Tandem Helicopter Control Experiment

1. Description of Tandem Helicopter Longitudinal Control

A tandem helicopter uses two main rotors to lift the vehicle, one on the front and one on the back. The rotors are counter-rotating so there is no tail rotor. The two most common tandem helicopters are the CH-46 and CH-47 (as shown in the figure below), both of which are manufactured by the Boeing Helicopter Division near Philadelphia. In the tandem configuration, vertical control is achieved by changing collective pitch on both rotors simultaneously (similar to a conventional single rotor helicopter). However, longitudinal control is primarily achieved using differential collective pitch (instead of cyclic pitch as is used on single rotor helicopters). When the pilot moves the control stick forward, it increases collective pitch on the back rotor and decreases collective pitch on the front rotor. This increases thrust in the back and decreases thrust in the front, which creates a moment that rotates the body of the aircraft nose down and causes the aircraft to move forward. When the control stick is moved backward the effect is exactly the opposite.

![CH-47D Tandem Helicopter (from www.boeing.com)](image)

The figure on the following page shows how a tandem helicopter transitions from hover to forward flight. In hover, each rotor generates enough thrust to lift about half the weight of the aircraft. As the pilot initiates the transition, he or she moves the stick forward to generate differential thrust, causing the aircraft to pitch nose down. The thrust is now tilted forward, so a component of the thrust causes the aircraft to accelerate. While accelerating, the total thrust needs to be increased, because the rotors are now lifting the helicopter weight and accelerating the helicopter forward. Once the helicopter is in trimmed forward flight, the nose of the helicopter is tilted down slightly, so that the rotors are lifting the aircraft and compensating for the aerodynamic drag on the body of the helicopter. However, the total thrust and the nose down attitude are usually less than when the helicopter is accelerating.
2. **Automatic Flight Control Systems**

It is now very common for aircraft of all kinds to use special sensors and computer systems to help the pilot control the aircraft. The flight control computer receives information from sensors that measure the motion of the aircraft. An example of a common sensor is a gyro, which measures the attitude or angular rate of the aircraft. The sensor measurements are used to adjust the control of the aircraft through a process called feedback control. Feedback control can be used to change the apparent handling characteristics of an aircraft and make it easier to fly. Most high performance military jets rely heavily on automatic control, because without it the aircraft would be unstable and pilots could easily lose control. Many airline jets use automatic control to make the aircraft fly more smoothly to improve passenger comfort. Automatic control systems can be particularly useful for helicopters, which tend to be inherently unstable and very difficult to fly. An example of a simple feedback system for a helicopter is illustrated below:
In this case the pilot’s collective lever is used to control a desired altitude of the aircraft. The actual altitude is measured and compared to the desired altitude, resulting in an error signal. The error signal is multiplied times a gain to calculate the collective pitch control on the helicopter (this is done electronically in the flight control computer). Thus, if the helicopter is flying too low, the collective pitch is increased and if it is too high the collective pitch is decreased. The selection of the “gain” is critical to the design of the control system. If the gain is too low the control system will not perform well, but if it is too high it can cause the helicopter to become even more unstable. An entire branch of aerospace engineering is devoted to this problem.

3. Tandem Helicopter Control Simulator

The tandem helicopter simulator is a lab experiment designed by Quanser Software to demonstrate the effects of automatic flight controls on the longitudinal flying characteristics of a tandem helicopter. The rotors are simulated using two fans driven by electric motors, which can be controlled electronically. The system simulates the longitudinal dynamics of a helicopter, as it is free to move up and down, pitch nose down and nose up, and move forward and backward (traveling around in a circle). The lateral-directional dynamics (rolling, yawing, and moving left and right) are not simulated. A counterweight is used to help lift the weight of the vehicle so that the simulator does not require dangerously large fans and motors. The thrust on the rotors is controlled by changing the speed of the fans. Note that this is different from real helicopters where thrust is controlled by changing collective pitch on the rotor (while the rotor speed is held relatively constant). However, the effects of differential and simultaneous changes in thrust are the same. Measurement devices, called encoders, are used to measure the pitch (nose up/down rotation), elevation, and travel of the helicopter. On a real aircraft the same data might be collected using a pitch rate gyro, an altimeter, and an airspeed sensor. The measurements from the encoders and the position of a joystick are fed to the computer, which in turn provides voltages (through amplifiers) to control the speed of the fans. Thus, the computer can be programmed to control the helicopter simulator in whatever way we desire. In addition, the measurements of the aircraft motion can be plotted on the computer screen and analyzed.
In this experiment we are going to evaluate the handling characteristics of the tandem helicopter simulator for different control systems.

Experiment #1 – Control of the helicopter using a joystick without feedback control

Try holding the helicopter in a steady hover using the joystick. None of the measurements of the helicopter position are being used to help control the helicopter. Make only quick and small adjustments to stabilize the helicopter. Can the helicopter be controlled?

Experiment #2 – Control of the helicopter using a joystick with feedback control

First bring the helicopter into a steady hover. Disturb the helicopter by pushing gently on the counterweight (this might simulate the effect of a wind gust). Note how the helicopter responds following the disturbance.

Perform the following maneuver using the joystick. Start from a hover and raise the helicopter up about one foot. Travel half way around the circle and then bring the aircraft to a hover. Lower the helicopter about one foot, and then travel back the other way to the starting point. How does the helicopter response when you move the joystick forward and backward? How does it respond when you move it left and right?

Experiment #3 – Feedback control with excessive gains

We are going to load a controller where some the gains have been increase threefold. Bring the helicopter to steady hover. Disturb the helicopter by gently pushing on the counterweight and note the response of the helicopter.

Experiment #4 – Autonomous Control

We are going to load a controller that automatically performs the maneuver described in experiment #3. The elevation and travel of the helicopter are plotted on the computer screen along with the desired trajectories. We will then attempt to perform the same maneuver in half the time.