Attachment 3 (Launch and Recovery) to Application for Certificate of Authorization (COA) Reference COA Draft #2627 for the U.S. Army Aeroflightdynamics Directorate RMAX Unmanned Aircraft System at Fort Ord, CA

1. Introduction

The AFDD Autonomous Rotorcraft Project operates two Yamaha RMAX helicopters (Fig. 1-1). This document describes the launch and recovery of the vehicle.

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

2. Manual Launch and Recovery

Manual launch and recovery is achieved using the RC transmitter described previously. When this method is used the autonomous flight control system is then engaged and disengaged while in a hover. The majority of this material is extracted from the original takeoff and landing test plan which is included in the attachments (Ref. 1).

3. Autonomous Launch and Recovery

This section describes the autonomous launch (takeoff) and recovery (landing). Several hundred autonomous takeoffs and landings have been performed with this system without incident.

3.1 Autonomous launch

This section describes the takeoff flight control logic and methodology. A detailed description of the ARP RMAX flight control system and its software implementation is contained in reference 2.

3.1.1 Takeoff control logic

Figure 3-1 shows the sequence for the takeoff. The bound count, which is a record of the maximum values of some of the internal states and performance parameters relevant to this test, is reset for diagnostic purposes. Next, the Sonar is turned on and the altitude is checked for a valid return. The weight-on-wheels (WOW) switches are checked to make sure the RMAX is on the ground. The GPS is checked to make sure the system is in fixed-differential mode. The UTM altitude is saved to establish where the ground is in UTM coordinates. The engine RPM is checked to make sure the engine is idling in a preset RPM range. To avoid an unintentional monitor trip, the Command Hardover monitor thresholds are increased (relaxed).

The system is then put into the bypass configuration to make sure there is no feedback from the control law and the pilot inputs from the transmitter are disabled so the safety pilot can move the collective without affecting the takeoff (see Section 3.1.2).

The actuators are moved to their zero position and the inner loop biases are reset at these positions. This sequence ensures the biases are consistent for each takeoff.

The configuration is then changed to a modified velocity-command/velocity-hold (Vc/Vh) configuration. First, the system is configured in Vc/Vh. Then, all pilot inputs are disabled. The RPM gain scheduling is enabled, which cause the lateral and longitudinal loop gains to drop with the measured RPM. The trim tables are not used in this special mode, so the fade-in to the tables is disabled. The pedal and collective loops are disabled and the lateral and longitudinal integrators are disabled. Finally, a check is made to ensure the lateral and longitudinal loops are ready. Once the loops are ready, the collective is raised to a target RPM just below the nominal hover RPM. If this should fail, then the sequence will abort to the takeoff abort sequence.

The takeoff abort sequence rapidly lowers the collective and resets the internal parameters of the control law so that the vehicle is ready for another takeoff attempt. Details of the takeoff abort sequence can be found in reference 3.

If the target RPM is reached, then the inner loop control inputs are reset and the collective is raised until a hover state is sensed. If this should fail, then the sequence will abort to the takeoff abort sequence.

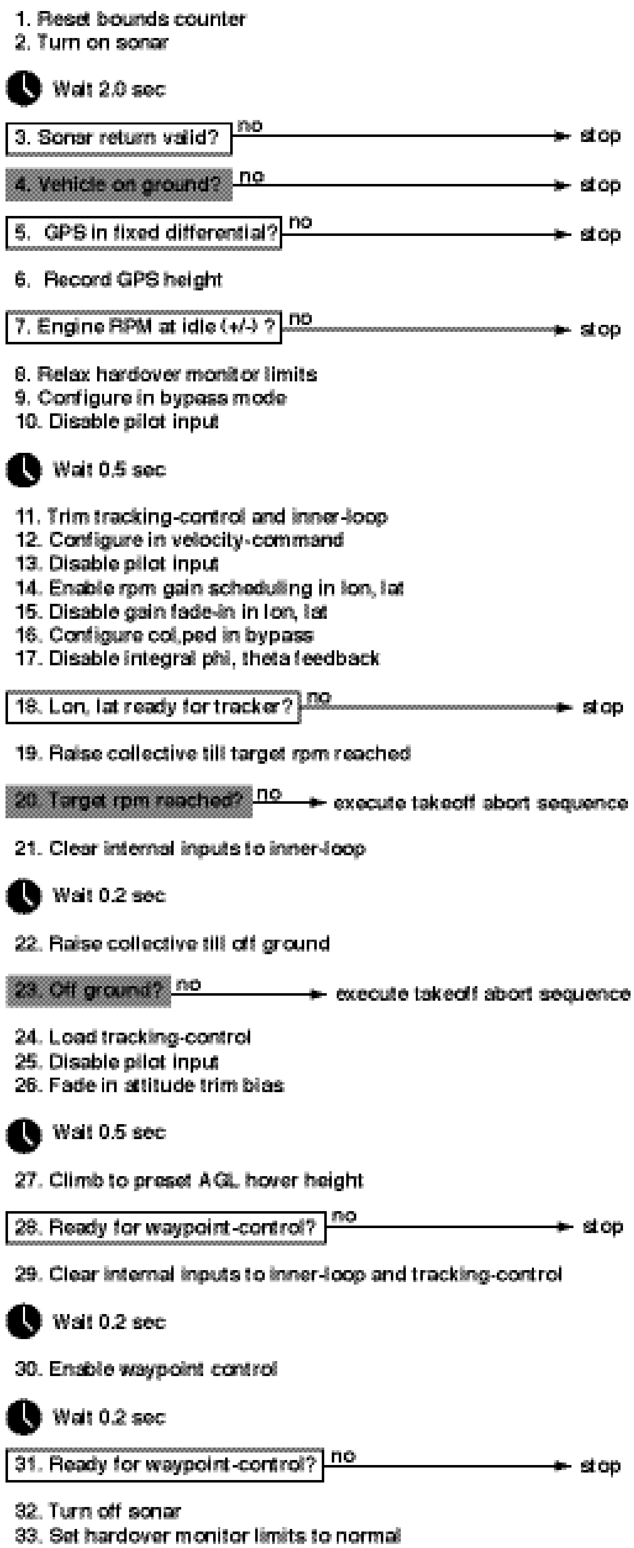

Fig. 3-1. Takeoff sequence.

Once three of the four WOW switches are open the helicopter is considered to be off the ground and the configuration is converted to position tracking control. The trim tables are also activated and the reference altitude is set to a predefined value above the previously sensed ground UTM altitude. After a check is done to make sure the tracking control is ready, then the sequence puts the system into waypoint control mode. The sonar is shut off and then the hardover monitoring thresholds are restored to their lower (more conservative) settings.

3.1.2 EP backup

The EP positions the transmitter collective in a manner that ensures the best chance of recovery should the research flight control system disengage.

The EP will leave the collective in the full down position until liftoff appears imminent, at which time he will move the collective to a position higher than that required for hover. This way if the flight control system disengages (or the EP manually disengages) during the initial portion of the takeoff sequence, the aircraft will rapidly return to a ground idle state. Likewise, if the flight control system disengages (or the EP manually disengages) during the latter portion of the takeoff sequence, the aircraft will climb away from the ground while the EP takes control.

3.2 Autonomous recovery

3.2.1 Landing control logic

The most vulnerable time for the landing is similar to that of the takeoff, which is prior to, and during the point where the vehicle is touching the ground. Descending to the ground is straight forward as the system is configured in tracking control, and thus, it is only required that the set point for the tracker be set to the just below the ground. The vehicle will approach the ground at a decelerating rate until the sonar altitude indicates a touch down, or the WOW switches are activated. Once on the ground, the collective is dropped in a measured way so it’s fast enough to keep the vehicle on the ground, but not so fast as to cause the vehicle to hit the ground too hard if is still just above the ground, and not too hard as to cause a large tip path plane droop in the rotor. As the rotor speed is reduced, some lateral and longitudinal stabilization is left active to prevent upsets from wind disturbances.

Figure 3-2 shows the sequence for landing. The bound count, which is a record of the maximum values of some of the internal states, is reset for diagnostic purposes. The Sonar is turned on and the altitude is checked for a valid return. Next, the WOW switches are checked to make sure the RMAX is in the air. The GPS is checked to make sure the system is in fixed-differential mode. To avoid an unintentional monitor trip, the Command Hardover monitor thresholds are increased (relaxed).

The system is configured in tracking control and a check is performed to make sure it is ready. Once it is ready, the inputs into tracking control are cleared, and then a function is run in which the sonar is checked for a valid altitude range and the current sonar AGL reading is used to set the inputs into the tracking control at the ground position.

At this point the aircraft will start to descend towards the ground. The landing algorithm considers the aircraft to be on the ground if any of the WOW switches indicates a continuous load or if the sonar reads less than 0.75 ft for a period of two seconds. If no touchdown occurs in the expected amount of time the landing abort sequence is run.

The abort sequence commands the vehicle back to the original starting altitude, preceding it with an initial altitude overshoot to cause the aircraft to rapidly climb away from the ground. The aircraft is then returned to waypoint control mode, the hardover monitoring thresholds are returned to normal, and the sonar is turned off. At this point the vehicle is ready to attempt another landing. Details of the landing abort sequence can be found in reference 3.

If the vehicle successfully reaches the ground, the tracking control loops are disabled and the configuration is changed to one with only the lateral and longitudinal loops enabled in the inner loop. All of the integrators, and trim tables are disabled. In addition, the gains are scheduled against the rotor speed so they decrease as the rotor speed decreases. The sequence then resets the inner-loop control inputs and lowers the collective to secure the aircraft to the ground.

The collective is lowered further to reach a target rotor speed. When it is reached, a final check is made to ensure the vehicle is on the ground. After passing this test, the system is configured into bypass mode to make sure there is no feedback from the control law, and the actuators are trimmed to the zero position on the ground. The sonar is then turned off and the Command Hardover monitors are restored to the low thresholds.

3.2.2 EP backup

EP procedure for the landing is similar to that for takeoff. The EP will leave the collective in a position higher than that required for hover until the aircraft has solidly touched down at which time he will lower it to full down. This ensures that if the flight control system disengages (or the EP manually disengages) during the initial portion of the landing sequence, the aircraft will climb away from the ground. Likewise, if the flight control system disengages (or the EP manually disengages) during the latter portion of the takeoff sequence, the aircraft will rapidly throttle down to ground idle.

This technique will be practiced in simulation and is included in the test matrix as test point 2.0.

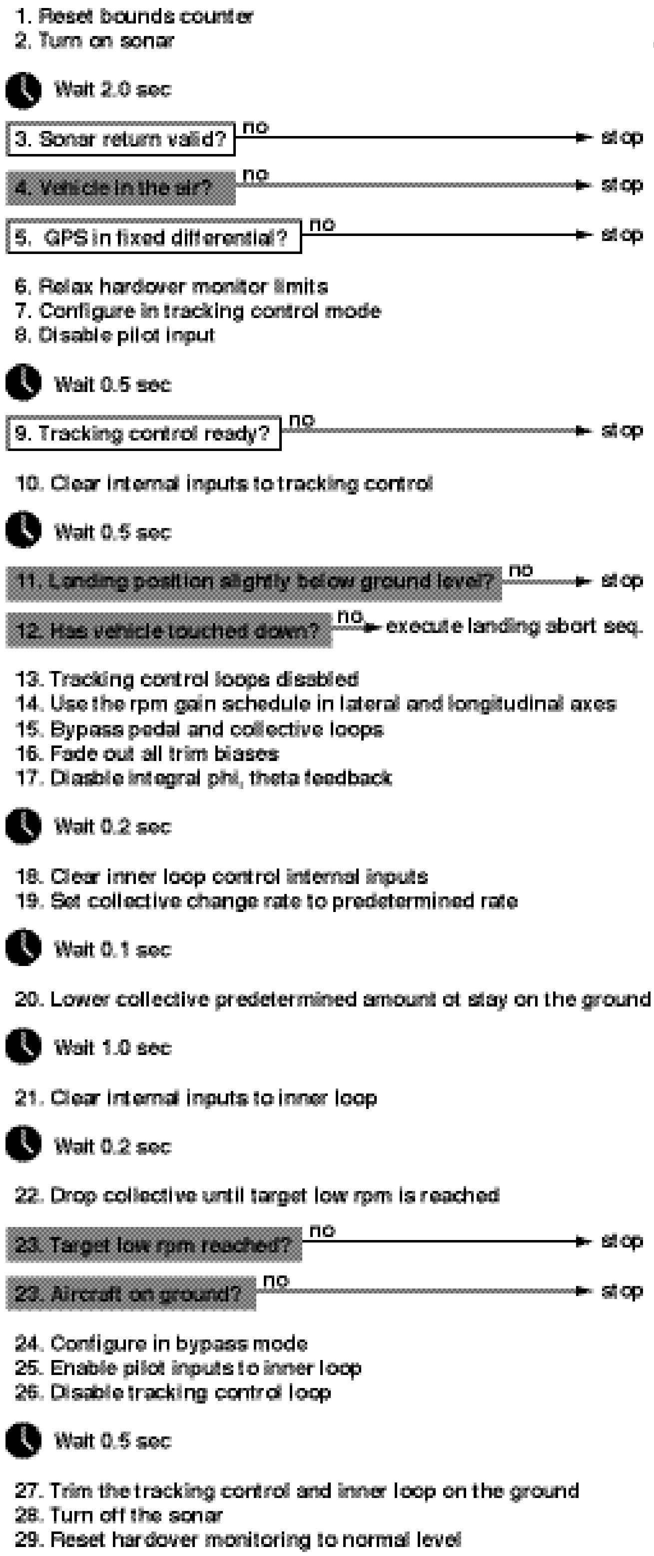

Fig. 3-2. Landing sequence.

4. References

1. ARP Phase 4 Flight Test Plan, Autonomous Takeoff and Landing (Rev B). October, 2004.
2. Flight Control Law Design and Implementation, Autonomous Rotorcraft Project Document No. A9444-RMX2-R7001 (rev C), September 2004.