United States Air Force Scientific Advisory Board

Report on

Operating Next-Generation Remotely Piloted Aircraft for Irregular Warfare

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United States Air Force
Scientific Advisory Board

Report on

Operating Next-Generation Remotely Piloted Aircraft for Irregular Warfare

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Foreword

The United States Air Force has long envisioned a strategic role for remotely piloted and autonomous aircraft. As early as May 1896, Samuel Pierpont Langley developed an unpiloted heavier-than-air vehicle which flew over the Potomac River. On V-J Day in August 1945, General Hap Arnold, US Army Air Forces, observed[1]:

> We have just won a war with a lot of heroes flying around in planes. The next war may be fought by airplanes with no men in them at all … Take everything you've learned about aviation in war, throw it out of the window, and let's go to work on tomorrow's aviation. It will be different from anything the world has ever seen.

Since these early days, extended range, persistence, precision, and stealth have characterized remotely piloted aircraft (RPA) advancements. RPAs have been employed in multiple combat roles and increasingly contested environments. This year, for the first time in history, the President's budget proposed a larger investment in RPAs than manned aircraft. A seemingly insatiable operational appetite for RPAs, however, has led to an Air Force manning bottleneck. This is exacerbated by a lack of common ground stations, unsatisfactory integration with civilian and international airspace, and vulnerabilities in communications and command and control links. Further complicating efforts, yet essential in irregular warfare, are directives to minimize civilian casualties. General David Petraeus sees this need as a direct way to support a key center of gravity:

> …We must fight the insurgents, and will use the tools at our disposal to both defeat the enemy and protect our forces. But we will not win based on the number of Taliban we kill, but instead on our ability to separate insurgents from the center of gravity - the people …[2]

Our Panel conducted an extensive set of visits and received numerous briefings from a wide range of key stakeholders in government, industry, and academia. Taking a human-centered, evidence-based approach, our study seeks to address operational challenges as well as point to new opportunities for future RPAs. That RPAs will be a foundational element of the Air Force's force structure is no longer debatable. The real question is how to maximize their current and future potential. Our intention is that this study will help provide both vector and thrust in how to do so in the irregular warfare context, as well as other applications.

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[1] Words on War: Military Quotes from Ancient Times to the Present, by Jay Shafritz, Prentice Hall, New York, 1990, pg. 104

[2] Tactical Directive. Headquarters ISAF 6 July 2009. http://usacac.army.mil/cac2/coin/repository/Tactical_Directive_09070.pdf

The undersigned express our sincerest appreciation to all the talented and dedicated study members and to the support of Lt Gen David Deptula and Lt Gen Phillip Breedlove. We also acknowledge the support of Executive Officers and the Air Force Scientific Advisory Board Secretariat for their excellent support to this effort.

Dr. Greg Zacharias
UIW Study Chair

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Executive Summary

Background

RPAs are revolutionary surveillance and weapons delivery systems – changing the way the Air Force builds situation awareness and engages enemy forces – but their full potential has yet to be realized. To begin to address this issue, the Air Force initiated this study to review the state-of-the-art in RPA operations, focusing on control and connectivity in an irregular warfare (IW) environment. The Panel was specifically tasked to identify RPA architectures and operational concepts centered on human-systems integration, distributed systems operations, and effective command and control – a cluster of concepts and technologies we subsequently labeled as "mission management" enablers. The Panel was also tasked to recommend mid- to far-term S&T development roadmaps for advancing these technologies to improve the flexibility and capability of RPA operations. The study terms of reference (TOR) identified a number of core issues which were further articulated by the Study Panel to include:

1. **Issue #1:** Manning and personnel shortfalls are concerns in RPA deployment. Exploiters represent the largest manning dependency (39 percent), exacerbated by expected significant exploiter growth from new sensor suites (e.g., ARGUS-IS, Gorgon Stare). Current sensors (e.g., Constant Hawk and Angel Fire) and expected sensors (e.g., ARGUS-IS) produce data at rates of 10 to over 1000 times projected communications data transmission capacities, and will far exceed human analytic capacity.
2. **Issue #2:** Manually intensive airspace management and integration requiring exclusion zones and Certificates of Authorization (COAs) make inefficient use of national and international airspace, will not scale to accommodate future RPA growth, hampers manned/unmanned integration, and presents special challenges for small RPAs.
3. **Issue #3:** Minimizing collateral damage (CD) and fratricide is not a requirement unique to RPA strike operations. For manned and unmanned platforms, the lack of positive ID (PID) and tactical patience are the most significant causes of civilian casualties (CIVCAS) in current conflicts (8 percent CIVCAS compared with 66 percent caused by insurgents). Persistence; up-close access; high-resolution intelligence, surveillance, and reconnaissance (ISR); improved situation awareness; and improved mission management will permit RPAs to minimize CD/fratricide. Small-focused lethality munitions and non-lethal options for RPAs promise to further minimize CD and CIVCAS (e.g., as low as 5 percent).
4. **Issue #4:** In spite of current low RPA losses, inexpensive physical threats (e.g., MANPADS, low-end SAMs, air-to-air missiles) and electronic threats (e.g., acoustic detectors, low cost acquisition radars, jammers) threaten future operations.

Findings

Following an extensive set of fact-finding meetings with operators, developers, trainers, analysts, maintainers, and scientists and technologists, together with data/evidence analysis where possible, the Panel distilled our findings into the following top-level observations regarding RPA mission management in irregular warfare environments:

1. **Key Finding 1:** Current RPA automation implementations either under-automate, over-automate, or fail to provide a flexible human-centric solution. Insufficient and inflexible automation/sensor processing increases pilot workload, increases incident rates, degrades mission performance and agility, and inhibits distributed cross-platform collaboration.
2. **Key Finding 2**: Poorly-designed Operator Control Stations (OCSs) fail to provide effective, robust, and safe RPA mission management because of a lack of accepted systems engineering design practices, a lack of Human-System Integration (HSI) design and implementation, and closed and stovepiped architectures that constrain "best of breed" component solutions.
3. **Key Finding 3:** Limited communications systems result in communications latency, link vulnerabilities, and lost-link events, which limits mission roles assigned to RPAs, operational flexibility, and resiliency in the face of unanticipated events.
4. **Key Finding 4:** Successful transition of the Beta program to Undergraduate RPA Training (URT) helps establish the RPA career field. This transition is a positive step to address the manning shortfalls, but shortcomings in crew selection and training continue to contribute to bottlenecks and compromise mission effectiveness and safety.
5. **Key Finding 5:** Concepts of RPA operation (CONOPS) and tactics, techniques, and procedures (TTPs) appear to be developed "after the fact," following development and deployment rather than as a concurrent effort.

Recommendations

As a result of our findings and extensive deliberations, the Study Panel makes the following key recommendations with associated offices of primary responsibility (OPRs):

1. **Recommendation 1:** Develop flexible levels of automation to enable situation-adaptive human interaction for improved mission effectiveness in the near term for single-platform task-level automation (ASC), in the mid term for mission-level automation (AFRL), and in the far term for multi-RPA collaboration and autonomy (AFRL).
2. **Recommendation 2:** Improve the operator control stations in the near term by applying human systems engineering practices to correct existing operator control stations (AFMC, ACC), in the mid term by developing a family of networked, interoperable systems (ESC, ASC), and in the far term by advancing human-

automation interaction science and technology to enable adaptive, mixed initiative, human-centric control (AFRL).

3. **Recommendation 3**: Develop assured communications, appropriate security, and a long term plan for a globally interoperable communications systems architecture (AFMC/ESC). Reduce bandwidth requirements, latency impacts, and security vulnerabilities by developing a unified communications architecture that in the short term provides "good enough" sensor security with high C2 link reliability and security (AFMC, AFRL/RB); in the mid term adopts increased platform automation and latency compensation including platform forecasting and target tracking (AFMC, AFRL/RB); and in the long term provides electronic warfare countermeasures, addresses scale, and supports networked operations of heterogeneous assets (AFMC/ASC, AFRL/RB, AF/A3/5).
4. **Recommendation 4:** Understand fundamental capabilities and skillsets required for each RPA specialty, select appropriately, and exploit current training and simulation technologies to reduce manning pipeline delays and deal with contested environments (AF/A3/5, ACC). In the near term, activities should be directed at developing scientifically based RPA career path enhancements that generate targeted selection procedures and accelerated training programs (AF/A3/5, ACC). In the far term, focus on developing higher level skillsets, including team coordination, communication, and mission planning.
5. **Recommendation 5:** Develop RPA CONOPS and TTPs concurrently with system development, considering all components that drive mission effectiveness (ACC). In the near term define how the current SOC/WOC/AOC structures can enable distributed global operations via "brokering" among operators, platforms/sensors, and "customers" (ACC). In the mid term, anticipate growth in RPA operations, growth in sensor capabilities, transition to integrated manned/unmanned operations, and more contested operating environments (AF/A9). In the far term, co-evolve CONOPS/TTPs for new platforms and missions as part of a focused acquisition process, leading systems development and informing systems requirements choices (ACC).
6. **Recommendation 6:** Transition the successful RPA prototypes to the acquisition process, incorporating rigorous systems engineering practices including Human Systems Integration (SAF/AQ). Continue successful use of the ACTD process to develop game-changing technology solutions, while upgrading, developing, and acquiring new RPA systems using accepted systems engineering practices (e.g. 2010 NDAA Section 804) to address operator-related issues via incorporation of HSI as part of the systems engineering process, and follow recommendations of two previous SAB studies[3,4].

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[3] United States. "Unmanned Aerial Vehicles in Perspective: Effects, Capabilities, and Technologies. Volume 1: Summary (Public Released)" SAB-TR-03-01 September 2003.

[4] United States. "Human-System Integration in Air Force Weapon Systems Development and Acquisition," Executive Summary and Annotated Brief, SAB-TR-04-04, July 2004.

Report Structure

The report is structured as follows. Following a background of and motivation for the study, the Panel summarizes the key RPA mission management issues. The Panel then details each of the key findings derived from a hypothesis-driven, evidence-based analytic process. A subsequent recommendations section details specific actionable recommendations designed to address the challenges uncovered in the findings section. A section on the implications of under-investments follows. The report concludes by summarizing the implications of our study. Report appendices detail assumptions, hypotheses, and future data collection requirements, study members, briefings, visits, acronyms, references, and report distribution.

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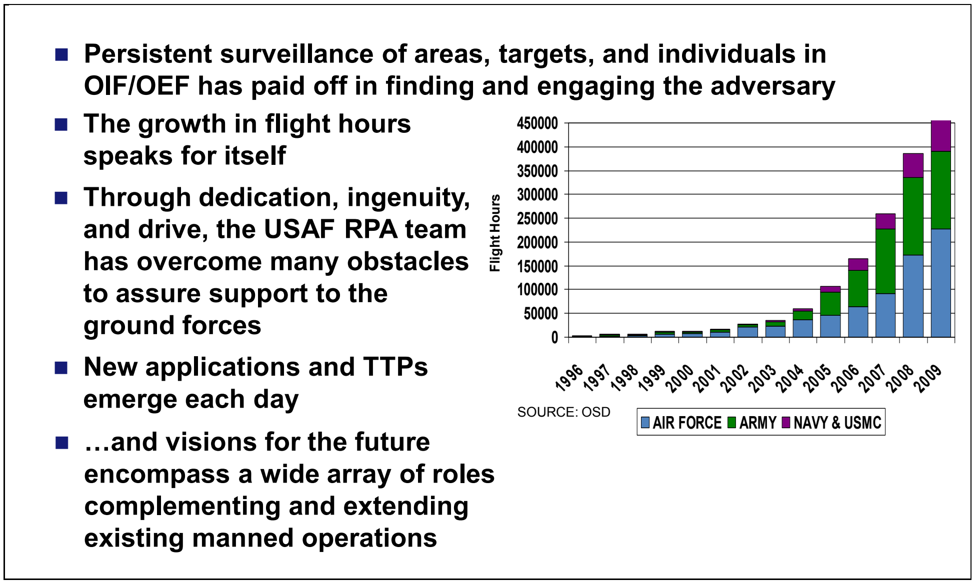
Chapter 1: Study Background

1.1 Background and Motivation

Remotely piloted aircraft (RPAs) have been acquired to perform dull, dirty, and dangerous missions for the Air Force. Dull missions include situation awareness missions, especially those involving persistent surveillance of unmoving targets or identifying the "normal" activities in an area so that unusual activities can be spotted. Dirty missions include flights/missions into areas in which suspected chemical or biological weapons or contamination are suspected. Dangerous missions include those in which the potential for loss of the aircraft can be high, but for which there is a high payoff for information that can bring weapons on targets.

As illustrated in Figure 1-1, RPAs have revolutionized operations in irregular warfare. RPA operations have grown rapidly in both volume and application. Approaching one half million annual flight hours across the services, RPAs have provided persistent surveillance and engagement with adversaries. Through dedication, ingenuity, and drive, the Air Force has overcome many obstacles to assure effective support to our ground forces. Daily air operators are continuously innovating with new missions and Tactics, Techniques, and Procedures (TTPs) to take advantage of RPAs. Future visions include many new missions and roles, complementing and extending manned operations.

The Air Force has introduced remote split operations to successfully reduce our operational footprint in the battlespace, by locating the majority of personnel at CONUS bases for mission command and control and the remainder at the operational airfields for take-off and landing operations. Overall, remote split operations increases the number of personnel involved in operating the aircraft while decreasing the risk of flight accidents during take-offs and landing.



- **Persistent surveillance of areas, targets, and individuals in OIF/OEF has paid off in finding and engaging the adversary**
- **The growth in flight hours speaks for itself**
- **Through dedication, ingenuity, and drive, the USAF RPA team has overcome many obstacles to assure support to the ground forces**
- **New applications and TTPs emerge each day**
- **…and visions for the future encompass a wide array of roles complementing and extending existing manned operations**

SOURCE: OSD

Figure 1-1: USAF RPAs Have Revolutionized Air Warfare in the IW Arena.

The wide range of RPA Groups and platforms illustrated in Figure 1-2 provides for a variety of capabilities to be used against a variety of targets, including surveillance, reconnaissance, and engagement targets under conditions we control rather than those controlled by adversaries. RPA payload and range is plotted on a log-log scale, showing the wide variation in platforms from a few pounds to thousands of pounds, and from a few miles range to thousands of miles. Although not plotted, altitude varies likewise, from a few feet to many tens of thousands of feet. The Air Force operates RPAs in all five Groups shown. Unfortunately this wide array of RPA vehicles, acquired under individual agreements, and operated and maintained by separate units and personnel further exacerbate the manpower demands to operate the aircraft in the field. Common control stations, common training protocols and systems, and common maintenance procedures could go a long way toward minimizing the number of personnel required to maintain an effective battlespace presence of such aircraft.

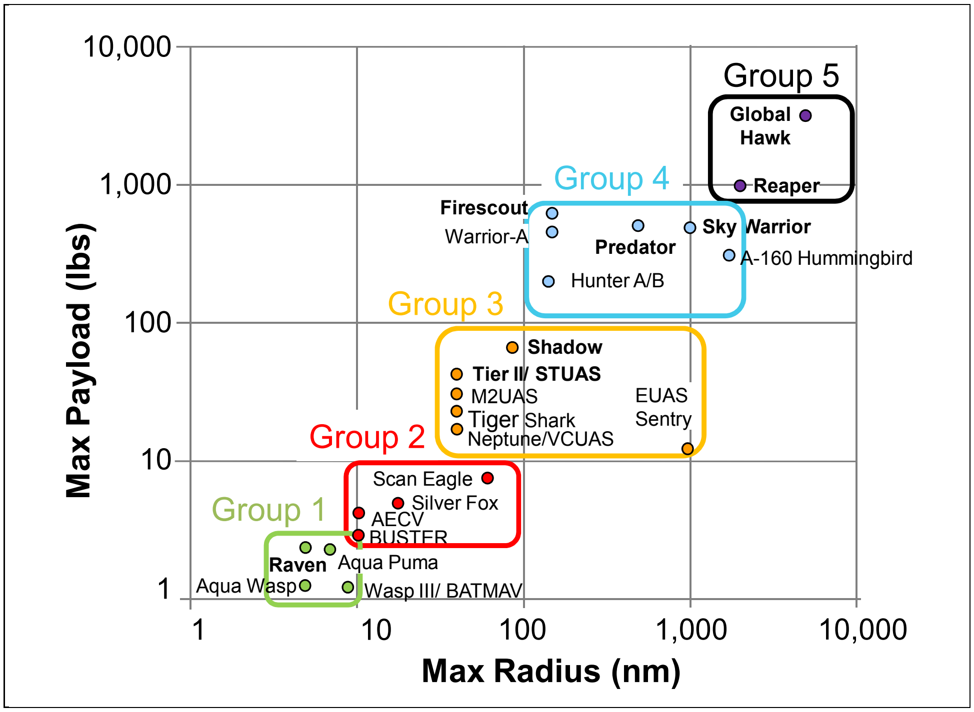


Figure 1.2: RPA Groups by Payload and Range.

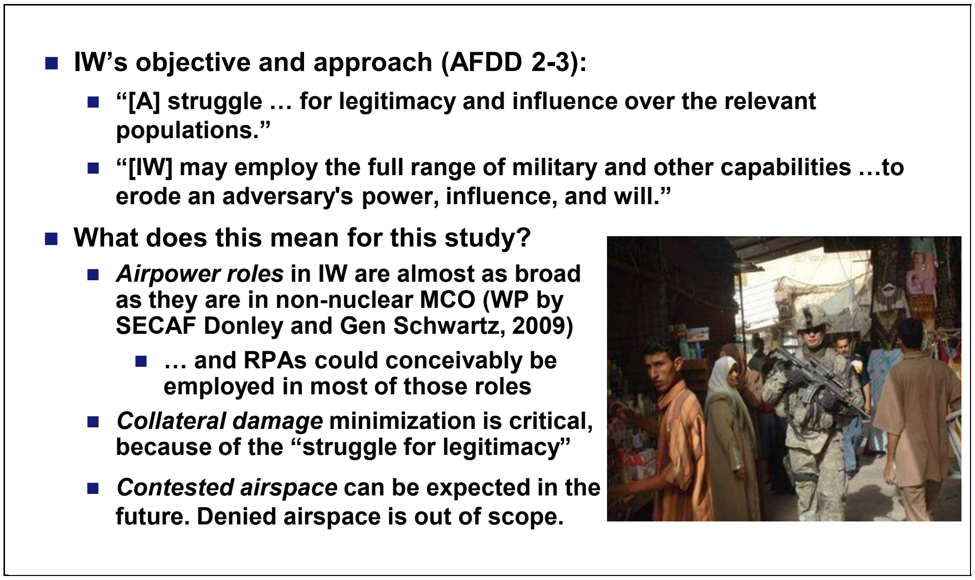
1.2 Scope of Study

The Study Panel was tasked to review the state-of-the-art in RPA operations, focusing on control and connectivity in an irregular warfare (IW) environment. The Panel was also asked to identify RPA architectures and operational concepts enabling low probability of collateral damage/fratricide. The Panel was also asked to identify enabling [mission management] technologies to include:

- *Human Systems Integration*, and potential for reduced manning, enhanced operator awareness, and multi-aircraft control (MAC)
- *Distributed System Operations*, and potential for multi-aircraft collaboration (manned and unmanned), and better airspace management and integration
- *Command and Control,* and potential for more efficient bandwidth use, and improved mission assurance in degraded or denied communications environments

Finally, the Panel was tasked to recommend mid- to far-term S&T development roadmaps for these technologies, with an emphasis on improving the flexibility and capability of RPA operations.

As shown in Figure 1-3, Air Force Doctrine Document 2-3 (1 August 2007) defines Irregular Warfare as “a violent struggle among state and nonstate actors for legitimacy and influence over the relevant populations. IW favors indirect approaches, though it may employ the full range of military and other capabilities to seek asymmetric approaches to erode an adversary's power, influence, and will."[5] In addition, because *airpower roles* in IW are almost as broad as they are in non-nuclear MCO[6] and because RPAs could conceivably be employed in most of those roles (given enough technological and operational advancements), it follows that RPAs could conceivably be used to apply a full range of (non-nuclear) airpower capabilities in an IW engagement. What this means for this study, because of the broad potential for RPA employment and engagement, is that *collateral damage* minimization is critical, because of the "struggle for legitimacy" over relevant populations in an IW engagement. Finally, though present IW operations enjoy uncontested airspace, we can expect contested airspace in the future, although for the purposes of this study, denied airspace is considered out of scope.



- **IW's objective and approach (AFDD 2-3):**
  - **"[A] struggle … for legitimacy and influence over the relevant populations."**
  - **"[IW] may employ the full range of military and other capabilities …to erode an adversary's power, influence, and will."**
- **What does this mean for this study?**
  - ***Airpower roles* in IW are almost as broad as they are in non-nuclear MCO (WP by SECAF Donley and Gen Schwartz, 2009)**
    - **… and RPAs could conceivably be employed in most of those roles**
  - ***Collateral damage* minimization is critical, because of the "struggle for legitimacy"**
  - ***Contested airspace* can be expected in the future. Denied airspace is out of scope.**

Figure 1-3: Irregular Warfare Constraints.

1.3 Study Approach and Methodology

The study process is characterized in the model represented in Figure 1-4. Focused by the bounds of the Terms of Reference (TOR), the Study Panel both reviewed past studies and visited a number of industry, government, and academic facilities to assess the current state of the art. The Panel brainstormed to generate hypotheses, but at the same time attempted to explicitly capture underlying assumptions (Appendices A1 and A2). The Panel then collected data from a broad range of sources attempting to confirm, deny, or refine its hypotheses, some of which became key operational issues to be addressed ("Background" as shown in Figure 1-5), and some of which became identified gaps in mission management associated with those issues ("Findings" in Figure 1-5). In a parallel and iterative fashion, we then turned our attention to generating

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[5] (AFDD 2-3)

[6] Donley and Schwartz 2009

recommendations in terms of technology, people, and processes to address these mission management gaps uncovered by our findings ("Recommendations" in Figure 1-5). A final phase consisted of group assessment of findings and recommendations and assignment of those to specific offices of primary responsibility (OPRs). At the beginning of the study, the study leadership met with key stakeholders to obtain clarity on Air Force senior leadership priorities. The Panel then met again midcourse to perform a vector check on the study's progress. The study results were then reported to senior Air Force leadership and key stakeholders.

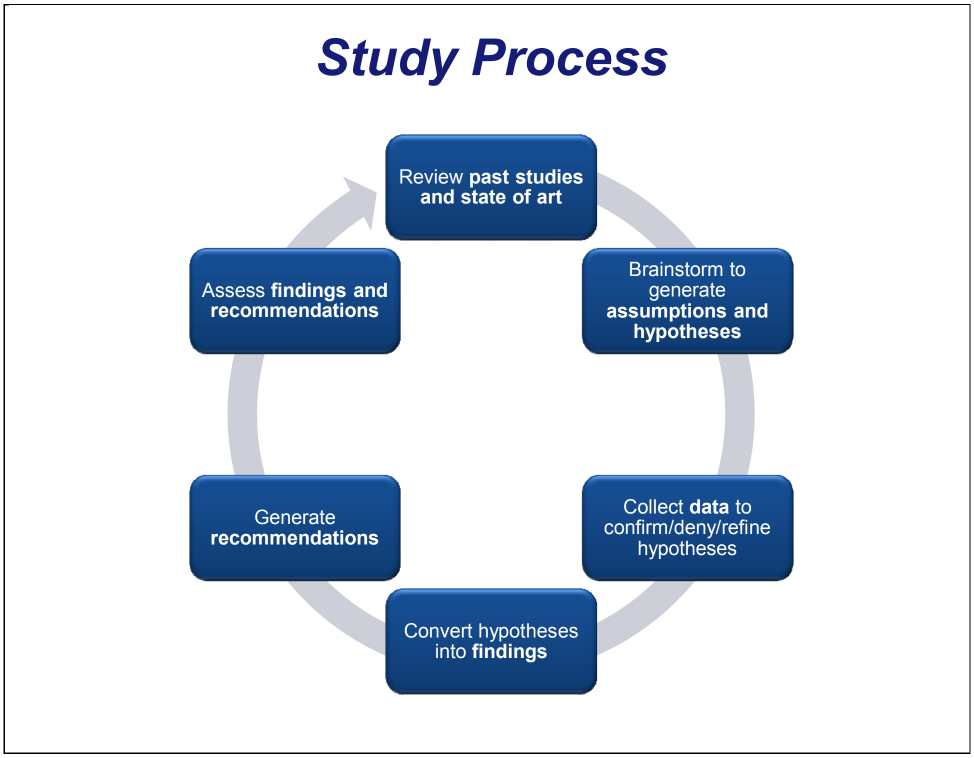
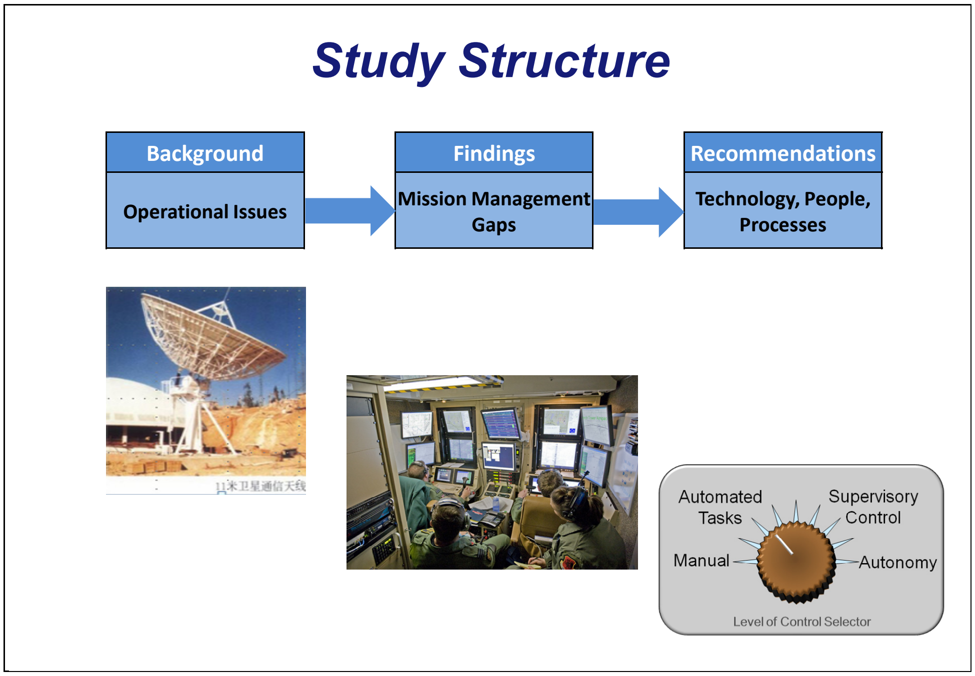


Figure 1-4: Study Process.



Study Structure

Background

Operational Issues

Findings

Mission Management Gaps

Recommendations

Technology, People, Processes

Figure 1-5: Study Structure.

1.4 Challenges

RPAs have provided the Air Force revolutionary capabilities such as persistence for dull missions, and safe and stealthy access for dirty and dangerous missions. However, there are challenges with current RPAs including:

- Significant personnel footprint per RPA combat air patrol (CAP)
- “Soda straw” sensors (i.e., narrow field of view) that serve up full motion video (FMV) that requires manual exploitation
- Human-intensive guidance and control (“in the loop” not “on the loop”), based on low-level remote control technologies
- Low operator situation awareness (SA)
- Human-intensive airspace management and deconfliction procedures
- RPAs acquired and operated as individual platforms
- Manual management of collateral damage/fratricide risk
- Heavy reliance on continuous long-haul (e.g. space-based) communications
- Capabilities that generally rely on uncontested battle space

A more integrated view of these issues (and others not listed) and potential capabilities, as they evolve over time, is given in Figure 1-6. Shown here are seven key factors: increasing threats, increased aircraft density, airspace integration, operating in all weather conditions, operating in multiple and increasingly challenging roles (e.g., strategic strike, SEAD), multi-aircraft control (MAC), and increasing levels of autonomy.

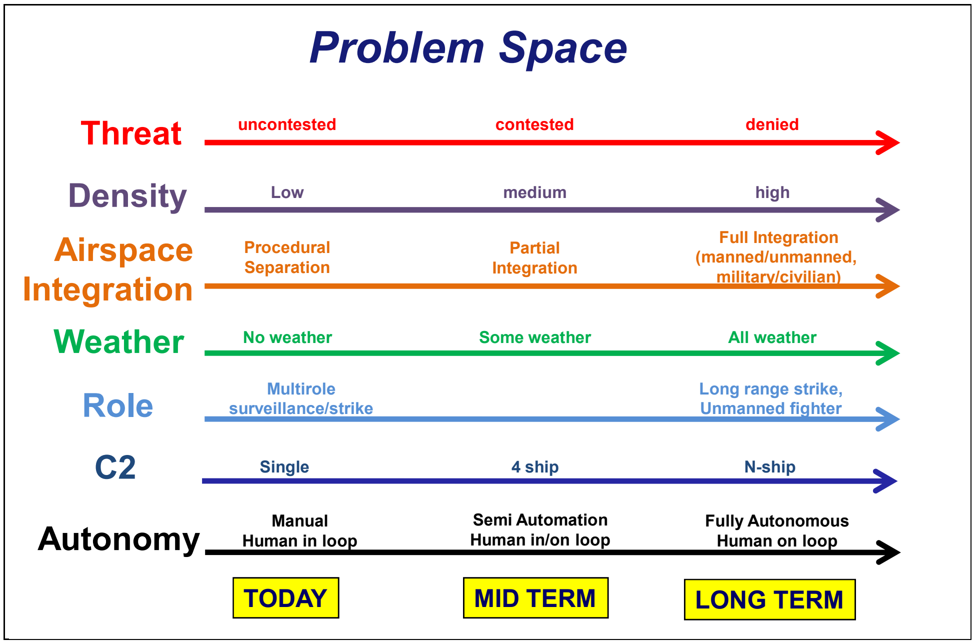


Figure 1-6: Problem Space.

Figure 1-7 illustrates some current limitations of RPAs and the promise for advanced solutions in the future. The Study Team believes the primary solution for these shortcomings is a unified mission management capability that integrates unmanned and manned assets into a more focused operational mission capability that relies on unmanned assets for the portions of the mission in which they are most capable. RPAs can perform many missions, but it is important for weapon delivery to have a person at the stage of weapon delivery making the trigger decision based on timely intelligence and accurate situation awareness to ensure low collateral damage.

Today	Tomorrow
Significant personnel footprint per RPA combat air patrol (CAP)	Progressive personnel reductions in pilots, sensor operators, exploiters, and maintainers through multiple advances in all areas.
Soda straw imagers serving up full motion video (FMV), manually exploited	Wide Area Airborne Surveillance (WAAS) with some/all processing, exploitation, dissemination (PED) done onboard.
Human-intensive guidance and control ("in the loop"), based on "remote control" technologies	Human supervisory control ("on the loop") enabled by architectural and algorithmic advances providing for multi-vehicle management, and better engineered HCIs.
Low operator situation awareness (SA)	Mission-specific SA enabled by fused sensors, health monitoring,…
Airspace management and deconfliction is human intensive	Airspace management and deconfliction for manned/unmanned operations done more autonomously (eg, onboard sense and avoid)
Operated as individual platforms	Operated collaboratively via multi-platform comms and coordination, across manned and unmanned platforms.
Collateral damage/fratricide risk managed entirely manually	Collateral damage/fratricide risk management supported by decision-aiding at mission control and/or onboard automation
Heavy reliance on continuous long-haul comms	More intermittent comms enabled by more autonomy when unlinked
Uncontested battlespace (mostly)	Operating in contested battlespace (from kinetic air/ground, EW, and cyber threats) via stealth, defensive systems, secure comms,…
Limited-mission capable (ISR, shooters)	Multi-mission capable (EW, counterair missile trucks, ...) via modular platforms, payloads, comms, and operator interfaces.

Figure 1-7: Today's Reality vs Tomorrow's Potential.

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Chapter 2: Mission Management Challenges

A number of key challenges that hamper effective mission management of remotely piloted aircraft (RPAs) were identified in the terms of reference and noted by the Study Panel as key issues. In particular, the Study Panel focused on manning shortfalls and personnel selection, airspace management and integration, minimizing collateral damage and fratricide, and contested airspace. We consider each of these issues in detail in the following sections.

2.1 Issue (1): Manning Shortfalls and Personnel Selection/Training

RPA manning difficulties are a direct result of the increase in use of RPAs for surveillance and interdiction missions. As Figure 2-1 illustrates, maintaining a Predator/Reaper combat air patrol (CAP) (which represent the vast majority of Air Force unmanned vehicle operations) for 24/7 coverage requires approximately 168 personnel[7] and four aircraft. In terms of overall Predator/Reaper RPA operations, there are 4 basic categories of personnel for a single CAP: exploiters (31 percent), maintainers (40 percent), pilots (6 percent), and sensor operators (6 percent), with the other 12 percent representing other administrative and support personnel. This distribution is similar for the Global Hawk, although the manning requirements are higher (approximately 300).

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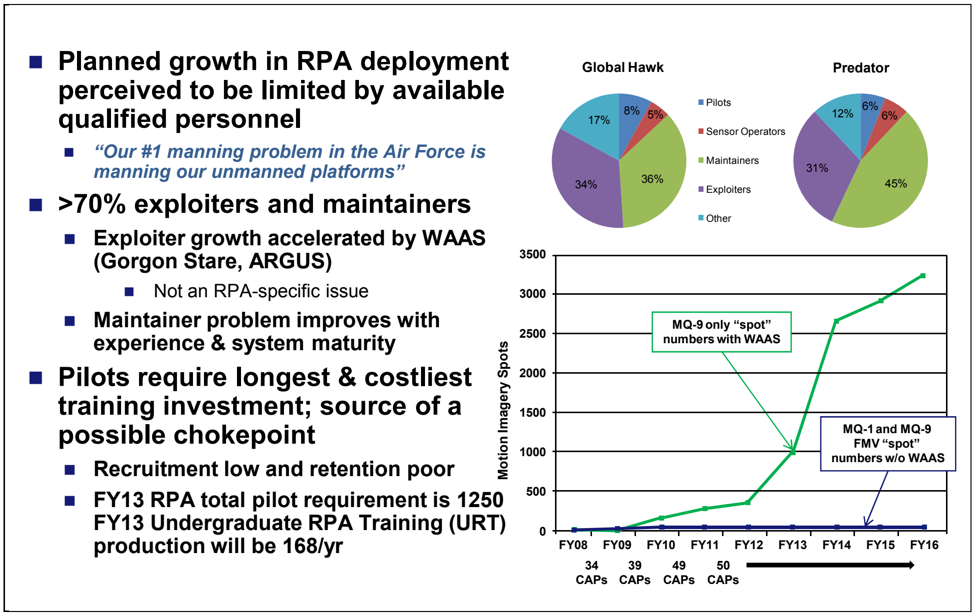
[7] Deptula, David. Lt. Gen. “The Way Ahead: Remotely Piloted Aircraft in the United States Air Force,” presented to the SAB, January 2010.



- **Planned growth in RPA deployment perceived to be limited by available qualified personnel**
  - *"Our #1 manning problem in the Air Force is manning our unmanned platforms"*
- **>70% exploiters and maintainers**
  - **Exploiter growth accelerated by WAAS (Gorgon Stare, ARGUS)**
    - Not an RPA-specific issue
  - **Maintainer problem improves with experience & system maturity**
- **Pilots require longest & costliest training investment; source of a possible chokepoint**
  - **Recruitment low and retention poor**
  - **FY13 RPA total pilot requirement is 1250 FY13 Undergraduate RPA Training (URT) production will be 168/yr**

Figure 2-1: Manning Growth.

Although the Air Force's focus has been on dealing with RPA pilot shortfalls, exploiters and maintenance personnel represent the largest manpower requirement. Whereas recruitment and retention of these personnel may not be considered to be a problem in the current climate, with systems like Gorgon Stare and ARGUS-IS coming on line with 10 to 65 additional full motion video (FMV) feeds ("spots") per platform, the manpower to support a single CAP could grow significantly (if 65 people are needed for a single video stream, 10 times 65 would be 650 people required for a Gorgon Stare feed – See Figure 2-2). Without changes in how such images are processed (e.g., simply delivering the imagery to ground forces versus exploiting them via reachback facilities), the insertion of new wide area sensing technologies is likely to overwhelm this aspect of operations, with the ultimate result that the majority of data will simply not be analyzed. Unless this problem can be addressed, the effective use of these technologies appears to be unrealistic.

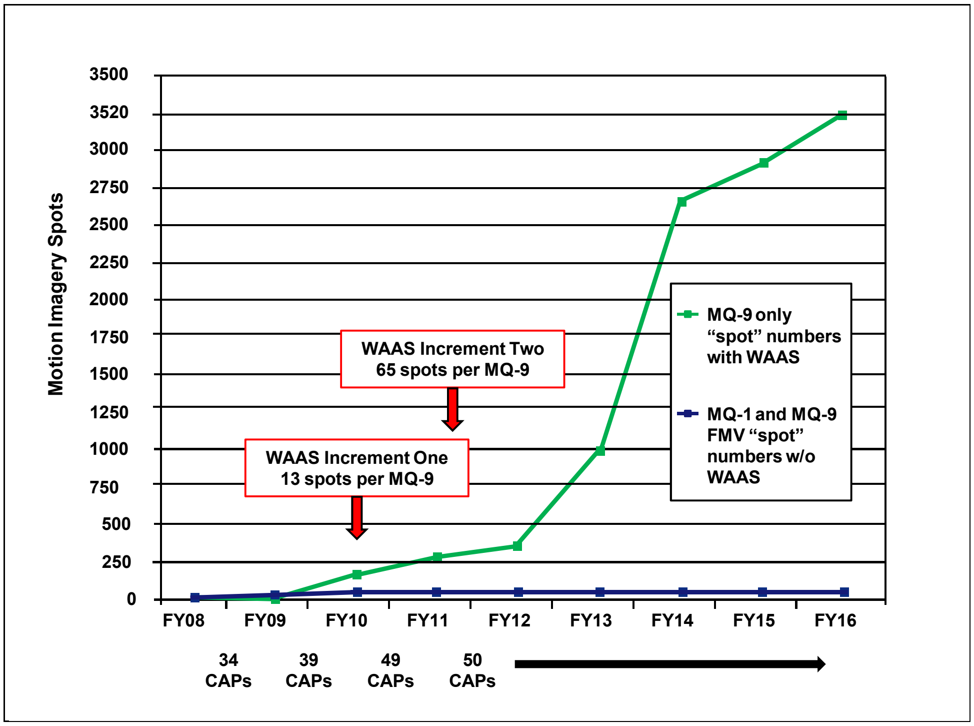
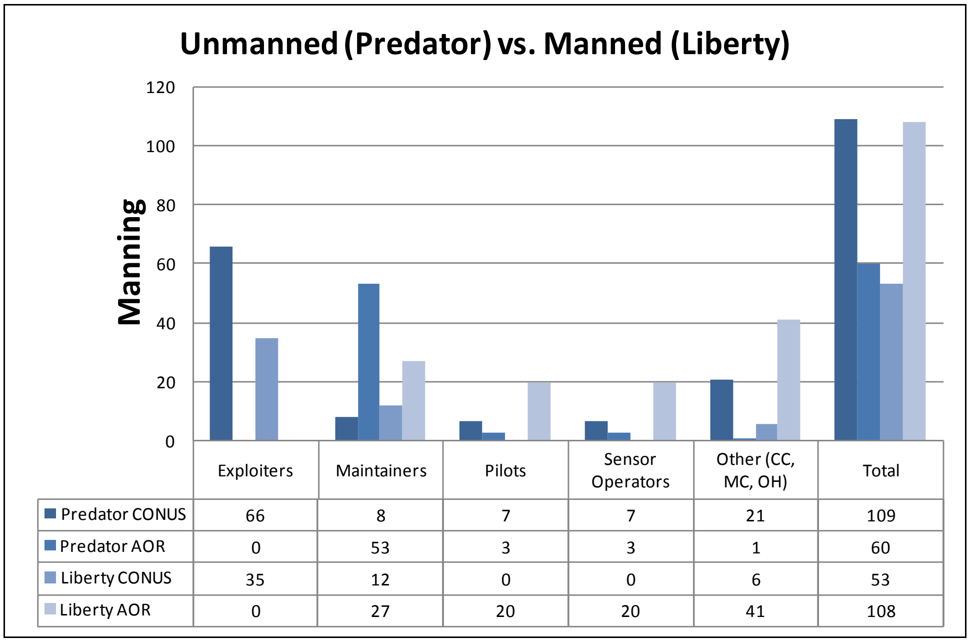


Figure 2-2: Effect of Wide Area Surveillance on Personnel Requirements.

The reality is that the RPA manning issue is more affected by FMV processing, exploitation, and dissemination (PED) than operation of the aircraft. A comparison of RPAs flying a 24-hour surveillance mission with a manned aircraft (MC-12 Liberty) flying a similar mission (Figure 2-3) shows that, in fact, operating the RPA requires fewer pilots and fewer aircraft because of the longer time on target offered by Predator/Reaper. The number of maintainers appears abnormally large for the Predator aircraft, but could be expected to decline as these aircraft mature and maintainers become more familiar with the aircraft.



	Exploiters	Maintainers	Pilots	Sensor Operators	Other (CC, MC, OH)	Total
■ Predator CONUS	66	8	7	7	21	109
■ Predator AOR	0	53	3	3	1	60
■ Liberty CONUS	35	12	0	0	6	53
■ Liberty AOR	0	27	20	20	41	108

Figure 2-3: Unmanned and Manned Aircraft Comparison[8].

Because exploiters are the real chokepoint for intelligence, surveillance, and reconnaissance (ISR) missions, the focus needs to be on training and improving the efficiency of the exploiters and the quality of the products they provide for the warfighter (targeting, time, and location stamping, friendly forces identification). A more urgent effort needs to be placed on providing better technology for these personnel to identify and date/time stamp targets of interest. Also, there is a need to provide better integration of target identification, sensor data, and pilot observations into the situation awareness data fed back to the warfighter (in the air and on the ground).

Currently, the Air Force is using on-the-job training to train exploiters in applying their capabilities to providing data to the warfighter. The problem with on-the-job training is that there is no way to introduce improved data integration in that environment or to improve the efficiency with which the product is developed. Additionally, there is no control over training material (e.g., anomalies, critical threats) when training occurs on the job.

If one's assumption is that training pilots (and non-pilots) to become RPA pilots is a major personnel issue (this may not be a valid assumption for long-term operations, as just discussed), there are two accession solutions: 1) train more pilots and/or 2) increase the number of vehicles pilots can manage. In addition, recruitment/retention is critical for keeping these personnel. Note that there is a feedback loop between the multi-vehicle solution (see below) and the retention issue, such that if pilots have higher job satisfaction and are not so bored and/or marginalized, retention will improve.

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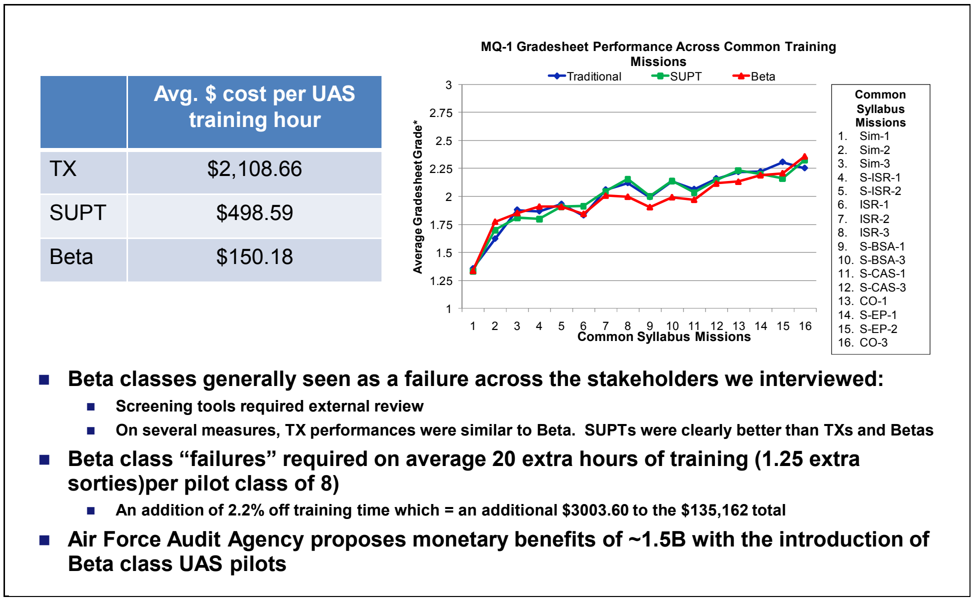
[8] AF/A2, "CAP Comparisons - MQ1~MQ9~RQ4~MC12 (20 Apr 10), Presented to SAB, June 2010; Brig. Gen. Blair Hansen, "Project Liberty 'MC-12'," Presented January 2010.

An analysis of costs per training hour[9] reveals that transition (traditionally trained) pilots cost approximately $2100/hour at the end of RPA training, SUPT (Specialized Undergraduate Pilot Training) pilots $500/hour, and Beta pilots[10] $150/hour, as shown in Figure 2-4. Thus, transition pilots cost more than an order of magnitude more per training hour than do Betas. Of note is the fact that current grade sheet analysis from the Predator schoolhouse (see Figure 2.4) shows that the transition pilots generally lag the SUPT pilots in performance, and on some measures, perform similarly to Beta pilots. So whereas transition pilots cost significantly more to train, they do not outperform their counterparts as would be expected given their training investment.



	Avg. $ cost per UAS training hour
TX	$2,108.66
SUPT	$498.59
Beta	$150.18

- **Beta classes generally seen as a failure across the stakeholders we interviewed:**
  - **Screening tools required external review**
  - **On several measures, TX performances were similar to Beta. SUPTs were clearly better than TXs and Betas**
- **Beta class "failures" required on average 20 extra hours of training (1.25 extra sorties)per pilot class of 8)**
  - **An addition of 2.2% off training time which = an additional $3003.60 to the $135,162 total**
- **Air Force Audit Agency proposes monetary benefits of ~1.5B with the introduction of Beta class UAS pilots**

Figure 2-4: Beta Class Performance.

Given that the training approach to generate more pilots can only partially address the RPA manning problem, one other solution is to have pilots control more than one vehicle simultaneously. Research has shown that one person can control anywhere from two to twelve independent RPAs, depending upon autonomy level and fidelity of decision support.[11] Although this may appear to be a clear technical solution, more

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[9] Assuming that 18 weeks of UAS training = 900 hours for SUPT and Beta, and 693 for TX pilots, source: Air Force Audit Agency Unmanned Aerial System Pilot Force Management Audit Report F2009-0005-fd4000 17 December 2008.

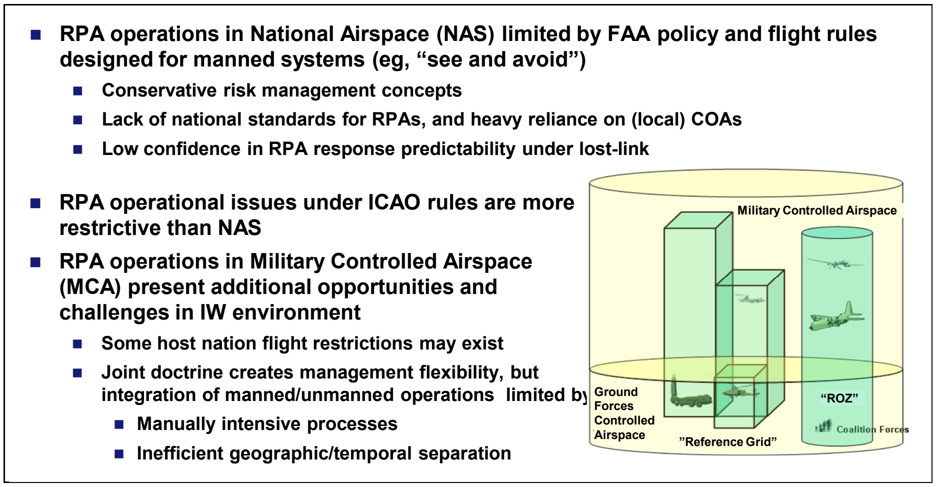
[10] The Beta program for training *ab initio* Remotely Piloted Aircraft (RPA) pilots was initiated to prove and refine training concepts and to alleviate pressure on conventional pilot training assets by creating a new pilot pipeline. A distinguishing characteristic of the Beta RPA pilot training track is reduced actual cockpit hours (44 hours in flight, versus approximately 200 or more hours in flight for conventional students). This results in reduced pipeline time and reduced expense, and helps evolve toward a professionally rewarding stand-alone RPA pilot career track.

[11] Cummings, M. L. et al. 2007. Automation Architecture for Single Operator-Multiple UAV Command and Control. *The International Command and Control Journal* 1(2): 1-24.

research is needed on how concepts of Operations (CONOPS) would and could change under this paradigm-shift, (i.e., should a pilot be on call for emergency events, are there certain mission types that require a pilot [like CAS or transit of the National Airspace (NAS)] while en route; can loiter missions be left to sensor operators with a pilot on call?).

2.2 Issue (2): Airspace Deconfliction and Management

A second issue identified in the TOR and illustrated in Figure 2-5 is airspace management and integration. The Federal Aviation Administration (FAA) is the governing agency responsible for establishing flight rules for the operation of air vehicles in the NAS, and their primary responsibility is to facilitate the flow of air traffic, while keeping the NAS safe for all operational users. The NAS is sub-divided into categories of airspace with various operational flight restrictions published to control traffic and mitigate risk. Operational rules such as flight under Visual Flight Rules (VFR) and Instrument Flight Rules (IFR), in concert with airspace categories and associated restrictions, help to manage the flow of a diverse variety of aircraft while deconflicting traffic and keeping the airspace safe for all users. These "rules of the road" were written with pilot capabilities as well as aircraft technical capabilities in mind, and the majority of the rules since their inception have been intended for manned vehicles.



- **RPA operations in National Airspace (NAS) limited by FAA policy and flight rules designed for manned systems (eg, "see and avoid")**
  - **Conservative risk management concepts**
  - **Lack of national standards for RPAs, and heavy reliance on (local) COAs**
  - **Low confidence in RPA response predictability under lost-link**
- **RPA operational issues under ICAO rules are more restrictive than NAS**
- **RPA operations in Military Controlled Airspace (MCA) present additional opportunities and challenges in IW environment**
  - **Some host nation flight restrictions may exist**
  - **Joint doctrine creates management flexibility, but integration of manned/unmanned operations limited by**
    - **Manually intensive processes**
    - **Inefficient geographic/temporal separation**

Figure 2-5: Airspace Management and Integration.

Managing the risks associated with flight in the NAS by a rapidly growing population of diverse RPAs, using VFR and IFR rulesets dependent upon pilot cockpit actions, presents challenging airspace management and integration issues for both the FAA and prospective NAS operators. While the FAA continues to study the full implications and risks associated with RPA flight in the NAS, unmanned flight risks are currently mitigated and permitted on a case by case basis, based on the application and approval of a formal FAA Certificate of Authorization (COA).

Approved COAs represent a "hand shake" between the Federal Government and the unmanned aircraft operator, to operate a specific aircraft in a defined geographic area under a set of flight rules for a specified period of time. COAs for governmental operators are typically approved for a year, and can be updated annually. While the COAs do permit flight in the NAS, and many are active today, most are very limited in nature, restricted to sparsely populated areas, and tend to avoid all major flight airways. COA approvals can take anywhere from months to years, which can seriously hamper Small Unmanned Aerial Systems (SUAS) development and testing.

For RPAs to be able to effectively integrate with manned aircraft in the NAS, the FAA continues to insist that the RPAs be capable of performing all of the flight rules which have been codified for pilot occupied cockpits. Flight by RPAs under VFR flight rules in Visual Meteorological Conditions (VMC) are fundamentally challenged by the ruleset which requires the pilot/RPA to be able to "see and avoid" and comply with published "right of way" maneuvers to avoid impending collisions. This requirement to see and avoid has become a show stopper for most UAS operators attempting to procure approved COA operations. As the RPA aircraft become larger, and the onboard systems more robust, there are more potential solutions (Traffic Collision Avoidance System [TCAS] with predictable avoidance maneuvers is one of these) which may provide the risk mitigations and capabilities that the FAA mandates.

It should be noted that TCAS was considered for implementation on Global Hawk and Predator Class vehicles; however, because of the bearing error data and low update rate of TCAS, the FAA and the International Civil Aviation Organization (ICAO) have stated that the TCAS display alone is not sufficient to provide the operator with enough situation awareness to avoid the threat. The inability to perform visual acquisition means that the traffic display information cannot be corroborated by the UAV operator, and therefore the certification authorities are concerned about its use.

The results of a dynamic simulation study conducted for Global Hawk indicate that a significant improvement in safety is provided by equipping the aircraft with TCAS in addition to its currently installed Mode S transponder.[12] Risk ratios from the TCAS-equipped cases in which the aircraft is permitted to fly a preplanned avoidance route are in the range of 0.003-0.079, compared to 0.004-0.058 for conventional aircraft; however, multi-aircraft avoidance, which might be required in military controlled airspace (MCA), was not considered. Also, if RPA pilots are required to disconnect the autopilot and fly the aircraft by hand, response times can vary significantly (because of communications latencies) and the risk increases accordingly. In addition, because TCAS operates by interrogating transponders on equipped aircraft, non-cooperative traffic, or aircraft without transponders, are not tracked by TCAS.

As illustrated earlier in Figure 1-2, RPAs are currently grouped into five categories, based upon size, and thus technical capability. In the top category, Group 5,

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[12] Billingsley, 2nd Lt. Thomas B., "Safety Analysis of TCAS on Global Hawk using Airspace Encounter Models", USAF Academy and MIT/Lincoln Labs, June 2006.

the USAF Global Hawk is a full sized aircraft with typical systems such as would be found in a manned aircraft. It includes all of the conventional instruments and navigation capabilities, is pre-programmed to fly precise navigation routes, and is connected to ground based operators thru the Ku Band Satellite infrastructure for real-time flight maneuvering. Group 4 includes the Predator/Reaper family of RPAs, also manned aircraft sized and very capable, comparable to the Global Hawk, and also flown thru the Ku Band system. The Department of Homeland Security has been flying the Predator Bin the NAS successfully on FAA COAs for more than five years. There are a very large number and variety of SUAS in the three smaller, Groups 1-3, but these aircraft are all subscale, with very limited technical capability in comparison those in Groups 4 and 5, and these aircraft are going to have a very difficult time getting approval for unrestricted flight in the NAS.

While the FAA works to adapt their legacy rulesets to accommodate RPA operations in the NAS, they continue to hold users to a very high standard, one which is unlikely to permit unfettered Group 1-3 RPA operation. Group 4-5 operation is a different case. An illustrative example is the Department of Homeland Security's (DHS) Predator B operation. The Predator family of RPAs has more than a million operational flight hours and has been in service for more than 15 years. It has all of the technical equipment found on the most sophisticated manned platform, including electro-optical/infrared (EO/IR) and synthetic aperture radar (SAR) sensors, and all of the necessary radios and navigation equipment to fly accurately and safely in the NAS. The aircraft is virtually flown by FAA certified pilots thru a Ku Band Satellite Link, has IFF (identification friend or foe) and TCAS (although the Air Force does not presently use TCAS). The aircraft are only flown from Department of Defense (DOD) operating bases on IFR Flight Plans, in the area of Positive Control (PCA). These missions are operational homeland security missions flown across the nation's borders, and the flights are under continual radar surveillance by local FAA and DOD radar sites that are actively monitored by the Air and Marine Operation System in Riverside CA. This facility is fully integrated with the FAA, with FAA controller presence and continual communication with all FAA Air Traffic Control Centers. When the aircraft is linked to the ground-based pilots, it can see and avoid on these missions better than a manned aircraft (because of additional ground feeds not normally available in a manned cockpit), but when link is lost, the aircraft navigates a pre-planned route, and it cannot see and avoid when it descends out of the PCA and enters the airspace where VFR rules mandate see and avoid capability.

In the last five years, DHS Predators have flown more than 6,000 operational hours in the NAS, and during all of that time, the RPA lost link only .05 percent of the time, with the longest lost-link period less than two minutes. The FAA considers lost-link a serious issue, and lost-link combined with unexpected aircraft motions in altitude control or navigation to be grounding errors.

Next Generation Air Traffic Control policies and technologies are being developed, and it is anticipated that the NextGen system will depend on cooperative onboard technologies to provide safe and effective airborne integration. The fact that the FAA plans to move away from non-cooperative ground based radars in favor of new onboard systems built on IFF, TCAS, and other emergent technologies does not bode well for small payload SUAS (Groups 1-3), but the larger RPAs in Groups 4 and 5 may be able to carry the new technology and meet future FAA rules for NAS flight.

In combat AORs, illustrated in Figure 2-6, the rulesets are defined by Military Controlled Airspace (MCA), and there is more flexibility in options for unmanned/manned integration. Combat theaters previously had more tolerance for collateral damage, gaining military advantage by easing flight rulesets. Today, the increased concern over collateral casualties among the civilian population and the ability to target individuals instead of areas, has led to a more stringently applied control and deconfliction between manned and unmanned systems, as well as joint operations by manned systems from various partner nations. In the combat theater there is more uniformity of operators and vehicle systems in various altitude regimes, and spatial-temporal exclusion zones provide the requisite degree of safety and separation necessary. The operation of RPAs in these environments is perhaps the best use for small subscale aircraft with high combat utility, but limited capability to meet FAA or ICAO rules for flight in the NAS. Group 4 and 5 RPAs are very capable in the MCA, and have the necessary potential for safe and unconstrained long range navigation in the NAS and in ICAO airspace on overseas missions. As onboard Next Gen technologies emerge, aircraft in this class that have the capacity to carry this new equipment should, with little problem, be able to safely fly the NAS along with manned aircraft .

In Military Controlled Airspace (MCA), the combat area is typically cordoned off into regions for flight of RPA Groups 1-3 at altitudes below 3,000 ft., which is controlled by ground forces (as shown in Figure 2-6). Closely associated with the requirement for enhanced situation awareness is the need to provide planners with the ability to rapidly conduct airspace reallocation to support mission re-planning. Currently, MCAs specified in the ACO remain in effect until the next ACO is published (normally every 24 hrs). This leads to an inefficient utilization of the air environment, as MCAs may only be required for a short time period. Even when an MCA is in use, it may be possible, with the ability to track assets within airspaces through enhanced SA, to temporarily reallocate potions of active airspaces to higher priority tasks. For example, if situation awareness allowed airspace managers to know that an airborne tanker was in the north of its designated orbit, they could temporarily reassign part the southern portion of the orbit to facilitate the transit of a Combat Search and Rescue (CSAR) package.

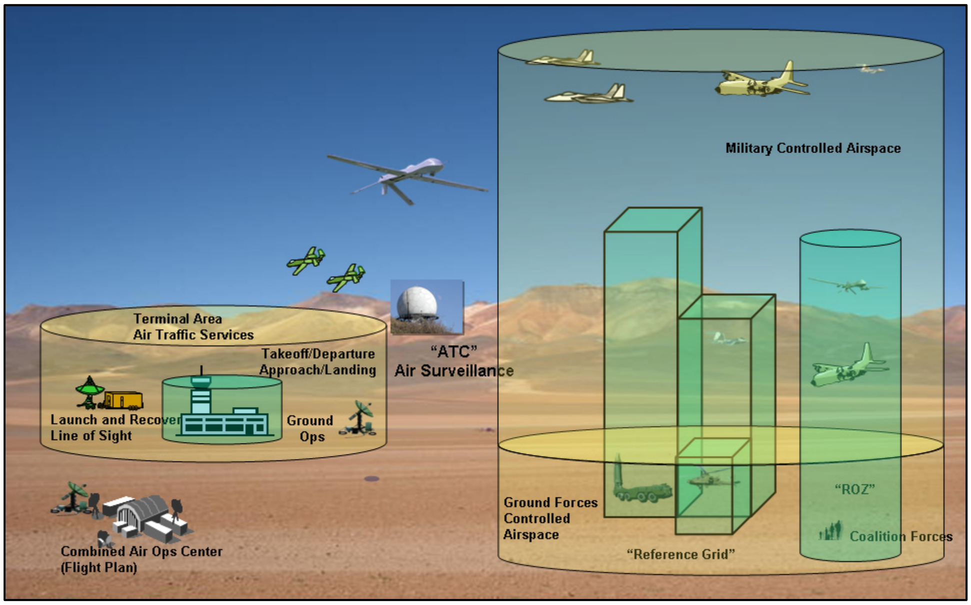

Figure 2-6: Improved Situation Awareness to Support Airspace Reallocation[13].

A long-standing problem in air warfare is the need to coordinate air and ground operations with the aim of preventing potential blue-on-blue engagements, both from the ground and from the air. This is a particularly relevant issue for the coordination of aircraft with ground-based air defense (GBAD). Airspace managers require improved situation awareness of air and ground operations, along with the current weapons control status, to ensure that appropriate measures are put in place to prevent fratricide incidents. This is especially germane in high-tempo operations in which both air and ground units are moving rapidly over wide geographical areas.

One of the greatest challenges facing airspace managers is their current inability to coordinate and deconflict the operation of RPAs. The unprecedented proliferation of RPAs in recent years, specifically within tactical level ground units and sub-units, has dramatically increased the risk to air operations. In Afghanistan, an Airbus 300B4 airliner with 100 personnel on board came within 170 feet of a German EMT Luna tactical RPA,[14] (see Figure 2-7) and in Iraq reports have indicated that helicopters have been struck by RPAs.[15]

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[13] "RPA Airspace Integration," Presentation to SAB by A3O, January 2010.

[14] "Near Misses Between UAVs And Airliners Prompt NATO Low-Level Rules Review," Flight International, March 2006.

[15] Erwin, Sandra I., "Controlling Iraq's Crowded Airspace No Easy Task," by Sandra I. Erwin, National Defense Magazine, November 2005.

Figure 2-7: German RPA in a Near Miss with an Airliner over Kabul (view from RPA)[16]*.*

This deconfliction issue becomes more complex when considering the integration of manned and unmanned vehicles in the same airspace. In this case, see and avoid becomes much more important, along with predictable avoidance maneuvers coupled with predictable lost-link maneuvers. Today's RPAs have not always exhibited these capabilities and thus we have reverted to assigned domains for each in segregated airspace.

However, the ability to exhibit these three attributes (sense and avoid, predictable avoidance maneuvers, and predictable lost-link maneuvers) are critical to both integrated military airspace and for integration into the national and international airspaces in the future. Thus, the Panel feels that working together with the FAA to determine reliable attributes for any RPA that would fly the NAS will not only reduce constraints in future CONUS operations, but will also move the Air Force ahead toward integrated air missions in the future in military controlled airspace.

Finally, operating RPAs in combat theaters around the world will necessitate compliance with International Civil Aviation Organization (ICAO) rules for flight operation in International Airspace. These rules, though similar in nature in terms of their flight procedures and risk mitigations, may be even more restrictive than flights in the NAS. Large RPAs in Group 4 and Group 5 with long range transit capabilities will be particularly susceptible to these issues during flights between operational areas in which the military are in control of airspace management and deconfliction.

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[16] Bundeswehr photo, 30 August 2004.

2.3 Issue (3): Minimizing Collateral Damage/Fratricide

A third issue identified by the Study Panel was collateral damage/fratricide (Figure 2-8). RPAs, originally developed for ISR operations, have become important weapons platforms for tactical and special strike missions in IW. Their expanded use in CAS missions in the future requires technology improvements for mission management to minimize fratricide, collateral damage (CD), and civilian casualties (CIVCAS).

In IW, success requires winning the "hearts and minds" of the population in the face of an adaptable and agile adversary hiding amongst them. A missile fired (e.g. Hellfire missile) from a RPA is no different from a Hellfire missile fired from other platforms like the AH-64 Apache. Causing collateral damage is not an issue unique to RPAs. Data obtained from the Afghanistan AOR[17] confirms that insurgents have caused approximately two thirds of CIVCAS. The exact number of CIVCAS caused by US forces was not reported, but an estimate from available data suggests the figure to be less than 10 percent. Of these CIVCAS, approximately half were caused by air-to-ground munitions, but the role of RPAs in these CIVCAS was also not reported. In the majority of these CIVCAS, inadequate acquisition and maintenance of positive target identification (PID) was the primary cause, and the ability to provide tactical patience during operations would have improved mission success and minimized CIVCAS. In an article by the Washington Post,[18] it was reported that within a recent 15-month period, the CIA conducted 70 RPA strikes using the low collateral damage focused lethality Scorpion weapon, killing 400 terrorists and insurgents while causing 20 CIVCAS. This CIVCAS figure was based on the use of RPAs to conduct pre-strike ISR and post-strike battle damage assessments. Because of precision targeting and focused lethality, CIVCAS is now primarily dependent on the human intelligence and situation awareness upon which the targeting decision is based.

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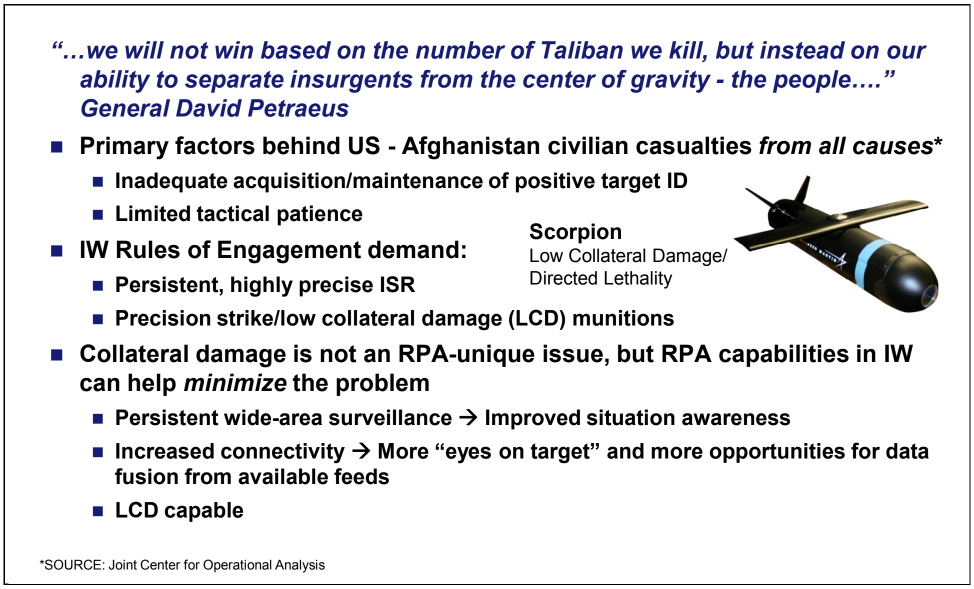
[17] Joint Center for Operational Analysis, Civilian Casualties in Afghanistan, 2010.

[18] Warrick, J., and Finn, P. "Amid outrage over civilian deaths in Pakistan, CIA turns to smaller missiles." Washington Post, April 26, 2010.



"…we will not win based on the number of Taliban we kill, but instead on our ability to separate insurgents from the center of gravity - the people…."
General David Petraeus

- **Primary factors behind US - Afghanistan civilian casualties *from all causes****
  - **Inadequate acquisition/maintenance of positive target ID**
  - **Limited tactical patience**
- **IW Rules of Engagement demand:**
  - **Persistent, highly precise ISR**
  - **Precision strike/low collateral damage (LCD) munitions**
- **Collateral damage is not an RPA-unique issue, but RPA capabilities in IW can help *minimize* the problem**
  - **Persistent wide-area surveillance → Improved situation awareness**
  - **Increased connectivity → More "eyes on target" and more opportunities for data fusion from available feeds**
  - **LCD capable**

Scorpion
Low Collateral Damage/
Directed Lethality

*SOURCE: Joint Center for Operational Analysis

Figure 2-8: Collateral Damage.

An advantage of the RPA is greater pre-strike surveillance capability that can better prevent collateral damage. RPAs provide the ability to conduct ISR to gather "pattern-of-life" information and thus allow their human operators to distinguish between non-combatants and legitimate targets. Importantly, the use of future RPAs in IW may well prove to be a solution to the CD dilemma, rather than an additional source of the problem.

In current IW operations, the Rules of Engagement (ROEs) emphasizing low collateral damage generate challenging requirements. To minimize targeting of non-combatants, persistent and highly precise ISR must be available. To minimize blast effects beyond the desired target, focused lethality strike weapons must be employed. An increased RPA ISR persistence capability needs to enable continuous tracking to improve target confidence via multi-sensor pods (e.g., Gorgon Stare), efficient cross-cueing, multi-INT fusion, and automated processing of FMV for event detection. To increase the likelihood of positive target identification future RPAs should provide high definition EO and IR FMV, and have the capability for high-definition (HD) single-frame photography.

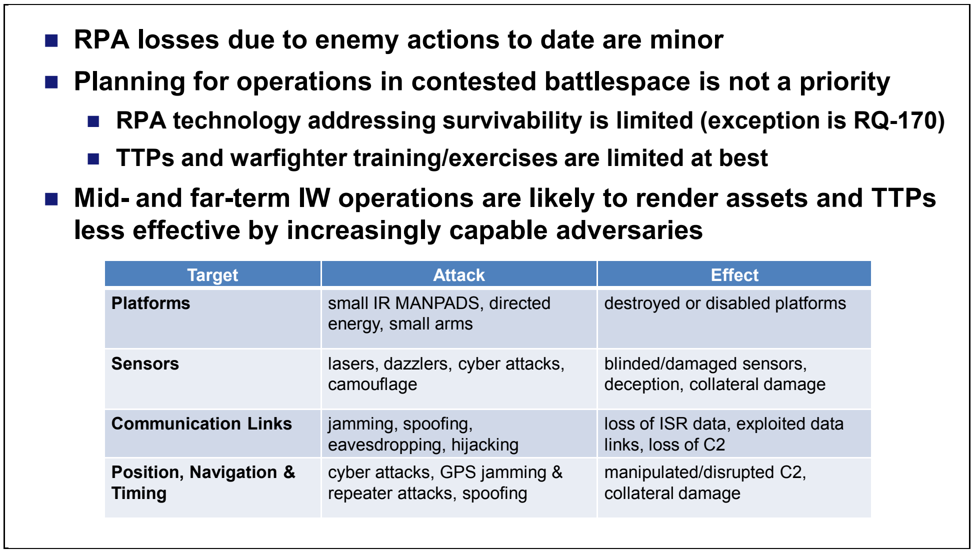
In future RPA operations, networked distributed operations promise to minimize CD by providing more "eyes on target" and thus better situation awareness and rapid transfer of flight control and munitions delivery to specialized operators best prepared for the dynamic tactical situation.

Future RPA missions in IW can benefit from the development of low collateral damage munitions that are optimized for focused lethality and directional kinetic effect. In IW, it can be more appropriate to capture rather than kill the enemy, so RPAs can be valuable in allowing for the use of less-than-lethal force to neutralize a target. Options for new non-lethal approaches (e.g., acoustic, directed energy) and expanding RPA capacity for non-kinetic operations (e.g., show of force, PSYOP, strategic communication) hold promise to enable RPAs to be an effective weapons platform while reducing the risk of collateral damage.

2.4 Issue (4): Operations in Contested Airspace

The nature of air warfare in irregular warfare is dramatically different from operation in denied anti-access airspace protected by a sophisticated Integrated Air Defense System (IADS). Today the Air Force employs theater-capable Group 4-5 RPA platforms primarily for ISR, tactical ISR, counter insurgency, and time sensitive target (TST) operations. The experiences in Iraq and Afghanistan in the absence of an IADS are that counter-RPA action is more a "pick up" collection of small arms, rocket propelled grenades (RPG), a few shoulder fired missiles, and some rudimentary electronic warfare (EW) jamming devices.

As noted in Figure 2-9, the Study Panel is aware of only a few instances of enemy fire destroying an RPA, all of that prior to 2006. In the midst of the challenges imposed by providing additional support to the ground troops, previous and ongoing experience makes preparations for operations in contested battlespace a low priority task. The impact of this is apparent both in the limited use of technology to enhance survivability (the notable exception is RQ-170), and in the limited development of TTPs and conduct of warfighter training/exercises.



- **RPA losses due to enemy actions to date are minor**
- **Planning for operations in contested battlespace is not a priority**
  - **RPA technology addressing survivability is limited (exception is RQ-170)**
  - **TTPs and warfighter training/exercises are limited at best**
- **Mid- and far-term IW operations are likely to render assets and TTPs less effective by increasingly capable adversaries**

Target	Attack	Effect
Platforms	small IR MANPADS, directed energy, small arms	destroyed or disabled platforms
Sensors	lasers, dazzlers, cyber attacks, camouflage	blinded/damaged sensors, deception, collateral damage
Communication Links	jamming, spoofing, eavesdropping, hijacking	loss of ISR data, exploited data links, loss of C2
Position, Navigation & Timing	cyber attacks, GPS jamming & repeater attacks, spoofing	manipulated/disrupted C2, collateral damage

Figure 2-9: Contested Environment Operations.

Although the threat today is limited, one can expect that the defenses against RPAs will improve in future IW scenarios, for two reasons: 1) as RPAs become more effective against IW operations, adversaries will be driven to finding countermeasures and 2) the simple diffusion of technology will provide the needed capability.

2.4.1 Threat to Platforms

The relatively large size of Group 4-5 platforms offers several opportunities for defense:

- In the future, relatively simple acoustic receivers capable of detecting and localizing RPAs are quite possible and could have a simple processing capability to classify the aircraft.
- Low-cost air acquisition radars could be in the hands of combatants, though probably effective only against the larger, faster RPAs. A rudimentary network, perhaps as simple as voice "forward-tell" will enhance the Find/Fix capability, but it unlikely that an IADS as we know it will appear in the short term.
- The most likely area of improvement in the air defenses of adversaries against the larger, faster, and higher RPAs in the IW of the future will be in the use of small shoulder-fired surface-to-air missiles (MANPADS), some developed in the US (Stinger) and Russia (SA-16/18), stolen or copied by these adversaries, but more likely manufactured by countries sympathetic to their cause. Though the range is limited to a few miles, improvements are likely, and such weapons are easily smuggled between countries. The use of mobile SAMs such as the SA-6, SA-11, and SA-17 that would be effective at the operating altitudes of the Predator/Reaper is less likely in IW, but with cases of strong backing by major military powers, they could appear.
- There have been a few RPA shoot-downs by aircraft. These have involved RPAs comparable to the Group 3 RPAs and have generally been attributed to IR missiles fired from fighter aircraft. The IW environment is unlikely to include such threats.
- The 2006 AF SAB Summer Study, "Air Defense Against Unmanned Aerial Vehicles," addressed the actions the US could take to defend against UAV/RPA attacks at home and abroad, and suggested near-term actions as well as both near- and far-term technology development programs. Though focusing on what systems the US could employ against enemy RPAs, it suggested several other possibilities worth considering as future threats. A potential enemy could obtain, at modest cost, small vehicle-mounted radar-directed high-rate guns already developed and tested in the US. Netted material could be launched into the flight paths of smaller RPAs flying at low altitudes. The Study Report is recommended for further review of potential threats.

For the larger Group 4-5 RPAs, there is a case for making the aircraft more survivable for the sophisticated defenses expected during Major Combat Operations (MCO). A modern IADS would quickly decimate the current Predator/Reaper fleet and be a serious threat against the high-flying Global Hawk. In the IW scenario, however, the case for highly survivable RPAs is less compelling. As discussed, MANPADS (particularly IR) are likely the greatest threat for these RPAs, so highly survivable designs may not be necessary.

Self-protection equipment such as jammers, RF and IR flares, towed decoys, etc. is not suggested for Group 1-3 RPAs, as the weight alone would require unacceptable reductions in payload or fuel. Group 4-5 RPA development efforts that are more advanced than Predator/Reaper (UCAV, UCAS, for example) have high price tags driven largely by design, manufacturing, and maintenance costs associated with high survivability requirements. Typically, active self protection techniques are additive and are costly as well. A limited suite matched to the likely threats (IR flares against MANPADS, etc.) that are fully automated should be considered for future IW engagements. Given the smaller nature of the RPA signatures, a new class of expendable decoys may be necessary.

The Panel feels that the costs of hardening a smaller RPA against even a modest threat would quickly become prohibitive. A better approach for the smaller Group 1-3 RPAs should be to reduce unit costs to a level at which moderate losses would be acceptable. Low cost, “expendable” RPAs will enable the extensive use of redundancy to mitigate threats and improve resilience. The use of “swarms” to accomplish the tasks at hand, coupled with multi-vehicle mission management concepts, including threat avoidance (route planning, pseudo-random flight paths [jinking], low cost decoys, etc.), and accepting the potential losses could be made cost effective.

Consideration should be given to manufacturing and deploying representative RPAs without the expensive mission equipment to be used as expendable decoys, drawing defensive fire and perhaps exhausting the adversary’s munitions. At a minimum, the decoys, flown with well-thought-out tactics will expose the location of the adversaries. These decoys (with visual, acoustic, and infrared signatures similar to those of the mission-focused RPAs) could be operated within the swarm, perhaps at lower altitudes to divert attention from the mission-focused RPAs. Critical to this concept is lowering the cost of manufacture of the airframes, engines, and communications links.

2.4.2 Threat to Sensors

Effective ISR operations can be degraded by sensor attacks that may include a number of methods. Examples include:

- Adversaries can use lasers and dazzlers to blind or damage EO/IR sensors.
- Widely available techniques for camouflaging can hide potential targets or can be used for deception.
- Cyber attacks for spoofing or distorting sensor downloads may lead to inaccuracies that can result in increased collateral damage.

The cost of RPA systems is dominated by the cost of the mission package (sensors, sensor processing, wideband data links, weapons, etc.). The hunger for higher-resolution and larger images, and bigger weapons effects is expanding in an uncontrolled fashion. Improved electronic manufacturing techniques coupled with higher production quantities can provide some cost reduction, but RPA mission packages will remain high cost items for the foreseeable future.

2.4.3 Threat to Communication Links

Current RPA operations depend on maintaining high reliability of communication links; therefore they are a primary target of the adversary:

- Jamming of commercial satellite communications (SATCOM) links is a widely available technology. It can provide an effective tool for adversaries against data links or as a way for command and control (C2) denial.
- Operational needs may require the use of unencrypted data links to provide broadcast services to ground troops without security clearances. Eavesdropping on these links is a known exploit that is available to adversaries for extremely low cost.
- Spoofing or hijacking links can lead to damaging missions, or even to platform loss.

Recognizing that there is a possibility that a determined adversary could employ relatively simple jammer techniques to disrupt navigation and communications, there are some actions that can be taken to reduce the effect of the jamming. Given that the character of a jammer used by an adversary in IW will probably have limited effective range, global position satellite (GPS) jamming can be mitigated by including a simple flight management auto-pilot that can just adopt/maintain a heading to clear the jammer (effecting a simple threat avoidance maneuver). As for communications jamming, a number of modest-cost electronic counter countermeasure (ECCM) radios exist and are in use for Group 4-5 (and perhaps Group 3) which, along with a communications architecture that includes alternate control communications paths, can similarly escape the jammed region. For the smaller Group 1-2 platforms, simple spread spectrum radios may escape detection and would survive some jamming. Such spread spectrum radios are already in use by model aircraft enthusiasts who want to avoid unintentional frequency conflicts and jamming.

Jamming or exploitation of wideband sensor communications is more complex as is the protection against such actions. NSA Type 1 encryption has been tested on Rover 5 radios used by forward personnel to receive RPA imagery and could be easily included in the future. Some current wideband communications systems have ECCM features that would likely survive the nature of countermeasures characteristic of IW forces.

2.4.4 Threat to Position, Navigation, and Guidance

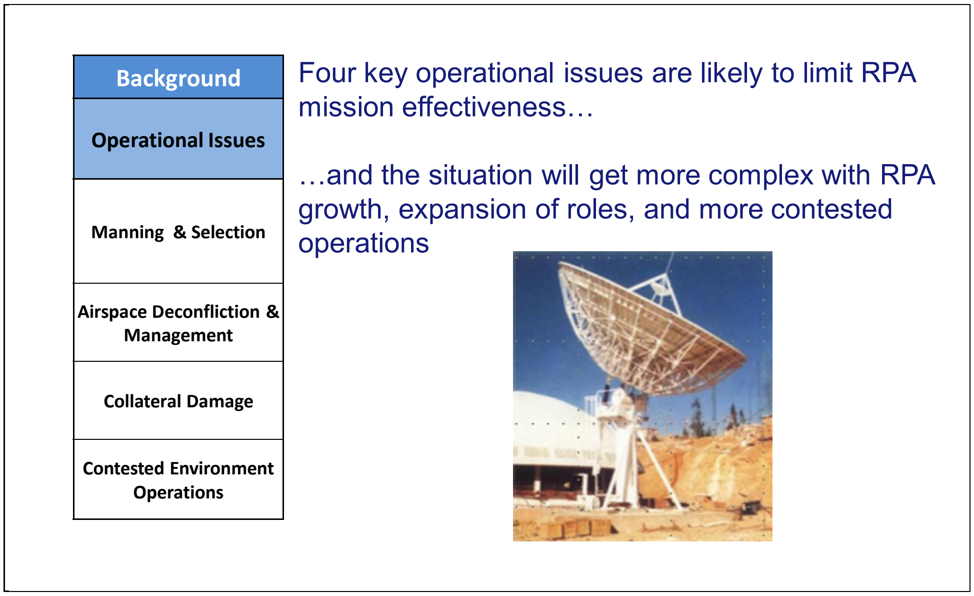
There is a wide range of methods that a determined adversary can use for attacking RPA guidance and navigation systems. The report mentions here only three categories of threats without going into the details:

- Small, simple GPS noise jammers can be easily constructed and employed by an unsophisticated adversary and would be effective over a limited RPA operating area.

- GPS repeaters are also available for corrupting navigation capabilities of RPAs.
- Cyber threats represent a major challenge for future RPA operations. Cyber attacks can affect both on-board and ground systems, and exploits may range from asymmetric CNO attacks to highly sophisticated electronic systems and software attacks.

2.5 Summary of Issues

RPA mission effectiveness will not reach full potential, unless the Air Force deals directly with four key operational issues including manning shortfalls and personnel selection, airspace management and integration, collateral damage and fratricide, and operations in contested environments (Figure 2-10). These issues will grow in severity with time for a variety of reasons including RPA growth in numbers and density, expansion of assigned operational roles, increasing importance of information operations in IW, and movement from advantaged (or benign) operating environments to more disadvantaged environments, stressed by weather conditions and/or adversary action. Having identified the major issues, in the following section the Study Panel identifies the key Mission Management gaps at the root of these issues.



Background

Operational Issues

Manning & Selection

Airspace Deconfliction & Management

Collateral Damage

Contested Environment Operations

Four key operational issues are likely to limit RPA mission effectiveness…

…and the situation will get more complex with RPA growth, expansion of roles, and more contested operations

Figure 2-10: Summary of Operational Issues.

Chapter 3: Major Findings

Following a process of data collection, interaction with subject matter experts, and Panel deliberation, the Study Panel identified several key findings that hamper the effective mission management of RPAs. As detailed below, in terms of technical findings, the Study Panel found insufficient and inflexible platform automation, poorly designed operator control stations, and limited communications systems. In terms of personnel and processes, the Study Panel found unsubstantiated selection criteria, costly, sub-optimal training, and lagging Concepts of Operations (CONOPS) and Tactics, Techniques, and Procedures (TTPs). These findings are now considered in detail.

3.1 Finding (1): Insufficient and Inflexible Platform Automation

The Study Panel's first finding was insufficient and inflexible automation. Current RPA automation implementations contribute to poor operator situation awareness (SA), increased workload, and reduced effectiveness (Figure 3-1).

Current RPA automation implementations either under-automate, over-automate, or fail to provide a flexible human-centric solution

- **Under-automation in key capability areas**
  - **Auto-takeoff/landing (MQ-1/9), dynamic route replanning**
  - **Sense and avoid**
  - **Auto target cueing/tracking; sensor-slaved flight control**
  - **Transfer of RPA control between OCSs**
- **Overly-automated tasks**
  - **Predator fully automated mission employment mode never used**
  - **Global Hawk automated mission execution resists response to *ad hoc* tasking**
  - **High levels of automation reduce human operator vigilance, skills**
- **Inflexible human-automation interaction deficiencies**
  - **Difficult to adjust automation levels to best fit mission need**
    - **No fine-grained control of automation**
    - **Abrupt transitions between automation levels disrupt missions ops**
  - **Lack of automation transparency/feedback decreases operator SA, safety**

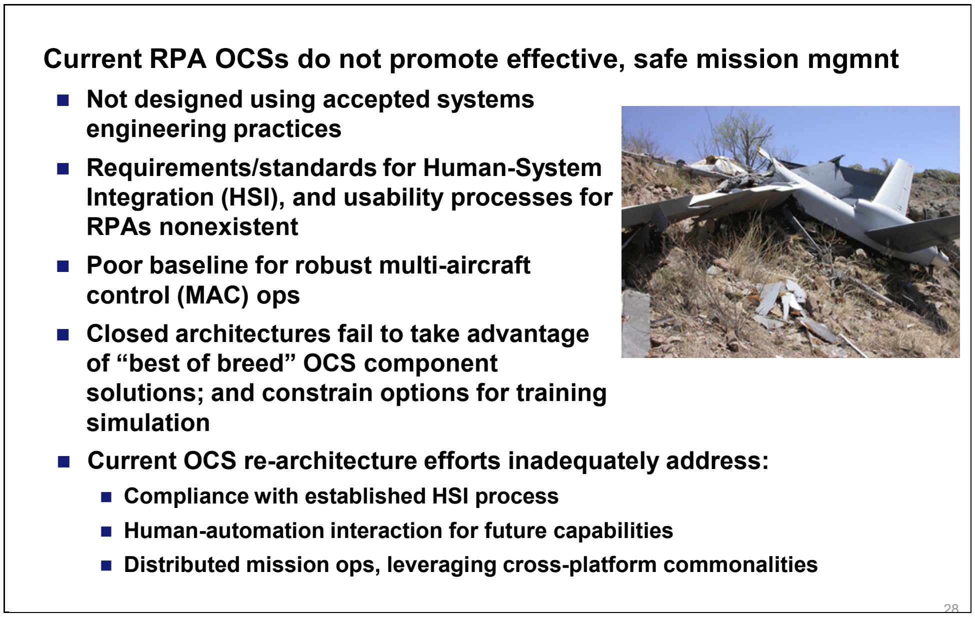
Figure 3-1: Automation Findings.

There is a lack of RPA automation in several key capability areas including airspace integration, contested airspace operations, and single/multi-vehicle control by a single operator. Examples include flight management (e.g., dynamic mission replanning, vehicle handoffs, sense and avoid, threat awareness/avoidance, terminal area operations) and sensor management (e.g., change detection, object identification and tracking in complex environments, event detection, cross sensor target cueing, sensor fusion) functions. As a result, these functions often require a significant amount of time (e.g., 20 minutes to transfer vehicular control of Predators between ground stations) and manual effort to accomplish (e.g., many individuals must simultaneously inspect full motion video for targets). In some cases, required automation is absent (e.g., there is currently no threat detection capability on AF RPAs and multi-aircraft control capability is very limited).

Secondly, automation that does exist is often poorly designed for the variety of missions experienced in dynamic real-world operations. Automation seems to have been applied where it was most feasible rather than where it was most needed. Current automation capability is narrowly focused and is often characterized by poor and inflexible human-automation interaction. As an example, the Predator/Reaper can theoretically perform entire missions in a fully automated manner, but this capability is never employed because the automation cannot accurately sense or respond to dynamic mission requirements. The Global Hawk is highly automated but requires significant time to fully plan the mission before a flight, and this automation is very cumbersome to override in flight in response to *ad hoc* tasking. In general, currently implemented automation is not adjustable, so that the RPA operator cannot quickly customize a response to a new situation by applying automation at a level (from no automation, to semi-automated, to fully-automated) that provides the most effective performance for the specific context at hand. In some cases, a fully automated response may be appropriate, while in others the human operator may need to more directly interact with the system at some level (e.g., information acquisition, situation assessment, decision making, action implementation) to achieve the desired outcome. As a simple example, the Predator pilot cannot control bank angle while in autopilot, resulting in suboptimal sensor standoff range during loiter unless the pilot completely disengages the autopilot. Additionally, operators are often not made aware of exactly what the automation is doing or planning to do, and why (a lack of mode awareness, lack of shared situation awareness, etc.). Two such examples involved Global Hawk altitude deviation incidents due in part to the operator being unaware of how the automation was responding to the current situation. This lack of automation transparency decreases operator SA and trust in the automation and it increases the potential for decision-making errors that reduce mission effectiveness or lead to unrecoverable events.

With exponentially increasing amounts of ISR data generated from current as well as soon-to-be-fielded wide-area persistent sensors (e.g., Gorgon Stare, ARGUS-IS), the need for sensor/image processing automation is greater than ever. If all this sensor information could be transmitted for viewing (itself a huge issue due to data link transmission rates), the existing cadre of sensor operators and image analysts would be impossibly overloaded. As a result, increased sensor and image processing automation will be required to assist sensor operators and image analysts in rapidly collecting and exploiting imagery to support upcoming IW missions. In addition, recognizing that current and envisioned sensor hardware can/will produce data at rates of 10 to over 1000 times available communications data transmission rates, significant sensor/image processing automation will likely need to be handled onboard the RPA. For example, experience with manned platforms (e.g., Constant Hawk and Angel Fire), as well as with ARGUS-IS components, provides evidence that automated change detection is a tool which can be used to identify within frame motion, support image-driven tracking of multiple objects, determine the need for increased/decreased frame transmission rates, and determine the need for resolution adjustments in selected portions of the imaged scene.

3.2 Finding (2): Poorly Designed Operator Control Stations



Current RPA OCSs do not promote effective, safe mission mgmnt

- **Not designed using accepted systems engineering practices**
- **Requirements/standards for Human-System Integration (HSI), and usability processes for RPAs nonexistent**
- **Poor baseline for robust multi-aircraft control (MAC) ops**
- **Closed architectures fail to take advantage of "best of breed" OCS component solutions; and constrain options for training simulation**
- **Current OCS re-architecture efforts inadequately address:**
    - **Compliance with established HSI process**
    - **Human-automation interaction for future capabilities**
    - **Distributed mission ops, leveraging cross-platform commonalities**

Figure 3-2: Operator Control Stations Findings.

The term "unmanned aerial vehicle (UAV)" is a misnomer, as illustrated by the Air Force desire to emphasize the term "remotely piloted aircraft." Although the crew is no longer on board the platform, there clearly remains a critical need for human involvement for RPAs to successfully perform missions today and well into the future. This is especially true for complex, rapidly changing, and time-critical mission areas such as tactical reconnaissance and close air support. Algorithms to enable autonomous RPA operations in these mission areas do not exist due to a variety of reasons: many relevant mission inputs are not digitized (and thus not available for input into these algorithms in real-time); target/friendly/non-combatant identification is complex, uncertain and variable; mission objectives vary constantly as does the ground situation; and decisions often must take into account abstract considerations such as ethics and secondary/tertiary effects of actions. Thus, even as automation matures, the human RPA operator will remain a critical element of the system, with the sole link connecting the human mind to the RPA being the operator control station (OCS).

However, for the three largest Air Force RPA systems (Predator, Reaper, Global Hawk), these key subsystems remain largely unimproved from their initial engineering prototype configurations developed under an ACTD 10-15 years earlier. As illustrated in Figure 3-3, current operator interfaces are replete with interface deficiencies, including inefficient and ineffective acquisition and processing of information, cumbersome control implementations, poor situation awareness, high workload at inopportune times, lack of automation mode awareness, and inadequate ergonomics.

As summarized in Figure 3-2, current OCSs are highly proprietary, platform-specific designs that do not follow a standard-based open architecture. This limits the potential for interoperability and plug-and-play modularity, while increasing personnel training time and costs. These OCSs (and those for smaller RPAs as well) were not designed using accepted systems engineering practices including Human System Integration and usability processes. These deficiencies have contributed to several mishaps as well as lower mission effectiveness.[19] As RPAs become more capable, mission sets expand, and network capabilities increase, the OCS will likely become a primary limiting factor towards mission success and safety unless immediate steps are taken to improve this critical component. As one example, a key vision of the AF RPA Flight Plan (and one often advocated by CSAF at recent briefings) is the ability of single crews to simultaneously control (i.e., supervise) multiple RPAs. Current OCS designs are not readily extendable to these multi-aircraft control operations[20], requiring significant advances in mission management of critical information and aircraft control systems.

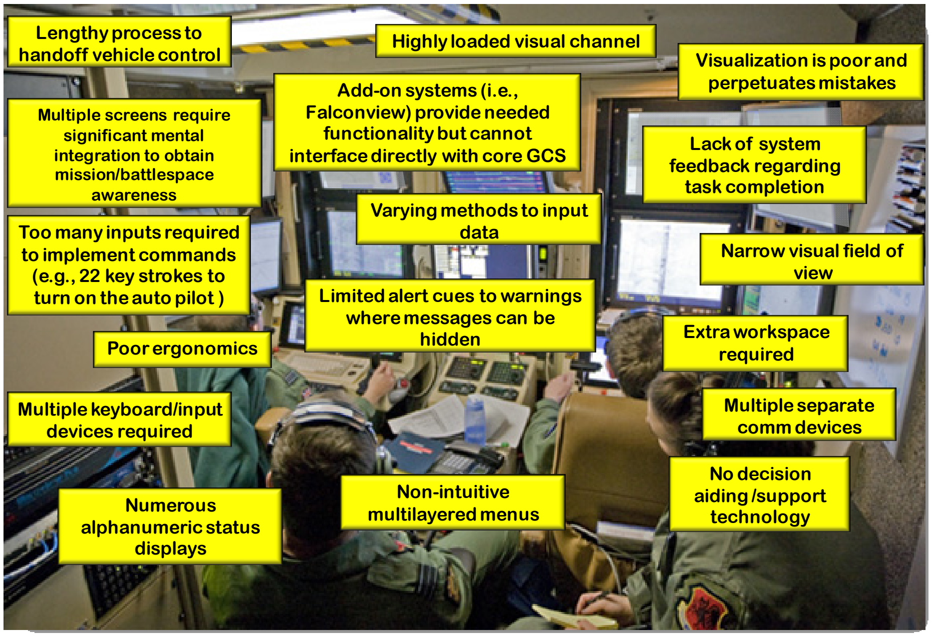


Figure 3-3: Human System Integration (HIS) Issues with Operator Control Stations for Predator/Reaper.

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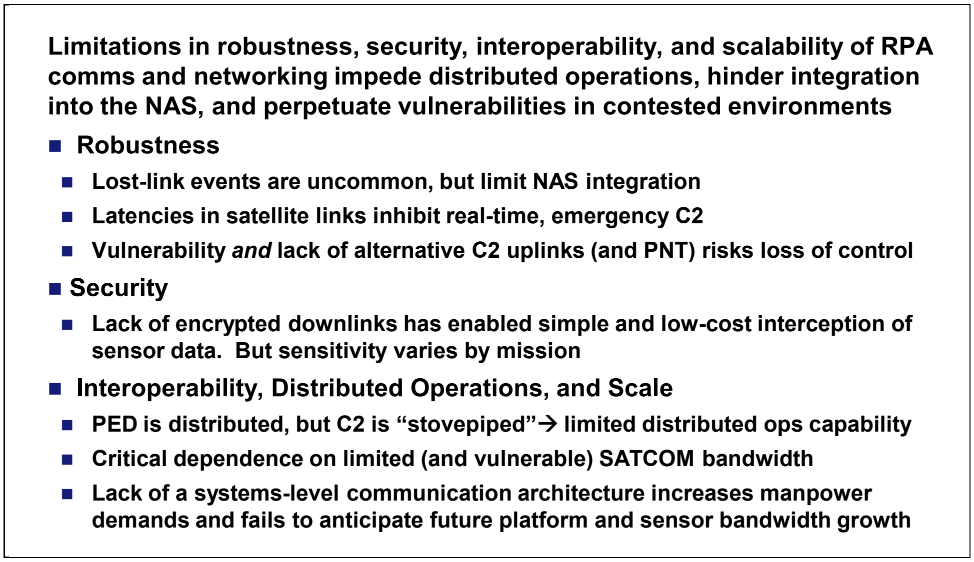
[19] Cooke, N. J., Pringle, H., Pedersen, H., and Connor, O. (Eds.) (2006*). Human Factors of Remotely Operated Vehicles.* Volume in *Advances in Human Performance and Cognitive Engineering Research* Series, Elsevier.

[20] ACC MAC Report.

Current acquisition efforts are now underway to improve the OCS of the three largest AF RPAs (e.g., Predator/Reaper Block 50 Advanced Cockpit Program, and the Global Hawk Ground Segment Re-Architecture Project). These efforts appear to be implementing some human-computer interface improvements as well as a more modular software architecture for the OCS. These efforts represent steps in the right direction, but they still do not fully address the need for: 1) improved system automation implementations with associated improvements to human-automation interaction; 2) future capabilities such as multi-aircraft control and globally-distributed RPA control (beyond designing for physical connectivity); 3) the potential for commonalities between major AF RPA OCSs; and 4) the need to follow an established Human-System Integration (HSI) process in acquiring systems that are fully matched to the knowledge, skills, and abilities of the human operator.

3.3 Finding 3: Limited Communications Systems

The Study Panel also found that limitations in RPA communications and networking impede distributed operations, hinder integration into the NAS, and perpetuate vulnerabilities in contested environments (Figure 3-4). The Panel identified issues with robustness, security, interoperability, and bandwidth.



Limitations in robustness, security, interoperability, and scalability of RPA comms and networking impede distributed operations, hinder integration into the NAS, and perpetuate vulnerabilities in contested environments

- **Robustness**
  - **Lost-link events are uncommon, but limit NAS integration**
  - **Latencies in satellite links inhibit real-time, emergency C2**
  - **Vulnerability *and* lack of alternative C2 uplinks (and PNT) risks loss of control**
- **Security**
  - **Lack of encrypted downlinks has enabled simple and low-cost interception of sensor data. But sensitivity varies by mission**
- **Interoperability, Distributed Operations, and Scale**
  - **PED is distributed, but C2 is "stovepiped"→ limited distributed ops capability**
  - **Critical dependence on limited (and vulnerable) SATCOM bandwidth**
  - **Lack of a systems-level communication architecture increases manpower demands and fails to anticipate future platform and sensor bandwidth growth**

Figure 3-4: Limited Communications Systems.

3.3.1 Security and Robustness

The Study Panel found limitations in security and robustness in terms of lost-link events, communication latency, and limited encryption.

3.3.2 Lost-Link Events

Lost-link events are operationally uncommon,[21] yet of primary concern for operations in the NAS. Risk mitigation techniques include ground-based and air-based sense and avoid (GBSAA and ABSAA, respectively). GBSAA may require augmentation of existing air surveillance radar with 3D position information, with an estimated installation time of 2-3 years (in excess of $3M per site). A cooperative ABSAA approach is better for lost-link events, as it only requires air-to-air communications over relatively short distances. Current Traffic Collision Avoidance System (TCAS) implementations are thought to be insufficient for ABSAA because of limited accuracy and deployment, but Automatic Dependent Surveillance Broadcast (ADS-B), required in all non-exempt aircraft by 2020, should suffice. Unfortunately, ABSAA with *uncooperative* aircraft is estimated to be more than 12 years out. In 2012, the *World Radio Conference* (WRC-12) will consider allocation of a reserved spectrum for implementing high reliability UAS command and control (C2) links (agenda item 1.3). This offers the potential of reducing interference from other spectrum users.[22] Lost-link, if persistent, can lead to loss of mission effectiveness while the aircraft diverts to a holding pattern or returns home.

3.3.3 Latency

A geosynchronous satellite (GEO), used today in RPA Remote Split Operations, imposes at least 250 milliseconds latency. Actual latencies may be twice these values or more because of queuing, framing, error correction, and coding, assuming only a single satellite hop is required; a multi-satellite hop could incur in excess of a second latency. Because interactive human-in-the-loop control activities require no more than about 200 milliseconds latency, any fine-grain rapidly interacting control of the platform, such as flight control during takeoff or landing must be accomplished in one of two ways: automatically via an on-board flight controller, or manually, via an operator located in the area of operations and linked to the platform by a line-of-sight (LOS) communications link (in this case, C Band comms) Because the USAF has chosen not to automate these flight critical functions (takeoff and landing), personnel need to be placed in or near the Area of Responsibility (AOR), operating OCSs near the airfield, connected to the platform by LOS communications links, at least for the takeoff and landing portions of the mission.

Even if some flight critical functions were to be automated, there could still be advantages gained in reducing latencies associated with CONUS-based OCSs, for example, in collision avoidance maneuvers in heavy traffic, or in jinking maneuvers to evade threats. Alternative satellite technologies (Low Earth Orbit [LEO], Medium Earth Orbit [MEO]) offer substantially decreased latencies (potentially under 50ms), but few

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[21] Sanitate, Guy, AF/A30-AOZ, (U) “UAS Link Vulnerabilities and Mitigation,” 16 Nov 09.

[22] Lacher, A., Zeitlin, A., Maroney, D., Markin, K., Ludwig, D., and Boyd, J. "Airspace Integration Alternatives for Unmanned Aircraft", AUVSI Unmanned Systems Asia-Pacific Conference, Feb 2010.

such systems are readily available and they do not in general guarantee assured access. Nonetheless, these could be used as alternative C2 channels for the full range of RPAs (Iridium has been demonstrated on Global Hawk). Sensor data, if delay-tolerant, could remain on GEO or use store-forward satellites since storage density has increased dramatically in recent years. Additional autonomy and onboard processing/exploitation could also relax the need to send sensor data (like full motion video [FMV]) with low latency to a remote operator.

3.3.4 Encryption and Potential C2 Link Vulnerabilities

Historically, sensor/data downlinks for some RPAs have not been encrypted or obfuscated. Unencrypted sensor data (e.g., FMV) is beneficial because the downlink is used to feed ROVER systems used by Joint Terminal Attack Controllers (JTAC) and other ground personnel, including uncleared coalition members and contractors. This is a life-saving capability. Nevertheless, not protecting against interception of sensor data has been criticized.[*] "Fixing" this security issue by mandating NSA Type 1 encryption is likely to lead to an unacceptable key management burden because of the large number of users of RPA data that have a wide variety of access rights. However, commercial-grade, NSA-approved cryptography is available ("Suite B"). Commercial cryptography of this kind does not require the same degree of rigor in handling key material and encryption devices, and is not limited in operation to cleared personnel. There is relevant Department of Defense (DOD) activity in this general area.[23]

Encryption has generally been used on C2 messages because the risks associated with compromise are higher (loss of the vehicle), and there is a greatly reduced need for sharing of the C2 data as compared with sensor data. However, crypto issues will likely be exacerbated when doing coalition/joint swarming across platforms that require shared C2 across security domains – a capability that is desired to fully exploit the potential of networked RPA operations.

3.3.5 Interoperability, Distributed Operations, and Scale

The Study Panel found limitations in interoperability, distributed operations, and scale as evidenced by stovepiped operations, insufficient satellite communications (SATCOM) bandwidth, and the need for a long-term communication architecture.

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[*] And not just because of the press coverage of Iraqi insurgent downlink capture (e.g., "Insurgents Hack U.S. Drones," Wall Street Journal, 17 December 2009). Although debated, access to RPA sensor data and accompanying meta-data can provide at least the following potentially sensitive information: detailed imagery of wherever the RPA travels (including takeoff and landing sites), effectiveness of adversary camouflage, behavior of weapon systems, TTPs in use, and "movies" of high-regret operations with potentially significant IO implications.

[23] see ASD/NII DTM-09-004 [April 2009]

3.3.6 Stovepiped Operations

Current RPA C2 systems tend to be stovepiped in the sense that they provide limited options for interfacing current mission state with other distributed system elements and, conversely, limited options for interfacing different types of OCSs with an aircraft after the commencement of a mission. AF operators reported a 20-minute delay is required to (manually) effect a "handoff" from one OCS to another. In addition, both the communications and software architectures of several fielded RPA systems (e.g., Predator) are proprietary, and do not allow processing of C2 or sensor data feeds from multiple, heterogeneous systems. The upshot of these deficiencies is that situation awareness is reduced, and more personnel are required (than should be) to produce a set of mission effects. If designs are less stovepiped, air assets, pilots, and analysts could be treated as common resources across multiple RPAs and missions, leading to a form of statistical multiplexing gain in operational efficiency.

3.3.7 SATCOM Bandwidth

Current Remote Split Operations are dependent on availability of satellite communications, much of which is purchased from the commercial sector. Assuming no radical departure from current practice is undertaken, future RPA-based sensor technologies (e.g., Gorgon Stare, ARGUS-IS) will require bandwidth on the order of 100 times more than that needed by current RPA sensors. This presents a significant challenge, as the current demand for SATCOM is already outpacing its availability. Depending on the operating environment, there may be alternatives to SATCOM (e.g., airborne relays, laser communications). One of these includes Battlefield Airborne Communications Node (BACN) as an airborne RPA communications relay, although this would introduce yet another ground station to integrate and operate and another airborne system to deconflict. In addition, sufficiently robust on-board sensor processing may reduce the need for off-platform communications, thereby reducing the impact on SATCOM demand.

3.3.8 Long-Term Communication Architecture

The current approach to RPA management has evolved based on an ACTD process leading to the stovepiped systems the Air Force has today. Consequently, RPAs and their corresponding OCSs are not easily interfaced with a broader distributed system. This is most acute in the command, control, and tasking aspects of RPA management. At present, sensor/intelligence products *are* managed in a somewhat distributed fashion (i.e., DCGS), yet C2 for one aircraft tends to be performed from a single OCS and handoff between one OCS and another is a laborious process. Greater efficiencies can be achieved if pilots, sensor operators, and aircraft could be dynamically tasked from one operation/AOR to another. However, achieving this capability requires common message sets, network interconnection, and resolution of potential security issues across multiple domains, potentially including coalition members and possibly non-government agencies (NGAs). In addition, intelligence analysts, pilots, and support personnel must be trained in TTPs that provide for tasking and mission requirements that may arise from any point on the network.

3.4 Finding (4): Inadequate Selection Criteria and Training

The identified gaps in crew selection and training relate directly to RPA manning issues and ultimately to mission effectiveness and safety. Legacy selection and training processes, established for manned flight positions have, until recently, created an RPA manning bottleneck. For instance, with the exception of the recent Beta program, RPA pilots have been experienced USAF fighter/bomber or airlift/tanker pilots on ALFA[*] tours.[24] Training has been costly and inefficient given that the ALFA pilots have been trained on other weapons systems first (Figure 3-5). In fact, the 2008 USAF Audit Report estimates that these legacy procedures, if continued, would cost the USAF over $1.3 billion dollars in the years from 2009-2014. This inefficiency is not only costly, but contributes significantly to the manning bottleneck.

The recent USAF transitioning of the Beta program to formal Undergraduate RPA Training (URT) establishes an RPA career field and is a positive step in addressing training costs and the manning bottleneck. However, there are other shortcomings in crew selection and training that continue to contribute to manning issues and compromise mission effectiveness and safety. Current selection of qualified candidates for an RPA path is not based on perceptual, cognitive, motor, and team capabilities required for each RPA position. Likewise, training programs, simulation capabilities, and training assessment methods are not guided by Mission Essential Competencies (MECs) and are not exploiting currently available training technologies.[25] MECs are “higher-order individual, team, and inter-team competencies that a fully prepared pilot, crew, or command and control team, requires for successful mission completion under adverse conditions and in a non-permissive environment.”[26]

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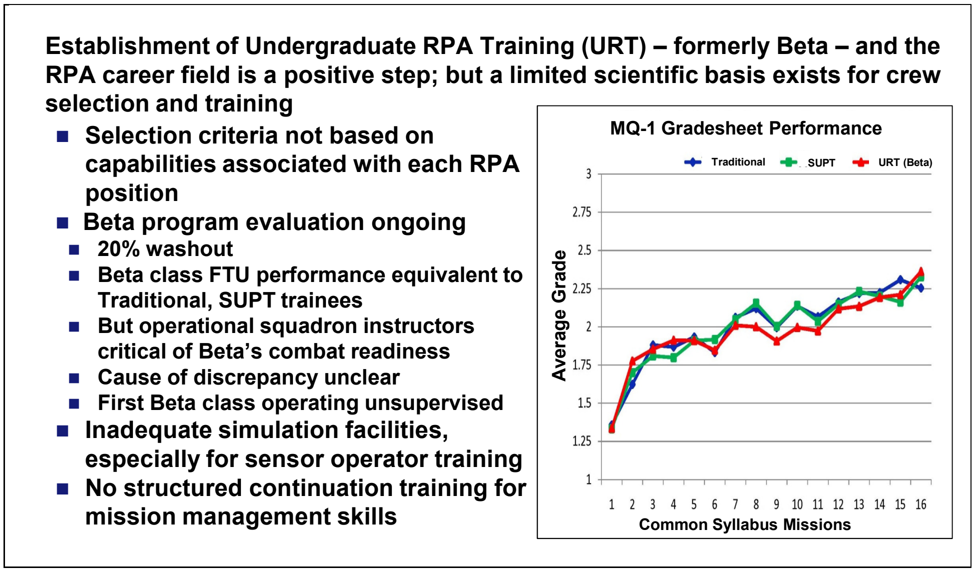
[*] ALFA is a Vietnam era acronym identifying the types of positions a pilot might fill on their tour, such as Air Education and Training Command (AETC) instructor, Lead-in Course instructor, Forward Air Controller, or Air Liaison Officers.

[24] Jensen, R. M. and Slater, J. W., Jr. 2008. Unmanned Aerial System Pilot Force Management, Air Force Audit Agency Report F2009-0005-FD4000.

[25] Gramm, Joshua and Pappan, Steven, “Insatiable Demand: ‘Manning’ the US Air Force’s Unmanned Aircraft Systems with Capable Pilots,” Harvard Kennedy School of Government, March, 2009.

[26] Alliger, G.M., Beard, R.M., Bennett, W., Jr., Colegrove, C.M. and Garrity, M. 2007. Understanding mission essential competencies as a work analysis method. AFRL-HE-AZ-TR-2007- 0034). Mesa AZ: Air Force Research Laboratory, Human Effectiveness Directorate, Warfighter Readiness Research Division.



Establishment of Undergraduate RPA Training (URT) – formerly Beta – and the RPA career field is a positive step; but a limited scientific basis exists for crew selection and training

- **Selection criteria not based on capabilities associated with each RPA position**
- **Beta program evaluation ongoing**
  - **20% washout**
  - **Beta class FTU performance equivalent to Traditional, SUPT trainees**
  - **But operational squadron instructors critical of Beta's combat readiness**
  - **Cause of discrepancy unclear**
  - **First Beta class operating unsupervised**
- **Inadequate simulation facilities, especially for sensor operator training**
- **No structured continuation training for mission management skills**

Figure 3-5: Inadequate Selection Criteria and Training.

Gaps in selection and training are evident in the ongoing assessment of the Beta pilots. There were two classes of 10 and 11 with initial washout of 20 percent in each class leaving 17 Beta pilots total. As seen in the graph in Figure 3-5, the Betas' Formal Training Unit (FTU) performance based on instructor grade sheet scores is statistically equivalent to that of other trainees (Traditional and Specialized Undergraduate Pilot Training [SUPT[). At the same time, operational squadron instructors are generally critical of Beta pilots' limited air sense and combat readiness, and as a result, the Beta pilots went on for additional supervised training after Mission Qualification Training (MQT).[27] Although the precise cause for these discrepancies in assessment of the Beta program are not known at this time, they point to: 1) the potential benefits of selection that is targeted for known capabilities required of each position; 2) the need for a richer set of assessment methods that meaningfully assess skills required; and 3) the need for training that is customized for the MECs required of the RPA career path. These issues are all tied to gaps in understanding the fundamental capabilities and skillsets of RPA positions.

RPA training is also limited at the more advanced end of the training spectrum. There is minimal exploitation of simulation training, Distributed Mission Operations (DMO) exercises, or the use of Live, Virtual, Constructive (LVC) entities. Sensor simulation fidelity is also low. Simulation for all RPA positions has been hindered by delays in simulator development and limited access to proprietary vehicle and system models and data. Additionally, there is no structured continuation training for RPA operators. As a result of this training gap, acquisition of team communication and coordination, advanced mission management skills, and other skills that could be exercised in continuation training have been largely relegated to on the job training.

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[27] Although, at the time of this writing, currently eight Betas are flying unsupervised missions.

In sum, though the establishment of a formal RPA career path is a positive step, selection and training for RPA operators has not kept pace with the state-of-the-art in selection and training including the exploitation of MECs, simulation technologies, and distributed mission operations. The potential consequences of such deficiencies in operational environments are compromised mission effectiveness and safety.

3.5 Finding (5): Lagging CONOPS and TTPs

The Study Panel also found that late development of CONOPS and TTPS has reduced the usefulness of RPAs (Figure 3-6). In the case of the Predator, initial delivery resulted from an Advanced Concept Technology Demonstration (ACTD) and the CONOPS significantly lagged the physical delivery. As a result, the system's operation was very much on an *ad hoc* basis. Lack of sufficient logistic support reduced the effectiveness of the system in its initial deployment to the Former Republic of Yugoslavia (FRY), for example. The same pattern seems to have been repeated in the deployment of the Reaper and, currently, with the Gorgon Stare sensor. There is also a need for a CONOPS for distributed management to enable the same flexibility of distributed operations currently enjoyed by exploiters given the distributed command ground station (DCGS). The Panel strongly supports the concept of developing an initial CONOPS well before deployment and using this CONOPS as the basis for equipage and operation.

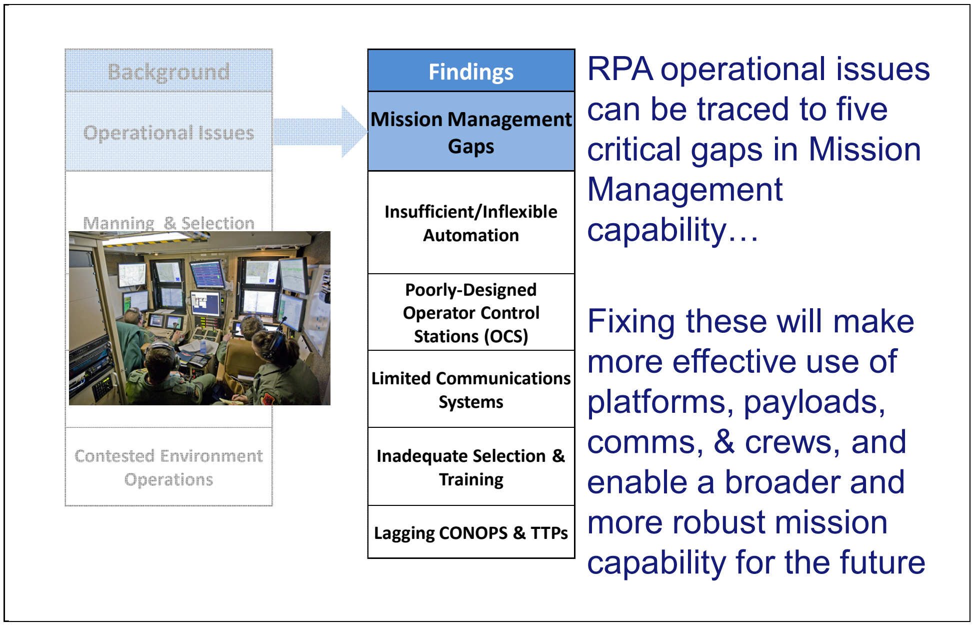
CONOPS/TTPs created *after* development have yielded systems difficult to operate in the NAS, a challenge for full manned/ unmanned integration, and vulnerable in contested environments

- **Predator/Reaper acquisition did not transition to the more traditional front-end requirements analysis and CONOPS development for full integration into the force structure, resulting in**
  - **Continuing NAS integration issues, and lack of clear plan for manned/ unmanned integration in MCA**
  - **No vision for dealing pro-actively with what may become an increasingly contested environment**
- **Gorgon Stare appears to be on the same path, with CONOPS TBD by ACC, *after* delivery**
- **A lack of CONOPS exists for distributed mission management, which will be another "technology push" response**

Figure 3-6: Lagging CONOPS and TTPs.

3.6 Summary of Findings

RPAs have provided significant value to the Air Force; however, their full potential is limited in several key mission gaps (Figure 3-7) including human-automation interaction, OCS design, communications, selection and training, and CONOPS/TTPs. Having identified and analyzed these limitations, the Panel next considers how to address these shortfalls.



Background

Operational Issues

Manning & Selection

Contested Environment Operations

Findings

Mission Management Gaps

Insufficient/Inflexible Automation

Poorly-Designed Operator Control Stations (OCS)

Limited Communications Systems

Inadequate Selection & Training

Lagging CONOPS & TTPs

RPA operational issues can be traced to five critical gaps in Mission Management capability…

Fixing these will make more effective use of platforms, payloads, comms, & crews, and enable a broader and more robust mission capability for the future

Figure 3-7: Summary of Findings.

Chapter 4: Recommendations

Having considered the implications of the above findings, the Study Panel identified and prioritized a number of possible recommendations. The Panel focused on eliminating mission management gaps through technology, people, and process enhancements. In terms of technology, the recommendations focus on platform automation/autonomy, enhanced Operator Control Stations (OCSs), and robust communications systems. In terms of people, the Study Panel recommends targeted selection and more effective training. In terms of process improvements, the Study Panel recommends enhanced operations through innovative Concepts of Operations (CONOPS) and Tactics, Techniques, and Procedures (TTPs), and improved acquisition through improved systems engineering and human systems integration.

4.1 Recommendation (1): Develop Flexible Levels of Automation

To fully achieve the capability envisioned in the Air Force RPA (Remotely Piloted Aircraft) Flight Plan, flexible levels of automation must be developed in several key areas involving both flight management and sensor management functions. However, increased automation alone is not sufficient. Just as critically, new automation functionality must be implemented in a user-centered, flexible manner to enable rapid, situation-adaptive human-automation responses for improved mission effectiveness across a wide range of conditions. Accordingly, the first recommendation of the Study Panel is to enable flexible levels of automation as depicted in Figure 4-1.

Develop flexible levels of automation enabling situationally-adaptive human interaction to improve single-platform, multi-platform, and mission-level effectiveness

- **Near: Single-platform *task-level* automation [ASC]**
  - **Flight control/guidance**
  - **Monitor environment, threat, health/status**
  - **Auto target cueing**
  - **Visualizations and alert aids: automation transparency, mode awareness**
- **Mid: Single-platform *mission-level* automation [AFRL]**
  - **Cross-cueing, information fusion**
  - **Contingency management (eg, dynamic mission planning)**
  - **Environment and threat prediction; sense and avoid capability**
- **Far: Multi-platform *mission-level* automation [AFRL]**
  - **Collaborative goal-based tasking to RPA teams**
  - **Assured autonomous behaviors (V&V)**

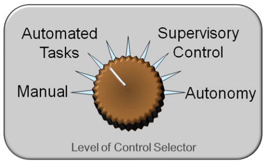


Figure 4-1: Improved Platform Automation.

In the near term, focus should be centered on single-platform *task-level* automation aiding (OPR: ASC). Rather than rely on the traditional “left-over” principle (automate as much as possible and whatever is left over is handled by the human), choices on what functions to automate should be based on that which most benefits the combined human-automation RPA system in completing the mission. Examples of task-level automation enhancements may include flight control/guidance (e.g., auto takeoff/landing, lost-link behavior), monitoring of health and status systems and the environment including threats, sense-and-avoid capability (in-flight), and improved target cueing/tracking technology. With regard to improved human-automation design, automation status and mode alerts must be clearly conveyed to the human operator through intuitive visualizations so that the operator is always aware of what the automation is doing or planning to do, along with the associated rationale.

In the mid term, emphasis should be extended to *single RPA mission-level* automation aids (OPR: AFRL). The human operator will generally assume a higher supervisory role and the automation will support greater aspects of the RPA mission. Examples of automation capability include enhanced contingency management (e.g., complex dynamic mission planning with alternative courses of action, vision-based navigation), information fusion/management from disparate sources, multi-target detection, tracking and identification, and transparent terminal area operations. Environment and threat prediction capability can also be addressed in the mid-term. Additionally, new RPA human-automation interaction methods need to be designed, evaluated and matured (i.e., delegation interfaces, adaptive automation, mixed-initiative interactions) to flexibly implement multi-level automation (optimized to function) across each of the above functions. The human operator will need fine-grained control over the initiation and application of supporting automation. Levels of automation and assigned authority need to be thoroughly researched, along with its effects on operator performance and trust, to determine the best methods of flexibly applying these systems to a wide variety of situations under differing levels of automation fidelity.

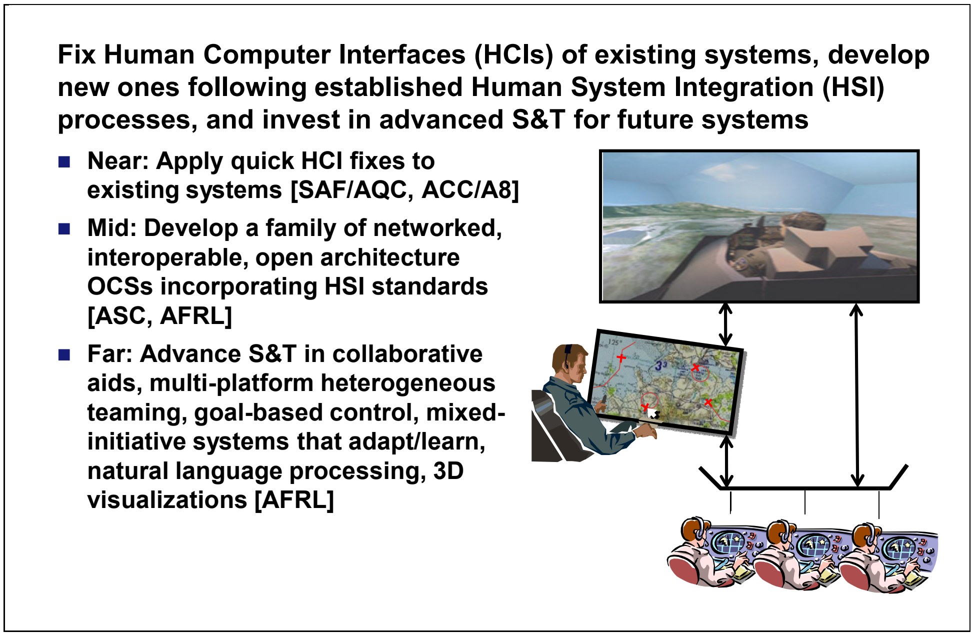
Because current and envisioned sensor hardware produces data at rates of 10 to over 1000 times the expected and available communications data transmission rates, more research is needed underlying the development of algorithms to process sensor data onboard to tag only a small portion of the recorded “scenes” for further immediate transmission and human analysis. Examples of enabling technologies underlying these future algorithms include pixel-velocity-based image stabilization, optimal foreground/background transmission rates for compression, moving-target indicators incorporating stability/compression advances, geo-registration aided by enabling techniques such as multi-scale geometric analysis, view interpolation and morphing algorithms, and continuing advances in miniaturized on-board processors such as graphics processing units. These investments will also lead to reductions in manpower associated with sensor data interpretation. These investments could usefully cover a range of efforts from signal processing techniques to implementation across a range of current and developing systems. Depending on the specific deployment scenario and environment (including adequate communications links), the automated analysis of sensor data from distributed sensors could in many cases provide improvement in signal-to-noise (e.g., through image comparison algorithms), reduction in convergence and identification times, and better geo-registration accuracy.

Finally, in the far term, efforts should be placed on developing and implementing *multi-RPA mission-level* automation (OPR: AFRL). Collaborative automation is a critical enabler at this stage, especially with regard to distributed manned-unmanned teams. Effects-based tasking (as opposed to platform-based tasking) will become the preferred method of RPA control, as RPA machine cognition (perception, intelligence, etc) and associated autonomy increases. Humans operators will need to collaborate with (and possibly negotiate with) increasingly intelligent automation associates in the planning and conducting of complex, multi-asset mission tasking. Collaboration across (both vertically and horizontally) the various command and control (C2) echelons will also be enhanced, allowing real-time visibility, oversight, and coordination of RPA operations across the battlespace. Swarming technologies should be explored for cheaper RPA systems. The key to an integrated battlespace is shared situation awareness that can be seamlessly handed from one platform/team to another as a situation changes. It will also become critical to develop verification and validation methods for increasingly complex RPA systems, which, on the one hand, will be engaging in increasingly "emergent" behaviors to satisfy the developer's goal for dealing with new situations in an autonomous fashion, and which, on the other hand, need to assure the user of "predictable" behaviors within some acceptable envelope of autonomy.

It is important to note that the themes associated with each category (near, mid, far) are intentionally simplistic to convey an easily understood framework for the general progression of automation capability. Certainly not all single-RPA automation issues will be solved in the near term or even the mid term, nor will collaborative automation development be entirely absent in the near term and mid term (for example, the task-level automation enabling a micro RPA to navigate an urban landscape and land on a window ledge at night while experiencing strong wind gusts during a thunderstorm is likely to remain a very difficult challenge well into the long-term).

4.2 Recommendation (2): Enhance Operator Control Stations

The Study Panel recommends that Operator Control Stations (OCSs) be improved by applying existing design methods and processes to design/develop new operator aids to reduce manpower requirements, enable airspace integration as well as force multiplication, increase interoperability, reduce potential for collateral damage, and increase resilience in contested environments (as detailed in Figure 4-2). This is facilitated in the near term by providing immediate fixes to existing OCSs that address critical operational needs, focusing on increasing the integrated presentation and management of information, and streamlining control inputs (OPR: SAF/AQC, ACC/A8). Additionally the Program Offices must be properly manned (and appropriately trained) for developing and applying Human-System Integration (HSI) processes to their respective programs.



Fix Human Computer Interfaces (HCIs) of existing systems, develop new ones following established Human System Integration (HSI) processes, and invest in advanced S&T for future systems

- **Near: Apply quick HCI fixes to existing systems [SAF/AQC, ACC/A8]**
- **Mid: Develop a family of networked, interoperable, open architecture OCSs incorporating HSI standards [ASC, AFRL]**
- **Far: Advance S&T in collaborative aids, multi-platform heterogeneous teaming, goal-based control, mixed-initiative systems that adapt/learn, natural language processing, 3D visualizations [AFRL]**

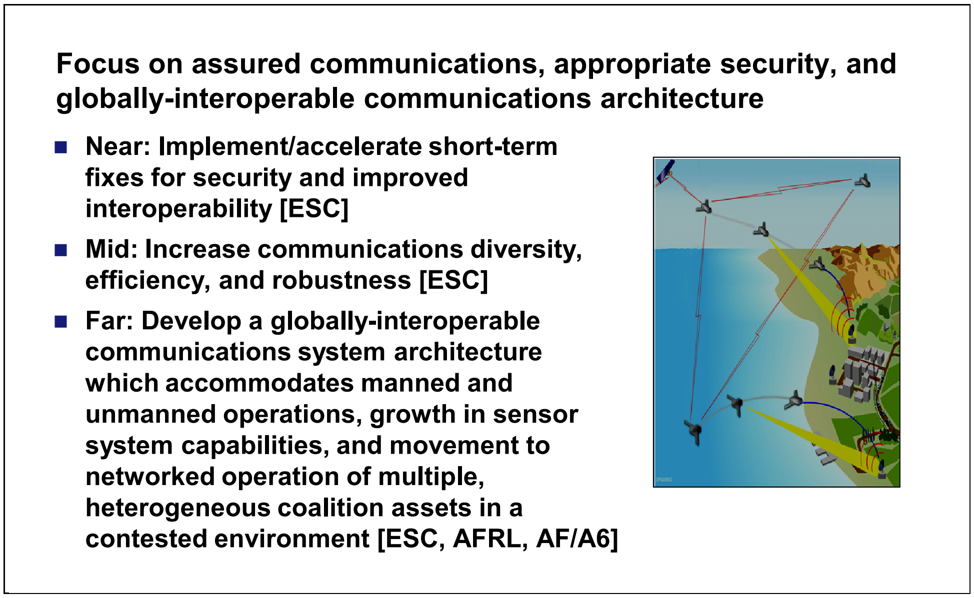
Figure 4-2: Enhanced Operator Control Stations.

In the mid term, employ a comprehensive HSI process and usability design/testing to develop a family of networked, interoperable OCSs with new non-proprietary, standards-based OCS architectures with plug-and-play components for a full range of functions that facilitate interoperability and modularity (OPR: ASC, AFRL). This effort should be aligned with direction provided by the Office of the Secretary of Defense (OSD) Unmanned Control Segment Working Group and other similar Department of Defense (DOD) activities. Human Computer Interfaces (HCIs) should be optimized to the intended function of the OCS such as multi-aircraft control (MAC) for supervising several RPAs during benign operations and transit, tactical operations (for rapidly evolving, uncertain, time critical, and collaborative combat operations), or sensor operation (focused solely on sensor management tasks). Efforts should also concentrate on improved information integration and presentation (including temporal displays) that support rapid decision making, attention directing cues that highlight high priority tasks, improved decision aids, and naturalistic multi-sensory interaction technologies, each tailored to the intended operating environment of the OCS (man portable/wearable, fixed facility, vehicle-based, etc). Future HCIs must also be designed to maximize human-automation interaction through better operator awareness of automation state and projected plans, and flexible intervention methods to intervene when automation does not accurately support mission need.

Finally, in the far term, advanced science and technology (S&T) research is needed in the areas of customized operator interfaces tailored to individual differences; collaborative aids for multi-platform heterogeneous teaming; goal-based control methods; advanced mixed-initiative systems that adapt/learn based on changes in the mission, environment, or operator functional state; natural language processing; tools supporting anticipatory decision making; and novel 3D visualizations of the battle space (OPR: AFRL). Additionally, even in the far term, the key to success will be to identify and apply the appropriate levels of human skill/attention to each mission task and provide operators powerful and intuitive automation tools so that they can focus their full attention at the mission execution level.

4.3 Recommendation (3): Create Robust Communications

The Study Panel recommends creating more robust communications supporting RPA operations, focusing on assured communications, appropriate security, and a globally interoperable communications architecture (Figure 4-3).



Focus on assured communications, appropriate security, and globally-interoperable communications architecture

- **Near: Implement/accelerate short-term fixes for security and improved interoperability [ESC]**
- **Mid: Increase communications diversity, efficiency, and robustness [ESC]**
- **Far: Develop a globally-interoperable communications system architecture which accommodates manned and unmanned operations, growth in sensor system capabilities, and movement to networked operation of multiple, heterogeneous coalition assets in a contested environment [ESC, AFRL, AF/A6]**

Figure 4-3: Create Robust Communications.

4.3.1 Near-Term Fixes for Security and Improved Interoperability

In the near term, the Study Panel recommends implementing/accelerating near-term fixes for security and improved interoperability (OPR: ESC). This would include appropriate cryptography, CONOPS/TTPs for communications alternatives such as relayed operations, and standardized, documented, and accessible networked interfaces for ground elements. More specifically, we recommend the following.

- **Cryptography**: In April 2009, ASD/NII DTM-09-004 called for use of FIPS 140-2 Security level 1 cryptography or better for unmanned aerial systems (UAS) Groups 2-5. It also called for the establishment of a UAS Encryption Working Group (UASEWG) to coordinate implementation and make additional recommendations. We recommend continuation of the UASEWG's work, and acceleration where possible. RPAs should in general be capable of operation using stronger forms of cryptography if deemed necessary, based upon mission objectives, though acknowledging that Type 1 cryptography may frustrate coalition operations due to the additional protective measures required.

- **CONOPS/TTPs for Relayed Operations**: There are numerous platforms that offer the potential to provide communications alternatives for RPAs. For example, the Battlefield Airborne Communications Node (BACN) package currently being fitted to Global Hawk Block 20 provides numerous capabilities that could be used to provide C2 for RPAs with less-advantaged communications (such as Predator/Reaper). Although the technical means for doing so appears to be available, CONOPS and TTPs are needed to exploit this capability further. Relaying provides (at least) two potential benefits: as an alternative to denied satellite communications (SATCOM), and as a potentially lower-latency communication path that enhances the effectiveness of remote operator controls.
- **Standardized, Documented, and Accessible Networked Interfaces for Ground Elements**: There are numerous ground elements involved in RPA operations including the primary control stations (e.g. MCE for Global Hawk or OCS for Predator), landing and recovery elements (LRE), and various ground terminals used primarily for viewing sensor data within a line-of-sight (LOS) area (e.g., ROVER and OSRVT). In addition, there is at present an effort to design a new generation of interoperable OCSs being pursued by the UAS Control Segment Working Group (UCS-WG). In the short-term, we recommend retrofitting existing OCSs with a physical network port (e.g., 100Mb/s Ethernet) capable of providing (or possibly consuming) essentially all sensor and mission meta-data using documented message sets over a TCP/IP based transport. Such a port needs to be "accessible" in the sense that appropriate accreditation must be provided to allow these messages to be processed by other equipment. Note that as a short-term recommendation, we do not require the application-layer messages to conform to a particular standard, but rather that they be accessible and documented.

4.3.2 Mid Term: Increase Communications Diversity, Efficiency, and Robustness

In the mid term, the Study Panel recommends increasing communications diversity, efficiency, and robustness (OPR: ESC). This would include evaluating the utility of potential solutions, including gateways, additional C2 diversity, and disruption tolerant communications, as well as the utility of state-of-the-art sensors incorporating on-board processing/exploitation, and non-geostationary satellites for C2 and sensors.

- **Evaluate Gateways, Additional C2 Diversity, and Disruption Tolerant Communications**: At present, there are a variety of communication capabilities available for each RPA type. For the less capable RPAs, SATCOM vulnerability is a significant concern. To provide additional communication options, we recommend evaluating a broad set of gateway packages, including BACN and the Defense Advanced Research Projects Agency's (DARPA) MAINGATE program, in addition to equipping existing communications-limited RPAs with additional link capabilities, including Common Data Link (CDL) and Link-16. Increasing the set of link options improves resiliency in contested environments (e.g., via the anti-jamming properties of Link-16) and reduces latency for other assets within the LOS area that wish to interact with the RPA. Size, Weight, and Power (SWAP) may be a concern with some of the additional radio systems, but modern radios have addressed this concern (e.g., L-3's "mini-CDL" 200 radio weighs 1.4lbs and uses 25-45W). Disruption Tolerant Networking (e.g., the DARPA DTN and WNaN programs) uses storage within the network to help overcome modest link or long-term link outages, especially for environments that do not require precise latency bounds for effective operation.

- **State-of-the-Art Sensors with On-Board Processing/Exploitation**: The Study Panel recommends improving algorithms for compression and sensor exploitation to limit off-platform bandwidth demands. In addition, on-board cross-sensor processing can be used to enhance resilience to sensor attacks (e.g., communications jamming or GPS spoofing) by performing a secondary or tertiary check on the validity of navigational and platform health information. In general, algorithms produce better results when provided higher-quality input (e.g., sensor) data. Thus, although the highest-resolution sensors may overwhelm certain (e.g., SATCOM) communication links, such sensors can lead to better autonomy with a higher degree of trust, thereby reducing the need for human operators to be shown all sensor data. Large onboard storage can be used to house raw sensor data for subsequent, on-the-ground, exploitation. For example, if it is assumed that uncompressed HDTV-quality video requires a storage rate of 1Gb/s (conservative), a 20-hour mission would require approximately 9 Tb of storage. With single drives now capable of storing 2.5 Tb, a modest amount (4 drives or fewer) of onboard storage would be required.
- **Non-GEO Satellites**: The Study Panel recommends evaluating options for non-geostationary satellites for RPA C2, as well as for low-data-rate sensor backhaul. There are two potential benefits, including lower latency (potentially allowing for more effective tactical control of the aircraft) and greater diversity/assuredness. In particular, if conventional GEO-based SATCOM were compromised or made unavailable, LEOs may provide a viable option, at least for C2. Unfortunately, there are a limited number of LEO constellations available (e.g., Iridium, Globalstar, Orbcomm). Nonetheless, encouraging results, including latencies below 100 milliseconds, have been observed (e.g., the National Aeronautics and Space Administration [NASA] "Flight Modem" work[28]). Note that Iridium announced plans for its next-generation satellite constellation (Iridium NEXT) on June 2, 2010.

4.3.3 Far Term: Develop RPA Communications Architecture

In the far term, the Study Panel recommends developing a globally interoperable communications system architecture which accommodates manned and unmanned

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[28] Morgan et al., "Telemetry Tracking & Control (TT&C) – First TDRSS, then Commercial GEO & Big LEO and Now Through LEO," 2001 (Document ID 20010020063)

operations and anticipates growth in sensor system capabilities for networked operation of multiple, heterogeneous coalition assets, operating in a contested environment (OPR: ESC, AFRL, AF/A6). The Study Panel recommends that a comprehensive communications architecture study be undertaken to determine what interfaces, TTPs, and capabilities are required to produce a fully-distributed network of RPAs, pilots, analysts, and maintainers. At present, there are a collection of stovepiped systems with limited interoperability and proprietary formats, leading to consequent difficulty in performing distributed control.

4.4 Recommendation (4): Develop Targeted Selection and Effective Training

The Study Panel recommends developing targeted selection and effective training (Figure 4-4). The Air Force should understand fundamental capabilities and skillsets required for each RPA specialty, use this knowledge to become more effective at selection, and exploit current training and simulation technologies to reduce manning pipeline delays, better enable NAS/MCA integration, and deal with future contested environments.

Understand fundamental capabilities and skill-sets required for each RPA specialty, select appropriately, and exploit current training and simulation technologies to reduce manning pipeline delays and deal with future contested environments

- **Near: Reduce manning bottleneck by targeted selection and accelerated training [AF/A1, AETC, AFRL]**
- **Mid: Develop and use training simulators more effectively [ASC, AETC, ACC]**
- **Far: Develop skills in team coordination, communication and mission planning/After-Action Review [AFRL]**

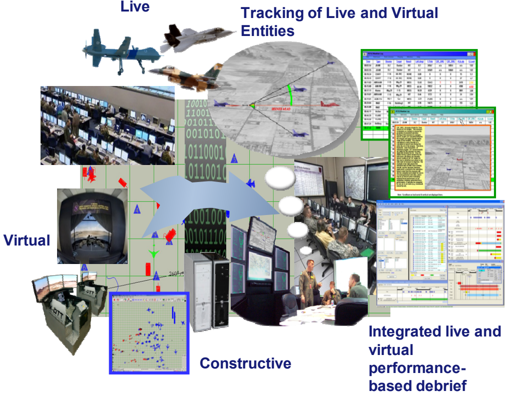


Figure 4-4: Training and Selection Recommendations.

Improving available training and selection technologies can result in tremendous cost savings and improved efficiencies in RPA training, while at the same time addressing the manning bottleneck and generating a future RPA force capable of dealing with contested environments. It is necessary to understand fundamental capabilities and skillsets required for each RPA specialty, train and select accordingly, and exploit current training and simulation technologies.

Near-term activities should be directed at developing scientifically-based RPA career path enhancements that generate targeted selection procedures and accelerated training programs. The new Undergraduate RPA Training (URT) classes should be appropriately selected, based on validated test methods and assessed in terms of training and operational performance using objective state-of-the art performance metrics. In addition, Mission Essential Competencies (MECs) should be used to optimize URT, Mission Qualification Training (MQT), and continuation training and selection, with independent paths developed for RPA pilots and sensor operators. (OPR: AF/A1, AETC)

Mid-term recommendations focus on the increased use of existing simulation technologies, as well as the development and application of new technologies to increase training effectiveness for non-LRE pilots and sensor operators. The use of flight simulators, including part task trainers, should be optimized for all task levels (e.g., individual, team, multi-team). Sensor operator training should also be enhanced with simulation, drawing from existing gaming technologies, Google Earth, and actual operational video footage. It is important to recognize that the simulators must be developed concurrently with an improved OCS. A simulator that replicates a poor human-machine interface is a poor foundation for training. (OPR: ASC, AETC, ACC)

In the far term, RPA skills in team coordination, communication, and mission planning/after action review (AAR) need to be developed. This can be accomplished via the development and use of an advanced RPA training and simulation facility for comprehensive continuation training and training research. In this context, simulation training for RPAs should be advanced to the current state-of-the art in simulation for fighter training, so that RPA operators can engage in multi-person, multi-vehicle exercises on par with Distributed Mission Operations (DMO) exercises. Through the advanced use of simulation, requisite skills can be trained for current and future RPA operations to include: CONOPS in realistic manned/unmanned, joint, and contested environments, team coordination, communication and mission planning, and after-action-review skills. (OPR: AFRL)

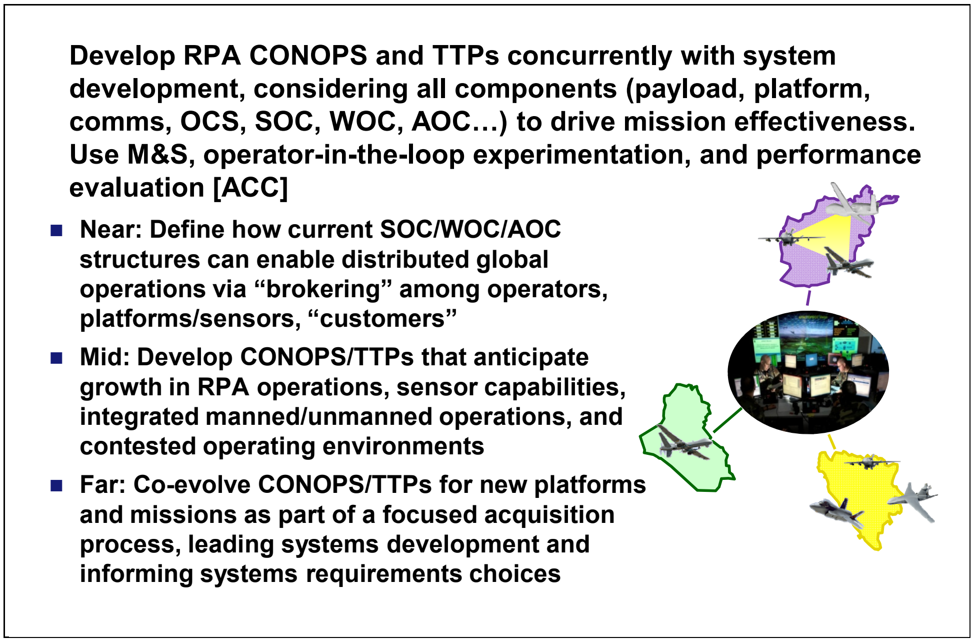
4.5 Recommendation (5): Improve CONOPS and TTPs

To more effectively drive mission effectiveness, the Study Panel recommends development of RPA CONOPS and TTPs concurrently with system development, considering all components including the payload, platform, communications, OCS, Squadron Operation Center (SOC), Wing Operation Center (WOC), and Air and Space Operations Center (AOC) (Figure 4-5). To support this development, the Panel recommends the use of modeling and simulation, operator-in-the-loop experimentation, and performance evaluation. (OPR: ACC)

In the near-term, the Air Force should formalize the concept of distributed global operations. The Air Force should define how current SOC/WOC/AOC structures can enable distributed global operations via “brokering” among operators, platforms/sensors, and “customers.” This would enable increased efficiency and effectiveness if “customers” could agree on a prioritization scheme which allowed for shifting assets to the areas of greatest need.

In the mid-term, the Air Force should develop CONOPS/TTPs that anticipate growth in RPA operations, sensor capabilities, integrated manned/unmanned operations, and contested operating environments. Development of models and simulations should be pursued so that conjectural ("what-if") analysis can be performed. This is particularly important as the Air Force considers ways to operate new platforms and payloads in mixed manned/umanned and contested environments.

In the far-term, the Air Force should enforce the necessary acquisition and development discipline to ensure that CONOPS and TTPs are co-evolved with new systems. This should be done as part of a well-structured systems engineering process which leads systems development and informs systems requirements, taking into consideration not just performance but also many of the standard "ilities", including: reliability, maintainability, and affordability.



Develop RPA CONOPS and TTPs concurrently with system development, considering all components (payload, platform, comms, OCS, SOC, WOC, AOC…) to drive mission effectiveness. Use M&S, operator-in-the-loop experimentation, and performance evaluation [ACC]

- **Near: Define how current SOC/WOC/AOC structures can enable distributed global operations via "brokering" among operators, platforms/sensors, "customers"**
- **Mid: Develop CONOPS/TTPs that anticipate growth in RPA operations, sensor capabilities, integrated manned/unmanned operations, and contested operating environments**
- **Far: Co-evolve CONOPS/TTPs for new platforms and missions as part of a focused acquisition process, leading systems development and informing systems requirements choices**

Figure 4-5: Improved Operating Concepts, CONOPS, and TTPS.

4.6 Recommendation (6): Ensure Effective ACTD Transition

The Study Panel recommends the Air Force ensure effective transition of successful RPA prototypes to the acquisition process (Figure 4-6), incorporating systems engineering practices including HSI, in accordance with AFI 10-601 and 63-1201 (OPR: SAF/AQ). The Air Force should continue successful use of the ACTD/JCTD (Advanced Concept Technology Demonstration/Joint Capability Technology Demonstration) process to develop game-changing solutions and transition them when appropriate. They should upgrade, develop, and acquire RPA systems using accepted Systems Engineering practices. This includes employing Section 804 of the 2010 National Defense Authorization Act which directs the Secretary of Defense to develop and implement a new acquisition process that follows best practices to include "(a) early and continual involvement of the user; (b) multiple, rapidly executed increments or releases of capability; (c) early, successive prototyping to support an evolutionary approach; and (d) a modular, open-systems approach."[29] Starting with a clear vision of the CONOPS and accounting for operations in contested environments are essential. It is also important that the Air Force establish RPA-specific HSI requirements (OPR: A5R) and guidelines (OPR: AFRL). Operator-related issues should be addressed via incorporation of HSI as part of the systems engineering process (OPR: AFMC), following the recommendations of two previous SAB studies.[30, 31] The remainder of this section discusses this recommendation in further detail.

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[29] Further details of the new acquisition approach can be found in the March 2009 Defense Science Board Task Force on Department of Defense Policies and Procedures for the Acquisition of Information Technology.

[30] United States. "Unmanned Aerial Vehicles in Perspective: Effects, Capabilities, and Technologies. Volume 1: Summary (Public Released)" SAB-TR-03-01 September 2003.

[31] United States. "Human-System Integration in Air Force Weapon Systems Development and Acquisition," Executive Summary and Annotated Brief, SAB-TR-04-04, July 2004.

Transition successful RPA prototypes to the acquisition process, incorporating Systems Engineering practices including HSI, in accordance with AFI 10-601 & 63-1201 [SAF/AQ]

- **Continue successful use of ACTD/JCTD process to develop game-changing solutions and transition when appropriate**
- **Upgrade, develop, and acquire RPA systems using accepted Systems Engineering practices (2010 NDAA Section 804)**
- **Establish RPA HSI requirements [A5R] and guidelines [AFRL]**
- **Address operator-related issues via incorporation of HSI as part of the Systems Engineering process [AFMC]**

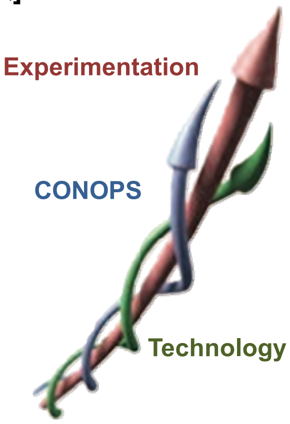

Figure 4-6: Effective ACTD Transitions for RPAs.

The ACTD process was initiated to permit the early and inexpensive evaluation of mature advanced technology to meet the needs of the warfighter. The evaluation is accomplished by the warfighter to determine military utility before a commitment is made to proceed with formal acquisition. ACTDs also allow the warfighter to develop and refine operational concepts to take full advantage of the new capability. Upon conclusion, a successful ACTD may leave behind a residual operational capability. The capability can be replicated, if only a few are required, or can be transitioned into the appropriate phase of formal acquisition.

The ACTD program is a pre-acquisition activity that allows warfighters to use and assess leading-edge capabilities. ACTDs are an integral part of reforming and revolutionizing the acquisition process. Success should be measured by the ability to quickly meet the warfighter's critical needs and by the extent to which ACTDs provide a vehicle for new concepts and technologies to be evaluated before acquisition decisions are made. Figure 4-6 highlights ways to ensure effective transition for RPAs.

ACTDs continue to provide a valuable streamlined approach to demonstrate feasibility and potential of emerging capabilities. They strike the right balance between fidelity and affordability for the intended purpose. The ACTD process and approach does not, however, apply well to the system engineering process required in complex acquisition programs. These acquisition processes are iterative; they take process inputs such as customer needs through exhaustive system design, requirements, and analysis loops while balancing all these needs through an overarching system analysis and control. The result is a decision database highlighting system configuration, and project baselines.

Nearly all current RPA procurements are the product of ACTD or ACTD-like approaches that have never benefited from the rigor of the systems engineering process. By simply continuing or extending the ACTD approach, the RPAs in use today completely missed or received limited engagement in the areas of CONOPS development and application, HSI, systems engineering, and sustainment. Understanding the user environment and mission objectives has been limited by lack of upfront user CONOPS input as exemplified in the DARPA Technology CONOPS Double Helix approach depicted in Figure 4-7.

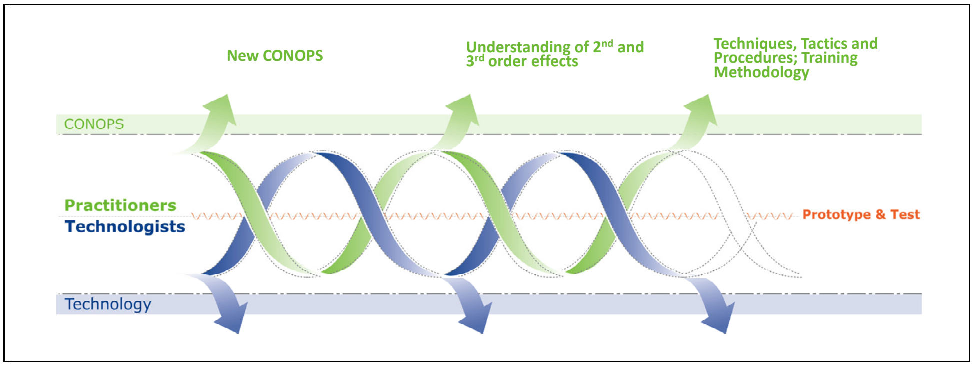

Figure 4-7: CONOPS Technology Double Helix.

With the RPA fleet, CONOPS development significantly lagged behind development, and resulted in mission performance deficiencies and inefficiencies. Systems engineering across these multi-element systems did not conform to DOD 5000 standards and led, in the case of Predator/Reaper, to fielding a closed architecture that is sole source (due to lack of data rights), unresponsive to meeting new operational requirements, and expensive to change. As a related issue, and as noted earlier, significant HSI deficiencies continue to exacerbate the development of CONOPS. ACTDs also typically do not focus on sustainment engineering and associated life cycle cost trades. This situation delayed deployment and sub-optimized ongoing logistics and support functions that continue to detract from mission effectiveness.

A more effective path is to use ACTDs for their intended purpose and cleanly transition to DOD 5000.02 after the decision to transition the demonstrated capability into a program of record is accomplished. ACTDs are not intended or structured to deliver production capabilities and should not be expected to do so. Two excellent examples of successful ACTD transitions are the Have Blue to F-117, and the Lightweight Fighter (YF-16) to the F-16 program.

Importantly, ACTC/JCTDs are fertile ground for groundbreaking, game-changing technologies. Without doubt, they are key sources of innovation; however, successful RPA prototypes must be transitioned into the acquisition process, incorporating Systems Engineering practices, including HSI in accordance with AFI 10-601/63-1201. To achieve their full potential, RPA programs must start with a clear vision of use and CONOPS, and anticipate operations in contested environments.

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Chapter 5: Analysis and Summary of Recommendations

This report began with a number of identified RPA issues (Chapter 2) associated with manning and selection, airspace deconfliction and management, collateral damage, and contested environments. We then identified mission management gaps contributing to these issues (Chapter 3), and put forth recommendations as to how these gaps might be eliminated or reduced with appropriate investments in technology, people, and processes (Chapter 4). We now present two sets of matrices, one showing the impact of mission management gaps on the operational issues, and the second showing the impact of technology investments on closing the mission management gaps. Although the impact assessments are qualitative, the matrices clearly illustrate that dealing with the issues requires a multi-pronged approach, across multiple dimensions.

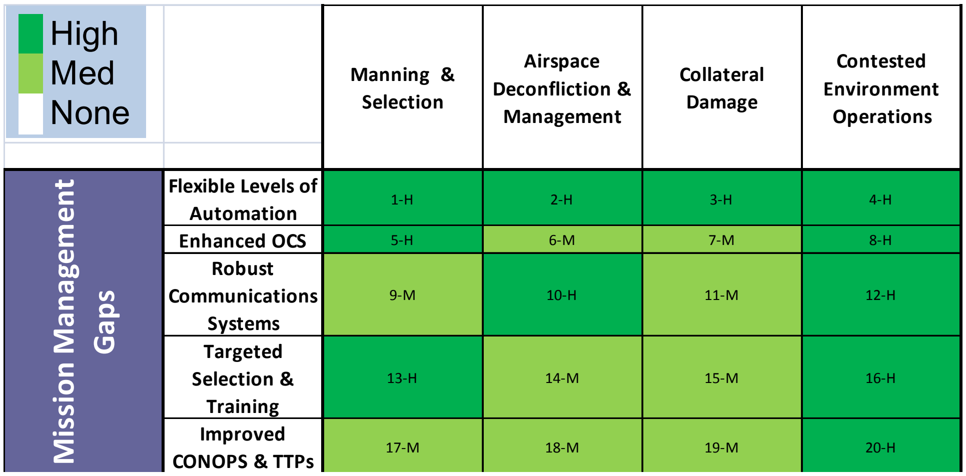
This chapter concludes with a brief summary of how each of the issues can be dealt with directly with a set of recommended actions, to provide a more compact summary of the study's overall findings and recommendations.

5.1 Impact Analysis of Recommendations

This section presents a qualitative assessment of the impact of the Study Panel's recommendations on identified gaps. Importantly, this analysis did not consider cost or quantitative impacts of various recommendations, but rather reflects expert judgment by the Panel based on individual and Panel expertise and experience. The assessments reflect the collective best judgment given the short study time. Accordingly, the Panel caveats its analysis as not being a formal life cycle cost/benefit analysis, which would require further effort.

The Study Panel's analytic method included considering the effects of closing the identified mission management gaps discussed in Chapter 3, in terms of ameliorating the operational issues articulated in Chapter 2 (i.e., manning and selection, airspace deconfliction and management, collateral damage, and contested environments). Figure 5-1 depicts a matrix illustrating the benefits of addressing known mission management gaps (rows) on the operational issues (columns). For example, investments in solving the mission management gaps associated with automation, Operator Control Station (OCS) design, communications, selection/training, and CONOPS/TTP (Concepts of Operations/Tactics, Techniques, and Procedures) will improve the identified operational issues. Each cell in the matrix is numbered and colored as green (high impact), light green (medium impact), and white (little or no impact) to indicate the degree of contribution an investment has in terms of correcting the operational issue. A justification for each assessment is captured in Appendix B, indexed by the cell number for ease of access. Rows indicate how improvements affect issues: thus cells 1 through 4 indicate how flexible levels of automation will contribute to the four operational issues.

For example, cell number 2 indicates how investments in automation will improve airspace deconfliction and management.

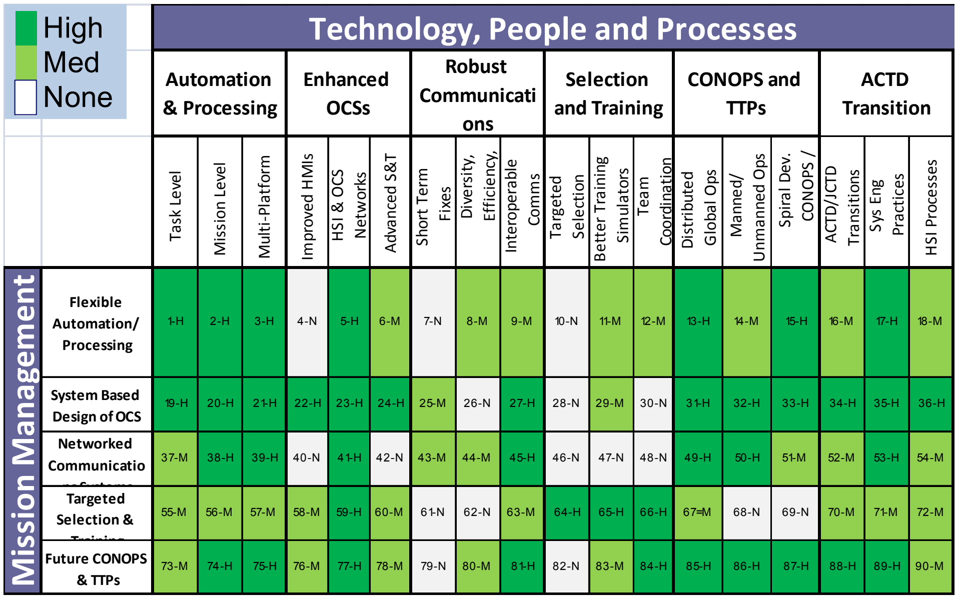


🟩 High
🟩 Med
⬜ None

		Manning & Selection	Airspace Deconfliction & Management	Collateral Damage	Contested Environment Operations
Mission Management Gaps	Flexible Levels of Automation	1-H	2-H	3-H	4-H
	Enhanced OCS	5-H	6-M	7-M	8-H
	Robust Communications Systems	9-M	10-H	11-M	12-H
	Targeted Selection & Training	13-H	14-M	15-M	16-H
	Improved CONOPS & TTPs	17-M	18-M	19-M	20-H

Figure 5-1: Effect of Addressing Mission Management Gaps on Operational Issues.

Figure 5-2 depicts a matrix illustrating the benefits of investing in technology, people, and processes (shown down columns) to fill known mission gaps (shown across in rows). That is, investments in solving automation/processing, OCS, communications, selection/training, CONOPS/TTPs, and Advanced Concept Technology Demonstration (ACTD) transitions will address the identified mission gaps such as the need for flexible automation. Each cell in the matrix is numbered and colored as green (high impact), light green (medium impact), and white (little or no impact) to indicate the degree of contribution an investment has to correcting a mission gap. A justification for each assessment is captured in Appendix B, indexed by the cell number for ease of access. For example, cells 21 through 25 indicate that implementing the Study Panel's mid-term enhanced OCS recommendation will significantly improve all gap areas, from enabling flexible automation to improving future CONOPS/TTPs. In particular, employing a cohesive Human-System Integration (HSI) process and usability design/testing to develop a family of networked, interoperable OCSs with new non-proprietary, standards-based OCS architectures with plug-and-play components for a full range of functions will enable automation, facilitate interoperability and modularity, improve networked communications, ease training, and support and foster novel CONOPS/TTPs. As is evident, all the main diagonals between major columns and their respective mission management gaps are equivalent (e.g., automation for automation), and are therefore left out of the detailed analysis.



🟩 High
🟩 Med
☐ None

		Technology, People and Processes																	
		Automation & Processing			Enhanced OCSs			Robust Communications			Selection and Training			CONOPS and TTPs			ACTD Transition		
		Task Level	Mission Level	Multi-Platform	Improved HMIs	HSI & OCS Networks	Advanced S&T	Short Term Fixes	Diversity, Efficiency,	Interoperable Comms	Targeted Selection	Better Training Simulators	Team Coordination	Distributed Global Ops	Manned/ Unmanned Ops	Spiral Dev. CONOPS /	ACTD/JCTD Transitions	Sys Eng Practices	HSI Processes
Mission Management	Flexible Automation/ Processing	1-H	2-H	3-H	4-N	5-H	6-M	7-N	8-M	9-M	10-N	11-M	12-M	13-H	14-M	15-H	16-M	17-H	18-M
	System Based Design of OCS	19-H	20-H	21-H	22-H	23-H	24-H	25-M	26-N	27-H	28-N	29-M	30-N	31-H	32-H	33-H	34-H	35-H	36-H
	Networked Communicatio	37-M	38-H	39-H	40-N	41-H	42-N	43-M	44-M	45-H	46-N	47-N	48-N	49-H	50-H	51-M	52-M	53-H	54-M
	Targeted Selection &	55-M	56-M	57-M	58-M	59-H	60-M	61-N	62-N	63-M	64-H	65-H	66-H	67=M	68-N	69-N	70-M	71-M	72-M
	Future CONOPS & TTPs	73-M	74-H	75-H	76-M	77-H	78-M	79-N	80-M	81-H	82-N	83-M	84-H	85-H	86-H	87-H	88-H	89-H	90-M

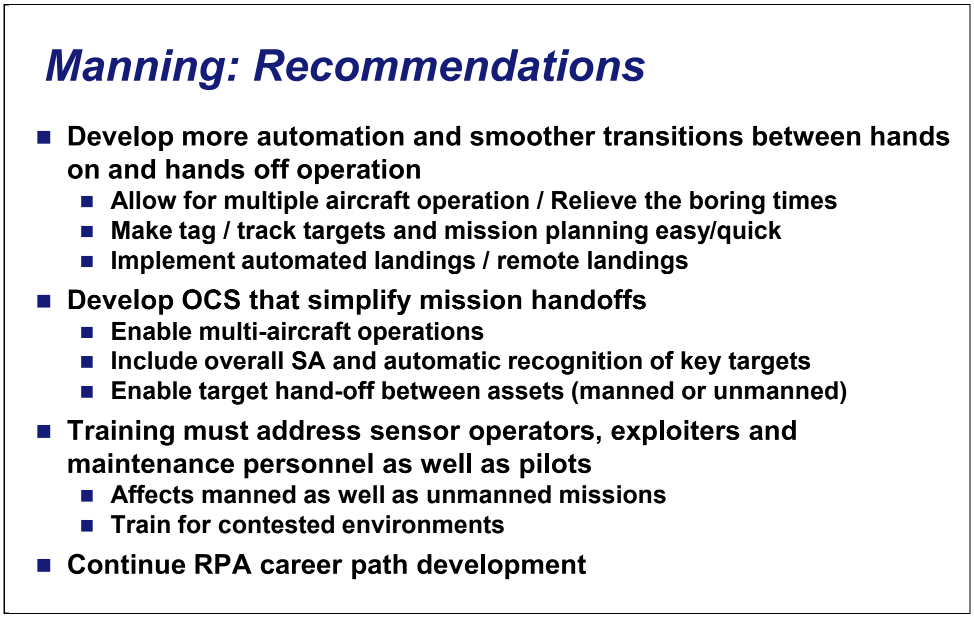
Figure 5-2: Technology, People, and Process Investments Fill Mission Gaps.

5.2 Summary of Recommendations

This chapter concludes with a brief summary of how each of the key issues can be dealt with directly with a set of recommended actions.

5.2.1 Manning and Selection Recommendations

The Study Panel recommendations directly addressing manning and selection, shown in Figure 5-3, are grouped in four main categories. First, the Air Force should develop more automation and smoother transitions between hands-on and hands-off operation. Ways to implement this would include, for example, enabling multi-aircraft control (MAC), especially during low activity and boring mission segments (a side benefit would be the relief of operators from loss of vigilance caused by boredom). Automation could also provide cross-cueing or tagging and tracking of targets, reducing or eliminating manually intensive processing; or to make mission planning easier and more rapid. Finally, automation can help implement automated landings, a cause for as much as 20 percent of RPA loss. Second, the Air Force should develop better OCSs which would simplify mission handoffs, enable multi-aircraft operations, improve overall SA with better integrated displays and via automatic recognition of key targets, and enable target hand-off between assets (manned or unmanned). Third, the Air Force should have training address sensor operators, exploiters, and maintenance personnel, as well as pilots. Training and training simulation need to incorporate both manned as well as unmanned missions, as well as training for contested environments. Finally, the Study Panel recommends continuing RPA career path development.



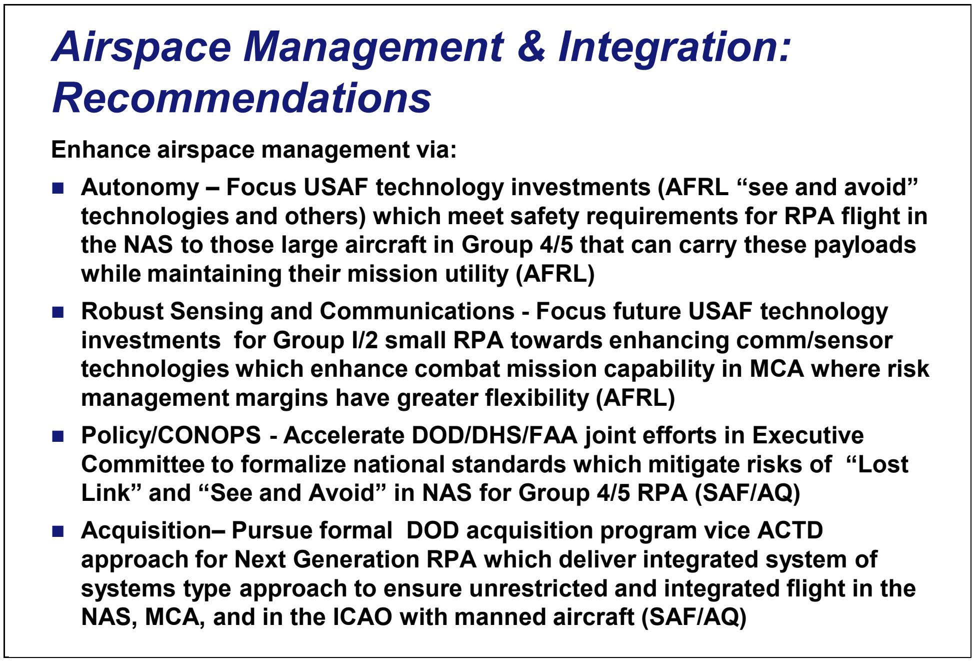
Manning: Recommendations

- Develop more automation and smoother transitions between hands on and hands off operation
  - Allow for multiple aircraft operation / Relieve the boring times
  - Make tag / track targets and mission planning easy/quick
  - Implement automated landings / remote landings
- Develop OCS that simplify mission handoffs
  - Enable multi-aircraft operations
  - Include overall SA and automatic recognition of key targets
  - Enable target hand-off between assets (manned or unmanned)
- Training must address sensor operators, exploiters and maintenance personnel as well as pilots
  - Affects manned as well as unmanned missions
  - Train for contested environments
- Continue RPA career path development

Figure 5-3: Manning and Selection Recommendations.

5.2.2 Airspace Deconfliction and Management Recommendations

The Study Panel recommendations directly addressing airspace deconfliction and management, shown in Figure 5-4, are grouped in four main categories. First, in terms of autonomy, the Air Force should focus on technology investments ("see and avoid" technologies and others) which meet safety requirements for Group 4-5 RPA flight in the National Airspace (NAS) (those vehicles that can carry the necessary payloads while maintaining their mission utility) Second, in the area of robust sensing and communications, the Air Force should focus future technology investments for Group 1-2 small RPAs towards enhancing communications and sensor technologies to enhance combat mission capability in the Military Controlled Airspace (MCA), where risk management margins have greater flexibility. Third, in terms of policy and CONOPS, the Air Force should accelerate DOD/DHS/FAA (Department of Defense/Department of Homeland Security/Federal Aviation Administration) joint efforts in Executive Committee to formalize national standards which mitigate risks of lost-link and see and avoid in the NAS for Group 4-5 RPAs. Finally, in the area of acquisition, the Air Force should pursue formal DOD acquisition programs, in place of the ACTD approach, for next generation RPAs, to deliver an integrated system of systems type approach to ensure unrestricted and integrated flight in the NAS, MCA, and in the International Civil Aviation Organization (ICAO) with manned aircraft (although the Panel also recommends that ACTD efforts still be pursued to explore and evaluate promising and potentially game-changing technologies in the RPA "space").



Airspace Management & Integration: Recommendations

Enhance airspace management via:

- **Autonomy – Focus USAF technology investments (AFRL "see and avoid" technologies and others) which meet safety requirements for RPA flight in the NAS to those large aircraft in Group 4/5 that can carry these payloads while maintaining their mission utility (AFRL)**
- **Robust Sensing and Communications - Focus future USAF technology investments for Group I/2 small RPA towards enhancing comm/sensor technologies which enhance combat mission capability in MCA where risk management margins have greater flexibility (AFRL)**
- **Policy/CONOPS - Accelerate DOD/DHS/FAA joint efforts in Executive Committee to formalize national standards which mitigate risks of "Lost Link" and "See and Avoid" in NAS for Group 4/5 RPA (SAF/AQ)**
- **Acquisition– Pursue formal DOD acquisition program vice ACTD approach for Next Generation RPA which deliver integrated system of systems type approach to ensure unrestricted and integrated flight in the NAS, MCA, and in the ICAO with manned aircraft (SAF/AQ)**

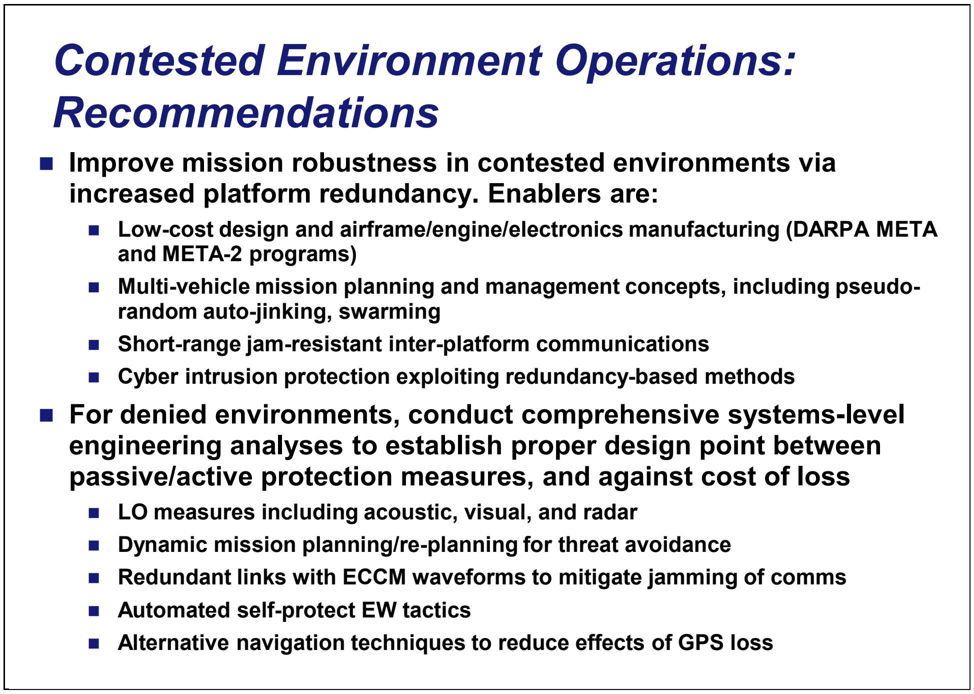
Figure 5-4: Airspace Management and Integration Recommendations.

5.2.3 Collateral Damage Recommendations

While the Study Panel found that collateral damage is not an RPA-unique issue, RPA capabilities in IW can help *minimize* the problem. First, persistent wide-area surveillance helps improve warfighter situation awareness. It also can enable tactical patience, a key enabler in limiting civilian casualties. Increased connectivity of split remote operations results in more "eyes on target" in the CONUS ground stations and more opportunities for data fusion from available feeds. Increased sensor fidelity can enhance positive identification, the lack of which is a key cause of civilian casualties. Finally, the employment of low collateral damage/directed lethality munitions on RPAs can help limit civilian casualties.

Contested Environments

The Study Panel recommendations directly addressing contested operating environments, shown in Figure 5-5, are grouped in two main categories. The Air Force can improve mission robustness in contested environments via increased platform redundancy. Enablers include low-cost design and airframe/engine/electronics manufacturing (as envisioned by the DARPA META and META-2 programs), multi-vehicle mission planning and management concepts, including pseudo-random auto-jinking, swarming, short-range jam-resistant inter-platform communications, and cyber intrusion protection exploiting redundancy-based methods. Second, for highly contested environments, the Air Force should conduct comprehensive systems-level engineering analyses to establish effective design tradeoffs that balance the cost of passive/active protection measures verses the cost of platform or sensor loss. This could include low observable (LO) measures (including acoustic, visual, and radar), on-board dynamic mission planning/re-planning for threat avoidance, redundant links with electronic protection (EP) waveforms to mitigate jamming of communications, automated self-protect electronic warfare (EW) tactics, and alternative navigation techniques to reduce effects of GPS loss.



Contested Environment Operations: Recommendations

- **Improve mission robustness in contested environments via increased platform redundancy. Enablers are:**
  - **Low-cost design and airframe/engine/electronics manufacturing (DARPA META and META-2 programs)**
  - **Multi-vehicle mission planning and management concepts, including pseudo-random auto-jinking, swarming**
  - **Short-range jam-resistant inter-platform communications**
  - **Cyber intrusion protection exploiting redundancy-based methods**
- **For denied environments, conduct comprehensive systems-level engineering analyses to establish proper design point between passive/active protection measures, and against cost of loss**
  - **LO measures including acoustic, visual, and radar**
  - **Dynamic mission planning/re-planning for threat avoidance**
  - **Redundant links with ECCM waveforms to mitigate jamming of comms**
  - **Automated self-protect EW tactics**
  - **Alternative navigation techniques to reduce effects of GPS loss**

Figure 5-5: Contested Environments Recommendations.

Chapter 6: Summary

RPAs provide many operational advantages today, but to achieve their full potential in the future – under more adverse operating conditions – four key issues need to be addressed. These are selection and manning, airspace management/integration, collateral damage and fratricide, and contested operations. As summarized in Figure 6-1, these issues can be addressed by providing for better mission management, via six enablers in technology, people, and processes including: platform/sensor automation/autonomy, enhanced operator control stations, robust communications systems, targeted selection and effective training, and innovative CONOPS/TTPs, and more effective transition of the prototypes of successful ACTD efforts. However, to achieve the full benefit of the operational advantages afforded by game-changing RPA weapons systems, the RPA development and acquisition community must embrace "acquisition normalization" which includes CONOPS-driven systems engineering and operator-centric human systems integration. In conclusion, investments in technology, people, and processes will define the future of RPAs for the Air Force.

Summary: Mission Management Will Shape Next-Generation RPA Operations

…but AF must influence Mission Management advances through coordinated investments:

Technology

- **Flexible levels of automation**
- **Enhanced Operator Control Stations**
- **Robust communications systems**

People

- **Targeted selection and effective training**

Processes

- **Improved CONOPS and TTPs**
- **Effective ACTD transitions**

Figure 6-1: Summary.

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Appendix A: Assumptions, Initial Hypotheses, and Data Requirements

A.1 Assumptions

The Study Panel identified the following assumptions with respect to remotely piloted aircraft:

- A1: RPAs provide global vigilance, global reach, and global power in dull, dirty, and dangerous missions.
- A2: RPAs can support a select range of military operations.
- A3: RPAs appetite and growth will continue (e.g., Predator/Reaper growing from 10 to 65 24/7 combat air patrols [CAPs]).
- A4: Projected manpower intensity (operators, exploiters) is unsustainable, driving a requirement for automation and autonomy.
- A5: Modularity can decrease life cycle cost, improve integration/adaptability, and enhance sustainability.
- A6: RPA standards will facilitate and possibly accelerate acquisition and enhance interoperability.
- A7: Existing and new sensors create an information deluge, driving a need to address tasking, processing, exploitation, and dissemination.
- A8: Adversaries can use RPAs for both offensive and defensive operations.
- A9: Adversaries will exploit our RPA vulnerabilities.
- A10: Counterinsurgency (COIN) Rules of Engagement (ROE) constrain operations (e.g., the protection of the civilian population is more important than killing a high-value target [HVT]).
- A11: Technology solutions for RPA challenges are available today that are not being employed.
- A12: Complexity will drive a shift to more software-intensive vehicles.
- A13: A net-centric environment and distributed command and control (C2) will require more links and more bandwidth.
- A14: Coalition and multi-service collaboration and interoperability are essential, but raise operational reasons (e.g., OPSEC).

A.2 Initial Hypotheses

The Study Panel identified and considered a number of hypotheses with respect to remotely piloted aircraft including:

- H1: Insufficient manning threatens sustainment of future growth in operations, as evidenced by:
  - "Our #1 manning problem in the Air Force is manning our unmanned platforms" (LtGen Deptula, 2010, SAB Briefing)
  - A freeze on all RPA operator re-assignments

This is exacerbated by insufficient training requirements, objectives, and methods.

- H2: Information overload threatens operational success because new, high bandwidth, wide area sensors challenge both limited communications bandwidth and limited human analytic capability.
- H3: Platform autonomy (e.g., take off, land/recover, navigation, collision avoidance including separation assurance (sense and avoid) and terrain avoidance) will increase RPA loiter, reach, effectiveness; and decrease the operator/RPA ratio (10 to 1).
- H4: Operator error, insufficient training, and system complexity are the primary contributors to operational failure
  - Decision-making error and skill-based error account for primary AF operational failures.[32]
  - Effective training, morale, and automation significantly improve performance (e.g., some attribute difference in Global Hawk vs. Predator mishap rates to differences in volunteerism, 100 percent former vs. 15 percent latter; and auto takeoff/land in the former).
- H5: RPA missions will increase in diversity and complexity (e.g., surveillance, counterinsurgency).
- H6: Threats against RPAs will increase in number and gain in sophistication.
- H7: Reliability will improve with increased system maturity, and can be accelerated with targeted efforts.
- H8: Multi-aircraft control (MAC) is a force multiplier and will increase mission effectiveness.
- H9: Increased autonomy will change the communication rate and bandwidth requirement (could go up and/or down).

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[32] (cf. UAV Mishaps 1994-2004).

- H10: Automated on-board processing is required to support Wide Area Airborne Surveillance (WAAS) in the face of fixed communications bandwidth.
- H11: Exploitation rate (TPED) is the primary limiting factor, not link bandwidth; bottleneck will shift in future.
- H12: Link vulnerability provides insurgents with an advantage.
- H13: Lack of RPA platform/sensor data link standards (most are proprietary and system unique) impede interoperability of ground and platform/sensor limiting control
    - Global Hawk is the only operational RPA with Common Data Link (CDL)
    - Need validation of STANAG 4586 and interoperability testing of systems.
- H14: ISR forensics are essential to counter insurgency, counter-IED mission.
- H15: Interoperability with joint and coalition partners is essential to mission effectiveness.
- H16: Advanced TTPs reduce support personnel per RPA CAP.
- H17: A Joint RPA/manned airspace management plan will increase airspace efficiency, safety, and mission effectiveness.
- H18: USAF RPA investment portfolio is not well matched to mission requirements/needs.

A.3 Data Requirements

During the process of testing hypotheses, the Study Panel identified a number of essential elements of information that are important to assessing the effectiveness and efficiency of RPA operations. The key ones are captured here to motivate their collection for future analyses.

A.3.1 Manning

- What is manning requirement by platform (e.g., Predator, Reaper, Global Hawk)?
- What skills, mission essential competencies (MECs), and experiences are required to successfully operate various platforms and missions?

A.3.2 Operations

- What are the flight hours breakdown by mission tasks (e.g., ferrying; intelligence, surveillance, and reconnaissance [ISR]; weapons engagement; battle damage assessment) by platform (e.g., Predator, Reaper, Global Hawk)?
- How many requirements/tasks (e.g., ISR, close air support, strike) that could be addressed by RPAs are not satisfied (e.g., requirement for coverage, speed)?

A.3.3 Civilian Causalities

- What percentage of civilian causalities is caused by RPAs?
- How many civilian causalities are avoided because of RPA persistent surveillance?
- What percent of initial enemy determinations were reversed with additional RPA data?

A.3.4 Training

- How many hours of training are required for various RPA roles (e.g., pilots, sensor operators, information exploiters, maintainers)?
- What is the distribution of training hours in terms of class room, simulator, and live operations?

A.3.5 Communications

- What is the experience of lost-link by percent of flight hours by platform (Predator, Reaper, Global Hawk)?
- What is the average duration and variance of lost-link?
- What are the causes of lost-link (e.g., mechanical failure, human error, interference, jamming)?
- What is the trained response to various link losses?

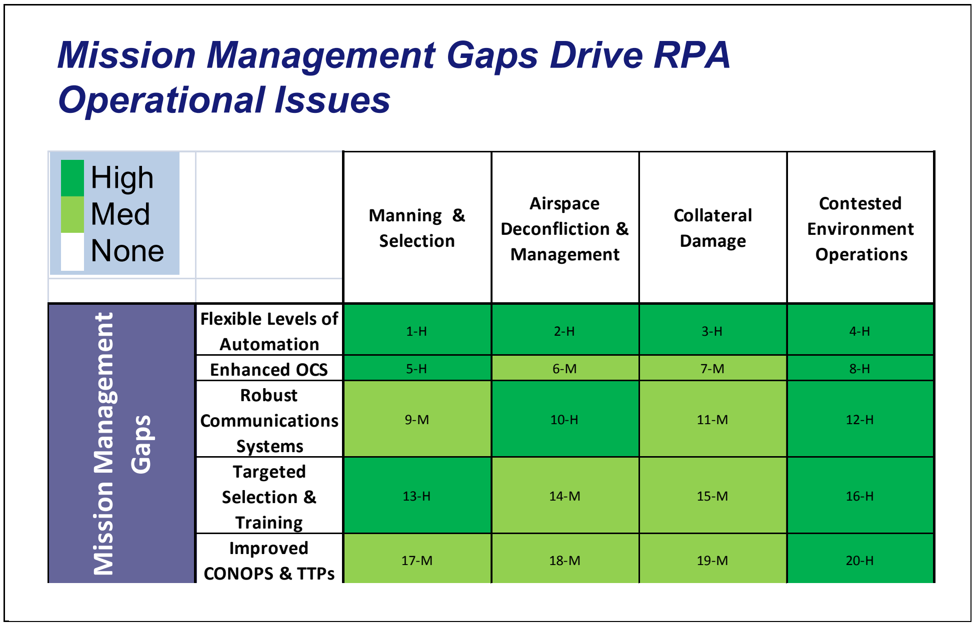
A.3.6 Contested Environments

- What kinds of threats and at what frequency are they experienced by area, platform (e.g., Predator, Reaper, Global Hawk), mission?

Appendix B: Analysis of Impact of Findings and Recommendations

This appendix captures a detailed qualitative assessment of the impact of the Study Panel's findings and recommendations on identified operational gaps. Importantly, our analysis did not consider cost or quantitative impacts of various recommendations but rather reflects expert judgment by the Panel based on individual and Panel expertise and experience. Our assessments reflect our collective best judgment given the short study time. Accordingly, we caveat our analysis as not being a formal life cycle cost/benefit analysis, which would require further effort.

The Study Panel's analytic method included considering the effects of closing the identified mission management gaps discussed in Chapter 3, in terms of ameliorating the operational issues articulated in Chapter 2 (i.e., manning and selection, airspace deconfliction and management, collateral damage, and contested environments). Figure B-1 depicts a matrix illustrating the benefits of addressing known mission management gaps (rows) on the operational issues (columns). For example, investments in solving automation the mission management gaps in Operator Control Station (OCS), communications, selection/training, and CONOPS/TTP (Concepts of Operations/Tactics, Techniques, and Procedures) will improve the identified operational issues. Each cell in the matrix is numbered and colored as green (high impact), light green (medium impact), and white (little or no impact) to indicate the degree of contribution an investment has in terms of correcting the operational issue. A justification for each assessment is captured below indexed by the cell number for ease of access. Rows indicate how improvements affect issues: thus cells 1 through 4 indicate how flexible levels of automation will contribute to the four operational issues. For example, cell number 2 indicates how investments in automation will improve airspace deconfliction and management. The following paragraphs explain the qualitative assessments made for each cell.



Mission Management Gaps Drive RPA Operational Issues

High
Med
None

		Manning & Selection	Airspace Deconfliction & Management	Collateral Damage	Contested Environment Operations
Mission Management Gaps	Flexible Levels of Automation	1-H	2-H	3-H	4-H
	Enhanced OCS	5-H	6-M	7-M	8-H
	Robust Communications Systems	9-M	10-H	11-M	12-H
	Targeted Selection & Training	13-H	14-M	15-M	16-H
	Improved CONOPS & TTPs	17-M	18-M	19-M	20-H

Figure B-1: Impact of Addressing Mission Management Gaps on Operational Issues.

Cell 1 (High): Increasing automation will reduce personnel and manning requirements for pilots, sensor operators, and exploiters. Automation can reduce the need for sensor operators, lessen selection criteria requirement for pilots, and enable multi-aircraft control (MAC). Improved automation will make aircraft handoffs more rapid and allow one pilot to handle more than one aircraft.

Cell 2 (High): Effective automation could enable more precise and timely flight planning and improve sense and avoid, and automate reactions to time-critical events. Automation is a key solution to Federal Aviation Administration (FAA) see-and-avoid requirements and will have significant impact on the ability of RPAs of all groups to successfully integrate with manned aircraft in the National Airspace (NAS).

Cell 3 (High): Effective and accurate automation could enhance automated target cueing/tracking and ease of adjusting levels of automation to best fit mission need, and could help avoid deadly errors in collateral damage estimation. Enhanced small RPA flight control could enable close-in access in contested environments, and automatic receipt of high resolution imagery could enable rapid and reliable human confirmation of targets with positive identification. Improved automation transparency/feedback could decrease operator situation awareness and safety.

Cell 4 (High): Automation of the recognition, avoidance, and/or countering of threats, as well as the ability to act autonomously to remain stealthy would increase effectiveness in contested environments. Readily available, prioritized ISR would allow more efficient operations in contested environments. Automation (particularly multi vehicle control, swarming, and group autonomy) would enable quick reaction to changing threat scenarios, rapid and automated reallocation of tasks across platforms, smart use of redundancy to recognize cyber intrusions, and could provide ways for coordinated response/recovery to damage and platform degradation.

Cell 5 (High): Improved/intuitive OCSs can ease selection and reduce training requirements by providing better situation awareness, enable multi-RPA operations and collaborative operations, including more rapid handoffs, and allow one pilot or sensor operator to handle more than one aircraft.

Cell 6 (Medium): Better OCSs could improve operator situational awareness (SA) of airspace (overcoming "soda straw" displays), a significant aspect of airspace management and deconfliction (e.g., see and avoid). Enhancements in RPA Command and Control communications will not solve all airspace deconfliction issues, but should limit RPA "lost-link episodes" and thus increase FAA confidence for flights in the NAS.

Cell 7 (Medium): Better OCSs can improve pilot SA of environment (overcoming "soda straw" displays), allowing better decisions to be made on strike opportunities to avoid collateral damage, although better sensors and georegistration would have an even higher impact. Current RPA OCSs do not promote effective, safe mission management because of inefficient and ineffective acquisition and processing of information, lower mission SA, and higher operator workload. Current OCS re-architecture efforts inadequately address: 1) automation and adjustable human-automation interaction, 2) human computer interaction (HCI) for future capabilities and 3) distributed mission operations.

Cell 8 (High): Better designed OCSs can make operations in contested environments (see and avoid) less challenging. Better OCSs are required for pilots to understand and react more rapidly and more effectively to the threats in contested environments. Improvements in sensor and communications links could improve the effectiveness of OCSs.

Cell 9 (Medium): Communications system improvements could partially improve some operator-RPA interaction, reduce demand for specialized skills, and, through distribution, increase platform and pilot/exploiter utilization with more efficient tasking.[33]

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[33] Briefing entitled "Globally Distributed Mission Management Operational Benefits Analysis", 2009, Booz Allen Hamilton

Cell 10 (High): Lost-link conditions are a major concern for FAA, particularly where sense and avoid systems are not fielded. Communications improvements could increase the likelihood of maintaining positive control of RPAs.

Cell 11 (Medium): Limited communications could inhibit weapon employment opportunities, latencies in satellite links inhibit real-time, emergency command and control (C2) and lack of interoperability limits distributed operations. Reduced latency links promise to enable random diverts and better communications and networking promises to increase SA and fusion from multiple assets, with the potential to improve target recognition/confirmation. In addition, an open communications architecture would enable not only distributed Processing, Exploitation, and Dissemination (PED), but also distributed global operations.

Cell 12 (High): A lack of diversity and dependence on existing systems (e.g. SATCOM) increases vulnerability in contested environments and limited communications inhibit real-time threat warnings. Increased redundancy in communication links increases resilience to communication link attacks. Better QoS provisioning will allow for quick adaptation to changing mission scenarios.

Cell 13 (High): Improving selection and training will mitigate manning problems. Scientifically based selection and training can help acquire the right personnel, accelerate training, and reduce attrition. Training and selection of pilot candidates can especially impact the desired capability to handle multiple RPAs.

Cell 14 (Medium): For RPAs that are "virtually manned," that is flown by pilots/operators remotely thru the Ku Band satellite infrastructure like the Predator series, better trained pilots will improve airspace management in NAS and Military Controlled Airspace (MCA). Also, simulation training in Distributed Mission Operations (DMO) environments can be used to test NAS CONOPS and train for airspace coordination.

Cell 15 (Medium): Selection criteria are not based on capabilities associated with each RPA position, and squadron instructors have expressed concern with the combat readiness of Beta pilot graduates. Improvements in simulation facilities, especially for sensor operator training, structured continuation training for mission management skills, and simulation training in DMO environments can be used to train mission coordination to prevent collateral damage. Training and simulation under stressful conditions could provide the needed experience for positive identification and tactical patience, both key to the prevention of collateral damage.

Cell 16 (High): Targeted selection and training for contested environment operations are crucial for mission assurance. Selection of warfighters who are able to make decisions under uncertainty and who can manage dynamic mission environments are essential for effective operation in contested space. Better simulators that incorporate realistic kinetic and electronic threats can enhance force resiliency. Finally, simulation training in DMO environments can be used to train mission coordination in contested environments.

Cell 17 (Medium): Improving CONOPs and TTPs helps identify possible inefficient RPA applications, particularly for exploitation. However, CONOPS and TTPs indirectly affect the manning requirements of RPAs, their use in contested environments, and whether a single pilot can handle multiple RPAs.

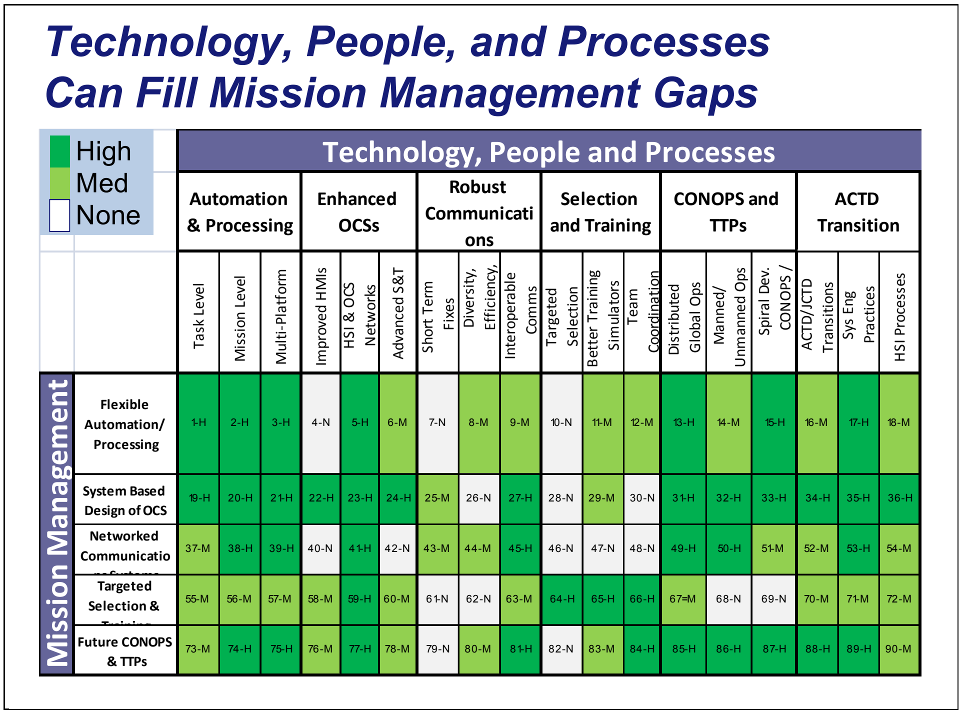
Cell 18 (Medium): Until CONOPs and TTPs are developed, airspace management will remain inefficient and difficult. Improvements in CONOPs and TTPs should improve effectiveness and efficiency of military RPA operations in MCA in combat AORs, but will not completely satisfy FAA deconfliction requirements in the NAS.

Cell 19 (Medium): CONOPS and TTPs are often developed "after the fact" following development and deployment, rather than as a concurrent effort in an "incremental development" program. CONOPs for distributed mission management and collateral damage avoidance should be part of well-structured TTPs. CONOPS and TTPs that ensure positive identification and tactical patience promise to reduce collateral damage.

Cell 20 (High): Adversarial actions dramatically increase uncertainty in mission execution. CONOPS and TTPs addressing contested environments and scenarios are important not only for warfighter preparation, but also for developing requirements for weapon systems.

Figure B-2 depicts a matrix illustrating the benefits of technology, people, and process investment (shown down columns) to fill known mission management gaps (shown across in rows). That is, investments in reducing existing limitations in automation, OCS, communications, selection/training, and CONOPS/TTPs will reduce the identified mission gaps, such as the need for flexible automation. Each cell in the matrix is numbered and colored as green (high impact), light green (medium impact), and white (little or no impact) to indicate the degree of contribution an investment has to correcting a mission management gap. A justification for each assessment is captured in the text remainder of this appendix, indexed by the cell number for ease of access. For example, cells 21 through 25 indicate that implementing the Study Panel's mid-term enhanced OCS recommendation will significantly improve all gap areas, from enabling flexible automation to improving future CONOPS and TTPs.

In particular, employing a cohesive Human-System Integration (HSI) process and usability design/testing to develop a family of networked, interoperable OCSs with new non-proprietary, standards-based OCS architectures with plug-and-play components for a full range of functions will enable automation, facilitate interoperability and modularity, improved networked communications, ease training, and support and foster novel CONOPS/TTPs. As is evident, the main diagonals between major columns and their respective mission management gaps are equivalent (e.g., automation for automation) therefore are left out of the detailed analysis.



Technology, People, and Processes
Can Fill Mission Management Gaps

🟩 High
🟩 Med
☐ None

Technology, People and Processes

		Automation & Processing			Enhanced OCSs			Robust Communications			Selection and Training			CONOPS and TTPs			ACTD Transition		
		Task Level	Mission Level	Multi-Platform	Improved HMIs	HSI & OCS Networks	Advanced S&T	Short Term Fixes	Diversity, Efficiency,	Interoperable Comms	Targeted Selection	Better Training Simulators	Team Coordination	Distributed Global Ops	Manned/ Unmanned Ops	Spiral Dev. CONOPS /	ACTD/JCTD Transitions	Sys Eng Practices	HSI Processes
Mission Management	Flexible Automation/ Processing	1-H	2-H	3-H	4-N	5-H	6-M	7-N	8-M	9-M	10-N	11-M	12-M	13-H	14-M	15-H	16-M	17-H	18-M
	System Based Design of OCS	19-H	20-H	21-H	22-H	23-H	24-H	25-M	26-N	27-H	28-N	29-M	30-N	31-H	32-H	33-H	34-H	35-H	36-H
	Networked Communicatio	37-M	38-H	39-H	40-N	41-H	42-N	43-M	44-M	45-H	46-N	47-N	48-N	49-H	50-H	51-M	52-M	53-H	54-M
	Targeted Selection &	55-M	56-M	57-M	58-M	59-H	60-M	61-N	62-N	63-M	64-H	65-H	66-H	67=M	68-N	69-N	70-M	71-M	72-M
	Future CONOPS & TTPs	73-M	74-H	75-H	76-M	77-H	78-M	79-N	80-M	81-H	82-N	83-M	84-H	85-H	86-H	87-H	88-H	89-H	90-M

Figure B-2: Impact of Investing in Technology, People, and Processes on Solving Mission Management Gaps.

Cell 1: Main diagonal.

Cell 2 (High): Automation aids will drastically affect OCS design and training requirements. Also, automatic transmission of high-value imagery will simplify OCS design and use.

Cell 3 (Medium): Single platform automation will enable network communication systems to support basic distributed control. In addition, on-board auto-compression and processing of imagery will greatly reduce the burden on networked communication systems.

Cell 4 (Medium): Single platform automation affects training and selection. Sensor operator training will be improved when realistic simulator conditions are available for single-platform automated imagery capabilities.

Cell 5 (Medium): Future CONOPS and TTPs will be enabled or disabled by the effectiveness of automation of platform and payload functions (e.g., imagery selection and compression in complex systems such as ARGUS-IS).

Cell 6: Main diagonal.

Cell 7 (High): Mission level automation aids will drastically affect OCS design and training requirements. Automatic selection of the highest-valued imagery from platforms will improve efficiency of OCS-related activities, particularly reducing the burden on the sensor operator.

Cell 8 (High): Combining automation and networked communications across multiple platforms enables global distributed RPA management. Automated compression of imagery from/among multiple platforms will greatly reduce the burden on networked communications systems.

Cell 9 (Medium): Multi-platform automation affects multi-platform training. Sensor operator training will be improved when realistic simulator conditions are available for multi-platform automated imagery capabilities.

Cell 10 (High): Future CONOPS and TTPs will be affected by mission level automation, eliminating many manual procedures and streamlining overall workflow.

Cell 11: Main diagonal.

Cell 12 (High): Multi-platform automation aids will drastically affect OCS design and training requirements. Auto-selection of the highest-valued imagery from/among multiple platforms and timely reporting of high-priority events will improve efficiency of OCS-related activities.

Cell 13 (High): Mission level automation can more effectively leverage networked communications which are required for distributed collaborative mission management. Automated compression and delivery-when-needed of images for particular missions can reduce the burden on communications systems and enhance their efficiency.

Cell 14 (Medium): Multi-platform automation affects multi-platform training. Sensor operator training will be improved when realistic simulator conditions are available for integrated multi-RPA-platform and for dealing with all-source imagery/intelligence.

Cell 15 (High): Multi-platform automation enables new concepts like globally distributed RPA management, but also enables new ways to perform multi-RPA collaborative missions, like swarms. Future CONOPS and TTPs will be affected by automation of imagery selection and compression from complex systems such as ARGUS-IS on multiple platforms when integrated automatically with all-source intelligence.

Cell 16 (None): Improved HMIs will leverage and facilitate incorporation of flexible automation.

Cell 17: Main diagonal.

Cell 18 (None): Improved HMIs would have little effect on networked communications.

Cell 19 (Medium): Improved HMIs will ease training somewhat, but not significantly.

Cell 20 (Medium): Improved HMIs will enable better operations.

Cell 21 (High): Open OCS architectures will enable new auto modules to be easily inserted.

Cell 22: Main diagonal.

Cell 23 (High): New, open architecture OCSs will enable interconnectivity and improved communications through standard protocols.

Cell 24 (High): New interoperable OCSs will streamline training through maximizing commonalities, reducing modeling and simulation requirements.

Cell 25 (High): New interoperable OCSs can significantly impact development of new CONOPS and TTPs by enabling control of heterogeneous RPAs from a single OCS.

Cell 26 (Medium): Advanced S&T promotes improvements in automation aids, which further enables flexible automation.

Cell 27: Main diagonal.

Cell 28 (None): Advanced S&T for OCSs (e.g. multiple heterogeneous platform teaming) could increase reliance on networked communications, but will not directly improve them.

Cell 29 (Medium): Advanced S&T will reduce manpower requirements by allowing fewer operators to do more (force multiplication).

Cell 30 (Medium): Advanced OCS operator aids will extend the ability of the human to supervise multiple RPAs simultaneously in collaborative missions.

Cell 31 (None): Short-term fixes to communications will not affect flexible automation.

Cell 32 (Medium): Immediate fixes to the communications systems will enable reading data from existing ground control stations (GCSs), and disseminating the information better throughout the network.

Cell 33: Main diagonal.

Cell 34 (None): Short-term fixes to communications will not affect targeted selection and training.

Cell 35 (None): Short-term fixes to communications will not impact future CONOPS and TTPs.

Cell 36 (Medium): Communications diversity, efficiency, and robustness will enable processing that is now done on the ground to be placed on-platform.

Cell 37 (None): Communications diversity, efficiency, and robustness will not affect OCS designs.

Cell 38: Main diagonal.

Cell 39 (None): Communications diversity, efficiency, and robustness will not affect targeted selection and training

Cell 40 (Medium): Use of relay options will enable new CONOPS/TTPs.

Cell 41 (Medium): As with Cell #8, but allows for dynamic load balancing or tasking (e.g., with facilities like cloud computing).

Cell 42 (High): Open and interoperable communications architectures will significantly enhance the functionality of OCSs by making them fully networked.

Cell 43: Main diagonal.

Cell 44 (Medium): Interoperable communications will enable distributed simulation and training.

Cell 45 (High): Implementation of a full communications architecture will enable CONOPS/TTPs that exploit networks of assets, not just operating platforms.

Cell 46 (None): Targeted selection and training will have no impact on automation.

Cell 47 (None): Selection and training will not affect OCS design and should not be a fix for poor design.

Cell 48 (None): Selection and training will not impact communications.

Cell 49: Main diagonal.

Cell 50 (None): Targeted selection will not affect future CONOPs/TTPs.

Cell 51 (Medium): Developing a realistic simulator could help identify the requirements for and/or design characteristics of automation (e.g., enabling the exploration of different levels of automation).

Cell 52 (Medium): Although better training simulators could improve operator performance, they won't necessarily directly result in improved OCSs. However, developing a realistic simulator could help identify the requirements for and/or design characteristics of a family of better OCSs.

Cell 53 (None): Better training simulations will not impact communications.

Cell 54: Main diagonal.

Cell 55 (Medium): Better training simulators could help develop and test CONOPs/ TTPs.

Cell 56 (Medium): Team coordination training can be conducted in the context of MAC and other human-automation experiences. Better team training could result in discovery of where mission level automation can help performance.

Cell 57 (None): Better training in team coordination will have no affect on the design of OCS.

Cell 58 (High): Team coordination will not improve networks and communications.

Cell 59: Main diagonal.

Cell 60 (High): Team coordination training environments can serve as testbeds for creating and evaluating human-in-the loop CONOPS/TTPs.

Cell 61 (High): Distributed global operations will depend on high levels of well-structured automation, and well-defined CONOPS/TTPs will drive appropriate automation.

Cell 62 (High): Well-articulated CONOPS/TTPs for distributed global operations can guide the design of OCSs which can result in more efficient and effective use of operators.

Cell 63 (High): Clarity of CONOPS/TTPS for distributed global operations will provide clear requirements for the design of robust, networked communications systems design.

Cell 64 (Medium): The skillsets mandated by distributed operations must be defined and included in personnel selection and training. Clear CONOPS/TTPs for distributed global operations will help focus personnel selection and training curricula.

Cell 65: Main diagonal.

Cell 66 (Medium): Integration of manned and unmanned operations on any significant scale will depend upon appropriate automation and be driven by requirements for manned/unmanned operations.

Cell 67 (High): Integrated manned and unmanned operations will be impossible without an appropriate OCS, but will not enhance the OCS.

Cell 68 (High): Clarity of CONOPS/TTPS for integration of manned/unmanned operations will provide clear requirements for the design of robust, networked communication systems design.

Cell 69 (None): Development of manned/unmanned CONOPs/TTPs will not affect targeted selection and training.

Cell 70: Main diagonal.

Cell 71 (High): A path toward well-engineered automation should be a part of each spiral.

Cell 72 (High): One of the major limitations of the current Predator and Global Hawk systems is the poor design of the OCSs. In large part, this arose from the way these programs were pursued, as Advanced Concept Technology Demonstrations (ACTDs) focused on technology, without a direct view towards acquisition or even operational needs. A clearer focus on the transition of ACTDs to an operational system should have resulted in a more successful OCS, and such should be pursued for future RPA concepts and missions.

Cell 73 (Medium): The spiral development of CONOPS/TTPS has a moderate impact on the design of the networked communications plan.

Cell 74 (None): Spiral development of CONOPs/TTPs will not affect targeted selection and training.

Cell 75: Main diagonal.

Cell 76 (Medium): Improving the transition process for moving the products of ACTDs into acquisition would have relatively minimal impact on the ability to introduce flexibility in the automation process. This is a developmental feature that would be incorporated in the technology design phase.

Cell 77 (High): Improving the transition process of advanced OCSs ACTDs into normalized acquisition would address a significant mission management gap for well-engineered OCSs.

Cell 78 (Medium): Effective transition of communications/networking ACTDs enables the demonstration of new communications approaches to address the current challenges of a contested, heterogeneous, and bandwidth hungry environment.

Cell 79 (Medium): An improved transition process should include training needs and processes. As such, the methodology for choosing RPA operators and determining a valuable training course, including meaningful metrics and means of providing operational feedback, should be part of the acquisition considerations.

Cell 80 (High): The development of future CONOPS/TTPs must inform the technology development and transition process. Indeed, one can argue that a significant limitation in current RPA systems has been that the technology was developed without a detailed understanding of the CONOPS. As such, the identification of future missions and employment strategies, including RPA interactions with other systems, is an essential part of an ACTD transition strategy.

Cell 81 (High): Proper systems engineering must include a detailed analysis of the degree of automation required for mission prosecution, and the required flexibility for such a system. This leads to a high degree of coupling between proper systems engineering practices and the ability to provide a "dial-in" capability in setting levels of autonomy appropriate for a given mission or operational phase. Detailed human-machine interaction studies are required, considering actual operational experiences with current RPAs, and projected future needs and uses.

Cell 82 (High): System engineering practices will have direct and significant impact on improved design of future OCSs.

Cell 83 (High): A systems engineering approach to communications/networking will result in more robust communications and interoperability enabling secure/distributed operations, although this may delay fielding of systems.

Cell 84 (Medium): Systems engineering should, by its nature, include some considerations of training and operator selection and a disciplined system engineering process should result in capabilities that ease or enhance training.

Cell 85 (High): Disciplined systems engineering practices can result in more robust, flexible, and effective systems that can enable future CONOPS/TTPs. Moreover, systems engineering practices can be applied to enhance the development of new CONOPS/TTPs.

Cell 86 (Medium): An essential role for an HSI evaluation team will be to determine the desired degree of autonomy for any RPA system, and the best way to incorporate that into operations.

Cell 87 (High): An HSI effort should have a major role in designing, or modifying, an OCS.

Cell 88 (Medium): Communications/networking systems that incorporate HSI will be more tailored to operator performance.

Cell 89 (Medium): Part of the analysis of human-machine interactions should include training issues, ease of use, and means of coupling training simulations to operator control stations.

Cell 90 (Medium): Effective application of HSI processes can better enable future, and potential future, RPA CONOPS/TTPs. Considering human-machine interface and human-human interaction during design can maximize flexibility across multiple mission scenarios and well as best engage human and machine talent in future CONOPS and TTPs.

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Appendix C: Study Members

Study Leadership
- Dr. Greg Zacharias, Chair
- Dr. Mark Maybury, Vice Chair

Study Membership
- Dr. Nancy Cooke
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- Maj Gen George Harrison, USAF (Ret)
- Mr. Neil Kacena
- Maj Gen Michael Kostelnik, USAF (Ret)
- Dr. Mark Lewis
- Dr. David Moore
- Mr. Charles Saff
- Dr. Robert Schafrik
- Prof. Michael Stroscio
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  - Col Michele Cook
  - Col Jeff Eggers
  - Col David Sullivan

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- Mr. Matthew Gorski, Deputy Program Manager

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- Lt Col Anne Johnson
- Lt Col Daniel Markham
- Lt Col Gary Mills
- Maj Harris Hall
- Capt Geoffrey Bowman
- Capt Amy Zwiers

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Appendix D: Visits and Briefings

Air Staff
AF/CC-SA
AF/A1
AF/A2
AF/A3/5
AF/A8
AF/A9

Operational Organizations
CENTCOM: J2, J3, J5, J8
SOCOM
AFSOC: CC, A2, A3, A5, A8, A9, 11 IS, USAFSOS
ACC: A2, A3, A8, 26 WPS, USAFWC, 432 WG, 11 RS, 480 Wing, DGS-1, DGS-2

Other Organizations
Army G2
JFCOM: J5, JCOA
NASIC
NGA
CIA
DIA
DHS/CBP
FAA

Related Activities/Studies
AF UAS Task Force
RAND Project Air Force
Defense Science Board

Acquisition
SAF/AQI
ASC
OSD-ATL
AAC/XP

Research
AFRL: RB, RH, RW, RY
Army AMRDEC
Arizona State University
DARPA: TTO, IPTO, AEO, STO
Johns Hopkins Applied Physics Lab
Marine Corps Warfighting Lab
MIT
MITRE
ONR
United Technologies Research Center

Industry
Airborne Technologies
BIT Systems
Boeing
General Atomics
Lockheed Martin
Northrop Grumman
Raytheon
SRS Technologies

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Appendix E: Acronyms

ACO	Air Coordination Order
ACS	Advanced Control Station
ACTD	Advanced Concept Technology Demonstration
AFRL	Air Force Research Laboratory
AFSOC	Air Force Special Operations Command
AMOC	Air Maritime Operations Centers
ANA	Afghanistan National Army
ANP	Afghanistan National Police
ARGUS	Autonomous Real-time Ground Ubiquitous Surveillance
Argus-IS	ARGUS Imaging Systems
ASOC	Air Support Operations Center
ATD	Advanced Technology Demonstration
ATO	Air Tasking Order
ATC	Air Traffic Control
AF	Air Force
BACN	Battlefield Airborne Communications Node
BFT	Blue Force Tracker
BPC	Building Partnership Capacity
BDA	Bomb Damage Assessment
C2	Command and Control
CAOC	Combined Air Operations Center
CAP	Combat Air Patrol
CAS	Close Air Support
CBP	Customs and Border Patrol
CENTCOM	Central Command
CIA	Central Intelligence Agency
CIVCAS	Civilian Casualties
COA	Certificate of Authorization
COCOM	Combatant Command
COIN	Counter Insurgency
CONOPS	Concept of Operations
COTS	Commercial off the Shelf
CT	Counter Terrorism
DCGS	Distributed Common Ground Station
DHS	Department of Homeland Security
DIA	Defense Intelligence Agency
DIB	DCGS Integration Backbone
DNI	Director of National Intelligence

DSB	Defense Science Board
DSO	Distributed System Operations
EA	Electronic Attack
ECM	Electronic Countermeasure
EP	Electronic Protection
ESOW	Expeditionary Special Ops Wing
EW	Electronic Warfare
FAA	Federal Aviation Administration
FBI	Federal Bureau of Investigation
FID	Foreign Internal Defense
FMV	Full Motion Video
GA	General Atomics
GD	General Dynamics
GCS	Ground Control Station
GEOINT	Geospatial Information Intelligence
GIG	Global Information Grid
GIG-BE	Global Information Grid Bandwidth Extension
GPS	Global Position Satellite
HART	Heterogeneous Airborne Reconnaissance Team
HUMINT	Human Intelligence
HSI	Human-System Integration
HCI	Human Computer Interaction
HVT	High Value Target
IADS	Integrated Air Defense System
IFR	Instrument Flight Rules
IMINT	Imagery Intelligence
ISAF	International Security Assistance Forces
ISR	Intelligence, Surveillance and Reconnaissance
IW	Irregular Warfare
IR	Infrared
JSOA	Joint Special Operations Area
JTAC	Joint Terminal Attack Controller
LMCO	Lockheed Martin Corporation
LO	Low Observable
LOS	Line-of-sight
LPI	Low Probability of Intercept
MASINT	Measures and Signatures Intelligence
MALE	Medium Altitude Long-Endurance UAV

MCA	Military Controlled Airspace
MEC	Mission Essential Competencies
MM	Mission Management
MTI	Moving Target Indicator
NAS	National Airspace System
NTC	National Training Center
NGA	National Geospatial Intelligence Agency
NRO	National Reconnaissance Office
NIPRNET	Non-classified Internet Protocol Router Network
OCS	Operator Control Station
OSINT	Open Source Intelligence
OSD	Office of the Secretary of Defense
PED	Processing, Exploitation and Dissemination
PI	Person Identification
PSYOP	Psychological Operation
RCS	Radar Cross Section
ROE	Rules of Engagement
ROZ	Restricted Operating Zone
RPA	Remotely Piloted Aircraft
SA	Situation Awareness
SAA	Sense and Avoid
SAM	Surface to Air Missile
SEAD	Suppression of Enemy Air Defenses
SIGINT	Signals Intelligence
SIPRNET	Secret Internet Protocol Router Network
SOCOM	Special Operations Command
SOUTHCOM	Southern Command
SPO	System(s) Program Office
SUAS	Small Unmanned Aerial Systems
TAO	Terminal Area Operations
TAOC	Terminal Area Operations Center
TCAS	Terminal Collision Avoidance System
TOR	Terms of Reference
TTP	Tactics, Techniques, and Procedures
TPED	Tasking, Processing, Exploitation, and Dissemination
UAS	Unattended/Unmanned Airborne System
UAV	Unattended/Unmanned Airborne Vehicle
UCAS	Unattended Combat Airborne System
UTOC	UAS Tactical Operation Center

UW	Unconventional Warfare
VFR	Visual Flight Rules
WAAS	Wide Area Airborne Surveillance
WAPS	Wide Area Persistent Surveillance
WOC	Wing Operations Center

Appendix F: References

Alliger, G.M., R.M. Beard, W. Bennett, Jr., C.M. Colegrove, and M. Garrity. "Understanding Mission Essential Competencies as a Work Analysis Method" (AFRL-HE-AZ-TR-2007-0034). Mesa AZ: Air Force Research Laboratory, Human Effectiveness Directorate, Warfighter Readiness Research Division. 2007.

Booz Allen Hamilton. "Globally Distributed Mission Management Operational Benefits Analysis, 2009." [Briefing provided to SAB during Summer Board Meeting in Irvine, CA, June 2010.].

Billingsley, 2Lt Thomas B. "Safety Analysis of TCAS on Global Hawk using Airspace Encounter Models", USAF Academy and MIT/Lincoln Labs, June 2006.

Card, Stuart K., Thomas P. Moran, and Allen Newell. *The Psychology of Human-Computer Interaction*. Hillsdale, NJ: Lawrence Erlbaum Associates, 1983.

Cooke, Nancy J., Heather L. Pringle, Harry K. Pedersen, and Olena Connor, eds. *Human Factors of Remotely Operated Vehicles.* Oxford, UK: Elsevier/JAI Press, 2006.

Cummings, Missy, Sylvain Bruni, Stephane Mercier, and Paul J. Mitchell. "Automation Architecture for Single Operator-Multiple UAV Command and Control." *The International Command and Control Journal, Vol. 1, No. 2* (2007): 1-24.

Erwin, Sandra I. "Controlling Iraq's Crowded Airspace No Easy Task." *National Defense Magazine*. December 2005. http://www.nationaldefensemagazine.org/archive/2005/December/Pages/UF-Controlling5482.aspx

Gramm, Joshua and Steven Pappan. 2009. "Insatiable Demand: 'Manning' the US Air Force's Unmanned Aircraft Systems with Capable Pilots," Harvard Kennedy School of Government, March 2009.

Lacher, Andrew, et al. "Airspace Integration Alternatives for Unmanned Aircraft," Presented at the AUVSI Unmanned Systems Asia-Pacific Conference. Pan Pacific Hotel, Singapore. 1 February 2010.

La Franchi, Peter. "Animation: Near Misses Between UAVs and Airliners Prompt NATO Low-Level Rules Review." *Flight International* 14 March 2006.

Morgan, Dwayne, Ron Streich, Barton Bull, and Chuck Grant. "Telemetry Tracking & Control (TT&C) – First TDRSS, then Commercial GEO & Big LEO and Now Through

LEO." NASA Technical Paper (Document ID 20010020063). 2001. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20010027550_2001035035.pdf

United States. AF/A2. "CAP Comparisons – MQ1~MQ9~RQ4~MC12 (20 Apr 10)." [Briefing provided to SAB during Summer Board Meeting in Irvine, CA, June 2010.]

United States. Defense Science Board. *Department of Defense Policies and Procedures for the Acquisition of Information Technology*. Washington, DC. March 2009. www.acq.osd.mil/dsb/reports/ADA495025.pdf

United States. Deptula, Lt Gen David. "The Way Ahead: Remotely Piloted Aircraft in the United States Air Force." [Briefing presented to SAB during Winter board Meeting in Arlington, VA, January 2010].

United States. Department of the Air Force. "The 21st Century Air Force Irregular Warfare Strategy White Paper." January 2009.

United States. Hansen, Blair, Brig. Gen. "Project Liberty 'MC-12'," Presented January 2009.

United States. Air Force Audit Agency. *Unmanned Aerial System Pilot Force Management*. F2009-0005-FD4000. Washington, DC. 17 December 2008.

United States. Joint Center for Operational Analysis. "Civilian Casualties in Afghanistan: 2007-mid 2009." [Briefing provided to SAB in May 2010.]

United States. Office of the Secretary of Defense. *FY2009-2034 Unmanned Systems Integrated Roadmap*, *Second Edition*. Washington, DC. April 2009.

United States. United States Air Force Scientific Advisory Board. *Unmanned Aerial Vehicles in Perspective: Effects, Capabilities, and Technologies. Volume 1: Summary.* SAB-TR-03-01. Washington, DC. September 2003.

United States. United States Air Force Scientific Advisory Board. *Virtual Training Technologies*. SAB-TR-09-01. Washington, DC. August 2009.

United States. United States Air Force Scientific Advisory Board. *Human-System Integration in Air Force Weapon Systems Development and Acquisition: Executive Summary and Annotated Brief*. SAB-TR-04-04. Washington, DC. July 2004.

Warrick, Joby and Peter Finn. "Amid Outrage over Civilian Deaths in Pakistan, CIA Turns to Smaller Missiles." *Washington Post* 26 April 2010: A1. http://www.washingtonpost.com/wp-dyn/content/article/2010/04/25/AR2010042503114.html

Appendix G: Initial Distribution

Air Force Leadership
SAF/OS - Secretary of the Air Force
SAF/US - Under Secretary of the Air Force
AF/CC - Chief of Staff of the Air Force
AF/CV - Vice Chief of Staff of the Air Force

Air Force Secretariat
SAF/AQ - Assistant Secretary of the Air Force (Acquisition)
SAF/CIO A6 – Information Dominance and Chief Information Officer

Air Staff
AF/CVA - Assistant Vice Chief of Staff of the Air Force
AF/RE - Chief of Air Force Reserve
AF/SB - Scientific Advisory Board Military Director
AF/ST - Chief Scientist of the Air Force
AF/TE - Test and Evaluation
AF/A1 - Manpower and Personnel
AF/A2 - ACS Intelligence
AF/A3/5 - Air, Space, and Information Operations, Plans, and Requirements
AF/A4/7 - Logistics, Installations and Mission Support
AF/A8 - Deputy Chief of Staff for Strategic Plans and Programs
AF/A9 - Studies and Analyses, Assessments, and Lessons Learned
AF/A10 - Director Strategic Deterrence and Nuclear Integration
NGB/CF - Chief of the Air National Guard

Air Force Major Commands
ACC - Air Combat Command for distribution to
    A2, A3, A8; 26 WPS; USAFWC; 432 WG; 11 RS; 480th Wing, DGS-1, DGS-2
AETC - Air Education and Training Command
    AU - Air University
AFMC - Air Force Materiel Command
    CC - Commander, Air Force Materiel Command
    EN - Directorate of Engineering and Technical Management
AFRC - Air Force Reserve Command
AFSOC - Air Force Special Operations Command
AFSPC - Air Force Space Command
AMC - Air Mobility Command
PACAF - Pacific Air Forces
USAFE - US Air Forces in Europe

Other Air Force Elements

AFOSR - Air Force Office of Scientific Research
AFOTEC - Air Force Operational Test and Evaluation Center
AFRL - Air Force Research Laboratories
AFRL/RB - AFRL Air Vehicles Directorate
AFRL/RB - AFRL Munitions Directorate
AFRL/RH - AFRL Human Effectiveness Directorate
AFRL/RI - AFRL Information Directorate
AFRL/RY - AFRL Sensors Directorate
AFSAA - Air Force Studies and Analyses Agency
AF UAS Task Force
AFISRA – Air Force ISR Agency
ASC - Aeronautics Systems Center
ESC –Electronics Systems Center
NASIC - National Air and Space Intelligence Center
SMC - Space and Missile Systems Center

<u>Other Service Elements</u>
Army/G2 – Deputy Chief of Staff for Intelligence
Army Research Laboratory
Marine Corps DC/S (A) Deputy Chief of Staff for Aviation
AMRDEC - Aviation and Missile Research Development and Engineering Center
NRL - Naval Research Laboratory
ONR - Office of Naval Research
US MCWL –Marine Corps Warfighting Laboratory

<u>Executive Office of the President</u>
National Security Council

<u>Office of the Secretary of Defense and Defense Agencies</u>
OSD AT&L - Under Secretary of Defense (Acquisition, Technology, and Logistics)
DDR&E - Director of Defense Research and Engineering
DARPA - Defense Advanced Research Projects Agency for distribution to offices:
    TTO, IPTO, AEO, STO

<u>Joint Chiefs of Staff</u>
Joint Secretariat for distribution to:
  Chair, Joint Chiefs of Staff
  Vice Chair, Joint Chiefs of Staff
  Joint Chiefs of Staff, Director of Manpower and Personnel (J-1)
  Joint Chiefs of Staff, Director of Intelligence (J-2)
  Joint Chiefs of Staff, Director of Operations (J-3)
  Joint Chiefs of Staff, Director of Logistics (J-4)
  Joint Chiefs of Staff, Director of Strategic Plans and Policy (J-5)
  Joint Chiefs of Staff, Director of C4 Systems (J-6)
  Joint Chiefs of Staff, Director of Operational Plans and Joint Force Development (J-7)
  Joint Chiefs of Staff, Director of Force Structure, Resources, and Assessment (J-8)

Combatant and Regional Commands
US African Command
US Central Command
US European Command
US Joint Forces Command
    USJFCOM Joint Center for Operational Analysis (JCOA)
US Northern Command
US Pacific Command
US Southern Command
US Special Operations Command
US Strategic Command
US Transportation Command

Intelligence Community
Central Intelligence Agency
National Geospatial-Intelligence Agency - Persistence Surveillance Laboratory
National Reconnaissance Office
Defense Intelligence Agency

Other Government Agencies
Department of Homeland Security/Customs and Border Protection
Department of Homeland Security/S&T
Coast Guard
Department of State
Federal Aviation Administration

Advisory Boards
Army Science Board
Defense Policy Board
Defense Science Board
Intelligence Science Board
Naval Research and Advisory Committee
Naval Studies Board

Other
Service Academies and Officer PME
National Defense University
Aerospace Corporation
Institute for Defense Analyses
Johns Hopkins Applied Physics Lab
MITRE
RAND

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ABSTRACT (Maximum 200 Words)
Operating Next Generation RPA for Irregular Warfare:

The Air Force (AF) tasked the SAB to examine how the AF operates remotely piloted aircraft (RPA) for irregular warfare, and make recommendations for reducing manning, enhancing operational effectiveness, and planning for future operations. The Study Panel observed 1) approximately 70 percent of the manning requirements represent exploiters and maintainers and are expected to grow, 2) manually intensive airspace deconfliction and management is inefficient, will not scale, and hampers manned/unmanned integration, 3) RPAs contribute to minimizing collateral damage because of persistence, increased "eyes on target", and use of focused lethality munitions, and 4) inexpensive and proliferating kinetic and electronic threats are an increasing RPA concern. Findings include 1) insufficient and inflexible platform and sensor automation, 2) poorly-designed operator control stations, 3) limited communications systems to address interoperability, lost-link, and scaling, 4) inadequate selection criteria and training, and 5) CONOPS and TTPs that lagged systems. Based on these findings, the Panel recommends the AF 1) improve automation to enable variable levels of autonomy, 2) enhance operator control stations, 3) create robust communications systems, 4) develop targeted selection and enhanced training, 5) improve CONOPS and TTPs, and support distributed operations, and 6) improve the transfer of ACTD results to acquisitions.

14. SUBJECT TERMS
remotely piloted aircraft, irregular warfare, remote split operations, human machine interaction, civilian causalities, airspace deconfliction, airspace integration

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