Aircraft Type and Model Description

1. Introduction

The Autonomous Rotorcraft Project operates two Yamaha RMAX helicopters (Fig. 1-1). This document describes the configuration of the vehicles as delivered by the manufacturer and a top-level description of the modifications made for autonomous flight. Yamaha factory-recommended operations and maintenance manuals can be found in references 1 and 2.

Fig 1-1. AFDD Autonomous Rotorcraft Project RMAX helicopter in operation at Fort Hunter Liggett in California.

2. Vehicle Description

This section describes the basic properties of the two Yamaha RMAX helicopters (serial numbers L15-100-444, L15-100-445) delivered to NASA Ames Research Center.

The Yamaha RMAX helicopter is designed primarily for agricultural purposes such as seeding and spraying. The RMAX replaces the Yamaha R-50 helicopter of which over 1000 have been delivered since 1988 and over 5500 pilots have been trained to operate. The R-50 and RMAX are currently used in Japan to apply pesticides and fertilizers to over 600,000 acres annually.

The RMAX incorporates improvements that were seen to be needed based on the operational experience with the R-50. Extensive structural improvements were made. A specially-designed, water-cooled two-stroke engine was installed. The payload was increased from 44 lbs. to 66 lbs. An onboard starter was added. Lastly, extensive health and safety monitoring equipment was added.

The R-50 and RMAX are also in use by several research institutions as test beds for UAV technologies. Research using both the R-50 and the RMAX is underway at UC Berkley, Georgia Tech, and Carnegie Mellon. For NASA's research purposes, Yamaha has modified the RMAX to provide access to the on-board digital data bus and has also installed an over-sized generator (Section 3).

2.1 Vehicle Dimensions

The overall vehicle dimensions are indicated in Fig. 2-1.

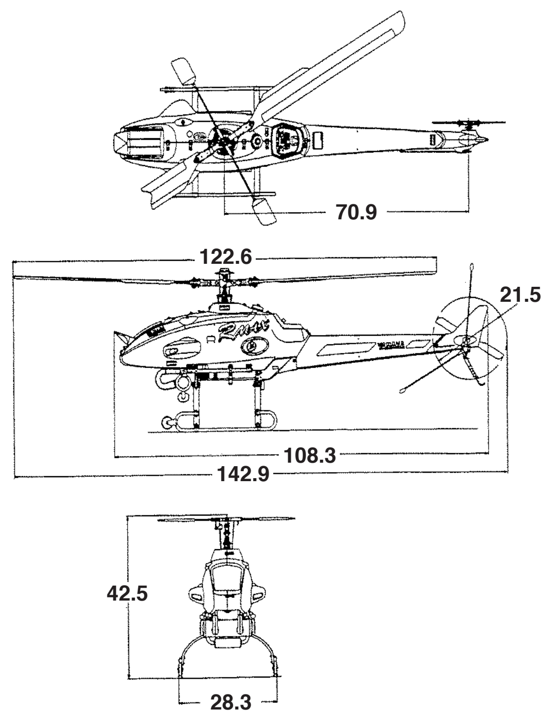

Fig 2-1. RMAX dimensions (inches).

2.2 Mass properties

The total vehicle weight as delivered by Yamaha is 127.9 lb. The payload limit is 66.1 lb. The only weight and balance recommendation from the manufacturer is that the cg be located within 40 mm. of the centerline of the main rotor mast.

2.3 Rotor system

The RMAX main rotor system consists of a two-bladed under-swung teetering main rotor with a Bell-Hiller stabilizer bar and a two-bladed tail rotor. The under-swung configuration of the main rotor (Fig. 2-2) reduces the Coriolis forces and the associated in-plane blade motion. The purpose of the Bell-Hiller stabilizer bar is to enhance vehicle stability by providing a mechanical lagged rate feedback in the pitch and roll axes. This additional feedback stabilizes the low frequency dynamics and improves disturbance rejection.

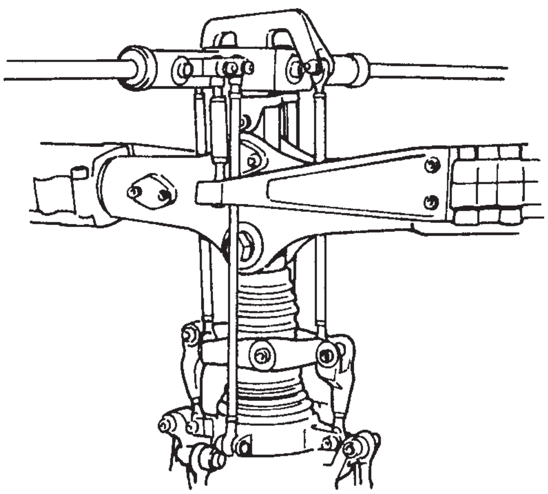

Fig 2-2. RMAX main rotor hub.

2.4 Engine

The RMAX is powered by a two-stroke gasoline engine (Fig. 2-3). It has two horizontally opposed cylinders with a bore and stroke of 56 and 50 mm with a total displacement of 246 cc. The engine normally operates at 6350 rpm and produces 21 horsepower and 2.6 kg-m of torque. It uses a 12 volt electrical system and has an electric starter. The engine is water cooled. The transmission system provides a 7.67 reduction ratio from the engine to the main rotor and 1.14 to the tail rotor. RPM is regulated via an engine governor.

Fig 2-3. RMAX engine compartment.

2.5 Electrical

The RMAX operates on a 12 volt electrical system. The generator produces 16 A at 14 V of three phase power (Fig. 2-4). The generator is intentionally oversized to provide a power source for any added research hardware (see section 3). A detailed wire harness drawing can be found in reference 3.

Fig 2-4. RMAX generator and engine flywheel.

2.6 Radio control system

The RMAX is controlled via FM pulse code modulation (PCM) radio. The PCM aids in the prevention of radio command interference. The two transmitters (Fig. 2-5) delivered by Yamaha produce 0.3 W of power at 72.110 MHz (tail no. L15-100-444) and 72.130 MHz (tail no. L15-100-445). The transmitter bandwidth is 10 kHz.

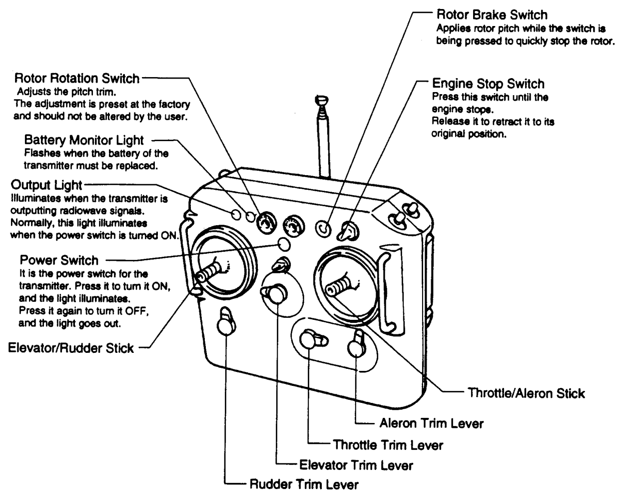

Fig 2-5. RC transmitter.

2.7 Yamaha Attitude Control System (YACS)

The factory flight control computer is termed the Yamaha Attitude Command System (YACS, Fig. 2-6). The YACS provides three flight control modes: S-mode which is highly stabilized and intended for inexperienced pilots, C-mode which is based on S-mode but with greater yaw sensitivity, and A-mode which is pseudo attitude-command. Mode selection is made via a rotary selector knob on the back panel of the aircraft prior to flight (Fig. 2-7).

Additional feed forward commands from the collective to the directional axis and the collective to throttle are calculated within the RC transmitter.

Manual flight control, i.e. direct actuator command, can be achieved by depressing the “control cancel” switch on the transmitter.

Fig 2-6. Yamaha attitude command system (YACS) aircraft hardware.

Fig 2-7. Back panel used for control mode slection.

2.8 Self monitoring

The RMAX is factory equipped with an extensive self-monitoring system. Vehicle status and health are indicated via warning lights both on the back panel and on the underside of the vehicle. Prior to engine start the system monitors and displays faults in the YACS, the backup control system, the signal system, the actuators, the IMU, the charging system, low fuel, and weak radio communication. The system will prevent engine start if any faults are detected. During flight the system monitors and display the same faults as well as low rotor RPM.

If a condition of very weak or non-existent radio communication persists for more than three seconds during flight than the flight control computer will automatically command a wings-level attitude and lower the throttle position and main rotor collective position to ground.

Fig 2-8. Rear warning lights.

3. Factory Research Modifications

3.1 Serial data bus access

THE RMAX aircraft delivered to NASA Ames were modified to include access to the on-board digital data buses. A radio system connection gives read-only access to the manual control commands, the output of the built-in throttle servo loop and the output of the yaw stabilization loop. An IMU connection provides read-only access to roll, pitch, compass heading, 3 axis rotation rates, and 3 axis acceleration information at an update rate of approximately 100 Hz. A control computer connection provides read-only access to system status, commanded actuator positions (after the stabilization system), and actual actuator positions.

The aircraft have also been modified to enable direct control via the control computer connection. Under normal RC operation, command inputs are passed directly from the radio system to the factory flight control computer. A software switch, activated via the RC transmitter, causes the radio system input to be overridden by commands from the control computer connection. Commands can either be in the form of inputs to the factory flight control computer or direct actuator position commands. Control reverts to manual radio system input if commanded to do so via the RC transmitter switch or if the update rate from the control computer connection falls below 5 Hz.

All connections use RS-232 signaling specifications to provide noise immunity and short circuit protection. All connections are provided on a single, locking connector on the back of the flight control computer. The data to and from the control computer uses a fixed initial sequence and a checksum to insure data integrity. The data from the radio or IMU uses parity to insure data integrity.

3.2 Increased generator capacity

The standard generator installed on the RMAX produces 10 A at 14 V of single phase power. However, Yamaha replaced this with a larger generator on both aircraft to provide a power source for the planned flight research hardware. The oversized generator produces 16 A at 14 V of three phase power. The aircraft systems require 6 A at 14 V which leaves 10 A at 14 V (140 W) for the research flight hardware.

The oversized generator adds approximately 0.7 lbs to the weight of the vehicle. This added weight combined with the additional load the generator places on the engine reduces the potential payload weight by an estimated 3.5 lb.

4. Added Avionics

4.1 Serial data bus access

The AFDD RMAX has been modified to include an avionics payload (Fig. 4-1) which carries a navigation and flight control computer, experimentation computer (typically used for vision processing), inertial measurement unit, GPS receiver, and radio communications equipment. The payload was designed for simple maintenance and to be easily transferred between aircraft. A mobile ground station provides support and acts as a base of operations for the testing.

Figure 4-1. Avionics payload and stub wing.

Separate from the avionics payload is a vibration-isolated stub wing on which various cameras can be mounted. A tilting mechanism supports a pair of monochrome 640x480 resolution progressive-scan IEEE-1394 cameras (Fig. 3). These stereo cameras have a one-meter baseline to provide accurate passive-ranging of obstacles at distances sufficient for path re-planning. The tilting mechanism provides +10 to –100 degrees of pitch travel. Cross-shafting provides sufficient stiffness to ensure the stereo cameras maintain proper alignment throughout their range of travel and under vehicle vibratory loads. Any process can interrogate or reposition the stereo camera tilting system using a simple DOMS message (see below). A color 640x480 resolution IEEE-1394 camera mounted alongside the left monochrome camera provides real-time progressive-scan streaming imagery to the ground at 10 fps. Communication with and power to the cameras is achieved via the IEEE-1394 connection. Compact 8-mm fixed-focal-length C-Mount lenses provide approximately 45x36 degrees field-of-view. Images are gathered simultaneously from the cameras at a rate of 30 fps and stored on-board. A video server software system has been developed to ensure that any process can access the camera imagery when needed; e.g. the stereo passive ranging system, a monocular tracker, and a video compression and downlink system can make simultaneous use of the imagery.

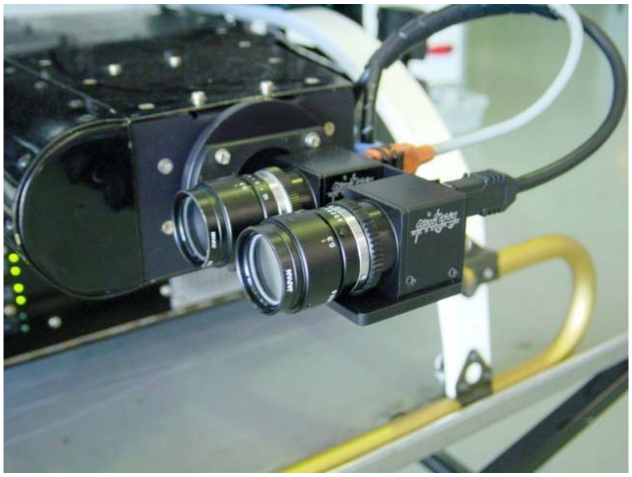

Figure 4-2. Digital cameras.

Mounted under the nose of the aircraft is a SICK LMS scanning laser used for obstacle detection and high-resolution mapping (Fig. 4). The sensor has been remanufactured and lightened from 9.9 lb to 3.6 lb for use on the helicopter. The mounting system provides vibration isolation. The device provides centimeter-accuracy range measurement every one degree over a field-of-view of 180 degrees. Scans are performed at 75 Hz. The maximum range of the sensor is 80 meters. The SICK laser is mounted on a servo actuator rotating mount oriented 60 degrees downward. The mount rotates at 0.5 Hz thus providing a scan of a hemispherical area in front of and below the helicopter once per second. The rotating mount can also be commanded to a constant orientation when necessary; e.g. during the final stages landing when a continuous height-above-ground measurement is desired.

Figure 4. SICK LMS Class I eyesafe scanning laser rangefinder.

5. References

1. Yamaha RMAX Operation Manual, L15-28199-01, First edition, Jun. 1998.
2. Yamaha RMAX Yearly Inspection items – Inspection Criteria and Replacement Assessment Criteria, cover letter dated 25 Sep. 2000.
3. Yamaha RMAX Electrical Schematic Drawing (no drawing number or date) with Supplemental RMAX Control System data, received 22 Nov. 2000.