Chapter 4

Platform Considerations

4.1 Candidate UAV Selection for Near-Term Emphasis

To progress toward a definition of the overall platform technology requirements for UAVs, the study grouped technology needs as is customary. It began with the 22 original UAV missions/tasks, assessed their attributes, and then pared down the candidate air vehicles to a limited number that represents the spectrum of platform requirements. The process is described below; the results are also presented in Table 3-1.

Vehicle-Defining Attributes. When considering a minimum set of representative vehicles as a basis for advocating an introductory pathway and deriving leverage technologies, several factors should be taken into account as listed in Table 4-1.

Table 4-1. *Vehicle-Defining Attributes*

Attributes
• **Mission Performance** - Altitude (sensor line-of-sight, survivability) - Payload Fraction (endurance per gross weight) - Speed (search rate, response time, survivability) - Endurance (on-station fraction, basing flexibility)
• **Logistics and Operating Economics** - Size (acquisition, operating, and basing cost) - Reliability (accident-related operating cost) - Storability (training, operating, and basing cost) - Maintainability
• **Payload Accommodation Flexibility** - Bay Volume - Aperture Real Estate - Weapons Integration and Launch - Auxiliary Power - Cooling
• **Survivability** - Observables (alert and track denial) - Vulnerability - Maneuverability

Five of these factors bear special mention:

> *Altitude* - Sensor and communication link line-of-sight reach is the primary driver, with survivability secondary. An altitude of 65,000 ft offers over 300 nm to the radio horizon (disregarding multipath difficulties) and over 100 nm for 5 degree grazing angle SAR or MTI. Flying at altitudes above 5,000 ft defeats most radar directed guns and above 15,000 ft defeats most shoulder launched homing weapons. Altitudes greater than 60,000

ft defeat the bulk of older SAMs and above 70,000 ft prevent fighters from reaching co-altitude. However, even at 70,000 ft air-to-air missiles can be launched to higher altitudes.

Endurance - The value of endurance is primarily in the economics of fleet size necessary to maintain one vehicle continually on station and secondarily in the flexibility of basing far from the theater of action. On-station to transit-time ratios of less than 1:1 require more than two vehicles (plus backup) to maintain one on station. An operating radius of 6,000 nm to station allows CONUS basing to cover most of the world. A nominal 3,000 nm radius allows nearly world coverage from four politically secure bases (Roosevelt Roads, Mildenhall, Diego Garcia, and Guam). A 1,000 nm radius is sufficient for most in-theater sanctuary operations.

Reliability - The accidental loss rate has been the single biggest contributor to the historic failure of UAVs to find their place in the force mix. Flight management systems (including onboard flight control, communication links, and ground station support) are the primary contributors to this shortfall. A mean-time-between-accidental-loss of greater than 20,000 hr is necessary to keep the imputed loss-related cost-per-flight hour below $500 for a $10M surveillance vehicle that might have a total operating cost of $2,000/flight hour.

Storability - For those unmanned vehicles with little peacetime application (e.g., weapon carriers and countermeasure vehicles), large savings in operations and maintenance (O&M) can be achieved by merely warehousing a large fraction of the fleet and relying on simulators and a small active fleet fraction for training. This requires a "wooden round" vehicle for fast surge response.

Aperture Accommodation - Antennas and optics apertures can interfere with signature reduction or, in the case of AEW aircraft, flight-efficient configuration. For ground imaging systems, a 3 ft x1 ft SAR/MTI antenna, 4 in. optics and 3 ft diameter SATCOM antenna is the minimum. For VHF/UHF radar, at least a 40 ft x4 ft antenna is necessary against LO/VLO cruise missiles and aircraft. For anti-TBM, 4 in. optics is considered minimal.

Near-Term Candidates. Of the original 22 vehicle classes listed in Chapter 3, three vehicle types can provide the size, configuration, observables, loiter altitude, endurance, payload, and payload power to economically support most of the priority mission tasks and appropriate sensor/weapon/communication suites *in the near-term*. The study group strived to limit the number of dissimilar vehicles recommended for development and arrived at the three candidate vehicle types described in Tables 4-2 and 4-3.

Table 4-2. *Notional Characteristics of Candidate UAVs*

Vehicle Type	*Observables*	*Speed*	*Altitude*	*Payload Power*	*Endurance*	*Aperture*
Penetrating HAE	VLO	M 0.6	>70,000 ft	2,000 lb 20 kW	64 hr	3 ft x 1 ft +3 ft dia +4 in. optics
Standoff HAE	Conventional	M 0.6	>70,000 ft	2,000 lb 100 kW	64 hr	40 ft x4 ft +3 ft dia +4 in. optics
Combat MAE	LO	M 0.6	>40,000 ft	2,000 lb 10 kW	21 hr	1 ft dia

Early forms of penetrating and standoff HAE vehicles have already been initiated as Predator (Tier 2), Global Hawk (Tier 2+), and DarkStar (Tier 3-) ACTDs. These ACTD programs should be completed to fully explore the potential mission options, degrees of autonomy, ground support, communication architectures, and acquisition strategies before deciding on the particulars of a formal, much improved design follow-on.

Table 4-3. *Applicability of Candidate UAVs*

Vehicle Type	*Functions Served*	*Missions Served*
Penetrating HAE	Surveillance, Reconnaissance, Interceptor Carrier	ISR, CWMD, Fixed, Mobile, SEAD, ATBM
Standoff HAE	Surveillance, Communications, Standoff Jammer, Interceptor Carrier	ISR, Fixed, Mobile, SEAD, Air-to-Air
Combat MAE	Strike Weapon Carrier	CWMD, Fixed, Mobile, SEAD, Air-to-Air

The Combat MAE concept is sufficiently embryonic as to need a “crawl-before-walk” requirements definition phase, particularly with respect to vehicle characteristics, which are highly dependent on anticipated, but undemonstrated, weapon size reduction. The Combat MAE UAV also encompasses an extremely broad spectrum of possibilities, ranging from weapon-bearing “trucks” that emphasize loiter to maneuverable aircraft that emphasize penetration. Automating existing combat aircraft could provide near-term surrogates to explore the vehicle/flight management, performance, tactics, and communication architecture issues before taking on a more expensive clean-slate combat vehicle demonstration program, ACTD or otherwise.

In the mid- to long-term, it will become possible and desirable to develop true combat UAVs that are the counterparts of present-day fighter planes. They will exploit various degrees of speed, stealth, maneuverability, and survivability and carry the necessary mission systems and weapons to make possible military actions deep within the heavily defended portions of enemy territory. These combat UAVs will be especially productive for CWMD missions and against extremely important fixed and moving targets and will minimize the exposure of Air Force pilots to danger. Much of their technology will have been developed for the endurance UAVs that precede them, although they will require special emphasis on mission systems and human systems over and above that otherwise available.

4.2 Platform Technology Challenges

This section sets forth, in what is judged to be priority order, the critical enabling technologies that must be developed. These conclusions are based upon several quantitative preliminary design analyses, such as for the SEAD mission vehicle described in Chapter 8, as well as the information gathered from various sources during the study. Since the development of adaptive-autonomous control systems technology; new propulsion systems; and advanced, lightweight, low-cost UAV structural design approaches are critical to future UAV designs.

Adaptive, Autonomous Control System Technology. Perhaps the most critical issue pacing the evolution of UAVs is that of manual (human) versus automatic (machine/computer) control of the wide range of functions to be executed during a mission. Human controllers have limitations (such as the number of parameters that can be controlled simultaneously and the speed at which humans can respond to sensed changes), but they also have unique abilities not yet replicated in automatic controllers. The human can *learn* to perform control functions and can thus *adapt* to unexpected inputs and demands. Humans can also *reason* effectively under conditions of uncertainty and perform higher order integration tasks.

One difficulty that a designer faces for both manned and unmanned systems is how to integrate human controllers with the vehicle platform systems. That *difficulty remains* and *may be exacerbated* in the complex “system-of-systems” in which UAVs are expected to operate. This topic is treated further in Chapter 7 of this Volume and in Chapter 6 of Volume II.

In a mission-oriented “system-of-systems,” a first consideration is the allocation of control functions to all systems within the overall “system-of-systems.” Single aircrew vehicles, multiple crew vehicles, unmanned vehicles, manned and unmanned ground stations, manned and unmanned satellites, and all other elements must have their functions determined (through simulations, models, analyses, and tests) and adjusted as operational concepts evolve. The goal is to achieve best performance at affordable cost.

Propulsion System Technology Development Requirements. The projected UAV missions call for a spectrum of requirements for propulsion system technology and a great difference in the level of necessary technology compared with existing engines. For the Combat MAE UAV, current engines appear to be adequate, and improved versions are being made available via the Integrated High Performance Turbine Engine Technology (IHPTET) program. For the HAE (higher altitude and longer endurance than Global Hawk) UAV however, there is a substantial gap between requirements and the existing technology.

The basic criterion for endurance aircraft is fuel usage; engine thrust-to-weight is less important. Issues to be addressed therefore, relate to the directions in propulsion system design that can decrease thrust specific fuel consumption (TSFC) relative to the TSFC of present engines in endurance aircraft. Gas turbine engines for long endurance are pushed in the direction of high cycle pressure ratio, high bypass ratio, and low flight Mach number during loiter, although freedom to vary the latter is severely constrained because of the need for high velocity to generate adequate lift at high altitudes, where the air density is extremely low.

The first question is engine type. The engines used for Tier 2+ are turbofans with bypass ratios of roughly 5. At this bypass ratio, lower TSFC (say 10% - 15%) has been achieved with higher cycle pressure ratio in large gas turbine engines for commercial aircraft, but these high pressure ratios have not been used in the smaller engines that would be appropriate for the UAVs discussed. Further improvements can be achieved by increasing the bypass ratio either in an ultrahigh bypass ratio (12-15) configuration or in an advanced turboprop.

There are several constraints on the engine design. For the penetrating endurance vehicle, a turboprop cannot be used since the blades must be shrouded. In addition, there is a size restriction on engine diameter, say 3 ft. For very high bypass ratios or high cycle pressure ratios, the core dimensions become much smaller than existing cores of high efficiency engines and the component efficiencies can be compromised.

It appears that for the proposed high altitude endurance UAVs, no existing propulsion system is well tailored. For gas turbine engines, no engine from the IHPTET program is optimized for TSFC at an altitude and Mach number consistent with the requirements of the two endurance UAV missions discussed. Several specific technology questions can be asked, even in the preliminary stages: If one designed an engine for an altitude of 70,000 ft and a cruise Mach number of 0.5 aimed at low TSFC as well as low manufacturing cost, what would it look like? What are the compressor and turbine configurations for these small engines that would best meet the mission goals?

In summary, considerable advantage could stem from design of an engine for UAV usage, but there are no current development efforts in this area.

UAV Structural Design. Some requirements/objectives unique to UAVs call for different approaches to structural design than those used in the past for manned vehicles. One of these is the increased need for integration of the different functions in a UAV to save weight and improve efficiency. The objective should be to achieve an empty weight fraction of 0.3. A second UAV objective is reduced cost, where the view is that many low-cost, possibly attritable vehicles with limited life are superior to small numbers of manned aircraft. The objective should be to produce UAV airframes at a cost of $500 per pound or less. A third requirement is maintainability and repairability, including readiness after long-term storage. A fourth objective is improved stealth to operate or penetrate through hostile airspace.

To achieve these objectives, the structural philosophy used to define loads and create structural forms must be changed from man-rated designs. The central point is that UAV structural design must be carried out in an integrated manner, rather than as a diverse array of stovepiped individual technology plans.

> *Changing Structural Design Philosophy* - Current design philosophy and loads criteria used for manned aircraft design are the result of 90 years of manned aircraft experience.

The rules for defining critical loads have not kept pace with advanced technology capabilities, for example the arbitrary setting of the factor of safety at 1.5 (structural weight increases with an increase in the factor of safety). This value is historical and originally represented the ratio of the ultimate stress to yield stress of a type of aluminum no longer used in aircraft. Future UAV designs must develop a definition of loads and safety factors related to the mission to achieve a rational, scientific design philosophy for this class of vehicles, rather than pursue evolutionary adaptation of existing manned aircraft design criteria.

New Materials Integration and Construction Processes - Composite materials, such as fiberglass and graphite tape and cloth, provide low structural weight fractions; however, the cost of manufacture of these materials can be high. Current quoted costs for aircraft composite structure are from $1,500 - $2,000 per lb; a near-term cost target for reduction of this should be $1,000 per lb. In addition to low weight, composite materials provide tailored surfaces for low observability. Further, there is ample room for innovative (and integrated) design for more structurally efficient high lift to drag (L/D) configurations.

The "ility" issues (including repairability, reliability, and maintainability) are different for UAVs than for manned aircraft that are used extensively during peacetime. Further, limited special use provides fewer opportunities for "friendly" damage and tends to dictate consideration of different construction materials such as composites.

UAV Life-Cycle Costs. Among the motivating factors for accelerating the development of UAVs for military applications is a significant *potential* for life-cycle cost savings. This potential manifests itself not only through the low costs projected for a new class of unmanned airborne platforms, but also in the promise of reduced operations and support costs. In discussing UAVs, there is a tendency to focus on the vehicle and its constituent subsystems, but the affordability issue must be addressed in a larger context that encompasses the interdependent elements of vehicle, weapon, and a highly integrated command and control capability. This section recognizes the investment that will be made over time in command, control, and communication systems for battlefield domination and addresses the potential that results from harnessing this capability to maximize platform performance while minimizing cost.

Operations and Support Costs - The combat UAV, reflected in concepts such as the Uninhabited Combat Air Vehicle described in the study "New World Vistas [4]" or the Unmanned Tactical Aircraft proposed by DARPA, affords unique opportunities for affecting airpower affordability. The potential for operations and support savings may be realized through a new paradigm in training, maintenance, and deployment. The key to this potential lies in two observations:

1. Most noncombat flying occurs as a result of the need to achieve and maintain pilot proficiency.

---

[4] United States Air Force Scientific Advisory Board Summer Study, *"New World Vistas: Air and Space Power for the 21st Century,"* 1995.

2. Training to “operate” a UAV can be made transparent to whether or not a vehicle is actually in flight.

The latter implies that training in the simulator and training in the aircraft are identical in principle and suggests an operational concept involving substantially less flying than today’s manned systems demand. It further suggests a leaner logistics ‘tail,’ including provisions for extended periods of aircraft storage and a concomitantly smaller team of maintainers, other support personnel, and infrastructure. Recent studies, sponsored by DARPA and conducted by several organizations, including a major U.S. aircraft manufacturer, have suggested cost savings potential approaching 90% overall in peacetime operations and support.

Storage of aircraft in a protective environment that permits rapid reconstitution of assets (minutes to hours) to meet wartime deployment or peacetime exercise requirements is a major and necessary part of the support concept. The study “Life Extension and Mission Enhancement for Air Force Aircraft[5]” addressed a “hermetically-sealed storage bag” concept that has been incorporated in recent combat UAV studies. Storage of aircraft in a dehumidified environment is a common practice by European air forces (Swedish, Danish, and British) as well as the United States Navy. In addition, the Swedish, German, and Israeli armies employ dehumidification storage for a variety of mechanical and electronic systems, including ground vehicles, with excellent success. In a recently released report[6] by the Logistics Management Institute, the benefits of dehumidified protection are clearly demonstrated.

The key to this result, and good news from a cost perspective, is the single requirement to maintain the relative humidity between 25% and 40%. Low-cost desiccant wheels can currently provide this environment on the flight line and under more permanent storage conditions. Flight line bagging, “clam shell” shelters, hangars, and special storage containers have all been combined satisfactorily with dehumidification systems in both operational and support scenarios. Storage for ease of maintenance, rapid deployment, and low cost appears to be readily available and will likely be used for both manned and unmanned aircraft in the near future. The study group spent considerable time examining the viability of the “wooden round” concept, especially as applied to existing cruise missiles, and was convinced that the idea had merit. The most important step is to build in this capability from the outset.

Another concept synergistic with extended aircraft storage is that of an “attritable” platform—a low-cost vehicle designed to take advantage of its limited life requirement. Aircraft built on this concept would be maintained and supported more like their expendable (e.g., missile) counterparts. This “quasi-wooden round” attribute also reduces the need for support personnel in peacetime.

---

[5] United States Air Force Scientific Advisory Board Summer Study, *“Life Extension and Mission Enhancement for Air Force Aircraft,”*1994.

[6] Logistics Management Institute White Paper LG518LN1, *“Using Dehumidified Preservation as a Maintenance Technology for DoD Weapon Systems and Equipment,”* McLean, VA., 1996.

Vehicle Acquisition Costs - 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 the human crew and related subsystems is conservatively estimated at 5%. However, substantially greater weight savings will 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.

4.3 Platform Summary

The study group organized its work around two distinctly different types of air vehicles for UAV applications: those that emphasize endurance and those that emphasize performance. Both categories have the potential to greatly improve the ability of the Air Force to execute its missions on behalf of the Nation.

The study group strongly believes that the current Tier programs for endurance air vehicles (Global Hawk, DarkStar, and Predator) are on the right course. Moreover, since they have ambitious goals in terms of their combinations of altitude, range, endurance, payload, and observability, these programs must be protected from external changes to maximize their chances of success. The current Tier UAVs have not been designed to accommodate weapons: addition of weapon carriage is likely to entail performance penalties and could disrupt these critical programs. However, advanced UAVs in these payload classes could be designed to be weaponized.

The future potential of unmanned aircraft extends beyond the baseline concepts presented in this report. Imagine the following types of UAVs, mention of which is intended to stimulate the reader to look beyond the near-term to the far future: a CONUS-based, hypersonic transatmospheric aerospace plane capable of overflying any location in the world and returning to base in less than two hours; a high altitude, global range, indefinite loiter VLO combat UAV; or a very large global range transport capable of providing emergency humanitarian aid without exposing an aircrew to danger.

(This page intentionally left blank)