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UNMANNED AIR VEHICLE/REMOTELY PILOTED VEHICLE ANALYSIS FOR LETHAL UAV/RPV

by

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An investigation was conducted to provide a comprehensive evaluation of current Unmanned Aircraft Vehicle/Remotely Piloted Vehicle (UAV/RPV) systems and its applicability as a lethal weapon system. Numerous systems were evaluated while concentrating on the Department of Defense more prominent programs, the Pioneer UAV, Vertical Takeoff and Landing (VTOL) UAV and BQM-147A (EXDRONE) UAV. Israel has proven time and time again, that UAVs/RPVs, when properly integrated into the combat arena as a lethal weapon system, can contribute significantly at a lower cost with less risk to an aircrew man in a manned aircraft system. In general the thesis shows many capable UAV/RPV systems designs are available in the market place today. These systems are assessed to determine their viability in the every changing combat environment.

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Unmanned Air Vehicle/Remotely Piloted Vehicle Analysis for Lethal UAV/RPV

by

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ABSTRACT

An investigation was conducted to provide a comprehensive evaluation of current Unmanned Aircraft Vehicle/Remotely Piloted Vehicle (UAV/RPV) systems and its applicability as a lethal weapon system. Numerous systems were evaluated while concentrating on the Department of Defense more prominent programs, the Pioneer UAV, Vertical Takeoff and Landing (VTOL) UAV and BQM-147A (EXDRONE) UAV. Israel has proven time and time again, that UAVs/RPVs, when properly integrated into the combat arena as a lethal weapon system, can contribute significantly at a lower cost with less risk to an aircrew man in a manned aircraft system. In general the thesis shows many capable UAV/RPV systems designs are available in the market place today. These systems are assessed to determine their viability in the ever changing combat environment.

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I. INTRODUCTION

During the past few years, despite budget cuts and force draw downs, increased interest has been shown by the US Armed forces in unmanned air vehicle/remotely piloted vehicle (UAV/RPV) systems for many military mission applications. The two primary advantages of UAV systems are mission effectiveness and cost effectiveness, especially in heavily defended combat environments where the high risk of manned aircraft loss may not be mission or cost effective. The overriding factor, though, is cost, in that an entire UAV system, including ground control stations and associated support equipment, may be less than one-tenth of the total cost of the manned aircraft system. Initially, bringing additional technology to bear on refining or optimizing the UAV system may increase costs somewhat, but with future procurements in sufficient numbers to generate economy of scale, the UAV system costs will still stay at a small fraction of manned aircraft system costs. In general this thesis shows many capable UAV/RPV system designs are available in the marketplace today and current Department of Defense (DoD) UAV/RPV procurement goals are in place to support a lethal UAV/RPV mission. With the advancements made in many key technologies in the past few years, it is time to evaluate the potential of unmanned offensive strike delivery systems to augment manned aircraft. This thesis should contribute to the United States Navy data base on UAV/RPV systems.

A. OBJECTIVES

The objectives of this thesis are twofold; to provide a comprehensive evaluation of current UAV/RPV systems and secondly to convince military leadership to push for the evaluation, development and incorporation of these systems into the strike weapon arsenal of the United States. The first objective was to divide the RPV technology fields into specific areas based on the RPV system components. These specific technology areas then became the primary sections of this report and include:

- vehicle technology
- propulsion technology
- guidance and control systems technology
- launch and recovery systems
- ground control stations
- mission payload/sensor technology

In each case, although it was attempted to provide general, descriptive information on all aspects of RPV/UAV technology, the focus was always on those specific systems or technology developments that would be of interest to the USN's development of a lethal UAV/RPV.

The term UAV (unmanned air vehicle) and RPV (remotely piloted vehicle) are used somewhat loosely, to include both radio-controlled vehicles and autonomous unmanned vehicle systems. Both terms will be used interchangeably throughout the thesis.

II. DEPARTMENT OF DEFENSE PROGRAMS

This chapter provides specifications for a family of UAVs required by all branches of the U. S. Armed Forces. These specifications include Short Range (SR), Close Range, and Medium Range (MR) UAVs.

A. UAV/RPV DEFENSE PROGRAMS

A summary matrix of the Major Defense Acquisition UAV Programs is depicted in Table 1. Only unclassified information is provided.

1. Short Range UAV System

SR capabilities support DoD division through echelons above corps (EAC) level and Marine Air-Ground Task Force (MAGTF) level. Enemy activities out to range of 150 km or more beyond the forward line of own troops (FLOT) or datum point (in USN operations) are the focus of SR activities. These UAV systems are more robust and sophisticated, can carry a wider variety of payloads, and can perform more kinds of missions than CR systems. The SR UAV system is the baseline for the family (i.e., SR, CR, Vertical Takeoff and Land (VTOL)) of UAVs. SR will provide near-real-time RSTA to U.S. Army (USA) EAC, divisions, and U.S. Marine Corp (USMC) expeditionary brigades out to 150 km beyond the FLOT, day or night, and in limited adverse weather conditions. SR is intended for employment in environments where immediate information feedback is needed, manned aircraft are unavailable, or excessive risk or other conditions render use of manned aircraft less than prudent. [Ref. 1,2]

TABLE 1

DOD UAV PLANNING

	CLOSE RANGE	SHORT RANGE	MEDIUM RANGE
SERVICE	USA, USN, USMC	USA, USN, USMC	USN, USAF, USMC
SERVICE ORGANIZATIONAL LEVEL	DIV, BDE (USA) BN & LOWER	CORPS, EAC, DIV (USA) RPV COMPANY (USMC) Ship (USN)	CVAW (USN):SQUADRON (USAF)
MISSION	RSTA	RSTA	PRE & POST STRIKE RECONNAISSANCE, BDA
RADIUS OF ACTION	50 KM (30 NM)	CLASSIFIED	650 KM (350 NM)
PAYLOAD CAPACITY	50 LBS	200 LBS	350 LBS
SENSOR	IMAGERY, MET	IMAGERY ECM	ATARS
GROWTH	EW, NBC	SIGINT, MET, COMM	EW, COMM/RELAY, EW, JAMMING, ELECTRONIC, SIGINT, MET, TARGET DESIGNATION
ENDURANCE	3 HRS	CLASSIFIED	2.5 HRS
LAUNCH/RECOVERY	STOL	CTOL	AIR LAUNCH; LAND/HELO RECOVERY
GROUND STATION	VEHICLE	VEHICLE	JSIPS (PROCESSING)
TOGW	TWO PERSON TRANSPORTABLE/200 LB CLASS	1,700 LBS	2,200 LBS
AIR SPEED	80 KTS	CRUISE < 90 KTS DASH > 110 KTS	500 KTS < 20,000 FT 9 MACH > 20,000 FT
ALTITUDE	10,000 FT	15,000 FT	MIN 500 FT AGL MAX 40,000 FT MSL
DATA LINK	ANTI-JAM CAPABILITY	ANTI-JAM CAPABILITY	JSIPS INTEROPERABLE, ANTI-JAM CAPABILITY

LEGEND
ATARS - ADVANCED TACTICAL AIR RECONNAISSANCE SYSTEM
BDA - BATTLE DAMAGE ASSESSMENT
BDE - BRIGADE
CTOL - CONVENTIONAL TAKEOFF AND LANDING
CVAW - CARRIER AIR WINGS
EAC - ECHELON ABOVE CORPS
EW - ELECTRONIC WARFARE
JSIPS - JOINT SERVICE IMAGERY PROCESSING SYSTEMS
MET - METEOROLOGICAL
NBC - NUCLEAR, BIOLOGICAL, CHEMICAL
RSTA - RECONNAISSANCE, SURVEILLANCE AND TARGET ACQUISITION
SIGINT - SIGNALS INTELLIGENCE
STOL - SHORT TAKEOFF AND LANDING
TOGW - TAKEOFF GROSS WEIGHT

The SR system consists of a mission planning station (MPS), two ground control stations (GCSs); remote video terminal (RVTs), eight air vehicles; modular mission payloads (MMPs), ground data terminal (GDTs), and launch and recovery equipment. The mission planning and control station (MPCS) collects, processes, analyzes, and stores data and distributes battlefield information by interfacing with present/planned Service C3I systems. [Ref. 1] Flight and mission commands are sent through ground data terminals to the air vehicles and modular mission payloads from the MPCS. RSTA information and air vehicle position data are sent by downlink either through airborne relays or directly to the MPCS or RVTs. [Ref. 2] Mission data may also be recorded onboard the air vehicle to prevent loss during interruptions in the downlink data flow. Data is received by the MPCS and can be distributed to RVTs located in tactical operations centers. [Ref. 2] Mission capability will be enhanced as advanced mission payloads which are discussed below become available. The specific modifications under development are [Ref. 1,2]

- **Autosearch** - Automatic pattern search of designated area
- **Autotrack** - Capability of automatically holding the air vehicle's sensor line-of-sight on a designated target
- **Manned surrogate trainer** - Allows the system to operate with a manned UH-60 helicopter carrying a sensor pod to provide mission training in restricted areas.
- **Heavy fuel engine** - The heavy fuel engine effort will design an engine with the capability to operate on diesel, JP-5 or JP-8 fuel.

The SR program also includes the advanced development, prototyping and testing needed to incorporate additional required sensor payloads, command, control and communications upgrades, survivability improvements, and data link hardening. Other issues under consideration are, electronic intelligence (ELINT), signals intelligence (SIGINT), radars, meteorology and lightweight hardened data link [Ref. 2].

2. Close Range UAV System

CR capabilities address the needs of lower level tactical units such as USA divisions and brigades/battalions and USMC battalions/companies for a capability to investigate activities within their local area of interest, (approximately 30 km beyond the FLOT). Systems must be easy to launch, operate and recover; require minimum manpower, training and logistics; and be relatively inexpensive. The employment concept for the CR UAV system is to perform launch, recovery, handling, mission/control and data distribution in close proximity to the FLOT. [Ref. 1] The joint service requirements at division and subordinate levels of command for near-real-time image intelligence is out to 30 km beyond the FLOT. Also driving the requirement for the CR UAV is the need for two person transportable system which can operate in a confined launch and recovery area. [Ref. 1,2]

The CR UAV program has proceeded with concept definition through analysis of data generated from other UAV programs such as the EXDRONE and Pointer Hand Launched UAV programs. This data, along with air vehicle technology demonstration efforts, has been used to define the system concept. In 1992 the CR program completed technical demonstrations of air vehicles and FLIR payloads. The objective of the demonstrations was to reduce risk by demonstrating the maturity of technology for the 200 lb class air vehicle and FLIRs less than 50 lbs. [Ref. 2]. FLIR demonstrations were successfully completed in January 1992, while the air vehicle demonstrations for 200 lb class were successfully completed in July 1992. The demonstrations proved that CR type air vehicles payloads are capable of performing within the technical parameters required for the CR system. [Ref. 1]

3. Medium Range UAV System, BQM-145 Specter

MR capabilities address the need to provide pre and post strike reconnaissance of heavily defended targets and augment manned reconnaissance platforms by providing high quality near-real-time imagery [Ref. 1]. They differ from other UAV capabilities in that the vehicle is designated to fly at high subsonic speeds and spend relatively small amounts of time over target areas of interest. Military operations in Vietnam, Lebanon, Grenada, and most recently, Southwest Asia, have shown severe tactical deficiencies in the collection of near real time reconnaissance data at radii of up to 350 nm [Ref. 3]. Further, as enemy forces become more mobile and weapon system technology advance, the gathering of tactical reconnaissance data by manned aircraft will become increasingly more difficult and hazardous. Tactical commanders need the capability to acquire real, or near real time reconnaissance data, day or night, in increasingly higher threat environments routinely and quickly [Ref. 3]. The MR UAV is an organic, low cost, highly survivable asset that can collect EO/infrared (IR) data on fixed targets at radii up to 350 nm, day or night, and provide this data to tactical commanders in near real time.

The MR UAV system is intended to provide multi-mission support to the C3I efforts required to conduct joint operations. As presently configured, the UAV system is capable of performing the following missions: reconnaissance, target acquisition, and battle damage assessment (BDA). The MR UAV complements manned tactical aircraft and other reconnaissance capabilities of the Services for the 1990s and beyond. Imagery data will be collected on fixed targets and locations at radii up to 650 km from the launch point. Imagery will be of sufficient resolution and accuracy to support targeting for air and ground delivered weapons and to provide BDA. The MR UAV will fly high risk missions in heavily defended areas over land and sea and provide a needed day/night, under the weather reconnaissance capability. The F/A-18C/D aircraft will be used for air launch by the USN and USMC, while the F-16R will be used by the USAF. A ground launch capability unique to USAF is planned to be used for about 80% of the USAF missions. The MR UAV will use existing Service mission planning/programming systems: The Tactical Aircraft Mission Planning System (TAMPS) for the USN and USMC and the Air Force Mission Support System (AFMSS) for USAF. The vehicle will be reusable and compatible with recovery on land, water, or in mid-air. [Ref. 1,2]

The MR UAV program is currently proceeding with both a risk reduction and engineering & manufacturing development programs. The risk reduction effort involves contractor flight testing of two graphite composite vehicles with development reconnaissance payloads. The first powered flight of the MR UAV (Specter) was conducted in May 1992, during which successful engine start, air launch, powered flight and recovery of the air vehicle were demonstrated [Ref. 4]. A second air-launched mission in July 1992 demonstrated autonomous flight, imagery collection, and recovery for the MR UAV (Specter). An air launched flight in December 1992 demonstrated the GPS navigation capability of the MR UAV as it traversed an instrumented course on a test range [Ref. 4]. In support of the design efforts, an F/A-18 loaded with an inert MR UAV will be operated in a simulated aircraft carrier environment to assess compatibility of the production design. Testing will examine critical F/A-18 launch, recovery, and flying qualities with an emphasis on vehicle-to-aircraft, and vehicle-to-deck clearance during arrested landing [Ref. 4].

B. OPERATIONAL SYSTEMS - PIONEER UAV SYSTEM

1. Purpose

The Pioneer system was acquired rapidly, as an interim system, to fill an immediate need to provide the operational forces with deployable tactical assets. The system provides day and night near-real-time reconnaissance, surveillance and target acquisition (RSTA), BDA, artillery fire correction/adjustment of fire, and battlefield management within line of sight of its ground control station (GCS) [Ref. 11]. The air vehicles low radar cross section (RCS) and infrared (IR) signature, and its ability to operate by remote control make it particularly useful in high threat environments where manned aircraft would be vulnerable [Ref. 19].

2. Concept of Operations

A Pioneer system consists of five air vehicles, five day television and four FLIR payloads, a GCS, a portable control station (PCS), up to four remote receiving stations, a pneumatic or rocket assisted launcher and net or runway arrestment recovery systems. The air vehicle is a short range, remotely piloted, pusher propeller driven, small fixed wing aircraft that may be either land based or ship based. It operates between 1,000 and 12,000 feet, 60 to 95 knots, and in excess of 100 nm from the GCS. The Pioneer air vehicle is operated real-time from a control station or can be programmed to fly independently. It relays video and telemetry information from its onboard reconnaissance payload systems. Line of sight between Pioneer and GCS must be maintained at all times for positive flight control and imagery data link. The air vehicle may be handed off from GCS to another GCS, effectively increasing the air vehicle's range to its fuel limit. This allows launch form one site and recovery at another. The Pioneer system can control two air vehicles simultaneously, although the video downlink and positive control can be managed for only one air vehicle at a time. In wartime, the Pioneer systems are deployed by Marine Air-Ground Task Force (MAGTFs), USN battle group commanders, or USA division commanders to provide real-time tactical information. During peacetime, Pioneer units will be tasked with proficiency and mobilization training, tactical intelligence collection, tactics and operational concept development, and support of MAGTF, battle group, and divisional training exercises [Ref. 1,2]. Since the decommissioning of the battleships, plans have been developed to install USN Pioneer systems on LPD class ships [Ref. 7]. The entire land based system can be transported with vehicles and trailers.

3. System Interfaces

The Pioneer system has two basic configurations, ship installed and shore based. The ship installation currently being completed for LPD is similar to the previous battleship installation in that permanent antennae, fuel storage, and recovery net fixtures must be in place. Aviation gasoline (AVGAS) for the air vehicle and the rocket assisted take off (RATO) launch bottle require special handling and storage procedures on board ship. Shipboard flight operations require special consideration of air space allocation, control frequency allocation, and electromagnetic interference caused by the launch ship and other ships in company. [Ref. 1,2]

The land based systems are self contained. However, they also require special facilities to operate. The air vehicle a needs prepared landing surface or runway to set up the arresting gear. There must be sufficient area cleared for the various ground support equipment. Safe AVGAS and RATO storage and handling facilities need to be in place. The vehicles used to transport the Pioneer system require service and maintenance facilities. [Ref. 1,2]

C. DEMONSTRATED SYSTEMS - VERTICAL TAKEOFF AND LANDING UAV SYSTEM

1. Purpose

The objective of the VTOL is to complete a risk reduction demonstration of a VTOL UAV capability which compliments the SR system and which is integral to ship's combat systems. The VTOL UAV system will provide: targeting and BDA; offboard electronic countermeasures (ECM) for antiship missile defense; and NADE RSTA support for land force. [Ref. 3]

2. Concept of Operation

A fielded VTOL UAV would incorporate the requirement of the UAV family architecture, achieve operational interoperability through incorporation of Joint Integrated Interface (JIIs), and would provide the USN, USMC, and USA an organic, tactical RSTA capability [Ref. 2]. The VTOL system concept for naval applications focuses on integrating SR UAV system software and hardware into ship subsystems. Thus, USN and USA forces may operate either the SR UAV or the VTOL UAV using organic command and control assets or may share resources and exchange air vehicle with another service's control stations. The air vehicle would be a high speed VTOL capable of carrying imaging sensors common with the SR and CR UAV programs, incorporating the SR command and control and video down link to ensure interoperability [Ref. 2]. SR system software will be hosted on an existing USN Tactical Advanced Computer-III (TAC III). An existing USN MK-III AN/SRQ-4 datalink will be modified to operate both the SR and VTOL [Ref. 1].

3. Systems Interface

The UAV JPO is coordinating with the SR program office and several other agencies for the VTOL UAV Technical Demonstration program. Coordination with Navy agencies include Space and Naval Warfare Systems Command (SPAWAR) for data link and battle force integration and Naval Sea Systems Command (NAVSEASYSCOM) for ship integration. Coordination with external agencies include ARPA for concept evaluations using distributed battle force simulations. [Ref. 2]

III. VEHICLE TECHNOLOGY

A. SYSTEM INTRODUCTION

In this chapter technology and engineering developments are discussed for numerous types of UAVs with and their expanded capability or incapability as a lethal UAV. The UAV systems from Europe, East Asia, and North America that

- carry a payload
- have an endurance greater than 1.0 hour

and are representative of the family of UAV systems (SR, CR, MR) outlined in Section II were considered. These systems are briefly described below.

RPVs FOR DISCUSSION

- **U.S. ARMY AQUILA:** A small (140-lbs) RPV with 3-hr endurance and 118-kt maximum speed. Planned missions include surveillance, target, acquisition, artillery adjustment, and laser designation for precision guided weapons. Special configurations provide spread spectrum communications, automatic link loss reacquisition, and adjustment linking (high-g avoidance maneuver).
- **U. S. NAVY PIONEER:** A (250-lbs) UAV with 5-hr endurance and 110-kt speed. Its missions to provide reconnaissance, surveillance, and target acquisition (RSTA) to both Navy forces at sea and USMC forces on land. The Pioneer air vehicle is capable of operating with a daytime TV camera payload or a day/night infra-red camera, both with near-real-time video downlink to the control station.

- **ISRAELI MASTIFF:** A small RPV used for battlefield and battle group surveillance. It weighs 250 lbs. and has a flight endurance of 6 hours.
- **ISRAELI SCOUT:** A larger propeller-driven RPV with a takeoff weight of over 300 lbs and a maximum cruising speed of 95 kt. It has been used for surveillance with a stabilized TV camera and for decoy operations by electronically emulating larger aircraft.
- **BRITISH ARMY PHOENIX**: A small RPV fitted with thermal imaging (infrared (IR) zoom) for both day and night surveillance.
- **USAF BQM-34:** A high-cost, high-performance (700-kt) radio command drone. Reconnaissance, EW, and warhead versions have been used. Weight is between 2500 and 5000 lbs, and range is up to 700 nm.
- **BOEING BRAVE 3000:** A low cost, completely autonomous, and minimal maintenance UAV. Mission objectives are long endurance, defense suppression, surveillance, and electronic warfare.
- **BOEING PENGUIN:** A low Reynolds number UAV, mission is an important one currently being studied for possible future flights in the atmospheres of other planets and for specialized military missions. The Penguin has robust control, highly durable, and carries a small payload.
- **BELL HELICOPTER POINTER:** A tilt-rotor VTOL, 600 lbs gross weight. The VTOL capability of its propulsion system obviates all launch and recovery equipment without forfeiture of high forward speeds during critical mission segments; in particular, shipboard operations can be readily conducted from small deck areas at sea.
- **USAF BQM-145A SPECTER:** In the engineering manufacturing and development phase of the acquisition cycle, and has a projected initial

operational capability in 1999. Carries the Advanced Tactical Air Reconnaissance System (ATARS) sensor suite and datalink. Payload capability up to 400 lbs - electronic intelligence, communications intelligence, jamming, weather-atmospheric, decoy.

UAVs are generally more complex than RPVs in their overall design because they are required to accomplish a higher degree of mission performance and to be considerably more controllable regarding their mission path or profile. Typically, UAVs and RPVs have long mission times and carry a variety of payloads that involve technical complexity. As roles are expanded, mission profiles may include any or all of the following:

- reconnaissance
- surveillance
- target detection and location
- airborne early warning
- suppression of enemy air defense
- attack of hard targets
- anti-ship missile defense
- anti-helicopter defense
- communications relay
- damage assessment
- NBC detection
- electronic surveillance
- electronic countermeasures
- decoy
- battlefield planning/assessment

- harassment
- and more

With such a varied mission capability it is readily seen that design requirements may be more rigid than those currently set forth. [Ref. 21]

B. AERODYNAMIC DESIGN

The aerodynamic design of the RPVs in question varies widely. The few high speed vehicles (0.7-0.9 Mach) all have tubular bodies and short wings or fins. (BQM-34,Brave 3000) They appear to be more of a traditional missile shape than anything else. The fixed-wing RPVs are also varied in appearance with the majority being straight or slightly tapered-wing monoplanes. Some monoplanes have constant-chord wings, of which some have right-left interchangeable wings and tails. There are delta wings or clipped-delta wings and some with folded wings that unfold at launch. Tail booms and twin tails are present on several of the more well-known models.

While there are some unusual configurations, by far most RPVs resemble large model aircraft commonly made by an intermediate or advanced hobbyist. Most are simple designs with uninspired aerodynamics. Calculated L/D values of cruise or loiter range from 1.0 to 2.4 for flights from sea level up to 1,500 feet, this being normal operating range of altitudes [Ref. 6]. Stall velocities are generally around 40-45 knots and maximum velocities are usually below 135 knots, with 100-110 knots the average Vmax [Ref. 6]. Aspect ratios vary between 3.7 and approximately 8. The high aspect ratio, low altitude and speed, and good fuel consumption of the reciprocating engines yield the good range/endurance characteristics. Aerodynamics generally are compromised to facilitate modular construction, lightweight, simple fastening devices, and high payload fractions.

1. Structural Design and Modularity

Most RPVs researched appear to be designed to be lightweight and modular. This is because they spend most of their time stored in crates on trucks or vans and must be quickly and easily assembled in the field. A complete RPV system occupies up to 3-5 vans, or trailers, pulled by trucks [Ref. 11]. The RPV must therefore be capable of being packaged for transport in the smallest possible vclume. There is also a need for the air vehicle to be handled during all phases by as few as 2-4 men; the fewer the better. Such handling nearly always includes what could be classified as "rough" handling and therefore requires a design concept of modular assembly and ruggedness. One additional factor is that, during operational or training flights, it is possible that the air vehicle could unintentionally experience in-flight g-loads of equal or greater magnitude than any manned aircraft. Launch and recovery can be under conditions of up to 9 g axially while in-flight maneuver g loads may be applied on all axes [Ref. 11].

It is not unusual to see such high strength-to-weight materials such as carbon fiber, kevlar, and epoxy resins used in RPV structural design. In fact, almost all RPVs composites. Structural designs utilize fiberglass, honeycomb, molded glass fiber-reinforced plastics (GRP) or wound glass fiber impregnated with resin. Wings may be molded integrally with the fuselage or one or two piece modular design with glass fiber skin and rigid poly-vinyl chloride injected foam core, wood frame with veneer skin, or rigid foam cores covered with anything from wood to nylon to aluminum.

Some structural concepts are driven by making certain components multi-purpose or multi-functional. For example, the Aquila design utilizes wings which can be installed on either the right or left with no modifications. The same approach is used on the tailplane (horizontal tail). Still other components, such as wingtips and nose cones, are either frangible or crushable and intended to be replaced after each flight. Virtually all RPVs are modular in construction to one degree or another.

While some of the structural approaches may appear to be elaborate, there is little technology employed that cannot be automated to construct the individual components. For example, a fuselage may be constructed almost entirely out of one sheet of GRP/honeycomb which is merely cut, folded, and bonded as on the Phoenix. Bulkheads are cut from the sheet and bonded in place, as are the hinged lids to give access to the engine, payload, and recovery parachute bays [Ref. 9]. GRP moldings form the nose and rear body failings. Being modular, the vehicies are then assembled using such quick-connect and disconnect methods as bolts, snaps, tabs and slots, and elastic cords [Ref. 9].

2. Materials and Maintainability

Material choices are made to minimize weight and reduce cost. As previously mentioned, frequent use has been made of kevlar, fiberglass, plastics, PVC foam, resins, and other materials which lend themselves to being used in composite construction methods. Also used are wood in structure, veneer in skin, sheet aluminum, extruded aluminum and other light alloys as well as steel. To one degree or another almost any material found in manned aircraft has been used, including balsa wood.

By far the most frequently used material is some form of fiberglass. Construction methods are many and so are the materials combined with fiberglass. However, the fact remains that the structural choice is fiberglass whenever it fits the requirements [Ref. 9]. With so much diversity in designs there does not appear to be an overwhelming choice in construction methods, but molded fiberglass with a rigid foam filling has been the most widely chosen material and manufacturing method. Slow speed RPVs utilize almost exclusively fiberglass construction, whereas high speed subsonic vehicles utilize a higher proportion of aluminum alloy in the fuselage and control surfaces due to higher dynamic and structural loads.

Modular construction lended itself to replacing components and even mentioned the norm of carrying certain component spares in the aircraft transport vehicle. Typical spare components are: landing bags, frangible structures, parachutes, canards, wingtips, nose cones, skids, tails and engines [Ref. 6].

Over the life of the vehicle, it can be expected to require some sort of airframe maintenance. Most have been designed to withstand normal operation for reasonable time as evidenced by special considerations such as toughened skids, expendable nosecones, landing bags, etc. Only two systems are known to have been designed for operation at sea (Pioneer and Phoenix). They are recovered from sea water where they land by parachute or net, are then washed with fresh water and serviced. The payload compartment is water-tight and the engine has a sealed, maintenance-free, electronic ignition system for use in a salt environment [Ref. 8]. A more complete description of shipboard/seabased recovery methods is provided in Chapter 3, Section E.

In summary, the maintenance concept for the vehicles of this paper is based for the most part on component replacement. Payloads as well as guidance and control features are covered in other sections.

3. Take-off Gross Weight vs. Payload and Size

One of the greatest trade-offs to be made in an RPV is that of payload and fuel. It would be difficult, if not impossible, to determine the design requirements of all the RPVs in this paper. However, it is intuitively evident that most were designed to carry specific payloads on specific mission profiles which in turn defined their fuel loads. All of the systems are volume and weight limited since designs do not exist that allow for excess volume or weight. Most probably, designs were driven by a desire to minimize physical size and maintain reasonable cost. The former is obviously desirable if systems are to be survivable in a hostile environment, and the latter is a pre-ordained requirement.

While all of the above observations have exceptions, most can be explained by the design mission or other special design characteristics. It is clear that care must be taken in selecting payload size and weight in order to maximize the fuel fraction if long endurance or range is of utmost importance.

One design, the Mastiff, is noteworthy in that it impacts endurance by limiting fuel loads [Ref. 18]. As far as can be determined, all RPVs in this analysis carry their fuel solely in the fuselage along the centerline and right on the CG such that fuel usage does not upset vehicle stability.

Physical size in a few of the RPVs does not appear to cause any handling problems since almost all are modular and each component is capable of being handled by one man. Take-off gross weights for low speed RPVs seldom get above 400 lb and physical dimensions of wing span and length each generally fall between 8 and 16 feet. With endurance up to 7.5 hours at TOGWs below 450 lb [Ref. 10]. It is hard to see how requirements would sensibly drive weights and dimensions much higher, especially since maximum packaging density in the vehicle volume has not been nearly approached. In some cases a very small amount of redesign could greatly increase the fuel load.

4. Radar/IR/Visual Cross-Section and Survivability

Most RPVs use designs and manufacturing methods that result in very survivable vehicles. For the Israeli RPVs which are combat proven, entire campaigns have been fought without a single RPV combat loss. A prime reason for this is the removal of the man from the cockpit. Just the man alone takes up over 10 cubic feet and weighs over 200 lb [Ref. 19] . When an environment and sensors of all kinds are provided to support an onboard aircrew, these numbers increase rapidly. This becomes a high price to pay to put the human sensor in the sky if the primary missions are reconnaissance, surveillance, targeting, etc., and they can be accomplished by an RPV.

RPVs generally have four or more hours of endurance, weigh about 400 lb or less and have wing spans between 11 and 16 feet [Ref. 6]. They generally fly around 1,500 feet at 75 to 90 knots when they are actively sensing the ground area and operate at higher altitudes when cruising or loitering. They normally produce little smoke, noise, or heat and are propeller or rotor driven. They are made of composite materials for the most part and have a low radar cross-section. In summary, they are not very detectable.

The low detectability of a target flying at a speed of 90 knots against a low-altitude, cluttered background (slant range of 8-10,000 ft.) makes the probability of survival remarkably high [Ref 19]. As the RPV closes range to target, the detectability will rise but the probability of kill remains low since it is proportional to the presented signature multiplied by possible engagement time. Since the presented signatures are low, the probability of kill may remain sufficiently low to not require a high-speed vehicle with its corresponding shorter endurance. The detectability of the radiating sensor signals that may be in use as well as the active data link, presents a separate problem. [Ref. 19]

The vast majority of the RPVs are constructed of non-metallic materials that are nearly radar-transparent. Even when they suffer a direct hit from ground-fire, the vehicles sustain little damage because they are constructed of low density materials such as fiberglass, PVC foam, wood, etc. [Ref. 19]. In addition, the RPVs can easily be manufactured or reconfigured by the operator or in pre-programmed mode, at least during cruise or loiter.

Radar detectability for those that are not nearly radar-transparent can still be difficult. Since detectability is determined by materials, size, shape and design, vehicles of the size considered here project a cross-section many orders of magnitude less than today's manned systems that would fly the same mission assignments [Ref. 19]. Combining small size, appropriate shapes, and near radar-transparent materials assures low detectability.

Apart from radar and IR detection there is always visual and noise detection. Here again, the small physical size tends to reduce the probability of visual detection. Even when the RPV comes within range to be heard on the ground, their small size delays detection and targeting which reduces the vehicle vulnerability. To reduce noise it is possible to suppress the exhaust to whatever degree is necessary [Ref. 19] . This is generally easier in a four-stroke engine than in a two-stroke engine.

5. Technology Needs

RPVs display a large variety of vehicle types and hence a wide spectrum of technology. In most cases, the vehicles are designed and built to accomplish a reasonably narrow range of missions and do not require advanced vehicle technology.

Most RPVs perform reconnaissance or surveillance missions as their prime role with secondary roles of target detection/tracking and electronic warfare. In such roles they require a reasonable payload and endurance in order to be effective and to reduce the number of vehicles required. Most RPVs payload is around 66 lb and the average endurance is over three hours. It would appear that these are reasonable values for the battlefield environment and therefore vehicle technology need not be pushed much further than has already been demonstrated. It is easy to envision US military requirements pushing these values higher, especially as the US experience grows and advantage is taken of RPV mission and operational characteristics such as a lethal UAV.

The need for improved technology to achieve more capable payloads and longer endurance is not exclusively tied to vehicle technology. In fact, with the insertion of microelectronics technology into defense weapons systems, payloads are beginning to shrink in volume and weight which allows for carriage of almost any type reconnaissance, surveillance or EW payload that is desired. Longer endurance can be achieved in two primary ways. The vehicle can carry more fuel or the propulsion system can operate more efficiently [Ref. 14]. Propulsion systems and their technology needs are addressed in Section III.

Increased fuel load could be achieved in almost every design. This is the highest payoff area for increasing endurance that also represents a low-risk and low-cost design enhancement. Several RPV designs have relatively large unused volumes which could be used for payload or fuel.

From an aerodynamic standpoint most vehicles of the fixed wing configuration could use a slight bit of cleaning up. There would be little gained relative to adding fuel or improving engine efficiently; however, there could be gains in payload volume if some of the vehicles were optimized to accommodate a wider variety of payloads. Overall, the design efficiency of many of the vehicles could have been optimized more than they were at little expense but with some improvement in payload and/or endurance. Aerodynamic technology needs are few for the vehicles, but optimization could add a lot to some designs based on specific mission requirements.

C. PROPULSION TECHNOLOGY

1. Propellers/Internal Combustion Engines

The most common propulsion mode for RPVs is a two-stroke piston engine with a two-bladed wooden pusher prop. Turbojet propulsion, coaxial rotors and electric powered propellers.

There is very little in the literature regarding the choice of propulsion. However, it is relatively apparent that two-stroke piston engines were chosen to drive propellers in the majority of cases because they are cheap, readily available, provide good fuel consumption, have low signatures (IR, noise, and smoke), and are generally of very high reliability. Two-stroke engines have probably been used in more different types of power applications than any other propulsion method, with the exception of electric motors.

The two-stroke engine represents a technology which has been developed and honed since the inspection of liquid fueled internal combustion engines have been in existence. They are manufactured in the appropriate sizes by the thousands and their adaptability in RPVs can be considered an obvious choice. Their biggest problem is vibration, which can be designed around such that detectable noise can be minimized. Most RPVs mount the exhausts pointing upward to reduce both the detectable noise and IR, and the prop wash generally aids in reducing IR signatures by mixing the exhaust and ambient air [Ref. 14].

The fuel used is generally a gasoline oil mixture (petrol) anywhere from 20:1 to 50:1. Petrol presents a problem for ship-based RPVs in the US Navy, because there is normally no gasoline or petrol aboard US Navy ships. Much effort and systems development was devoted over the past 20 years to removing aviation gasoline from aircraft carriers because of its volatility and associated dangers of explosion and fire. It is highly desirable to see Naval RPVs (including those for the US Marine Corps use on land) to be fueled by either JP-5 or diesel fuel. Ideally, the engine should run on either without adjustment or modification [Ref. 8]. The only current RPVs meet this criteria are the turbojet and turboshaft versions which run on JP-4 fuel and have a JP-5 capability with only a density adjustment required in the fuel control. A possible solution would be a diesel fuel burning Wankel or rotary combustion engine similar to the RC-2-90 built by the Curtiss-Wright Corporation and modified by them for the US Navy to utilize either diesel or JP fuels [Ref. 14]. The RC-2-90 is a fuel injected, spark ignition, rotary combustion engine designed for marine use which was never put into production. It is water-cooled but the same basic engine was built in an air-cooled, gasoline-fueled version for aircraft. [Ref. 8]

While neither engine went into production, they were built and tested in the proper environment. The air-cooled engine technology does not conflict with the heavy fuel technology, indicating there is no reason that the combination of these technologies should not work.

The Rotary and Wankel engines have a long history of success in smaller sized engines such as are required for RPVs. For example, rotary combustion engines have been mass produced for snowmobiles, lawn mowers, motorcycles, and even model airplanes. From their very inception they have been run on almost every fuel in existence [Ref. 14].

A typical two-stroke engine weighs almost one pound per horsepower in the sizes used in RPVs, as does the Wankel. Fuel consumption figures are not generally published along with other data about RPVs but calculations show that most use from 1.0-2.5 US gallons per hour of mission time based on 3-7 hour missions [Ref. 14]. Again, fuel consumption increases as maximum speeds increase because the RPVs are then generally over-powered for cruise and loiter. This is a trade-off that is particularly sensitive and when one examines endurance and power to TOGW as biased by payload and maximum velocity. The best endurance is obtained in those systems with low power to gross weight ratio. Other systems with low power to gross weight and low endurance have either a higher maximum speed or a high useful payload weight which reduces fuel load ratio. Some cases are attributable to VTOL capability such as in the helicopter configurations [Ref. 8].

Since most engines used are two-cycle engines using a gasoline-oil mixture such as petrol, they are simple and without complex features. They operate over quite a small envelope which generally does not exceed 135 knots and altitudes above 10,000 to 15,000 feet. The normal operating condition is generally in the 50 to 90 knot range at altitudes above 5,000 feet. Under these conditions, and assuming a design life of 500 flight hours, there would be little maintenance required other than filter changes, spark plug changes, and fluid refills [Ref. 14]. With reasonably reliable engines there would be a high probability that one or two spares for every 5 RPVs would suffice and there would be no need for skilled repair or maintenance personnel.

2. Turbojets

Turbojets have been selected for those applications where high speed was judged to be a requirement of the mission. Fuel consumption is very high in small turbo jets relative to reciprocating engines of similar size. Since engine weight is not critical, the weight advantage is the ability to provide high speed. Again, this is a trade-off that is very sensitive in terms of endurance time. Since survivability of an RPV does not appear to depend mainly on high speed, there must be other reasons to choose high speed as a design criteria [Ref. 19]. Most turbojet-powered RPVs had their origin as target drones where high speed is to reach a target area for reconnaissance or surveillance rapidly when that target area is a relatively long distance away [Ref. 14]. In this case time is the overriding factor.

3. Rotors/Autogyros

The helicopter-type RPV offers a flexibility of take-off and landing without nearly as much launch and recovery space or equipment. These RPVs can operate from almost any site that they can be brought to by their transport configuration that would be suitable for all types of shipboard operation because of their VTOL capability [Ref. 8].

All helicopter-type RPVs such as the VTOL, have coaxial, counter-rotating rotors and operate without tail rotors. All are very streamlined with spheroid vehicle shapes [Ref. 8,17]. They carry respectable payloads but fall on the low end of endurance as a natural penalty for rotary wing propulsion with VTOL capability. Careful attention to payload versus fuel could improve endurance when combined with a slight upscale of present designs.

The structural designs do not suffer from VTOL capability in that they are constructed of near radar-transparent materials as are fixed-wing RPVs [Ref. 8]. They generally exhaust upward, avoiding noise and IR signatures as much as possible. Some allow remote control landings in high wind conditions or in a high sea state. Others could have capability of being winched down by cable to a simple landing device or platform for a semi-automatic landing.

One autogyro vehicle (Penguin) carries a very large payload and is a relatively large vehicle. It has a long endurance which can be optimized depending on wind availability over the mission flight path. Good wind conditions can drastically increase endurance. To be useful in remote sites and/or aboard ship it would probably be scaled down slightly from its present rotor diameter of 20 feet. The concept does not allow VTOL since the rotor is never powered beyond an initial spin up at take-off, which is a normal ground run of 60+ yards beyond an initial spin up at take-off, which is a normal ground run of 60+ yards in still air [Ref. 8]. Landing is significantly shorter, on the order of 20 yards [Ref. 8].

4. Technology Needs

Aside from the fuel problem of all current RPVs using petrol, there is a need for specific engine design for RPV applications. Almost none of the current engines were specifically developed for RPVs and most have higher than necessary fuel consumption and vibration levels. British Aerospace has a UAV (Phoenix) powered by an engine specifically designed for ultralight aircraft and it displays the best fuel consumption of any RPV [Ref. 6]. They claim that the vibration levels were reduced by taking the output power at a relatively low speed from the camshaft which is gear-driven at half the crankshaft RPM [Ref. 6]. there engine is a four-stroke design that is significantly quieter. It is modular in construction and can be expanded from two cylinders to four or six cylinders with a maximum of common parts. This approach has obvious advantages and requires no real "Advanced Technology."

The fuel problem of petrol is the real challenge. It is desirable for RPVs on ships to use diesel (or jet fuel) and it is also desirable for land-based RPVs to use the same fuel supply as either diesel trucks or jet aircraft (or another readily available fuel).

D. GUIDANCE AND CONTROL SYSTEMS

1. Types of Guidance and Control

The type of guidance and control will be dictated by the RPV operational mission requirements and is dependent on the range of loiter time involved. A mission profile that does not take the vehicle beyond line-of-sight of a ground operator will have different guidance and control requirements from a vehicle that must go out 100 miles or more and loiter for four hours. The type of guidance and control for most RPVs/UAVs fall under one or more of the following categories of systems as discussed below: [Ref. 22]

1. Autonomous
2. Pre-programmed flight profile
3. Direct ground control from remote ground station

By far the most prevalent method is pre-programmed flight profile with data link update capability. The difference between autonomous and pre-programmed RPVs is only in the equipment used. Autonomous capability refers to systems with relatively sophisticated navigation equipment such as inertial navigation, Doppler radar, terrain contour matching systems, global positioning systems (GPS) or other navigation systems that require no external control inputs [Ref. 22]. Pre-programmed flight profile uses less sophisticated sensors such as speed, heading and altitude reference sensors, rate gyros and dead reckoning systems which may be used in microprocessor flight navigation calculations. In addition, many RPVs have beacons or transponders to generate tracking signals for radio or radar tracking. Direct ground control of an RPV from a remote ground station implies monitor and tracking of the RPV flight path as well as uplink (data link) control signals transmitted to and received by the RPV [Ref. 10].

2. Guidance and Control Configuration

In most guidance and control systems the parameters which are generally controlled are: altitude, heading, yaw, roll, speed, sensors on/off, engine on/off, yet even more configurations of systems within each general type. While functional guidance methods may be similar, equipment configuration seldom is. This is true of the guidance and control equipment that is part of the ground control station as well. It can be as simple as a single person with a hand-held control unit operating within line-of-sight as in the Pointer, all the way to a relatively large van, crammed with sophisticated electronic transmitters, receivers and display units. Again, from system to system the functions are similar but the systems equipment configurations are different. One further aspect of guidance and control is landing or retrieval control [Ref. 13]. Several RPV systems have ground homing beacons to position the vehicle in the final stages of flight to assure the accuracy of landing approach [Ref. 13]. This can be true even for the several types of different retrieval systems as discussed in Section V.

Fully autonomous guidance and control is achieved by a sophisticated system which represents a true "launch and forget" mode. Such a system is very expensive and consumes a high fraction of total vehicle weight which could be used for either fuel or sensor payload. Few systems are fully autonomous, most being of the pre-programmed type which will be discussed in the next paragraph. In order to maintain extreme navigation accuracy requirements of arriving at the predetermined target area, performing the required search pattern, locating targets, and then returning to the launch site or a separate retrieval site, the guidance and control system must have the ability to determine a present position without reference to a previous position, thereby avoiding the compounding of navigational error [Ref. 15]. Current capabilities would include use of inertial navigation systems or GPS. Future capabilities might include use of inertial navigation systems or GPS. Future capabilities might include updating of the ring laser gyros, fiber-optic gyros or terrain contour matching (TERCOM) systems for positions [Ref. 16]. There are obvious advantages in attaining extreme accuracy, but there are also significant disadvantages in achieving small, low cost payloads. For example, the extra weight detracts from both fuel for endurance and sensor/data link electronics payloads which contribute to the RPV mission success. In addition, the Navstar GPS or Omega systems are not jam-proof and extra weight and complexity would be required to make such a system secure [Ref. 15]. As mentioned before, few RPV systems will have or are anticipated to have such sophisticated guidance and control systems.

A pre-programmed flight profile is very similar to an autonomous system in that it can achieve a "launch and forget" mission. Most RPV systems, however, will provide periodic data link update capability. This RPV guidance and navigation system has less accuracy due to less sophisticated navigational instrumentation and computer capability and also due to the inaccuracy of relative navigation compounding errors. Such a system uses programmed and computerized waypoint data for a dead reckoning mode with continuously calculated positioning which may be updated and/or corrected by communication with a ground control station, remote control station, or an aircraft or other manned control base. The obvious disadvantage here is that such updating is not achieved in RF silence. If, however, inaccuracies of about 2% of mission range are acceptable, this system would be sufficient without updates. In general, with a dead reckoning navigation system, navigation errors of 2-5% of range can be expected without update [Ref. 16].

Direct ground control from a ground station, remote station, aircraft or other manned base is by necessity accomplished without RF silence and within line-of -sight of the controlling station [Ref. 7]. The radius of action as measured from the launch site can be extended by passing off to secondary and subsequent control stations with the current controlling station always being within line-of-sight. Accuracy is relatively high in that real-time data links usually provide constant vehicle position data as well as either TV or thermal image data. This type of guidance and control is the most commonly used in RPVs. Even those RPV systems that have pre-programmed flight capability have the ability to maintain direct ground control of the RPV during all phases of flight when within direct ground control of the RPV [Ref. 7].

3. RPV Control

The control of the RPVs is accomplished in much the same way as any other unmanned aircraft in that electronic commands received by the RPV computer generate electrical signals which cause actuators to move control surfaces in maintaining the desired flight profile. In addition to control surfaces, there are requirements for other actuators or switches such as throttle positioning, sensors on/off, data links on/off, sensor positioning, parachute deployment, engine on/off, etc. Typical control surfaces for RPVs are rudders, elevons, ailerons, elevators.

Most RPVs have provisions for emergency controller mission termination in the event of an equipment failure which prevents normal mission completion. In the case of an RPV indirect ground control, the most probable emergency would be either loss of data link or an engine failure. Loss of data link on some RPVs causes the RPV to automatically return to its original launch area and initiate parachute recovery to the ground [Ref. 16]. In some RPVs the loss of data link causes the engine to shut off and the parachute to deploy. Loss of the engine calls for the parachute to deploy immediately. If the RPV is not in direct ground control, but in a pre-programmed flight mode, the probability is for an automatic return to launch site if sensors are lost or immediate descent by parachute if the engine stops [Ref. 16]. Another alternative, would be for self-destruction of the vehicle.

4. Technology Needs

Navigation systems technology is presently available to achieve any degree of navigation accuracy desired/required for RPV missions. The main problems are size, weight and cost of equipment. While the mission requirements will establish the accuracy needed, there is still a need to achieve smaller size, lighter weight and less cost. The systems used by RPVs to meet navigation needs will most likely not come from sophisticated, high-cost systems in manned aircraft, so there will be a definite need to pursue the appropriate technology for RPVs [Ref. 13].

As RPVs are used over time, their roles and missions will expand. It can be expected that vehicle size will grow as payloads increase, speeds increase and endurance requirements grow. This will increase demands on control systems by putting higher load and power requirements on actuators as well as control surfaces themselves. At the same time considerable emphasis will be given to maintaining small physical size to preserve survivability characteristics. Higher speeds will result in higher load factor and also higher actuator power requirements. All weather conditions and salt exposure due to at-sea operations will cause added durability problems due to the severity of the environment.

Most systems are only designed to operate on dry land in less severe environments. Marinization is a required technology effort that few address when designing flight control systems [Ref. 8].

Some specific concerns are those associated with environmental hazards. An example would be seals for all types of equipment. Seals are required on payload compartments, engine ignition systems, control surface actuators, electric motors, gearboxes, and optical lens covers as well as many other exposed components. Among other environmental hazards to control systems will be EMI, EMP, sand, high and low temperatures, and both high and low humidity. While these environmental extremes are not new to aeronautical equipment, they do place severe burdens on many components of current RPV systems.

Producing equipment able to withstand such environments will increase the cost of guidance and control equipment for non-expandable RPV systems. It is therefore required to determine life-cycle cost trades to optimize designs for specific life-cycles based on missions, flight hours, at-sea recoveries, or other measures of RPV life durability [Ref. 8]. It would not be desirable to have infinite vehicle life due to high design and manufacturing cost, nor would the other extreme of expandability be desirable with such sophisticated payloads. Exact technology needs can only be determined by life-cycle cost analysis based on mission duty-cycle requirements and available state-of-the-art technology.

E. LAUNCH AND RECOVERY SYSTEMS

Launch and recovery systems and the associated technology provide as diverse an array of equipment as guidance and control systems. Yet there is one launch system and one recovery each that seem to be most frequently employed. The most used launch system is the rail coupled with a rocket booster which falls away shortly after launch. The most used recovery system is the parachute either as a primary system or as a backup.[Ref. 6]

1. Launch Systems

There are a number of different type launch systems used by manufacturers and operators. The following is a list of launcher types followed by a description of each [Ref. 6]:

- rocket
- flywheel
- pneumatic
- hydraulic
- elastic cord
- conventional
- VTOL

The rail launcher with a rocket is by far the most widely used. Even some of the RPVs which use other systems of launch have the ability to launch using a rocket boost. With a rocket launch the system is essentially a zero-length launch since the rail is the same order of magnitude in length as the RPV itself [Ref. 8]. As such it is particularly adaptable to launch aboard ships. Rocket launch has other advantages such as low cost, high predictability, and low time between launches. It also has disadvantages of pyrotechnic storage, corrosive products of combustion, and logistics.

A flywheel provides a rail launcher energy source which can be powered by either electric motors or liquid fueled engines, such as the drive train of the transport vehicle required to pull the launcher system. Electric motors or dedicated gasoline or diesel engines present added maintenance problems, but use of the engine in the transport vehicle would utilize this prime power source, which is already maintained to a high degree [Ref. 8]. Advantages of the flywheel launcher include low cost, freedom from ordnance hazards, and consistent and reliable launch velocity at relatively low acceleration rates with less than 10 g imposed on the vehicle at up to 35 meters/sec launch velocity [Ref. 6]. A disadvantage of the flywheel is its large size. As the size of the RPV grows, the size of both the flywheel and rail grow proportionally. While no production RPV that is ground launched is too big for a flywheel launcher, there is some upper limit for a practical launcher which is still mobile enough for military use. Another disadvantage is the relatively long recovery time after launch prior to subsequent launch readiness being reached.

A pneumatic launcher uses a compressed gas such as air or nitrogen to power a shuttle along a rail which varies in length with the weight of the RPV. The volume and pressure of gas also varies with the RPV weight. Such a system is quiet and relatively simple. The biggest disadvantage is the large amount of jerk (rate of change in acceleration) at the beginning of the stroke of the launcher [Ref. 6]. The pneumatic launch system is very fast in recovery for a subsequent launch and usually has a reserve tank good for up to 100 launches for light vehicles. Up to 50 Kg TOGW, and 10 for heavier vehicles (150 Kg). There appears to be no problem in temperature extremes between -70C and +65C. The following data is for a 300Kg RPV launched at an end speed of 35 meters/sec (68 kts) [Ref. 6].

G LOAD	LAUNCHER LENGTH
10 g	8 meters
20 g	5 meters
50 g	1.5 meters (zero length)

Most RPVs can withstand about 15-20 g's at launch; however, payloads vary tremendously in their g-load bearing capability [Ref. 6].

A hydraulic launcher uses hydraulic fluid as a controller to control jerk at launch initiation and generally uses compressed gas (nitrogen or air) as a power source [Ref. 6]. Again, size becomes a problem as vehicle weight increases. In addition, there are ever-present leaks in most hydraulic systems. For all practical purposes everything said about a pneumatic launcher is true about a hydraulic launcher, with the exception of the added complexity of a hydraulic drive system.

An elastic cord or bungee is a simple launch system and hence very inexpensive. It has the advantage of quiet operation and quick recovery. It does have several disadvantages not found in other launch systems. It is severely restricted during cold weather unless the bungee cord is kept heated to above 0C (32F) to assure elasticity. The bungee is also severely limited in weight of RPV that can be launched [Ref. 8].

Any RPV that has wheels can be conventionally launched from a smooth surface in a relatively short length. Closely associated with a conventional take-off is a circular runway. The circular runway places the RPV at the end of a radial wire or cord and allows it to use a circular area as a runway. The RPV takes off, leaving behind a wheeled frame or trolley and the RPV is subsequently recovered without wheels. Both the conventional and circular runway take a lot of area or length to accomplish the take-off and would not be suitable in areas where access is restricted because of obstruction or uneven terrain [Ref. 6].

There are obvious advantages in accomplishing vertical take-off and landing, (VTOL), where space is constrained. VTOL does, of course, place the complexity and penalty in the vehicle itself and shows up as a compromise in speed, maneuverability, endurance and/or range [Ref. 8]. If the compromises in terms of these performance characteristics are not enough to reject the Remotely Piloted Helicopter (RPH) as a concept, then the launch advantages will make this system extremely attractive. It is superb in its lack of sensitivity to wind gusts and the RPH can be made stable enough that it is easily controllable close to the ground or in the vicinity of obstacles. The RPH will therefore have more flexibility in launch environments than any other launch concept.

All of the launch methods outlined above, except for conventional, would be readily adaptable to ships. Even conventional would be applicable if ship deck space were not so expensive and necessary for so many other uses, especially on larger ships. Practical considerations tend to demand that launch systems, especially aboard smaller ships, be as near zero-length launch as possible [Ref. 8]. This indicates an immediate preference for rocket rail launch or pneumatic launch within the weight and g limits previously described. RPH offers a take-off that is almost independent of any launch equipment. Certainly it does not require even a zero-length rail of any kind. Since it is insensitive to wind gusts, the wind normally present on the aft portion of any ship should be no problem. Its good control near the deck and obstacles, such as superstructures, makes the RPH very attractive as a ship-based RPV.

2. Recovery Systems

Like launch systems there are a number of different type recovery systems used by manufacturers and operators. The following is a list of recovery systems followed by a description of each [Ref. 13]:

- parachute
- skids
- conventional
- VTOL
- net

Most RPVs overwhelmingly use the parachute as the main landing or recovery method. Even when another method is used, some have opted to put a parachute aboard for emergency use [Ref. 13]. Even though the parachute is the overwhelming choice, it does have one or more disadvantages depending on environmental conditions. Accuracy is severely impeded by high winds and operational site personnel may be required to retrieve the vehicle from a substantial distance away, from the top of a tree, from over a steep cliff, or other perilous terrain. In addition, parachute landings invariably take their toll in vehicle damage which requires specific spare parts to be on hand. Most RPVs recovered by parachute have rather elaborate schemes to either prevent or repair impact damage. The use of airbags is popular, which in most cases requires compressed gas replenishment. [Ref. 13]

Many RPVs routinely land on hardened skids on the underside of their fuselage and have hardened wing tips to prevent damage. In general the RPVs that use skids are among the lightest. This type recovery requires a certain range of terrain to be available which must first of all be relatively flat. Grass or soft earth also helps prevent damage. Skid distances are extremely short so great expenses of area are not required. Accuracy is not a problem for normal flying conditions under which a mission would be flown.

Conventional landings require the most available landing space and also require a range of terrain similar to skid recovery. In general, most RPVs that take-off conventionally, land conventionally, or land by skids if take-off is made on a trolley such that wheels are left behind [Ref. 13].

Vertical take-off and landing vehicles have an obvious advantage where there is constrained space or numerous obstacles. Of course, the penalties of VTOL vehicles as mentioned under launch systems still apply [Ref. 8]. The lack of gust sensitivity and good controllability are probably even more important during the landing phase than during the take-off. Certainly the lack of equipment such as nets, parachutes, or other retrieval gear is attractive. No other system uses such a small amount of space for retrieval nor does any appear to offer the potential to reduce space requirements near to that of an remotely piloted helicopter (RPH).

Recovery by a net stretched out so the RPV can fly into it is less prevalent, but the Israelis, utilize this as one of their primary recovery systems [Ref. 18]. Other operators have shied away from nets because of fears of damage to both the RPV and the net and in some cases, the Pioneer UAV missed the net and hit the superstructure of the ship. The large net is a difficult to piece of equipment to manage which requires an additional vehicle to be added to the total system. If nets were made smaller than 7 by 9 meters then accuracy requirements would increase and invariably require more complex guidance instruments or an automatic landing system [Ref. 13].

While conventional landings are impractical for the same reason as conventional take-offs in a shipboard situation, VTOL would be attractive if the associated penalties to range, endurance, and speed could be accommodated. The advantages of controllability and lack of sensitivity to gusts are very attractive when landing aboard a ship. Only the RPH offers those advantages as well as the lack of necessity for special retrieval equipment. Serious consideration must be given to determine if the required compromises to payload and endurance for an RPH can meet at least some of the mission requirements of the Navy and/or the Marine Corps. The RPH certainly is the most promising to solve the retrieval aboard ship challenge.

On calm seas a skid landing could probably be made very routinely by almost any RPV. While there is no consensus of technical solution to the shipboard recovery problem, there appear to be strong feelings as to the preferred approach, backed up by testing and operational experience in the case of parachute/sea surface recovery [Ref. 6].

3. Technology Needs

A technology area for which there are no hard solutions available is the all-weather, day/night, and environmental extremes application. All the current RPVs operate in fair weather and what could be called moderate environments. Visual beacons are available for clear nights and some semi-automatic landing is available for net recoveries, but only under visual conditions. Technology is available for fog landings in terms of thermal imaging but is not known to have been applied.

F. GROUND CONTROL STATION

1. Ground Control Station Concept

The Ground Control Station (GCS) is the vital link between the RPV and the small crew of personnel required to successfully operate the RPV system. While the specific design of any one GCS will be tailored to the missions that are to be performed, there are certain fundamental concepts all GCS units must accommodate. These units must be mobile, capable of sustaining combat operations in the field, and habitable. The GCS displays must present the sensor data, received from the RPV, to the ground crew in an efficient, clear, and concise manner. The control and display equipment should relieve the operators of all mundane tasks which distract from their main functions of observation, interpretation, and decision-making. The degree of GCS system automation necessary is dictated by the complexity and variety of the missions performed. The following paragraphs address complete GCS units to the various degrees of sophistication found in most RPV systems.

2. Ground Control Station Equipment

GCS units contain all the electronic and mechanical equipment necessary for the RPV to start, execute and complete its mission. An important key to mission success is the electronics equipment carried aboard the RPV as payload which ties it to the GCS via data link. Real-time video may be displayed and recorded, including television video, infrared (IR) linescan imagery thermal imaging and forward looking IR. All ESM/ECM/ECCM/C3CM mission functions can be monitored and controlled, including electronic warfare active devices such as jammers, IR decoys, visual decoys, as well as the control of all data links [Ref. 7]. In addition, provision is made for the processing and analysis of all sensor payload data to allow for interpretation and dissemination of information to the operational commander. Various other support equipment is generally available in support of RPV mission planning and execution as well as operational force mission planning and execution. Such equipment includes mini- or micro-computers, associated software, interactive display graphics, jamming and anti-jamming equipment, communications/data terminals and man machine peripheral support equipment [Ref. 7].

In addition to an extremely wide variety of electronic equipment, there is also a vast array of different makes, models, and manufacturers involved in the RPVs ground station equipment [Ref. 6]. Like other major components of RPV systems, the GCS units have shown little or no standardization in choice of equipment.

3. GCS Support Equipment

In addition to electronic mission tracking and analysis, vehicle control and support equipment, the GCS system complex is required to provide maintenance facilities not only for the RPV itself but all other parts of the ground station. RPVs, as noted before, are surprisingly survivable and even when hit by small arms fire are easy to repair. For example, an engine can be changed in no more than 5 minutes if the fuselage mounts are in good condition [Ref. 7]. Repairs to non-structural parts of RPVs, such as holes in wings or similar modules, can be made in a matter of minutes with rapidly curing materials. Therefore, supplies, tools, and personnel must be provided. Some modules may not be as immediately repairable, and in those cases, spare modules are provided for in one of the transport vehicles that make up the total ground control station and RPV system concept.

4. RPV Mission Impact on GCS Design

Another consideration that may impact the size and complexity of the GCS unit is the tremendous variety of missions that the RPV may be required to perform. The list of missions in section II contains 17 distinct and separate missions and the list can be expanded. Most RPVs have been developed to carry a variety of payloads and fly a wide range of military missions. With so many different RPV systems in existence, it is not surprising to find several companies devoting a large portion of their marketing efforts to civil areas of RPV application. Success in these ventures will increase the diversity of the systems and will most likely have a favorable impact on ground station design. Civil users will demand longer-life systems and components, and cost will be a driving consideration. Most companies are already completely dedicated to design and manufacture low-cost, efficient RPV systems [Ref. 7].

In addition to fully equipped GCS mobile units, less sophisticated, remote or portable control stations are also available. there are many uses for remote control stations including range extension past line of sight. In this case the remote/portable ground station would require tracking, guidance, RPV control, and some communications equipment along with required support material such as aerials, power source, etc. [Ref 10]. One use for man-portable remote control stations is to operate the RPV from a position of acceptable terrain where the larger GCS unit could not be positioned. Still a further use would be to provide support unit commanders and mobile unit commanders with real-time data while the RPV is being controlled from elsewhere. In this case the remote or portable station would not require control equipment; only real-time data reception. It is obvious that ground control stations design can be as flexible and varied as the RPVs and their associated mission requirements.[Ref. 7,10]

5. Ground Control Station Functions

With all the types of equipment mentioned above, the functions performed by operators and users of the GCS are many. In general GCS units must provide capability to [Ref. 7]:

- monitor and track the flight paths of one or more RPVs
- communicate with and control the navigation of one or more RPVs
- command and control the payload of each RPV
- receive, display, interpret and analyze RPV payload data/imagery
- execute successful RPV mission flight profiles utilizing operators to monitor and control the mission operational flight
- communicate with outside tasking agencies and/or the operational field commander as well as supporting elements.

GCS units are generally designed and built by the RPV manufacturer using components obtained from specialty electronics manufacturers, who make the many different types of display and control equipment necessary to perform the many functions required by operators and users. Specific designs are always dictated by the mission roles that the RPV must perform. Two other important considerations are the environment of operation and, of course, economics. Components are generally searched out that perform the required functions within size and weight constraints and in the required environment [Ref. 7]. Many GCS systems match exacting functions to available equipment to avoid developing systems that may only provide marginally better capability or more functions, but at a considerable increase in cost.

Typical GCS units for use by the military provide a display of sensor data which may be transmitted directly or further processed for greater accuracy of interpretation and analysis. Image and signal processing takes place either on the RPV (rarely) or in the GCS [Ref. 7]. Since most RPVs have more than one sensor type, provision must be made for selecting the sensor and controlling its operation. The typical GCS unit is run by two or three personnel, which will cover all vehicle and sensor controls, as well as data interpretation. Displays are usually interactive presentations so that a light pen can be used to mark targets displayed, select from available menus, and perform command input functions. Such displays are usually also dynamic since they may display real-time data.

In addition to sensor displays, GCS units are usually equipped with a moving map display which can project a variety of scales of area and at the same time superimpose the RPV position, flight path, future way-points, task point identification, sensor footprint and various tactical information [Ref. 10]. Some systems display vehicle and sensor operational data along the edges of the display or on separate displays. Many times the vehicle flight data is presented in both analog and digital formats to provide both rate-of-change estimation and precision.

In addition to displaying sensor data and RPV control information, some other important functions that are performed in GCS units include [Ref. 7]:

- automatic alerts and prompts
- data analysis/signal processing
- recording data and record-keeping
- communication with both headquarters and support activities

- mission planning
- post-mission assessment
- battle area tactical decision-making
- report generation
- NBC monitoring
- directing launch and recovery detachments.

Not all GCS have all these functions, and the functions are accomplished in a variety of equipment. Some GCS may contain a sensor station, mission commander/pilot station, and a targeting station. The targeting station can be used for sensor data interpretation and analysis if required. The sensor station could contain a boresight TV camera control, TV monitor, VCRs, and a control panel with sensor controls, platform controls and antenna controls [Ref 10]. The mission commander/pilot station might contain digital flight instrument displays, real-time and mission clocks, status displays, TV monitor, digital map plotter, and a control panel with RPV mode controls, TV freeze-frame controls, differential and digital uplink controls, and various payload controls. The targeting station might contain TV monitors, CRT computer displays, TV freeze-frame controls, targeting processor, and a keyboard for operating the targeting system and programming missions. Other equipment found in the some GCS are communications systems, printers and recorders, bubble memory modules, a mission program computer, and the power supply system. [Ref. 10]

6. Technology Needs

There are quality GCS units equipped to support any RPV system under all missions. If there is any technology needed, it will most likely involve better analysis of the man-machine interface and the degree to which operator monitor and control functions are automated in the GCS design [Ref. 7]. Additional automation can lead to reduced operator requirements and allow for reductions in equipment size and weight to make GCS units even more highly mobile and flexible. The additional automation may initially make the GCS more expensive, but with the reduction in electronics bays, operator controls, displays and modules, there will be the potential for cost reduction in the overall GCS system. All GCS units are suitable for shipboard operation with the assumption to reduce size and weight as much as possible as shipboard space is always at a premium [Ref. 7].

G. MISSION PAYLOAD/SENSOR TECHNOLOGY

From the perspective of this thesis, one of the most important aspects of the RPV/UAV is the useful mission payload, which provides the remote forward observer's "eyes and ears" to fleet or battlefield operational commander. Because this thesis is only concerned with unmanned air vehicles which can carry a mission payload and ideally a weapons payload, this section provides detailed, technical information on those avionics, electronic or electro-optic systems and weapons which make the UAV/RPV system of significant value to the operational commander.

1. Payload Installation Methods

To minimize size and reduce drag most mission payloads are contained within the RPV fuselage structure and integrally mounted with flush or protruding sensors from the bottom of the vehicle. Those vehicles which employ protruding sensors have to provide protection for the sensors during take-off and landing with a clear plastic bubble dome (Brave 3000, Mastiff, Phoenix) [Ref. 18,6].

Other vehicles , employ an entire mission payload pod or housing on a pylon fairing below the fuselage (Pioneer, Scout) [Ref. 18]. This design approach allows for rapid change of mission vehicle aerodynamics and design and may significantly increase drag. The pod design approach also offers problems in the launch and recovery modes because it makes conventional take-off and landings more difficult. Many of the configurations applied to sensor equipment will apply to weapon loading, however internal weapon placement in a Bombay configuration is ideal.

Sensor mounting to account for vibration and stabilization must be considered. Vibrating due to aerodynamic or engine effects must be minimized for framing or imaging sensors, and such sensors are usually mounted on shock/vibration mounts in the fuselage structure. Imaging or targeting sensors must be capable of tracking a point on the ground regardless of vehicle attitude; therefore, many mission sensors are gimbaled or gyro stabilized to allow continuous ground position pointing or target tracking as required by the mission [Ref. 12].

There are a variety of defense-related mission roles for which the RPV may be utilized. Each specified mission role and associated performance requirement will dictate a specific mission payload design. Thus, if an RPV system is envisioned to be capable of performing 3-4 different missions, then it must be capable of carrying 5-10 different mission payload configurations, allowing that a single mission role such as area reconnaissance may require a variety of sensors and perhaps more than one payload configuration. This proliferation of payloads for a multi-mission role RPV dictates that the mission payload must be small, lightweight and modular so that various mission payloads can be interchanged rapidly between flights.

2. Types of Mission Sensors

Several types of sensors are available in the marketplace which cover a broad range of electromagnetic spectrum from acoustic low frequency sensors to EO/IR/UV micrometer wavelength devices. The types of sensors listed below are ranked in relative order of their frequency of usage in RPVs for various mission requirements [Ref. 21].

a. TV-Visual Sensors

This is the most commonly used sensor for reconnaissance and surveillance because of the availability in the commercial marketplace of conventional TV scanners that are small, compact and light-weight (available on all UAVs). Conventional vidicon tube TV scanners are available at reasonable prices that can fit in a 6 x 6 x 10 inch volume including the electronics unit. The TV raster picture can be directly data linked to the ground station or it can be processed or stored on conventional tape or disc for future playback. Both the military and commercial raster scanners are based on a 525 line raster. The primary disadvantage with the TV sensor is that it is limited to day, visual meteorological conditions and it cannot see through haze, smoke, fog or clouds. The TV raster scan with zoom optics should be able to detect tanks on the battlefield at 5-8 km in clear air mass conditions [Ref. 12].

b. UV/EO/IR Sensors

Sensor technology in the IR spectrum has received considerable emphasis for reconnaissance, surveillance and target imaging in the battlefield environment because of adverse weather conditions, haze, fog and expectations that much of the initial movement of defense forces may occur a night [Ref. 21]. It is true that IR sensors cannot see through dense moisture environment such as rain and heavy fog, but they are still quite effective in haze, dust and certain fog conditions. Plus, considerable intelligence information can be gathered between day and night comparisons of thermal imagery of identical geographical scenes. Both forward-looking (FLIR) and IR linescanners (IRLS) are readily available in the marketplace in small, compact units and at reasonable prices. British Aerospace, for example is developing mini-IR linescan systems that are small and compact enough for RPV installations [Ref. 12]. Their fully contained MIRLS (Mini-IR linescan System) is an experimental development program that will fit in a 6 x 6 x 8 inch volume and weigh less than 5 kg. GEC avionics has developed the Thermal Imaging Common Module (TICM) which operates in the 8-13 um far-IR spectrum and provides high resolution IR surveillance and targeting [Ref. 21]. These types of sensors are getting considerable attention in the NATO defense systems arena and are expected to play an important role in battlefield surveillance in addition to pictorial imagery based on the thermal target/background contrast within the surrounding scene [Ref. 6]. It is expected that IR sensors will be able to detect tanks in the battlefield at 3-6 km and identify them at somewhat shorter ranges. IR sensors are more readily adaptable to digital data processing, storage or transmission than conventional photographic systems; so these sensors are ideal for real-time data linking of reconnaissance, surveillance or targeting data to a ground station for analysis and/or tactical action. Thermal images are completely passive and provide no clues to the enemy of RPV location on the battlefield.

c. *Laser Sensors*

Several companies have developed and built compact laser systems for use in small military vehicles or airborne platforms. Laser radars have also developed for various applications which provide very high resolution target discrimination characteristics. Laser systems may also be used for range finding or height measurement and provide a very low probability of intercept (LPI) altimeter for accurate vertical positioning over rough terrain or seas [Ref. 21].

d. *Active Radar Sensors*

Few RPV systems were noted which included radars in their potential mission payloads (UAVs with radar capability, include the BQM-34, Phoenix and VTOL). However, some considerations should be given to X, Ku, Ka and millimeter (mm) wave frequencies to achieve high resolution target detection and classification, even in adverse weather conditions [Ref. 21]. For small component size, packaging and antenna aperture, mm wave radars provide highest resolution at short ranges are affected by moisture or rain. Research and development efforts are ongoing in several nations to develop compact, high resolution synthetic aperture radar (SAR) systems for airborne tactical reconnaissance [Ref. 12]. Most mm wave radars under development in the U.S. are envisioned for use in target detection, classification and weapons designation in conjunction with other sensors, such as thermal imagers or laser target designators. The obvious disadvantage associated with an active radar sensor is the added vulnerability caused by enemy interception, tracking and direction-finding (DF) of this emitted signal from the RPV, thus making the RPV more susceptible to tracking and ground fire.

e. *Passive Electromagnetic Sensors - ESM*

Electronic warfare support systems (ESM) passive surveillance sensors can also be used covertly to detect enemy use of the electromagnetic spectrum, especially at radio frequencies (RF). With the advent of microelectronics circuit technology and microprocessors/microcomputers, these ESM systems can be packaged into small, compact, lightweight modules suitable for use in small aircraft or RPVs. Many electronics firms are actively pursuing research in microelectronic device technology and in micron-scale silicon and gallium arsenide semiconductor materials for thin film and thick film integrated circuits. All of this microelectronic component and device research and development is resulting in manufacturing capability being developed to produce state-of-the-art electronic warfare (EW) systems for defense requirements. Several companies are currently producing small, lightweight airborne EW systems for U.S. aircraft and other national defense requirements. Some of these systems have led to small, compact EW payloads suitable for RPV use [Ref. 21].

Difficult signal processing decisions must be made in RPV ESM systems. A dense signal environment could saturate a small solid state ESM receiver and data link unless some signal processing and discrimination is done on-board to make threat/non-threat signal determinations and select only the signals analyzed as threats. Several microelectronics EW houses are manufacturing rapid scanning superheterodyne receivers, IFMs or digitally tuned/scanned receivers with sophisticated signal processing and analysis, but compressive receiver technology and digital signal deinterleaving techniques for complex signals are still mainly in the development stage. Most EW systems development programs that are planned for RPV application are either classified or in early stages of development [Ref. 11].

f. Active ECM Systems

This EW capability directly follows from what was presented in the previous paragraph and includes active noise jamming, deception jamming for self-defense, barrage jamming, communications jamming and active decoy techniques. Development programs are ongoing in several of these areas, but the details are for the most part classified.

g. Communications Relay

Certain missions a requirement to use the RPV as a communications relay over long distances to pass battlefield information back to a rear echelon operational commander. Communications intercept receivers and wideband data link systems are available to support this special mission design requirement.

h. Acoustic Sensors

Considerable interest exists in RPV employment of acoustic sensors for battlefield target detection, classification of tanks and also surface/subsurface detection at sea, but very little information was available at the unclassified level.

i. Chemical Sensors

Considerable national interest exists for using RPVs to detect and sample the battlefield chemical atmosphere, especially during or after a possible nuclear, biological or chemical attack. No details concerning such chemical sensors are available, but i .:nown that certain companies are developing or producing systems to support this mission requirement [Ref. 21].

H. ASSOCIATED RPV AVIONICS/ELECTRONICS

1. Power Supplies

All RPVs that carry a mission payload and have a data link capability must have a power generating source for AC/DC electrical power. Most conventionally powered piston engines utilize an alternator on direct drive from the engine to generate electrical power. Most RPV systems use 28 V DC power to drive the various mission sensors and avionics equipment. DC power outputs of less than 500 watts are typical for smaller engines (5-10 HP). More robust RPVs with longer ranges or endurance utilize larger engines (20-30 HP) and carry a larger payload (20-40 lbs); therefore, a larger power supply output is required - typically greater than one kilowatt [Ref. 20]. Most RPVs also carry 28 V DC batteries to provide back-up data link control of the vehicle if the engine should fail or the power supply system should malfunction. This back-up battery power would allow RPV retrieval if the engine has not also failed. Current RPV alternators and rectifiers are compact, robust and suitable for RPV system reliability. However, they should not be ignored in the overall engineering or design development effort [Ref. 6].

2. Mission Computers/Microprocessors

Any RPV that carries a mission payload and utilizes a data link for control must have a data link receiver-processor as a minimum to convert the data link signal to electrical signals which actuate the RPV controls. From this basic minimum processor requirement, the small size and complexity, which the RPV computer may be designed to, is dictated by the autonomous guidance and control system which may require a large, digital, solid-state, on-board computer for autonomous navigation computations, mission payload operation and video image processing and data linking to the ground station [Ref. 7]. Because of the size and weight constraints, most current RPV systems employ a small computer or microprocessor built into a single electronics unit. By using a modular circuit board or integrated circuit (IC) card concept, a small electronics unit can be designed which includes most of the vehicle electronics requirements and allows 3 to 5 board slots for mission-related electronics as well. These can be changed as the mission payload is changed [Ref. 7]. Other modular design concepts include the mission sensor electronics in the sensor payload module, thus when the sensor is changed, the sensor mission electronics are changed as well.

With the current emphasis in software programmability, many of the surveyed RPVs have capability to store RPV flight paths, waypoints, targets, sensor and data link on/off positions as well as mission information libraries or threat data lists prior to flight. In flight the computer can be updated, waypoints can be changed, flight profiles modified and the navigation position corrected via the uplink from the ground station. All of this computer sophistication increases cost somewhat, but for the additional operational flexibility provided, this is probably cost-effective electronics technology that should be included in the RPV system based on the mission requirement.

The RPV computing philosophy seems to be based on doing minimum computer processing on-board the vehicle, where space and weight are at a premium, and instead placing the bulk of the computer processing requirements in the ground control station or controlling aircraft where space and weight constraints are not as severe. Therefore, the two-way data link becomes an integral part of the RPV computer processing, command and control system -- it is the electronic communications link which ties the vehicle and the ground station together via their respective computer systems [Ref. 7].

3. Data Link

The C3 type data links are essential to RPVs which are remotely controlled or pre-programmed with in-flight update capability. An autonomous vehicle has no requirement or provision for external control. Therefore, no data link (uplink) is required. The data link is RF line-of-sight limited which affects the maximum controllable range of the RPV. Most RPVs employ data links for external control, and the majority of these provide communications uplinks in the VHF/UHF region (100-1000 MHz), which allows for line-of-sight bending with the earth's curvature, especially at the lower frequencies (100-300 MHz) [Ref. 7]. This RF propagation phenomenon allows approximately 15% increase in reception range over visual line-of-sight, so at 5,000 ft RPV altitude, maximum detection range is approximately 100 NM and at 10,000 ft, the maximum range is about 140 NM under standard atmospheric conditions. Some RPV systems designers limit their RPV to maximum data range, but most RPV systems have the capability to utilize pre-programmed flight paths as discussed in Section IV, and therefore fly beyond data link maximum range in a preprogrammed guidance mode.

Airborne data link control can also be considered to extend the range of RPVs. The data link can add to the vulnerability of the RPV system because it is an RF signal that can be detected and jammed. The control data link (uplink) gives away the ground station position through direction-finding (DF) on the signal, and any beacon transponder or video data link (downlink) transmitted from the RPV could give away the RPV position. Most RPV systems encountered could be preset or programmed to "dump" data via the downlink at specified times or when queried by the ground station [Ref. 7]. Several RPV system developers have put considerable emphasis on real-time mission sensor data link capability to the ground station. In fact, the Israelis have deployed real-time data links in RPVs over the past ten years, with successful operations in a combat environment [Ref. 18].

4. Antennas

The basic requirement for any RPV with a data link capability is to have a data link transmit and receive antenna which is the proper size. Most RPVs surveyed had conventional vertical dipole wire antennas for VHF and blade antennas for UHF or higher frequencies [Ref. 7]. These antennas are omni-directional and give little directional gain but provide acceptable reception regardless of vehicle heading or location relative to the ground station. Other antennas may be required for EW mission payloads, but their special design requirements are beyond the scope of this thesis. It is sufficient to say that any DF-receive antenna requirements on the RPV will probably employ phase or amplitude comparison antenna ports in a single antenna to approximate RF signal direction-of-arrival .

5. Data Recorders

Any RPV mission payload that collects reconnaissance, surveillance, targeting or EW intelligence data will probably require both a data link and an on-board storage or recording capability. All digital or analog data recorders will consume some space and payload weight, but the value of the data for such missions often offset the cost, size and weight penalties to ensure the data can be retrieved and analyzed, especially if the vehicle is outside of downlink line-of-sight to the ground station. Some RPV mission systems selectively store mission sensor data in the on-board computer, but most multi-role capable RPVs are designed to carry on-board data recorders with a storage and "data link on request" capability [Ref. 7].

6. Technology Needs

With the continued emphasis on microelectronic technology developments, the overall reliability and design efficiency of electronics, sensors and avionics systems is increasing while the size and weight of these devices and systems is decreasing. This technology trend is beneficial to defense systems in general and especially so for RPV systems. As has been discussed earlier, the RPV is severely weight and volume constrained. For longer duration missions a larger fuel load is required, and the size and weight of the useful mission payload will always be severely restricted. With the introduction of very high speed integrated circuit (VHSIC) and very large scale integrated circuit (VLSIC) technology into microelectronics systems design over the next 5-20 years, a continued increase in RPV mission payload electronic performance and reliability is expected while maintaining existing sizes and volume or even with some decrease in required space and weight. Another relevant aspect of this technology is cost. Initially, it is expected that microelectronics systems design and development will be very expensive, especially to meet defense MIL-STD ruggedization and testing requirements. This high cost may preclude widespread use of microelectronics technology insertion into RPV electronics systems payloads until the space program and commercial procurements have helped to bring the high cost of this technology down. The cost-effectiveness trade-off will be driven by the importance of the mission requirement against the size and weight of the equipment to accomplish the mission within the physical constraints of the vehicle design.

Related to the mission requirements for reconnaissance, surveillance and targeting, sensor technology is being driven toward higher resolution while reducing sensor size and weight [Ref. 21]. The limits of the basic laws of physics are already being approached with regard to optical focal lengths, IR resolution, sensitivity and field-of-view [Ref. 21]. With these high resolutions achieved in very small mission payload sensors, the emphasis is then focused on image processing and enhancement techniques using ground processing algorithms. Considerable research is being conducted in this area. Much of the work is company proprietary or classified. Directly related to this effort is research on high speed, high throughput digital signal and data processing methods. these techniques will speed-up image reconstruction time to allow near-real-time display in the ground control station. This entire technology area is receiving significant emphasis, and the primary concern for RPV system developer is to ensure that he has incorporated the best and most efficient signal processing algorithms in his ground control station computer architecture.

Another technology used is the requirement for efficient transmission, reception and processing of high data rates via wide band data links. Although wide band data links are available today, the choice of data word format and data processing technique is very important in maximizing data transmission rates. Data compressive and processing techniques can significantly increase data transmission rates. In summary, the technology emphasis for future RPV electronics are both hardware and software related, and coordinated efforts in both areas is required to ensure an optimum RPV system design is achieved, which will meet the demanding requirements of any future combat scenario.

I. UAV/RPV SUMMARY

There is little doubt at this point that the UAV/RPV system has a role to play in the battlefield scenario of the future; the problem is in defining the appropriate balance or mix of manned/unmanned air vehicles and the various ways these systems can be completely or mutually supportive in the variety of mission roles. The more immediate problem is for the USN/USMC to study and evaluate future UAV/RPV requirements based on the US Marine Corps amphibious and land-based tactical doctrine and US Navy sea-going battle group force requirements. Results of this thesis will define the lethal mission requirement and the UAV/RPV performance parameters which will in turn shape the design and development of future USN/USMC UAV/RPV systems .

The technology impacts on UAV/RPV system design and development are thus summarized as technology needs .

1. Summary of Technology Needs

The key to low-cost UAV/RPV systems, is simple, efficient design processes that result in easy-to-operate, easy-to-maintain, yet effective systems. Simple, efficient fixed-wing, propeller-driven RPV like the Pioneer satisfy many of the requirements; but where a lethal mission is of primary importance the Pioneer is inadequate. On the other hand the MR UAV (Specter) is more than adequate. The vehicle design must continue to emphasize modularity, ease-of-maintenance and assembly in the field, along with relatively long range/endurance and low detectability. There is a need to address increased fuel capacity and efficient aerodynamic design without sacrificing useful mission payload-carrying capability. To meet USN/USMC tactical employment requirements, there is a need to provide vehicle propulsion systems which can run on military diesel or jet fuel, without being concerned about a logistics pipe to bring special aviation fuel or petrol to the operational user.

Turning to guidance and control systems, ground control electronics and mission payload/sensor devices, the technology trends in microelectronics are toward higher reliability and design performance and efficiency while decreasing the weight and volume of the electronics components and devices. This favorable trend will result in higher performance and better reliability for electronics equipment while actually reducing the number of electronics modules or decreasing the required size and weight for such electronics equipment. This technology trend is certainly beneficial to the RPV system and will allow the design engineer to concentrate on increasing the fuel fraction or the packing density within the vehicle structure. Initially, electronics and payload technology will drive the cost of the RPV system, but as this technology matures and finds greater commercial and military applications, the production costs should come down.

Technology needs in these areas of vehicle electronics, mission payloads and ground control stations are closely tied to the mission requirements and do not present any insurmountable problems to the electronics system design engineer. Almost any electronics system or mission sensor can be developed or procured to meet the operational requirement. The important consideration is for the military program planner to not overspecify the electronics and payload requirements, because this will rapidly escalate the RPV system costs. Keeping in mind that many of these vehicles may never return from their mission in a real combat environment should emphasize to the military program planner that he should keep the entire RPV system design as simple and efficient as possible to allow reasonable unit cost, which will in turn allow him to purchase larger quantities of vehicles to provide for combat attrition.

An important safety factor impacting the guidance and control electronics which must be addressed by the RPV system designer and military operational user involves emergency procedures to retrieve the air vehicle in the event of critical vehicle failures, such as propulsion, flight control or electrical power. Obviously, it is desirable to recover the vehicle if at all possible, despite a critical flight failure, and certain return-to-base guidance and control modes should be designed into the RPV system. Failing that, the military requirement may dictate an airborne destruct capability to prevent the vehicle from crashing into populated areas or falling into the hands of the enemy.

IV. LETHAL UAV / RPV

A. BACKGROUND

The modern concept of using remotely controlled or remotely piloted vehicles for missions having low probabilities of survival was developed prior to World War II. During the War, the United States and Great Britain actually used a limited number of controlled glide bombs in the Pacific theater and some explosive-laden unmanned aircraft against certain hard and well-defended targets in Europe. Although we learned many lessons from the "great war," the lesson of replacing a fragile man in a costly aircraft with a much cheaper, expendable, pilotless vehicle for lethal attack missions was not one of them. Our thinking relative to the use of RPVs has changed very little in the past 40 years. We still consider the RPV mainly as a candidate for low probability to survive missions, i.e., long range and long endurance reconnaissance, target vehicles for other weapons, and various intelligence gathering missions [Ref 1]. As was evident in Desert Storm, USN UAV assets were used for battleship target selection, spotting naval gunfire during combat missions and BDA [Ref 3]. The USMC used their assets to direct air strikes and provide near-real-time reconnaissance for special operations and target location. In 1993, the Department of Defense, UAV/RPV Master Plan summarized the service needs for RPVs for each service, as shown in Table 2. It is obvious that future applications and missions are not being projected into the lethal mission category.

TABLE 2

DEPARTMENT OF DEFENSE UAV REQUIREMENTS

	CLOSE	SHORT	MEDIUM	ENDURANCE
OPERATIONAL NEEDS	RS, TA, TS, EW, MET, NBC	RS, TA, TS, MET, NBC, C2, EW	PRE-AND POST-STRIKE RECONNAISSANCE TA	RS, TA, C2, MET, NBC, SIGINT, EW, SPECIAL OPS
LAUNCH & RECOVERY	LAND/SHIPBOARD	LAND/SHIPBOARD	AIR/LAND	NOT SPECIFICIED
RADIUS OF ACTION	NOTE STATED	150 KM BEYOND FORWARD LINE OF OWN TROOPS (FLOT)	850 KM	CLASSIFIED
SPEED	NOT SPECIFIED	DASH > 110 KNOTS CRUISE < 90 KNOTS	550 KNOTS < 20,000 FT 9 MACH > 20,000 FT	NOT SPECIFIED
ENDURANCE	24 HRS CONTINUOUS COVERAGE	8 TO 12 HOURS	2 HRS	24 HRS ON STATION
INFORMATION TIMELINESS	NEAR-REAL-TIME	NEAR-REAL-TIME	NEAR-REAL-TIME/ RECORDED	NEAR-REAL-TIME
SENSOR TYPE	DAY/NIGHT IMAGING*, EW, NBC	DAY/NIGHT IMAGING* DATA RELAY, COMM RELAY, RADAR, SIGINT, MET, MASINT, TD, EW	DAY/NIGHT IMAGING* SIGINT, MET, EW	SIGINT, MET, COMM RELAY, DATA RELAY, NBC, IMAGING, MASINT, EW
AIR VEHICLE CONTROL	NOTE STATED	PRE-PROGRAMMED/ REMOTE	PRE-PROGRAMMED	PRE-PROGRAMMED/ REMOTE
GROUND STATION	VEHICLE & SHIP	VEHICLE & SHIP	JSIPS (PROCESSING)	VEHICLE & SHIP
DATA LINK	WORLD WIDE PEACE TIME USAGE, ANTI-JAM CAPACIBILITY	WORLD WIDE PEACE TIME USAGE, ANIT-JAM CAPABILITY	JSIPS INTEROPERABLE WORLD WIDE PEACE TIME USAGE, ANTI-JAM CAPABILITY	WIORLD WIDE PEACE TIME USAGE, ANTI-JAM CAPABILITY
CREW SIZE	MINIMUM	MINIMUM	MINIMUM	MINIMUM
SERVICE NEED/ REQUIREMENT	USA, USN, USMC	USA, USN, USMC	USN, USAF, USMC	USA, USN, USMC

*Baseline Payload Capability

LEGEND

C2 - COMMAND AND CONTROL
EW - ELECTRONIC WARFARE
JSIPS - JOINT SERVICE IMAGERY PROCESSING SYSTEM
MASINT - MEASUREMENT AND SIGNATURES INTELLIGENCE
MET - METEOROLOGY
NBC - NUCLEAR, BIOLOGICAL AND CHEMICAL RECONNAISSANCE
RS - RECONNAISSANCE AND SURVEILLANCE
SIGINT - SIGNALS INTELLIGENCE
TA - TARGET ACQUISITION
TS - TARGET SPOTTING
TD - TARGET DESIGNATOR

Through the late 1970s, advanced airborne weapon systems satisfying strike weapon requirements were developed. However, in the late 1970s and early 1980s, some original thinking was being devoted to the suppression of enemy air defense systems. In 1982, Israel preceded a manned aircraft attack against Syrian air defense units in the Bekaa Valley with flights of unmanned RPVs, thereby forcing the Syrians to activate their missile tracking radars in preparation for Surface to Air Missiles (SAM) engagement. Once the tracking radars were turned on, radar homing missiles were launched from manned Israeli aircraft and the Syrian radars were destroyed. This event marked, the first time in armed conflict, the benefit of integrating low-cost unmanned systems with manned airborne platforms.

The Israeli raid into the Bekaa Valley increased the awareness of a few military planners and tacticians to the potential contributions of RPVs in future conflicts. The next logical question was " if an RPV can find and locate a target, why not have the same RPV attack it?" The outcome of this thinking brought us the first advanced high technology RPV systems such as the Tacit Rainbow and Brave-3000, both of which are capable of accurate target location and highly lethal attack [Ref. 11] . These systems, while capable of independent operation on the battlefield, are single-minded in their purpose. They search out and attack a very narrow spectrum of targets over a preestablished portion of the battlefield. Now, however, technology advances in the fields of electronics, avionics, propulsion systems, materials, seekers, sensors and flight control systems - many of which have been discussed in detail in this thesis, have brought us to a point where a new question needs to be asked. That question is "Do we have the necessary building blocks to produce high-performance unmanned air vehicles capable of both autonomous navigation and selective attack?"

B. LETHAL UAV/RPV MISSION

To simplify the discussion of the operational concept for integrating RPVs and UAVs with manned aircraft, it might be useful to describe typical candidates for each mission. Nonrecoverable, single-mission RPVs are envisioned for both the battlefield and the tactical support missions. The major difference is that the RPVs for the battlefield mission would be capable of engaging multiple targets within a single target area of approximately 1 square nautical mile (nm), while those for the tactical support missions would be capable not only of engaging multiple targets within the same area, but of engaging as many as three target areas separated by 8 to 10 nm. A candidate as a lethal UAV capable of multiple target acquisition is the MR Specter. A candidate as a Single target small area UAV might be the Aquila, Mastiff or the Pioneer. All UAVs investigated are capable of battlefield and tactical support missions. These types of vehicles will be capable of performing preplanned missions in a reliable and effective manner. They will react to exterior stimuli, which could be commands from a friendly operator or reaction to target detection by on-board sensors, which would then provide a preprogrammed response to those stimuli. However, even a UAV that contains the intelligent logic processing capability of a pilot associated black box is not expected to be capable of totally autonomous operation. Therefore, while these vehicles can perform a number of strike mission tasks, they certainly are not, at the present time, an efficient combat replacement for manned strike systems. At some future point in time, an automated system will be more efficient than a manned system.

Presently, a manned strike system, to accomplish its mission, must compete against unmanned defensive systems that are becoming ever more capable and intelligent. Surface-to-air defensive weapons within the next 10 to 15 years will have velocities of 2.5 to 3.0 nm. per second, and even those weapons will be replaced by beam weapons 10 to 20 years beyond that. RPVs and UAVs incorporating new and emerging technologies will provide the stimulus for developing new operational concepts to counter these defensive systems. However, in the interim RPVs and UAVs can be integrated into a combined strike force that will provide significant improvement in combat effectiveness and cost effectiveness beyond what either a manned aircraft or an RPV/UAV could provide as an independent combat element.

For many years, R&D programs supported by government contracts have been directed to reduce the performance penalties imposed on combat aircraft by external stores [Ref. 2]. These penalties include combat aircraft range reduction, maneuverability restrictions and increased radar signatures. The strike-support concept proposed here removes from the aircraft all weapons used for direct target attack, and places them onto a new class of direct attack RPVs or UAVs. The manned aircraft is now upgraded to an airborne battle manager with increased ECCM and self-protection jamming, active and passive decoys, and air-to-air missiles for self-defense. Additional avionics packages are added to the manned aircraft to enable it to control 7 to 15 unmanned vehicles in an integrated manned/RPV strike formation. All of these efforts are to increase the probability of survival of manned combat aircraft, which will play an even more pivotal role in the future than they do today.

The strike support concept uses a group of 2 to 15 RPVs. The primary element in a force of this size is the command, control and communication with each RPV, and eventually the manned aircraft. As the formation approaches the target area, the individual RPVs would be maneuvered to a predetermined position where the final phase of their mission could be directed by strike controller, via data link or released to perform their preassigned mission in an autonomous manner. Once all RPVs have been released, the strike controller would be free to initiate the exit phase of the mission. The RPV flying as wing man to the strike controller could be used to perform battle damage assessment. High-quality video would be recorded on board the reconnaissance RPV and the data would also be data linked to the strike controller. This proposed tactic considers as the primary controller, a manned aircraft. The same consideration could be given to a ground control station limited by line of sight.

V. CONCLUSIONS

The UAV is a vital asset, and it is recognized that the UAV systems will play a major role in conjunction with manned aircraft and other deployed forces in future combat environments. It is also recognized that, for the most part, the technology is currently available to expand the role that UAV systems may play in meeting US defense requirements as a LETHAL UAV. Advancements in materials and electronics technology have certainly allowed UAV/RPV systems to achieve better performance at lighter take-off gross weight (TOGW) with equivalent or even lower costs. The challenge for the military program planner is to carefully articulate the operational requirements and to specify an RPV system which will accomplish those requirements without adding capability and complexity which will drive up the cost.

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