Sikorsky Aircraft's Unmanned Aerial Vehicle, Cypher: System Description and Program Accomplishments

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Abstract

Sikorsky Aircraft is developing an unmanned vertical take-off and landing (VTOL) system to meet a wide variety of civil and military mission requirements. The Sikorsky system, named Cypher, is based on a shrouded rotor VTOL unmanned aerial vehicle (UAV) designed to be versatile, safe, and simple to operate. The validity of the Cypher concept has been proven through the development and flight testing of a Cypher Technology Demonstrator aircraft. A background description of the Cypher program and a summary of the flight test results are presented in this paper.

Introduction

The Cypher UAV, Figure 1, is based on a combination of proven coaxial rotor technology, demonstrated with the Sikorsky Advancing Blade Concept (ABC) aircraft of the 1970s, and shrouded fan tail technology, demonstrated with the Sikorsky S-67 aircraft in the 1960s and the 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 shrouded rotor design is inherently safer than exposed rotor configurations by virtue of the elimination of possible contact between rotors and obstacles or personnel. Thus, the shrouded rotor vehicle is able to operate in confined areas without the risk of blade strikes.

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The Cypher aircraft system is portable and requires no special launch or recovery equipment. The compact vehicle size provides a low observable signature for increased aircraft survivability in high threat environments. The Cypher aircraft is also very easy to operate and requires only minimal operator training. These attributes, along with low

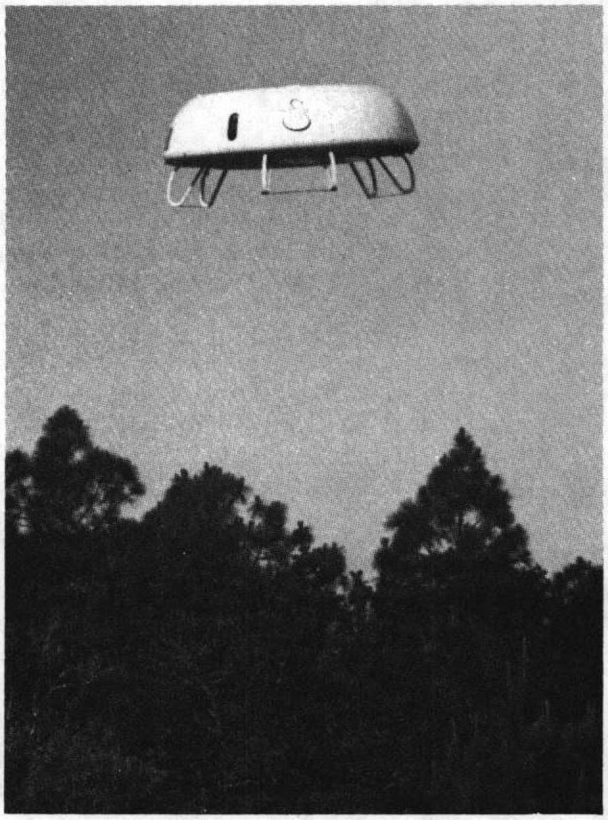

Figure 1
Sikorsky Aircraft Cypher unmanned air vehicle is very easy to operate and requires only minimal operator training.

maintenance and tow operation cost, make it an ideal candidate for a variety of military and civil applications, such as reconnaissance, search, surveillance, targeting, mine detection, and precision placement of payloads.

Background

In July 1986, the Defense Advanced Research Projects Agency (DARPA) funded a Sikorsky conceptual design study of a rotary wing UAV that would survive in a high threat battle environment. When the contract ended in March 1987, Sikorsky initiated a development program using Independent Research and Development (IR&D) funds. Sikorsky conducted risk reduction efforts which led to the design, fabrication, and testing of a proof-of-concept vehicle which first flew during the summer of 1988. This vehicle had a gross weight of 44 pounds. and carried no payload, but it did successfully demonstrate the validity of the shrouded rotor concept. In 1989, an experimental model was fabricated and tested in Sikorsky's hover stand test facility to quantify the interactions between the rotor and shroud for various conditions. The experimental model was tested in the United Technologies Research Center (UTRC) large subsonic wind tunnel during 1990. The results of this model testing led to the design, fabrication, and testing of a Cypher Technology Demonstrator (TD) aircraft in 1991.

General Description

The Cypher shrouded rotor UAV is a VTOL aircraft that incorporates two counter-rotating rotors surrounded by a composite shroud. The shroud supports the rotors, produces a portion of the lift, and acts as an airframe to house propulsion, avionics, fuel, payload, and other flight-related hardware. The air vehicle computer, called the vehicle mission processor integrates various functions such as airborne sensors, navigation, flight controls, mission management, and communications. This level of automation relieves the operator from "joy stick" flying and maximizes the time available for imagery evaluation and mission execution.

The Cypher concept is an innovative approach to UAVs because it is the first and only ducted configuration that uses collective and cyclic pitch on the rotor blades to control lift and moments about the three-body axes. The coaxial, counter-rotating rotor system also provides torque equilibrium and a means of directional control. The result of this approach is a versatile VTOL platform that is maneuverable, controllable, and efficient in hover.

The physical characteristics of the Cypher aircraft are presented in Table 1, and a brief description of the major subsystems follows.

Table 1

PHYSICAL CHARACTERISTICS

OVERALL DIMENSIONS		
	Fuselage Length	6.5 ft
	Fuselage Height	1.6 ft
WEIGHTS		
	Weight Empty	170 lb
	Normal Takeoff Weight	250 lb
	Max. Gross Weight	300 lb
	Usable Fuel Weight	40 lb
	Sensor Payload Weight	40 lb
GENERAL		
	Number of Rotors	2
	Rotor Radius	2.0 ft
	Blades per Rotor	4
	Tip Speed	650 ft/sec
	Engine rpm	6,500

Mechanical System

The rotor system is all-composite and bearingless, designed for enhanced reliability and maintainability at a reduced weight. In the Cypher bearingless rotor, pitch motions of the blade are accomplished by twisting rectangular shaped flexbeams. The flexbeams are stiff in bending but torsionally soft. A torsionally stiff torque tube surrounds the flexbeams and transfers control motions from the actuators to the outboard end of the flexbeam. Six actuators, three connected to each swashplate, are incorporated to provide independent control of each rotor. The coaxial counter-rotating rotor system eliminates the need for an antitorque device. Directional control is accomplished by using differential collective.

The Cypher airframe is an all-graphite structure that consists of an inner shroud, outer shroud fairing, bulkheads, support struts, and center mounting structure. The inner shroud wall is the support structure for mounting the engine, fuel tank, avionics, and payload sensor. Externally, the airframe is shaped to be aerodynamically efficient in both hover and forward flight.

The Cypher aircraft is powered by an Alvis UAV rotary engine. The Alvis engine has a high power-to-weight ratio and good partial power fuel consumption. The engine is a combination air and liquid cooled design that produces 50 hp at 7,000 rpm. The original engine used for the Cypher-TD aircraft incorporated a magneto-powered twin spark plug ignition system. That engine has recently been upgraded to incorporate an electronic fuel injection system to increase the available power without an increase in weight. The upgraded engine produces 58 hp at 7,000 rpm. Engine operation is controlled and monitored by the aircraft flight control system.

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.

Avionics System

The avionics architecture is based on a centralized processor, Figure 2. The vehicle mission processor (VMP), the brain of the system, integrates airborne sensors and controls aircraft flight, navigation, vehicle management, payload, and communications functions. For the demonstration aircraft a Honeywell integrated flight management unit (IFMU) was selected for the VMP. The IFMU comprises an integrated measurement module (IMM), 80960 processor module, and flexible input/output module. The IMM utilizes state-of-the-art ring-laser gyros and highly accurate accelerometers for inertial measurements. The IFMU has recently been upgraded to incorporate an integrated global positioning system (GPS) module.

The VMP receives rates and accelerations from the IMM, and through strapdown navigational software, provides the flight control system with three-axes linear accelerations, angular rates, linear velocities, vehicle attitudes, and position. The strapdown equations are updated by the GPS via Kalman filters resident in the VMP. To improve sensor and navigational accuracy, the internal GPS module receives differential GPS corrections transmitted to the vehicle from a ground station. A radar altimeter provides accurate above ground level (AGL) altitude and assists in vertical control of the vehicle.

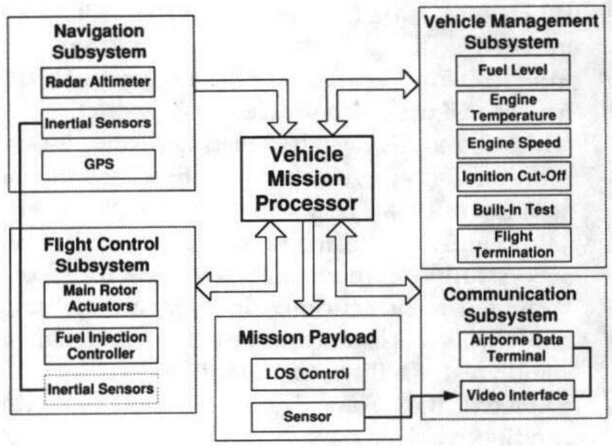

Figure 2
Cypher avionics architecture supports semi-autonomous operation.

All software in the VMP is written in Ada. There are three top level modules hosting mission management, flight controls, and navigational software. The mission management and flight control software was developed by Sikorsky. The navigational software was an integral part of the Honeywell IFMU.

Mission Sensor

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 from the area of interest. The Cypher UAV has been designed to accommodate a variety of sensors, which include electro-optical (EO), forward looking infra-red (FLIR), or small radars. Depending on the quality of the image desired, range of use, and stability method, the aircraft can be easily reconfigured with a new sensor for different missions.

The mission payloads for the Cypher-TD aircraft consist of a video camera or a FLIR. Each sensor is mounted on a single-axis platform for elevation control. Azimuth control is achieved by rotating the air vehicle about its center of rotation. A magnetometer was also integrated into the Cypher aircraft to demonstrate the system's effectiveness in performing aerial searches for metallic objects on or under the ground.

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 to the ground station. The airborne portion of the command and control system, the air data terminal utilizes mil-standard 1553B, RS-422, analog, and discrete interfaces to the mission processor. The terminal communicates with the ground via two omni-directional antennas. This system can be programmed for various carrier frequencies within the C-band.

The ground control station is divided into two sections, an operator section and a test section. Both are mounted on portable self-contained racks. The UAV operator selection includes the mission control panel for vehicle and payload control, a personal computer displaying vehicle status data, a video monitor, and a video recorder. The test section includes a display of test and validation data, a strip chart recorder, and a PCM data recorder. The pulse-code modulated (PCM) data stored on the recorder can be post processed for a complete analysis of the vehicle's performance.

Figure 3 shows the ground control station installed in a mobile utility van configuration.

Operator/Vehicle Interface

A major objective of the Cypher aircraft program was the development of an air vehicle which could be flown by unskilled personnel, thereby avoiding the requirement for using highly trained pilots as the operators. From the beginning, the vehicle was designed for highly automatic operations. This approach enables the operator to act more as a mission manager, monitoring mission progress and initiating high level commands, as opposed to a pilot actively flying the vehicle.

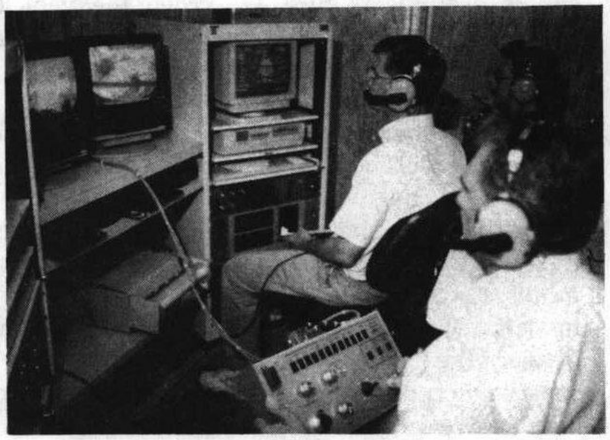

Figure 3
The Cypher aircraft operator console provides an integrated display of the external situation.

To achieve this very simple operator/vehicle command interface, the flight control system was designed to accept a series of simple operator commands such as takeoff, hover, cruise, return home, and land, as well as basic flight commands, such as the desired heading, speed, and altitude. The flight control system interprets commands and automatically achieves the desired flight conditions. Once this level of automated operation was attained, the operator/vehicle interface would be further simplified by integrating mission manager software with the flight control system to enable automatic mission execution through a series of operator programmed way points.

Flight Control Development

Development of the flight control system consisted of a series of incremental segments of analysis and testing, each building on previous accomplishments. The process started with the definition of requirements using analytical vehicle models based on Sikorsky's General Helicopter (GenHel) simulation environment. The GenHel model of the Cypher-TD vehicle was originally based on the early wind tunnel and ground tests data. It has since been continually refined based on results of system and subsystem level test.

Linear state space models for various flight conditions were developed From the GenHel model.. These linear models served as a basis for developing control laws and determining specifications for system components, such as servo simple example, Figure 4. When the vehicle is directly in front of the operator and both operator and vehicle are facing the same direction, the operator's and vehicle's reference systems are the same. So if the pilot inputs a right stick command, the vehicle will move to his right. With the vehicle yawed 180 degrees such that it is facing the operator, the vehicle's and operator's reference frames are exactly opposite. That is, if the operator inputs a right command, the vehicle will move to his left. This problem is amplified as the distance between the operator and vehicle increases, and it is especially confusing with symmetrical vehicles, such as Cypher, where the front of the vehicle is not easily determined visually.

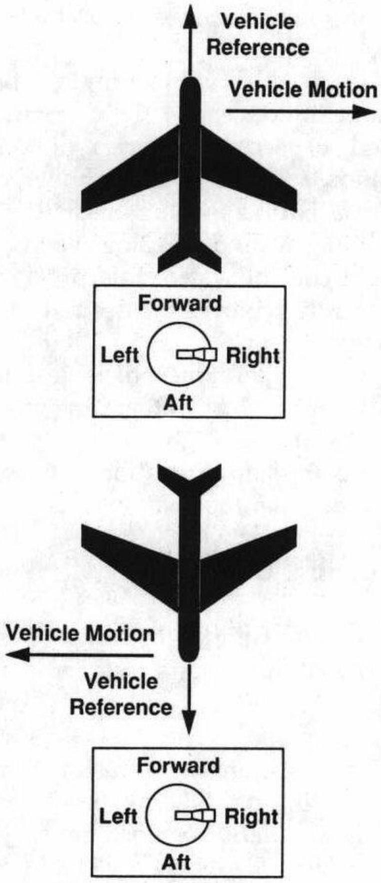

Figure 4
Operators vehicle reference frame problem is easily solved in the Sikorsky Cypher aircraft.

To alleviate this problem, Sikorsky devised an algorithm which allows the operator to always input commands using his earth-referenced orientation. This routine continually keeps track of the vehicle's heading with respect to the operator's reference system and determines the appropriate aircraft commands to move the vehicle according to the operator's earth-referenced command. In other words, when the operator tilts the stick to the right, the vehicle will always move to his right regardless of its heading orientation. As a result, the vehicle is very easy to operate and maneuver.

Initial tests were all performed in the attitude hold mode. The philosophy was to utilize this proven mode as tool to define the basic flight characteristics of the vehicle. Once the basic flight characteristics were defined and the simulation verified, the more advanced flight modes could be developed more readily.

This approach proved wise, since what followed was a relatively quick succession of progress in the flight development effort. By upgrading the vehicle's stand-alone commercial grade GPS to receive differential GPS corrections the position and velocity accuracy of the system were improved. Improved speed and location accuracy's were required to develop the velocity hold and position hover hold control algorithms. The velocity hold mode maintains the vehicle at an operator-commanded ground speed. When velocity hold is engaged, the operator commands velocity from the same control panel joysticks otherwise used for pitch and roll attitude hold commands. Displacing the joystick from its spring-centered position generates a velocity command proportional to its angular displacement. The operator commands zero ground speed by returning the joystick to its center position, maintaining the vehicle in a hover. Velocity hold is susceptible to external disturbances such as wind, so a position hover hold algorithm was developed to close the control loop around vehicle position whenever a zero velocity hover is commanded. This allowed the vehicle to automatically maintain itself at a specific hover position with no operator intervention.

The vehicle flight controls were further expanded to incorporate altitude hold and heading hold algorithms. Each of these modes receive absolute commands from the operator via control dials. The algorithms ensure that the vehicle automatically achieves the desired conditions while not exceeding the operational limits of the vehicle. Additional flight control system improvements included incorporation and verification of an operator-

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