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SIKORSKY AIRCRAFT UAV DEVELOPMENT

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SIKORSKY AIRCRAFT UNMANNED AERIAL VEHICLE (UAV) PROGRAM

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INTRODUCTION

The Persian Gulf war established the major contribution Unmanned Aerial Vehicles (UAVs) can make to the success of operational forces. UAVs were used extensively for Reconnaissance, Surveillance and Target Acquisition (RSTA) missions in support of US Forces and Allied Forces.

US battleships used UAVs to obtain real-time target acquisition, artillery adjustment and bomb damage assessment without relying on external spotting and intelligence assets for naval gunfire support. The US Army and Marines employed the Pioneer UAV, Figure 1, to pin-point enemy artillery and troop positions; to support artillery counterfire; and to keep the enemy off balance. One source stated, "not one round of enemy artillery fell on US Forces prior to and during the breech of Iraqi lines".

The first ever surrender of enemy troops to an UAV occurred on Faylaka Island. In addition, UAVs detected early advances of Iraqi tanks on the Saudi Arabian town of Al-Khafji, days before the attack, although the information was not distributed until just before the attack because the intelligence center was overwhelmed by with inputs.

Operational experience in the Gulf War proved that UAVs can significantly improve the quality and timeliness of battlefield information; reduce the risk of capture or loss of troops; and allow for more rapid and informed decision making by battlefield commanders. In addition to the RSTA missions, UAVs possess substantial capabilities to support electronic warfare (EW), electronic support measures (ESM), command and control, and special operations missions.

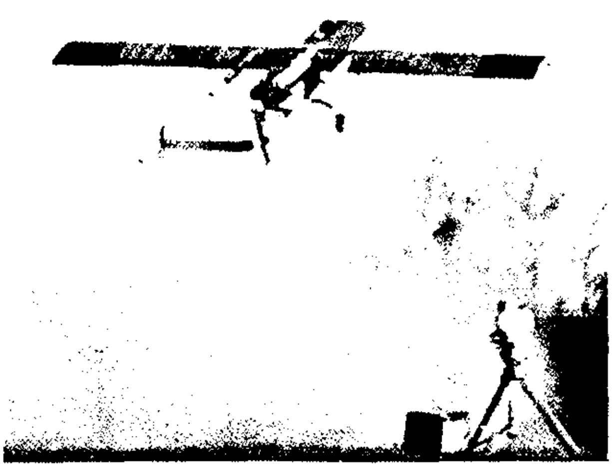


Figure 1. Pioneer - Combat Proven System

UAVs are a particularly valuable adjunct to the manned aircraft. They can perform inherently hazardous missions such as operations in contaminated environments; missions with unacceptable political risks for manned aircraft and those with extremely long flight times. Allocating these dirty, dull and dangerous missions to UAVs increases the survivability of manned aircraft and frees pilots to do missions that require the flexibility of the manned system.

New and emerging technologies such as composite materials that are both strong and lightweight; miniaturized and less expensive electronics; and small imaging sensors make UAVs more viable weapon systems.

These new technologies, compelling economic constraints and favorable results in Desert Storm are the major reasons UAVs are gaining in acceptance and financial support.

Current US UAV Programs

The US Joint UAV Program Office has established four categories of UAVs (Close, Short, Medium, and Endurance) to satisfy validated requirements, as shown in Figure 2. The following paragraphs

	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 and recovery	Land/shipboard	Land/shipboard	Air/land	Not specified
Radius of action	None stated	150 km beyond forward line of own troops (FLOT)	650 km	Classified
Speed	Not specified	Dash > 110 kts Cruise < 90 kts	550 kts < 20,000 ft .9 mach > 20,000 ft	Not specified
Endurance	24 hrs continuous coverage	8 to 12 hrs	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	None stated	Pre-programmed/remote	Pre-programmed	Pre-programmed/remote
Ground station	Vehicle and ship	Vehicle and ship	JSIPS (processing)	Vehicle and ship
Data link	Worldwide peace time usage, anti-jam capability	Worldwide peace time usage, anti-jam capability	JSIPS interoperable worldwide peace time usage, anti-jam capability	Worldwide 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

Figure 2. US JPO Requirements

describe the vehicles and programs in progress to satisfy each of these requirements.

SHORT RANGE

The Short Range (SR) UAV will support Divisions, Corps, and Echelons above Corps at ranges up to 150 KM beyond the Forward Line of Troops (FLOT). The system will provide near-real-time information, day or night, and in limited adverse weather conditions.

The SR system consists of a mission planning station and control station; two ground control stations and remote video terminals; multiple air vehicles; modular mission payloads; ground and air data terminals; launch and recovery equipment; and Integrated Logistics Support (ILS).

The SR program has completed engineering development which concluded with a competitive fly-off between two contractors; McDonnell Douglas Missile Systems Company with the "Sky Owl" air vehicle and the team of Israeli Aircraft Industries (IAI) and TRW with the "Hunter" air vehicle, Figure 3. IAI/TRW was selected as the winner of that competition and after a brief delay, production activity is underway.

Figure 3. Short Range UAV-Hunter

Medium Range

The MR UAV is designed to fly at high subsonic speeds with ranges out to 650 KM from the FLOT in support of the Air Force and Navy. It provides the capability to accomplish pre- and post-strike reconnaissance of heavily defended targets and augment manned reconnaissance platforms by providing high quality, near-real-time imagery.

The MR system being developed by Teledyne Ryan Aeronautical had a initial operational capability (IOC) planned for mid 1997.

Endurance

The Endurance UAV can fly for as long as ten hours at a ranges believed to exceed 800 KM. This system will respond to a wide variety of mission needs and possess the capability to carry many types of payloads.

VTOL UAV

The VTOL UAV (formerly Maritime) requirement was originally conceived as a derivative of the SR UAV but has currently focused on two novel configurations: tilt-rotor and slaved tandem-free wing, Figure 4.

The Navy would like the VTOL UAV to provide an organic, unmanned system for the expanding battle space of surface combatants. The VTOL missions of over the horizon targeting (OTH-T), naval ship fire support, battle damage assessment, and ship classification will generally be performed 150 to 200 KM from the host ship.

This program has gone thru a competition phase with the two contractors competing for an air vehicle demonstration contract.

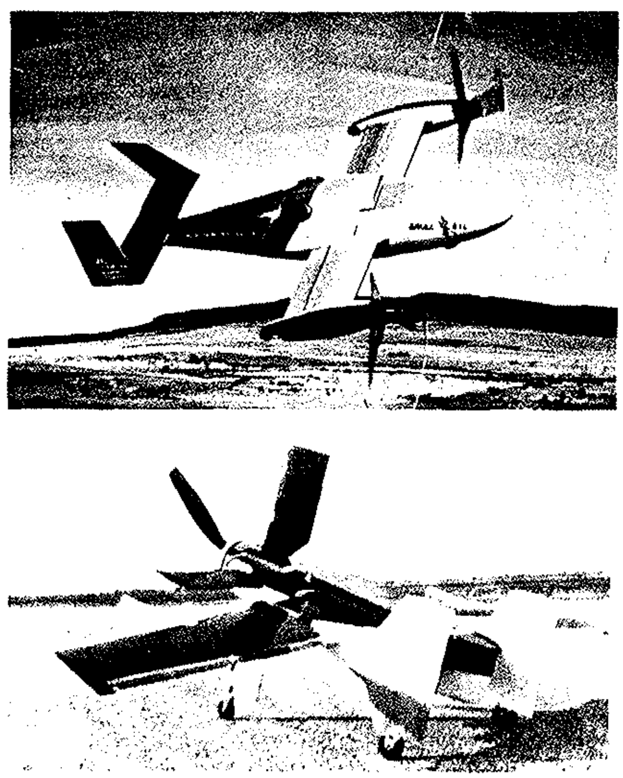


Figure 4. VTOL Maritime Candidates

Close Range

The Close Range (CR) system will provide near-real-time RSTA capabilities out to 30 km to 50 km beyond the FLOT to support the commanders at the Army division and brigade level and the Marine Air-Ground Task Force. The equipment to be fielded consists of a small UAV with a day/night sensor and meteorological sensors controllable from a ground control station (GCS). The Army system will be augmented with a ground control station and associated hardware from the SR system, while the Marine system will use a small portable ground control station downsized from the SR configuration. The system will be operable by two persons and will be transported on a single high mobility multipurpose wheeled vehicle (HMMWV) and standard trailer.

In 1992 the Government completed technical demonstrations of six 200 lb class air vehicles to assess their capability of performing within the technical parameters required for a CR system. The six air vehicles are shown in Figure 5.

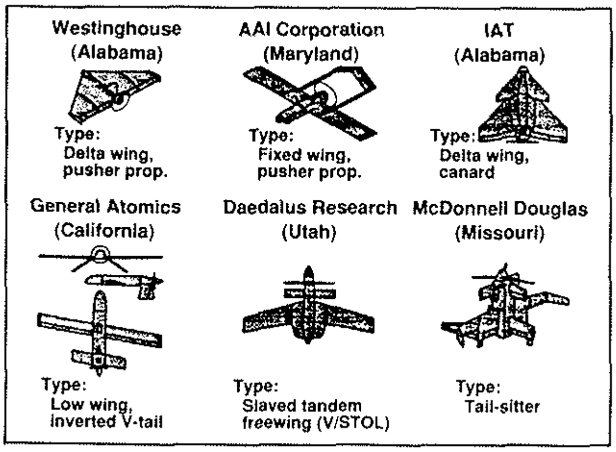


Figure 5. Close-Range Technology Demonstration Vehicles

Ducted Rotor Alternative

Sikorsky has conducted trades of numerous air vehicle configurations for the CR UAV and has arrived at a balanced technical and operational design. The ducted rotor solution is an attractive choice because of its inherent capabilities. The ducted rotor's symmetrical shape inherently provides very attractive survivability characteristics. In addition, the duct structure provides a major safety benefit by isolating all moving blades from the ground crew, as well as, eliminating the need for time consuming field assembly of wings and/or rotor blades.

Ducted configurations date back to the late 1950s, through the 1960s, when they were being explored for flying platforms or air jeeps. In general, none were successful at that time for various technical reasons. The technology in areas of aerodynamics, power plants, controls, avionics, and structures held back ducted configuration development during that timeframe. Companies such as Chrysler, Piasecki, Curtiss-Wright, Hiller, Bensen, and others, all had developed flight hardware which we now see as being 30 years ahead of its time, Figure 6. Current technology allows us to avoid the problems encountered by those early configurations and to go much further. The era of microelectronics now allows solutions to stability, automatic navigation, up/down links for control and sensors. Rotary engines now provide excellent power-to-weight ratio at impressive fuel consumption. Computational aerodynamics and extensive wind tunnels tests offer much improved aerodynamic solutions. Composite materials now allow better structures at reduced weights.

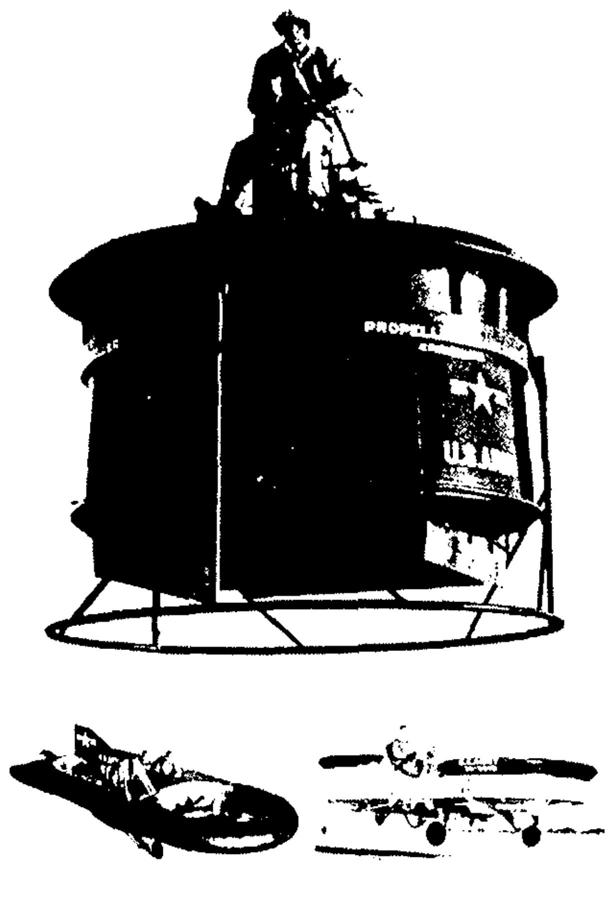


Figure 6. 1960 Ducted Sky Jeeps

The relative loading of the ducted solutions produces excellent platform stability in turbulent conditions. Compared to the low loadings for fixed wing and rotary wing vehicles, the ducted solution is superior since the response to turbulence is roughly inversely proportional to the loading.

Sikorsky's Cypher™ UAV

Sikorsky Aircraft has developed a Vertical Take-off and Landing (VTOL) system that increases the operational effectiveness of tactical commanders, as well as, meet the CR requirements. The Sikorsky concept is based on a shrouded rotor VTOL UAV which is simple to operate, survivable in high threat environments and requires minimal logistics support. The Sikorsky system, named Cypher, is easily transported on a standard trailer towed behind a High Mobility Multipurpose Wheeled Vehicle (HMMWV) or a truck of equivalent capability. Cypher is a unique system which can efficiently satisfy missions that require maneuverability in confined areas and efficient hover capabilities. In addition to the traditional military surveillance missions, Cypher has application to numerous civil and commercial missions such as hazardous waste site mapping, explosive ordnance disposal and surveillance in support of police departments, Drug Enforcement Agency or the Forest Service.

BACKGROUND

In July of 1986 DARPA funded a Sikorsky nine-month conceptual design study of a rotary wing UAV that would survive in a high threat battlefield environment. Since that initial contract Sikorsky has developed the technical data base to support the design and development of a prototype air vehicle.

Current Status

During 1991 Sikorsky Aircraft initiated a program to design, fabricate and test a Cypher-Technology Demonstrator (Cypher-TD) aircraft, Figure 7. The Cypher-TD aircraft has undergone an extensive development test program. Individual components have been validated, vehicle shakedown was completed during ground runs, the flight control system was optimized during tethered tests, and free flight hover and low speed flights have demonstrated the vehicle's mission capabilities.

The first flight, free of all tethers took place on April 30, 1993. By May 5th, an altitude of approximately 150 feet had been achieved and operation from an unprepared grass strip was being accomplished routinely. Testing has

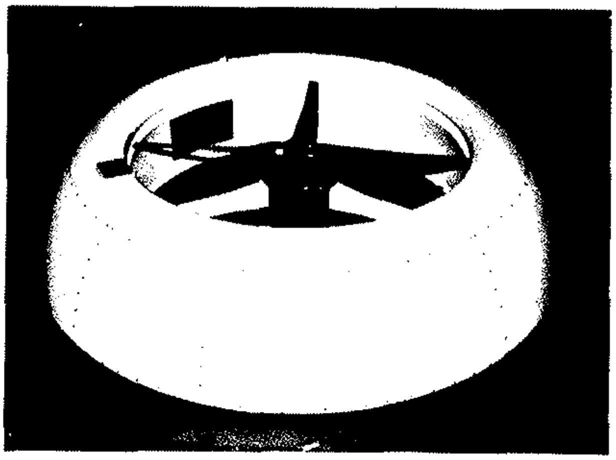


Figure 7. Sikorsky Cypher-TD

proceeded into the transition speed range with adequate margins being confirmed, Figure 8.

Current testing is leading to expanded forward flight and an operational demonstration. The forward flight test program is being done at Sikorsky's West Palm Beach Flight Test Facility. The flight test portion of the program will develop takeoff and landing techniques from sloped terrain, define the flight operating envelope, evaluate performance characteristics, establish flying qualities and conduct level flight speed sweeps. The testing will include a TV sensor payload and will demonstrate payload/AV synchronization, telemetry of payload imagery data to the ground station and overall mission capability.

TECHNICAL DESCRIPTION

The Cypher UAV is based on a combination of proven coaxial rotor technology demonstrated with the Sikorsky Advancing Blade Concept (ABC) aircraft of the 1970's and shrouded fan tail technology demonstrated with the S-67 aircraft and

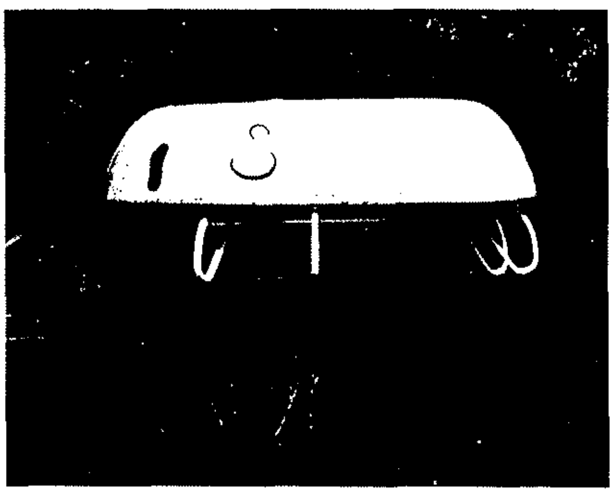


Figure 8. Cypher Free Flight Testing

S-76 LH Fantail Demonstrator aircraft. The Cypher UAV is configured with two counter-rotating four bladed rotors shrouded by the airframe. The airframe or shroud houses propulsion, avionics, fuel, payload, and other flight related hardware. The Cypher concept is an innovative approach to UAVs because it is believed to be the only ducted configuration that uses collective and cyclic pitch on the rotor blades to control lift and moments about the three body axes. The result of this approach is a very maneuverable platform with excellent hover efficiency.

The performance characteristics of the Cypher UAV are a function of both the rotor and the shroud trim states. Performance predictions required the superposition of classical duct aerodynamics with the nonuniform flow which occurs from the cyclic blade pitch used for aircraft trim. As a ducted device transitions from a hover state, the shroud will see two components of flow. The simplest is flow over the shroud as it would occur without the presence of a rotor. This flow has been tailored, through external shroud shaping, to produce a negative (nose down) moment to partially offset the second flow component. The second flow component is the induced flow through the duct, which will be nonuniform due to both the forward flight velocity and the cyclic blade pitch. The nose-up pitching moment due to induced flow is zero in hover, increases to a maximum at 20-25 knots and then diminishes, Figure 9. Increased rotor blade cyclic balances out this moment. The rotor cyclic trim requirements, however, result in an increase in power from the hover condition.

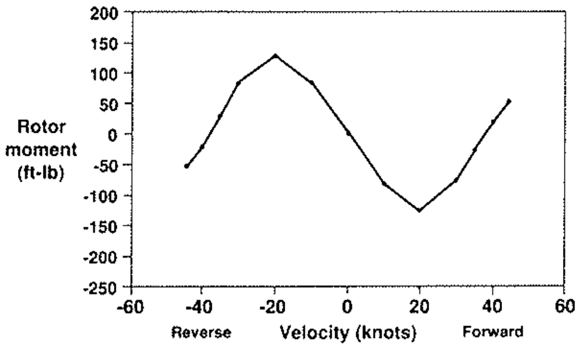


Figure 9. Cypher Trim Moments

The physical characteristics of the Cypher-TD aircraft are presented in Table 1 and a brief description of major subsystems follows:

Rotor

The rotor for the Cypher-TD aircraft is an all-composite, bearingless system,

Overall Dimensions	
• Fuselage circumference	6.5 ft
• Fuselage depth	2.0 ft
• Rotor diameter	4.0 ft
Weights	
• Normal takeoff weight	250 lbs
• Maximum gross weight	300 lbs
• Sensor payload weight (max)	40 lbs
General	
• Number of rotors	2
• Blades per rotor	4
• Tip speed	600 ft/sec
• Engine	6,700 rpm
• Engine/gear ratio	2:1
• Sea level power @ 7,000 rpm	50 hp

Table 1. Physical Characteristics

designed for enhanced reliability and maintainability at a reduced weight. In the bearingless rotor, pitch motions of the blade are accomplished by twisting rectangular shaped beams. The beams are stiff in bending but torsionally are soft. A torsionally stiff torque tube surrounds the flexbeams and transfers control motions from the control actuators to the outboard end of the flexbeam, Figure 10. Six actuators, three connected to each rotor swashplate, are incorporated for independent control of each rotor. By using a coaxial, counter-rotating rotor system, no anti-torque device is required since differential collective is used for directional control.

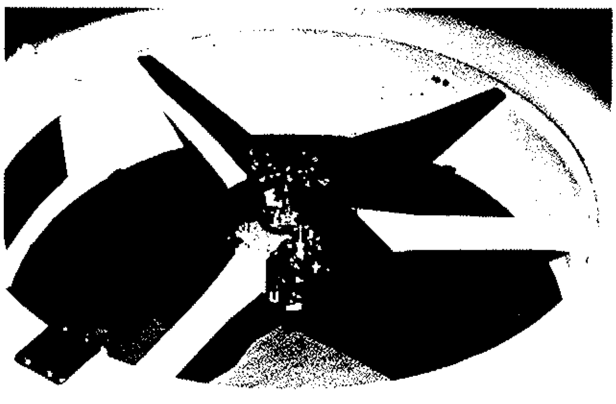


Figure 10. Cypher Rotor Systems

Airframe

The Cypher-TD airframe is an all graphite structure that consist of an inner shroud, outer shroud fairing, bulkheads, support struts and center mounting structure. The inner shroud wall is the major support surface for mounting the engine, fuel tank, avionics and payload sensor. The support struts are primary structure providing a load path between the rotor system and the external shroud. Externally the airframe is shaped to be aerodynamically efficient in both hover and forward flight.

Engine

The Cypher-TD aircraft is powered by a ALVIS rotary engine. The ALVIS engine has a high power-to-weight ratio and a good partial power fuel consumption. The NR801T is a combination air and liquid cooled engine that produces 58 hp at 8000 RPM. The engine used for the Cypher-TD incorporates a magneto powered twin spark plug ignition system. Engine operation is controlled and monitored by the aircraft flight control system.

Transmission

The transmission drive system consists of a gearbox and driveshaft connected to the rotary engine. The gearbox has a spiral bevel gear set located between the two rotors. Torque is transmitted through the driveshaft, to the pinion, through the bevel gears, and into the vertical torque shafts, thereby turning the rotor hubs and blades. An override unit is incorporated in the drive shaft.

Avionics

The avionics architecture is based on the philosophy of a central processor. The Vehicle Mission Processor (VMP), the brain of the system, integrates airborne sensors and controls aircraft flight, navigation, vehicle management, payload and communications. For the demonstration aircraft the Honeywell Integrated Flight Management Unit (IFMU) was selected for the VMP. The original IFMU was comprised of a GG1308 Integrated Measurement Unit (IMU), 1750A processor module, a power supply module, and flexible I/O module. Recently the 1750A processor was upgraded to a 8960 processor which provides improved processing speed and memory. The IMU utilizes state of-the-art ring laser gyros and highly accurate accelerometers for inertial measurements.

The VMP receives rates and accelerations from the IMU, and through strapdown navigational software, provides the flight control software with 3-axis linear accelerations, angular rates, linear velocities, vehicle attitudes and short-term vehicle position. The strapdown equations are updated by a Global Positioning System (GPS) via a Kalman Filter resident in the VMP. A radar altimeter is incorporated to provide accurate altitude and assist in the vertical control of the air vehicle during automatic launch and recovery.

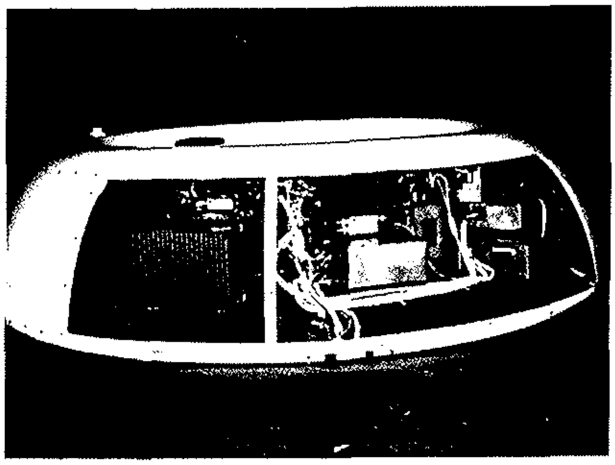


Figure 11. Cypher Avionics Bay

The avionics bay is shown in Figure 11.

All software in the VMP is written in Ada. There are three top level modules hosting mission management, flight controls, and strapdown navigational software. The mission management and flight control software was developed, coded and integrated by Sikorsky. The navigational software was an integral part of the Honeywell IFMU. Software integration and validation was conducted on an integrated hot bench consisting of a real time simulation model and actual flight hardware.

Automatic Modes

One of the major objectives of the Cypher-TD program is to demonstrate a user friendly VTOL UAV that can be easily controlled with simple operator commands. For this reason the flight controls software is configured to receive simple inputs such as vehicle heading, altitude and cruise velocity. The aircraft automatically calculates the required rotor inputs to achieve the desired flight conditions. With simplified operational commands the operator can spend more time with payload operations rather than piloting the aircraft. Automatic modes including heading hold, altitude hold, velocity hold and position hover hold are being incorporated to simplify vehicle positioning during a mission or operation from confined areas.

In the future, auto takeoff and auto land capability will be incorporated.

Command and Control

The command and control system incorporates a ground control station, a data uplink for transmission of control commands and a downlink for transmission of vehicle status and payload information. The airborne portion of the command and control system is the Air

Data Terminal (ADT) which utilizes standard 1553B, analog, and digital interfaces to the VMP. The ADT communicates with the ground via two omni-directional antennas and can be programmed for various carrier frequencies within the C-band range.

The ground control station is divided into two sections, an operator section and a test section, both on portable self contained racks. The UAV operator side includes the mission control panel (vehicle and payload), a PC displaying vehicle status data, a video monitor and a video recorder. The test section includes a PC display of test and validation data, a strip chart recorder, and a PCM data recorder.

Mission Payload

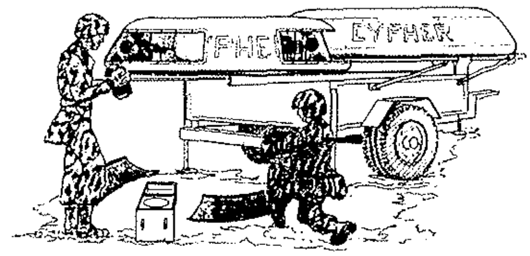
An important part of the Cypher system is the mission payload sensor. The payload sensor is the "eyes and ears" from which the ground operator obtains vital information on the area of interest. The Cypher UAV has been designed to accommodate a variety of sensors including EO, FLIR and/or small radars. Depending on the quality of the image desired, range of use, and stability method, the aircraft can easily be reconfigured with a new sensor for a different mission.

The mission payload for the technology demonstrator consists of a video camera with a zoom lens to provide different fields of view. The operator has both elevation and azimuthal control of the payload sensor. The sensor is mounted on a single-axis platform for elevation control with azimuthal orientation being accomplished by rotating the air vehicle about its center of rotation. Operator payload controls also include tilt, zoom, focus and brightness.

Operational Aspects

Two air vehicles transported by a standard trailer, towed behind a HMMWV containing the ground station, Figure 12, can be fully maintained, supported and operated by two men. The trailer would have provisions to carry two air vehicles, appropriate spare parts, fuel, ground power and multiple mission payload sensors. The aircraft can be handled by two men without fuel and payload. The vehicle can be launched from any cleared area that is approximately twice its diameter.

To launch the air vehicle, the ground operator needs only remove the aircraft from the trailer; install the payload and fuel; start the engine; run the built-in-test functions and engage the launch control. The aircraft takes off vertically and stabilizes a set distance



- Launchable from ground or trailer
- Minimum prelaunch requirements
- Avionic built-in test functions

Figure 12. Cypher Ground Operation

off the ground and holds that position in space. The operator then selects a preprogrammed mission profile or enters the coordinates of the area of interest. During flight, payload sensor imagery is sent from the aircraft via data-link back to the ground operator in real time for viewing and recording.

Missions

One of the more traditional limitations faced by military forces is the inability to provide the front line commander with real time Reconnaissance, Surveillance, Target Acquisition (RSTA) information to support tactical maneuvers. The capability to "look over the next hill" is an age old requirement of the tactical commanders and is currently accomplished with sophisticated and costly airborne platforms or scouting parties which place solders in potentially dangerous situations.

The ability to vertically takeoff and land, coupled with the ability to hover on station and travel at low speeds makes the Cypher UAV ideal tool for gathering RSTA information for tactical units.

An illustrative example of a mission in a forward area might begin with an intelligence report from higher headquarters which indicates a large motorized or armored force moving toward the tactical commander's area of interest, Figure 13. The high speed avenue of

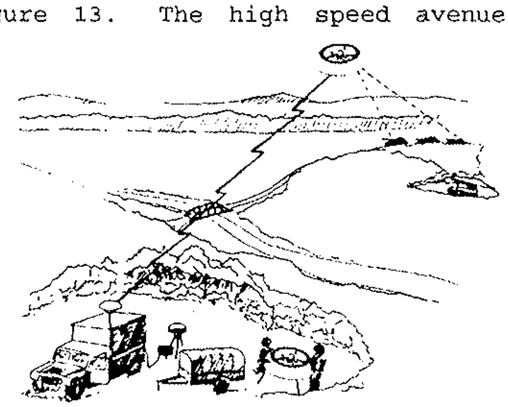


Figure 13. Reconnaissance: A Major Role

approach is expected to be along two roads that intersect. Taking either road, the enemy force must cross a river before he reaches the tactical unit area. The commander needs to know which road the enemy takes so that he may initiate a planned response to destroy the bridge. The Cypher UAV will provide a singular means to both ascertain the enemy route and coordinate weapon engagement against the bridge.

SUMMARY

The Cypher VTOL system provides the maneuver unit commander with an organic capability to "See Without Being Seen" and without dependence on higher level assets. This VTOL UAV system provides flexibility that can be safely employed in any situation, at any time. The air vehicle will fly itself needing only top level operator inputs to perform its mission. The inherent survivability characteristics allow the air vehicle to operate throughout the battlefield with the lowest probability of detection. The system is simple, survivable and inherently safe.