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U.S. UNMANNED, AERIAL VEHICLES (UAVS) AND NETWORK- CENTRIC WARFARE (NCW): IMPACTS ON COMBAT AVIATION TACTICS FROM GULF WAR I THROUGH 2007 IRAQ

by

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March 2008

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13. ABSTRACT

Unmanned aerial vehicles (UAVs) are an increasingly important element of many modern militaries. Their success on battlefields in Afghanistan, Iraq, and around the globe has driven demand for a variety of types of unmanned vehicles. Their proven value consists in low risk and low cost, and their capabilities include persistent surveillance, tactical and combat reconnaissance, resilience, and dynamic re-tasking.

This research evaluates past, current, and possible future operating environments for several UAV platforms to survey the changing dynamics of combat-aviation tactics and make recommendations regarding UAV employment scenarios to the Turkish military.

While UAVs have already established their importance in military operations, ongoing evaluations of UAV operating environments, capabilities, technologies, concepts, and organizational issues inform the development of future systems. To what extent will UAV capabilities increasingly define tomorrow's missions, requirements, and results in surveillance and combat tactics?

Integrating UAVs and concepts of operations (CONOPS) on future battlefields is an emergent science. Managing a transition from manned- to unmanned and remotely piloted aviation platforms involves new technological complexity and new aviation personnel roles, especially for combat pilots. Managing a UAV military transformation involves cultural change, which can be measured in decades.

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LIST OF ACRONYMS AND ABBREVIATIONS

A/A	Air to air
AAA	Antiaircraft artillery
ACDT	Advanced-concept technology demonstrations
ACN	Airborne-communication node
AEW	Airborne early warning
AIM	Air-intercept missile
AJCN	Adaptive, joint, C4ISR node
AOR	Area of responsibility
ARM	Anti-radiation missile
ATARS	Advanced, tactical, airborne-reconnaissance system
ATC	Air-traffic control; automatic target cueing
ATOLS	Automatic takeoff and landing system
ATR	Automatic target recognition
AWACS	Airborne warning-and-control system
BAMS	Broad-area maritime surveillance
BDA	Battle-damage assessment
BLOS	Beyond line of sight
C^2	Command and control
C^3I	Command, control, communications and intelligence
C4I	Command, control, communications, computer, and intelligence
CAOC	Combined aerospace operations center

CCD	Charge-coupled device; camouflage, concealment, and denial; coherent-change detection
CDL	Common data link
CFACC	Combined forces, air-component commander
CMD	Cruise-missile defense
CN	Counter-narcotics
CNC	Computer numerical control
COMINT	Communications intelligence
CONOPS	Concept of operations
CONUS	Continental United States
COTS	Commercial, off-the-shelf
CR	Close range
CSAR	Combat search and rescue
CW/BW	Chemical warfare, biological warfare
CWMD	Counter- weapons of mass destruction
DARPA	Defense Advanced Research Projects Agency
DE	Directed energy
DEAD	Destruction of enemy air defense
DoD	Department of Defense
DTED	Digital terrain-elevation data
EA	Electronic attack
ECCM	Electronic counter-countermeasures
ELINT	Electronic intelligence

EMD	Engineering and manufacturing development
EMP	Electromagnetic pulse
EO	Electro-optical
ESA	Electronically scanned array
ESM	Electronic support measures
EW	Electronic warfare
F2T2EA	Find, fix, track, target, engage, and assess
FLIR	Forward-looking infrared
FOPEN	Foliage penetrating
GCCS	Global command-and-control system
GCS	Ground-control station
GDT	Ground data terminal
GMTI	Ground moving-target indication
GPS	Global-positioning system
GSE	Ground-support equipment
GWOT	Global war on terrorism
HAE	High-altitude endurance
HAZMAT	Hazardous material
HFE	Heavy-fuel engines
HPM	High-power microwave
I3	Integrated intelligence and imagery
IADS	Integrated air-defense systems
IAI	Israeli Aircraft Industries

ICBM	Intercontinental ballistic missile
IFR	Instrument flight rules
IMC	Instrument meteorological conditions
IMINT	Imagery intelligence
IR	Infrared
IRST	Infrared search and track
ISAR	Inverse synthetic-aperture radar
ISR	Intelligence, surveillance, reconnaissance
ISS	Integrated sensor suite
IUP	Israeli UAV Partnership
JDAM	Joint direct-attack munition
JITC	Joint Interoperability Test Command
JOTBS	Joint operational test-bed system
JSTARS	Joint surveillance and target-attack radar system
JTF	Joint task force
J-UCAS	Joint unmanned combat air systems
LADAR	Laser detection and ranging
LD	Laser designation
LIDAR	Light detection and ranging
LOS	Line of sight
LRE	Launch-and-recovery element
LRF	Laser rangefinder
MAE	Medium-altitude endurance

MAGTF	Marine air–ground task force
MALE	Medium altitude, long endurance
MASINT	Measurement and signature intelligence
MCE	Mission-control element
METOC	Meteorology and oceanography
MIAG	Modular Integrated Avionics Group
MMH/FH	Maintenance man-hours per flight hour
MOSP	Multipurpose optical, stabilized payload
MPEG	Motion Picture Experts Group
MPR	Maritime-patrol radar
MP-RTIP	Multi-platform, radar-technology insertion program
MR	Mishap rate
MSL	Mean sea level
MTBF	Mean time between failure
MTI	Moving target indicator
MTS	Multi-spectral targeting system
MWIR	Mid-wave infrared
NATO	North Atlantic Treaty Organization
NBC	Nuclear, biological, chemical
NCA	National Command Authority
NCW	Network-centric warfare
NIIRS	National imagery-interpretability rating scale
NRT	Near-real time

OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OOTW	Operations other than war
OSD	Office of the secretary of defense
OTH	Over the horizon
O&S	Operations and support
PAT	Pointing, acquisition, and tracking
RF	Radio frequency
ROE	Rules of engagement
RPV	Remotely piloted vehicle
RSTA	Reconnaissance surveillance and target acquisition
RT	Real time
RTB	Return to base
RVT	Remote video terminal
SA	Situational awareness; surface to air
SAB	Scientific advisory board
SAM	Surface- to-air missile
SAR	Synthetic aperture radar
SATCOM	Satellite communication
SEAD	Suppression of enemy air defenses
SFC	Specific fuel consumption
SIGINT	Signal intelligence
SIPRNET	Secret Internet Protocol Router Network

SYERS	Senior Year Electro-optical Reconnaissance System
TAF	Turkish armed forces
TAI	Turkish Aerospace Industries
TAMD	Theater air-missile defense
TARPS	Tactical air-reconnaissance pod system
TEI	Tusas Engine Industries
TEL	Transporter erector launcher
TESAR	Tactical, endurance, synthetic-aperture radar
TIES	Transportable image-exploitation system
TMD	Theater missile defense
TST	Time-sensitive target
TUAF	Turkish air force
UA	Unmanned aircraft
UAS	Unmanned-aircraft systems
UAV	Unmanned, aerial vehicle
UCAV	Unmanned, combat, aerial vehicle
UCN	UAV communications node
UGS	Unattended ground sensor
UHF	Ultra-high frequency
U.S.	United States
WAS	Wide-area search
WMD	Weapons of mass destruction

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I. INTRODUCTION

Network-centric warfare (NCW) is defined as an information-superiority-enabled concept of operations that generates increased combat power. The NCW objective is to achieve shared awareness, synchronized forces, increased speed of command, faster tempo of operations, greater lethality, greater survivability, and a degree of self-synchronization by networking sensors, decision makers, and shooters. In essence, NCW translates information superiority into combat power by effectively linking geographically or hierarchically dispersed entities in the battlespace [1]. Having a better, near-real-time picture of what is happening in the battlespace reduces the level of uncertainty—the gap between what a commander needs to know and does know—in a meaningful way. Furthermore, NCW has the potential to contribute to the merging of the tactical, operational, and strategic levels of war.

Network-centric warfare recognizes the potential for decoupling sensors from specific actors and separating both sensors and actors from platforms in a geographically dispersed force. It also recognizes the centrality of information by specifying knowledgeable assets in a dynamic environment. Recent military operations analyzed in Chapter III have highlighted the power of new types of relationships among sensors, deciders, and actors that is now possible with network-centric force enhancements. In these operations, the sensor was operated by actors at a single location. The information collected by the sensor was analyzed by decision makers at multiple dispersed locations and at various levels of command; mission-critical information was then transmitted in near-real time to decision makers on disparate command and control platforms and thence to area-of-responsibility (AOR) shooters, who engaged the targets the UAVs had sensed [1].

In the present NCW-enabled, command-and-control shift, sensor networks emerge as key enablers of increased combat power, serving as a unified framework for both decision-making procedures and situational awareness. The operational value or benefit of sensor networks is derived from their ability to generate more complete, accurate, and timely information than can be generated by sensors standing alone [1].

The networking of sensors that can perform numerous missions such as intelligence, surveillance, and reconnaissance in near real time provides the basis for developing and leveraging information superiority for battlespace awareness. Network superiority can directly affect the pace of operations.

> For instance, the time from target acquisition to release of weapons (i.e., the sensor-to-shooter gap) has been reduced from days or hours in the Gulf War of 1991 to hours or minutes in Operation Iraqi Freedom. As one example, in Afghanistan a Predator UAV communicated reconnaissance data directly to an AC-130, not only obviating the need for time-consuming data transfers (and Combined Air Operations Center analysis-and-evaluation delays), but also allowing the AC-130 to fire during first overflight without a reconnaissance flyby [2].

UAVs as sensors in the NCW concept have great potential to transform the battlespace information by providing tactical responsiveness and extending the sight and reach of military power. For example, the global command-and-control system (GCCS) is a comprehensive, worldwide network (classified and unclassified) that provides the National Command Authority, joint staff, combatant and functional unified commands, services, defense agencies, joint task forces, and their service components with information processing and dissemination capabilities required for the command and control (C^2) of dispersed forces. The primary objective of GCCS is to implement an architecture consisting of C^2 forces and elements within a highly flexible and adaptive system. In support of operations, the GCCS must be able to collect, process, disseminate, support and protect information to gain information and decision superiority. It supports the National Command Authority and subordinate elements in the generation and application of national power [3].

> GCCS provides the warrior a fused, real-time, true picture of the battlespace and the ability to order, respond, and coordinate horizontally and vertically to the degree necessary to successfully prosecute the warfighting mission in that battlespace [4].

GCCS creates a broadly connected, joint system of joint systems that provides total battlespace information, as shown in Figure 1.

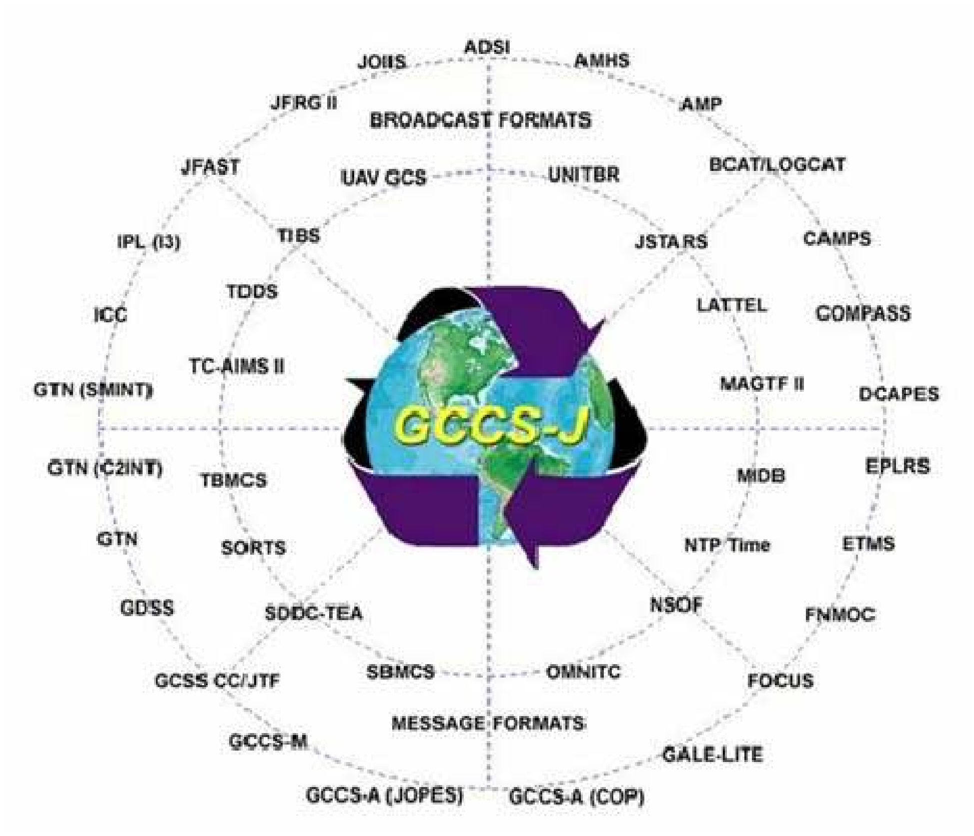

Figure 1. GCCS Interfaces (From: Joint Interoperability Test Command (JITC) Web Page) http://jitc.fhu.disa.mil

As one of the GCCS interfaces, a UAV GCS (unmanned, aerial vehicle; ground-control station) appears to have an important role in networked sensors. The objective is to produce a uniform, accessible, situational-awareness picture in which information from the various domains works together in useful forms. With the UAV GCS interface, commanders control a Predator UAV GCS by means of electro-optical-infrared surveillance and an ultra-high-frequency, voice-relay package to improve the warfighter's operational capabilities and battlefield situational awareness (SA). The unmanned aircraft can instantaneously transmit payload imagery, aircraft position, and target data to the command center in real time to enable the center to record and rebroadcast the information via network and satellite to commands around the world. A global-command-and-control system, joint, integrated, intelligence-and-imagery (GCCS-J I3) suite can process and display video made available to commands via tape, the Secret Internet Protocol Router Network (SIPRNet), wide- and local-area networks, and satellite. A video-ingestor workstation collects the data and provides it to all I3 nodes in the network. The workstation can also be used as an imagery client that requires a special MPEG encoder card; currently one per input source or channel is used. GCCS-J I3 utilizes the video-ingestor and text grabber to decipher telemetry received by network/broadcast from the UAV ground-control station [5].

Advanced technology, improved sensors, new collection platforms such as satellites, UAVs etc., and improved concepts enabled by greater computing power have combined to increase battlespace awareness and reduce uncertainty for information superiority. Network-centric concepts are also enhancing current force applications and enabling new warfighting capabilities in the battlefield.

> During Operation Allied Force, the Kosovo air operation, U.S. and coalition aircrews flew more than 36,000 sorties in support of a wide range of missions. The UAVs were employed as stand alone platforms and in conjunction with a wide range of other ISR (intelligence, surveillance, and reconnaissance) assets, including assets such as Joint Surveillance and Joint Target Attack Radar System (JSTARS), RIVET JOINT, Airborne Warning and Control System (AWACS), U-2, and other coalition and service sensors [6].

By the SA gained by NCW, a commander on the battlefield may have more current and accurate information. This concept is very important in today’s information-rich operating environment, and even more important than in the past. Warfighters can benefit from information traditionally held by higher-level commanders and from direct feeds from platforms such as UAVs [6]. The idea of having the right information at the right time can be a significant force multiplier for militaries.

Networking amounts to getting the right information, faster, to the right forces, who in turn can take the right action faster, as the basis for accomplishing the military objective in a dynamic and complex battlefield. It can shorten what is often called the ”kill chain,” i.e., the process of detecting, deciding, attacking, and assessing. It also reduces the resources required to move through each link in command and control. Information gathering and sharing are the essence of network-centric, warfare-getting data for those who need it, when they need it. A key method for gathering that data is the use of UAVs. A network-centric fighting force relies heavily on data provided by UAV sensors. Therefore, this study analyzes and draws conclusions about UAV impacts on NCW and military transformation.

The remainder of this study examines several major UAV platforms in terms of their roles and capabilities in past and current operating environments. The questions examined in this thesis are as follows:

1. Based on four recent combined-force conflicts (two Iraqi conflicts, and one each in Bosnia and Afghanistan), how has introduction and increasing use of UAVs affected U.S. aviation-combat tactics?

2. How have UAVs expanded into different aviation mission areas under the U.S.'s NCW framework?

3. What performance indicators are used to assess UAVs?

4. What are the future direction and primary challenges facing the planning and integration of UAV platform and tactics?

Chapter II discusses the background of UAVs, including the Hunter, Pioneer, Predator and Global Hawk. Chapter III looks at past and current operating environments for UAVs. Chapter IV gives an analysis of each UAV and its mission, as well as UAV utilities, limitations, and performance metrics as observed during tests and operations. In Chapter V, the future direction of UAVs is examined; this section is based on DoD Unmanned Aircraft System (UAS) Roadmap 2005-2030. Chapter VI looks at the Turkish armed forces' utilities in regard to current UAV types and needs. Chapter VII includes conclusions and recommendations to Turkish forces based on mission, UAV, and NCW analysis. Supporting documentation is contained in the Appendix.

II. BACKGROUND OF UAVS

A. EMPLOYMENT OF UAVS

This chapter defines unmanned, aerial vehicles (UAVs) and describes the reasons and the changes that lead to the employment of particular UAVs in four conflicts (Gulf War I, Bosnia, Afghanistan and Gulf War II) while looking at the UAVs employed during these conflicts. Political and economic considerations are offered, including relevant technological advancements. UAV impacts on these four conflicts are examined in the next chapter.

Since the beginning of unmanned aviation, unmanned aerial vehicles have been called by many different names (pilotless aircraft, remotely piloted vehicles (RPVs), drones, etc.) These assets are defined by the DoD as:

> A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semi-ballistic vehicles, cruise missiles, and artillery projectiles are not typically considered UAVs [7].

Commanders and soldiers have wanted to see what is behind the next hill since the first battle. The ability to see distant battlefields anytime by UAV sensor is a major battlespace advantage. Tactical commanders with UAVs at their disposal can obtain intelligence preparation needed for potential problem areas. This organic capability can reduce dependence on manned aircraft, including in some cases the ability to deliver weapons without pilot endangerment.

UAVs are becoming an intelligence, surveillance, and reconnaissance (ISR) platform of choice, allowing observation of the enemy by more efficient means and increasing SA through real-time intelligence. Since Gulf War I, UAVs have undergone rapid growth in capability and numbers and will continue to proliferate as the U.S. military finds new ways to employ them.

With such capabilities, force-enhancing options for UAVs are easy to imagine. In addition to these options, there are other factors behind the recent push in UAV development. The advances that have boosted the perceived military value of UAVs are outlined in [8] as:

- Improved command, control, and communications, image processing, and image-exploitation capabilities [8]
    - Dramatic increases in computer-processing power and associated software advances [8]
    - Advanced sensor technologies that make possible high-resolution collection with much-reduced sensor size and weight [8]
- Increased recognition by UAV advocates in industry and government that aerospace-quality expertise is essential because a model-airplane, hobby-shop approach to development will not yield reliable and militarily useful unmanned air systems capable of supporting demanding missions [8]
    - Advances in efficiency and reductions in size and weight of propulsion systems [8]
    - The availability of robust, long-endurance UAV platforms resulting from visionary investments by the Defense Advanced Research Projects Agency (DARPA) [8]

The maturation of UAV key developments is illustrated in Table 1.

Technology	Past	Present	Future
Affordability	Marginal	Design to Cost Implemented	Low Lifecycle Cost Realized
Data Links	Analog/Low Bandwidth	Digital, High Cost for Bandwidth	Standardized for USAF Architecture, Modular,
Engines	Whatever Available	Off-the-Shelf Commercial	Designed for UAVs, More Fuel Efficient
Human Systems	Automate What Was Technically Feasible; Human Filled the Gaps	Inconsistent Function Allocation; Minimum Attention to Human Factors	Simulation-based Design for Systems Relevant to Human
Low Observables	None	Current Technology: Some Penalties Perceived Costly	Lower Penalties, Lower Signatures,
Mission Planning	Little Automation	Some Automation, Slow, Inflexible	Automated, Flexible, Fast, Utilizing Parallel
Onboard Processors	Limited Capability	Good Capability at Reasonable Cost	Excellent Performance/Low Cost
Producibility	Not Emphasized	Major Advances, Low Cost Tools for Composites	Designed for Low Rate, Low Cost Production
Sensors	Heavy, Bulky, Marginal Reliability	Major Improvements	Modular, Lightweight, UAV-Tailored
System Design	Modified Manned Aircraft Techniques	Design Automation System Simulation	Integrated Design/ Simulation/
System Reliability	Marginal	Better, but not Acceptable	Robust Systems, Very Low Failure
Training	Reliance on Prior Experience and OJT	Delegated to Contractors; Military Training Evolving	Crew Selected and Trained Using Modern Methods
Vehicle Management Systems	Off-the-Shelf, No Integration, No Automation	Some Integration, Rudimentary Automation	Optimized for UAVs: Performance, Weight, Cost, Automation
Vehicle Structure	Manned A/C Metal Approach, Large Parts Counts	Composites Not Fully Exploited, Reduced Part Count	Tailored Composite Structure, Very Low Part Count, High Fuel Fraction
Weapons	None	Little Consideration	Small, Modular, Integrated System

Table 1. Technologies for UAVs (From: *Autonomous Vehicles in Support of Naval Operations*)

In each key technology, significant advances have been made. For example, vehicle structures have moved to lightweight, special-composite materials; data-link designs have responded to high-capacity demands offering substantial throughput; sensor designs have significantly improved performance while reducing weight; engines, endurance, and manufacturing have adopted proven aerospace designs; and some automation has been accomplished in mission planning, enabling more time for the mission itself. Also, the results of significant advances in propulsion and aerodynamics have increased the range, persistence, and altitude capabilities of UAVs, providing much greater endurance than manned aircraft.

In addition to these technological advancements and changes, critical world events mentioned in [9] have encouraged the use of UAVs to perform missions without personnel risk and with lower operational costs than comparable manned systems. The details of four of these engagements are provided in Chapter III. Consider the following world events that highlight some of the military and strategic utility of UAVs:

- The collapse of the Soviet Union mitigated the requirement for billions of dollars spent on strategic intelligence systems and community infrastructure. The “new world order” that arose was less predictable, nontraditional, and unsuitable for appraisal by our strategic intelligence system. The requirement for intense monitoring of Soviet ballistic-missile submarines, intercontinental, ballistic-missile (ICBM) testing, aircraft development, and the status of Warsaw Pact ground forces was vastly reduced [9].
- Shrinking defense budgets post-1989 appeared to be just another fact of life. The hordes of intelligence analysts, the “stove piped” architectures and disciplines, and classification “green doors” guarding critical intelligence data were also rapidly disappearing. The U.S. military was striving to find cheaper solutions to military needs, including providing more mission flexibility to handle emerging dynamic, unpredictable, and unfamiliar situations [9].
- Another catalyst for change was Desert Storm, not from its military success, but from its intelligence failures. Many military experts involved at the operational and tactical levels during that conflict assert that the intelligence system broke down and did not support the tactical commander. In fact the intelligence system did exactly what it was designed to do, which was to support the national command authority and the CINC at the strategic and operational levels of war. Desert Storm, from an intelligence standpoint, was an unforeseen type of war. What seemed “broken” was a lack of forethought in fielding intelligence-support systems for warriors at the forefront of conflicts. Another outcome, probably with more consequence to the future of armed conflict than highlighting

> intelligence-system failures, was the paucity of U.S. casualties during the war. Apparently, U.S. and other western nations have become extremely sensitive to conflict-inflicted human suffering [9].

An additional good reason for the increased demand in UAV development is the growing need for real-time intelligence. As one UAV expert stated:

> The reason for this increase in interest and market size is fairly simple: the use of the "vertical dimension" to gather or relay information is becoming vital to successful operations in the post-Cold War era. Moreover, UAVs may start to replace manned aircraft for the transportation and delivery of goods and services under benign, or routine, conditions.... Unmanned aircraft may perform as effectively as and more cheaply than either satellites or manned aircraft. Thus, UAVs complete the array of capability necessary to fully populate this vertical dimension of the rapidly growing information world [10].

The essential intelligence principle that the one who can see all and use the intelligence in near-real time dominates in the battlespace is the main reason for the demand for immediate and real-time intelligence. Sun Tzu's dictated the importance of intelligence as follows: "Know your enemy and know yourself and you can fight a hundred battles without disaster [10]."

The emphasis on systems' providing total battlefield intelligence is common sense as long as the information reaches the end user in acceptable format and when needed. After the Gulf War, there were many stories of available national intelligence not reaching users [10]. The employment of UAVs can enable commanders to adapt to collection methods and receive the intelligence they need in near-real time.

A few additional reasons for the rapid development of UAV roles and missions include lower development and operational costs and reduced losses in both the vehicle itself and personnel. As one military analyst stated about UAVs and their inherent low-risk and high-payoff intelligence returns, "Since UAVs are designed to penetrate and loiter in threat environments deemed too risky for manned aircraft, they are naturals for the cat-and-mouse contests between electronic-warfare (EW) systems and air defense and other threat emitters [10].” To the extent that defense forces are threatened by decreasing budgets, cost- and pilot-saving platforms become more attractive. The fact that UAVs are cheaper to develop, maintain, and operate than manned aircraft makes them extremely attractive to the services especially when faced with increased “operations other than war” (OOTW) requirements.

Another reason for the recent interest in UAV development is the fact that the operations tempos faced by the services has increased. This rise in operational deployments is primarily derived from supporting global OOTW, placing additional strain on the national military strategy, which cites numerous roles and missions for the services and appears to contribute directly to a faster operations tempo [10]. One defense analyst indicated the magnitude of the increase in operations tempo by stating “since the fall of the Berlin Wall, operations tempo has increased by over three-hundred percent [10].”

> Another factor encouraging UAVs’ takeover of manned-aircraft roles is the public’s aversion to casualties in OOTW. As the United States increases its participation in OOTW, the nation’s focus on justified casualties heightens the importance of force protection. The necessity to minimize casualties builds a strong case for increased UAV usage and force protection. This emphasis on force protection is often highlighted by media coverage depicting forces executing OOTW. This attention is especially acute when casualties are broadcast on national television. Military and political leaders are well aware of the power of the media [10].

As Napoleon once said, “Four hostile newspapers are more to be feared than a thousand bayonets [10].”

B. DESCRIPTION OF UAVS EMPLOYED IN RECENT CONFLICTS

The following material highlights four UAV systems (RQ-2B Pioneer, RQ-5 Hunter, MQ-1B Predator and RQ-4 Global Hawk) used in recent combat situations. Most of the following information in Section B was derived from [11].

1. RQ-2B Pioneer

a. Features

The Pioneer is a both a shipborne and land-based, tactical, close-range UAV that can perform a wide variety of missions such as reconnaissance, surveillance, target acquisition and battle-damage assessment and provide the commander with real-time imagery of the battlespace. It has a great degree of cover as a result of its low radar cross section, reduced silhouette, low infrared signature, and remote-control versatility.

b. Background

The RQ-2B Pioneer has been in the service of the Navy, Marine Corps, and Army since 1986. It was first developed for employment in gunnery spotting on battleships and evolved to perform ISR missions for amphibious forces. Launched by rocket assist, pneumatic launcher, or from a runway, it recovers on a runway with arresting gear after flying up to five hours with a seventy-five-pound payload [11]. It uses a C-band, line-of-sight (LOS) data link to relay analog video in real time. The Pioneer has performed ISR missions since the Persian Gulf War in 1991 and is still supporting Marine forces in Operation Iraqi Freedom (OIF). The Navy transferred Pioneer to the Marine Corps in 2002, ending its operations. The Marine Corps is preserving the Pioneer until a successor is available.

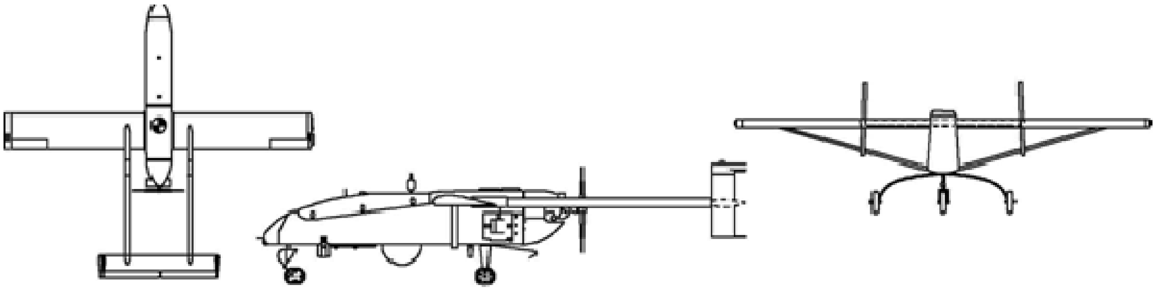

Figure 2. The RQ-2B Pioneer

2. RQ-5A/MQ-5B Hunter

a. Features

The Hunter is a joint-tactical UAV that is capable of performing ISR, battle-damage-assessment, target-acquisition, and battlefield-observation missions.

The primary payload on the RQ-5A is the multipurpose optical stabilized payload (MOSP), which includes television and forward-looking infrared (FLIR) to provide day and night surveillance [12]. Also, some Hunters are equipped with new sensors such as a third-generation FLIR and a spotter for the daytime TV camera. The other advanced mission payloads that the Hunter can carry include a laser designator, electronics-countermeasure payloads (i.e., a communications warning receiver, communications jammer, and radar jammer), a communications-relay payload that extends VHF/UHF communications beyond line of sight [12]. The Hunter can operate in relay with two air vehicles airborne simultaneously over a C-band, LOS data link.

b. Background

The RQ-5A Hunter was originally a joint Army-Navy-Marine Corps short-range UAV that the Army intended for division- and corps-level requirements [11]. The program was initiated in 1989 and the first Hunter entered the service in 1996. It was deployed to Macedonia to support NATO Balkan operations in 1999 and to Iraq in 2002 [11]. The MQ-5B's first flight was in 2005 and is still fielded by the U.S. Army in Iraq and Afghanistan. MQ-5B Hunter dropped a laser-guided bomb on a target in Iraq in September 2007 [12]. It is planned that Hunter will remain in service through 2009.

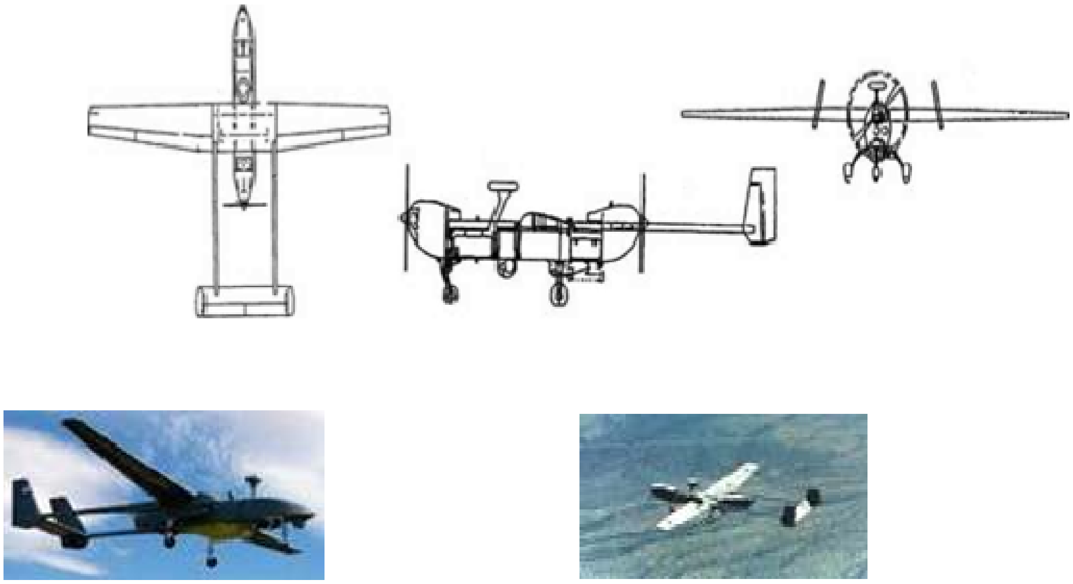

Figure 3. The RQ-5A/MQ-5B Hunter

3. MQ-1B Predator

a. Features

The MQ-1B Predator is a medium-altitude, long-endurance UAV which is employed as a theater asset for ISR and target acquisition in support of joint-force commander, even though it is a hunter-killer for critical, time-sensitive targets.

A fully operational Predator system consists of four aircraft, a ground-control station, a primary satellite link, and approximately fifty-five personnel for deployed round-the-clock operations [13]. The aircraft can be dismantled and the ground-control system can be transported in a C-130 transport aircraft.

> The basic crew for the Predator is one pilot and two sensor operators who fly the aircraft via a line-of-sight data link, or a satellite data link for beyond line-of-sight flight. The aircraft is equipped with a color nose camera, a variable-aperture daytime TV camera, a variable-aperture infrared camera for low light and nighttime missions, and a synthetic-aperture radar (SAR) to look through smoke, clouds and haze. The cameras produce motion video while the SAR produces still-frame radar images [13].

The MQ-1 Predator can employ two laser-guided AGM-114 Hellfire antitank missiles with the multispectral targeting system (MTS).

b. Background

The Air Force MQ-1 Predator was one of the initial advanced-concept technology demonstrations (ACTD) in 1994 and transitioned to an Air Force program in 1997 [13]. It has flown ISR missions in four recent conflicts since 1995. It was re-designated from RQ-1 to MQ-1 after gaining the ability to employ Hellfire antitank missiles in 2001. The Air Force employs twelve Predator systems stationed in three squadrons.

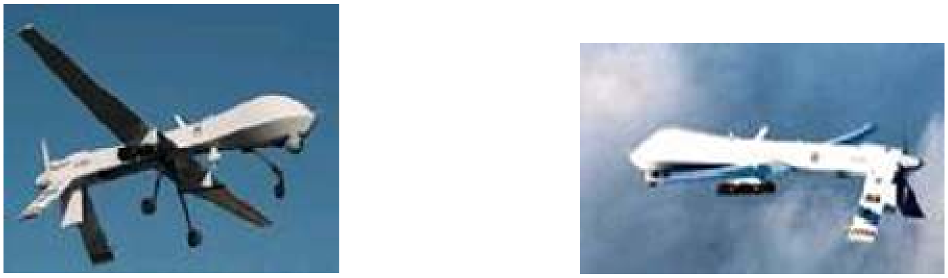

Figure 4. The MQ-1B Predator

4. RQ-4 Global Hawk

a. Features

RQ-4 Global Hawk is a high altitude, long-endurance UAV capable of precise targeting of weapons and protection of forces through superior surveillance. Cruising at very high altitudes, the Global Hawk can provide battlefield commanders and decision makers with near real-time, high-resolution ISR imagery.

> Global Hawks carry both an EO/IR sensor and a SAR with MTI capability, allowing day-and-night, all-weather reconnaissance. Sensor data is relayed over CDL LOS (X-band) and beyond-line-of-sight (BLOS) (Ku-band SATCOM) data links to its mission-control element (MCE), which distributes imagery to up to seven theater-exploitation systems [11].

Once mission parameters are programmed into Global Hawk, the UAV can autonomously taxi, take off, fly, and remain on station-capturing imagery before returning and landing [14]. The navigation and sensor plans can be changed during flight by the operator in GCS.

b. Background

The Global Hawk completed its first flight in February 1998 and entered the engineering and manufacturing development (EMD) phase of defense acquisition transitioned in March 2001. They entered the service for OEF after the terrorist attacks in September 11, 2001 and are still serving in OIF.

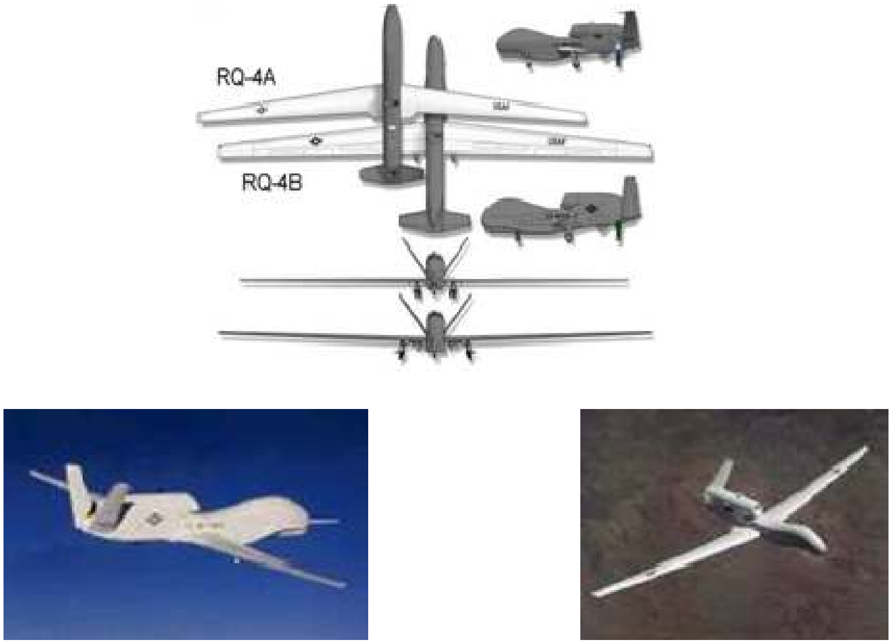

Figure 5. The RQ-4A/RQ-4B Global Hawk

Table 2 and Table 3 compare UAV systems in terms of characteristics and performance, respectively.

	MQ-1B PREDATOR	**RQ-2B PIONEER**	**RQ-4A GLOBAL HAWK (Block 10)**	**RQ-4B GLOBAL HAWK (Block 20, 30, 40)**	**RQ-5A HUNTER**	**MQ-5B HUNTER**
Length	26.7 ft (8.1 m)	14 ft (4.2m)	44.4 ft (13.5 m)	47.6 ft (14.5 m)	22.6 ft (6.8 m)	23 ft (7 m)
Gross Weight	2,250 lb (1,020.5 kg)	452 lb (205 kg)	26,750 lb (12,134 kg)	32,250 lb (14,628 kg)	1,620 lb (734.8 kg)	1,800 lb (816.4 kg)
Fuel Capacity	665 lb (301.6 kg)	76 lb (34.4 kg)	14,700 lb (6,667 kg)	16,320 lb (7,402 kg)	Moto Guzzi 421 lb (191 kg) HFE 280 lb (127 kg)	Moto Guzzi 421 lb (191 kg) HFE 280 lb (127 kg)
Engine Make	Rotax 914F	Sachs SF 350	Rolls Royce AE-3007H	Rolls Royce AE-3007 H	Moto Guzzi (x2)	Moto Guzzi (x2) Mercedez HFE (x2)
Data Link(s)	BLOS LOS	LOS C2	LOS BLOS (SATCOM)	LOS BLOS (SATCOM)	LOS	LOS
Wingspan	48.7 ft (14.8 m)	17 ft (5.1 m)	116.2 ft (35.4 m)	130.9 ft (39.9 m)	29.2 ft (8.9 m)	34.25 ft (10.4 m)
Payload Capacity	450 lb (204.1 kg)	75 lb (34.1 kg)	1,950 lb (884.5 kg)	3,000 lb (1360.7 kg)	200 lb (90.7 kg)	200 lb (90.7 kg)
Fuel Type	AVGAS	AVGAS	JP-8	JP-8	MOGAS	JP-8
Power	115 hp	26 hp	7,600 lb (SLS)	7,600 lb (SLS)	57 hp (x2)	57 hp (x2) 56 hp (x2)
Frequency	Ku-band C Band	C Band UHF	UHF X Band Ku-band INMARSAT	UHF X Band Ku-band INMARSAT	C-band	C-band

Table 2. Comparison of UAVs' characteristics (After: DoD UAS Roadmap 2005-2030)

	MQ-1B PREDATOR	RQ-2B PIONEER	RQ-4A GLOBAL HAWK (Block 10)	RQ-4B GLOBAL HAWK (Block 20, 30, 40)	RQ-5A HUNTER	MQ-5B HUNTER
Endurance	24+ hr/clean 14 hr/external stores	5 hr	32 hr	28 hr	11.6 hr	18 hr
Ceiling	25,000 ft (7,620 m)	15,000 ft (4,572 m)	65,000 ft (19,800 m)	60,000 ft (18,300 m)	15,000 ft (4,572 m)	18,000 ft (4,586 m)
Takeoff Means	Runway	RATO/ Runway/ Pneumatic Launch	Runway	Runway	Runway	Runway
Sensor	EO/IR SAR	EO/IR	EO/IR SAR/MTI	EO/IR SAR/MTI	EO/IR	EO/IR
Max/Loiter Speeds	118/70 kt (218/130 kmph)	110/65 kt (204/120 kmph)	350/340 kt (648/630 kmph)	340/310 kt (630/574 kmph)	106/89 kt (196/164 kmph)	106/89 kt (196/164 kmph)
Radius	500 nm (926 km)	100 nm (185.2 km)	5,400 nm (10,000 km)	5,400 nm (10,000 km)	144 nm (266 km)	144 nm (266 km)
Landing Means	Runway	Net/ Runway with Arresting Gear	Runway	Runway	Runway/ Wire	Runway/ Wire
Sensor Make	Raytheon AN/AAS-52 Northrop Grumman AN/ZPQ-1	Tamam POP 200	Raytheon	Raytheon	Tamam MOSP	Tamam MOSP

Table 3. Comparison of UAVs' performances (After: DoD UAS Roadmap 2005-2030)

III. OPERATING ENVIRONMENTS

> When the United States Air Force's scientific advisory board (SAB) conducted a study in 1996 on the role of UAV technologies in military operations, its principal conclusion was that UAVs would enhance the United States' ability to project military power [15]. An equally important conclusion was that these vehicles could perform tasks that pose difficulties for manned aircraft, including attacking chemical-warfare and biological-warfare (CW/BW) facilities and suppressing enemy air defenses (SEAD). The SAB study concluded that UAVs are more survivable than manned aircraft and that, as a technological development, UAVs have profound implications for the American military force of the future [16].

The effectiveness of UAVs in recent conflicts such as Gulf War I (1991), Bosnia, Afghanistan, and Gulf War II (Iraq) has attracted attention to the many advantages of unmanned, aerial vehicles in modern warfighting. The history of UAVs as used in military operations, including research and demonstration testing, has clearly revealed their weaknesses and strengths. It is important for other military forces to learn lessons and gain insight into how UAV utility can be implemented and improved. In military operations, UAVs are now playing valuable roles and are essential for sensitive and risky missions formerly performed by manned aircraft.

This chapter focuses on how the introduction and increasing use of UAVs has affected U.S.-aviation combat tactics, based on four recent combined-force conflicts in Iraq, Bosnia, and Afghanistan. In the material that follows, brief overviews of the roles UAVs played in these conflicts will be discussed.

A. GULF WAR I

The concept of UAV utilization did not emerge until operations Desert Shield and Desert Storm. During Desert Storm, UAVs emerged as a critical source of intelligence at the tactical level in addition to the American fleet's manned tactical-reconnaissance assets. The force commanders' need for cost-effective, unmanned, over-the-horizon (OTH) targeting, reconnaissance, and battle-damage assessment (BDA) capability resulted in a search for concepts and platforms. The UAV applications and their operational success created the first general awareness and military-wide acceptance of the mission utility of UAVs [9].

> In response to earlier operations in Grenada and Libya, the Navy started the Pioneer UAV program in the late 1980s. By the time Iraq invaded Kuwait in 1990, the Navy, Marine Corps, and Army all operated UAVs. With 85% of the U.S.'s manned tactical reconnaissance assets committed in Kuwait, UAVs emerged as a must have military asset. Six Pioneer systems (three with the Marines, two on Navy battleships, and one with the Army) participated. They provided highly valued, near-real-time reconnaissance, surveillance, and target acquisition (RSTA) and BDA, day and night. They often worked with JSTARS, the airborne battle management and C^2 platform, to confirm high-priority mobile targets [9].

During Operation Desert Storm, high-level commanders using technical resources could view the entire battlespace, perceive detailed information about the enemy, and lead coalition forces to a new level of precise engagement never seen before. They used numerous collection platforms such as satellites, joint STARS, AWACS, UAVs, and others. The utilization of UAVs clearly demonstrated that the capacity to interoperate with other information systems provided a valuable battlespace view to all commanders, from tactical level commanders to operational decision makers. Before the Gulf conflict, assets that provided reconnaissance were manned, airborne platforms, including U-2, SR-71, JSTARS, AWACS, Guardrail, ES-3, Advanced Tactical Airborne Reconnaissance System (ATARS) on F-16 and F/A-18 aircraft, and satellites. Manned platforms were adapted to multiple mission scenarios and could loiter in the conflict region with air refueling up to the endurance limitations of the crew, which was about eight hours. Crew limitations such as the reaction time to global conflicts, weight allowances associated with crew requirements and cost of manned systems were the major concerns at the time. But the significant concern and limitation of manned platforms was the personal risk to the crew [9].

Satellite reconnaissance could see virtually anywhere in the world for different time ranges, depending on their capability. Remote-sensing satellites gathered information via instruments across wide areas at no risk to life. Orbital mechanics generally limited a satellite's coverage of a conflict area to about twenty minutes per orbital pass, with only about three to four passes a day, depending on target latitude. Continuous coverage of an area of interest or conflict region would require an expensive and large satellite constellation. Also, constant and predictable satellite orbits put enemies at a disadvantage whenever the satellites is overhead, and therefore adversaries conceal their activities and forces at times of overflight. Satellites considered as high-value national assets, used primarily by high-level commanders and decision makers to acquire strategic and operational intelligence for the tactical battlefield commander, turned out to be a major failure in the national information-systems concept during the Gulf conflict [9].

Operations have proved that UAVs have the potential to fill the gap between manned aerial platforms and satellite-reconnaissance platforms. UAVs provide valuable capabilities to the battlefield commander at every level, giving near-real-time information by conducting direct and indirect gunfire support, day and night surveillance, rapid BDA, target acquisition, route and area reconnaissance, and battlefield management in dynamic threat environments and heavily defended areas where the risk to loss of a high-value manned platform is likely [9] [17].

> According to the interim DoD report to Congress on Desert Shield and Desert Storm, UAVs performed direct and indirect gunfire support, day and night surveillance, target acquisition, route and area reconnaissance, and BDA. The Pioneer system appears to have validated the operational employment of UAVs in combat [9].

After Israel's success in UAV concept development and the increasing U.S. military requirement for a cost-effective, unmanned, airborne-reconnaissance platform, the Navy started the Pioneer program in 1985. The major UAV employed during the Gulf conflict, the Pioneer complements other information systems and provides high-value intelligence for tactical commanders in the battlefield [9].

U.S. forces deployed forty-three Pioneers to the combat theater, flying 330 sorties and completing over a thousand flight hours. During the conflict, Pioneer UAVs enabled the Army to deactivate threat enemy artillery to support friendly forces. After that, the manned tactical fighters entered to the combat zone to cut off and destroy Iraqi forces in the Kuwaiti theater of operations. The Navy utilized UAVs to monitor the Kuwaiti coastline and Iraqi naval facilities and search for mines. The Pioneer's ability to spot each sixteen-inch round fired by U.S. battleships in real time increased the accuracy of the big guns. One of the primary uses of Pioneer was to fill the gap created by the retirement of the RF-4s. Although the imagery resolution provided by Pioneer did not match that of the RF-4s, the BDA and target information significantly supported Marine air power in the battlefield [9].

> Because the Pioneer was an organic Marine asset, information from the UAVs went directly to the First Marine Aircraft Wing. This provided a notable increase in the availability of imagery for Marine aviation, which had experienced coordination problems in obtaining information from external sources. Despite requirements for resolution imagery higher than the Pioneer was able to provide, the increased information it did supply seems to have been significant in the application of Marine air power in the Gulf [18].

The attack on the Iraqi-held Kuwaiti airport was another example of the utility of Pioneer UAVs. During that encounter a real-time Pioneer UAV image indicated a battalion of Iraqi tanks poised on the north end of the airfield for a counterattack. The Iraqi force was broken up by airborne and naval gunfire attacks before it could strike the advancing Marines [19]. In another instance, Iraqi soldiers surrendered to a Marine Pioneer during battle in Kuwait. During the operations, the Pioneer UAV supported the U.S. forces with invaluable near-real-time reconnaissance, surveillance, target acquisition, and BDA. The UAV operations in the Gulf War proved to be important in developing new concepts for further UAV applications and directly led to the development of Predator, DarkStar and Global Hawk [19].

> The U.S. Navy flew the Pioneer for 213 hours and sixty-four sorties from the USS battleships Missouri and Wisconsin conducting target selection, naval-gunfire support, battle-damage assessment, maritime-interception operations, and battlefield management. Collected information was provided to both theater and component commanders, resulting in the detection of numerous Iraqi patrol boats, a successful strike on two high-speed boats, location of two Silkworm anti-ship missile sites, 320 ship identifications, location of antiaircraft artillery positions, and pre- and post-assault reconnaissance of Faylaka Island. As the war progressed, Navy Pioneers sent back images of surrendering Iraqi troops and the retreat of major armored units. The Army's Pioneers flew 155 hours and forty-six sorties, providing a quick-fire link that allowed the targets they identified to be quickly engaged by other systems. Army Pioneers also helped tactical commanders to conduct situation development, targeting, route reconnaissance, and BDA. Marine UAV companies flew 318 hours and 138 missions during Operation Desert Shield and 185 missions and 662 hours during Operation Desert Storm [19].

> In ten years, the U.S. Pioneer system has flown nearly 14,000 flight hours and supported every major U.S. contingency operation to date [9].

B. BOSNIA

During the Bosnia War, friendly forces were not ground force-complemented, as is usually done to identify targets for airborne systems. It was clear that virtually all targets were mobile and rapidly moved because of the unique Bosnian force-employment concept. The concept for targeting was to receive targeting intelligence from the combined air-operations center (CAOC) via UAV collection and fuse the data with stored area imagery and then send the result to a strike aircraft. As part of its advanced concept technology development (ACTD) activities, the Predator was successfully deployed to the Balkans in support of NATO, the United Nations, and U.S. forces. The first deployment in the conflict involved three Predators with the payload sensors of electro-optical infrared (EO/IR) and line-of-sight and ultra-high-frequency (UHF) satellite communications (SATCOM) data links. Despite losses due to hostile fire and engine failure, the Predator system showed obvious improvements in operations during the Bosnian War. The system's unique live video and dynamic re-tasking capabilities increased commanders' battlefield awareness. Although the system was utilized effectively, adverse weather was the principle limitation for missions. The meteorological conditions such as icing, precipitation, high cross winds, and cloud cover limited the preplanned missions [9].

> The Predator helped determine the course of the Bosnia conflict. During September 1995, after several diplomatic and operational initiatives to relieve shelling and intimidation of civilian enclaves, NATO forces resorted to active bombing to bring the warring factions to the negotiating table. Many previous agreements to remove field weapons from the area had been broken, but NATO forces could not hold the violators responsible without confirmation. With Predators, however, weapons movements became subject to long-dwell video surveillance, and continuous coverage of area roads showed no evidence of weaponry being withdrawn. This single ISR resource thus gave NATO commanders the intelligence underlying their decision to resume the bombing campaign that, in turn, led to the Dayton peace accord signed in December 1995 [20].

In March 1996, Predators deployed again to the Bosnian AOR. Based on the previous experiences, the systems were modified to carry high capacity payloads supported by an expanded data-dissemination structure, and air-traffic control was provided via the Boeing system (AWACS). The enhancements included a tactical, endurance, synthetic-aperture radar (TESAR), an EO/IR sensor turret, an over-the-horizon, Ku-band satellite communications system, active de-icing capabilities for the wings, and an expanded information-dissemination infrastructure. This deployment with advanced technology resulted in a Predator-generated imagery hand-off to an E-8 JSTARS in the first demonstration of UAV/JSTARS interoperability. During the Balkan operations, the Predator system successfully integrated into the complex command, control, communications, computer, and intelligence (C4I) architecture. [9].

The operations in Bosnia proved the ability of UAVs to provide reliable ISR to commanders and decision makers. During the conflict, the Predator UAV logged over 20,000 hours and made several combat deployments to the battlefield. The operations showed that the Predators provided critical and invaluable real-time target intelligence with other UAVs and ISR collection platforms [17].

> At least three different UAV systems -the Pioneer, Hunter, and Predator- have seen action as part of U.S. operations in the former Yugoslavia. The U.S. Navy deployed the Hunter UAV to support its missions during the Kosovo conflict; the earlier Pioneer drone had proven itself eight years ago in the Gulf War. Target planners were able to watch live video feed of occupying Serbian soldiers and weaponry. The most significant advance in UAV technology, however, was demonstrated by a combination of the Predator UAV, commercial satellite TV, and a wide-bandwidth, secure, tactical-Internet connection through fiber-optic cables and commercial satellite transponders. Known as the Bosnia command-and-control augmentation initiative, the Predator and other components transmitted live images to theater commanders via the Joint Broadcast Service. All that was needed to receive broadcasts was a twenty-inch receiving antenna, cryptological equipment, and authentication codes. Commanders could select from programming received over their 30 Megabit-per-second downlinks over direct-broadcast satellites. Compared to the 9.6 Kilobit-per-second modems available during the Gulf War, that is over 3,100 times more data per second [19].

During Operation Allied Force, the Predator UAV was able to provide long-duration ISR over the Kosovo engagement zone. Potential capabilities and missions changed rapidly in the UAV concept from strategic to tactical level. The political and regional conflicts have caused the DoD to step up and define requirements for UAV utilization in order to support an increasing variety of peace-through-war operations and the need for numerous types of UAVs to fill the gap in the operational envelope [21].

C. AFGHANISTAN

Afghanistan's rough terrain presented a unique and complex challenge to U.S. fighter and bomber platforms seeking access. Although the enemy was ill equipped, with an archaic air defense, location and movement detection complicated U.S. targeting opportunities in an asymmetric environment.

The air war in Afghanistan was apparently different from other conflicts. Due to the dynamic environments involved, strike aircraft missions had shifted from preplanned targets to targets of opportunity, or flexible targets. The fighter pilots and bomber aircrews had no detailed target information until after takeoff. The idea was to keep the aircrafts in a continuous orbiting over the battlespace until appropriate and valid targets were identified. The potential target information was transmitted to the fighters and bombers via voice or data-link transmissions. In Afghanistan, ISR platforms provided nearly twenty-four-hour coverage of the battlespace with responsive reporting and engagement of time-sensitive targets (TSTs) [22].

The Predator armed with Hellfire missiles became a hunter used to destroy both stationary and moving targets. With the Hellfire, the Predator could watch a potential target for hours and eliminate it without any risk to aircrew, combining the best of reconnaissance and strike assets cost effectively. The Predator operated as an airborne forward air controller and located targets within the approval time accomplished in minutes. Its geographically dispersed and protected pilot managed the flight and directed the strike, providing target information, altitude, and geographic deconfliction. Predators provided instant battle-damage assessment that allowed for immediate follow-on strikes [23].

> The first Hellfire missile was successfully fired by a Predator UAV in Oct 2002 against a car carrying six Al-Qaeda suspects in Yemen. The Global Hawk UAV also saw its share of action in Afghanistan; however two of the five experimental vehicles were lost over Balochistan for technical reasons [24].

> In press releases issued on the 8th and 11th of February 2002, the Department of Defense confirmed that the CIA was using armed Predator UAVs in Afghanistan, and a reference was made to a 4 February strike on a suspected Al-Qaeda complex near Zawar Kili in eastern Afghanistan [25].
>
> As of 10 December 2002, the USAF was reporting that Global Hawk UAVs deployed in support of Enduring Freedom had generated surveillance and reconnaissance images of potential enemy targets in the course of fifty combat missions that exceeded a thousand flight hours in all [25].
>
> Returning to Predator operations, 3 and 4 November 2002 is reported to have seen a “weaponised” CIA Predator UAV used to eliminate six suspected Al-Qaeda operatives (including Qaed Salim, probable mastermind of the October 2000 attack on the USS Cole) in an attack on a motor convoy some 160 km east of Yemeni [25].

D. GULF WAR II (IRAQ)

In Iraq, due to complex and dynamic environment, the U.S. needed faster and better intelligence gathering. UAVs have played a major role and become the link between information-age technology and industrial-age aircraft. The progress in computing, sensor technology, and improvements in wireless and network communications have made UAVs cost effective and enabled their proliferation. The capability of sharing real time data, images and video became the required features in UAV utilization.

During OIF, the American Forces used multiple Predator UAVs to support CAOC operationally. CAOC was the air-operations center that supports joint, allied, and coalition warfare and plans, executes, and assesses aerospace operations during a contingency or conflict. Basically, the objective was to integrate the Predator’s common operating picture with the Falcon View mission-planning system. In Iraq, Predators collected intelligence, launched Hellfire missiles, provided time-critical targeting information via streaming video to other weapon systems. In sixteen missions, it is indicated that, Global Hawks located thirteen surface-to-air missile (SAM) batteries, fifty SAM launchers, over seventy SAM transport vehicles and over 300 tanks [15].

> In OIF, the Global Hawk was given a chance to showcase new concepts in time-sensitive targeting with ISR assets. Although the U-2 had employed these concepts in 1999 in Kosovo, it was the Global Hawk's unmanned attribute that allowed its employment in the OIF missile engagement zone during combat operations. As a result, even though Global Hawks flew only 5% of the OIF high-altitude missions, they accounted for 55% of the time-sensitive targeting against enemy air-defense equipment [26].

All four conflicts discussed in this chapter showed that UAVs have emerged as an important weapon of modern warfare, capturing the imagination of military planners and decision-makers. The technology that is being incorporated into the UAV systems is continually advancing. Advanced technologies such as synthetic-aperture radars, highly capable microprocessors, increased data-link rates, radar-absorbing materials, the use of high-bandwidth communications, and SATCOM-equipped navigation systems integrated onto UAV platforms making them an invaluable key asset to military forces. The global war on terrorism (GWOT) has directed attention to a primary UAV capability: intelligence gathering. UAVs provide high-resolution data; can be employed in unpredictably; can focus on a specific target area; and, depending upon the system, dwell over an area of interest or target for extended periods. They have shortened the process of searching, finding, identifying, and destroying a target, as known as, the kill chain or sensor-to-shooter cycle. Another key reason for UAV mission success is that their elevated flight altitudes and slow speed make them difficult for common enemy sensors to detect or recognize. UAVs offer advantages over manned aircraft in cost effectiveness, numerous applications, and preservation of life. The U.S. services have innovated with and employed the potential capabilities of UAVs in recent conflicts (i.e., arming the Predator UAV with missiles) [27].

The employment of primary UAV systems in recent conflicts, including Pioneer, Hunter, Predator and Global Hawk, demonstrated the potential of unmanned platforms and gave insight into further applications. The challenge for the Turkish armed forces is to develop indigenous systems and concepts and improve current applications to meet national requirements. The primary technical challenge for world militaries is to integrate manned, UAV, and satellite systems to create a common operational picture.

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IV. UAV ANALYSIS

This chapter focuses on evaluating UAV mission areas under network-centric warfare, as well as several indicators used to assess UAV performance. To understand the importance of UAVs and how they affect tactical networks and combat tactics, it is important to explore the reasons, results, and impacts of UAV use within past, current, and future operating environments. A number of driving factors were considered in an attempt to characterize the UAV contribution to operational mission success. These factors, which include mission areas, characteristics, capabilities, limitations, and performance indicators, are discussed below.

A. UAV MISSION AREAS

To analyze the need, usage, and impact of UAVs for specific missions, it is important to focus on intended objectives, operational environments, and enabling technologies. Before specifying critical UAV missions for the Turkish armed forces, examining the change and evolution of mission types will set the stage for our study.

The missions listed below were selected as critical to Air Force needs by the United States Air Force's scientific advisory board in 1996 [28].

- Counter- weapons of mass destruction
- Theater missile defense: ballistic missiles and cruise missiles
- Fixed-target attack
- Moving-target attack
- Jamming
- Suppression of enemy air defenses
- Intelligence, surveillance, and reconnaissance

- Communications and navigation support
- Air to air

After UAV usage in the recent conflicts and demonstrations, the mission areas open to UAVs were listed in the *DoD Unmanned Aircraft Systems Roadmap 2005-2030.* Although EO/IR/SAR sensors have been the predominant payload in recent conflicts, Table 4 identifies potential missions involving a number of other payloads previously flown on UAVs in proof-of-concept demonstrations. These demonstrations indicate that UAVs can perform the tasks and roles inherent in these mission areas and be a potential solution, depending on requirements. UAVs should be the preferred solution over manned platforms when the requirements involve the familiar three jobs best left to UAVs according to [11]: the dull (e.g., long dwell), the dirty (e.g., sampling for hazardous materials), and the dangerous (e.g., extreme exposure to hostile action). Table 4 is a representative cross section of other payloads that have been demonstrated on UAVs [11]. It is not meant to be an all-inclusive list. Acronyms are expanded in the acronyms section.

Requirements	**Justification for UAV Use**			**UAV Experience**
(Mission Areas)	"Dull" *Long dwell*	"Dirty" *Sampling for HAZMAT*	"Dangerous" *Extreme exposure to hostile action*	(UAV/Payload, Place Demonstrated, Year)
ISR	X		X	Pioneer, Exdrone, Pointer/Gulf War, 1990-91 Predator, Pioneer/Bosnia, 1995-2000 Hunter, Predator, Pioneer/Kosovo, 1999 Global Hawk, Predator, /Afghanistan, Iraq 2003-Present Hunter, Pioneer, Shadow/Iraq-2003-Present
C2/Comm	X			Hunter/CRP, 1996; Exdrone/TRSS, 1998 Predator/ACN, 2000
Force Protection	X	X	X	Camcopter, Dragon Drone/Ft Sumner, 1999 FPASS, Dragon Eye, Pointer, Raven, Scan Eagle/Iraq-Present
SIGINT	X		X	Pioneer/SMART, 1995 Hunter/LR-100/COMINT, 1996 Hunter/ORION, 1997 Global Hawk/German Demo, 2003; Iraq, 2004-Present
Weapons of Mass Destruction (WMD)		X	X	Pioneer/RADIAC/LSCAD/SAWCAD, 1995 Telemaster/Analyte 2000, 1996 Pointer/CADDIE 1998 Hunter/SAFEGUARD, 1999
Theater Air Missile Defense (TAMD)	X		X	Israeli HA-10 development, (canceled) Global Hawk study, 1997
SEAD			X	Hunter/SMART-V, 1996 Hunter/LR-100/IDM, 1998 J-UCAS/TBD
Combat Search And Rescue (CSAR)			X	Exdrone/Woodland Cougar Exercise, 1997 Exdrone/SPUDS, 2000
Mine Counter Measures			X	Pioneer/COBRA, 1996 Camcopter/AAMIS, 1999 (Germany
Meteorology and Oceanography (METOC)	X	X	X	Aerosonde/Visala, 1995 Predator/T-Drop, 1997 Predator/BENVINT ACTD, 2002
Counter Narcotics (CN)	X		X	Predator/Ft Huachuca, 1995 Pioneer/So. California, 1999 Hunter, Shadow/Ft Huachuca, 2003-2004
Psychological Ops			X	Tern/Leaflet Dispensing, 2004
All Weather/ Night Strike			X	DASH/Vietnam, 1960s Predator/Afghanistan/Iraq, 2001

				Global Hawk/Iraq, 2003
Exercise Support	X			Predator/Joint Operational Test Bed System (JOTBS), 2002
Navigation	X			Hunter/GPS Pseudolite, 2000

Table 4. UAV Mission Areas (From: *DoD UAS Roadmap 2005-2030*)

UAV mission concepts have high practical and technological potential for strengthening the current Turkish armed forces' capabilities by complementing existing force structures. UAVs could be used to gather target-location data, complementing manned aircraft or other UAV weapon employment. UAVs could gather this target-location data and attack the targets in autonomous areas of operation (i.e., designated kill boxes). Categories of UAV platform as well as mission systems and weapons that have been established for each major military mission are shown in Table 5. Table 6 shows UAV mission-system elements for each operational task.

Mission	Platform	Mission Systems	Weapons
CWMD	P-HAE (Find/Attack) C-MAE (Find/Attack)	NBC Sensors, Target Geolocation, UGS Relay	Penetrator Missile with Thermitic Warhead or Employing Sealant Foam
TMD/CMD	S-HAE (Find/Attack) P-HAE (Find) C-MAE (Attack)	SAR/MTI Radar, Air-to-Air Tracking Radar, EO/IR Imaging Fire Control	Hypervelocity Missile with IR Seeker and Kinetic Kill Vehicle w/ Divert Thrusters
Fixed Target	S-HAE (Find) P-HAE (Find/Attack) C-MAE (Attack)	SAR, EO/IR Imaging, Target Geolocation, Fire Control	Range of Choices Depending on Target Hardness; New Lethal and Small Warheads (Flying Plate, HPM, Thermite) for Future
Moving Target	S-HAE (Find) P-HAE(Find/Attack) C-MAE (Attack)	SAR/MTI Radar, Target Geolocation, Fire Control	Wide Area Submunitions or Homing Missiles such as TOW, Hellfire, Maverick in Near-Term; 3.5 in. Modular Missile for Future
Jamming	S-HAE	ESM Sensors, Escort/Area Jammer, Comm Jammer	N/A
SEAD	S-HAE (Find) P-HAE (Find) C-MAE (Attack)	ESM, Emitter Geolocation, Escort/Area Jammer, Comm Jammer	Weapon Dispenser on UAV, ARM, or Dispensing Submunitions in Near-Term, HPM Warhead or

			Submunitions on Hypervelocity Missile in Future
ISR	S-HAE (Find) P-HAE (Find)	SAR/MTI Radar, Air-to-Air Tracking Radar, FOPEN Radar, ESM, Emitter Location, Target Geolocation	N/A
UCN	S-HAE P-HAE	Comm Gateway/Relay, GPS Augmentation	N/A
Air-to-Air	S-HAE (Find/Attack) P-HAE (Find) C-MAE (Find/Attack)	Air-to-Air Tracking Radar, Fire Control	AIM-120 and AIM-9 In Near-Term, Hypervelocity Missile in Future
(ALL)		Command/Data Links, Nav/Positioning, Self-Protection, Onboard Processing, Sensor ECCM	GPS Weapon Initialization, Weapon Launch System

Table 5. UAV Platforms (From: *UAV Technologies and Combat Operations*)

Abbreviations:

P-HAE: Penetrating, high-altitude endurance UAV

S-HAE: Standoff, high-altitude endurance UAV

C-MAE: Combat, medium-altitude endurance UAV

Mission System Elements	**CWMD**	**TMD**	**Moving Target Attack**	**Jamming**	**SEAD**	**ISR**	**Comm/ Nav Support**	**A/A**
Radar								
• SAR	X	X	X	X	X	X		
• MTI	X	X	X			X		
• Air-to-Air		X				X		X
EO/IR Sensors								
• Imaging/FLIR	X	X	X		X	X		
• IRST		X						X
• LADAR/LIDAR	X					X		
• Designator	X	X	X		X			
• Laser Ranger	X	X	X					X
ESM								
• Intercept/ Exploitation	X	X		X	X	X		
• Emitter	X			X	X	X		
Special Sensors								
• Meteorology						X		
• Chem/Bio	X							
• Nuclear	X							

ECCM								
• RF Sensors	X	X	X		X	X		X
• EO/IR Sensors	X	X	X		X	X		X
COMM								
• Data Links	X	X	X	X	X	X	X	X
• Relay/Switch	X	X	X	X	X	X	X	X
NAV								
• Positioning	X	X	X	X	X	X	X	X
• Target	X		X	X	X	X	X	
• GPS	X		X	X	X		X	
ECM								
• Self Protection	X	X	X	X	X	X	X	X
• Escort/Area Jammer	X		X	X	X			
• Comm Jammer	X			X	X			

Table 6. UAV Mission System Elements (From: *UAV Technologies and Combat Operations*)

Recent conflicts substantiated that theater commanders require a cost-effective, responsive, long-endurance, real-time reconnaissance capability to collect, process, and report intelligence in any environment. The primary requirement for commanders and decision makers is the ability to obtain reliable data at any time and in all conditions. Endurance UAVs contribute to this objective and complement other information systems and platforms. The three types of endurance UAVs under development—low, medium and high altitude—are intended to provide flexibility and fill the gap in supporting various levels of conflict and risk. The primary advantages of UAVs, such as their usefulness in conducting sensitive operations without risk, provide operational flexibility to the theater commander that may not exist via manned platforms. Since their operating profiles differ greatly, threats to the Predator and Global Hawk will vary depending on the platform involved. UAV systems are designed to operate in any area, depending on how the airframe and environment might affect mission success [29].

As *DoD UAS Roadmap 2005-2030* indicated, for the next twenty-five years the DoD will focus research on mission areas including ISR, SEAD, destruction of enemy air defense (DEAD), electronic attack (EA), anti-surface-ship warfare, antisubmarine warfare, mine warfare, ship-to-objective maneuvers, communications relay, and derivations of these themes. The other required missions such as offensive and defensive counter-air and airlift missions will remain on the to-do list pending improvements in autonomy and cognitive capabilities [11].

The Turkish armed forces face emerging challenges. UAVs used in ways that enhance Turkey's national power and promote force transformation appear to be a potentially strong contributor to those goals. Based on the results of operations in conflicts, demonstrations, and research in the missions discussed, the following UAV missions may be most critical to the Turkish military as it responds to national need:

1. Intelligence, surveillance, and reconnaissance
2. Time-sensitive targeting
3. Electronic attack
4. Suppression of enemy air defense
5. Communication relays

The source for the majority of the following information about critical UAV missions is *DoD UAS Roadmap 2005-2030.*

1. Intelligence, Surveillance, and Reconnaissance (ISR)

According to [11], the ISR mission can be divided into three distinct segments: 1) standoff, in which collections are made while recognizing the sovereign airspace of other countries; 2) overflight, when ISR platforms fly in the sovereign airspace of another nation with or without consent but at low risk to the mission; and 3) denied, which is similar to overflight except the nation-state being flown against possesses a credible capability to deny access. Space assets are usually employed globally in denied-access roles; however space assets cannot conduct unforewarned collection due to adversaries' foreknowledge and hence repositioning of the collection asset. Only an aircraft possesses the ability to show up by surprise in a region. Together, space and airborne systems provide a collection architecture that can afford surprise, information dominance and situational awareness. The UAV advantages of persistence, flexibility and "no human aboard" provide significant opportunities to achieve unforewarned data collection [11].

In peacetime, the majority of airborne land and littoral ISR missions use standoff techniques. Standoff UAV can also be used during military operations considered too risky for exposure of valuable platforms, or when political sensitivities mandate constraint. Standoff UAV designs need to emphasize long endurance so as to achieve the benefits of persistence. If broad-area coverage or extremely long-range sensor performance is required, high-altitude capability must also be emphasized [11].

Overflight concerns may be present in peacetime when political conditions support maritime surveillance, peacekeeping, or GWOT activities, or in combat when a sufficient reduction in hostile air defense has occurred. There is no broad set of capabilities required for overflight, unlike standoff and denied access. If persistence is desired, typically it would be achieved via long-endurance attributes in airframe shaping and engine choice. Altitude would likely be dictated by the mission equipment employed. For collections against very faint signals or requiring very high degrees of resolution, medium- to low-altitude UAVs are probably good choices. However, this introduces weather as a design consideration, since medium- to low-altitude aircraft must operate in areas plagued by icing and turbulence [11].

It is indicated in [11] that airborne penetrating capability is advantageous because arriving unforewarned prevents the adversary from foiling data collection by capitalizing on the predictability of orbits. But the disadvantage of traditional, manned platforms in a denied-access collection is the potential for aircrew loss and diplomatic problems.

The "targeting cycle" is the cyclical activity of detection, identification, tracking, engagement, and assessment—this loop summarizes the pattern of an air force in a bombing campaign. Potential targets are found and their identity determined; if hostile, they are followed and hit; and finally the strike is evaluated to determine whether to repeat. One key measure of effectiveness is the duration of this targeting cycle [30].

By Desert Storm in 1991, intelligence dissemination had changed significantly. While many ISR systems still used wet-film techniques, many were digitized, permitting much faster transmission and processing. Internet technology and electronic mail permitted very rapid transmission of digitized data [30].

In 1999's Allied Force campaign, the U.S. Air Force fielded a large fraction of its E-8 JSTARS fleet and deployed the new RQ-1A Predator UAV to gather battlefield intelligence. Operation Enduring Freedom was the first opportunity to apply the new generation of ISR systems. Afghanistan was swept by JSTARS, Predators, U-2s, Global Hawks, TARPS (tactical, air-reconnaissance pod systems) pod-equipped F-14s gathering radar and electro-optical imagery, and RC-135V/W Rivet Joint, EP-3E Aries and EA-6B Prowlers gathering electronic data, especially communications intelligence [30].

> Persistent bombardment was coupled with the ISR constellation to achieve, on some occasions, targeting cycles as short as three minutes between detection and a bomber's arriving overhead. Afghanistan became the proving ground for a new type of ISR-driven air campaign in which persistent bombers waited in orbit to pounce on emerging targets as soon as the ISR constellation could unambiguously determine identity [30].

Focal-area surveillance assets such as Predator and Global Hawk UAVs can orbit for tens of hours with searching targets in a specific area of interest.

With advanced lower-power radars and optical systems these systems provide more detailed and closer information of the battlespace to warfighters with a smaller footprint [30].

> The Global Hawk was used more flexibly, both as a complementary imaging-surveillance system and for reconnaissance. The single Global Hawk used was claimed to have accounted for 55% of time-critical Integrated Air Defense Systems (IADS) targets, including thirteen SAM batteries, fifty SAM transporter erector launchers (TEL), 300 missile storage canisters, and seventy missile transloader vehicles. It was also credited with 300 armored vehicle detections [30].

Coherent change-detection (CCD) techniques were also used in the Predator ground station. CCD takes terrain imagery from exactly the same point in space at different times and digitally compares the images pixel by pixel. The confirmed differences are highlighted in color as an overlay over the image for the analyst in quickly finding changes. This technique is exceptionally powerful and invaluable to use with both SAR imagery and optical or thermal imagery, as in predictive battlespace awareness. Though it deceive a human observer, a camouflage net in the battlefield is apt to produce enough shadowing or contrast difference for CCD detection [30].

2. Time-Sensitive Targeting (TST)

The changing nature of warfare increases the need for special capabilities in an asymmetric environment. The developments that make UAVs ideal for time-sensitive targeting are:

- Increasing autonomy
- Decreasing size
- Smaller and lighter displays

ISR sensor-to-shooter timeliness has improved since Operation Desert Storm. Despite terrain challenges and performance degradation, two E-8 JSTARS aircraft were used successfully to direct airborne controllers and strike aircraft against targets of opportunity in the conflict. In the absence of formal targeting processes and training, creative processes were developed to disseminate information from sensor to shooter. For example, Predator UAV real-time images were received translated in the CAOC into targets and passed to orbiting strikers for prosecution. In another case, a U-2 aircraft detected a possible SA-6 threat and disseminate the information to an F-15E for engagement [31].

> A critical component of the find, fix, track, target, engage, and assess (F2T2EA) process was the ability of U.S. and coalition ISR assets to find and fix immediate Iraqi targets. Eighty U.S. and coalition ISR platforms, flying approximately a thousand sorties, supported the effort while space-based assets provided operational and tactical-level support that included Iraqi missile-launch detection. The ISR aircraft included RC-135 Rivet Joint, U-2, P-3 Orion, E-3 Sentry AWACS, E-2 Hawkeye AEW, E-8 JSTARS, MR-2 and R-1 Nimrod, PR-9 Canberra aircraft, as well as numerous UAVs, including the Global Hawk and Predator. In addition, nontraditional ISR methods including the use of fighter targeting pods, and the B-1 moving-target indicator also contributed capability towards the huge demand for actionable intelligence and assessment [31].

The use of the Global Hawk UAV to maintain persistent ISR coverage over Baghdad resulted in a dramatic increase in actionable dynamic-target intelligence to the CAOC TST cell. The Global Hawk located up to fifty surface-to-air missile (SAM) launchers, in excess of ten SAM batteries, and approximately seventy missile-transport vehicles. Once the Global Hawk’s platform became integrated into the Combined Forces Air Component Commander (CFACC)-prioritized DEAD campaign, the CAOC TST cell successfully prosecuted SAM-related dynamic targets, culminating with the effective takedown on the area of interest [31].

3. Suppression of Enemy Air Defense (SEAD)

UAVs have two attributes that are attractive for SEAD, strike, and armed-reconnaissance missions when compared to manned assets:

- Elimination of risk to crew

- Potential for greater survivability by reducing signatures through optimal shaping impossible with traditional manned-aircraft design and through greater maneuverability (beyond human tolerance) [11]

These attributes can be used to improve operational effect or reduce cost while maintaining the same level of operational effect.

It is clearly stated in [11] that UAVs would be used against heavily defended targets for two reasons. First, a UAV can theoretically achieve levels of survivability that manned aircraft cannot. Signature control without the need for human caretaking becomes less difficult, and maneuverability could be increased beyond human tolerances if necessary to enhance survivability.

In [11], SEAD is analyzed as two different types of missions: preemptive SEAD, in which a pathway is cleared prior to the ingress of strike aircraft, and reactive SEAD, in which the SEAD asset must react rapidly to pop-up, enemy air-defense threats during the execution of a strike. Since closing with that threat will be required, the survivability of the vehicle must be assured through a combination of speed, stealth technology, and high maneuverability. Execution of both the preemptive and the reactive SEAD mission imply several critical design criteria for the UAV platform and mission-control system. These attributes would be similar to those of a UAV in a strike roll against heavily defended targets [11]. UAV accomplishing preemptive SEAD missions would also be expected to possess the following system characteristics:

- Extremely high mission reliability, as follow-on force assets (many of them manned) will depend upon the protection of a SEAD UAV asset.

- BDA so operational commanders can properly determine whether strike go/no-go/continue criteria have been met.

    - If BDA is organic, this reduces the reliance on other systems outside the SEAD UAV platform, but puts other design requirements on the SEAD UAV that complicate signature control.

  - If BDA is not organic, SEAD UAV design requirements are simplified, but complications arise in the integration of other ISR capabilities as a family of systems attempting to achieve effect in the SEAD mission.

- Weapons optimized for concept of employment. If using direct-attack munitions (short range), then a robust signature reduction design, or standoff weapons with appropriate support from onboard or off-board sensors to find, fix, track, and target intended threats must be employed.

- The use of direct-attack munitions is a major cost avoidance compared to the integration and use of standoff weapons.

- However, standoff weapons provide an opportunity to relax signature design requirements and thus avoid significant low-observable costs [11].

Execution of the reactive SEAD mission implies further design criteria:

- Enemy defensive systems' operations must be detected rapidly, implying an onboard capability to detect threats or a well-integrated system of systems.

- Reaction time from detection to neutralization of enemy defenses must be very short (seconds).

- When using weapons to neutralize defenses, the flight time of the weapon must be reduced by the ability to stand in close to the target (high survivability) or by the use of a high-speed weapon.

- Robust, anti-jam, data links are required.

- Reactive SEAD will require low-latency human interaction with the system or high autonomy within the system for determination of ROE criteria.

- Reactive SEAD implies the integration of manned and unmanned aircraft in a single strike event [11].

4. Electronic Attack (EA)

Many of the attributes that make UAVs attractive for SEAD also make them attractive for the EA mission, because UAVs can theoretically achieve levels of survivability that manned aircraft cannot. Signature control without the need for human caretaking becomes less difficult. Additionally, maneuverability could be increased beyond human tolerances to enhance survivability. Finally, as stated before, should survivability measures fail, the use of an unmanned system removes the risk of losing a human life, perhaps the greatest reason for using a UAV in combat [11].

In developing unmanned systems for the EA mission and as discussed in [11], the following attributes are considered critical:

- The ability to build a very stealthy unmanned vehicle could mean closer approaches to targeted systems, requiring less radiated power to complete the EA mission and the ability to detect and exploit much lower levels of targeted system radiation.

- The potential use of high-power, directed-energy (DE) weapons or electromagnetic pulse (EMP) weapons in future EA missions argues for the use of an unmanned platform, since the weapon may pose a significant risk to the crew of any delivery vehicle [11].

According to [11], the use of unmanned systems in the EA mission also brings several challenges:

- When using EA to neutralize defenses in support of manned strike forces, it will be critical for the SEAD UAV to be within sufficient range to be effective. A systems-engineering tradeoff between EA effectiveness and survivability needs to be fully understood.

- A UAV is more dependent upon outside communications than manned systems. Self-jamming (interference with command-and-control communications by electronic-attack emissions) could limit the ability to change the unmanned system’s mission once the electronic attack has begun.

  - The potential for self-jamming and increased vulnerability due to a dependence upon communications means a great degree of autonomy will be required in the unmanned EA system.

- A manned EA aircraft allows a crew to evaluate large quantities of tactical data on the threat environment and to change the mission plan as required for strike support. The appearance of previously unknown threat-defensive-system modes, frequencies, or tactics may only be detected by the human operator's ability to recognize patterns in the context of previous experience, a very difficult, and as yet undeveloped, ability for autonomous systems.

  - Without the development of autonomous EA operating capability, the transmission of large amounts of data describing the tactical environment must be provided to remote human operators in real time. These large transmissions would be limited by available bandwidth and self-jamming and could increase the unmanned system's vulnerability.

- A signature-controlled vehicle loses the advantage of stealth when radiating. "Home on jam" threat systems could put the unmanned EA aircraft at risk.

- Execution of the electronic-attack mission implies several critical design criteria and questions for the unmanned platform and mission-control system:

  - Mission reliability must be extremely high, as manned assets will depend upon the UAV for protection.

  - The tradeoff between effective apertures for the radiation of jamming electronic energy will have to be balanced against the negative impact on the signature and survivability of the unmanned system.

  - The EA mission will require a highly autonomous system that can operate and handle aircraft- and mission-related contingencies while unable to communicate with mission control (due to self-jamming and covert operations).

- Reaction time from detection to neutralization of the enemy defenses must be very short.
    - Enemy defensive operations must be detected and countered rapidly.
    - When using EA to neutralize defenses in support of manned strike forces, it will be critical for the UAV to be within sufficient range to be effective. A tradeoff between EA effectiveness and survivability needs to be fully explored.
- The EA mission implies the integration of manned and unmanned aircraft in a single strike event.
- Robust, anti-jam data links are required.
- The amount of energy required for effective EA is large unless the delivery platform is very close. The ability to generate this power could drive up aircraft size and cost. In addition, an aircraft small enough to go unobserved close to the target may not have the mobility (speed and range) to close the target or persist in the target area for a sufficient time. These considerations argue for the use of expendable jammers from unmanned aircraft as one means of delivering low-cost EA performance [11].

5. Communications Relay

In [11], it is anticipated that to create a wide communications footprint the UAV platform must have extreme endurance, high altitude, and adequate power. It would provide an airborne augmentation to current tactical and operational beyond-line-of-sight and line-of-sight retransmission capability. A more focused footprint to support brigade-and-below combat elements will require tactical communication relays to address urban canyons and complex terrains. Support of the communications-relay mission will require continuous coverage around the clock and sufficient redundancy to meet assured-connectivity requirements [11].

> By 2010, existing and planned capacities are forecast to meet only 44% of the need projected by Joint Vision 2010 to ensure information superiority. A separate study, “Unmanned Aerial Vehicles as Communications Platforms,” dated November 4, 1997, was conducted by OSD (C^3I) [11].

The communications-relay mission primarily depends on the concept of airborne communication nodes (ACNs). An ACN is a remotely accessed, high-altitude, tactical communications and networking node intended for use on UAVs. The primary conclusions regarding the use of an UAV as an ACN were:

- ACNs have advantageous over satellites in tactical communication [15].
- Capacity and connectivity solutions can be enhanced with ACNs [15].
- UAVs should be improved for meeting high-capacity communications needs [15].

ACNs can enhance theater and tactical communications capacity and connectivity by 1) providing more efficient use of bandwidth, 2) extending the range of existing terrestrial LOS communications systems, 3) extending communication to areas denied or masked to satellite service, and 4) providing significant improvement in received power density compared to that of satellites, improving reception and decreasing vulnerability to jamming.

> DARPA’s AJCN is developing a modular, scalable communication-relay payload that can be tailored to fly on an RQ-4/Global Hawk and provide theater-wide support (300 nm diameter area of coverage) or on an RQ-7/Shadow for tactical use (60 nm diameter area). In addition to communications relay, its intended missions are SIGINT, electronic warfare, and information operations. Flight demonstrations began in 2003, and the addition of a simultaneous SIGINT capability is planned by 2010 [11].

B. UAV CHARACTERISTICS, CAPABILITIES AND LIMITATIONS

1. Pioneer

The Pioneer UAV was procured to provide imagery intelligence for tactical commanders on the battlefield. Pioneer UAVs flew over 300 reconnaissance missions in combat operations during Persian Gulf operations in 1990-1991 and have flown in contingency operations over Bosnia, Haiti, and Somalia since 1994 [22].

It is indicated in [11] that the RQ-2A/Pioneer achieved less-than-desired reliability metrics. According to the analyses, this could be due to several factors. The Pioneer UAV was an Israeli platform purchased as a non-developmental system in an accelerated procurement. In operation, the users quickly identified several deficiencies that compromised reliability. General Charles C. Krulak, then commandant of the U.S. Marine Corps noted that:

> The Pioneer does not have an automatic takeoff, landing, or mission-execution capability and that has led to a high accident rate [11].

The other factor was shipboard electromagnetic interference, which caused several crashes. Also, the engines were thought to be too small for the platform and easily overstressed within time. In addition to a more reliable engine, Marine Corps users found that the system needed a smaller logistical footprint and longer endurance as important requirements [11].

The current version of Pioneer, the RQ-2B, is essentially a digital version of its analog predecessor with modifications on RQ-2A airframes. The analog air-data system was replaced with a digital, modular, integrated, avionics group (MIAG). [16].

2. Hunter

The Hunter UAV was developed to support armed forces with near-real-time imagery intelligence within a 125 km direct radius of action. The concept of communication relay exploited initially to an extendible range of 200 km by using another Hunter as an airborne relay. The primary mission was to provide a day-and-night ISR and target-acquisition airborne asset to corps and Marine air–ground task force (MAGTF) commanders. The multi-role tactical Hunter was the Army's first fielded UAV served as an extended-range, multipurpose, fixed-wing air vehicle. It allowed the commanders to cover and search the area of interest by collecting and relaying real-time information back to ground control and mission-monitoring stations. After demonstrations, Hunters have been modified to carry munitions in addition to sensor payloads [22].

The Hunter UAV has automatic launch and recovery systems that utilize a rolling takeoff and landing to a hard surface. The design of the system makes it possible to operate from a paved or unpaved road only, with a minimum width of fourteen meters and at least 300 meters' length at sea level. Experience proved that detailed site preparation would likely be necessary, unless the site were an airfield or other suitable location such as a highway. On the other hand, rocket-assisted takeoff from an open area of 250 meters may be used as an alternative to launch the Hunter UAV. The operator uses an external flight-control box during launches and recoveries. Under normal circumstances, the UAV is returned to its base launch site and recovered by the operator, and an arresting hook at the rear of the fuselage engages cables to bring the Hunter UAV to a halt. In emergencies, a backup parachute-recovery system is utilized. The system uses GPS information in flight in order to compute UAV geographic position [22].

The Hunter program has demonstrated many improvements and been used in recent conflicts within a wide range of payloads including SIGINT, chemical-agent detection, and communication relay [11].

> The high mishap rate of the early Hunter is comparable to that of early Pioneers and, based on that similarity can be largely attributed to poor Israeli design practices for their UA in the 1980s. The significant improvement in Hunter's mishap rate achieved since the mid-1990s is reflective of (1) joint government/contractor-focused oversight, (2) a rigorous review and analysis process being put in place, and (3) qualitative improvements in a number of failure-critical components (servo-actuators, flight control software). [11].

3. The Predator

The Predator UAV is a theater-level asset utilized to provide cued and non-cued ISR and target-acquisition capability to warfighters. The vehicle can carry electro-optical (EO), infrared (IR), and synthetic-aperture-radar (SAR) sensor payloads. The Predator's launch and recovery takes place via hard-surface runway operations. The UAV can operate both autonomously or under continuous manual control, although takeoff and landing must be manually controlled. The Predator pilots in GCS manipulate aircraft flight controls in real time using the LOS data link for takeoffs and landings. In flight, the pilot couples the autopilot to the navigation system, and the aircraft navigates to selected waypoints. The lack of beyond-line-of-sight (BLOS) communications capability in Predator's launch-and-recovery element (LRE) forces the system to maintain LOS until transferring control to the GCS. The pilot in the GCS controls the vehicle remotely and receives the required data from sensory products [11] [22].

The Predator's EO/IR sensors are in a gyrostabilized platform capable of rotating for a 360-degree field of regard. The EO subsystem has two colored, identical, daylight-video cameras with spotter and continuous-zoom lenses. The IR subsystem has three fields of view available in operations and a doubler for a total of six discrete fields of view, if required [22].

> The EO and IR payloads were designed to provide imagery of level six on the NIIRS (National Imagery-Interpretability Rating Scale) at 15,000-foot slant range. NIIRS six corresponds to a ground-resolvable distance of between forty and seventy-five centimeters (sixteen and thirty inches) [22].

It is vital for airborne vehicles to be supported with a de-icing system comprising ice detectors that provide the capability to transit through moderate icing conditions at any time during the flight. Weather conditions are the primary limitation and concern in Predator operations. The Predator is not certified by the U.S. Air Force to operate in instrument meteorological conditions (IMC) under instrument flight rules (IFR). In addition to IMC constraints, there are limitations in terms of launch and recovery under visual flight rules. For example, the Predator UAV cannot be launched in adverse weather with visible moisture such as rain, snow, ice, frost, or fog and the crosswind limitations for takeoff and landing are 17 knots. The assessment of the operational deployments to the Balkans, lessons learned from three CONUS (continental United States) exercises, and one demonstration indicated that weather caused the cancellation of 17% of planned missions and early return to base (RTB) in 19% of missions flown. Predator's weather limitations affected its missions and value to commanders negatively more than any other factor [22].

> The Predator experienced low mission-completion rates during its initial deployment in the Balkans in 1995-1997. While the primary cause was weather related, system failures accounted for 12% of incomplete missions [11].
>
> The Predator carries four sensors: a daytime TV spotter, daytime TV continuous zoom, IR, and SAR; only the daytime TV spotter's camera demonstrated the ability to recognize targets at a 30,000-foot slant range with a probability of recognition of 0.69. The IR camera could detect the existence of targets (something versus nothing), but could classify them (e.g., tracked versus wheeled) only 21% of the time and recognize (e.g., T-72 versus M1A1) only 5% of the time. The daytime TV camera could detect targets, but not classify or recognize them. In darkness or inclement weather, the sensor suite can detect but not classify or recognize targets at a 30,000-foot slant range [22].
>
> For missions where high resolution is an obvious necessity, such as BDA or reconnaissance missions to recognize and classify targets, the Predator must fly closer to provide adequate imagery. On the other hand, surveillance missions do not require such high resolution and adequate imagery can be obtained at longer ranges.

> For surveillance missions, the IR sensor provided adequate imagery for all ranges collected, out to 38,000 feet, and the daytime TV provided adequate imagery between 10,000 and 22,500 feet [22].
>
> The Predator is vulnerable to threats because of its operating envelope. The MAE UAV's concept of operations includes operating at altitudes no greater than 25,000 feet mean sea level (MSL), at airspeeds of 60-110 knots; 15,000 feet and 85 knots are the nominal altitude and airspeed. Additionally, the EO and IR sensors provide enhanced resolution at lower altitudes (5,000 feet versus 15,000 feet MSL). The threat to the Predator in this environment is broad: radio-frequency and infrared- guided surface-to-air missiles; antiaircraft artillery; and second-, third-, and fourth-generation combat aircraft equipped with air-to-air missiles, guns, and rockets. Notably, even with friendly air superiority, a Predator UAV operating at an altitude of 5,000 feet could find itself in the threat envelope of the less-sophisticated, visually acquired AAA and man-portable SAM systems. Although the Predator was not specifically designed to meet low signature requirements, its relatively small size, composite materials, and shape enhance its low signature. It does not contain an onboard EA system. Depending on its operating altitude for a given mission, it will be necessary to operate either in a standoff role or overfly target territory outside known engagement envelopes to defeat hostile SAM and aircraft systems [29].

4. The Global Hawk

The Global Hawk is optimized for reconnaissance and surveillance missions in low-to-moderate threat areas with supreme range and endurance. The imaging range of the UAV payload is 20 to 270 kilometers. The Global Hawk UAV is designed for fully autonomous operations during any mission from start-up, to taxi, takeoff, mission execution, and recovery. The system is capable of fully automated takeoffs and landings on paved runways [22].

Global Hawk's unique operating profiles, based on the air vehicle's operating altitude at above 50,000–65,000 feet, enable the system to operate with fewer payloads and weapon systems capable of threatening the mission. In contrast to the Predator UAV, threats to the Global Hawk HAE system include both high-altitude SAM systems and high-altitude airborne interceptors. The threats posed to the Predator would not be a factor against a Global Hawk HAE UAV mission. Standoff tactics and the use of onboard and off board early threat detection and warning capabilities will assist with dynamic threat avoidance in complex environments and enhance the platform's survivability [32].

> The Global Hawk provided extensive mission support in Afghanistan and Iraq. The LRE launched a Global Hawk from a forward operating location. LRE controls the aircraft via LOS common-data link (CDL), LOS ultra-high-frequency (UHF), and BLOS UHF radios. Shortly after launch, the LRE transferred mission control to the forward-deployed mission control element (MCE). MCE contains all the aircraft control functions of the LRE and provides for sensor control as well as receipt and dissemination of the product. The MCE maintains situational awareness. During combat operations, the Global Hawk initially flew a preplanned mission, but quickly transitioned to an ad-hoc operation [11].
>
> Secure chat via Secret Internet Protocol Router Network (SIPRNET) was established between the Global Hawk pilot/sensor operator, the liaison officer at the CAOC, and the intelligence-mission operations commander at the exploitation center. This provided situational awareness and enabled command of the mission in response to ongoing operations and other emerging requirements [11].

C. UAV PERFORMANCE INDICATORS

As defined in [11], the highest priorities for improving UAV capability in combat operations are:

- Improving tasking and collection efficiencies through a common, joint-use, ISR tasking and collection-management capability that integrates tactical and theater-level requirements and capabilities

- Improving UAV data dissemination and platform access through the use of common, secure, tactical data links using less congested spectra

- Improving product access and better situational awareness of the current operational picture through improved distribution and networking capabilities

- Improved delivery of critical, time-sensitive, actionable data to tactical units through improved mobile, two-way communications capability and associations

- Improved cross-service-integrated UAV and manned CONOPS that provide improved overall collection capability [11].

These capabilities are vital for the success of critical UAV missions based on known UAV characteristics, capabilities, and limitations. There is no doubt that UAVs had, and are still having, positive impacts on the operations they support. But to analyze, evaluate, and draw conclusions of operational capability in a meaningful way, defining critical UAV performance indicators has an important role.

Several performance parameters are identified in this chapter to highlight the features of UAV systems and allow these systems to be compared against conventional methods. The metrics include:

1. Costs (development, procurement, and operations and support)
2. Personnel-training time and cost
3. Reliability and mishap ratings
4. Imagery, sensors, and data-link capabilities

Most of the following information related to UAV performance indicators was derived from [34].

1. Cost

Currently, the per-unit and per-pound development and procurement costs of medium and large UAVs are similar to the costs associated with manned vehicles, as will be shown [26]. The U.S. Air Force continues to emphasize the application of advanced technology and processes for unmanned (as well as manned) platforms, using common subsystems (manned and unmanned) where feasible. Additionally, the systems-engineering process looks for every opportunity to offload system requirements and gain design space through the removal of the man from the aircraft [26]. It can easily be seen that the exclusion of aircrew improves efficiency. Further, removing the man from the aircraft reduces developmental and operational time and costs significantly.

At the beginning of manned aviation, the pilot-vehicle interface was not a big concern. However, the developmental resources spent on life support and cockpit design has increased with the complexity of aircraft.

> It costs approximately $17 billion to design and implement the F-22's advanced pilot-vehicle interface. Almost 30% of the total F-22 cost is invested in the pilot alone. The cost of flight training for a single U.S. fighter pilot is now estimated at $2 million and rising and that's just initial training cost. The maintenance cost of two thousand actively flying F-16 pilots runs close to a billion per year [33].

In view of these human-related costs, removing the pilot results in significant savings in dollars and design burdens.

> While the largest potential for cost savings remains in the new support concept, opportunities for savings also reside in the acquisition of these vehicles. The development and fielding of a smaller, less-complex replacement for manned attack aircraft cannot be ignored. The reduction in size and weight directly attributable to a crew and related subsystems is conservatively estimated at 5%. However, substantially greater weight savings result from reduced load margins, elimination of man-rated components, reduced levels of redundancy, increased use of true composite structure (not just materials), extensive use of "more electric aircraft" components, and overall added simplicity [28].

Any full and fair comparison of manned and unmanned aircraft costs must consider the three phases of any weapon system's lifecycle cost: development, procurement, and operations and support (O&S) [34]. Whether the UAV can achieve the same mission objectives more economically than its manned counterparts is more important than whether it can match performance.

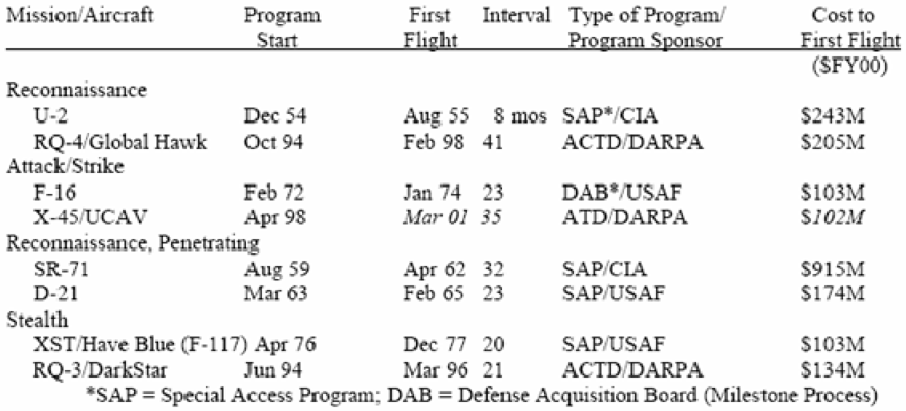
Most of the information regarding to cost (developments, procurement, and O&S costs) below was derived from [34].

a. Development Costs

According to *DoD UAS Roadmap 2000-2025*, UAVs have been developed for DoD use through:

- Contractor initiatives (e.g., Shadow 200)
- Defense-acquisition (milestone) programs (e.g., the Aquila UAV)
- Advanced-concept technology demonstrations, (e.g., the Predator) [34]

The shorter ACTD system-development timelines (3–5 years versus a decade or more) and lessened oversight requirements have provided an alternative means for several recent UAV programs to rapidly reach Milestone II [34]. The table below shows that the adjusted costs to reach first flight for both manned and unmanned aircraft have historically been the same. This is reasonable given that the engineering required to get a new design airborne for UAVs is driven more by aerodynamics and propulsion than by human factors and avionics [34].



Mission/Aircraft	Program Start	First Flight	Interval	Type of Program/ Program Sponsor	Cost to First Flight ($FY00)
Reconnaissance					
U-2	Dec 54	Aug 55	8 mos	SAP*/CIA	$243M
RQ-4/Global Hawk	Oct 94	Feb 98	41	ACTD/DARPA	$205M
Attack/Strike					
F-16	Feb 72	Jan 74	23	DAB*/USAF	$103M
X-45/UCAV	Apr 98	*Mar 01*	*35*	ATD/DARPA	$*102M*
Reconnaissance, Penetrating					
SR-71	Aug 59	Apr 62	32	SAP/CIA	$915M
D-21	Mar 63	Feb 65	23	SAP/USAF	$174M
Stealth					
XST/Have Blue (F-117)	Apr 76	Dec 77	20	SAP/USAF	$103M
RQ-3/DarkStar	Jun 94	Mar 96	21	ACTD/DARPA	$134M

*SAP = Special Access Program; DAB = Defense Acquisition Board (Milestone Process)

Table 7. Manned vs. UAV development costs (From: *DoD UAS Roadmap 2000-2025*)

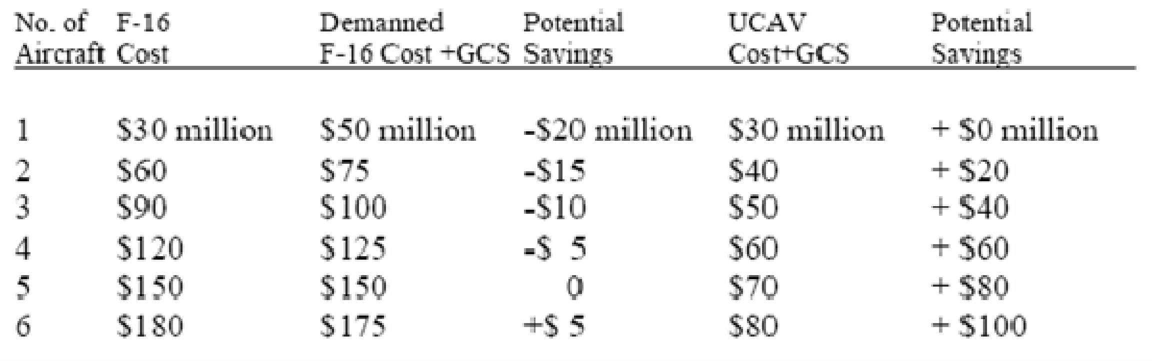
b. *Procurement Costs*

The aviation industry has long recognized an informal rule that the production cost of an aircraft is directly proportional to its empty weight (before mission equipment is added), which is currently some $1500 per pound based on Joint Strike Fighter in FY94 [34]. Estimates of the weight attributable to the pilot (ejection seat, displays, oxygen and pressurization, survival gear, canopy, etc.) are 3000 lbs for single-seat aircraft and 5000 lbs for a dual-seat cockpit, or ten to fifteen percent of the manned aircraft's empty weight [34]. The costs and weights of UAVs are illustrated in Table 8.

System	**Aircraft Cost (FY04$*)**	**Aircraft Weight (lbs*)**	**Payload Capacity (lbs)**	**System Cost (FY04$)**	**Aircraft Cost/Weight ($/lbs)**
Dragon Eye	$28.5K	3.5	1	$130.3K	8.14K
RQ-7A Shadow	$0.39M	216	60	$12.7M	1.80K
RQ-2B Pioneer	$0.65M	307	75	$17.2M	2.11K
RQ-8B Fire Scout	$4.1M	1,765	600	$21.9M	2.32K
RQ-5A Hunter	$1.2M	1,170	200	$26.5M	1.02K
MQ-1B Predator	$2.7M	1,680	450**	$24.7M	1.61K
MQ-9A Predator	$5.2M	3,050	750**	$45.1M	1.70K
RQ-4 (Block 10) Global Hawk	$19.0M	9,200	1,950	$57.7M	2.06K
RQ-4 (Block 20) Global Hawk	$26.5M	15,400	3,000	$62.2M	1.72K
*Aircraft costs are minus sensor costs, and aircraft weights are minus fuel and payload capacities ** Internal payload weight capacity only					

Table 8. UAV Costs and Weights (From: *DoD UAS Roadmap 2000-2025*)

To illustrate this trade-off in procurement costs, compare a number of single seat F-16s at $30 million each with the cost of a "de-manned" F-16 ($25 million by subtracting 3000 lb at $1500/lb) having a ground-control system (GCS) of equal cost, then with Defense Advanced Research Projects Agency (DARPA's) UCAV counterpart costing $10 million each and a GCS cost equal to that of two UCAVs ($20 million) [34]. The table below illustrates the procurement costs of F-16 and UAVs and potential savings based on number of aircraft.



No. of Aircraft	F-16 Cost	Demanned F-16 Cost +GCS	Potential Savings	UCAV Cost+GCS	Potential Savings
1	$30 million	$50 million	-$20 million	$30 million	+ $0 million
2	$60	$75	-$15	$40	+ $20
3	$90	$100	-$10	$50	+ $40
4	$120	$125	-$ 5	$60	+ $60
5	$150	$150	0	$70	+ $80
6	$180	$175	+$ 5	$80	+ $100

Table 9. Manned vs. UAV procurement costs (From: *DoD UAS Roadmap 2000-2025*)

The outcome illustrated on the table is that acquirement of a “clean-sheet design” UAV has a greater potential in terms of procurement savings—in this case, two flights (four aircraft each) of the comparable UAV system for the same cost as one four-ship flight of F-16s [34].

c. Operations & Support Costs

Simply reducing weight by de-manning an aircraft doesn’t necessarily correspond to the total savings achieved by designing a clean-sheet, unmanned system for the same type of mission.

> Compare the objective of the DARPA/Boeing UCAV to deliver two 1000-lb joint direct-attack munitions (JDAMs) over a 650 NM radius to using today’s F-16 for that mission. The weapon delivery performance for the two (i.e., 1.3 million lb-nm) is essentially the same, but the cost of the 7500-lb UCAV is estimated to be half or less than that of the 19,000-lb F-16. The UCAV is to have a design life of 5,000 hrs, half of which could be spent in combat operations under its CONOPS. The 8,000-hour F-16 will spend 95% of its in-flight life conducting training sorties, accumulating some 400 hours supporting combat operations before retirement. The depreciation rate, in terms of dollars per combat hour flown, of the UCAV is one twelfth (six times the hours at half the initial investment) that of the

> F-16 in this example, implying UCAVs could suffer twelve times the combat-loss rate of F-16s and still be cost effective by the standards applied to today's manned fighters [34].

Seventy percent of noncombat aircraft losses are attributable to human error, which also figures in a large percentage of the remaining losses [34]. Three factors mentioned in *DoD UAS Roadmap 2005-2030* should combine in unmanned operations to significantly reduce this percentage:

- UAVs today have demonstrated the ability to operate completely autonomously from takeoff through rollout after landing; Global Hawk is one example. Software-based performance, unlike its human counterpart, is guaranteed to be repeatable when circumstances are repeated. With each UAV accident, the aircraft's software can be modified to remedy the latest mishap, learning the corrective action indelibly

- The need to conduct training and proficiency sorties with unmanned aircraft actually flying could be reduced in the near term with high-fidelity simulators. Such simulations could become indistinguishable from actual sorties to the UAV operator with the use of virtual-reality-based simulators

- With such simulators, the level of actual flying done by UAVs can be reduced, resulting in fewer aircraft losses and lowered attrition expenditures. Of 301 total U.S. F-16 losses to date, six have been in combat and the rest (98%) in training accidents. While some level of actual UAV flying will be required to train manned aircraft crews in executing cooperative missions with UAVs, a substantial reduction in peacetime UAV attrition losses can probably be achieved [11].

2. Personnel Training Time and Cost

Management of the majority of training requirements is carried out by contractors for all the DoD UAVs in operation today. With the exception of the Army's Hunter and Shadow training programs, each UAV has a dedicated training program, underscoring the lack of interoperability among these systems in the field [11]. The table below illustrates the training programs of different UAVs.

System/Course	Service	Location	Duration (weeks)	Throughput	Flt. Hours	Staff
Global Hawk	Air Force	Beale AFB, CA				10
Pilot			26	48/yr	32	
Sensor Operator			12	18/yr	48	
Maintenance			5	77/yr*		
Hunter	Army	Ft Huachuca,				300**
Internal Pilot			24	40/yr	21.5	
External Pilot			16	4/yr	30	
Maintenance			10	20/yr		
Technician			11	20/yr		
Pioneer	Navy	OLF Choctaw,				37*****
Mission Commander			3	17/yr	10	
External Pilot			17	24/yr	102***	
Internal Pilot/Payload			14	40/yr	56	
Mechanical			7	18/yr		
Technical			9	24/yr		
Predator	Air Force	Indian Springs AFAF, NV				22
Pilot			13	48/yr	38	
Sensor Operator			14	48/yr	37.5	
Maintenance			4	95/yr****		
Shadow	Army	Ft Huachuca,				300**
Operator			24	240/yr	14.5	
Maintenance			8	40/yr		
Technician			9	40/yr		

*Number of graduates is total from the seven Global Hawk Maintenance courses. Duration is average length of the seven courses.

**Total staff supporting Hunter and Shadow instruction at the U.S. Army UAS Training Center.

***Consists of some 80 hours flying subscale RC models plus 22 hours flying the Pioneer.

**** Number of graduates is total from the five Predator Maintenance courses. Duration is average length of the five courses.

*****Total staff supporting Pioneer training at OLF Choctaw.

Table 10. UAV Training Programs (From: *DoD UAS Roadmap 2005-2030*)

> UAV training presents the first real opportunity to make maximal utility of the latest high-tech, high-fidelity, simulation systems. The difference between operating a console during a real mission and a simulation is minimal. UAV simulators can reduce training time and risks, especially in initial flight-training operations [29].

The table below presents failure modes analyses for each UAV model.

	Power/ Propulsion	**Flight Control**	**Comm**	**Human/ Ground**	**Misc**
RQ-1A/ Predator	23%	39%	11%	16%	11%
MQ-1B/ Predator	53%	23%	10%	2%	12%
RQ-2A/ Pioneer	29%	29%	19%	18%	5%
RQ-2B/ Pioneer	51%	15%	13%	19%	2%
RQ-5A/ Hunter	38%	5%	31%	7%	19%
RQ-7/ Shadow	38%	0%	0%	38%	24%

Table 11. Summary of UAV failure (From: *DoD UAS Roadmap 2005-2030*)

As illustrated in Table 11, failure due to human and ground-related issues is a big part of overall failure. Also, such failure is significantly lower for the MQ-1B Predator, largely due to the increased use of simulators for Predator training [11].

> To assess the benefit of training, a study examined aviation accidents involving manned aircraft from 1987 through 1997. It was discovered that of 1,400 accidents involving thirteen models of commercial- and general-aviation aircraft, pilots who received enhanced training were 80% less likely to be involved in an accident. Furthermore, the data from this decade indicated that only about 20% of high-risk emergencies and maneuvers could be practiced in an actual flight environment. The remaining 80% are too dangerous to train in real circumstances (e.g., engine failure on takeoff, inclement-weather emergencies, stalls and spins) [35].

Based on the facts above, training similar to that of manned aircrafts would be beneficial for UAV pilots. For example, the benefit of training is credited with a favorable reduction in the percentage of human and ground-related errors between the RQ-1A and the MQ-1B (16% to 2%) [35]. It is possible to do such training economically. The manned-aircraft community needs costly simulators with high fidelity to simulate the operational environment. By contrast, most UAV systems are already suited for a realistic training concept at their existing ground stations.

> The training implications of UAVs are potentially great. Today's manned aircraft are flown over 95% of the time (50% for ISR aircraft) for peacetime training of aircrews, complete with attendant operations and maintenance costs because aircrews must practice to maintain proficiency. Remove the crew, and today's costly training paradigm requires reexamination. UAV operators could receive the majority of their training in simulators, making their training and qualification significantly less expensive in terms of cost and time. By decoupling flight training from the number of training aircraft available, more UAV operators may be trained in a given period for the same cost as manned systems. More air-vehicle operators would help mitigate today's low-density, high-demand operational tempo problem. Lower sortie rates could also lead to related reductions in certain support personnel, with their associated training and sustainment costs [36].

While per-unit procurement costs may rival that of manned systems, lifecycle operating and maintenance costs may be significantly less [26]. For example, operator training is done via robust mission simulators that reduce the need for training with the actual aircraft. Fewer training flights results in less maintenance and greater availability for operational use [26]. Today, flying-hour costs for the T-38 are $1500 and $3800 for the F-16. In comparison, flying-hour costs for the Predator are under $200, significantly less expensive [37]. A study reported the cost of training fifteen B-52 pilots to be an average of $685,051, versus training fifteen UAV operators at an average of $13,000 [38].

3. Reliability and Mishap Ratings

UAV reliability is another important criterion because of the underlying affordability and mission availability of UAVS and their acceptance into civil airspace. Most of the information related to reliability and mishap ratings was derived from [35].

Improved reliability offers potential savings by reducing maintenance man-hours per flight hour (MMH/FH) and decreasing procurement of spares and attrition aircraft [35]. Some terms need to be defined to better understand the reliability of UAVs and manned aircrafts. These terms related to the reliability are defined in [35] as:

> Reliability is defined as (1) the probability that an item will perform its intended function for a specified time under stated conditions, or (2) the ability of a system and its parts to perform its mission without failure, degradation, or demand on the support system. Reliability is given as a percentage that represents the probability that a system or component will operate failure-free for a specified time, typically the mission duration [35].
>
> Availability is a measure of how often a system or component is in an operable and committable state when the mission is called for at an unknown (random) time. It describes how a given aircraft type is able to perform its mission compared to the number of times it is tasked to do so. It is measured in terms of the percentage of time a system can be expected to be in place and working when needed [35].
>
> A class A mishap rate (MR) is the number of accidents (significant vehicle damage or total loss) occurring per 100,000 hours of fleet flight time. As no single UAV model has accumulated this many hours, each model's mishap rate represents its extrapolated losses to the 100,000-hour mark. Mishap rate is expressed as mishaps per 100,000 hours [35].
>
> Mean time between failure (MTBF) is essentially the ratio of hours flown to the number of maintenance-related cancellations and aborts encountered. It is expressed in hours [35].

Figure 6 shows the numbers of Predators, Pioneers, and Hunters lost in class A mishaps by year for the period 1986 through 2002. Class A mishaps are those aircraft accidents resulting in loss of aircraft (in naval parlance, a “strike”), human life, or $1,000,000 in damage [35]. These data show a cumulative mishap rate (i.e., class A accidents per 100,000 hours of flight) of thirty-two for the Predator, 334 for the Pioneer, and fifty-five for the Hunter (reduced to sixteen since the major reliability improvements in 1996). In comparison to manned-aviation mishap rates, general-aviation aircraft suffer about one mishap per 100,000 hours, regional and commuter airliners about a tenth that rate, and larger airliners about a hundredth that rate [35].

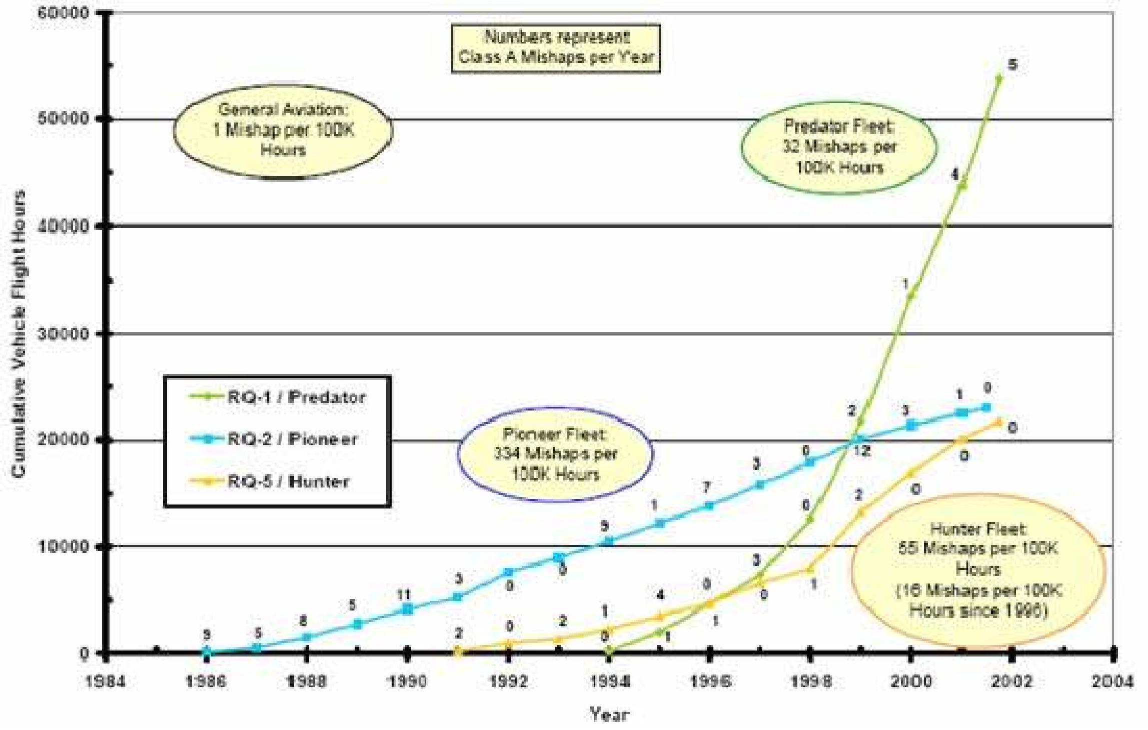


Figure 6. U.S. Military UAV flight hours and mishaps, 1986-2002 (From: *UAV Reliability Study*)

These statistics make it apparent that UAV reliability needs to improve to become as safe as manned aircraft.

In terms of achieving this goal, the declining trend in mishap rates, as shown in Figure 7, is encouraging. Both Pioneer and Hunter have achieved an order of magnitude improvement of 9.5 and 15 respectively.

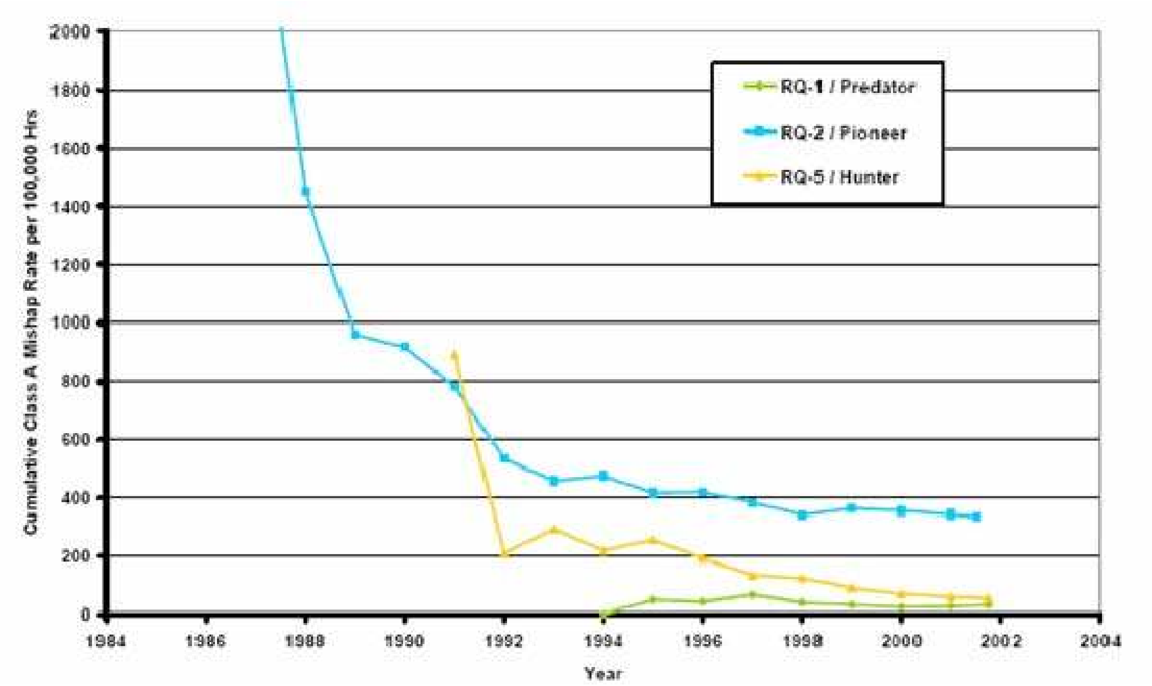


Figure 7. Cumulative mishap rate per 100,000 hours (From: *UAV Reliability Study*)

		MTBF (hrs)	Availability	Reliability	Mishap Rate per 100,000 hrs (Series)	Mishap Rate per 100,000 hrs (Model)
RQ-1A/ Predator	**Requirement**	n/a	n/a	n/a	n/a	32
	Actual	32.0	40%	74%	43	
RQ-1B/ Predator	**Requirement**	40	80%	70%	n/a	
	Actual	55.1	93%	89%	31	
RQ-2A/ Pioneer	**Requirement**	25	93%	84%	n/a	334
	Actual	9.1	74%	80%	363	
RQ-2B/ Pioneer	**Requirement**	25	93%	84%	n/a	
	Actual	28.6	78%	91%	139	
RQ-5/Hunter (pre-1996)	**Requirement**	10	85%	74%	n/a	55
	Actual	n/a	n/a	n/a	255	
RQ-5/Hunter (post-1996)	**Requirement**	10	85%	74%	n/a	
	Actual	11.3	98%	82%	16	

Table 12. Comparison table of UAV Reliability (From: *UAV Reliability Study*)

Table 12 summarizes the reliability metrics for some UAVs examined in this thesis.

Aircraft	Mishap Rate (per 100,000 hrs)	MTBF (hours)	Availability	Reliability
General Aviation	1.22	*Data proprietary or otherwise unavailable*		
AV-8B	10.7		*Data unavailable*	
U-2	6.5	105.0		96.1%
F-16	3.35	51.3		96.6%
F-18	3.2			
Boeing 747	.013*	532.3	98.6%	98.7%
Boeing 777	.013*	570.2	99.1%	99.2%
Predator/RQ-1	31	55.1	93%	89%

Table 13. Manned Aircraft Reliability (From: *UAV Reliability Study*)

As illustrated in the table, commercial airlines have less than 0.02 mishaps per 100,000 flight hours. High-performance military aircraft have much higher mishap rates because of the dangers inherent in military flying. However, the mishap rates for UAVs tend to be much higher; the rate for the Hunter is fifty-five, Pioneer shows a whopping 334; and even the relatively advanced Predator, at thirty-two per 100,000 flight hours, has a mishap rate ten times that of the F-16.

> These numbers are somewhat deceiving though, especially for the Predator. This aircraft has much less than 100,000 total flight hours, so there has been less opportunity to fix design flaws. Most manned aircraft have high mishap rates when first introduced; the F-16 had a mishap rate of almost 175 during its first thousand hours of operation. The rate dropped quickly as flight time built up and flaws were resolved. If the mishap rates of the Predator and Global Hawk are compared to those of other military aircraft, they are not much higher for their relatively low flight hours, suggesting that, with equal attention to refinement, they could achieve similar rates. The UAV reliability report of the Defense Science Board suggests, however, that no such attention is being paid. Since lives are not endangered, there is less motivation to put money into analyzing accidents and redesigning the aircraft. However, particularly for the more expensive systems, if the lifetime of the

> aircraft is considered, the cost of addressing design flaws early is much lower than the cost of so ignoring them [39].

4. Imagery, Sensors, and Data-Link Capabilities

When UAVs were first employed for surveillance missions, they used a film-based camera to provide high-quality photography. This limited their role to performing BDA after preplanned air strikes.

> The camera system was not applicable to the dynamic nature of target acquisition because of the time it took to recover the UAV and remove the film for processing and exploitation. Although many UAV variants included a video link to the operator, the camera was analog and therefore limited in the quality and resolution of its imaging. These film and video systems were also degraded by weather and camouflage. Until recently, SAR sensor technology was not mature enough to allow cost-effective payloads small enough for UAV employment. Therefore, only manned reconnaissance platforms (e.g., U-2, SR-71, JSTARS, etc.) provided the flexibility, responsiveness, and quality needed on the dynamic battlefield [9].

The electronics developments in 1990s have provided technology that enables UAVs to perform most battlefield reconnaissance missions more economically. Today's electronics, microprocessors, and communications networks allow the Predator, using GPS navigation, to fly autonomously or be dynamically re-tasked in flight, loiter over an area of interest for twenty-four hours while collecting high-quality EO/IR and SAR imagery, and transmit that imagery over commercial satellites to warfighters at all echelons throughout the world [9]. We therefore have the technology to employ UAVs with capabilities as good as or better than their manned counterparts for imagery-collecting missions.

Image collection with UAVs has some advantages, such as being economical and flexible compared to conventional image collection. Through recent developments, current UAVs have the ability to transfer images to earth receivers by VHF or UHF. Aerial, wireless-relay links are needed while UAVs are navigating beyond the communication capability of earth receivers to provide persistent image transmission, but those links can be configured as well [40]. The advantages of UAVs as aerial data-relay nodes are lower cost, greater flexibility, and good compatibility.

> Recent flight operations of UAVs have demonstrated remarkable capabilities in airborne reconnaissance and surveillance. An integrated sensor suite (ISS), containing SAR, visible, and mid-wave infrared (MWIR) sensors has been developed and integrated on the Global Hawk, to provide long-endurance, high-altitude tactical reconnaissance for theater commanders. The value of this multi-sensor system has been demonstrated for target detection, classification, and geolocation in all weather conditions, day and night. The system has been credited for contributing to successes in OEF and OIF. It has significantly shortened the time for transferring time-sensitive targeting information from sensor to shooter [41].

The Global Hawk’s large payload, including SAR, EO camera, and third-generation infrared sensor, has been reported to provide mission-support imagery three times more persistent than manned aircrafts’ [42].

> The single Global Hawk operational during OIF flew only 3% of all aircraft imagery-collection sorties and only 5% of high-altitude missions, but collected data on 55% of all air-defense-related, time-sensitive targets. The Global Hawk reportedly located at least thirteen SAM batteries, fifty SAM launchers, 300 canisters, and seventy missile transporters. It also imaged 300 tanks, 38% of Iraq's total known armor force. By comparison, the U.S. Air Force's U-2, which provided 80% of total imagery during Operation Allied Force in Kosovo, was used in Iraq primarily for its SIGINT capability [43].

Global Hawk UAVs have the capability to remain on a specific station for twenty-four hours while carrying the full ISS at an altitude of 60,000 feet. The ISS collects radar imagery concurrently by either MWIR imagery or visible. Data collected is processed onboard, turned into real-time imagery and transferred to the ground station for multiple users. The operators can either preplan the ISS or re-task it dynamically in real time during flight so it can respond to emerging needs in the battlefield. Each sensor can collect many thousand square kilometers of strip-map imagery per day and thousands of two-kilometer-by-two-kilometer spotlight images per day [41].

The Global Hawk sensors were designed as an integrated sensor suite. The ISS contains a synthetic-aperture radar, visible sensor, and MWIR sensor [41]. While the MWIR sensor provides high-resolution, day-and-night imagery, the SAR provides day-and-night, long-range imagery in all weather conditions. On the other hand, the visible sensor provides the highest-resolution imagery, but is limited to daytime operation only. Imagery may be collected using a wide-area search (WAS) mode for maximum ground-coverage rate, or spot mode for detailed imagery of known target locations [41].

> In spot mode, coverage is 1,900 spots a day with spot size 2 km^2 to a geological accuracy of a twenty-meter-circular error of probability. In wide-area searches, the swath is ten kilometers wide and the coverage is 40,000nm^2 a day. The system can obtain images with three-foot resolution in WAS mode and one-foot resolution in spot mode [44].

A ground moving-target indication (GMTI) radar mode is also provided on Global Hawk. The ISS outputs imagery and GMTI data in real time to a ground station via a direct line-of-sight data link or a SATCOM reach-back data link [41]. The requirements that UAV data links have to satisfy are mentioned in [45] as follows:

- Maximum feasible range
- High mobility
- Low mass and size
- High reliability and jamming resistance
- High data rates [45]

The SATCOM link used in Global Hawk satisfies most of these requirements except low mass and size and some restrictions on jamming resistance. High overall-data rates in excess of 45 MBit/s are achieved by combining a number of standard 1.5 MBit/s SATCOM channels [45].

With their imagery collecting and transfer capabilities, UAVs have accomplished battlefield reconnaissance missions as well as, or better, than manned aircraft.

V. FUTURE DIRECTION OF UNMANNED AERIAL VEHICLES

Technological advancements and growth in the capabilities and scope of current UAV systems raise the question, “what range of near and long term UAV capabilities is possible?” This chapter aims to answer by exploring trends, including processor, communications, platform and sensor technologies, and potential UAV capabilities and associated missions. Also discussed is the employment of new UAVs and some current experiments. Most of the information in Chapter V was derived from [11].

A. TECHNOLOGY

Unmanned aviation has spurred many key technical advances in aviation such as the inertial navigation system (INS), the autopilot, and digital data links. Although UAV development was hampered by lack of technology throughout most of the 20th century, some basic problems of automatic stabilization, remote control, and autonomous navigation have been overcome by military research. The last several decades saw improvement in the technologies that support these capabilities, largely through the integration of increasingly capable microprocessors in UAV mission-management computers and flight controls [11]. A fully autonomous flight (from takeoff to landing without human intervention) was performed by a UAV as early as 1989. Advancements in the biological and nano sciences and continually improving microprocessors are influencing military aviation in near- and long-term tactics and planning [11]. We’ve come a long way since 1989.

> The two basic approaches to implementing unmanned flight, autonomy (illustrated by the RQ-4) and pilot-in-the-loop (illustrated by the MQ-1), rely predominantly on microprocessor and communication (and associated data link) technology, respectively. While both technologies are used to differing levels in all current UAVs, it is these two technologies that compensate for the absence of an onboard pilot and thus enable unmanned flight. Advances in both are driven today by their commercial markets, the personal

> computer industry for microprocessors and the wireless communication industries for data protection and compression to enhance throughput. This chapter focuses on forecasting trends in these technologies over the coming two decades [11].

The directors of the service research laboratories have adopted a layered, onion-like series of capabilities to define the autonomy of UAV sophistication. These definitions run the gamut from tele-operated and preprogrammed flight by single aircraft to self-actualizing group flight [11]. Figure 8 illustrates where example UAVs stand in comparison with a ranked set of ten autonomy levels.

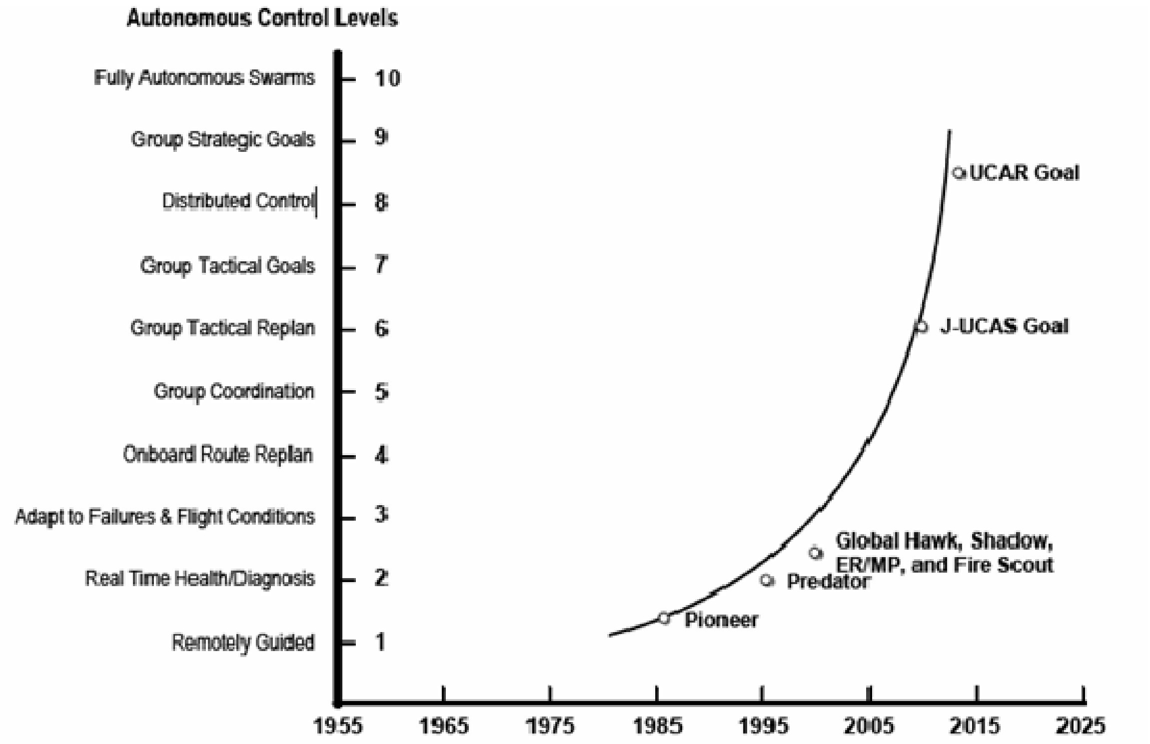


Figure 8. Trend in UAV Autonomy (From: *DoD UAS Roadmap 2005-2030*)

1. Processor Technologies

Although today's processors allow UAVs to fly entire missions with little or no human intervention, if the ultimate goal is to replace a pilot with a mechanical facsimile of equal or superior thinking speed, memory capacity, and response times (algorithms) gained from training and experience, then processors of human-like speed, memory, and situational adaptability are necessary [11].

Figures 9 and 10 illustrate processor-technology progress since 1940, projected to 2030. The figures show that today's supercomputers are within a factor of 10 of achieving human equivalence in speed and capacity and will likely achieve human equality by 2015. The cost of a supercomputer is uncompetitive with that of a trained human; but for comparison, by 2030 the cost of a hundred-million-million-instructions-per-second (MIPS) processor should approach $10,000 [11].

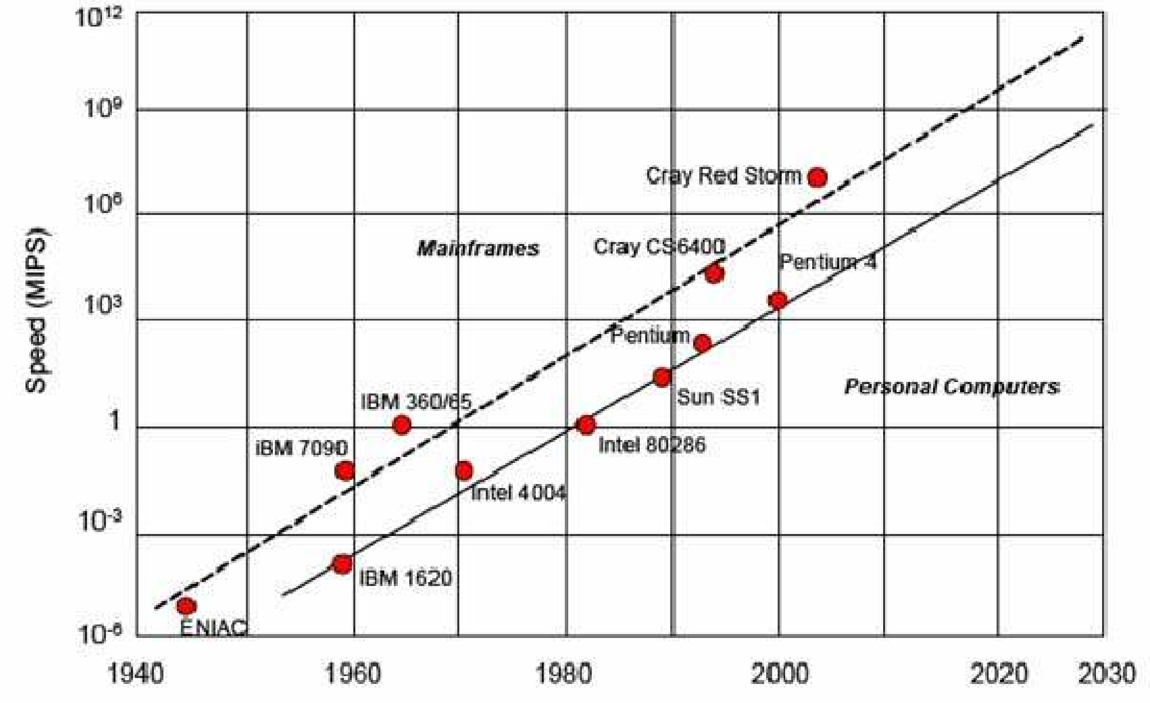


Figure 9. Trend in processor speed (From: *DoD UAS Roadmap 2005-2030*)

As shown in Figure 10, human capabilities are generally agreed to equate to 100 million MIPS in speed and 100 million megabytes (MB) in memory [11]. The dotted boundary in the above curve crosses this same capability level for computers in roughly the year 2015.

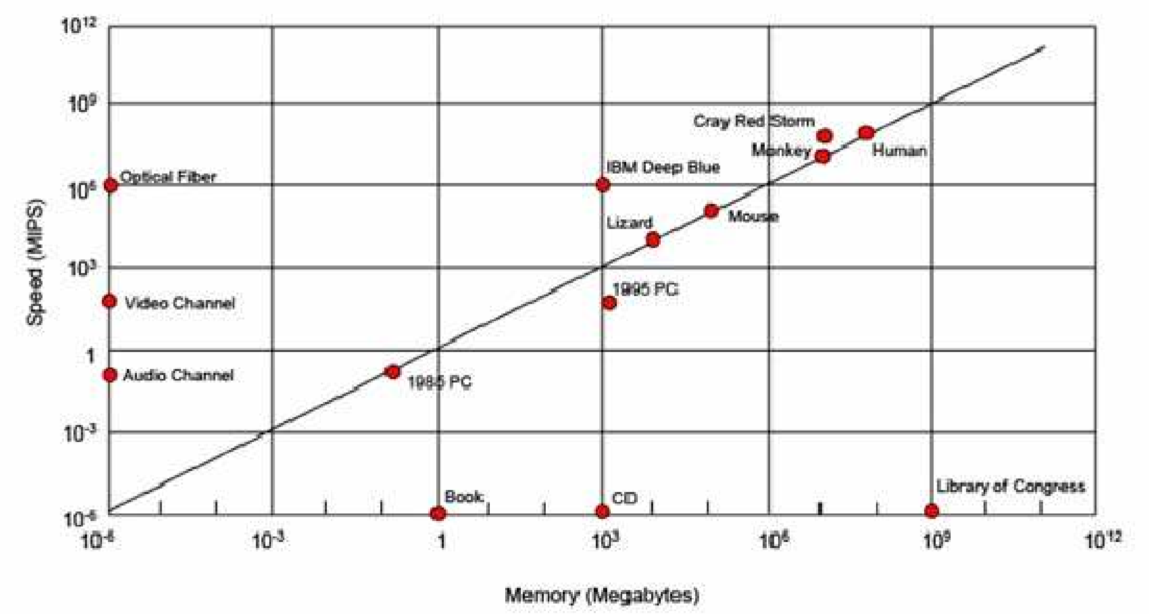


Figure 10. Relationship of processor speed and memory (From: *DoD UAS Roadmap 2005-2030*)

2. Communications Technologies

The main issues in today's communications technologies are flexibility, adaptability, and controllability of bandwidth, frequency, and information/data flows (e.g. separate data routing in terms of priority and latency) [11]. This means that network services such as C^2, data management, and data-flow controls will be integrated into the systems and concepts of operation (CONOPS) of the net-centric environment of the future. Reusing certain communications paths in different ways (such as restrictions on power and operating range) will be the solution to spectrum and bandwidth issues.

a. Data Links

The rapid improvements achieved in airborne data-link rates and processor speeds are the key enablers of future UAV capabilities. The ideal use of data links today, and in the near-term, is to relay all airborne data to ground-support services and process it there for decision making. Eventually, onboard processing power and data-link capabilities will allow UAVs to relay processed and analyzed airborne data to ground stations for interpretation and decision making. It is expected that data-link rate requirements in certain applications such as imagery collection will drop significantly. Also, the existence of band-limited communications will continue to require data compression for the data transfer, although the near-term throughput requirements of advanced sensors are unlikely to be solved by data-compression algorithms only [11].

> Airborne optical data links, or lasercom, will potentially offer data rates two to five orders of magnitude greater than those of the best future RF systems. However, lasercom data rates have held steady for two decades because their key technical challenge was adequate pointing, acquisition, and tracking (PAT) technology to ensure the laser link was both acquired and maintained. Although mature RF systems are viewed as lower risk, and therefore attract investment dollars more easily, Missile Defense Agency funding in the 1990s allowed a series of increasingly complex demonstrations at Gbps rates. The small apertures (3 to 5 inches) and widespread availability of low power semiconductor lasers explains why lasercom systems consume less power and provide for lower signatures, greater security, and better jam resistance [11].

Radio frequency (RF) is likely to remain dominant at lower altitudes because of its better all-weather capability, even though it can be exceeded by lasercom in terms of data-transfer rates. Rates of up to 10 Gbps (forty times currently fielded capabilities) are considered possible at current bandwidths [11]. As a result, both RF and lasercom should continue to progress in order to handle future data-flow and transfer requirements.

b. Network-Centric Communications

Highflying UAVs, such as the Global Hawk or Predator, provide coverage that lends itself well to network-backbone and transit-networking applications [11]. Fielding these services depends on the migration of the networked communications capabilities to provide capacity, stability, reliability and rich connectivity/interoperability options. Large stable UAV systems are perfect in terms of providing theater backbone services. On the other hand, smaller UAVs can also provide similar networking services and capability but on a smaller scale.

Concepts that need development in future UAVs and networks are identified in [11] as:

- the role of autonomy
- the definition of team coordination, cooperation, and collaboration
- the role of cognitive decision aids
- the importance of airspace layer and control [11]

3. Platform Technologies

a. Airframe

Future aircraft projects may require cooperation between bioengineers and aerospace engineers. The need for stronger but lighter aerostructures precipitated an evolution from wood and canvas to aluminum, titanium, and composites; transgenetic biopolymers are seen as the next step in aircraft skins. One biopolymer nearing commercialization has twice the tensile strength of steel yet is twenty-five percent lighter than carbon composites, and is flexible [11]. In an aircraft skin made of such a biopolymer, the servo actuators, hydraulics, electric motors, and control rods of today's aircraft-control surfaces could be replaced by the ability to warp wings and stabilizers by flexing their skin, much as the Wright brothers first conceived [11]. The material can responsively shape itself in order to reduce reflection. This ability of the material and its nature can enhance the signature control.

> Even though composites have enabled lighter airframes, the repair of damaged composites is weaker than the original because of the loss of the material's originally played construction, which is called

> aeroelastic tailoring. Researchers have recently developed a material called autonomic, or self-repairing material that has embedded microcapsules of "glue". In case of a damaged skin area, the capsules will open and seal the crack before it can propagate. Another material, which will be of most value in long endurance and strike UAVs, is called isomers. They are self-healing, in which the damaged structure regenerates itself to original condition and are still being researched [11].

b. Control

Future UAVs will be increasingly independent vehicles able to assess, receive, and take action to perform general and tailored missions. This level of autonomy—particularly in platforms carrying weapons—requires sophisticated machine and computer processing linked to the more variable processing capabilities of human beings. Moore's Law predicts the speed of microprocessors will reach parity with the human brain around 2015, while others estimate the capacity of a personal computer will equal that of human memory closer to 2030 [11].

> As for those UAVs remaining under human control, the controller will eventually be linked to his remote charge through his own neuromuscular system. Today's ground station vans are already being superseded by wearable harnesses with joysticks and face visors allowing the wearer to "see" through the UAV sensor, regardless of where he faces. Vests will soon provide him the tactile sensations "felt" by the UAV when it turns or dives or encounters turbulence. Eventually, UAV pilots will be wired so that the electrical signals they send to their muscles will translate into instantaneous control inputs to the UAV. To paraphrase a popular saying, “the future UAV pilot will transition from seeing the plane to being the plane [11]”.

c. Propulsion

UAVs already exploit more forms of propulsion than do manned aircraft—from traditional gas turbines and reciprocating engines to batteries and solar power—and are exploring scramjets, fuel cells, reciprocating chemical muscles, beamed power, and even nuclear isotopes [11]. In the past, military-sponsored research used to lead the technological advances in propulsion. However, these advances are now driven by the commercial sector (e.g. advances in fuel cells by the automotive industry and batteries by the computer industry.) UAVs are therefore more likely to rely on commercial, off-the-shelf (COTS) or COTS-derivative power plants than their manned predecessors were; Global Hawk and Dark Star both selected business-jet engines in their design [11]. Since UAV power-plant endurance is considered a paramount superior attribute over manned counterparts, propulsion technologies remain crucial.

4. Payload Technologies

DoD UAS Roadmap 2005-2030 divides payloads currently in use on UAVs into four general categories:

- sensors (electro-optical, radar, signals, meteorological, chemical-biological)
- relay (communications, navigation signals)
- weapons
- cargo (leaflets, supplies) [11].

a. Sensors

Requirements for UAV sensing payloads extend beyond intelligence collection, reconnaissance surveillance, target acquisition and real-time operational support into weapons delivery. This is due primarily to high reliance on target detection and identification to meet rules of engagement (ROE) constraints while maintaining accuracy [11].

The main requirement for sensing is mentioned in [11] as:

- imaging (visible, infrared, and radar)

- signals (for the SIGINT and SEAD missions)
- chemical, biological, and radiological (WMD)
- meteorological (METOC)
- magnetic (antisubmarine warfare (ASW) and mine countermeasures (MCM)) [11].

Figures 11 through 15 depict expected developments in imaging, signals, and measurement and signal-intelligence (MASINT) sensors over the next twenty years by technology and by system, as well as describing the regimes in which such sensors must perform, the enablers necessary to improve present capabilities, and the missions for which each is applicable [11]. Figure 16 then forecasts developments by sensor type between 2005 and 2015.

Terms in the following figures are defined as follows:

Automatic Target Cueing / Automatic Target Recognition (ATC/ATR): The ability of an algorithm or device to recognize and cue targets or objects based on data obtained from sensors [46]

Multi-Platform Radar Technology Insertion Program (MP-RTIP): A "modular, active, electronically scanned, array-radar system" designed to be scaled in size so it can be carried aboard different platforms such as UAVs [47]

Foliage penetration (FOPEN): An airborne VHF/UHF, dual-band, synthetic-aperture radar for imaging concealed targets [48]

Digital Terrain-Elevation Data (DTED): A uniform matrix of terrain-elevation values that provides basic quantitative data for systems and applications requiring terrain elevation, slope, or surface roughness [49]

Electronically Scanned Array (ESA): A type of radar whose transmitter and receiver functions are composed of numerous small transmit/receive (T/R) modules [50].

Ground / Airborne Moving-Target Indicator (GMTI/AMTI): Ground- or aerial-vehicle tracking system that uses Doppler frequency shift frequency in the returned signal to distinguish moving ground vehicles from stationary surroundings [51].

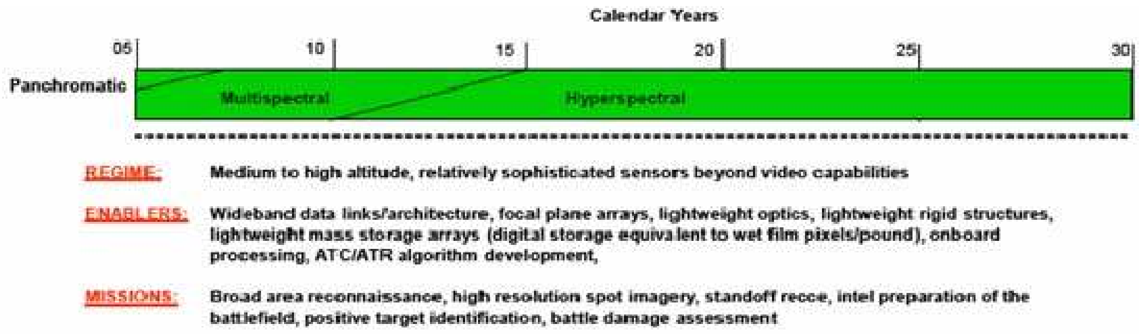
Light Detection and Ranging (LIDAR): An optical, remote-sensing technology that measures properties of scattered light to find range and other information of a distant target [52].

Signals Intelligence (SIGINT): A category of intelligence comprising (individually or in combination) all communications, electronic, and foreign-instrumentation signals intelligence, however transmitted [7].

Measurement and Signature Intelligence (MASINT): Intelligence obtained by quantitative and qualitative analysis of data (metric, angular, spatial, wavelength, time dependent, modulation, plasma, and hydromagnetic) derived from technical sensors for the purpose of identifying any distinctive features associated with the emitter or sender and to facilitate subsequent identification and measurement of the same [7].

Communications Intelligence (COMINT): Technical information and intelligence derived from foreign communications by unintended recipients [7].

Electronic Intelligence (ELINT): Technical and geolocation intelligence derived from foreign noncommunications electromagnetic radiations emanating from other than nuclear detonations or radioactive sources [7].

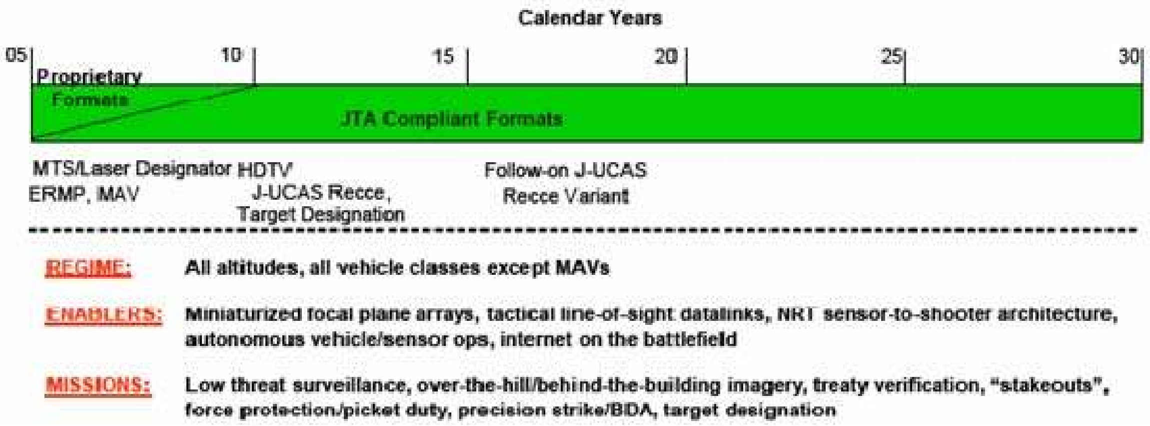


REGIME: Medium to high altitude, relatively sophisticated sensors beyond video capabilities

ENABLERS: Wideband data links/architecture, focal plane arrays, lightweight optics, lightweight rigid structures, lightweight mass storage arrays (digital storage equivalent to wet film pixels/pound), onboard processing, ATC/ATR algorithm development,

MISSIONS: Broad area reconnaissance, high resolution spot imagery, standoff recce, intel preparation of the battlefield, positive target identification, battle damage assessment

Figure 11. Still-Imagery Sensor Technology Forecast (From: *DoD UAS Roadmap 2005-2030*)

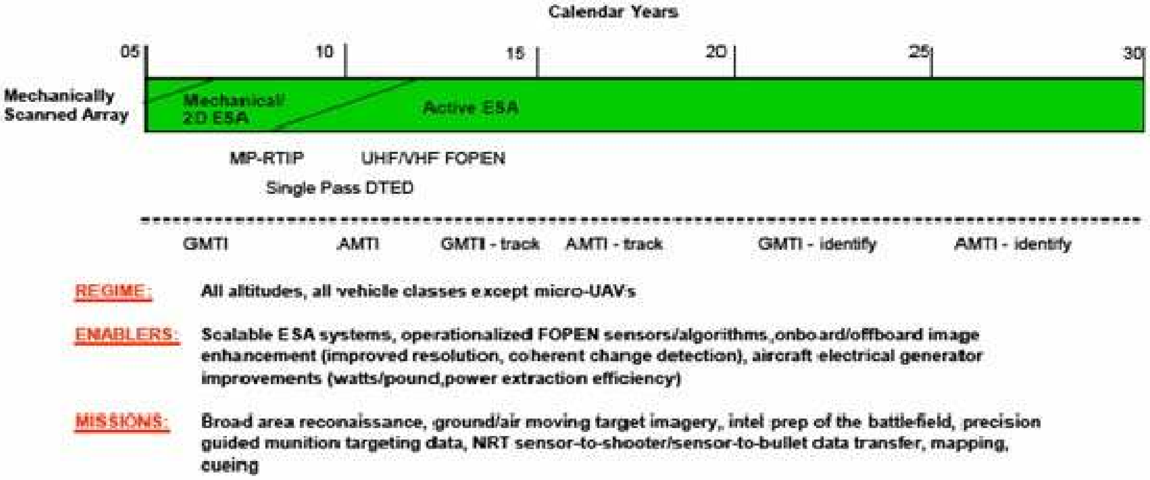


REGIME: All altitudes, all vehicle classes except MAVs

ENABLERS: Miniaturized focal plane arrays, tactical line-of-sight datalinks, NRT sensor-to-shooter architecture, autonomous vehicle/sensor ops, internet on the battlefield

MISSIONS: Low threat surveillance, over-the-hill/behind-the-building imagery, treaty verification, "stakeouts", force protection/picket duty, precision strike/BDA, target designation

Figure 12. Motion/Video-Imagery Sensor Technology Forecast (From: *DoD UAS Roadmap 2005-2030*)

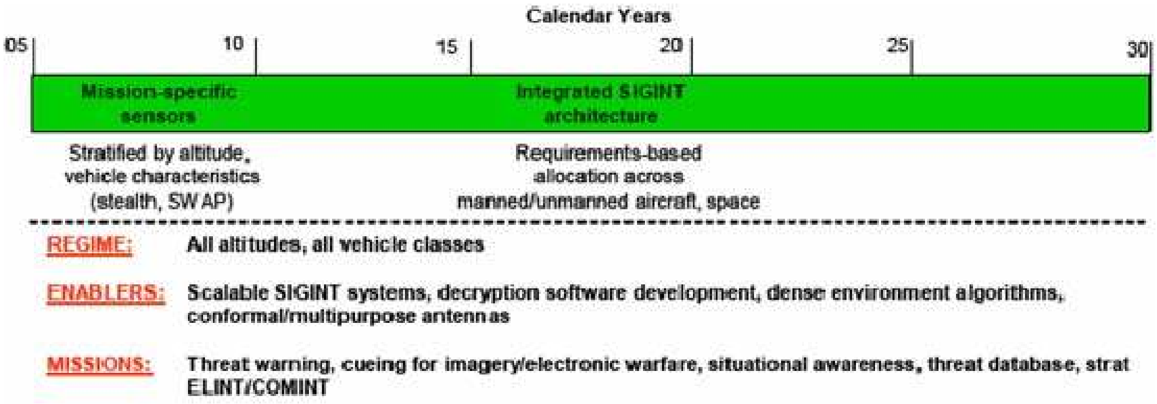


REGIME: All altitudes, all vehicle classes except micro-UAVs

ENABLERS: Scalable ESA systems, operationalized FOPEN sensors/algorithms,onboard/offboard image enhancement (improved resolution, coherent change detection), aircraft electrical generator improvements (watts/pound,power extraction efficiency)

MISSIONS: Broad area reconaissance, ground/air moving target imagery, intel prep of the battlefield, precision guided munition targeting data, NRT sensor-to-shooter/sensor-to-bullet data transfer, mapping, cueing

Figure 13. Radar-Imagery Sensor Technology Forecast (From: *DoD UAS Roadmap 2005-2030*)

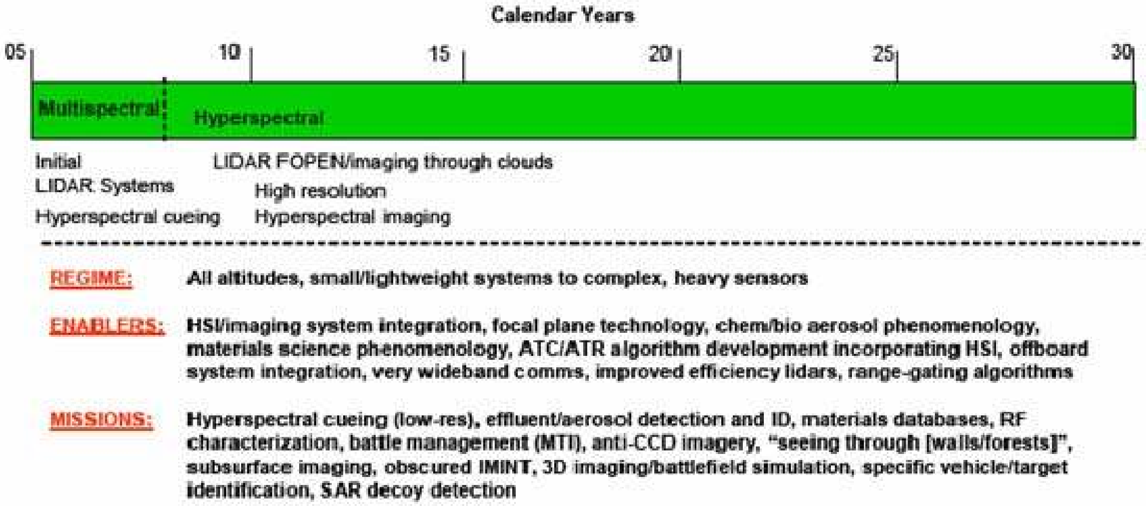


REGIME: All altitudes, all vehicle classes

ENABLERS: Scalable SIGINT systems, decryption software development, dense environment algorithms, conformal/multipurpose antennas

MISSIONS: Threat warning, cueing for imagery/electronic warfare, situational awareness, threat database, strat ELINT/COMINT

Figure 14. SIGINT Sensor Technology Forecast (From: *DoD UAS Roadmap 2005-2030*)

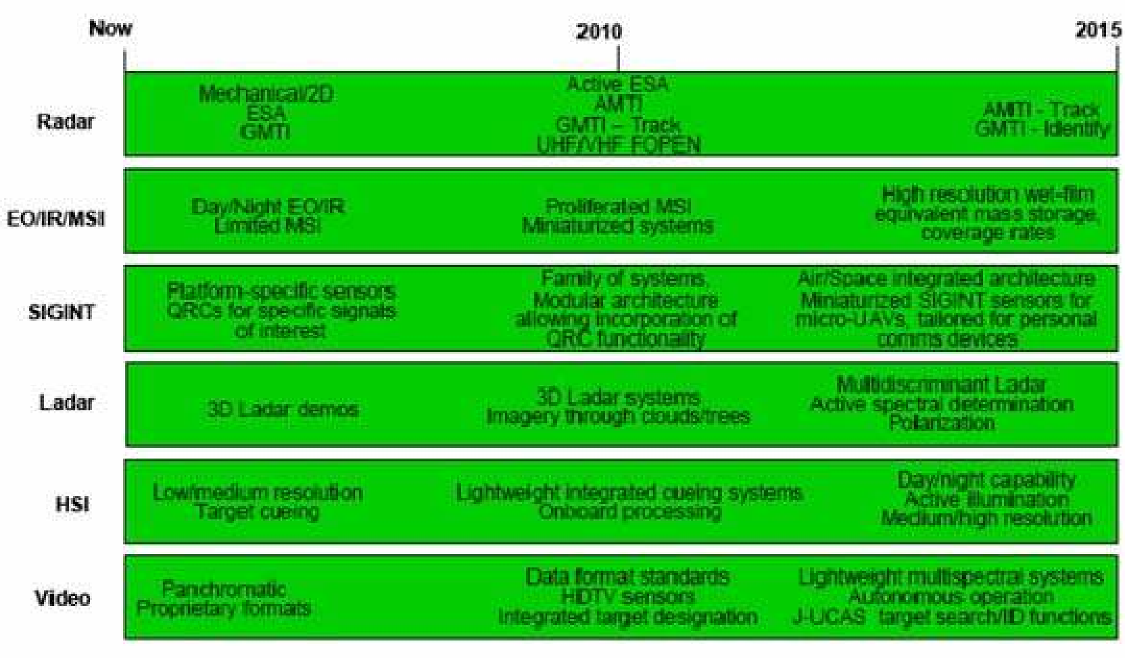


REGIME: All altitudes, small/lightweight systems to complex, heavy sensors

ENABLERS: HSI/imaging system integration, focal plane technology, chem/bio aerosol phenomenology, materials science phenomenology, ATC/ATR algorithm development incorporating HSI, offboard system integration, very wideband comms, improved efficiency lidars, range-gating algorithms

MISSIONS: Hyperspectral cueing (low-res), effluent/aerosol detection and ID, materials databases, RF characterization, battle management (MTI), anti-CCD imagery, "seeing through [walls/forests]", subsurface imaging, obscured IMINT, 3D imaging/battlefield simulation, specific vehicle/target identification, SAR decoy detection

Figure 15. MASINT Sensor Technology Forecast (From: *DoD UAS Roadmap 2005-2030*)



	Now	2010	2015
Radar	Mechanical/2D ESA GMTI	Active ESA AMTI GMTI – Track UHF/VHF FOPEN	AMTI - Track GMTI - Identify
EO/IR/MSI	Day/Night EO/IR Limited MSI	Proliferated MSI Miniaturized systems	High resolution wet-film equivalent mass storage, coverage rates
SIGINT	Platform-specific sensors QRCs for specific signals of interest	Family of systems, Modular architecture allowing incorporation of QRC functionality	Air/Space integrated architecture Miniaturized SIGINT sensors for micro-UAVs, tailored for personal comms devices
Ladar	3D Ladar demos	3D Ladar systems Imagery through clouds/trees	Multidiscriminant Ladar Active spectral determination Polarization
HSI	Low/medium resolution Target cueing	Lightweight integrated cueing systems Onboard processing	Day/night capability Active illumination Medium/high resolution
Video	Panchromatic Proprietary formats	Data format standards HDTV sensors Integrated target designation	Lightweight multispectral systems Autonomous operation J-UCAS target search/ID functions

Figure 16. Forecast Sensor Capabilities (From: *DoD UAS Roadmap 2005-2030*)

b. Communication Relay

By 2010, existing and planned capacities are forecast to meet only forty-four percent of the need projected by Joint Vision 2010 to ensure information superiority [11]. A separate study, *Unmanned Aerial Vehicles as Communications Platforms,* dated November 4, 1997, was conducted by the office of the secretary of defense. Its major conclusions regarding the use of an UAV as an ACN were:

- Tactical communication needs can be met much more responsively and effectively with ACNs than with satellites.

- ACNs can effectively augment theater satellite capabilities by addressing deficiencies in capacity and connectivity.

- Satellites are better suited than UAVs for meeting high-capacity, worldwide communications needs.

According to [11], ACNs can enhance intra-theater and tactical communications capacity and connectivity by:

- providing more efficient use of bandwidth
- extending the range of existing terrestrial LOS communications systems
- extending communication to areas denied or masked to satellite service
- providing significant improvement in received power density compared to that of satellites, improving reception and decreasing vulnerability to jamming [11].

> DARPA's AJCN is developing a modular, scalable, communication-relay payload that can be tailored to fly on an RQ-4/Global Hawk and provide theater-wide support (300 nm diameter area of coverage) or on an RQ-7/Shadow for tactical use (60 nm diameter area). In addition to communications relay, its intended missions are SIGINT, electronic warfare (EW), and information operations (IO). Flight demonstrations began in 2003, and the addition of a simultaneous SIGINT capability is planned by 2010 [11].

c. Weapons

Since UAVs will have smaller weapons than manned counterparts, their lethality must be increased for equal or greater mission effectiveness. Increasing lethality with smaller weapons requires either more precise guidance or more lethal warheads. With the advent of some innovative wide-kill-area warheads, hardening guidance systems (e.g., resistance to GPS jamming) appears to be the imperative technological requirement [11]. A potentially significant advantage to smaller, more precise, weapons and penetrating launch platforms such as J-UCAS is reduction in collateral damage. In some cases, these platform and weapons combinations could reduce an adversary's ability to seek sanctuary within noncombatant areas [11].

B. CAPABILITIES

This section brings together the requirements and desired capabilities with emerging technological and operational opportunities in an effort to stimulate the planning process for UAV development over the next twenty-two years [11].

To relate the warfighter priorities to the technologies coming available within the next twenty-two years, examples of capability metrics illustrated on Table 14 were derived from *DoD UAV Roadmap 2005*. They define availability timeframes for anticipating when capabilities will be. All references to years refer to the dates these capabilities are expected to come available, based on the technological trends presented at the beginning of the chapter. By bringing together a plot of the predicted appearance of the listed capabilities in Table 14 with the timeline of current and planned DoD UAV programs, a roadmap of opportunity for applying emerging capabilities to forthcoming UAVs is created [11].

Operational Requirement*	Technology Requirement	Example Capability Metrics	Availability Timeframe
BA, FL	Endurance	Field a heavy fuel-powered tactical UAV	2005-10
BA	,,	Field fully automated aerial refueling capability	2010-15
BA	,,	Achieve 40% increased time-on-station with same fuel load	2015-20
FP	Signature	Field an UAV inaudible from 500 to 1,000 ft slant range	2005-10
BA, FA	Resolution	Field a sensor for detecting targets under trees	2005-10
FP	,,	Distinguish facial features (identify individuals) from 4 nm	2005-10
BA, FA	„	Achieve 3 inch resolution in SAR resolution over a 20 nm wide swath	2010-15
BA	Data Rate	Relay entire COMINT spectrum in real time	2005-10
BA	”	Relay entire ELINT spectrum in real time	2025-30
BA, FA	„	Relay 100-band hyper-spectral imagery in real time	2010-15
BA, FA	„	Relay 1,000-band ultra-spectral imagery in real time	2025-30
BA, FA	Algorithm Processor	Automatic Target Recognition capability for large numbers of military vehicles	2005-10
C2	Processor Speed	Provide human-equivalent processor speed and memory in PC size for airborne use	2025-30
BA, FP	”	Map surf zone sea mines in real time	2015-20
BA, FA, FL	”	Reduce DTED level 5 data in real time	2020-25

* Based on Joint Functional Capabilities identified in COCOM IPLs.

BA = Battlespace Awareness; FL = Focused Logistics; FP = Force Protection; C2 = Command and Control FA = Force Application

Table 14. Example Capability Metrics (From: *DoD UAS Roadmap 2005-2030*)

The upper half of Figure 17 plots the predicted appearance of capabilities over the next twenty-two years, with the dates centered within a five-year window of estimated availability for fielding. As an example (see dotted lines on Figure 17), the information-processing speed needed to extract the presence of sea mines in surf zones in real time from UAV video (some 1.8 THz) should become available between 2015 and 2020, which corresponds to the planned introduction of the naval variant of J-UCAS—making this a reasonable capability to express as a requirement, if desired [11].

The terms used in the following figure are defined as follows:

Heavy-Fuel Engines (HFE): Engines using heavy fuels (JP-5, JP-8 and diesel) versus gasoline [53]

Specific Fuel Consumption (SFC): An engineering term that describes the fuel efficiency of an engine design with respect to a mechanical output [54].

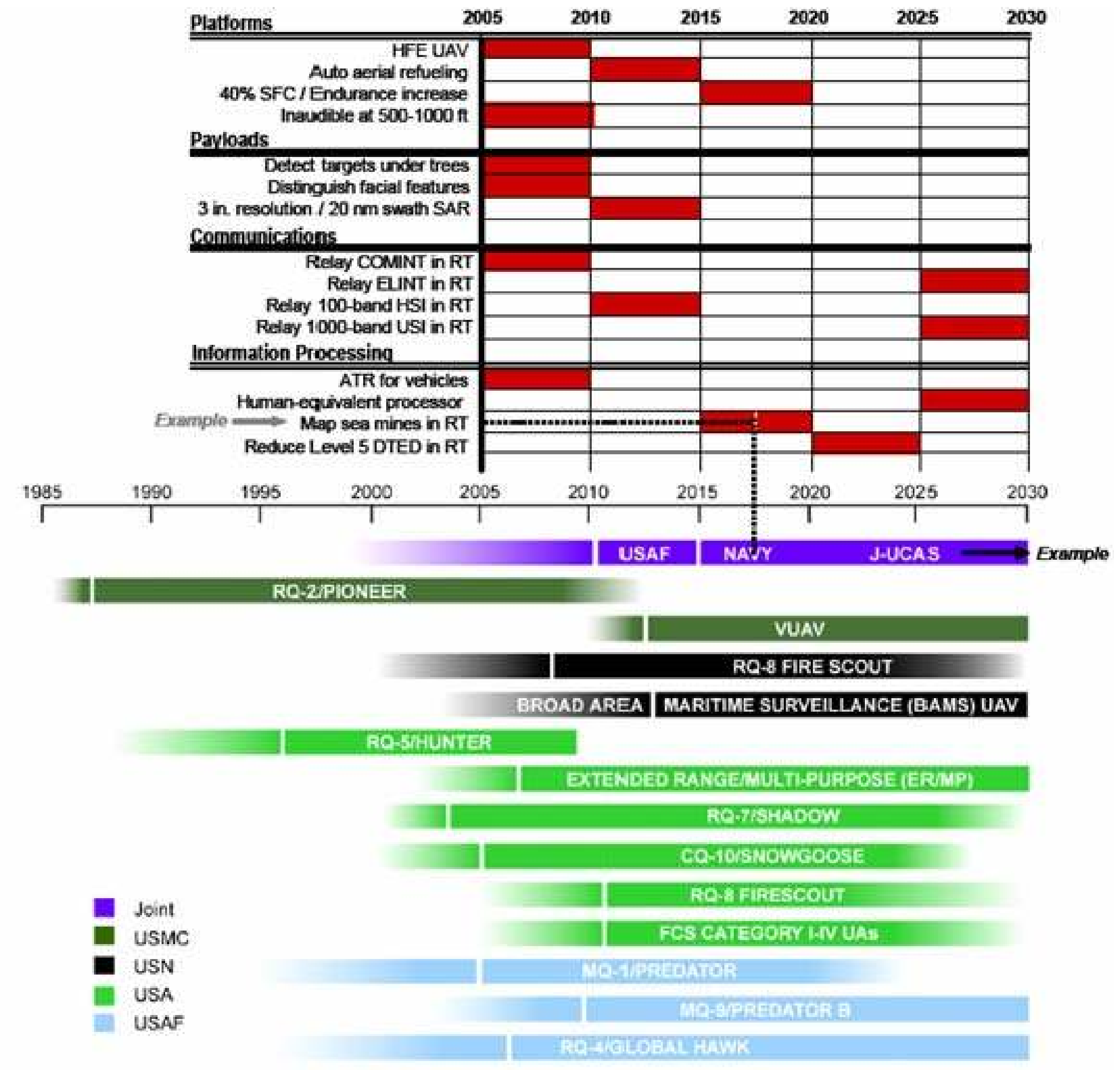


Figure 17. UAV Capabilities Roadmap (From: *DoD UAS Roadmap 2005-2030)*

C. MISSIONS

UAV missions have historically been limited to ISR (Global Hawk) and strike (Predator) missions. Taking the man from the cockpit can translate into persistent, safe surveillance and fewer of sorties. Fewer flight hours are lost due to the transit time that shorter-range aircraft require [11]. Reduced sorties mean fewer takeoffs and landings, reduced wear and tear, and less opportunity for pilot mishap. Similarly, reduced sorties affect ground operating tempo. The ability to operate in distant theaters using CONUS ground stations means affected crews can fly operational missions without deploying forward, i.e., reduced in-theater footprint and support costs, including less demand for force-protection components [11]. Fewer deployments also leads to less family stress, as well as reduced maintenance and training costs.

> High-endurance, unmanned aviation enables CONOPs attributes that can't be fully reflected in aircraft unit costs. But they enable a future where counter-air operations may quite conceivably be supported by crews, operational staffs and CAOCs that substantially remain in either CONUS or established headquarters far away from the point of intended operational effects. The J-UCAS program, which focused on developing a network-centric strike capability, will let us take another step toward such a future [11].

As shown in the Figure 18, two major families of missions, one emphasizing payload capacity and persistence and the other autonomy, survivability, and weapons employment, need to drive UAV design and development over the next twenty-two years [11].

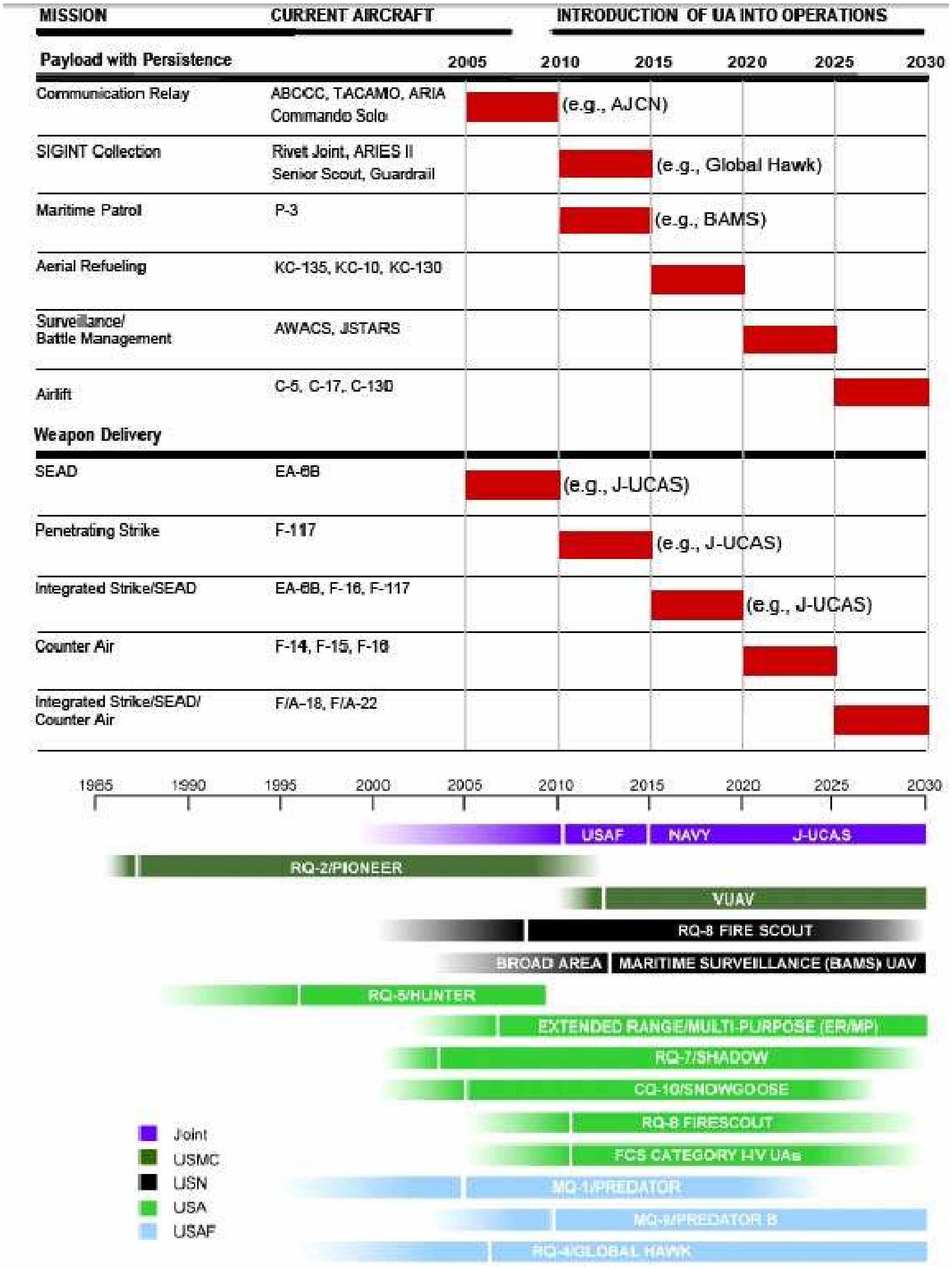


Figure 18. UAV Missions Roadmap (From: *DoD UAS Roadmap 2005-2030*)

In the upper half of Figure 18, endurance UAVs are employed as communication relays, SIGINT collectors, tankers, maritime-patrol aircraft, and airlifters. Design-wise, these roles may use one or assorted common platforms, but they must provide significant payload capacities (power as well as weight) and endurances greater than twenty-four hours [11].

> The DARPA AJCN, with the potential to deploy a Global Hawk-based communication relay payload in the 2005-2010 timeframe, represents a significant step in the "payload with persistence" direction for UAVs. From there, the mission similarities of the AJCN and the Global Hawk imagery reconnaissance UAV could be combined in an unmanned SIGINT collection platform by placing the mission crews of the Rivet Joint, ARIES II, and Senior Scout aircraft in vans on the ground, as is accomplished for U-2 SIGINT missions today. The profile for aerial refueling, long duration orbits along the periphery of hostilities, resembles that of the SIGINT collection mission but adds the complexity of manned (receiver) and unmanned (refueler) interaction. Unmanned airlift hinges on overcoming a psychological and a policy barrier, the former being that of passengers willing to fly on a plane with no aircrew and the latter on foreign countries allowing access to their airports by robotic aircraft. An interim step to unmanned airlift could be manned aircraft that have the option of being unmanned [11].

In the lower half of Figure 18, UAVs are employed in weapon-delivery roles. Progress in the weapon-delivery direction for UAVs depends on developing increasing levels of autonomy.

Do increasing levels of autonomy portend a completely unmanned flying force? The projected direction of UAVs and technological advancements provides evidence of an ever-increasing UAV presence but not to the exclusion of unmanned aviation. Certain missions, such as ISR and communications support, are more likely to be manned than others, such as air interdiction and close air support—which will soon be completely unmanned [55]. The evidence favors an integrated manned- and unmanned force at least through 2030, as forecasted in *DoD UAS Roadmap 2005-2030*. Technological advances could permit a completely unmanned flying force. On the other hand, a mindset in support of autonomous warfighting may not be present.

1. Goals for UAVs

According to [11], the following goals are consistent with current strategic planning guidance (SPG) and are intended to promote transformational, interoperable, cost-effective, unmanned aircraft across the U.S. services.

- Develop and operationally assess fielding of a joint, unmanned, combat-aircraft system capable of performing SEAD/strike/electronic attack/ISR in high-threat environments. (Office of the Secretary of Defense [OSD], United States Air Force [USAF], United States Navy [USN])

- Field secure common-data-link (CDL) communications for aircraft-control and sensor-product data distribution for all tactical and larger UAVs, with improved capability to prevent interception, interference, jamming, and hijacking. (OSD, United States Army [USA], USAF, USN, United States Marine Corps [USMC])

- Ensure compliance with the existing National Geospatial-Intelligence Agency (NGA) metadata standard for all full-motion-video-capable UAVs. Operationally demonstrate and field near-real time (less than three minute) UAV metadata-derived targeting capability for coordinate seeking weapons. (OSD, USAF, USA, USN, USMC)

- Foster the development of policies, standards, and procedures that enable safe, timely, routine access by UAVs to controlled and uncontrolled airspace, to include:

    - promoting the development, adoption, and enforcement of industry-wide airworthiness standards for the design, manufacturing, testing, and employment of UAVs (OSD)

    - coordinating with Federal Aviation Administration procedures for operating DoD UAVs in unrestricted airspace like manned counterparts (i.e., aircraft, light-sport aircraft, and radio-controlled model aircraft) (OSD)

    - developing and fielding the capability for UAVs to "see" and autonomously avoid other aircraft, providing a level of safety similar to that of comparable manned systems (USAF, USA, USN, USMC)

- Improve combatant commander UAV effectiveness through improved joint service collaboration. (OSD, Joint Forces Command [JFCOM], USAF, USA, USN, USMC)

- Develop and field reliable propulsion alternatives to gasoline-powered, internal-combustion engines on UAVs, specifically their replacement with heavy-fuel engines. (OSD, USAF, USA, USN, USMC)

- Improve adverse-weather UAV capabilities to provide higher mission availability and -effectiveness rates. (OSD, USAF, USA, USN, USMC)

- Ensure standardized and protected positive control of weapons carried on UAVs. Develop a standard UAV architecture including weapons interface for all appropriate UAVs. (OSD, USAF, USA, USN, USMC)

- Support rapid integration of validated combat capability in fielded and deployed systems through a more flexible test- and logistical-support process. (OSD, JFCOM, USAF, USA, USN, USMC) [11].

DoD is taking a much broader view of the entire unmanned systems landscape and opportunities for military transformation. Clearly, this is a multiple technology- and human-capability realm that delivers priceless information to battle commanders, remains operative for long durations, and saves pilots' lives. Several overarching concepts are outlined in [11] as:

- Integration within unmanned systems (and with manned systems) will be high, necessitating a greater degree of interoperability from the outset, not added later as an afterthought.

- The trade space between capability and cost will become much greater, offering a wider range of options but producing much more complex and integrated systems, challenging the current “platform” focus on weapons acquisition

- Unmanned systems may be grouped more by technology, and less by traditional classifications; e.g. small UAVs may have more in common with unmanned, ground vehicles (UGVs) than with larger UAVs [11].

Because the ultimate goal is to integrate human and unmanned systems into the battlespace seamlessly, the common UAV interface under development should include suitability to other unmanned platforms.

The overall interoperability of unmanned platforms will be supported by broad efforts to establish and expand standardization and interoperability. Communication standards established by the global information grid will provide infrastructure and its components to support net-centric information sharing among platforms. Joint command-and-control interfaces will provide standard message sets and procedures for exchange of situational awareness and tasking among unmanned platforms [11]. Specific data standards for applications such as ISR will further support information exchange across systems.

D. CURRENT PROJECTS

J-UCAS, the leading UAV project of DARPA, is a joint DARPA/Air Force/Navy effort to demonstrate the technical feasibility, military utility, and operational value of a networked system of high-performance, weaponized, unmanned, aerial vehicles to effectively and affordably prosecute 21st century combat missions, including SEAD, surveillance, and precision striking within the emerging global command-and-control architecture [56]. The J-UCAS project’s primary goal is to provide all services of the military with a system that has worldwide combat capability. More robust hardware and software solutions and advanced communications capabilities are required for this project.

1. Aircraft

Two aircraft are being developed under the J-UCAS program: the X-45 (by Boeing), and the X-47 (by Northrop Grumman). They are now being tested and improved. Both are flying prototypes.

a. Boeing X-45

The Boeing X-45 project was initially intended as a platform for software testing, but it became a fully autonomous, weaponized, SEAD platform. Its first flight was on May 22, 2002 [39].

In April 2004, the X-45 dropped GPS-guided bombs autonomously. By permission of a human operator, the aircraft released its bombs after autonomously navigating to a predefined target [39]. This first weapon release from a UAV was a big step in development.

In August 2004, the program demonstrated another huge gain in the form of multi-vehicle capabilities. Two aircraft taking off separately met, flew in formation, and followed a virtual lead aircraft. They maintained precise position by sharing information over a data link. One of the most impressive aspects is that this feat was overseen by a single human operator monitoring aircraft status—a good demonstration of the X-45's autonomous capability. The system will eventually fly with four aircraft under one operator's control. Boeing plans to have the X-45C ready for mission by 2010 [39].

Figure 19. The X-45C

b. Northrop Grumman X-47B

The X-47B will be a transformational, carrier-capable, and survivable multi-mission UCAV. With its long-range, high-endurance capabilities, it will perform a various missions such as ISR and time-sensitive targeting and strike.

> X-47 is envisioned as a ship-based force multiplier that will complement manned systems by building and maintaining a common operational picture; providing targeting for other weapons and weapon systems; taking lethal action against designated fixed or moving targets; and collecting and disseminating post-strike information. This aircraft will provide longer range with a 1,000 nm combat radius, the ability to loiter over a target for up to 2 hours, and the ability to carry 4,500 lbs of payload. This aircraft is also being designed to meet Air Force requirements, and so could prove to be a multi branch aircraft [39].

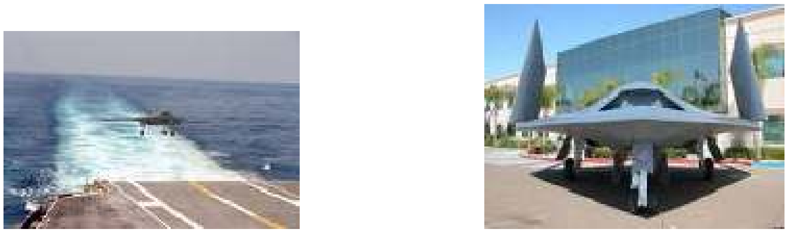


Figure 20. The X-47B

The program will identify the critical technologies for the suitability of an autonomous UAV for aircraft-carrier operations. Flight testing is scheduled to begin in late 2009 and carrier landings in 2011; the program will conclude in 2013 [57].

2. Common Operating System

The common operating system (COS) is a software platform being developed to meet the design requirements of the J-UCAS project and is intended to combine weapons, sensors, and communications for all UAV platforms. Every aspect of software that goes beyond a single component is considered part of the COS. This includes communications protocols, both within the system and to external sources, interfaces between different hardware components (such as weapons, sensors, and aircraft), and human interfaces that allow on-the-fly reprogramming [39]. The COS is a key component of the J-UCAS project with its capability to provide the autonomy, flexibility, and interoperability necessary for the success of the system.

> COS provides the autonomous system ”intelligence” for the overall J-UCAS. It enables interoperability among multiple air vehicles and control stations, facilitating the integration of other system components such as sensors, weapons, and communications. It encompasses the software architecture, algorithms, applications and services that provide command and control, communications management, mission planning, much of the interactive autonomy, the human systems interface and the many other qualities associated with the J-UCAS system [56].

The idea is to develop a control mechanism that can handle the rapidly changing capabilities of different UAV platforms without requiring redesigned. Thus, the COS will be platform independent and able to work with both present and future systems.

As a result of promising advances, UAVs are now considered highly effective assets in various types of missions. It will not be long before the armed services have truly combat-capable UAVs in addition to their successful ISR aircraft [39]. *DoD UAV Roadmap 2002* predicts that “twenty-five years from now (2027), UAVs may exist with morphing airframes, able to optimize their shape for various missions and flight conditions with stretching skins and shape memory alloys permitting aerodynamic maneuvers impossible for manned aircraft.” This may seem fanciful; but fully autonomous combat aircraft seemed fanciful twenty-five years ago, and they are now within reach [39].

VI. TURKISH ARMED FORCES UTILITIES

Review of UAV missions in Chapters III and IV, shows successful completion of a variety of operations and great military utility; and of course, UAVs have flown many successful missions since Operation Desert Storm. But the use of unmanned, aerial vehicles as tactical weapons and military force multipliers is a new concept to the Turkish armed forces.

Turkey's initial UAV studies began in the 1990s, when Savunma Sanayii Mustesarligi-SSM, working in the undersecretariat for defense industries, was charged to define the development, production, and defense-systems procurement needs of the Turkish armed forces and national-defense industrial infrastructure. Throughout the 1990s, Turkey invested in critical UAV technologies such as airframe design, communication-subsystem design, and system integration, via several manned aircraft codevelopment and joint-venture programs [58].

UAV capabilities and missions have been predominantly viewed as supplemental to manned aircraft and space-based platforms. What has been demonstrated in conflict, however, is the UAV's excellence in asymmetric environments, including unique-target identification and strike capability. Doubtless, military-decision makers will remain more comfortable with the proven abilities and performance of manned aircraft for some time. With many high-level personnel being former pilots, the decision "manned vs. unmanned" may still be very difficult [27]. This study merely points to the powerful array of UAV accomplishments and, for the consideration of planners and decision makers, cites their potential ability to transform military platforms.

Advances in technology and systems under integration into UAV platforms include electro-optical imaging, synthetic-aperture radar, increasingly capable microprocessors, sensors, jammers, increased data-link rates, radar-absorbing materials, the use of high-bandwidth communications, and SATCOM-equipped navigation systems, making UAVs a formidable asset to all combatants, including the Turkish armed forces. UAVs' altitudinal diversity and relatively slow speed make them difficult to detect or recognize. Operating restrictions are typically not as limiting for UAVs. Additionally, UAV missions, typically carried out over enemy territory and against sophisticated, integrated, air-defense systems, eliminate the pre-eminent mission constraint: risk to life and to hugely expensive aircraft. For combatant commanders, accomplishing mission objectives without friendly-force loss is becoming paramount as societies increasingly expect modern warfare to be conducted with little to no collateral damage and death [27].

Because UAVs perform missions that are considerably more efficient and economical than manned aircraft, innovative uses will continue to arise. Besides tactical and strategic military functions, UAVs could provide greater flexibility in Turkish border and coastal-patrol missions.

A. TURKEY'S UAV BACKGROUND

TAI (Turkish Aerospace Industries) developed the first Turkish UAV platform in the early 1990s, named UAV X1, and successfuly executed wheeled launch and recovery with an endurance of approximately one hour. To better define the requirements of the Turkish armed forces, SSM procured an off-the-shelf system, the Gnat-750. Gnat-750, later upgraded as I-Gnat, was put into operational use in the mid-1990s and Turkish armed forces accumulated extensive experience from the operation of a UAV system [58].

Throughout the 1990s, Turkey continued to invest in critical UAV technologies like airframe design, communication-subsystem design, and system integration, via several manned-aircraft codevelopments and joint ventures.

By the end of the 1990s, Turkey had categorized UAV requirements as mini, tactical, and medium altitude, long endurance (MALE) UAV systems. The

SSM stategy was to launch national development programs for each category and for immediate needs, to make off-the-shelf procurements with local content by Turkish industry [58].

Turkish industrial capacities for UAV systems provided by major local companies include unmanned, air-vehicle design and manufacture, command-and-control subsystems, data linkage, payloads, image interpretation and exploitation, and engines.

Turkish Aerospace Industries is the main design and manufacturing source for UAVs, including design and manufacturing of drone systems, which are converted into reconnaissance systems by integrating a day-TV payload. MALE category UAV design has completed its initial phase and is proceeding to final design; the system-level integration of the UAV system has also been accomplished by TAI. The Kalekalıp/Baykar and Vestel Savunma companies design and manufacturing mini UAVs. Their tactical UAV design is started and mini-UAV projects are underway for SSM acceptance [58].

STM, Ayesas, and Milsoft are companies responsible for command- and-control subsystems and software capabilities. SAVRONIK company is the designated subcontractor for UAV command and control and video-data linkage. Savronik company is developing Ku-band, spread-spectrum data links to be utilized for EO/IR and synthetic-aparture-radar data downlink. ASELSAN company is the designated subcontractor for EO/IR laser designation (LD) and laser rangefinder (LRF) payload. ASELSAN and SDT companies are jointly developing a synthetic-aparture radar, and are in the design phase. Milsoft is responsible for an image-interpretation and explotation station, now in the development phase, and will be able to provide intelligence information from EO/IR video images, SAR/ISAR, and satellite images. Tusas Engine Industries (TEI), in the UAV field, is currenty working on turboprob engine development for the MALE+ category of UAV. [58]

B. TURKEY’S UAV PROGRAMS

It is deemed vital for the Turkish armed forces (TAF) that indigenous technologies play a major role in UAV employment. Adaptable, flexible, and accurate UAV platforms are the basis for interoperability in a linked environment built for superior situational awareness. Following TAF need, Turkey’s UAV program strategy consists of;

- mini UAV development and production
- tactical UAV development
- MALE UAV development
- MALE UAV procurement

Kalekalıp/Baykar company contracted for the mini-UAV program in October 2006. Required performance characteristics for the mini UAV, as specified in [58], are:

- one-hour endurance
- hand launchability
- parachute recoverability
- day- and night-vision capability
- pre- and inflight programability
- full autonomy

National development on tactical UAVs started in fall, 2007, with Kalekalıp/Baykar and Vestel Savunma companies developing systems under competition. The targeted performance characteristics derived from [58] for the tactical UAV are;

- six-or-more-hour endurance
- sixteen Kft.+
- catapult launchability
- parachute recoverability
- day and night-vision capability
- pre- and inflight programability

- full autonomy

MALE UAV development was launched in December 2004. Initial flight is expected in 2010 and prototype completion is targeted for 2011. In accordance with UAV-program strategies and in parallel with the national MALE development program, an off-the-shelf system procurement has been performed. An IAI-made Heron UAV system in the MALE category will soon be in inventory, filling the operational-needs gap until the nationally developed UAV system enters inventory [58].

In 2004, Turkey attempted to acquire ten off-the-shelf, medium-altitude, long-endurance UAVs and equipment, to be distributed between the three major military services. The U.S. company General Atomics offered the Predator UAV, while the Israelis, bidding as the Israeli UAV Partnership (IUP), offered the Heron. In April 2005, Turkey had chosen to accept the Israeli Heron UAV. Turkey's defense-industries undersecretariat (SSM) and Turkish Aerospace Industries signed a contract in May 2005 with IUP, a partnership of Israel Aircraft Industries and Elbit Systems, that called for thirty percent of the project to include Turkish subsystems and services. Ten UAVs with associated surveillance and ground command-and-control systems will be delivered to the TAF in from two to three years. It was also stated that the Turkish air force will get four UAVs, with four going to the army and two to the navy [59].

At the same time, TAI has decided on the development of six indigenous UAV systems under a sixty-five million USD contract concluded with the SSM. The first of these is deliverable to the TAF in 2009–10. In the second phase of the project, Turkey had planned to acquire forty-six Harpy II drones from Israeli Aircraft Industries (IAI) for suppression of enemy air defenses. This would allow standardization with the 108 Harpy drones already in TAF inventory, ordered in 1999 and delivered in 2002. However, in early 2006, Turkey decided not to proceed with the purchase of additional Harpy UAVs [59].

Emerging needs, technological advances, and UAV successes in conflict are starting to change the perceived value of UAVs in the TAF, and Turkey's investments and projects in current UAV programs are steadily progressing. It is considered strategically important for Turkey to maintain the know-how and experience gained from the UAV program and projects and to integrate all applicable subsystems. The indigenous-development programs and procurements are analyzed in the following section.

1. Baykus

As a result of the advanced technologies and activities regarding unmanned vehicles—which are of great importance in the aviation sector—and taking into consideration the requirements for tactical, unmanned, aerial vehicles, TAI designed and developed an ISR UAV called *Baykus*. The ground tests of Baykus were successfully completed [60].

Figure 21. The Baykus

2. Marti

The Marti aircraft used for pilot training has been in service since 2003. As a very stable platform, it is also used in the aerial, digital, photographic-image gathering and numerical image analysis carried out with TUBITAK (the Scientific and Technical Research Council of Turkey). The shots taken by Marti in Mersin in 2004 were found more successful than the old balloon method [60].

Figure 22. The Marti

3. Pelikan

Pelikan was designed and developed by TAI within the framework of continuous activities regarding unmanned vehicles and taking into consideration the requirements for the tactical, unmanned, aerial vehicles for the TAF. Pelikan is the half-scale, training version of Baykus. Flight tests of Pelikan are ongoing [60].

Figure 23. The Pelikan

4. Gozcu

The Gozcu close-range (CR) tactical UAV is an indigenous TAI design and development, intended to meet short- and long-term tactical-UAV requirements; flight tests were successfully completed. The system comprises the air vehicle, ground-control station, catapult launcher and ground generators, and can easily be used on any runway with catapult takeoff and parachute recovery. All hardware and software in the system, which features waypoint navigation and autonomous flight, were developed by TAI engineers [60].

Technical Specifications:

Basic performance specifications of the Gozcu system derived from [59] are as follows:

Service ceiling: 3,050 m (10,000 ft)
Endurance: >2 h
Cruising speed: approximately 100 kt (185 km/h; 115 mph)
Mission (data link) radius: 27 n miles (50 km; 31 miles)
Maximum payload: approximately 8 kg (17.6 lb)
Maximum launching weight: 85 kg (187 lb)
Power plant: One 28.3 kW (38 hp) piston engine; two-blade pusher propeller
Wingspan: 3.75 m (12 ft 3.6 in)
Length overall: 2.45 m (8 ft 0.5 in)
Height overall: 0.66 m (2 ft 2.0 in)

Figure 24. The Gozcu

5. Bayraktar

The Bayraktar mini-UAV system is designed for aerial reconnaissance and surveillance for the Turkish army. The V-tail form, aerodynamically stable, fixed-wing platform is manufactured with materials such as carbon fiber, Kevlar, glass fiber and computer numerical control (CNC)-machined aluminum parts. The mini UAV system can be hand launched and land on its body. The power system is composed of two electric motors. Rapid system setup and deployment satisfies mobility needs for both military and commercial applications requiring aerial surveillance and reconnaissance. The system's advanced avionics with embedded, real-time software handle stabilization, waypoint navigation, digital communication, and digital-image transferring modes. The autopilot supports autonomous flight, takeoff and landing, and half-automatic control through joystick and manual controls with a secure, digitally encrypted link [61].

The ground-control system (GCS) provides a link between the operator interface, running on a ruggedized, Windows-based PC system, and the UAV. The system supports real-time command, control, and monitoring of the UAV in flight. In addition, the flight can be visualized in a 3D-environment such as Microsoft Flight Simulator. The software architecture of the Bayraktar's electronic systems is based on multi-UAV systems applications and on the development phase [61].

Technical Specifications:

Basic performance specification for the Bayraktar system derived from [62] is as follows:

Service ceiling: 2,000 ft
Endurance: 1 h
Cruising Speed: 15.4 m/s
Mission (data link) radius: 15 km
Maximum launching weight: 4.5 kg
Wingspan: 1.6 m
Length overall: 1.2 m

Figure 25. The Bayraktar

6. MEDIUM ALTITUDE, LONG ENDURANCE UAV (TIHA)

> The contract regarding the development of a medium altitude, long endurance (MALE) unmanned, aerial vehicle (UAV) system for the reconnaissance requirements of the TAF became effective on 24 December 2004. Within the framework of the program, a total of three prototypes and ground systems are planned to be designed, developed, manufactured and flight-tested by the end of 2010 [60].

The Turkish indigenous MALE UAV (TIHA) system components derived from [60] will be:

- Air vehicles (A/V)
- A ground-control Station (GCS)
- A ground data terminal (GDT)
- An automatic takeoff and landing system (ATOLS)
- A transportable image-exploitation system (TIES)
- A remote-video terminal (RVT)
- Ground-support equipment (GSE).

The indigenous TIHA system is designed to support night and day missions in adverse weather. The system performs real-time image intelligence, surveillance, reconnaissance, target detection, recognition, identification, and tracking, and has the potential to carry weapons [60].

According to [59], the TIHA UAV is configured to carry the following payloads onboard, with an open architecture to support numerous potential missions:

- Electro-optical, color, day camera (ASELFLIR-300T EO)
- Electro-optical, infrared, laser camera (EO/IR/LRF/LD/Spotter) (ASELFLIR-300T)
- SAR/GMTI, ISAR payload

> The whole composite airframe is composed of a monoblock fuselage, detachable wing and V-Tail, retractable landing gear, redundant control surfaces, avionics and payload bays and service doors. The sandwich skin structure is reinforced by composite or metallic frames, ribs and supports. Propelled by a pusher type heavy fuel engine, the aircraft is furnished with fuselage fuel tanks and fuel system, ice protection system, environmental control system, lighting system, redundant electrical system with battery backup and harness system [60].
>
> The platform is also equipped with a digital flight-control system, electromechanical actuators, and flight-control sensor systems such as: pitot-static air-data computer, navigation sensor, transducers, temperature, pressure, displacement sensors, etc. Various tasks are distributed along flight management computers and auxiliary control boxes. Identification and communication units and interface computers are employed in order to establish real-time, wideband communication and provide test and diagnostics functions. An air-traffic radio is also integrated in the communication system for integration of the aircraft into the civilian airspace. All flight critical equipments are dual or triple redundant and emergency modes of operational scenarios are taken into consideration for fail-safe design [60].

The system-level integration of the UAV and flight-software configurations embedded on both air and ground equipment are being developed indigenously by TAI. In a similar manner, all required mission hardware and software are slated for indigenous development by national subcontractors [58].

The TIHA GCS has the capability to manage, monitor, and control the whole-mission segments of the air vehicle, including payloads. The mission plan can be programmed and loaded before flight or altered during flight. Operators can display and record all the payloads' imagery stream in real time. An automatic takeoff and landing terminal allows the UAV to operate without operator intervention. The system can analyze and sort out valuable intelligence information and distribute real-time imagery data to other nodes in the battlefield. Upper-level commanders can monitor the network of TIHA systems and benefit from the gathered intelligence information. [60].

Technical Specifications:

The basic performance specification of the TIHA system derived from [59] is as follows:

Service ceiling: 9,140 m (30,000 ft)
Endurance: 24 h
Cruising speed: >75 kt (139 km/h; 86 mph)
Mission (data link) radius: 108 n miles (200 km; 124 miles)
Maximum fuel weight: 250 kg (551 lb)
Maximum payload: 200 kg (441 lb)
Maximum launching weight: 1,500 kg (3,306 lb)
Power plant: One (unspecified) piston engine driving a pusher propeller. Fuel tank in center fuselage
Wingspan: 17,313 m (56 ft 9.6 in)
Length overall: 10.00 m (32 ft 9.7 in)

Figure 26. The MALE UAV (TIHA)

7. Harpy

Harpy is a lethal UAV used to detect, attack, and destroy radar emitters. Harpy is designed as a fire-and-forget, all-weather, day or night, autonomous weapon system, launched from a ground vehicle or ship. Harpy suppresses hostile SAM and radar sites for long durations by detecting signals with an onboard passive radar receiver, attacking and destroying radar targets with high accuracy. Harpy provides the most effective solution to the hostile-radar problem, at the lowest price [63].

Harpy is sealed in its launcher to endure battlefield conditions and can be fueled in the launcher to retain readiness at all times. The Harpy system is air transportable by a C-130-class aircraft. The system uses periodical built-in testing to maintain full readiness. In 1999, the TAF took delivery of Harpy lethal UAVs from IAI. Reports suggest that more than a hundred were delivered [59].

Technical Specifications:

The basic performance specification of the Harpy system derived from [59] is as follows:

Maximum level speed: 250 km/h
Ceiling: 3,000 m (9,840 ft)
Mission radius: 400-500 km
Endurance: 2 h (400 km mission radius)
Overall height: 0.36 m
Wingspan: 2.00 m
Overall length: 2.30 m
Weight: 32 kg (warhead); 120-135 kg (UAV)

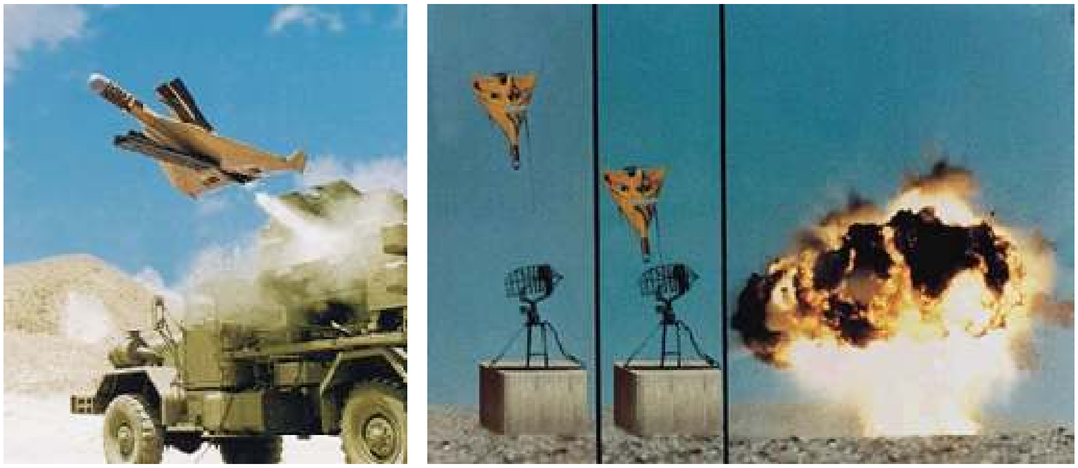


Figure 27. The Harpy

8. Heron

The Heron UAV was developed by IAI / Malat as an operational long-endurance, medium-altitude system with fully automatic takeoff and landing. Heron can perform real-time missions including deep penetration, wide-area intelligence collection, surveillance, target acquisition, target tracking, elint, comint, and communications/data relay. All missions can be planned before takeoff; flight is automatic, with the ability to transmit changes in real time and to introduce route changes during flight. The GCS is a derivative of the GCS-3000 developed for the Hunter UAV and consists of two operator consoles and one command/control console. The GCS allows for all mission planning, control, command, and processing functions to operate the UAV and payloads. The Heron UAV system initially deployed with the Indian defense forces for high-altitude land surveillance and maritime patrol. The Heron has been acquired by the Israeli air force and Turkish defense forces for strategic reconnaissance and surveillance [59].

According to [63], the Heron’s main features and payload capabilities are:

- Multiple operational configurations
- Adverse weather capability
- Safe, reliable, and easy operation

- Simultaneous, four-sensor capability
- Satellite communication for extended range (SATCOM)
- Two proven, simultaneous, automatic-takeoff-and-landing (ATOL) systems for maximal safety
- Fully redundant, state-of-the-art avionics
- Retractable landing gear
- Payloads
    - Electro optical (TV & IR combi or triple sensor TV/IR/LD)
    - Synthetic-aperture radar (SAR)
    - Maritime-patrol radar (MPR)
    - COMINT and ESM capability
    - Customer-furnished sensor suites
    - Communication-relay package
    - Integrated ATC radio

Technical Specifications:

The basic performance specification of the Heron system derived from [59] is as follows:

Service Ceiling: 8,075 m (26,500 ft)

Endurance: 45 h

Cruising Speed: 125 kt (231 km/h; 144 mph)

Mission radius: LOS Data link - 108 n miles (200 km; 124 miles)

Mission radius: BLOS Data link - 189 n miles (350 km; 217 miles)

Maximum fuel weight: 430 kg (948 lb)

Maximum payload: 250 kg (551 lb)

Maximum launching weight: 1,150 kg

Power plant: One 73.5 kW (98.6 hp) turbocharged Rotax 914 F four-cylinder, four-stroke engine; two-blade, variable-pitch, pusher propeller. Wet-wing integral fuel tank plus fuselage tank; combined capacity 720 liters (190 U.S. gallons)

Wingspan: 16.60 m (54 ft 5.5 in)

Length overall: 8.50 m (27 ft 10.6 in)

Figure 28. The Heron

9. Keklik-Tracking Target Drone

The Keklik system, designed for use in non-firing tracking training with radar and optical guided missiles or barreled antiaircraft guns, is a low-cost training target. The system consists of an aircraft, launcher, ground-control system, and ground-support equipment. The aircraft has a low delta wing and composite structure with tractor-type power plant and is launched manually by bungee catapult. The aircraft does not need a runway for takeoff and landing and recovers by a remotely controlled parachute on land or sea. Its compact structure and light weight provide ease of takeoff, flight, and recovery and convenience and flexibility in transportation, deployment, and operations. The system has short assembly and transportation periods and can be operated by two crews from any terrain [60].

The Keklik is an indigenous, cost-effective, and practical training option due to its fifteen minutes turnaround time, including fuel supply, preflight checks, and maintenance. The aircraft can reach high speeds while sustaining long endurance because of low aerodynamic drag. The system is composed of COTS items, based on modularity and simple architecture [60].

Technical Specifications:

The basic performance specification of the Keklik-Tracking Target Drone derived from [59] is as follows:

Endurance: 30 min

Maximum LOS control radius: 1,500 m (4,920 ft)

Cruising speed: 81 kt (150 km/h; 93 mph)

Stalling speed: 27 kt (50 km/h; 31 mph)

Weight empty: 7.0 kg (15.4 lb)

Maximum launching weight: 10.0 kg (22.0 lb)

Power plant: one 2.1 kW (2.8 hp) OS-MAX 91 Fx single-cylinder piston engine; two-blade propeller

Wingspan: 1.61 m (5 ft 3.4 in)

Length overall: 1.36 m (4 ft 5.5 in)

Height overall: 0.32 m (1 ft 0.6 in)

Figure 29. The Keklik

10. Turna Target-Drone System

The Turna target-drone system was designed and produced indigenously by TAI for TAF air-defense training. The system is used for exercises in tracking and firing radar; optically, thermally, or manually controlled, barreled antiaircraft guns; and guided missiles, such as Rapier and Stinger. The system can also be used for tactical ISR and target detection when equipped with a high-resolution digital camera, EO or IR camera, video downlink, and laser rangefinder [59].

Turna target-drone systems entered the inventory of TAF in 2001 for the high-speed and low-cost air-defense units' training needs. The system can simulate all aerial threat elements, ranging from aircraft to missiles with high maneuverability, and measure their firing performance. Turna is an automated, transportable, and modular system with GCS including takeoff and landing. It takes off with a bungee catapult launcher and recovers by parachute. The system can take off from Knox-class battleships and skid-land in emergencies. The avionics and ground-control system are GPS supported and data is coded during transmission and receiving. Operators can monitor and control multiple aircraft, digital moving maps, imagery displays, and records. In a datalink failure, Turns aircraft can execute a predefined emergency flight procedure, loiter till the link is reestablished, or return home. The system transfers all real-time flight data to operators by line-of-sight data-link equipment. The Turna can handle payloads such as IR thermal-heat source detector, smoke, photographic camera, video camera, and passive radar cross-section generators [60].

> Since the Keklik system uses the common command infrastructure with “Turna,” both aircraft can be operated with the same command equipment, and Keklik is also utilized for transition flights of Turna. [60].

Technical Specifications:

The basic performance specification of the Turna target drone, derived from [59], is as follows:

Endurance: 1 h 30 min

Ceiling: 3,000 m (9,840 ft)

Maximum LOS control radius: 0.8 n miles (1.5 km; 0.9 miles)

GCS: 8.1 n miles (15 km; 9.3 miles)

Cruising speed: 59 kt (110 km/h; 68 mph)

Maximum cruise speed: 216 kt (400 km/h; 248 mph)

Weight empty: 45 kg (99.2 lb)

Maximum launching weight: 75 kg (165 lb)

Maximum payload: 15.0 kg (33.1 lb)

Power plant: one 28.3 kW (38 hp) UEL AR 741 rotary engine; two-blade wooden, fixed-pitch, pusher propeller. Fuel capacity: 14 liters (3.7 U.S. gallons; 3.1 Imp gallons)

Wingspan: 2.67 m (8 ft 9.1 in)
Length overall: 2.66 m (8 ft 8.7 in)
Height overall: 0.57 m (1 ft 10.4 in)

Figure 30. The Turna

Turkey has a wide range of UAV operational requirements in mini, tactical, and MALE categories. Turkish industry has gathered experience on UAV system integration, subsystem design, manufacturing, and expending its capabilities with a wide range of indigenous-development programs. It is important for Turkey to become a developer of indigenous UAV systems to meet all the requirements of the TAF.

The course of improvement in the analyzed programs and projects will determine whether UAVs replace or supplement current manned systems in TAF inventory; because UAVs will make a significant contribution only to the extent that they are tightly linked to other NCW platforms.

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VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSION

This thesis explored past, current, and possible future operating environments involving the use of several unmanned, aerial vehicles (UAVs) to better understand the changing dynamics of combat-aviation tactics. Also examined were major UAV platforms in terms of various roles and capabilities, including UAV utilities, limitations, and performance metrics. Technological advancements and political and economical considerations leading to the use of UAVs in four recent conflicts were discussed to illuminate the evolution of UAVs. This study examined the potential of UAVs as sensors in a network-centric environment, particularly in a rapidly changing battlespace.

The argument as to whether UAVs or their manned counterparts are more effective in projecting combat power has attracted increasing interest. While manned aircraft have clearly been effective since WWI, UAVs are emerging as a viable way to reduce pilot risk while maintaining air dominance. Increased usage is rising alongside increasing demands for battlefield intelligence, tighter defense budgets, faster operations tempos, and lowered tolerance for casualties. UAV advantages over manned platforms keep multiplying and they include critical considerations such as reduced cost and personnel risk, higher payoff in intelligence returns, greater flexibility in mission profiling and tasking, better performance in hostile environments, and ability to undertake dull, dirty, and dangerous, and protracted missions. Lessons from previous conflicts created a misconception that manned platforms are obsolete, thereby increasing UAV employment over increasingly diverse platforms. To the extent that generating a common operational picture based on near-real-time data culminating in maximal battlespace awareness remains a paramount aim in modern warfare, UAVs may be poised to dominate over their manned counterparts simply because they are self-contained units that satisfy that objective exceedingly well. With technological advancements and growth in capabilities, UAVs are becoming indispensable to commanders in lifting or reducing the fog of war. All serious military powers are advised to heed the emerging roles of the multiple types of UAVs as they do practically everything required of a military asset except exposing a pilot to harm.

1. U.S. UAV Utilization Issues:

Lessons about UAV utilization derived from four U.S. conflicts are helpful in guiding corrective actions for the issues that TAF faces or will face, and problems encountered by the U.S. in their development and fielding of UAVs are important to the TAF's UAV applications and programs. Below is a summary of [11] UAV utilization issues concerning GWOT:

- The low-density/high-demand nature of the limited UAV force and the operational demands placed on it created a conflict in priorities between employing UAVs in its two key roles, sensing and shooting. In both Afghanistan and Iraq, Predators were tasked to find targets, designate them for manned strike, and strike them themselves. Both the limited number of weapons carried and the coordination time required to obtain permission to employ them subtracted from UAV availability to pursue mobile targets, a key concern of intelligence staffs.

- Weather, in particular high winds, posed a major constraint on UAV operations due to their lighter weights and higher-aspect-ratio wings compared to manned aircraft. Winds up to seventy knots in the theater significantly reduced the availability of most UAVs, and accompanying dust storms degraded their ability to use EO sensors; however, Global Hawk, carrying an EO/IR/SAR combined sensor, was still able to perform effectively during dust storms.

- Despite the capability of operating multiple UAVs per system simultaneously, the limited number of frequencies available often restricted the number to one UAV airborne at a time.

- Integration of unmanned aviation into the national airspace system is needed to enable file-and-fly operations by UAVs to improve their responsiveness and fidelity of training.

- The dynamic nature of the joint operational environment for which UAVs are employed in Afghanistan and Iraq indicates a need for centralized command and control to ensure functional integration (intel, ops, and communications) that prioritizes UAV sensing-operations support.

- A comprehensive and integrated dissemination architecture is needed to optimize bandwidth usage and maximize requirement satisfaction.

- A net-centric approach to UAV integration and interoperability is needed to provide situational awareness at all command echelons. Consistent with the DoD's net-centric data strategy, there should be additional capability for archiving and discovery of full motion video collected by UAV. UAV positional and sensor pointing information enable enhanced airspace and sensor management.

- Frequency interference (loss of UAV link) was more often from friendly than hostile sources.

- Urban combat is hostile to high-bandwidth, wireless, data communications and can result in loss of connectivity even at short distances. This effect is compounded by short LOS distances, making visual reconnaissance difficult. Urban combat terrain is also rapidly changing, and pre-conflict battlespace awareness can become useless unless continually refreshed [11].

B. RECOMMENDATIONS

The first two chapters of this thesis supported a “reasonable” comparison of manned vs. unmanned systems. With the exception of reliability (and UAV reliability is rapidly improving), analysis indicates that UAVs compare favorably in mission-support areas to conventional, manned aircrafts. Further, when considering the inherent advantages in employing unmanned systems, the TAF are encouraged to increase emphasis towards the use of UAVs.

We have considered a wide range in mission scenarios and included a wide variety of unmanned systems. Based on our evaluations and our apprehension of current Turkish UAV military technology, we recommend:

- TAF increase political and military exposure to emerging UAV capabilities, including communicating the strategic, operational, and tactical significance of UAV funding and prioritization within the resource framework of TAF decision makers.
- TAF increase efforts to aggressively develop, acquire, test, and field UAVs in training and operational environments. To attack this goal will require evaluating procurement needs according to system requirements and system size and complexity, e.g., development costs of some unmanned systems are much higher than procurement costs.
- TAF define the relationships between requirements (such as high-, medium-, or low altitude, endurance, speed and payload) and UAV mission tasks, including sensors and other systems related to operational tasks—that is, indicate the criticality of a given mission system to a task and the availability of the technology to support the need [28].
- TAF integrate UAV testing with joint and combined exercises to develop concepts, tactics, techniques, and procedures (TTPs) and doctrines for their utilization. TAF might reconsider current doctrines, procedures, and policies to conclude how UAVs could fit the existing structure. TAF might examine whether UAVs need to be designed to fit existing restrictions, or policies and procedures need to be adapted to the technology.
- TAF can encourage high levels of interoperability and standardization between unmanned platforms employed by different services. Establishing communications standards and providing infrastructure and components to share data among platforms will provide standard message sets and procedures for exchange of SA and tasking among these platforms.
- TAF can coordinate the services to mitigate costs, by developing common UAVs, GCSs, software, and payloads.
- TAF can increase involvement of civilian institutions to develop the technologies critical to the success of UAVs, e.g., take advantage of university brainpower to help with technological challenges.

Additional TAF recommendations with respect to the incorporation of UAVs as a military resource are provided in the Appendix.

Considering the advantages of UAV employment in today's rapidly changing battlespace and considering Turkey's geopolitical and geographical position, TAF is advised to embrace to the fullest extent possible the promise that UAVs will magnify Turkish military capability, alongside the expectation of ever-greater achievements through the emerging technological prowess of unmanned vehicles.

> The way to gain a military advantage is not necessarily to be the first to produce a new tool or weapon. It is to figure out better than anyone else how to utilize a widely available tool or weapon [65].

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APPENDIX: RECOMMENDATIONS

This appendix includes additional recommendations for the TAF concerning UAVs and future UAV programs:

- Each Service can begin to identify separate areas of added value by using UAVs in their military operations and to consider the employment of UAVs in the following circumstances, which are included in [33]:
    - When the lethality of the airspace to be penetrated is too great for manned aircraft
    - When the airspace to be penetrated is too politically risky for manned aircraft
    - When the airspace to be penetrated is too toxic for human operators
    - When lower-priority missions could be performed by UAVs to free highly skilled airmen to handle higher-priority tasks
    - When overall mission effectiveness could be improved with UAVs [33].
- Based on the conflicts analyzed in Chapter III, applications, systems and programs, and future directions analyzed in Chapter V, a UAV would be deemed to fulfill the following basic requirements outlined in [64]:
    - Perform efficient surveillance and reconnaissance missions for the armed forces
    - Conduct day and night operations
    - Succeed in a wide range of weather conditions
    - Fly at various altitudes
    - Operate beyond line of sight (BLOS)

  - Operate in real-time

  - Demonstrate multi-mission capability [64].

- TAF can match UAV capabilities to mission needs and to interfaces with ongoing programs. Interfaces can be addressed by integrating the UAV with an infrastructure for C^3I. Each mission creates its own C^3I integration needs, including design considerations for the vehicle, sensors, onboard computers, and weapon components, if any. Crucial C^3I factors include the vital need to maintain positive control of UAVs, including the ability of human operators to intervene quickly to regain an errant, autonomously controlled vehicle [28].

- Interoperability with C^3I architectures appears feasible as long as high-level planning includes UAV capabilities and performance constraints. The principal C^3I challenge remains positive control in shared airspace with manned forces, and the key technology needed for TAF is indigenous or procured software and hardware to enable real-time, onboard mission replanning for the complex set of UAV missions that are anticipated [28].

- TAF can organize intelligence products derived from UAVs to be available through multiple sources, including direct transmission to field units and other services as necessary, i.e., agile distribution paths permit users at all levels and services to access intelligence information.

- TAF can create a training syllabus satisfying FAA requirements to operate as a pilot would in controlled airspace. It should also satisfy the services’ strict requirements for engrained military flight discipline and at the same time be tailored to meet the unique training requirements of UAV operations.

- TAF can develop a micro-UAV capability and support research and development into future concepts using micro- electro-mechanical systems (MEMS) technology (micro-UAVs cost an order of magnitude less than current TUAVs, including a smaller logistical requirement, man portability, expendability, difficult detection, and ease in flying) [19]. The successful development and employment of micro-UAVs can increase SA of small units.

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