Chapter 5

Mission Systems and Enabling Technologies

5.1 General

The study group examined the functional requirements and enabling technologies for the electronic systems used by UAVs in performing operational tasks, with particular reference to the nine selected baseline missions/tasks. The analysis presented in detail in Volume II includes both assessment of the mission systems needed to perform the nine operational tasks that are the focus of this study and an overall evaluation of the state-of-the-art in key technology areas.

For each of the nine baseline operational tasks listed in Chapter 3, a mission systems package was defined and first-order functional requirements were derived. Details are given in Volume II, Chapter 4. Table 5-1 summarizes the mission system elements involved in each task. It shows both the extremely diverse range of UAV avionics needed for these tasks and the areas in which continued investment in technology development has high potential to improve the combat effectiveness and affordability of UAV systems.

UAVs can carry a very wide range of mission systems. These include virtually every type of airborne sensor, from area surveillance and target location to weather reconnaissance; communications and navigation systems for both UAVs themselves and service to customers; electronic countermeasures for self-protection and neutralization of hostile defenses; and support to weapons delivery from UAVs or other platforms. The study group broke out onboard processing, distributed function management, and integrated information management as separate technology areas because they are central to the effectiveness of UAVs in many operational tasks and they are among the most important areas in which continued investment in technology advancement and demonstration is critical.

A high-quality digital terrain data base and the ability to accurately and flexibly convert it to high-fidelity displays for human viewing are important in a number of ways to future applications of UAVs. Accurate data are essential for precision geolocation of targets from various kinds of sensors. Digital terrain maps (DTMs) may also be important in providing accurately surveyed reference points in a sensor image from which comparably accurate coordinates of other objects in the scene can be derived. The lack of good (Level 3 or better) Digital Terrain Elevation Data files for much of the world and the overall problem of maintaining high-quality DTMs for all areas of interest on Earth are challenges with which the Defense Mapping Agency is currently dealing. In addition, all UAVs, by definition, employ some form of remote or automated pilotage, so that the human operator is not in a position to actually see the ground over which the vehicle is flying.

One of the most important findings of this study, from the mission systems viewpoint, is that in most operational tasks, UAVs frequently should be employed in coordinated clusters (just as many manned aircraft are) rather than as independent platforms. The reasons for this are:

- Large aperture baselines can be obtained by cooperative receivers on widely separated platforms, achieving high directivity for tasks such as emitter location.

- Cooperative functioning of threat warning, jamming, communications, and other systems can greatly complicate an enemy's task in locating and targeting UAVs; e.g., an individual jamming platform that has been locked up by a threat system can be alerted to go silent while other jammers neutralize the threat.

Table 5-1. *Mission System Elements Required for Each Operational Task*

Mission System Elements	*CWMD*	*TMD*	*Fixed Target Attack*	*Moving Target Attack*	*Jamming*	*SEAD*	*ISR*	*Comm/ Nav Support*	*Air to Air*
Information									
Onboard Processing:									
• Data Processing	X	X	X	X	X	X	X	X	X
• Signal Processing	X	X	X	X	X	X	X	X	X
• ATC	X	X	X	X	X	X	X	X	X
Distributed Functional Management:	X	X	X	X	X	X	X	X	X
Integrated Information Management:	X	X	X	X	X	X	X	X	X
Sensor									
Radar:									
• SAR	X	X	X	X	X	X	X		
• MTI	X	X		X			X		
• Air-to-Air		X					X		X
• FOPEN		X	X				X		
EO/IR Sensors:									
• Imaging/FLIR	X	X	X	X		X	X		
• IRST		X							X
• LADAR/LIDAR	X						X		
• Designator	X	X	X	X		X			
• Laser Ranger	X	X	X	X					X
ESM:									
• Intercept/ Exploitation	X	X			X	X	X		
• Emitter Location	X				X	X	X		
Special Sensors:									
• Meteorology							X		
• Chem/Bio	X								
• Nuclear	X								
ECCM:									
• RF Sensors	X	X	X	X		X	X		X
• EO/IR Sensors	X	X	X	X		X	X		X
Communication									
Communications:									
• Data Links	X	X	X	X	X	X	X	X	X
• Relay/Switch	X	X	X	X	X	X	X	X	X
Navigation:									
• Positioning	X	X	X	X	X	X	X	X	X
• Target Geolocation	X		X	X	X	X	X	X	
• GPS Augmentation	X		X	X	X	X		X	
Other									
ECM:									
• Self Protection	X	X	X	X	X	X	X	X	X
• Escort/Area Jammer	X		X	X	X	X			
• Communications Jammer	X				X	X			
Fire Control									
	X	X	X	X		X			X

- Many UAV functions are more effectively performed at close range rather than from standoff to take advantage of the $1/r^2$ dependence of RF propagation and to reduce response times for time-critical targets; this implies use of multiple platforms to achieve area coverage.

- Separate platform concepts often allow higher value assets, such as high-performance sensors, to be less exposed to enemy threats, while those that must fly in harm's way can be made more attritable.

- Most ISR situations dealing with difficult targets (e.g., when the enemy uses cover, concealment, and deception) are best attacked through the use of one or more sensors to cue one or more other sensors and through fusion of multiple target signatures; practical design constraints dictate that multiple platforms will be used to carry this ensemble of sensing and information processing equipment.

The inventory of UAVs available in any operational situation is likely to be limited by economics, which could have an impact on an air commander's ability to deploy clusters as just described. However, sound design practices applied to payloads will do much to mitigate this concern. In particular, modular hardware and software will allow each available platform to be uploaded with the specific mix of functions needed in a given mission and will facilitate mixed payload functions (e.g., ISR collection and communications/navigation support on the same UAV). Then a platform which functions as part of a cluster for one activity (e.g., emitter location) could also work individually (e.g., as an imagery collector).

Another consequence of cooperative missions is that UAVs increasingly require robust, high-performance networking both for information exchange among platforms and for real-time interaction of human system operators, engagement controllers, and aircrews participating in a given mission. UAVs have high potential to enhance the effectiveness of the entire force structure by providing connectivity and interoperability among ground and air forces and by supplementing GPS with more jam-resistant navigation support for the growing number of systems that depend critically on GPS positioning. Collectively, these networking requirements place increased importance on C2 architecture and systems. The results of the C^3I Architecture Cell of this study (Volume II, Chapter 7) and of the concurrent SAB C2 Vision study[7] are thus extremely important adjuncts to the mission systems discussion.

In keeping with the overall sense that SEAD is an area of particular importance and one where valuable operational capability can be demonstrated in a relatively short time through exploitation of existing technologies, the study group devoted particular attention to the jamming and SEAD operational tasks. Specifically, it carried the requirements analysis and system concept description for these tasks to a relatively higher level of detail to support planning for a focused, near-term demonstration program aimed at an increasingly critical shortfall in our capabilities for electronic warfare.

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[7] United States Air Force Scientific Advisory Board Study, *"Vision of Aerospace Command and Control For the 21st Century,"* SAB TR-96-02, 1996.

5.2 Enabling Technology Status and Required Development

An important overall finding of this study is that most of the enabling technologies required for these mission system concepts are in hand or in an advanced state of development. This is particularly true for basic UAV functions that focus on individual platforms. Most of the required developments concern technologies for higher levels of autonomy, including functions that require automated coordination of multiple platforms and systems. In particular, onboard digital processing and data storage will continue to experience dramatic improvements through leverage of huge investments in commercial technology, making increasingly processing-intensive system designs feasible. This trend extends to the gradual replacement of analog electronics, including those in RF and EO/IR systems, by digital processors. Table 5-2 summarizes the enabling technologies for the missions systems identified.

Table 5-2. *Summary of Enabling Technologies for UAV Mission Systems*

Mission Systems Element	***Enabling Technologies***
Sensors	
• SAR/MTI Radar	Efficient, Broadband Solid State Power Devices Super-Resolution/ATC/ATR
• Air-to-Air Radar	Lightweight, Low Cost, LO Apertures F-22/JSF Technologies Efficient, Broadband Solid State Power Devices
• FOPEN Radar	Broadband UHF/VHF Power Sources Super-Resolution/ATR
• EO/IR Passive Imagers	RFI/Jamming Mitigation Advanced Focal Plane Arrays
• LADAR/LIDAR	Advanced Video Processing Techniques Compact, Efficient, Tunable Lasers
• ESM/Emitter Location	Optical Phased Arrays Single-Chip Receivers Gigasample A/D Converters GPS Location and Timing References
• Meteorological Sensors	Automated Signal Exploitation Multispectral/Doppler LIDAR Microwave Radiometry
• Chem/Bio Sensors	Compact Dropsondes Active and Passive Multispectral EO/IR UV Fluorescence
• Nuclear Sensors	UAV-Serviced UGS Chem Sensors for Nuclear Materials
Comm/Nav	
• Data Links	ATC/ATR/Data Thinning Broadband AJ/LPI Waveforms Advanced Coding/Compression

• Relay/Gateway Node	Network/Gateway Architectures Lightweight, Efficient Receiver-Transmitters Co-site Interference Mitigation
• Navigation/Positioning	Tightly Coupled INS/GPS Guidance MEMS
• Target Geolocation	Imagery Derived Location Improved Digital Terrain Data
• GPS Augmentation	Available RF & Digital Technologies
Onboard Processing	Algorithms for Higher Levels of Autonomy Commercial-Derived Processors/Storage Advanced Analog-to-Digital Converters
ECM/Jamming	Microwave Power Modules Advanced Techniques/Jamming Waveforms
Fire Control	F-22/JSF Technologies Compact, Efficient Laser Designator

It is important to stress that the maturity of available technology is such that significant operational capability can be demonstrated and fielded in the near-term. To illustrate this point, Table 5-3 lists a number of system concepts which the study analysis identified as having high operational value and being well-suited to UAV platforms. For each, we provide an assessment of the timeframe in which a demonstration of mission systems leading to accelerated fielding of the system can be completed.

Table 5-3. *Recommended UAV Mission System Technology Demonstrations*

Operational Tasks	***Mission System Technology Demonstration***	***Near-Term: (1996-2005)***	***Mid-Term: (2006-2015)***	***Far-Term: (2016-2025)***
Jamming & SEAD	EW UAV Cluster w/ ESM, TDOA Emitter Location, & Smart Jamming	Ã		
ISR	ISR Sensors w/Onboard Image Screening	Ã		
Fixed & Moving Target Attack	Image-Derived Precision Target Geolocation	Ã		
Communications/Nav Support	Communications Relay w/ GPS Augmentation	Ã		
CWMD	Nuclear & Chem/Bio Remote Sensing		Ã	
TMD - Ballistic	IRST & Hypervelocity Missile Fire Control for BPI		Ã	
TMD - Cruise	UAV Pulse Doppler Radar & AAM Fire Control		Ã	
Air-to-Air	Air-to-Air Targeting and Weapon Guidance for Highly Agile Platform		Ã	
Other Missions	Advanced Technology Concepts			Ã

The clear message is that, in the judgment of the study group, much can be done in the near-term, while enhancements to yield still higher levels of performance and affordability can be incrementally implemented over time.

As Table 5-3 indicates, a number of technology areas require additional investment, including the following:

- Current UAVs are limited in their onboard functionality, e.g., image formation and data compression. The algorithmic basis for higher levels of autonomy is currently largely heuristic. Greater autonomy has enormous leverage for system performance and affordability. For example, a level of pattern recognition that allows real-time screening of imagery to select only content of interest for full resolution transmission to the user can dramatically reduce the required bandwidth of data links and thus the size and cost of data terminals and antennas. Other high-payoff functions are adaptive sensor operation including self-cueing, management of system resources and circumvention of failures, and support for the kind of cooperative functioning of UAV clusters that was described earlier in this chapter.

- Distributed function management is regarded as a technology in its own right, one that is, relatively speaking, in its infancy. Advances in spatially distributed processing, distributed sensing, automated management of multiple systems, and other aspects of the problem have high leverage on overall force structure effectiveness, mission planning, required data link capacity, and the complexity and workload of system operator stations.

- The capabilities enabled by UAVs greatly enrich the information sphere of the battlespace. Effective use of this information depends in large measure on progress in the technology of data bases, information access tools, truth maintenance across distributed data bases, human machine interfaces, and the like. While UAV systems can exploit the progress being made in these areas by the information industry, focused attention to information architectures and implementations that can meet the unique demands of UAVs will continue to be essential.

- Most UAV concepts require high survivability in the presence of enemy air defenses. A combination of methods will be required to achieve this capability. Continued investment in apertures with low RCS as well as in RF power management techniques and use of passive sensing modes like bistatic radar to reduce platform emissions are important elements. Furthermore, self-protection and cooperative multiplatform operating modes can limit required emissions and thus contribute significantly to survivability.

- A general technology theme for mission systems is maintaining present levels of performance while dramatically reducing size, weight, power consumption, and especially, cost. This area is rich with opportunities for high return on investment. Novel antenna structures composed of easy-to-fabricate sandwiches of layers with printed metallization and methods of packaging COTS components to survive the flight environment are just two examples. Again, the use of modular, open architectures is critical to affordable and rapid insertion of technologies to improve both affordability and performance.

- In a related vein, technology insertion for affordability can be effective in dealing with concerns about UAV attrition. Trade studies supporting the definition and selection of such projects should consider the operational payoffs of using UAVs more effectively because lower cost makes losses easier to accept.

In short, most of the technology portfolio for the UAV mission systems described in this report is low risk and targeted funding of high-leverage enabling technologies like those just listed can greatly enhance the robustness, affordability, and combat effectiveness of these systems.