspace using a ground-based system of sensors, displays, communications, and software. The sensors perform detect and track functions while algorithms and/or displays assist the pilot/operator with the requirement to evaluate, prioritize, declare, and determine the best course of action to avoid a hazard. The mission-critical information is provided to the pilot/operator in a GCS or at the operating station to enable the pilot/operator to

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make decisions to safely navigate the airspace. Future developments may automate maneuvers and allow more efficient use of the airspace and the easing of air traffic management tasks.

### 5.5.1.2.2 Airborne Sense and Avoid (ABSAA) Systems

ABSAA development efforts are focusing on an onboard capability to perform both self-separation and collision avoidance to ensure an appropriate level of safety. The capability is intended to give pilot/operators the ability to avoid conflict and collision avoidance with other aircraft in a safe and efficient manner in all classes of airspace. Early versions of this technology may function similarly to early phases of GBSAA by requiring the pilot/operator to initiate maneuvers, but work is being done to enable autonomous action by the aircraft, or pilot-on-the-loop operations, where the system can identify and react to conflicts. Current programs have phased validation schedules for flights within airspace in which DoD is authorized to operate with due regard, en-route/Class A, and divert/Class E/Class G operations as technology innovation and integration allow.



### 5.5.1.3 Sensors and Displays

Although developing common and interoperable sensors across multiple types of control systems and extensible to multiple platforms is best for the current fiscal environment, UAS sensors must be customized to the mission environment. Miniaturization of sensors will allow additional capabilities on smaller UAS and/or will enable the capability to collect more information aboard a single platform. Displays built for SAA functions should be common and compatible across the Services, regardless of GBSAA or ABSAA applications, as well as across air traffic services (see Figure 32). This compatibility will reduce training costs and allow the development of common terminology and understanding.



**Figure 32. UAS Pilot Simulator Training**

### 5.5.1.4 Separation Algorithms

For the foreseeable future, a pilot/operator will have direct decision authority for all UAS actions; this approach is known as “pilot in the loop.” Predicated on the failure of self-separation and approaching collision avoidance scenarios, the addition of separation algorithms will aid the pilot/operator in completing the mission. Such algorithms will also be needed for autonomous systems. This capability applies in the NAS, foreign airspace, and combat zones, but may be most applicable in open ocean and other areas where flights would be conducted under “due regard” regulations where air traffic services are not available.

### 5.5.1.5 Interoperability

UAS will be operating in an increasingly crowded airspace with the potential need to interact with manned assets. The UI2 CBA identified and prioritized IOP gaps in airspace

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integration and interoperability capabilities. Decision makers on the ground must be able to access sensor systems for both manned and unmanned aircraft to enhance situational awareness. Video data must be capable of transferring between aircraft to maintain ISR continuity. Therefore, interoperability standards must be in place so the right information gets to the right people. Initial stages of this type of interoperability were demonstrated during the Army's Manned Unmanned Systems Integration Capability (MUSIC) exercise in September 2011. This technology needs continued maturation across the military departments to meet DoD interoperability goals.

### 5.5.1.6 Other Technologies

Technology can be used to improve survivability under hostile environments and also improve overall reliability of unmanned systems. Improved reliability will make them more acceptable to a cautious public. Power systems can allow the endurance of a UAS to expand further beyond today's limited envelope. Also, as sensor payloads continue to improve and collect more data (such as FMV), data processing techniques must be able to smartly filter relevant data to pass to the ground within the limited bandwidth available.

## 5.5.2 Unmanned Ground Systems

The ability to maneuver effectively in a wide range of environments is a requirement that a UGS must meet. Those environments could include being thrown or launched, climbing hills or stairs, and hopping and landing upright. The technologies for advancing this capability are primarily autonomy, sensors, and avoidance algorithms.

### 5.5.2.1 Autonomy

The ability of the UGS to navigate autonomously is largely dependent on the accuracy and robustness of its perception system, which seeks to create an accurate model of its environment. Designing a perception system capable of dealing with all types of environments is very challenging with the current technology. To constrain the problem, current state-of-the-art UGS are designed from the ground up to operate within an assumed environment(s). If these assumptions are valid, the UGS often operate effectively. The UGS will fail to operate as intended, however, when circumstances are different from assumed. To alleviate this problem, it is desirable to have a perception system that can adapt to various environments. To be able to adapt, the UGS must understand the context of its environment and recognize when that context changes. One possible method of understanding context is through the classification of video imagery. Once an environment is classified, UGS require perception adjudication that specifically addresses the perceptual needs of the UGS at run-time. A number of factors dictate the perceptual needs of UGS, including mission awareness, environmental complexity, mobility requirements, and the sensor capabilities necessary to build contextual information from the environment. The



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enabling technology supporting these factors includes hardware and software related to autonomy, communications, power, vision, architecture, warfighter machine interfaces, manipulators, terrain mobility, and payloads.

### 5.5.2.2 *Sensors and Avoidance Algorithms*

Although collision avoidance systems on unmanned systems have been tailored for UAS, there is also a great need to apply them to ground systems. Examples of this technology include collision avoidance algorithms, traffic pattern recognition, and navigation. While avoidance systems for UGS may come about from UAS technologies, a good opportunity to leverage developments comes from the auto industry. The auto industry has a much greater ability to apply research and development technology funding with the initial focus on improving safety, and many of these technological developments will apply to making UGS safer as well.

### 5.5.2.3 *Other UGS Technologies to Consider*

Other technologies may also give UGS greater flexibility within its intended environment. Interoperability may be a very important consideration to reduce costs and add efficiency, especially as the sensors become more complex. Issues such as dual-use sensors, high/low data, data storage, and secure communication links may all be very important to evaluate. Vehicle-to-vehicle communications have the potential to greatly increase safety by sending and receiving data messages across equipped vehicles and translating the data into warnings to the driver of potential collisions. Several top auto manufacturers are quickly developing prototypes with varying technologies for civil auto applications. These technologies will benefit the civil community through fuel and time savings and improved safety and will certainly have benefits to DoD as well.

## 5.5.3 Unmanned Maritime Systems

UMS may be used for a variety of purposes. They can ensure security within harbors, scan for problems on a ship hull, sweep an area for mines, secure critical waterways, provide ocean tracking, and more. Because of the operating environment, the technology that allows these capabilities is unique. Like UAS, persistence is a key capability that UMS can provide; however, unlike UAS, UMS allow more than just persistence. For example, the largest issue with UAS is their inability to operate in bad weather or low visibility. UUVs, on the other hand, can operate in poor weather conditions. Therefore, DoD can continuously scan for mine drops or follow an enemy threat such as a submarine. In any case, persistence requires improved power and propulsion systems, autonomy and data processing, improved communication systems, and advanced sensors.



### 5.5.3.1 *Power Systems*

Certainly powering for long-term persistence is a large challenge. Having the ability to sprint at high speeds to intercept a target is not the only power requirement. Towing also requires power; for example, the mine warfare mission typically requires a significant tow load — much



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more than a normal craft's capability. Certain supporting payloads are also very power intensive. A USV carrying other UUVs or USVs would have to recharge or refuel the other payloads, and this requirement would require more power.

### 5.5.3.2 *Autonomy and Data Processing*

Like UAS or UGS, UMS can be preprogrammed for certain missions. For example, UUVs can autonomously scan the hull of a ship for threats or other foreign objects within harbor or scan a geospatial area for mines. However, the technology gets more complex as the level of autonomy increases. The appropriate autonomy level plays a key role in persistence during clandestine missions, e.g., the ability to sense and avoid hostile forces and to detect and avoid obstacles such as approaching vessels, fishing nets, or more conventional obstacles like rock formations or coral heads. Autonomy may also play a key role in the capability to diagnose and react in a proportional manner to UMS internal failures (fault management) during long missions, especially in clandestine missions. For these types of missions, the UMS needs the capability to send important, relevant information as needed, such as relaying the track of a detected threat.

Data processing enables the transmission of a reduced amount of data like beam-formed sonar images instead of raw, stove data, without compromising quality. Not only is there a need to use preprocessing to reduce the amount of data transmitted, but also automated target recognition enables target discrimination, i.e., reporting contacts of interest instead of sending entire images for human interpretation.

### 5.5.3.3 *Communication Systems*

Communication systems on UMS drive the need for advanced data processing techniques. Undersea C2 limitations preclude teleoperated solutions, and such limitations drive UUV autonomy needs. Bandwidth is much lower with acoustic signals compared to RF signals; therefore, wireless data rates are reduced. In clandestine operations, C2 links must extend over long distances into the undersea environment to provide operators with situational awareness and supervisory control over a UUV.

### 5.5.3.4 *Advanced Sensors*

New technologies enable real-time adaptation and optimization of sensor settings and unattended tactical planning for sensor employment according to the environmental conditions. Because a human is not around to recognize that the sensor is not operating optimally, sensors need the capability to adapt to optimize their abilities. In addition, they must improve in other areas:

- **Marinization.** Typically most commercial sensors are built for UAS. Their environment is simpler compared to USVs and UUVs. Not only is salt water a problem, but the accelerations and shock from bumps are well above anything experienced by a UA.





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- **Built-in test.** Sensors must have the ability to know and report when they are not working correctly so the control system can take appropriate action.
- **Data fusion.** To be truly useful in the future, sensor data output must be standardized for incorporation into a fusion engine providing for a better world view (i.e., understanding of the environment around the unmanned system).
- **Additional capability.** Sensors must allow for faster operation (i.e., as speed of a USV increases, cameras and radars must be able to see further and clearer to determine the proper course of action so the vehicle has time to react).

Sensors must continue to be developed and improved to gain even more capability and robustness in a maritime environment.

### 5.6 Way Ahead

To operate within the existing regulatory environment, programs must comply with existing policy framework or get policy waivers because policies tailored to unmanned systems are still in development. Regulatory and cultural hurdles must be carefully considered early in system development. In this paradigm, technology development and tests will help shape the appropriate requirements, standards, and regulations. Industry will help frame what is possible as the “state of the art,” and programs will define what is fiscally responsible. Once the standards and regulations are complete, PORs can then create requirements for their systems with a complete set of expectations.

### 5.7 Case Study: Air: Airworthiness and GBSAA

Services programs and CCDRs that require UAS must define the types of airspace they require for their missions. The CONOPS should define the operating environment, considering the NAS for training before deploying overseas in a foreign airspace. Two important factors, although not the only factors, for UAS flights in the NAS are the airworthiness of the vehicle and the SAA solution to comply



with FAR or COA requirements. Below, we quickly examine these factors in a case study of the Army Gray Eagle at Fort Hood, Texas. The Gray Eagle currently requires a COA to transit from Joint use Class D airspace to restricted airspace a short distance away.

Like manned systems, the Gray Eagle vehicle must be certified as airworthy and properly equipped to fly in the intended airspace. The aircraft structure, propulsion system, control redundancies, software, and control links must all be certified to a certain standard defined by the Service’s technical airworthiness authority (TAA). However, the Army has determined that certification costs are prohibitively expensive to certify the Gray Eagle to manned aircraft

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standards. Therefore, the Army TAA takes into account the potential risk of a failure and the population density below the intended flight path, which would cross over a road. To minimize risk to people and property on the ground, the Gray Eagle will fly perpendicular to the road and take other similar precautions.

The Army has a clear understanding of the airspace the UAS must transit, equipage requirements for that airspace, normal aircraft traffic patterns, surrounding terrain, and other potential hazards to accomplish its training mission. The Army decides that GBSAA is the chosen SAA solution based on mission requirements and costs. The GBSAA radars monitor the airspace for potential conflicting traffic, and algorithms assess the potential for conflicts and suggest heading changes to the operator to maintain separation.

The combination of these efforts allows the Army to confidently navigate the airspace safely with regard to other airspace users as well as people and property on the ground. This solution provides the capability to accomplish the training mission without incurring high costs such as transiting the entire unit to another location.

### 5.8 Summary

Technology is evolving rapidly, and this fast evolution is challenging regulatory authorities to keep pace with needed rules and regulations as well as challenging military departments to keep costs down when abiding by DoD acquisition and management processes. Every aspect of the operating environment, including the physical and regulatory, should be kept in mind at every stage of the acquisition life cycle. Guidance is currently available from each Military Department although the requirements and standards must still be developed.

Unmanned systems are ideally suited to increase the envelope for the physical environment. They are often built with the intent of putting them in harm's way and avoiding risk to a pilot, operator, or controller. The timeline in Figure 33 shows the technical path toward successful increases in capability across the domains for the next 25 years.

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Goals		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2030+
Technology Projects		<u>Near Term</u>					<u>Mid Term</u>				<u>Far Term</u>		
	UAS	Secure C2 Links. Certified GBSAA. Certified Displays. Improved Sensors. Interoperable payload					Certified ABSAA and Separation Algorithms. Integrated equipment				Integrated SAA. Evolution with NextGen		
	UGS	Expand physical architectures. Increase Autonomation for Specific Tasks. V2V Comms					Expanded Autonomy Systems and Avoidance Algorithms				Autonomous Architecture		
	UMS	Improved Power, Comm, and Sensor Systems					Effective Autonomy Systems and Avoidance Algorithms. Security Architectures						
Desired Capability	UAS	Incremental access to the NAS. Effective information fusion					Routine Access to the NAS. Due Regard capability. Effective exploitation				Increased safety and efficiency for flights in NAS and worldwide. Effective forensics		
	UGS	Robust physical capabilities					Effective manned-unmanned teaming				Adaptable Systems		
	UMS	Autonomy for specialized missions in localized areas. Increasingly networked systems					Increased missions in expanded geographical areas				Autonomous missions worldwide		

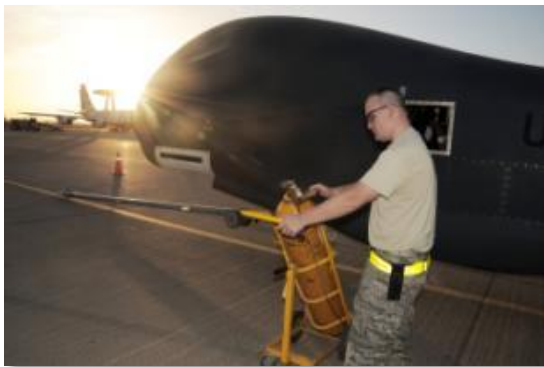
Figure 33. Operating Environment Technology Development Timeline

## 6 Logistics and Sustainment

### 6.1 Current Sustainment Environment

The rapid development and fielding of large numbers and types of unmanned systems present DoD with a significant sustainment challenge. Reliance on joint operations and multinational coalitions further complicates that sustainment challenge. Joint mission requirements need matching logistics capabilities that meet the specific mission requirements of the CCDR.

Evolving requirements often force premature system redesign efforts to meet emerging warfighter needs. Rapidly evolving technology and economic conditions affect the requirement and the ability of unmanned systems to meet stated reliability, maintainability, and affordability requirements. Original equipment manufacturer (OEM) assertions of proprietary interests complicate organic support. As budget pressures increase, programs must develop more cost-effective sustainment solutions. The transition from supporting the warfighters' immediate capability requirements to creating an affordable, long-term sustainment environment will require a flexible blend of OEM and organic support to meet logistics support objectives.



### 6.2 Problem Statement

The first generation of fielded unmanned systems was focused on the rapid delivery of immediate capability to the warfighter. Because of the need to rapidly develop and field these initial capabilities, long-term sustainability planning has often occurred late in the development cycle. Many programs have been procured as vertically integrated, vendor-propriety solutions relying on a single prime contractor who was often held accountable to meet many criteria, including a compressed delivery schedule. These rapidly fielded programs are often immature in terms of reliability and supportability and are heavily reliant on contractor logistics support (CLS). In most cases, unmanned systems are no different from manned platforms and require



investments in reliability and maintainability to provide availability at an affordable cost. However, reliability, maintainability, and lifecycle costs have been secondary considerations, and early application of reliability and maintainability engineering activities to the design has been neglected. As programs plan for long-term sustainment, they must establish lifecycle sustainment strategies that can cost-effectively meet documented warfighter requirements and comply with statutory requirements and DoD policies.

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### 6.3 Challenges to Logistics and Sustainment

The need to quickly field unmanned capability led to shortcomings in the area of logistics and sustainment planning and implementation. Challenges include

- Sustaining non-PORs
- Limited RAM data
- Delayed core logistics capability requirements
- Transition from CLS for Life to Organic capabilities
- Immature or lack of lifecycle sustainment planning

#### 6.3.1 Sustaining Non-PORs

Programs initially fielded as user operational evaluation systems or as rapid acquisitions in response to JUONs have since transitioned to PORs that provide enduring warfighting capabilities. Many involve procurement quantities of hundreds of units that will be sustained for the foreseeable future. The Services have focused on “getting product out the door,” rather than maturing and improving sustainability within systems because of the urgent goal to meet immediate warfighter needs with unmanned systems capabilities. The programs often have not developed the data strategies to support the system for the long term, including procuring failure and product support usage data. The Services have met the needs of the warfighter by fielding developmental versions of the PORs as quick reaction capabilities, fielding non-POR sensor and weapons capabilities on POR platforms, and fielding multiple POR low-rate production units prior to completion of the initial operational test and evaluation (IOT&E) and formal declaration of IOC.

The Services have also developed innovative, and sometimes ad hoc, logistics concepts to support near-term in-theater warfighter readiness. For instance, in 2006, the Army Materiel Command chartered the RS-JPO to provide in-theater support via the Joint Robotics Repair Facility (JRRF) and the Joint Robotic Repair Detachments (JRRDs). JRRF provides a one-stop shop for fielding, sustainment, training assessment, and asset accountability. It also provides support, e.g., operational instruction, preventative maintenance checks, services, and troubleshooting. The JRRDs, established in Kuwait and Afghanistan, fill an Army maintenance capability gap created by the acquisition and deployment of commercial off-the-shelf (COTS) robotic systems in theater. These organizations operate outside the standard Army logistics system and force structure to provide training and to issue and repair robotic equipment. The facilities are staffed with a mix of Government personnel and contractors.



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### 6.3.2 Limited RAM Data

Much of the unmanned systems capabilities were delivered with large numbers of developmental and low-rate production assets that were not fully matured or proven to meet the system's RAM requirements. The lack of proven reliability creates a challenge to long-term system availability and affordability because reliability is typically the single largest design-controllable driver of operations and sustainment costs. While providing a tremendous capability to the warfighter, when IOT&E does occur, systems often do not meet their operational sustainment thresholds and are deemed not suitable.

### 6.3.3 Delayed Core Logistics Capability Requirements

The rush to deliver these critical capabilities to the field led to a reliance on the OEM to satisfy sustainment requirements. Prime contractors have been responsible to provide CLS to ensure the operational readiness of their systems in the field. In many cases, little organic maintenance capability at the military organizational and intermediate (field) level has been established. Program offices have relied on the capacity of the prime contractors' production lines to satisfy depot maintenance requirements. The delay in the establishment of organic depot capabilities sometimes put programs at odds with statutory requirements. Several programs have begun the transition from contractor support to an organic capability. However, contractor assertions of proprietary technical data rights,<sup>74</sup> investment costs for support equipment and facilities, parts obsolescence, and frequent software upgrades create challenges to establishing depot capability in the near term. In an effort to create organic maintenance efficiencies and commonalities between the programs, the Services have begun to work together to identify potential synergies in establishing common sustainment concepts and capabilities. An FY2011 UAS Organic Depot Study recommended the establishment of repair capabilities at a limited number of depots based on major subsystems to take advantage of existing depot capabilities and capacity (see Figure 35 in 6.7.1). The Joint Logistics Board endorsed the workload assignment consolidations and directed that Air Force avionics, ground electronic, software, and sensor workloads be further evaluated for potential consolidation.

### 6.3.4 Transition from CLS for Life to Organic Capabilities

For UAS, the same FoS was often selected to meet the requirements for ISR and weapons platforms of different Services; therefore, a large degree of commonality exists among the various platforms and sensors. However, because of the initial strategy of using the prime contractor for CLS for life to sustain rapidly deployed and evolving capabilities, the various program offices are just beginning to recognize and take advantage of commonalities by establishing common logistics infrastructures to reduce investment costs as they develop plans to transition to organic support late in the development cycles.

Contracts for CLS, in many cases, have not been performance based, i.e., requiring specified levels of readiness, but rather cost-plus-award-fee arrangements providing flexibility to respond to changes in requirements and OPTEMPO. While these arrangements provide an

<sup>74</sup> 10 USC 2320 provides that in the case of an item developed by a contractor or subcontractor exclusively at private expense, the contractor or subcontractor may restrict the right of the United States to release or disclose technical data to persons outside the Government. The statute further states that these restrictions do not apply to technical data that are necessary for operation, maintenance, installation, or training.



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immediate advantage to quickly field warfighter operational capability, more affordable sustainment solutions are required as fleet sizes have grown.

### 6.3.5 Immature or Lack of Lifecycle Sustainment Planning

Fielded unmanned systems are frequently not managed or maintained as other platforms are within the inventory. For instance, with Army UGS, the operational urgency and uniqueness of these platforms required a nonstandard approach in integrating these technologies into the force. This understandable and needed deviation created, as a byproduct, a parallel management system that bypassed many established processes and procedures. The RS-JPO sustainment strategy for the family of robots includes improvements and upgrades to current platforms with the latest technologies. Due to the drawdown from theater, RS-JPO is developing a responsible drawdown strategy that includes long-term storage and future disposition of robotic systems.

The Army lacks adequate maintenance doctrine to address the technologies incorporated into robotic systems. Robotic maintenance doctrine has not been delineated in Army doctrine. Only a small group of operators and personnel within the Army working in the development, testing, and acquisition of robotic technologies is well acquainted and/or understand the impact of these technologies. RS-JPO initiated efforts to improve the maintenance strategy by improving databases and how data are analyzed, decreasing top sustainment parts cost drivers, and outsourcing repairable parts. By improving the way data are collected and analyzed in the Cataloging Ordering Logistics Tracking System, JRRF hopes to identify and increase MTBF and identify systemic parts problems to reduce the number of parts consumed. Also RS-JPO is currently working with the OEMs to analyze the repair-versus-replace cost of their top sustainment parts cost drivers to determine whether the return maintenance actions are being accomplished efficiently. Future plans also include the possible outsourcing of parts repairs to a non-OEM contractor. JRRF continues to develop and refine repair processes and serve as the center for technician support for all the detachments and training sites.

Multiple challenges exist for sustainment due to the many different configurations of nonstandard equipment (NSE). The optimum goal is to have modularity across platforms for plug-and-play adaptability. This approach will reduce the number of required repair parts and allow plug-and-play payload options to fulfill multiple capability requirements. This effort will also maximize the life of the current fleet and save a substantial amount of money in repairs and spare part purchases.

### 6.4 The Way Ahead

For unmanned systems to move from an environment of rapid development and fielding to an environment of long-term sustainment, programs must take a lifecycle management approach. Affordable lifecycle sustainment solutions that meet the warfighter's threshold requirements must be generated to maintain the capabilities of the first generation of unmanned systems over the foreseeable future. As new unmanned systems and capabilities are developed, new programs must apply lessons learned to ensure long-term sustainability is addressed early in the development process.

In September of 2011, USD(AT&L) directed that sustainment plans be developed for all unmanned acquisition programs and be reviewed for improved affordability and effectiveness.

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Lifecycle logistics planning and analysis execution is important from the acquisition phase through operations to the retirement phases of the weapon system life cycle. Cross-functional planning and integration are essential to ensure that supportability requirements are addressed comprehensively and consistently with cost, performance, and schedule during the life cycle. The objective is operational effectiveness through an affordable, effective support strategy that meets goals for optimum readiness and facilitates iterative technology enhancements during the weapon system life cycle. See Figure 34.



**Figure 34. Lifecycle Sustainment Planning Analysis Way Ahead**

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### 6.5 Planning for Organic Depot Maintenance

Central to sustainment planning and execution is the concept of core depot-level maintenance capabilities. First codified in 1984, the current statute<sup>75</sup> states, “It is essential for the national defense that the Department of Defense maintain a core logistics capability that is Government-owned and Government-operated (including Government personnel and Government-owned and Government-operated equipment and facilities) to ensure a ready and controlled source of technical competence and resources necessary to ensure effective and timely response to a mobilization, national defense contingency situations, and other emergency requirements.”

The National Defense Authorization Act (NDAA) for FY2012, as further amended in the FY2013 NDAA, introduced several new provisions of law relating to the identification and implementation of core logistics capabilities that affect the sustainment of UAS. The law now specifically requires a determination of the applicability of core logistics requirements by Milestone A and an estimate of core logistics capabilities and sustaining workloads by Milestone B. The identification of core capability requirements and sustaining workloads is now a three-stage process linked to the acquisition cycle. The Milestone Decision Authority (MDA) must now certify pursuant to 10 U.S.C. 2366a(a)(4), “that a determination of applicability of core depot-level maintenance and repair capabilities requirements has been made,” prior to Milestone A approval.<sup>76</sup> Milestone B approval may not be granted until the MDA certifies, “An estimate has been made of the requirements for core depot-level maintenance and repair capabilities...and the associated sustaining workloads to support such requirements.”<sup>77</sup> Additionally, “Prior to entering into a contract for low-rate initial production of a major defense acquisition program, the Secretary of Defense shall ensure that the detailed requirements for core logistics capabilities...and associated workloads required to support such requirements have been defined.” This three-stage process is designed to identify organic depot-level maintenance requirements early in the acquisition cycle to reduce the necessity for interim CLS and to allow for the timely establishment of organic capabilities. The determination that a function is core requires that government-owned and government-operated depot-level maintenance and repair capabilities and capacity, including the facilities, equipment, associated logistics capabilities, technical data, and trained personnel, shall be established not later than four years after a weapon system or item of military equipment achieved IOC or is fielded in support of operations.<sup>78</sup>

The early identification of core requirements and sustaining workloads will drive programs to identify and acquire data required to establish repair capabilities early in the acquisition process. DoD must also be ready to challenge assertions that unmanned systems were developed exclusively at private expense, or at a minimum be prepared to aggressively assert its “Government purpose rights” (under the provisions of 10 USC 2320) to the technical data required to maintain these systems.<sup>79</sup>

<sup>75</sup> 10 USC 2464, Core depot-level maintenance and repair capabilities.

<sup>76</sup> 10 USC 2366a, Major defense acquisition programs: certification required before Milestone A approval.

<sup>77</sup> 10 USC 2366b, Major defense acquisition programs: certification required before Milestone B or key decision point B approval, section (a)(3)(F).

<sup>78</sup> Ibid.

<sup>79</sup> 10 USC 2320, Rights in technical data.

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### 6.6 Sustainment Metrics and Performance-Based Logistics

Recent JCIDS guidance requires the establishment of a Sustainment KPP for all ACAT 1 programs in the capability development document and Capabilities Production Documents (CPDs) for the system.<sup>80</sup> ACAT II and below programs with materiel solutions are required to include the Sustainment KPP or sponsor-defined sustainment metrics. The Sustainment KPP is stated as a Materiel Availability threshold and objective and is supported by key system attributes for reliability and for Operations and Support (O&S) costs. Establishing these metrics early and tracking them throughout the life cycle of the program will help ensure that the programs can meet the warfighter's requirements at an affordable price. The flowdown of these metrics into performance-based logistics strategies to achieve operational effectiveness and system affordability is the preferred approach to systems support.<sup>81</sup>

Establishment of rigorous *reliability growth* programs to ensure that programs are meeting reliability thresholds has great potential to enhance the long-term affordability and availability of unmanned systems. Incorporating *design* features to enhance maintainability and supportability into future UAS has the potential to greatly increase readiness and lower O&S costs. Incorporating modularity and common interfaces that can accommodate integration of new sensor, weapons, and communication capabilities without requiring major platform redesigns and retrofits can potentially improve maintainability by simplifying the fault isolation, removal, and replacement of subsystems. In-flight diagnostic and prognostic technologies have the potential to improve repair turnaround and improve readiness. As the unmanned systems portfolios mature, responsible program executive offices (PEOs) and program offices can create opportunities for efficiencies by adopting policies and processes that encourage the use of common components and configuration elements, such as batteries, fasteners, electrical distribution panels, and support equipment. Commonality creates opportunities for common supply chains, sources of repair, and other product support elements.

### 6.7 Joint Logistics Integration

#### 6.7.1 Unmanned Aircraft Systems

As the sustainment of UAS becomes more institutionalized within the organic support infrastructures for maintenance, supply, and transportation, the accomplishment of much of the field- and depot-level maintenance will transition from CLS to the Government and military. Because of similar platform characteristics, subsystems, and manufacturing and repair processes, there is great potential for UAS programs to team together to reduce investments and operations and maintenance costs. The use of tools such as public/private partnerships (PPPs) and performance-based logistics contracts should be explored as methods to reduce sustainment and infrastructure costs. Agreements across different programs and Services can also reduce the costs of establishing organic repair capabilities and incentivize increases in systems reliability. As a result of these efforts, overall O&S costs can be reduced.

To facilitate the identification of opportunities to reduce overall investment and O&S costs, the UAS Task Force has established a Logistics and Sustainment IPT with the Services. In

<sup>80</sup> CJCSI 3170.01, Joint Capabilities Integration and Development System, 19 January 2012.

<sup>81</sup> DoDI 5000.02, Operation of the Defense Acquisition System, 8 December 2008, pg 29, enclosure 2.

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FY2011, a depot WG was established to recommend depot sources of repair for UAS major subsystems. The group recommended the establishment of depot repair capabilities at a limited number of depots based on major subsystems to take advantage of existing depot capabilities and capacity (see Figure 35). The Joint Logistics Board endorsed the workload assignment consolidations and directed that Air Force avionics, ground electronic, software, and sensor workloads be further evaluated for potential consolidation. The recommendations resulted in rational depot source of repair assignments for UAS core workloads and generated large cost avoidances and savings.

#### UAS Organic Depot Maintenance Sources of Repair Approved Consolidations

Commodity	CCAD	LEAD	TYAD	FRC E	FRC SE	FRC SW	OC-ALC	WR-ALC	OO-ALC
Airframes/Composite	A				N	N		N, AF	A, AF
Engine/Engine Components	A			N	N		A, N, AF		
Sensors (Electro-optic)			A		A, N, AF			AF*	
Sensors (Infrared)			A		A, N, AF			AF*	
Hydraulics	A			N	N	N	AF		A, N, AF
Pneumatics	A			N			A, N, AF		A
Landing Gear	A			N	N	N			A, N, AF
Ground Station	A	A	A, N, AF			N		AF	AF
Ground Data Link			A, N, AF			N		AF	AF
Avionics			A	N	N	N		A, N, AF	AF*
Environmental		A		N	N	N	A, N, AF		
Fuel System Components	A			N	N	N	A, N, AF	AF	
Flight Controls	A			N	N	N		A, N, AF	
Targeting			A		A, N, AF				
Targeting (laser)			A		A, N, AF				
Radar (ground)			A, N, AF						
Radar (air)			A*			N		N, AF	
Software			RSA		NAWC			AF	AF
Communications (Ground)			A, N, AF			N		AF	
Propellers	A							A, N, AF	

Service Workload Designations: A = Army AF = Air Force N = Navy \* = workloads fall in on existing repair capability

Sources of Repair					Highlights:
Army	CCAD = Corpus Christi Army Depot	LEAD = Letterkenny Army Depot	TYAD = Tobyhanna Army Depot	RSA = Redstone Arsenal	Green = Approved
Navy	FRC E = Fleet Readiness Center East	FRC SE = Fleet Readiness Center Southeast	FRC SW = Fleet Readiness Center Southwest	NAWC = Naval Air Warfare Center	Red Circle = Considering
Air Force	OC-ALC = Oklahoma City Air Logistics Complex	OO-ALC = Ogden Air Logistics Complex	WR-ALC = Warner Robins Air Logistics Complex	AF = Air Force Sustainment Activity	Current: 1/30/13

**Figure 35. Organic Depot Maintenance Sources of Repair Approved Consolidations**

In FY2012, the Logistics and Sustainment IPT met to create a forum to discuss lessons learned and to foster sustainment synergies. The IPT has identified potentially high payoff strategies of creating partnerships with industry to support families of components, such as sensors and communication links common across the Services. The UAS programs are researching opportunities to use existing manned aircraft capabilities to sustain similar UAS components. The Air Force's Reaper program and the Army's Gray Eagle program will use the Navy's Fleet Repair Center Southeast, Jacksonville, Florida, repair capability for H60 helicopter MTS-A sensors to repair their MTS-B sensors.

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### 6.7.2 Unmanned Maritime Systems

The Navy is currently supporting UMS through a combination of OEM and organic support. In the next few years, the sustainment strategy and infrastructure for UMS must be formalized and standardized to gain better control of the supportability resources and become more responsive and effective. The quantities of USVs and UUVs being developed and fielded in the next decade demand that attention be given to effective system sustainment. An organic support infrastructure for configuration control, supply support, maintenance, storage, and transportation is essential to bring efficiencies and cost effectiveness to these critically important systems. A planning yard should be established for UMS.

### 6.7.3 Unmanned Ground Systems

For UGS, due to the tremendous amount of dollars invested into NSE to meet the warfighter capability gap for the current conflict, the Army's Capabilities Development for Rapid Transition process categorized NSE robots into three categories: 1) recommend POR, 2) retain to support in theater, and 3) terminate. The majority of the NSE robots fall into category 2. A significant quantity of NSE robotic systems has been purchased and is being maintained using other contingency operations dollars. These NSE robots have proven to provide a needed capability to the warfighter and have saved lives. Also, these NSE robotic systems provide some of the capabilities outlined in the documents of developing PORs that meet current and future operational commander's capability requirements, but these PORs are not scheduled to be fielded until FY2015 and beyond. The strategy is to utilize some of the NSE robots as a bridging capability to the PORs until the PORs are fielded, store them for future contingencies, or utilize them as training aids. Nevertheless, these NSE robots still require a sustainment package that can be provided by JRRF or the OEM.



## 7 Training

### 7.1 The Need to Train

Training is a critical link in delivering warfighter capability. DoD can acquire and deliver the most technologically advanced equipment, but if the operators, maintainers, leaders, planners, users, and support personnel are not properly trained on the equipment or do not have a thorough understanding of its CONEMP, the advantages offered by this warfighting capability will be lost through its misapplication. A study by the Defense Science Board found that “U.S. armed forces have a training superiority that complements their technological superiority.”<sup>82</sup> The report points out, however, that this superiority can be eroded if the acquisition process does not properly integrate training into equipment development, testing, and fielding. The criticality of acquisition and training integration is emphasized by the requirement for acquisition program managers to “work with the training community to develop options for individual, collective, and Joint training” as part of the acquisition process.<sup>83</sup> The report also emphasizes that failure to deliver adequate training venues, where needed, will negate technical superiorities of hardware. Operators, maintainers, users, support personnel, and leaders must, therefore, be properly trained at the appropriate levels and intervals throughout their careers using the optimum mix of live, virtual, and constructive or blended reality training domains so they can use equipment effectively and to its full design capability. This chapter describes the current state of training for unmanned systems, some of the challenges involved, and the way ahead.

### 7.2 Problem Statement

Unmanned systems have been a warfighting success story, but work must still be accomplished in the institutionalized training environment. As operations in Afghanistan draw down and decisions are made about which systems transfer to a peacetime footing, the Services will have to make serious decisions about training. These decisions will not be limited to simply stating recurring training requirements. Rather, the details of how the training will be implemented must be planned and weighed so that every training opportunity is maximized to offset its incurred costs. At play will be cultural and political realities; interacting dynamics of technology, policy, and regulation; and fiscal constraints. Failure to meet the training challenges will result in a loss of combat-gained experience and an inability to effectively employ these systems in the future.

### 7.3 Challenges to Training

Even with the success unmanned systems demonstrated on the battlefield, DoD faces challenges in training. These challenges, as discussed in 7.4, relate not only to the types of unmanned systems (e.g., UAS, UGS, UMS), but also to acquisition, regulations, technology, manpower and other assets, and policy and documentation. This discussion is by no means exhaustive or in any particular order of precedence. Furthermore, DoD fully expects that as new generations of unmanned systems develop, the variety of missions they perform expands, and

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<sup>82</sup> Report of the Defense Science Board Task Force on Training Superiority & Training Surprise, OUSD(AT&L), Washington, DC, January 2001.

<sup>83</sup> DoDI 5000.02 Operation of the Defense Acquisition System, 8 December 2008, p.61.

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priorities change based on circumstances such as wartime, OPTEMPO, NAS restrictions, new challenges will arise.

### 7.4 Current Training Environment

Today's training environment for unmanned systems is similar to that characterized for logistics and sustainment, i.e., one of playing catch-up, in this case, to provide training support for the rapid fielding of unmanned systems. The term "disruptive technology" was coined by Clayton Christenson in 1995 to describe a situation where a technology introduces new priorities and value structures requiring significant structural adjustments to processes, organizations, and operational paradigms. The rapid development and fielding of large numbers and types of unmanned systems to meet expanding contingency needs is an example of a disruptive technology, which has resulted in significant challenges for the training community. The challenges presented by sheer unmanned systems numbers, diversity, and rapid fielding are complicated by the imminent drawdown of forces in theater and their return to a peacetime footing with a more stringent regulatory environment.

Improvements in joint operations integration, both at the individual and unit levels, are necessary to be able to employ combat capability synergistically:

- Operators must receive tailored training specific enough to support unique Service mission sets, yet broad enough to allow operators to integrate and contribute in a coalition environment.
- Training programs must adequately encompass initial qualification and proficiency/refresher training while also providing room to accommodate growth as technology and TTPs improve and evolve.
- Training programs must be integrated into the institutional base.

These challenges include such things as availability of resources, policy, and regulation. DoD is cognizant of these challenges and is making progress toward meeting them. In the future, the use of common equipment may also significantly reduce overall program costs and time to train.

#### 7.4.1 Unmanned Aircraft Systems

UAS are fielded by all four Services. UAS training has undoubtedly received more attention than UGS and UMS training. Service training programs are at different stages of maturity; however, as unmanned systems have matured, so too have the Service training programs. In an effort to establish minimum levels of training across the Services, the Joint Staff developed CJCSI 3255.01, which serves as the foundational crewmember training enabler with the FAA toward UAS integration into the NAS.<sup>84</sup> To achieve initial manning levels and arrive at a steady-state throughput, the Services have used varying mixes of organic and nonorganic UAS training, a variety of approaches for the different groups of UAS, and various personnel strategies.

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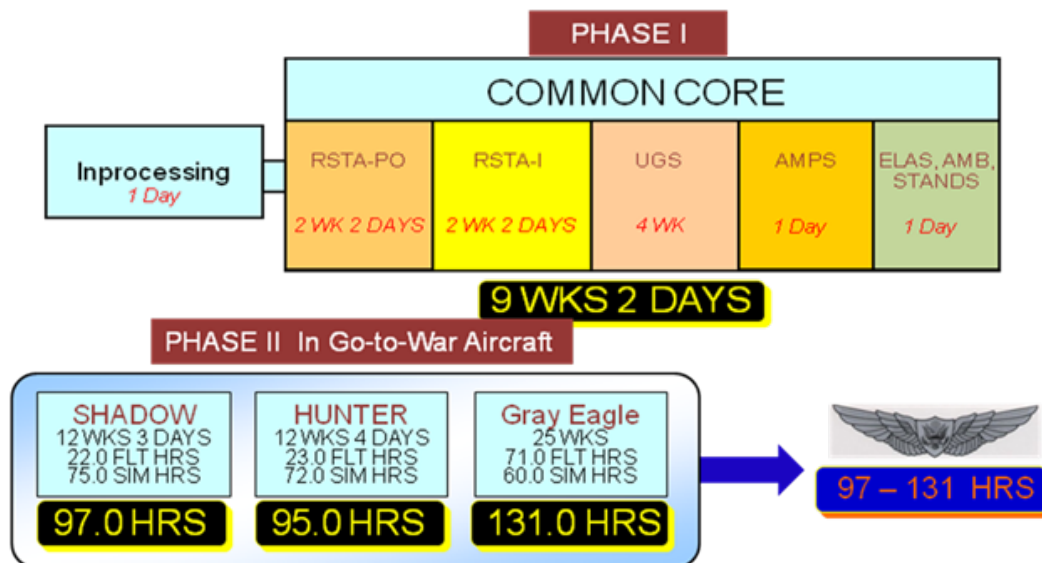
<sup>84</sup> CJCSI 3255.01, Joint Unmanned Aircraft Systems Minimum Training Standards.

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### 7.4.1.1 Army

The Army architecture for its Group 3 and above UAS operations includes an aircraft operator and a payload operator. The Army operates and maintains its RQ-7 Shadows, MQ-5 Hunters, and MQ-1C Gray Eagles. The 2nd Battalion, 13th Aviation Regiment (2-13th Aviation), formerly Army UAS Training Battalion (UASTB), located at Fort Huachuca, Arizona, conducts initial entry and military occupational specialty (MOS) training for all operators, maintainers, and leaders on Group 3 and above UAS. Operators attend a two-phase training program (see Figure 36) and receive a 15W MOS plus an additional skill identifier (ASI) for the aircraft they are qualified to operate. Maintainers attend a 17-week common UAS repairer course graduating with a 15E MOS, which qualifies them to maintain the Shadow. Additional courses and skill identifiers are required for qualification in Hunter and Gray Eagle maintenance. Additionally, 2-13th Aviation supports the Joint community by training Marine Corps and Navy UAS personnel. In FY2012, they trained more than 2,100 UAS personnel.<sup>85</sup>

The Raven is the Army's primary SUAS. Ravens are lightweight, man-portable, and operated and maintained by a single soldier. The Army's Maneuver Center of Excellence at Fort Benning, Georgia, currently conducts all Army Raven UAS training. As of 1 October 2012, the Army has transitioned to a SUAS Master Trainer program to train experienced operators at Fort Benning. These Master Trainers then return to their respective units to train SUAS operators at home station; this approach reduces the impact to the unit and enhances training flexibility. Uniformed instructor mobile training teams that deploy to units to deliver the syllabus are used to supplement training needs. Training is provided primarily to enlisted soldiers, but officers are also trained. Upon completion of the course, personnel are qualified to program, launch, fly, retrieve, and maintain Ravens. Qualification does not result, however, in the award of an MOS or Specialty Identifier.



**Figure 36. Army Group 3 and Above UAS Operator Training Flow**

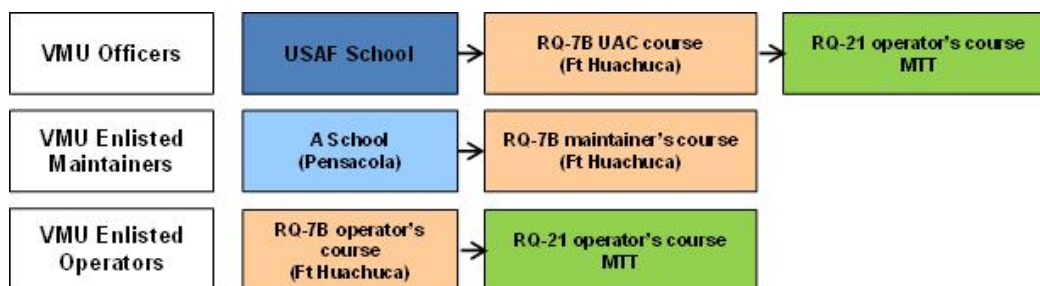
<sup>85</sup> Eyes of the Army, U.S. Army Unmanned Aircraft Systems Roadmap 2010-2035.

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### 7.4.1.2 Marine Corps

The Marine Corps uses a three-person crew for its RQ-7B Shadow training. The crew consists of an unmanned aircraft commander (UAC), an air vehicle operator (AVO), and a mission payload operator (MPO). RQ-21A Small Tactical Unmanned Aircraft Systems (STUAS) are crewed by a UAC and an AVO, who performs the MPO function as well. UACs are officers, while both AVOs and MPOs are enlisted positions. Currently, Marine Unmanned Aerial Vehicle Squadron (VMU) officers are sourced from the existing pool of qualified aviation officers; however, with the establishment of the VMU Officer Primary Military Occupational Specialty (PMOS), new second lieutenants will begin to be qualified as UACs. This dual sourcing strategy will continue until grade shaping of the MOS is achieved. AVOs and MPOs are sourced as entry-level positions, and each is also assigned a unique UAS MOS identifier.

The Marine Corps utilizes Army, Navy, and Air Force schools to train its VMU personnel, including maintenance personnel. The flow for Marine Corps Group 3 training is depicted in Figure 37. The Marine Corps is currently exploring the feasibility of standing up a UAS schoolhouse to standardize training for its RQ-7B and RQ-21A UACs, operators, and maintainers. This schoolhouse will build on joint training primary schools and maximize the use of simulation.



**Figure 37. Current Marine Corps Group 3 UAS Operator Training Flow**

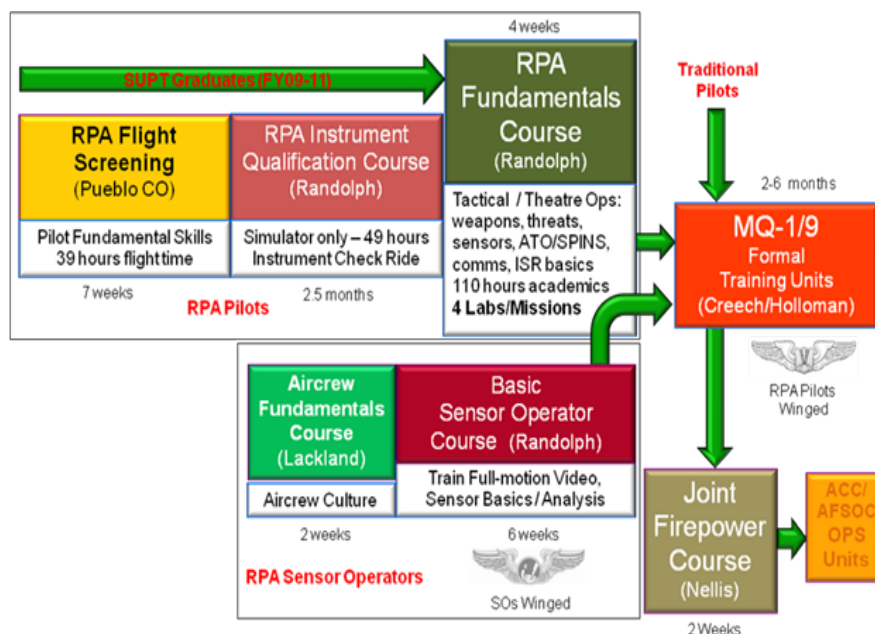
In July 2012, the Marine Corps stood up a Group 1 SUAS training activity at Camp Lejeune, North Carolina, to provide standardized non-MOS training for enlisted Marine Corps operators of SUAS. One of the goals of this schoolhouse is to relieve the line units from the burdens of providing initial SUAS training for their operators. By providing a centralized schoolhouse co-located with 2<sup>nd</sup> Marine Division, efficiencies in training and logistics have been achieved. A similar SUAS training activity is planned for Camp Pendleton, California, in support of 1<sup>st</sup> Marine Division.

### 7.4.1.3 Air Force

The Air Force classifies its Groups 4 and 5 UAS (MQ-1 Predator, MQ-9 Reaper, and RQ-4 Global Hawk) as Remotely Piloted Aircraft (RPA). RPA pilot and sensor operator aircrews are formally trained to operate the aircraft. Officer RPA pilots are sourced from the current rated pilot community or through the newly established Undergraduate RPA Training (URT) program, similar to Specialized Undergraduate Pilot Training (SUPT) program for manned aircraft. URT is another dual accession strategy to reach initial USAF RPA manning requirements. Sensor operators are enlisted airmen sourced similarly to pilots, some from current intelligence career

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fields and others through the newly created RPA sensor operator career field. The Air Force created new career fields and associated specialty codes for both its new rated RPA pilots and sensor operators. The training flow for these positions is depicted in Figure 38 (NOTE: The formal training unit for the Global Hawk is at Beale AFB, California.)



**Figure 38. Air Force MQ-1/9 Pilot & Sensor Operator Training Flow**

The Air Force has also created a Mission Intelligence Coordinator position to manage real-time/near-real-time intelligence information available to MQ-1/9 RPA pilots and/or sensor operators. Mission intelligence coordinators are sourced primarily from existing squadron intelligence positions and intelligence officer positions. Candidates undergo an initial qualification training course at either Creech AFB, Nevada, or March Air Reserve Base, California, and further mission qualification training at a squadron to attain mission-ready status.

Air Force RPA maintenance training is accomplished at three Air Force skill levels. RPA maintenance fundamentals are taught at the maintenance school at Sheppard AFB, Texas. Following RPA training at Sheppard AFB, initial and advanced skills maintenance training occurs at the operational RPA squadron.

The Air Force classifies its Groups 1 to 3 UAS, such as the Raven, Scan Eagle, and Shadow, as SUAS. They are operated by qualified SUAS operators, primarily enlisted airmen. These SUAS operators attend a formal, 10-day training course approved by Air Force Special Operations Command and conducted by Det 1, 371 SOCTS at the Eglin Range Complex in Florida. Curriculum has been developed and approved for the RQ-11B and is in development for the RQ-20A. SUAS operators are interchangeably qualified as vehicle operators and mission operators, the two crew positions required to operate the system. Qualification as an SUAS operator does not result, however, in the award of an Air Force Specialty Code or Special Experience Identifier.

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### 7.4.1.4 Navy

While the formal deliberative process for developing training to support emerging large-scale Navy PORs is in the infancy stage, the Navy has the advantage of drawing on lessons learned from the other Services. Current training during system development for PORs and rapid deployment capability efforts is being supported and provided by the associated program offices through contractor arrangements.

The Navy recently opened up a MQ-8 Fire Scout operator and maintainer training center at Naval Air Station Jacksonville. The aircraft and personnel are dual qualified in SH-60 Seahawks and assigned to mixed aviation squadrons containing both Seahawks and Fire Scouts. A similar organizational and basing construct is being examined for the MQ-4 Triton, the UAS complement for the Navy's fleet of P-3/8 aircraft to conduct ISR missions. Triton is currently operated at a demonstration level with training of initial operational evaluation crews slotted for late FY2014 followed a year later by initial cadre training. In June 2010, the Navy and Air Force signed a Triton and Global Hawk synergy memoranda of agreement (MOA) that specifies Navy and Air Force WGs to "Identify and incorporate every appropriate synergy in basing, maintenance, aircraft C2, training, logistics, and data requirements for processing, exploitation, and dissemination (PED) functions."<sup>86</sup>

Viable long-term training solutions for Navy systems are currently being developed within the framework of the basic UAS qualification standards outlined in the CJCSI 3255.01 and the Naval Education and Training Command Course Development and Revision Process.

### 7.4.1.5 Continuation and Joint Training

The focus of Service training efforts and strategy thus far has centered on developing initial skill sets and qualifying personnel to man a rapidly increasing UAS fleet. How to maintain and advance these skill sets through continuation training and education at the individual, crew, and collective levels has been largely overshadowed by the contingency environment. While Services have established currency requirements for their operators, currency is typically maintained through real-world operations rather than in a training environment. Furthermore, additional challenges impact domestic training. These challenges are being mitigated largely by the use of simulators and surrogates, but the full mix and balance of the live, virtual, and constructive domains and blended reality must be identified for the future.

Given that individual, crew, and collective continuation training constitutes the majority of training requirements and activity, the Services will need to continue efforts in these areas. These training programs are necessary to prepare operators for joint training and pre-deployment exercises.

While surrogates and virtual substitutes do address some challenges, the lack of home station UAS training opportunities and codified TTPs can limit the training experience of units preparing for deployment into theater. For example, combat training centers have observed units that were not adequately trained in UAS operations at home station prior to capstone training

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<sup>86</sup> Memorandum of Agreement between Broad Area Maritime Surveillance (BAMS) and the RQ-4 Global Hawk system, signed 12 June 2010



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exercises. Such units routinely receive UAS hands-on immersion training following deployment into theater during mission execution.

Attempts are being made to incorporate unmanned systems into joint and multinational exercises at every level. As a high-demand/low-density asset, live unmanned systems are often unavailable for exercises and pre-deployment training. The use of manned surrogate platforms to replicate aspects of unmanned platform behavior, such as FMV feeds, is common and useful in ensuring the exercise participants are trained and familiar with unmanned systems capabilities when deployed. Additionally, exercise and pre-deployment training scenarios use computer-generated, simulated video feeds to support joint exercises and to ensure warfighters are able to incorporate unmanned systems into their training even when actual systems are not available.

### 7.4.2 Unmanned Ground Systems

The Army provides UGS training through the RS JPO. Headquartered in Warren, Michigan, the RS JPO's training mission is twofold: 1) to develop, integrate, and manage UGS training operations, requirements, plans, and products through partnerships with organizations and entities internal and external to the RS JPO and 2) to execute joint functional operator and technical training for COTS and POR systems to support force capability generation and unit resetting through mobile training teams and resident courses. Since its inception, RS JPO has been tasked as the equipment support activity manager for supporting the "in theater" and "training center" sustainment operations for UGS for the Army, Navy, Air Force, and Marine Corps. Currently, training is from neither a systems approach nor a MOS organizational construct identified or designated to perform the training function.

In 2004, the RS JPO established the JRRF in response to urgent operational needs and in support of the joint forces engaged in the theatre of operations for all Joint Service NSE robotic systems. The JRRF's support areas include in-theater sustainment support and individual and unit operations training of robotic systems. RS JPO conducts operator certification courses on all robotic systems currently fielded and intended for users in the theater of operations. Training is currently conducted at Fort Leonard Wood, Missouri; Selfridge Air National Guard Base (SANGB), Michigan; and unit home stations through mobile training teams.

The small robot certification course is a two-day course that provides the operator system uses, characteristics, capabilities, limitations, component identification, pre-mission mechanical and functions checks, and hands-on practical application. Personnel are required to successfully complete a practical exercise performance evaluation to obtain certification. The M160 operator course is six days long and currently conducted at Fort Leonard Wood.

All robot technicians are trained on tasks that are required for the repair and maintenance of robotic systems supported by RS JPO. This training is achieved via a 10-week robot maintenance and repair course currently taught at SANGB. The course totals 400 hours of training in which the technicians are certified to work on RS JPO-supported robotic systems. Technicians receive operator training and hands-on training in troubleshooting; removing and replacing line replaceable units on currently deployed robotic systems; and using maintainer tools, special tools, and test equipment to maintain robotic platforms.

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Due to increasing robotic sustainment and training demands, RS JPO opened the Robotic University at Fort Leonard Wood on 4 April 2012. This detachment consists of technician bays and classrooms, warehouse space, and office space. Robotic University is truly a one-stop-shop with the ability to repair, supply, and train robotic systems. The Robotics University and SANGB training sites, with their equipment, materials, technicians, and instructors, give service members the required skills and confidence in the robotics.

### 7.4.3 Unmanned Maritime Systems

The Navy currently has a number of UMS consisting of USVs and UUVs that perform a variety of missions including mine warfare, mine neutralization, reconnaissance, surveillance, hydrographic surveying, environmental analysis, special operations, and oceanographic research. These systems vary in size and displacement and run from man-portable systems to systems 40 feet in length and several thousand pounds in displacement. These systems are predominately launched from submarines or surface ships and recovered and maintained aboard those vessels. The new Littoral Combat Ship (LCS) employs the largest inventory of unmanned systems for a variety of missions including surface warfare (SUW), anti-submarine warfare (ASW), and mine countermeasures (MCM).

UMS training consists of an assortment of methodologies that provide an optimal learning environment and include classroom as well as hands-on training. Classroom instruction consists of the fundamentals of operation and maintenance while the hands-on training covers the practical application of that knowledge. Follow-on and refresher training is provided by computer-based training (CBT) that includes online simulations of actual operations. Training is conducted at the appropriate training center, such as the Mine Warfare Training Center in San Diego, California, or at the Warfare Center that is the core support center for the specific system.

LCS Detachments consisting of up to 15 officers and technicians are assigned to LCS for each of the respective Mission Modules (i.e., SUW, ASW, MCM) and undergo classroom and hands-on training before boarding LCS for a deployment. As the personnel rotate on and off one LCS to other assignments and then back again, refresher training is provided at the Shore Based Trainer in San Diego. It includes individual CBT consoles and team training consoles to help sharpen previously learned skills. There are also CBT modules that can be downloaded for continuous training while aboard the LCS. Additional training centers will be established in Fort Lauderdale, Florida, and at various overseas locations as warranted to maintain detachment proficiency.

### 7.4.4 The Acquisition Process

Much has already been said in this document about the challenges created by the rapid acquisition of unmanned systems in response to urgent operational needs. As the immediacy of urgent operational needs begins to slow, the unmanned systems acquisition process will begin to normalize. As requirements for new generations of unmanned systems are generated, training must be developed concurrently with the new systems. Associated costs should be appropriately addressed across the program life cycle. The training KPP is required to eliminate ad hoc training systems at delivery.

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### 7.4.5 The Regulatory Environment

The regulatory environment is a unique challenge to unmanned systems operations, particularly in peacetime. While all systems are governed by regulatory requirements of one sort or another, unmanned systems bring with them an additional set of procedural and safety concerns because they are *unmanned*. These concerns are further increased with discussions of system autonomy. Much attention is being given to UAS autonomy, but it is not unique to UAS. How to train with an unmanned truck, for example, designed to move along roadways in a combat environment presents challenges when trying to traverse the U.S. interstate system and local county roads. Regulatory oversight may have the most significant impact on basing decisions and training operations, especially for UAS.

### 7.4.6 Technology

Technology challenges for training can be grouped into two categories: 1) the need to train to new missions and affiliated technologies and 2) technology impacts on training. New missions, hardware developments, and software integration appear to be endless. Each has to be accompanied by associated training. For example, access to airspace may be enhanced by SAA technologies that open up more opportunities for live training. Conversely, high-fidelity simulators and the availability of surrogate platforms could lessen the dependence on live training. Some technology impacts may not be so direct, but may be important none the less. For instance, a common control system not only has a training component, but could also lessen manpower requirements by leveraging the ability of a single operator to control multiple systems simultaneously. As a result, training throughput requirements and manpower resources could be decreased.

### 7.4.7 Manpower

Training faces several manpower challenges. First is the need for a sufficient instructor cadre. With ongoing contingency operations, qualified and potential instructors are often unavailable. Second, the Services have to address personnel qualifications and requirements, to adjust force structure, and to revise personnel processes to accommodate the new technologies. These actions affect the training audience. The coordination and integration of operators, force structure, and data analysts impact how training is accomplished and how training affects human resources. Manpower considerations for training must be fully explored to attain mission efficiencies and readiness.

### 7.4.8 Asset Availability

Adequate training resources are another challenge. First, similar to unavailability of instructors because of real-world operations, actual unmanned system platforms are often not available for training. This lack of platforms can be mitigated by leveraging the use of simulation and surrogates. Second, programs need training capability assets, such as realistic target sets in representative terrain, runways, scoring and feedback systems for crewmember after action reviews, access to airspace and frequency spectrum, simulators and surrogates, communications infrastructure, and C2 organizations and processes at ranges. Low-cost training munitions that replicate the service munitions of weaponized platforms will also need to be developed to facilitate realistic training within budgetary constraints and installation range limitations. These

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assets can be integrated into training requirements and plans. Moreover, the assets can influence basing decisions, operations, and funding strategies.

### 7.4.9 Policy and Documentation

Processes for capturing lessons learned and developing Service and joint doctrine and TTPs must be established and institutionalized through policy and documentation. Policy and documentation serve as the basis from which the Services develop training CONOPS, requirements, and plans. DoD, Service, and Joint plans identify and describe how the populations will be exposed to unmanned systems through professional military education and training. Training strategies for weaponized unmanned systems must identify the types and quantities of munitions required to maintain operator, crew, or unit proficiency in a training environment. Additionally, policy, documentation, and plans codify career paths and expectations for unmanned systems leaders, operators, planners, maintainers, and users.

### 7.5 The Way Ahead

Despite the challenges introduced by the rapid acquisition and fielding of unmanned systems, these systems are providing valuable capabilities to CDRs today. Introduction of new systems and processes are traditionally fraught with growing pains, including in training. It is through their perseverance, ingenuity, and professionalism that our soldiers, sailors, airmen, and marines can adjust to ever-changing circumstances to maintain mission readiness and combat effectiveness. As DoD moves toward an environment where unmanned systems needs are more mature and the acquisition process normalizes, training processes and systems will also mature. While the real-world environment flexes with real-world contingencies and the realities of domestic unmanned systems training become more imminent, DoD is addressing training challenges as follows:

- The requirement and acquisition processes will continue to be reviewed for inclusion of training plans throughout a program's development to help improve the rapid acquisition process. Current policy requires a draft training plan at each acquisition milestone. Additionally, new policy is being developed to strengthen those requirements and provide guidance for developing training for rapid acquisition programs. The policy will also offer a training plan template for the Services to support an appropriate training strategy.
- Organizations within DoD are working with regulators, other government organizations, and industry on how to safely incorporate these new technologies into today's world on an ongoing basis. For example, the Airspace Integration IPT and UAS ExCom, discussed in Chapter 5, will continue to implement products and activities to incrementally gain access to the NAS with the goal of attaining the level of UAS access to the NAS necessary to complete training and readiness requirements.
- Training plans will be developed and updated to reflect modifications to legacy systems and introduction of new systems. DoD will continue to develop SAA technologies to gain access to the NAS, increase commonality across control systems, increase autonomy of systems, and align fidelity of simulators for appropriate phases of training. Additionally, long-term success can be economically achieved with increased commonality of hardware to reduce unnecessary unique systems training.

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- As forces redeploy, the availability of instructors to fill training positions at all levels is expected to increase. As initial manning quotas are met, cross-flow accessions will be curtailed, and schoolhouses will transition to steady-state throughputs. As newly established career fields grow, season, and develop, experience levels will increase and normalize, similar to other career fields across the forces. Personnel systems will continue to align to the new technologies and mature.
- As forces return to home station from the current operational contingencies, decisions will be made about which systems become enduring PORs and transition back with the forces. It is envisioned that the redeployment will increase the availability of assets for training. Service and Joint training plans will need to mature and add the specificity needed to make prudent basing and resourcing decisions that enable effective training.
- Service roadmaps will continue to evolve and mature along with the doctrine, training plans, and documentation needed to support robust training systems. Emphasis will be put on fostering jointness and incorporating cross-service participation during exercises. A comprehensive training strategy will be developed to guide the myriad of efforts across DoD and help ensure effective and efficient training. The strategy will leverage work already completed or underway within the Services and Joint Staff. Its scope will be broad to address the totality of UAS training, from the smallest to the largest systems, at all echelons, for all appropriate personnel, and across the training continuum.

A notional timeline for UAS training objectives is presented in Figure 39 and will be further refined upon completion of the UAS training strategy in FY2013. By overcoming these training challenges and developing a DoD-wide training strategy, future unmanned systems will deliver more effective warfighting capabilities to the battlefields of tomorrow.

Goals	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2030+
Technology Projects	<b>Near-Term:</b> Improved simulator fidelity & integration of payloads onto surrogate platforms				<b>Mid-Term:</b> Integration of commonality efforts with simulator development				<b>Far Term:</b> Integration of simulators and surrogates into the live, virtual, and constructive and a blended reality training environments			
Capability Needs	<b>Near-Term:</b> Develop and implement DoD UAS Training Strategy; develop doctrine to support use of UAS operations; inform acquisition of surrogates and simulators; identify airspace requirements						<b>Mid- &amp; Long-Term:</b> Continue implementation and refine DoD UAS Training Strategy; refine UAS training programs to adjust for changes in doctrine; monitor acquisition for incorporation into training programs					

**Figure 39. UAS Training Objectives**

## 8 International Cooperation

### 8.1 Introduction

DoD international cooperation efforts include the cooperative research, development, test, and evaluation of defense technologies and systems with foreign partners as well as the procurement of defense articles, systems, and services from foreign partners. It also includes participation in NATO capability groups. The objectives of international cooperation are

- **Operational.** To increase military effectiveness through interoperability and partnership with allies and coalition partners.
- **Economic.** To reduce weapons acquisition cost and achieve better buying power by sharing costs and economies of scale, avoiding duplication of development efforts, and cooperatively producing or selling more weapons systems to our allies and friends.
- **Technical.** To access the best defense technology worldwide and minimize the capabilities gap with allies and coalition partners.
- **Political.** To strengthen alliances and relationships with other friendly countries.
- **Industrial.** To bolster domestic and allied defense industrial bases.

### 8.2 Methods of International Cooperation

Three primary methods are used for international cooperation:

- International agreements such as memoranda of agreement/understanding (MOAs/MOUs) aimed at joint research, development, and/or procurement of, or investment in, new defense technologies and systems
- Foreign military sales (FMS)
- Direct commercial sales (DCS)

#### 8.2.1 MOAs and MOUs

DoD has entered into bilateral and multilateral agreements with a variety of international partners for the joint development of defense technologies and systems. Under such agreements, DoD works with its foreign counterparts and shares existing technology, expertise, and resources to develop new technical information; develop new technology, defense systems, or platforms; or improve existing products. DoD has entered into several such international cooperative agreements with foreign partners to advance UAS. For example, The Technical Cooperation Program (TTCP), a collaborative defense S&T program involving the United States, Great Britain, Canada, Australia, and New Zealand, was established to familiarize all partners with each other's national defense S&T programs and to cooperate in a broad range of defense S&T activities and projects. The results of TTCP activities assist each participant in meeting defense requirements, while avoiding unnecessary duplication of effort. The participants of TTCP have an active UAS program to share and conduct joint experiments in areas such as autonomous C2, novel aircraft configurations and systems, UAS self-protection, and counter-UAS. This activity has spawned an International Operators' Group, which includes both operators and researchers to identify and address pervasive issues, as well as a number of bilateral agreements with individual nations.



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### 8.2.2 Foreign Military Sales (FMS)

The FMS program is the U.S. Government's program for transferring defense articles, services, and training to other sovereign nations and international organizations. Under FMS, DoD procures defense articles and services on behalf of the foreign customer using the same acquisition process DoD uses for its own military needs. Countries approved to participate in this program may obtain defense articles, services, or training by paying with their own national funds or with funds provided through U.S. Government-sponsored assistance programs. In certain cases, defense articles, services, and training may be obtained on a grant basis. The Defense Security Cooperation Agency administers the FMS program for DoD. FMS cases must be reviewed/approved through the Department of State (DoS), and, in some cases, the U.S. Congress must be notified through the Congressional Notification process. In general, these government-to-government purchase agreements tend to ensure standardization with U.S. forces, provide contract administration services that may not be available through the private sector, and help lower unit costs by consolidating purchases for FMS customers with purchases for DoD.

### 8.2.3 Direct Commercial Sales (DCS)

Under DCS, U.S. companies obtain commercial export licenses from either DoS (for munition items) or the Department of Commerce (DoC) (for dual-use items). These licenses allow the companies to negotiate sales directly with foreign customers. All DCS are subject to the approval of DoS or DoC and, in some cases, the U.S. Congress and must comply with applicable U.S. exports laws and regulations. DCS allows the foreign customer more direct involvement during contract negotiation, may allow firm-fixed pricing, and may be better suited to fulfilling nonstandard requirements.

### 8.2.4 NATO

The military alliance promotes cooperation and interoperability through information exchange and the development of standards (see <http://nsa.nato.int/nsa>). For example, airworthiness standards have been developed and adopted by member nations and are being incorporated in MIL-HDBK-516B.<sup>87</sup> Additionally, the alliance is acquiring (under DCS) the NATO Alliance Ground Surveillance (AGS) System, a derivative of the U.S. Global Hawk system. Five Europe-based AGS aircraft will serve alliance missions and, in turn, reduce demand for U.S. ISR systems to meet NATO requirements. See Appendices B and C of this roadmap for additional information on alliance standards, and see the publication AAP-03<sup>88</sup> for established procedures for the production, maintenance, and management of NATO standardization documents in accordance with NATO regulations.

## 8.3 International Cooperation Authority, Jurisdiction, Approval, and Disclosure

The U.S. Government has split export licensing authority for FMS and DCS among multiple organizations. The two primary Government regulations are the International Traffic in

<sup>87</sup> MIL-HDBK-516B, Airworthiness Certification Criteria.

<sup>88</sup> AAP-03, Production, Maintenance and Management of NATO Standardization Documents, Edition J, Version 2, November 2011 (<http://nsa.nato.int/nsa>).

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Arms Regulation (ITAR), which controls defense articles and services under the jurisdiction of DoS, and the Export Administration Regulation (EAR), which controls dual-use items under the jurisdiction of DoC.

### 8.3.1 Authority and Jurisdiction

#### 8.3.1.1 *International Traffic in Arms Regulation (ITAR)*

The Arms Export Control Act (22 U.S.C. 2778) authorizes the President to control the export and import of defense articles and services. Pursuant to Executive Order 11958, this statutory authority was delegated to the DoS. ITAR implements that authority and is the governing regulation controlling the export of defense articles and services. ITAR includes the U.S. Munitions List, a list of defense articles controlled by ITAR. It further defines the export licensing requirements and procedures needed to export a defense article or perform a defense service as well as the process to determine the jurisdiction of a commodity (i.e., whether an item is controlled under ITAR or EAR).

ITAR provides a number of exemptions to the licensing requirements for defense articles and services. Many of these exemptions are country specific (e.g., through implementation of UK and Australian defense trade treaties, the Canadian exemption) while others are transaction specific (e.g., shipments by or for U.S. Government agencies). Most ITAR exemptions have rigorous procedures, documentation, and record-keeping requirements associated with their implementation. Each of the U.S. military services, as well as other select DoD organizations, has been delegated limited export authority by the DoS.

#### 8.3.1.2 *Export Administration Regulation (EAR)*

EAR implements the Export Administration Act (EAA) of 1979. DoC has statutory authority for implementing EAA, which governs the export of the dual-use items identified in EAR's Commodity Control List (CCL). "Dual use" refers to EAR-controlled items that can be used both in military and other strategic uses and in civil applications and are distinguished from items with weapon and military-related use or design that are subject to DoS control or the Department of Energy's nuclear-related controls. EAR delineates license requirements for dual-use controls and, similar to the ITAR, provides for licensing exemptions. Note that not all items on the CCL require a license for release to all countries, and some commodities not specifically listed on the CCL could require an export license for select end uses and end users.

#### 8.3.1.3 *Foreign Disclosure*

Decisions to disclose classified military information are often tied to security assistance and arms cooperation programs or to the transfer of defense articles; therefore, the National Disclosure Policy (NDP-1) must be in compliance with the provisions of the Arms Export Control Act and the Conventional Arms Transfer Policy. The release of classified military information for all U.S. Government disclosure activities must support U.S. foreign policy and military objectives. The basis for the release or denial of classified military information is twofold: a judgment by designated disclosure authorities that 1) the foreign recipient has the capacity and intent to provide adequate security protection to the information and 2) the national interest (foreign policy or military) will benefit.

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The policy provides for operation by exception. Exceptions to the policy may be decided by the Secretaries of State and Defense, their principal deputies, or the National Disclosure Policy Committee (NDPC). In most instances, the NDPC grants exceptions to policy. After deliberation by the NDPC, disclosure authority is delegated to the heads of departments and agencies responsible for the information within certain security classification limits (e.g., top secret, secret, or confidential) for specified categories of classified military information. Considered in establishing these limits for each country or international organization are the following factors:

- Evaluation of the capability to protect the information based on a favorable NDPC security survey and/or a Central Intelligence Agency assessment of the risk to the information
- Existence of a formal government-to-government security agreement providing for the protection of the information
- Existence of a mutual defense or similar arrangement
- Frequency of disclosure

### 8.3.2 Approval and Disclosure

#### 8.3.2.1 Technology Security

DoD has created 12 technology security review processes. Each process has responsibility for select technologies. For example, these processes include low-observable and counter-low-observable technology, GEOINT, communications security (COMSEC) devices, intelligence data, GPS, data links and waveforms, and night vision devices. Prior to the export (or implied export) of any item or technology controlled by the various technology security processes, the responsible process must be engaged and provide its concurrence with the proposed transfer.

#### 8.3.2.2 Conventional Arms Transfer (CAT) Policy

The CAT policy is the standing Presidential policy guidance on arms transfers.<sup>89</sup> It is intended to promote restraint in the transfer of U.S. weapons systems, while supporting U.S. national security and foreign policy objectives and meeting the legitimate defense requirements of allied and friendly nations. DoS is responsible for articulating this policy and plays a major role in any proposed changes to it. DoS action officers use the CAT policy in case-by-case reviews of proposed transfers to determine whether a particular transfer of military equipment and/or services meets the 12 criteria established by the policy. This list of criteria can be found at <http://www.state.gov/t/pm/rsat/c14023.htm>.

#### 8.3.2.3 Congressional Notifications

Pursuant to Section 36(b) of the Arms Export Control Act, the Executive Branch is required to formally notify the Senate Foreign Relations Committee and the House Foreign Affairs Committee when a potential FMS meets or exceeds specified dollar thresholds. Bureau of Political-Military Affairs Office of Regional Security and Arms Transfer (PM/RSAT) officers

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<sup>89</sup> Presidential Decision Directive 34 (PDD-34), Conventional Arms Transfer Policy, 17 February 1995.

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work with Bureau leadership and DoD to make the required notifications, including briefing Congressional staff on the potential arms sale and how it will serve U.S. interests.

### 8.4 Special UAS-Related Considerations

In addition to the above general constraints, certain considerations are unique to UAS, i.e., they normally do not apply to other unmanned systems.

#### 8.4.1 Missile Technology Control Regime (MTCR)

MTCR is an informal and voluntary association of countries that share the goals of nonproliferation of unmanned delivery systems capable of delivering WMDs and that seek to coordinate national export licensing efforts aimed at preventing WMD proliferation. MTCR rests on adherence to common export policy guidelines that are applied to an integral common list of controlled items. The greatest restraint (i.e., “a strong presumption of denial”) is applied to what are known as “Category I items.” These items include UAS with capabilities exceeding a 300 km/500 kg range/payload threshold, the production facilities for such systems, and any major subsystems.

#### 8.4.2 Armed UAS

DoD and DoS both place a high level of scrutiny on the export of armed UAS. In addition, the U.S. Congress has previously expressed reservations over the release of armed UAS to any but our closest allies.

### 8.5 Reform Efforts

The U.S. Government and DoD have initiated a wide variety of reform efforts that will affect the DoD processes and procedures involved in international cooperation. Although not an exhaustive list, 8.5.1 through 8.5.4 highlight some of the current major reform efforts that will likely affect international cooperation related to unmanned systems.

#### 8.5.1 Security Cooperation Reform

The FY12–16 Defense Planning and Programming Guidance<sup>90</sup> called for establishing a task force to conduct a comprehensive review of DoD’s security cooperation processes. Specific requirements included the development of options for adjusting the operational direction, control, and authority of agencies implementing security assistance; options for aligning and streamlining security assistance and technology transfer processes, organizations, and regulations; a plan to implement a certification curriculum for security cooperation professionals similar to that for the defense acquisition workforce; and a plan to consider authorities, alignment of planning and resources, organizational change, and key processes. After analysis and outreach, the Security Cooperation Reform Task Force (SCRTF) revealed a series of findings and took a two-pronged approach to build an “anticipatory” system with a “fast-track” capability for urgent partner needs.

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<sup>90</sup> FY12–16 Defense Planning and Programming Guidance, para. 6.3, Reform Security Cooperation (U), pg. 30, 20 May 2010.

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SCRTF identified a set of 58 recommendations across five focus areas: planning, FMS process (i.e., contracting, procurement, transportation, and distribution) improvement, accelerated delivery, workforce development (training and education), and technology security and foreign disclosure.

In July 2011, SECDEF directed that the SCRTF recommendations be implemented and that SCRTF — under the direction of the Chairman of the Joint Chiefs of Staff and the USD(Policy) — oversee implementation of the recommendations in the report.

### 8.5.2 Defense Exportability Features (DEF)

The DEF program is intended to ensure that the design and engineering of export variants of U.S. systems are initiated early in the acquisition process to increase the security of sensitive U.S. technology, avoid the high cost of developing an export variant from a fully engineered and implemented U.S. system, and achieve better buying power through the economies of scales realized through increased international procurement. The DEF pilot program was authorized in the FY2011 National Defense Authorization Act. In FY2012, four programs, including a Navy UAS, conducted DEF feasibility studies. These assessments identify the potential benefits and costs of providing protection to critical program information for the export variants in the design.

### 8.5.3 Export Control Reform (ECR) Initiative

In August 2009, the President directed a broad-based interagency review of the U.S. export control system, with the goal of strengthening national security and the competitiveness of key U.S. manufacturing and technology sectors by focusing on current threats and adapting to the changing economic and technological landscape. This review determined that the current export control system is overly complicated, contains too many redundancies, and, in trying to protect too much, diminishes our ability to focus our efforts on the most critical national security priorities. The Administration has determined that fundamental reform of the current system is necessary to overcome the inefficiencies and redundancies of a set of systems within a system.

As a result, the Administration launched the ECR Initiative, which is a common sense approach to overhauling the nation's export control system. The ECR Initiative, which is not related to the President's National Export Initiative, is designed to enhance U.S. national security and strengthen the ability of the United States to counter threats such as the proliferation of WMDs. The purpose of export controls is to ensure that items do not end up in the hands of someone who intends to harm the United States or its allies. It is a risk-based system, where items are generally authorized for export to low-risk destinations, while other items may be allowed to other destinations after closer scrutiny and some items may be denied.

The Administration is implementing the reform in three phases. Phases I and II reconcile various definitions, regulations, and policies for export controls, while building toward Phase III, which will create a single control list, single licensing agency, unified IT system, and enforcement coordination center. This implementation plan is designed to resolve core problems first, before focusing on Government reorganization. The consolidation plan in the final phase would eliminate the need to keep the systems within a system fully synchronized, by eliminating these separate systems. This common sense approach is good government, especially in this era of tightening budgets.

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### 8.5.4 Technology Security and Foreign Disclosure (TS&FD)

The Export Control Reform Task Force Report (issued 29 January 2010) recommended the initiation of an effort “to streamline and harmonize” U.S. Government TS&FD processes. As a result, the Deputy Secretary of Defense tasked USD(AT&L) and USD(Policy) to conduct a review of DoD-led TS&FD processes and provide alternative TS&FD system concepts to enhance transparency, predictability, and timeliness while maintaining the overall high quality of U.S. Government decision making in this key area.

The U.S. Government currently has 13 separate, internal TS&FD processes in which DoD either leads or is a key participant. These processes are generally reactive in nature and do not anticipate building partner nation capacity requirements. Since these processes are neither integrated nor harmonized with each other, the lack of transparency and predictability in the U.S. Government TS&FD decision-making processes makes it difficult to synchronize U.S. Government activities to build partner nation capacity, which includes Washington arena, country team, CCDR, partner nation, and U.S. and foreign industry involvement.

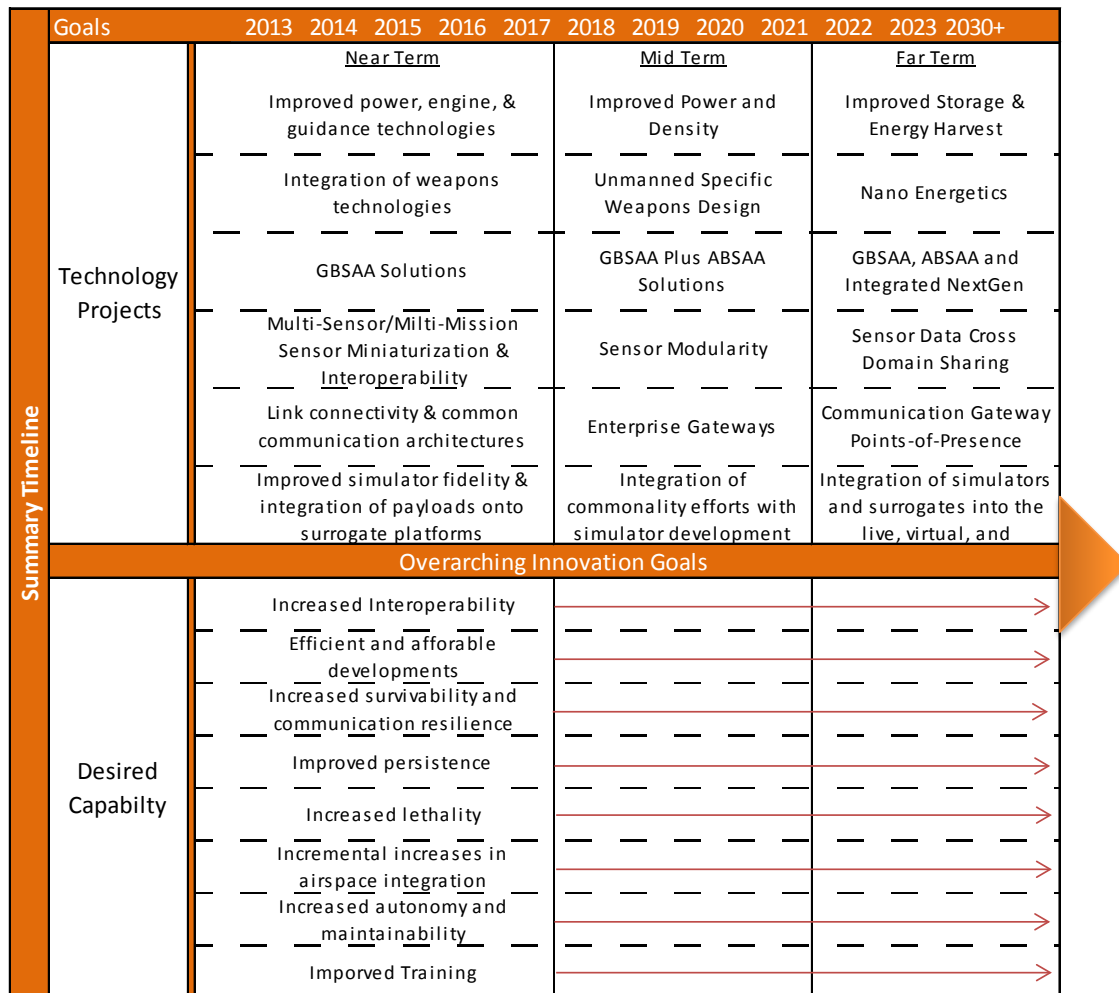
DoD’s current TS&FD activities are focused on three areas:

- Establishing a TS&FD office to serve as the central processing organization of DoD decisions that affect DoD aspects of TS&FD release requests.
- Developing and issuing revised DoD and U.S. Government policy guidance to consolidate and restructure current U.S. Government TS&FD decision-making processes to enhance the quality, timeliness, and efficiency of DoD’s overall TS&FD decision making.
- Implementing overarching improvements in DoD for building partner nation capacity, defense exportability features, industry and partner outreach, and DoD workforce initiatives oriented toward proactive — rather than purely reactive — TS&FD decision making.



## 9 Summary

While DoD unmanned systems development funding may taper off over the early part of this decade, unmanned capabilities hold much promise for domestic commercial applications and personal consumer use. This trend could indeed reduce the price point of these systems for the military, which is good news for the U.S. taxpayer. However, if the technical challenges to unmanned systems development and operations are addressed by accomplishing the technical projects and tasks described in this roadmap, advances in capability can be readily achieved by the Services well beyond what is achievable today. See Figure 40.



**Figure 40. Overarching Innovation Goals Timeline**

As the unmanned industry moves toward more deliberate and traditional program developments, it is imperative these future capabilities be addressed by the Service requirements managers as new programs are initiated. Working together with industry, academia, and other agencies, DoD will continue to map an affordable path using emerging technologies as a basis for future warfighter capabilities.

## **Appendix A      FOUNDATIONAL DOCUMENTS AND REFERENCES**

*Air Force Science & Technology Plan*, Department of the United States Air Force, 2011.

Carter, Ashton B., Under Secretary of Defense, Acquisition, Technology, and Logistics, “Implementation Directive for Better Buying Power — Obtaining Greater Efficiency and Productivity in Defense Spending.”

Carter, Ashton B., Under Secretary of Defense, Acquisition, Technology, and Logistics, “Should-cost and Affordability Memorandum.”

Chairman of the Joint Chiefs of Staff Master Positioning, Navigation and Timing Plan, 13 April 2007.

Committee on National Security Systems (CNSS) Policy (CNSSP) 15.

*Defense Budget Priorities and Choices*, Department of Defense, January 2012.

DoD GPS Security Policy, 4 April 2006.

Eyes of the Army, U.S. Army Unmanned Aircraft Systems Roadmap 2010-2035.

“Fiscal Year 2012 President’s Budget Request (PBR) for the DoD S&T Program,” briefing, Mr. Bob Baker, Deputy Director, Plans & Programs, Assistant Secretary of Defense & Engineering, 21 June 2011.

“FY12–16 Defense Planning and Programming Guidance,” 20 May 2010.

International Telecommunication Union (ITU), *Radio Regulations*, Geneva, Switzerland. 2007 Edition.

*Joint CONOPS for UAS*, Third Edition, November 2011.

*Joint Operational Access Concept (JOAC)*, Department of Defense, 17 January 2012.

Lundberg, Kent H., *High-Speed Analog-to-Digital Converter Survey*, MIT Press, 2002.

*Naval Science and Technology Strategic Plan*, Office of Naval Research, September 2011.

National Telecommunications and Information Administration (NTIA), *Manual of Regulations and Procedures for Federal Radio Frequency Management*, Washington, DC, January 2008 edition, September 2009 revision.

Presidential Decision Directive 34 (PDD-34), Conventional Arms Transfer Policy, 17 February 1995.

“Quadrennial Defense Review Report,” Department of Defense, February 2010.

Report of the Defense Science Board Task Force on Training Superiority & Training Surprise, OUSD(AT&L), Washington, DC, January 2001.

Robotic Collaborative Technology Alliance (RCTA) FY2012 Annual Program Plan.

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Shaud and Lowther, “An Air Force Strategic Vision for 2020–2030,” *Strategic Studies Quarterly*, Spring, 2011.

“Sustaining U.S. Global Leadership: Priorities for 21<sup>st</sup> Century Defense,” Defense Strategic Guidance, January 2012.

“Teal Group Predicts Worldwide UAV Market Will Total \$89 Billion in Its 2012 UAV Market Profile and Forecast,” *Press Release Newswire*, United Business Media, 11 April 2012.

“Terms of Reference-Defense Science Board Study on Technology and Innovation Enablers for Superiority in 2030,” USD(AT&L) Memorandum, 15 March 2012.

*Unmanned ground systems roadmap*, Robotic Systems Joint Program Office, July 2011.

Unmanned Interoperability Initiative (UI2) Capability Based Assessment, 1 March 2012 and 14 May 2012.

Unmanned Systems Integrated Roadmap FY2011-2036.

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**Appendix B      PRIORITY INTEROPERABILITY STANDARDS**

The list of standards below is not all-inclusive; rather the list focuses on priority standards for joint interoperability and UI2 CBA gaps. To be effective, policy and standards require DAE and SAE commitment, oversight, and enforcement prior to approving applicable JCIDS milestones (and DoD architecture framework products), Interoperability Certification and Information Support Plans (ISP). These priorities will be updated during biannual reviews of this Roadmap (or sooner by exception).

- **USIP 1.1 Line of Sight Transmission of Motion Imagery for Battlespace Awareness Using Standard Common Data Link.** Mandated standard available on DISR, 30 November 2010. Interoperability Profiles (IOPs):

IP 1.1: Motion Imagery for Situational Awareness Governing Standards. These standards are the basis for the implementation and take precedence.

- ✓ MISP 5.1, Motion Imagery Standards Profile, December 2008
- ✓ Motion Imagery Standards Board (MISB) Standard 0601.2 UAS Datalink Local Metadata Set, October 2008
- ✓ MISB EG 0902, MISB Minimum Metadata Set, May 2009
- ✓ IETF RFC 0768, User Datagram Protocol, August 1980
- ✓ IETF RFC 0791, Internet Protocol (IPv4), September 1981

**Other Applicable Standards.** These references are cited by the governing standards and provide further specification detail to completely define the implementation.

- ✓ MISB Standard 0807, DoD/I/NSG Motion Imagery Metadata Registry
- ✓ MISB Standard 0604, Time Stamping Compressed Motion Imagery
- ✓ MISB Standard 0102.5, Security Metadata Universal and Local Data Sets for Digital Motion Imagery
- ✓ MISB RP 0603, Common Time Reference for Digital Motion Imagery Using Coordinated Universal Time
- ✓ MISP RP 0903, Video Moving Target Indicator Local Data Set
- ✓ ISO/IEC 13818-1:2007, Information Technology — Generic Coding of Moving Pictures and Associated Audio Information: Systems
- ✓ SMPTE 335M-2001, Metadata Dictionary Structure
- ✓ SMPTE 336M-2007, Data Encoding Protocol Using Key-Length Value
- ✓ SMPTE RP210.10-2007, Metadata Dictionary Registry of Metadata Element Descriptions
- ✓ NGA.STND.0024-2\_1.0, Sensor Independent Complex Data (SICD) for complex SAR imagery
- ✓ NATO STANAG 4676, NATO Intelligence, Surveillance, Reconnaissance Tracking Standard (NITS)—Key enabler for UAS information fusion, currently used to “make sense” of GMTI “dots”
- ✓ NATO STANAG 4607, Ground Moving Target Indication Format (GMTIF)
- ✓ NATO STANAG 4559, NATO Standard Image Library Interface (NSILI)—currently edition 3, the next edition will be XML capable—used to share and expose data between systems

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- ✓ NATO STANAG 3277, Joint ISR Task and Request Data Format—cross-cue and sensor task request implementation
- ✓ Theater Net-centric Geo-location (TNG) Joint Interface Control Document (JICD)—SIGINT interoperability
- ✓ JPEG 2000, Interactive Protocol (JPIP)—useful in large format sensor applications like wide area surveillance sensors
- ✓ SMPTE 296M-2001, 1280 x 720 Progressive Image Sample Structure — Analogue and Digital Representation and Analogue Interface
- ✓ SMPTE 274M-2008, 1920 x 1080 Image Sample Structure, Digital Representation and Digital Timing Reference Sequences for Multiple Picture Rates
- ✓ SMPTE 295M-1997, 1920 x 1080 50-Hz — Scanning and Interface
- ✓ NATO STANAG 4609, AIR (Edition 2) — NATO Digital Motion Imagery Standard
- ✓ AEDP-8 (Edition 2), NATO Motion Imagery (MI) STANAG 4609 (Edition 2) Implementation Guide
- ✓ MIL-STD-2500C, National Imagery Transmission Format (NITF) Version 2.1 for the National Imagery Transmission Format Standard

### IP 2.1: Managed Configuration of STD-CDL Terminals Governing Standards:

- ✓ Specification Number 7681990, Rev H, Performance Specification for the Standard Common Data Link Waveform
- ✓ Specification Number 60038365, Capstone Specification for the Network -Centric Common Data Links
- ✓ NATO STANAG 7085, Interoperable Data Links for Intelligence, Surveillance, and Reconnaissance (ISR) Systems, Edition 3, pending promulgation  
<https://gtg.csd.disa.mil/uam/marketing.jsp>
- **UAS Control Segment (UCS) Architecture Release 3.1**  
<https://ucsarchitecture.org>
- **National Geospatial-Intelligence Agency (NGA) GEOINT Metadata Standards** (OUSD-I Memo 31 AUG 2011) for MIL STD 2500C, MISP and STANAG 4607.
  - ✓ DoD IT Standards and Profile Registry (DISR) Online  
<https://gtg.csd.disa.mil/uam/marketing.jsp>
- **DoD Common Data Link (CDL) Policy** 7 August 2009.
- **Joint Fire Support Executive Steering Committee (JFS ESC) Digitally Aided Close Air Support (DACAS) Engineering Change Proposals (ECPs).** ECP # 8 Unmanned Aircraft System (UAS) Integration as a Strike Platform.  
[https://community.apan.org/joint\\_close\\_air\\_support/jcas/dacas\\_ci\\_usc/default.aspx](https://community.apan.org/joint_close_air_support/jcas/dacas_ci_usc/default.aspx)
- **CJCSI 6212.01F NET READY KEY PERFORMANCE PARAMETER (NR KPP),** 21 March 2012.

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- **NATO STANAG 4586, Standard Interface of the Unmanned Control System (UCS) for NATO UAS Interoperability**
- **DoD Architecture Framework (DoDAF), Version 2.0**  
<http://dodcio.defense.gov/dodaf20.aspx>



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### Appendix C DOD INITIATIVES TO INCREASE INTEROPERABILITY AND MODULARITY

#### UI2 CBA

This CBA is the culmination of a joint WG effort to conduct an operational assessment of unmanned systems interoperability task needs, identify and prioritize gaps in the ability to satisfy these needs, and identify potential DOTMLPF-P priorities to mitigate the identified capability gaps. Each military department and agency will find aspects of the CBA relevant to its mission responsibilities. The I-IPT under the UAS Task Force will continue to work with the military departments and agencies to close gaps identified within the CBA to ultimately improve capability to the warfighter.

The CBA effort derived the 29 prioritized joint UAS interoperability gaps, which are listed below. The complete approved CBA is available on the USD(AT&L) restricted Unmanned Warfare Information Repository website.

- Detect or sense and avoid other airspace users in accordance with NAS standards and tactical requirements for deconfliction and collision avoidance.
- Provide selectable ISR data in joint approved network formats and waveforms.
- Provide ISR, tracking data, and location information in common, discoverable, retrievable, selectable formats to authorized subscribers across domains, including C2 interfaces such as Blue Force Tracker.
- Provide accurate position reporting sufficient for joint common operational picture and joint common air picture applications.
- Provide location information from all sensors for ISR contacts of interest from UAS to authorized subscribers, including the transfer of targets in different domains, e.g., for the transfer of a subsurface maritime contact by a UA. (Authorized subscribers include direct machine-to-machine data exchange.)
- Provide accurate UA position reporting sufficient for safe and effective operation in NAS airspace and theater airspace.
- Enable vehicle/payload control by all authorized joint users with approved control mechanisms.
- Provide UAS sensor point and area of interest location information to authorized subscribers in the specified format.
- Enable multiple authorized controllers (subscribers/requests) to control and transfer control of the vehicle (and/or payloads) and to accept transfer of control between approved control nodes (including when payloads are able to support multiple users simultaneously) (will require the capability to assess and prioritize requests).
- Provide communication gateway and aerial network or network node services compatible with appropriate joint networks.
- For appropriately equipped UAS, provide target designation in accordance with requirements of precision joint munitions (such as JAGM, Hellfire, and small diameter bomb).
- Provide and/or exchange payload and mission information to authorized subscribers in the specified format.

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- Transmit, relay, or retransmit required voice transmissions or sensor data in accordance with joint standards to authorized DoD and non-DoD subscribers.
- Provide fire support functions that are compatible with joint targeting control systems and procedures.
- For both manned and unmanned platforms, provide airborne handoff of missions or services between platforms.
- Enable authorized users to access data archive and retrieval systems.
- Integrate with the unmanned systems environment to C2 sensor fields using other unmanned sensors and platforms.
- Provide and enable joint information operations and information warfare effects including electronic attack, electronic protection, and EW support that is compatible with joint EW attack systems and appropriate requirements for “hardening” against EW threats.
- Deliver lethal or nonlethal effects in accordance with joint TTPs.
- Provide battle damage assessment input data in joint approved formats to authorized subscribers and assessment teams.
- Provide meteorological and oceanographic data in common, discoverable, retrievable format to authorized subscribers.
- Provide chemical, biological, radiological, nuclear, and high-yield explosive data in prescribed format to authorized subscribers.
- Simultaneously control multiple air vehicles of either similar or dissimilar types from a single control station.
- Provide multiple authorized users (GCS or manned aircraft) with the capability to control target designation and weapon launch in accordance with joint TTP.
- Provide nonmilitary data compatible with federal and state agencies in support of a range of disaster, wildfire, and rescue operations.
- Provide platform-operating status by UAS class sufficient to facilitate transfer of control (handover) of the air vehicle or systems within the joint force to facilitate safe operation.
- Provide platform health indicator information to authorized controllers in the specified format.
- Perform launch and recovery under the control of multiple authorized and capable joint users and facilities (terminal phase of operations).
- In situations involving a loss of control link or loss of communications, comply with DoD contingency procedures.

### *Standards and Governance Efforts*

DoD can accomplish unmanned systems interoperability by standardizing critical interfaces within the overall UAS architecture and implementing standard IOPs. DoD must clearly and consistently define the communication protocols, message formats, and implementation methods across these interfaces. The I-IPT will work with DoD partners, the Services, and the Joint Staff to define and enforce the standard IOPs through the USIP WG and the UCS WG for incorporation into the JCIDS processes. This effort will facilitate the mandated acquisition, technology, and logistics lifecycle management efficiencies across current and future UAS programs.

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The OSD defines OA as follows:<sup>91</sup>

A multifaceted strategy providing a framework for developing joint interoperable systems that adapt and exploit open-system design principles and architectures. This framework includes a set of principles, processes, and best practices that:

- ✓ Provide more opportunities for competition and innovation
- ✓ Rapidly field affordable, interoperable systems
- ✓ Minimize total ownership cost
- ✓ Optimize total system performance
- ✓ Yield systems that are easily developed and upgradeable
- ✓ Achieve component software reuse

UCS OA is the business model foundation on which all USIPs and Service IOPs should be based. In some instances, USIPs and/or Service IOPs may be incorporated into the UCS framework; however, the overarching intent is to ensure synchronization and compatibility among UCS, USIP, and Service IOP directives.

### *UCS Architecture*

The UCS Architecture is a framework representing the software-intensive capabilities of current and emerging UAS programs in the Army, Navy, and Air Force inventories. The goal is to develop an architecture based on SOA principles, which will be adopted by each Service as a common business model for acquiring, integrating, and extending the capabilities of the control systems for UAS. Under direction from the USD(AT&L) Acquisition Decision Memorandum (11 February 2009), the UAS Task Force chartered the UCS WG to develop and demonstrate a common, open, and scalable architecture supporting UAS Groups 2–5. The UCS WG comprises Government and industry representatives and operates collaboratively using a technical society model where all participants are encouraged to contribute in any area of interest. In this context, the UCS Architecture supports the following OSD-stated high-level business objectives:

- Acquisition flexibility for control segment subsystems and components
- Cost control
- Innovation at all levels of industry
- Reduced integration time for new capabilities
- Reuse across Service and joint UAS programs where appropriate

Upon completion of UCS Architecture version 2.1, the UCS WG is planning to transition to the Army's Aviation and Missile Research, Development and Engineering Center (AMRDEC) Joint Technology Center/Systems Integration Lab (JSIL) at Redstone Arsenal for enduring governance, oversight, management, and custodianship of the UCS business model, interfaces, web repository, and future revisions to the UCS Architecture and/or interfaces. JSIL will establish the UCS Steering Committee (SC) and continue to support OSD and the service acquisition portfolio managers. JSIL will stay synced with USIPs, ICWGs, and IOPs and will be the Government lead for both the UCS SC and USIP SC. In this capacity, JSIL will act as an

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<sup>91</sup> Terms and Definitions, Defense Acquisition University: <https://acc.dau.mil/CommunityBrowser.aspx?id=22108>.

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unbiased third party to routinely advise OSD, the Joint Staff, and Service acquisition executives on all UCS issues.

The restricted website is <https://fusion.dynetics.com/project/UCSWG>. To request access, visit the I-IPT public website (<http://ucsarchitecture.org>), and follow the instructions for requesting access to the restricted website.

### *Unmanned Systems Interoperability Profiles (USIPs)*

USIPs are the implementation of the mandate by the Deputy Secretary of Defense's "Unmanned Aircraft System (UAS) Memorandum 14667-07" (13 September 2007) to develop standard IOPs linked to JCIDS documents. They help drive the implementation of approved DoD and/or joint interoperability priorities at the Service level and may even require a new Service IOP or revision to an existing IOP.

USIPs also support the CJCSI interoperability requirement by creating specific points of "capability-based interoperability." The purpose of a USIP is to define profiles of standards sufficient to guarantee interoperability in support of a specific mission capability. A USIP may reference DoD standards, Intelligence Community standards, Service-specific IOPs, and commercial standards to achieve capability-based interoperability. All approved USIP standards can be found on DISR.

The USIP WG is currently run by the JSIL and comprises Government and industry representatives in the same enduring governance, oversight, and management role as the UCS SC. This new USIP SC will form an advisory group that is responsible to the UAS Task Force and serves in an unbiased, coordinating role for all UAS Task Force IPTs involved in USIP development, implementation, and initiation. The USIP SC shall coordinate staffing and approval of proposed USIPs with the UAS Task Force, JROC, and JCA functional capabilities boards as required. The USIP SC will remain engaged with the Service ICWG/IOP processes to ensure synchronization and foster the vertical and horizontal cooperation essential to joint interoperability.

The intent of the USIP development and management process is to leverage existing processes within both the DoD acquisition management system and the JCIDS process to develop more capable and interoperable unmanned systems.

- USIP 1 (LOS FMV), approved, in DISR release 11-1.
- USIP 2 (BLOS FMV), to be submitted for DISR release 12-1.
- USIP 3 (Bandwidth Efficient LOS), on hold pending BE-CDL Rev B outcome.
- USIP 4 (Video Control Interface for Region of Interest Delivery), in progress. This effort relates to wide area sensors.
- USIP 5 (Weaponization), in progress.

The restricted website is <https://software.forge.mil/sf/go/proj1887>. To request access, visit the I-IPT public website ([https://software.forge.mil/sf/projects/usip\\_universal\\_systems\\_interoper](https://software.forge.mil/sf/projects/usip_universal_systems_interoper)), and follow the instructions for requesting access to the restricted website.

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### *Service Interface Control Working Groups (ICWGs)*

The intent of a Service-level ICWG is to ensure that UAS program and product managers, developers, Services, and end users actively participate in the development and implementation of Service-specific interoperability solutions. This collaborative organization (Government-industry partnerships) serves as the standards recommendation body chartered within each Service to promote interoperability across various product lines.

The ICWG is a technical “engineering-level” body focused on identifying interoperability solutions for the respective Service’s UAS FoS. These select requirements and implementation strategies are published within a set of IOPs and are for use by developers and implementers of new (and potential) UAS and related capabilities. IOP implementation across UAS products facilitates diverse levels of interoperability and is intended to provide the end user with an increased payload utility, a reduced tactical footprint, and an expanded unmanned aircraft platform availability.

The Services as a whole have made significant progress in establishing these ICWGs for unmanned systems for the end-to-end management of interface control. Each Service’s ICWG has an independent process for IOP development and configuration control. To ensure horizontal and vertical integration, each Service’s ICWG staff is represented within the other’s ICWG consortia unmanned systems, including the I-IPT, UCS WG, and USIP WG. Members from both the UCS SC and USIP SC are also represented. The Army established the ICWG process within PEO Aviation’s UAS project office. The Navy recently followed suit and is actively working to establish its program under PEO Unmanned Warfare. The Air Force is in the process of vetting approval for the same for unmanned systems and organizations.

In coordination with the USIP SC and UCS SC, ICWGs are ideal bodies to nominate and/or implement USIPs either as a bottom-up nomination or a top-down implementation directive from OSD/Joint Staff. It is envisioned that applicable Service IOPs may be candidates for DoD/joint implementation through the USIP nomination process. Conversely, USIPs and/or UCS Architecture requirements may drive the development of new Service IOPs or modification of existing IOPs. In either case, the overarching intent is to avoid duplicative or conflicting Service IOPs.

### *Service IOPs*

Historically, unmanned systems have used very deterministic point-to-point interfaces; however, provisions of network-centric warfare require UAS programs to implement common standards in support of an FoS type of architecture. Widely accepted or approved standards are often too broadly defined and inadvertently allow compliance but not necessarily interoperability (e.g., CDL standards and MISB standards). Interface “standards” vary and allow for diverse implementation strategies and interpretations. To be truly interoperable, an FoS requires the Service-level development of IOPs.

IOPs provide implementation guidance, best common practices, and profiles of standards to help ensure interoperable systems within a Service. IOPs are tightly coupled to program offices and industry partners because each sponsoring entity (e.g., program, industry partner) typically signs off on the IOP. Service system integration laboratories test against their IOPs to

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ensure program compliance. IOPs perform a similar function to USIPs but typically have a broader scope. A single IOP may touch on several interrelated capabilities and their associated standards, profiles, practices, etc. IOPs that have support across multiple Services are good candidates for nomination as new bottom-up USIPs.

IOPs are managed by their respective Services and are developed through a collaborative process of various product offices and private industry partnerships. Within IOPs and related publications, each Service attempts to set and enforce only the standards critical to respective UAS interoperability. This approach provides the level of commonality required for interoperation while minimizing the impact on the native capabilities and design for each platform. IOPs contain interface requirements specific to interoperation capability within the various UAS. Additionally, IOP-related products (such as associated performance specifications, implementation guides, and interface control documents) support IOP implementation strategies, provide clarity of intent, and promote the use of emerging technologies expected for future standardization. In Service-specific cases, IOPs may be posted on DISR depending on the nature and approved enforcement or testing mechanisms.

### *Joint Interoperability Test Command (JITC)*

JITC is an organizational element of the DISA Test & Evaluation Directorate and has DoDI 4630 responsibility for certifying joint and combined interoperability of all DoD IT and NSS. JITC follows the processes outlined in DoDI 4630, the DoD CIO Interim Guidance Memorandum, and the JITC Interoperability Process Guide (10 September 2012) to perform joint interoperability testing and certification. It works closely with the Services, Joint Staff, OSD, and DoD CIO to provide recommendations to the Interoperability Steering Group for waivers, extensions, and ultimately full interoperability certification and compliance status reporting to DAEs and SAEs. OSD and JITC are committed to testing reciprocity agreements with the various joint and Service testing facilities to encourage compliance testing earlier in the acquisition and product development process and to support the USIP SC, UCS SC, and ICWGs.

The restricted website (DKO) is available on the public website: (<http://jitic.fhu.disa.mil/index.html>).

### *Joint Technology Center/Systems Integration Laboratory (JSIL)*

JSIL supports the assessment of system integration readiness during the product development process, prior to actual flight testing. JSIL provides for distributed hardware-in-the-loop testing of payloads, air vehicles, ground system components, and joint interfaces using MUSE in globally distributed command exercises and experiments. The purpose of JSIL is to provide simulation, integration, and a full range of test support to the joint UAS family.

More recently, JSIL was resourced in a program decision memorandum to support OSD, the UAS Task Force, and I-IPT plan of action and milestones. As the UCS WG and USIP WG transition to an enduring role, JSIL will continue to lead the UCS SC and USIP SC in direct support to OSD's acquisition oversight roles for establishing, maintaining, and reporting USIP/UCS implementation and compliance.



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The restricted website is provides more information. To request access, visit the I-IPT public website ([https://software.forge.mil/sf/projects/usip\\_universal\\_systems\\_interoper](https://software.forge.mil/sf/projects/usip_universal_systems_interoper)), and follow the instructions for requesting access to the restricted website.

### *DoD IT Standards and Profile Registry (DISR)*

DISR is an online repository of DoD IT and NSS standards and related information, formerly captured in JTA, version 6.0. DISR replaces JTA. All approved USIPs are submitted to DISR.

In addition to the definition of common capability descriptions, standards, data models, and architectures, DoD, through OSD, continues to promote the development of OA tools and implementations to aid system acquisition and development in embracing the OA concepts. These efforts extend across the technology and unmanned vehicle spectrum, from software development kits, to complete architectures, addressing UGS, UMS, and UAS, across the Services. Examples of such tools include the following ongoing efforts on the ground, in maritime spaces, and in airspaces:

1. The JAUS Tool Set (JTS) is a tool to help developers build JAUS-compliant software components without having to be intimately familiar with the details of JAUS. JTS allows an unmanned systems designer to focus on behavior, rather than on messaging, protocol, and other considerations, by providing a graphical user interface service editor, validator, internal repository, C++ code generation, and Hypertext Markup Language (HTML) document generation.

The Navy and OSD have supported and promoted the use of JTS and have had success incorporating it into development and acquisition efforts. Use of JTS on programs accrues benefits to a number of stakeholders in the acquisition chain and research and development and T&E communities. These benefits include enabling a fair basis for competition among vendors so that true capabilities are evaluated, reducing vendor lock-in on unmanned systems, and enabling the development of a “service repository” for JAUS capabilities that have been developed and are available for reuse. JTS reduces the threshold for entry into developing JAUS-compliant systems, opens the market to small businesses, and drives competition and innovation focused on core technology. In addition, JTS provides an accepted, common validation capability, which is critical to ensure systems maintain compliance with JAUS.

2. The NATO STANAG 4586<sup>92</sup> Compliance Toolkit (4586CT) is an integrated set of software tools that provides passive, interactive, and automated test capability. Its core function is to verify the structure and content of data link interface (DLI) messages against both NATO STANAG 4586 and “private” messages as defined to support service-, mission-, or platform-specific requirements. This nonintrusive capability is provided either in real time or during post-run analysis. Additionally, 4586CT can be interoperable with other DLI-compatible systems in either manual mode (where an engineer monitors and injects DLI messages into the network) or automated mode (in

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<sup>92</sup> NATO STANAG 4586, Standard Interface of the Unmanned Control System (UCS) for NATO UAS Interoperability.

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which 4586CT interacts directly with other DLI systems according to user-defined scripts and procedures).

These capabilities enable 4586CT to perform compliance testing of unmanned systems relative to NATO STANAG 4586 and other, more specific IOPs, at both the message level and the higher level protocol session levels. Complex DLI message dialogs can be monitored and system interaction sequencing verified as 4586CT follows user-defined test programs. As 4586CT can function as a proxy for other unmanned system components, it is also used during system development and task-specific integration testing and can provide insight into unmanned systems interaction and performance. Multiple instances of 4586CT can also be employed to perform rapid prototyping of interoperation protocols during profile design; as a result, 4586CT can be a useful tool during the development of interoperability standards themselves.

### *Future Airborne Capability Environment (FACE)*

**Near Term.** The Army COE is an approved set of computing technologies and standards that enable secure and interoperable applications to be rapidly developed and executed across a variety of computing environments. Within the COE initiative, FACE is Army Aviation's implementation. The objective of FACE is to establish a standard COE to support portable, capability-based applications across DoD avionics systems.

FACE will reduce lifecycle costs and time to field, obtain industry and DoD program management endorsement, and facilitate conformance with standards to maximize interoperability between applications within the avionics system. The environment builds on OAs, integrated modular avionics, and a modular open systems approach (MOSA) and is designed to be portable, modular, partitioned, scalable, extended, and secure. By expanding on the MOSA and OA principles, FACE uses abstraction layers at key interfaces to diminish the need for new standards. The FACE technical strategy is to create a software environment on the installed computing hardware of DoD aircraft that enables FACE applications to be deployed on different platforms with minimal to no impact to the FACE application.

### *SPIES Initiative*

**Near Term.** The goal of the SPIES initiative is to develop EO/IR sensor-platform interface standards that enable reduced acquisition, integration, and lifecycle costs; improve agility; promote OA and interoperability objectives via Navy/DoD standardization; and maintain system performance, reliability, maintenance, and availability.

SPIES will also work to enable a methodology and process for maintaining and revising the standards and adding new standards, as required. By following the computer peripheral model, the intent is for all devices and components to operate over standard buses and use standard connectors and basic database protocols. With SPIES, the expected total ownership cost savings is expected to be around 25%, with additional benefits, including reduced integration risk.

### *IOPs Defined for UGS*

As payloads, sensors, software, and computing devices are anticipated to evolve much faster than base platforms, creating interoperable interfaces for enhanced modularity represents

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an opportunity to minimize future lifecycle costs and adapt rapidly to changing threats or new available technologies. The RS-JPO I-IPT, formed in 2009, is working to establish, adopt, and apply interoperability standards for UGS by working with the combat developers, the S&T community, and private industry. The effort is focused around utilization of the SAE AS-4 standard for JAUS with the implementation guidance being defined by the UGS IOP.

**Near Term: IOP V0.** In December 2011, the IOP v0 development process and content were presented to a joint executive board, consisting of Government leaders from the material developer, combat developer, and S&T communities. The joint executive board voted unanimously to approve and publish IOP V0. The IOP enables tailoring based on the use of interoperability attributes. Not every interoperability requirement will apply to every future system; therefore, the IOP provides a mechanism to independently specify these requirements in a composable manner. Interoperability attributes applicable to the specification and design of a system can be identified and used to filter applicable requirements from the IOP to support system design, development, conformance, and validation testing, IOT&E, and fielding. This approach shrinks the “design space” of future UGS interfaces from infinite to a small number of options. RS-JPO will require the use of IOPs in future requests for proposals for PORs. For industry, this interoperability approach means that companies with business models that favor closed-architecture products will ultimately either lose market share or need to adapt their business strategies. In the near term, the core interoperability team within RS-JPO and the Tank and Automotive Research, Development, and Engineering Center will be defining program- and system-specific instantiations of IOPs. Program-specific IOP instantiations will become part of future IOPs, and system-specific instantiations of IOPs will be used to determine whether there is any supporting business case to upgrade existing fielded systems to be fully or partially IOP compliant.

**Middle Term: IOP V1.** In addition to the capabilities already resident in widely fielded systems, IOP V1 will include interfaces for unmanned applique kits, explosive detection and marking payloads, modular controller interfaces, and a basic interface with SUAS assets. In IOP V1, the focus will be on increasing the interoperability with other domains, such as overarching networks, UAS, and manned systems.

**Long Term.** Future UGS are anticipated to interface with tactical and enterprise networks, such as GIG. The Army has defined a strategy for realizing a COE network into which UGS are anticipated to eventually interface. While achieving this interface would entail significant acquisition challenges in terms of information assurance planning, this interface would provide great opportunities for increasing the capabilities of UGS for warfighters. For example, a warfighter equipped with a COE-connected mobile device could search for software applications that are needed to conduct the mission, including UGS video feed and sensor-control applications. In addition, geospatial models and other data structures available in the COE could significantly enable UGVs to navigate autonomously. Autonomous operations could reduce the amount of computing power necessary on platforms and controllers and may reduce the wireless communication bandwidth required in UGS radios.

DoD will also increase coordination between ground and air domains. Although UAS and UGS are based on different standards (NATO STANAG 4586 for large UAS and SAE AS-4 (JAUS) for UGS), it is feasible for future systems to use an inward (ground) facing SAE AS-4 protocol and an outward (air) facing NATO STANAG protocol to interoperate. In addition, as

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UGS become more accepted and embedded in the force structure, interoperability with manned ground systems will be necessary. It is anticipated that the vehicular integration for C4, ISR, and EW interoperability (VICTORY) standard will provide the interoperable interfaces for communicating with manned ground systems. As a result, RS-JPO's interoperability profiles must eventually define the protocols for interfacing with VICTORY-based systems.

### *AEODRS Common Architecture*

Currently, fielded EOD robotic systems are modified commercial products with different OCU, limited autonomy, different architectures and designs, and company proprietary software. AEODRS is being executed by the Naval Explosive Ordnance Disposal Technology Division via the Navy Program Office for Explosive Ordnance Disposal (PMS 408) to provide joint forces with an improved and modular EOD capability to respond to unexploded ordnance, counter-improvised explosive devices, and WMD missions. AEODRS comprises three system variants, utilizing Government-owned common system architecture and interfaces, which will be fielded in an incremental approach. The common architecture is present at the physical, electrical, and logical interface levels for the UGS FoS to enable modular plug-and-play components and interoperability.

**Near Term: Intraplatform Modularity.** AEODRS Increment 1 is partitioned into nine separate capability modules (CMs) designed to function as standalone components across the variant platforms in the family of vehicles. Each CM is task and function specific and is designed to perform specific functions within the overarching system. Because major interfaces are defined and available to CM and subsystem competitors, the OA model aims to promote future technology infusion in a truly competitive environment. Increment 1 is broken down into three major subsystems including the OCU, the UGV, and the communication link. CMs within the UGV include CM-MOB (mobility), CM-PWR (power), CM-MAS (master), CM-MAN (manipulator), CM-VIS (vision), CM-EEF (end effector), and CM-AB (autonomous behaviors).

**Middle Term: Interplatform Modularity/Interoperability.** The AEODRS program consists of an FoS including three system variants that will be fielded in an incremental approach. Increment 1 (dismounted operations) will be fielded first, followed by Increment 2 (tactical operations) and Increment 3 (base/infrastructure operations). Use of common architectures and task- and function-specific capability modules will enable use of modules, software, and OCUs across platforms for all three system variants. The OA throughout the FoS allows interoperability between platforms through Government-defined and -controlled electrical, physical, and logical interfaces, in addition to the commonality of the OCU. In addition, the FoS is characterized by interchangeable modules that can be integrated in plug-and-play fashion without proprietary issues for each subsystem.

### *Interface Standards and IOPs*

DoD has long recognized the value in fostering collaboration among Government, industry, and academia in open unmanned systems to address interoperability and common standards. To that end, a number of IPTs, WGs, and other communities have formed to address the interoperability challenge. These forums for unmanned systems have enabled the Government to engage with industry at all levels to aid in the systems and architecture design process, rather than just be customers. These collaborating communities exist within a variety of

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national and international standards bodies, span the domains of unmanned systems (air/ground/maritime), and address key cross-domain areas as well as domain-unique capabilities. DoD intends to continue to support this type of collaboration as it fosters the development of interoperability and standards WGs. Examples include the following:

- NATO Joint Capability Group Unmanned Aerial Vehicle (JCGUAV) is engaged in interoperability efforts in unmanned aviation. JCGUAV subsumed NATO's three military department UAS-related groups (i.e., PG-35, Air Group 7, and Task Group 2) in 2006. Its major accomplishments to date include NATO STANAG 4586 for UAS message formats and data protocols, NATO STANAG 4660 for interoperable C2 links, NATO STANAG 4670 for designated UAS operators training, and NATO STANAG 4671 for UAS airworthiness, and NATO STANAG 7085 for the CDL communication system, which has been mandated by OSD since 1991.<sup>93</sup>
- Current USIPs produced by the I-IPT define the standard interface for payload products and the data link between a control station and air vehicle for LOS and BLOS scenarios. Future USIPs will address other aspects of interoperability, including data encryption, different data link technologies such as BE-CDL, and enhanced capabilities provided by future sensors.
- JAUS began in 1995 as an effort by the Army's program office for UGS in the Aviation and Missile Research, Development and Engineering Center (AMRDEC) at Redstone Arsenal to establish a common set of message formats and data protocols for UGS made by various manufacturers. Deciding to convert JAUS to an international industry standard, the program office approached the SAE, a standards development organization (SDO) with robotics experience, which established the AS-4 Unmanned Systems Committee in August 2004. The AS-4 committee has three subcommittees focused on requirements, capabilities, and interfaces and an experimental task group to test its recommended formats and protocols before formally implementing them. The migration to the SAE has been completed, and the first set of SAE JAUS standards, focusing on the JAUS Service Interface Definition Language, core services, mobility services, manipulation services, and environmental sensing services, has been balloted and released. Although AS-4 committee members may create standards on other aspects of unmanned systems beyond message formats and data protocols for UGS, much of this broader work is now being undertaken by other UAS-related SDOs. NATO STANAG 4586 is unmanned aviation's counterpart to JAUS.

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<sup>93</sup> NATO STANAG 4660, Standard for UAV Interoperable Command and Control Data Link (IC2DL); NATO STANAG 4670, Recommended Guidance for the Training of Designated Unmanned Aerial Vehicle Operators; NATO STANAG 4671, Unmanned Aerial Vehicle Systems Airworthiness Requirements; and NATO STANAG 7085, Interoperable Data Links for Intelligence, Surveillance, and Reconnaissance (ISR) Systems, Edition 3, pending promulgation.

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### Appendix D UNMANNED SYSTEMS T&E CAPABILITIES CURRENT STATUS

#### *Unmanned Aircraft Systems*

UAS T&E activities are heavily leveraging existing manned air systems T&E capabilities to test unmanned systems. Capabilities are being added to address differences for T&E of unmanned systems for primarily Level 1 autonomy systems (e.g., JUAS–Mission Environment). The C2 of today’s UAS is located both on the surface (land and water) and in manned aircraft. For example, the Army recently demonstrated control of a UAS from an Apache helicopter. Today, the air vehicle decision solutions are made with deterministic algorithms. As autonomy levels increase, for example, Autonomous Aerial Cargo Utility System (AACUS) Innovative Naval Prototype (Ref 3), the systems will incorporate an ever-increasing number of nondeterministic algorithms in the UAS. T&E of how and why decisions are reached by these algorithms is a challenge that requires new improved processes and resources. As UAS embody more Level 2 to Level 4 autonomy capabilities in the future, improved tools will be needed for efficiently and effectively testing these higher levels of autonomy.<sup>94</sup>

#### *Unmanned Ground Systems*

UGS T&E capabilities across the Services are primarily derived from manned vehicle test capabilities. These capabilities are environment and terrain specific and were successfully used in the past to verify the safety, performance, and effectiveness of early UGS, which were controlled remotely, teleoperated, or possessed very low levels of supervised autonomy. The sensing and perception capabilities of autonomous systems are increasing rapidly, and obstacles on the terrain are equal, if not more important, to safety, performance, and effectiveness as actual terrain types and geometries.

The challenges facing the operational test community will involve the safe use of UGS integrated with warfighters and manned systems during events as well as the ability to assess mission effectiveness based on a finite number of possible physical scenarios that can be efficiently construed. Warfighters are on the ground or mounted in formation with these vehicles. Before placing these systems in the presence of the warfighter, safety and performance must be proven under controlled conditions.

To date, traditional evaluations have yet to be performed with UGS. Evaluations of currently fielded systems have been based on documenting, verifying, and assessing system safety and performance capabilities, unlike traditional evaluations, which correlate a capability to a system or mission requirement. Existing evaluation techniques based on manned systems fail to adequately assess sensing, perception, and intelligent control.

It is imperative to test UGS to verify they are safe to operate among dismounted personnel and other moving vehicles. Each Service, as well as several public and private entities, offers some degree of T&E capability required to prove the safety, suitability, and effectiveness

<sup>94</sup> For a description of autonomy levels, see table 3 on page 46 of the Unmanned Systems Integrated Roadmap FY2011-2036: <http://www.acq.osd.mil/sts/docs/Unmanned%20Systems%20Integrated%20Roadmap%20FY2011-2036.pdf>.



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of future UGS. Existing ranges and test facilities have been adequate to test systems with very limited autonomous capabilities and systems operated through teleoperation.

### *Unmanned Marine Systems*

Existing ranges are limited to support the testing of UMS in a fully autonomous mode. Long-endurance mission profiles and limited tracking coverage restrict the test envelope for comprehensive autonomous testing behavior.

UUV test capabilities remain largely centered on underwater T&E ranges familiar with weapon systems that have attributes in common with a number of UUVs. Many UUV T&E requirements can be accomplished on these traditional underwater tracking ranges, which provide accurate track, simulation/stimulation, and acoustic acquisition and some of the required bathymetry. Many of the ranges offer additional operational areas with challenging bathymetry and environmental conditions, which help meet the T&E needs for UUV missions.

Advances in power systems and autonomy and the need for extended missions of up to a month at a time are stretching the ability of current underwater tracking ranges. Extended power capabilities and a high degree of autonomy allow newer UUVs to operate over extended areas and increase the risk of loss of these very high value, one-of-a-kind, assets. The ability to maintain track or provide areas with low risk of surface and underwater target (SUT) loss is important in these future T&E events.

The ability to safely launch and recover UUVs as SUTs presents challenges for T&E. The Navy does not have submarine platforms dedicated to T&E, and the introduction of developmental systems into the operational platform is a daunting process. This situation, coupled with limited at-sea time, challenges the comprehensive testing evolutions to demonstrate the suitability of the integrated host/UUV platform to the mission.

## Appendix E      MANNED UNMANNED TEAMING (MUM-T) AND MUSIC

### *Manned-Unmanned Teaming (MUM-T)*

The concept of MUM-T is to combine the inherent strengths of manned platforms with the strengths of UAS, with product synergy not seen in single platforms. MUM-T combines robotics, sensors, manned/unmanned vehicles, and dismounted soldiers to achieve enhanced situational awareness, greater lethality, improved survivability, and sustainment. Properly designed, MUM-T extends sensor coverage in time and space and provides additional capability to acquire and engage targets.

The pilot can use the sensor on the UAS, just as a sensor would be used aboard an aircraft, except that the position of the UAS sensor can be up to 80 km ahead from the aircraft. The MUM-T capability provides an unprecedented standoff range from threat weapons and acquisition systems. MUM systems largely depend on mission, enemy, terrain, troops, time, and civil considerations. The transfer of sensor data between the UAS and the manned system reduces risk to both platforms and increases the mission effectiveness and survivability rates of friendly forces. Environmental conditions affect the efficiency of MUM-T employment.

### *Manned Unmanned Systems Integration Capability (MUSIC) Exercise*

Interoperability has been a top objective of the Army and the UAS project office for years. Interoperability greatly increases efficiency in Army systems through common interfaces and shared assets. Development, integration, and testing of interoperability standards into UAS universal products, such as the universal GCS and the universal ground data terminal, are top objectives of the UAS project office in the near term. In an effort to streamline and coordinate interoperability initiatives across products, the UAS project office, under oversight of PEO Aviation, hosted its first MUSIC exercise in September 2011 with plans to continue conducting exercises every two years or as needed.

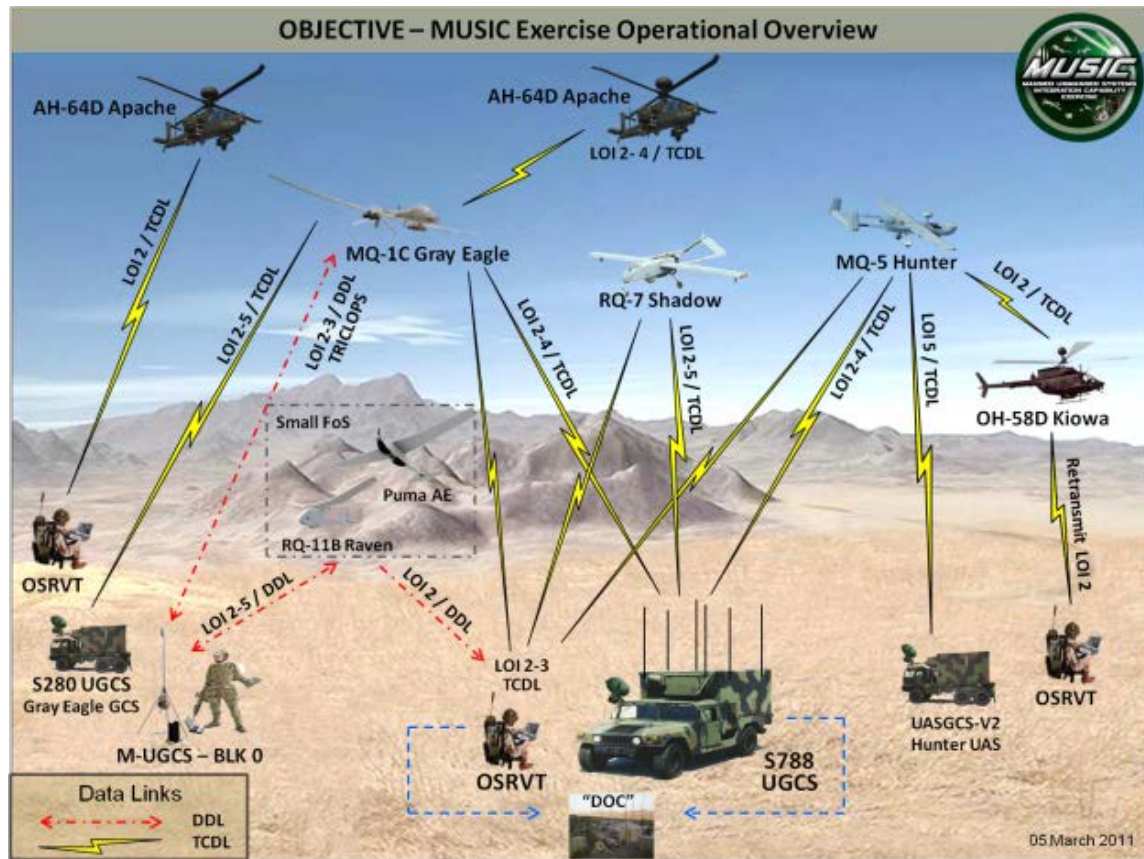
The MUSIC exercises showcase to the soldier and Army community the progress being made in unmanned interoperability and emerging technologies through common interfaces. Exercises also act as a strategic planning tool by driving integration and test of the various platforms to a common hardware and software baseline.

#### *MUSIC I Exercise*

**Overview.** The objective for the MUSIC I Exercise was to showcase interoperability progress and emerging technologies in accordance with the 2.x series of the Army UAS IOPs. The exercise took place in Dugway Proving Grounds, Utah, at the UAS Rapid Integration & Acceptance Center on 16 September 2011. Weeks of pre-ground and -flight checks culminated into a live two-hour demonstration to a group of media, contractors, and Army officials. The audience witnessed real-time video feeds from the unmanned and manned payloads, screen captures from the GCSs, video feeds from within the shelter, and visual aids through an operational scenario to help demonstrate the capabilities and achieve a better understanding of how they benefit the soldier. Successful execution of the MUSIC exercise provided the product office with a wide range of lessons learned across multiple areas, including system usability, reliability, integration, and configuration control.

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**Capabilities.** MUSIC I showcased four main capabilities as outlined in Figure 41 and Table 2.



**Figure 41. MUSIC I Operational View (OV-1)**

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Table 2. MUSIC I Capabilities and Use Cases

Capability	Description	Use Case
Universal Ground Control Station (UGCS)	A single ground control station with common hardware and software for each of the large AV, Gray Eagle, Shadow, and Hunter with the ability to consecutively control each of the large aircraft through an IOP compliant exclusive control handover sequence	Shadow UGCS control of a Gray Eagle AV via a class B handover from a Gray Eagle native GCS
		Shadow UGCS control of a Hunter AV via a class B handover from a Hunter native GCS
		Shadow UGCS control of a Shadow AV
Bi-Directional One System Remote Video Terminal (OSRVT)	A Bi-directional capability that allows the OSRVT operator the ability to control the payloads on the large UAVs under supervised through an IOP compliant handover sequence	OSRVT control of the Gray Eagle Payload
		OSRVT control of the Shadow Payload
		OSRVT control of the Hunter Payload
Manned-Unmanned Teaming (MUM-T)	The ability to partner with Army Aviation manned platforms through the sharing of video.	Kiowa Warrior retrans through the Hunter AV to extend the range to the OSRVT operator on the ground
		Apache BLK II receipt of UAS video in Apache cockpit
		OSRVT receipt of Apache BLK II payload video
		OSRVT receipt of Kiowa Warrior payload video
Mini-Universal Ground Control Station/TRICLOPS	A common controller for the Small UAS, Raven and Puma, via the Digital Data Link as well a control of Gray Eagle TRICLOPS payloads. TRICLOPS payloads are two additional payloads on the wings of the Gray Eagle that can be accessed independently from the main payload by M-UGCS operators on the ground.	M-UGCS control of Raven
		M-UGCS control of Puma
		M-UGCS control of Gray Eagle TRICLOPS payloads

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### Appendix F CASE STUDY MQ-9 REAPER

#### *Need to Transition from CLS to Long-Term Organic Capability*

The MQ-9 Reaper program began as a quick reaction capability program in October 2001. Due to the urgency to deliver the system to the field, much of the sustainment planning was skipped. The program manager determined a CLS sustainment strategy for the life of the program. After a review, based on the statutory requirements of 10 USC 2464, the Commander, Air Force Materiel Command, determined that core capability requirements were applicable to the MQ-9 and issued a core depot decision memorandum (6 August 2008). The MQ-9 program was directed to transition into the organic depot-maintenance support.

The Reaper program also relied on CLS for field-level support because of the speed with which it was fielded. As the projected number of deployed capabilities increased, this sustainment strategy proved unaffordable. The Air Force needed to transition to military maintainers. Since the program was erroneously designated CLS for life, the program manager had not developed a data strategy or established the Government's requirements and rights for technical data. The MQ-9 was dependent on OEMs for sustaining engineering support and supply support. Initial funding estimates for data and equipment to accomplish the transformation to organic depot were also not affordable in the Air Force budget.

#### *Initial Reliability Requirements Not Met*

Typical of many programs that have been rapidly developed and deployed, the reliability requirements of the Reaper system were initially not well understood or developed. The primary reliability metric being measured and tracked was mean time between critical failure (MTBCF) as documented in the CPD of August 2006. This metric received a deferment from the Air Force Requirements Oversight Council after the 2008 IOT&E report noted the original MTBCF values were not achievable based on system performance. Additionally, because of the lack of redundant systems, all failures were interpreted as "critical failures." In 2011 it was recognized that deferring the achievement of the reliability goal until a future block upgrade would not be sufficient. The Air Force needed to reevaluate the requirement against test and operational data to determine a realistic reliability goal and then establish a reliability growth program to ensure that the system could continue to meet the goal.

#### *Sustainment Transformation*

Since 2009, the program office has been executing a strategy to transform the sustainment of the Reaper program to focus on long-term affordability. The transformation planning by the program office culminated in the development of a lifecycle sustainment plan that details the results of the program's planning efforts and documents the overall framework for optimal sustainment of the MQ-9 system throughout its life cycle at minimum lifecycle cost. The plan emphasizes the following major elements: requirements stability and reliability growth, depot transition, data strategy, and business case analysis (BCA).

#### *Requirements Stability/Reliability Growth*

The program established a Joint Reliability Maintainability Evaluation Team in 2012. The team reviewed field failure data and made recommendations to the warfighter community



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for new Threshold and Objective MTBCF values. The MQ-9 reliability and maintainability growth program has been established to manage the growth of reliability with an emphasis on identifying reliability readiness and cost drivers that have a substantial return on investment to the warfighter.

### *Depot Transition*

10 USC 2464 (a)(3)(B) states the requirement, “Core depot-level maintenance and repair capabilities and capacity, including the facilities, equipment, associated logistics capabilities, technical data, and trained personnel, shall be established not later than four years after a weapon system or item of military equipment achieves initial operational capability or is fielded in support of operations.”<sup>95</sup> In December 2009, the program established the Depot Maintenance Actions Working Group (DMAWG) to stand up organic repair. A three-phased approach was established to target the major repair and cost drivers:

- The first phase, Early Induction, identified items with low activation risk and includes the MQ-9 EO/IR sensors and a selection of items from the aircraft, engine, and communication equipment. The initial induction program will stand up in FY2013.
- The second phase will expand the initial partnership to cover items that generate 80% of the repair costs and will be put in place between 2014 and 2015, seven years after core was first determined to be applicable.
- The final phase will include more than 500 components with low repair rates.

Throughout the DMAWG process, the program is working with the Army Gray Eagle program to identify opportunities for leveraging similar efforts. The programs are working together to establish sensor capability with the Navy’s Fleet Repair Center South East in Jacksonville, Florida.

### *Data Strategy*

PPPs between OEMs and depots is one method to assure that the Government will have access to repair data without requiring a procurement or re-procurement data package. In addition to pursuing these partnerships, the Reaper program office continues to pursue Government ownership of data and is leveraging the Army Gray Eagle program’s research of the Government’s rights.

The program continues to provide contractor field service representatives (FSRs) while developing interactive electronic technical manuals, which will greatly enhance the military organization-level maintainer’s ability to troubleshoot and repair the system while reducing the need for contractor FSRs and depot-level field assistance.

### *Business Case Analysis (BCA)*

In December 2009, the program began a BCA to recommend a long-term sustainment strategy for the MQ-9 weapon system. The scope of the analysis included a full evaluation of the MQ-9 sustainment alternatives, including the implementation of performance-based logistics,

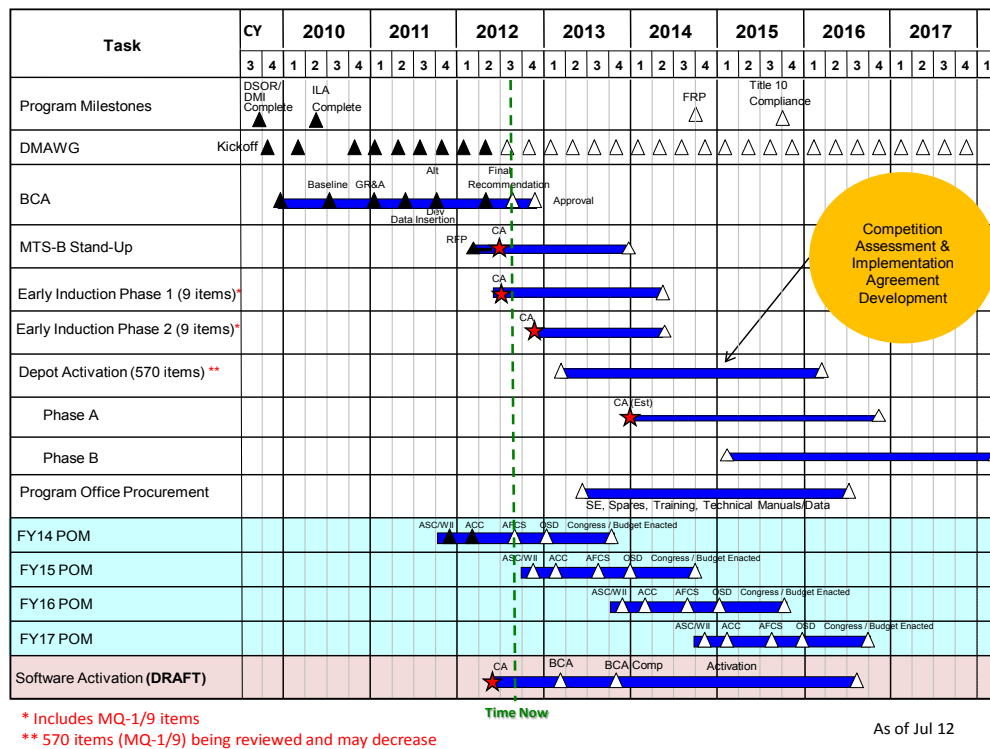
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<sup>95</sup> As amended by P.L. 112-81 in 2011. Previously there was a requirement to identify core capability within four years of IOC.



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initiation of PPPs, and the evaluation of organic sustainment support. A baseline report was presented in July 2010. After a strategic pause to incorporate critical repair data and lessons learned from other BCA efforts, the MQ-9 BCA effort resumed in May 2011 and was completed in June 2012. The final BCA recommended separate performance-based agreements for the sensors, aircraft, and engine between the OEMs and depots and recommended that supply chain management be transitioned to the Government. See Figure 42.



**Figure 42. MQ-9 Reaper Sustainment Plan**

### Conclusion

The MQ-9 Reaper case study illustrates the strategy and actions required, when proper initial lifecycle sustainment planning was not done, to transform the sustainment of unmanned systems from a short-term, rapid-fielding environment to a long-term sustainment environment. The transformation of unmanned systems will require dedicated effort over the next decade to develop and execute lifecycle sustainment strategies that ensure the long-term affordability of the systems. In the case of the Reaper program, the lifecycle sustainment strategy end state of organic support is expected to be fully achieved by 2018 — almost 10 years after the Air Force established the requirement and many years after statutory mandates. As new programs are developed, it is critical for programs, in conjunction with their Services and warfighters, to begin to formulate a lifecycle sustainment strategy at program inception so that requirements for availability, reliability, and affordability are considered in the design, sustainment resources are identified early, product support packages are tested with the system, and long periods of interim contractor support are avoided once the programs are fielded.

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## Unmanned Systems Integrated Roadmap FY2013-2038

**Appendix H      ABBREVIATIONS****.....A**

A2/AD	Anti-Access and Area Denial
ABSAA	Airborne Based Sense and Avoid
ACAT	Acquisition Category
AEODRS	Advanced Explosive Ordnance Disposal Robotic Systems
AFB	Air Force Base

**.....B**

BAMS	Broad Area Maritime Surveillance
BCA	Business Case Analysis
BLOS	Beyond Line-of-Sight

**.....C**

C2	Command and Control
C4	Command, Control, Communications, and Computers
CAT	Conventional Arms Tracker
CBA	Capability-Based Assessment
CCDR	Combatant Commander
CCL	Commodity Control List
CDL	Common Data Link
CIO	Chief Information Officer
CJCSI	Chairman of the Joint Chiefs of Staff Instruction
CLS	Contractor Logistics Support
COA	Certificate or Waiver of Authorization
COE	Common Operating Environment
COLREGS	Collision Regulations
COMSATCOM	Commercial Satellite Communications
CONEMP	Concept of Employment
CONOPS	Concept of Operations
CONUS	Continental United States
COTS	Commercial Off The Shelf
CPD	Capabilities Production Document
CPI	Critical Program Information
CRADA	Cooperative Research and Development Agreements

## Unmanned Systems Integrated Roadmap FY2013-2038

## .....D

DAE	Defense Acquisition Executive
DARPA	Defense Advanced Research Projects Agency
DAR	Data at Rest
DCGS	Distributed Common Ground Station
DCS	Direct Commercial Sales
DEF	Defense Exportability Features
DISA	Defense Information Systems Agency
DISN	Defense Information Systems Network
DISR	DoD IT Standards and Profile Registry
DMAWG	Depot Maintenance Actions Working Group
DoC	Department of Commerce
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DoS	Department of State
DoT	Department of Transportation
DOTMLPF-P	Doctrine, Organization, Training, Materiel, Leadership and education, Personnel, Facilities, and Policy
DSA	Dynamic Spectrum Access
DSB	Defense Science Board

## .....E

E3	Electromagnetic Environmental Effects
EAR	Export Administration Regulations
ECR	Export Control Reform
EMI	Electromagnetic Interface
EMS	Electromagnetic Spectrum
EO/IR	Electro-Optic/Infrared
EOD	Explosive Ordnance Disposal
EPOCHA	Estimation and Prediction of Orbits and Clocks to High Accuracy
EW	Electronic Warfare
ExCom	Executive Committee

## .....F

FAA	Federal Aviation Administration
FACE	Future Airborne Capability Environment
FAR	Federal Aviation Regulation
FCB	Functional Capability Board
FMS	Foreign Military Sales
FMV	Full-Motion Vehicle
FoS	Families of Systems
FY	Fiscal Year



# Unmanned Systems Integrated Roadmap FY2013-2038

FYDP Future Years Defense Plan

## .....G

GBS	Global Broadcast Service
GBSAA	Ground-Based Sense and Avoid
GCS	Ground Control Station
GEOINT	Geospatial Intelligence
GFMSA	GEOINT Functional Manager Seal of Approval
GIG	Global Information Grid
GMTIF	Ground Moving Target Indication Format

## .....H

HALE	High-Altitude Long-Endurance
HiDRA	High Dynamic Range Atom
HURL	Hydra Universal Rail Launcher

## .....I

ICAO	International Civil Aviation Organization
ICWG	Interface Control Working Group
IER	Information Exchange Requirements
IF	Intermediate Frequency
I-IPT	Interoperability Integrated Product Team
IMU	Inertial Measurement Unit
IOC	Initial Operational Capability
IOP	Interoperability Profile
IOT&E	Initial Operational Test and Evaluation
IP	Internet Protocol
IPL	Integrated Priority List
IPT	Integrated Product Team
ISR	Intelligence, Surveillance, and Reconnaissance
IT	Information Technology
ITAR	International Traffic in Arms Regulations

## .....J

J-8	Force Structure, Resources, and Assessment Directorate of the Joint Staff
JALN	Joint Aerial Layer Network
JAUS	Joint Architecture for Unmanned Systems
JCA	Joint Capability Area
JCIDS	Joint Capabilities Integration and Development System
JIIM	Joint, Interagency, Intergovernmental, and Multinational
JITC	Joint Interoperability Test Command
JROC	Joint Requirements Oversight Council
JRRF	Joint Robotics Repair Facility

## Unmanned Systems Integrated Roadmap FY2013-2038

JS	Joint Staff
JSIL	Joint Technology Center/Systems Integration Lab
JTA	Joint Technical Architecture
JUON	Joint Urgent Operational Need
<b>.....K</b>	
KPP	Key Performance Parameter
<b>.....L</b>	
LOS	Line-of-Sight
LPI/LPD	Low Probability of Intercept/Low Probability of Detection
<b>.....M</b>	
MDA	Milestone Decision Authority
MIMO	Multiple-Input, Multiple-Output
MISB	Motion Imagery Standards Board
MOA	Memorandum of Agreement
MOS	Military Occupational Specialty
MPSF	Mission Package Support Facility
MTBCF	Mean Time Between Critical Failure
MTBF	Meantime Between Failure
MUM-T	Manned and Unmanned Teaming
MUSE	Multiple Unified Simulation Environment
MUSIC	Manned and Unmanned Systems Integration Capability
<b>.....N</b>	
NAS	National Airspace System
NGA	National Geospatial-Intelligence Agency
NIAT	NSG Interoperability Action Team
NLOS	Non-Line-of Sight
NR KPP	Net Ready Key Performance Parameter
NRL	Naval Research Laboratory
NSA	National Security Agency
NSE	Nonstandard Equipment
NSG	National System for Geospatial-Intelligence
NSS	National Security Systems
<b>.....O</b>	
O&S	Operations and Support
OA	Open Architecture
OCO	Overseas Contingency Operations
OCONUS	Outside the Continental United States
OCU	Operator Control Unit
OEM	Original Equipment Manufacturer

# Unmanned Systems Integrated Roadmap FY2013-2038

OODA	Observe, Orient, Decide, Act
OPTEMPO	Operating Tempo
OSD	Office of the Secretary of Defense
<b>.....P</b>	
PED	Processing, Exploitation & Dissemination
PEO	Project Executive Office
PINS	Precision Inertial Navigation Systems
PNT	Position, Navigation, and Timing
POM	Program Objective Memorandum
POR	Program of Record
PPBE	Planning, Programming, Budgeting, and Execution
PPP	Public-Private Partnership
<b>.....R</b>	
RAM	Reliability, Availability, and Maintainability
RCTA	Robotic Collaborative Technology Alliance
RDT&E	Research, Development, Test, and Evaluation
RPA	Remotely Piloted Aircraft
RF	Radio Frequency
RITP	Research and Intelligence/Technology Protection
RS-JPO	Robotic Systems Joint Project Office
<b>.....S</b>	
S&T	Science and Technology
SAA	Sense and Avoid
SAASM	Selective Availability Anti-Spoofing Module
SAE	Service Acquisition Executive
SANGB	Selfridge Air National Guard Base
SATCOM	Satellite Communications
SC	Steering Committee
SCRTF	Security Cooperation Reform Task Force
SDS	Spectrum-Dependent Systems
SECDEF	Secretary of Defense
SOA	Service-Oriented Architecture
SoS	System of Systems
SPIES	Sensor/Platform Interface and Engineering Standardization
SSRA	Spectrum Supportability and Risk Assessment
STANAG	Standardization Agreement
STUAS	Small Tactical Unmanned Aircraft System
SUAS	Small Unmanned Aircraft Systems
SWaP-C	Size, Weight, Power and Cooling

## Unmanned Systems Integrated Roadmap FY2013-2038

### .....T

T&E	Test and Evaluation
TAA	Technical Airworthiness Authority
TS&FD	Technology Security and Foreign Disclosure
TS/SCI	Top Secret/Secret Compartmented Info
TTP	Tactics, Techniques, and Procedures

### .....U

UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
UCLASS	Unmanned Carrier Launched Airborne Surveillance and Strike System
UCS	UAS Control Segment
UGS	Unmanned Ground Systems
UGV	Unmanned Ground Vehicle
UI2	Unmanned Interoperability Initiative
UMS	Unmanned Maritime Systems
UMV	Unmanned Maritime Vehicle
U.N.	United Nations
USC	United States Code
USD	Under Secretary of Defense
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
USD(I)	Under Secretary of Defense for Intelligence
USIP	Unmanned Systems Interoperability Profile
USV	Unmanned Surface Vehicle
UUV	Unmanned Undersea Vehicle
UVDS	Unified Video Dissemination Service

### .....W

WG	Working Group
WGS	Wideband Global Satellite
WMD	Weapons of Mass Destruction

