Flight Control Design Characteristics of a Civilian Powered Lift Category Aircraft

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ABSTRACT

The purpose of this paper is to educate the reader in the unique fly-by-wire flight control design characteristics for the BA609 that allow the aircraft to fly in both the helicopter and airplane modes of operation. The helicopter mode is considered to be the flight regime where the aircraft takes off, lands and flies like a helicopter and the airplane mode is considered the flight regime where the aircraft is flown during forward flight as compared to an airplane. There is also another flight regime called the conversion stage, which is when the left and right nacelles are rotated forward or aft and converts the aircraft between the vertical lift and fixed wing stages of flight. A top level overview and comparison will be provided for both modes of operation as they relate to traditional rotary wing and fixed wing aircraft. The major components that allow the conversion mode to take place and information on the aircraft’s three hydraulic systems will also be discussed.

INTRODUCTION

As our technology has continued to advance with respect to composites, avionics and digital fly-by-wire flight controls, they have contributed greatly to the design and development of powered-lift category aircraft. The powered-lift category was developed by the Federal Aviation Administration (FAA) specifically for the BA609 and other similar aircraft that may produced in the future (Gerzanics, 2008). As defined by the Federal Aviation Regulations (FARs), the Federal Aviation Administration (FAA) defines powered-lift as “means a heavier-than-air aircraft capable of vertical takeoff, vertical landing, and low speed flight that depends principally on engine-driven lift devices or engine thrust for lift during these flight regimes and on nonrotating airfoil(s) for lift during horizontal flight” (Federal Aviation Regulations, 2011).

Examples of powered-lift category aircraft are the Boeing Vertol VZ-2 tilt-wing aircraft that first flew in August of 1957, Bell Helicopter’s XV-15 tiltrotor that first flew in 1977, the McDonnell Douglas AV-8B Harrier with vectored thrust that first flew in November of 1978, and the Bell/Boeing V-22 Osprey tiltrotor that first flew in March of 1989. As you can see, powered-lift technology has been in work for over fifty years and the only aircraft that have actually gone into production and in service are the military’s AV-8B Harrier and the V-22 Osprey.

In November of 1996, Bell Helicopter and Boeing announced a partnership to design and produce the 609 civil tiltrotor. In March of 1998 Boeing withdrew as a partner for the tiltrotor and in September of 1998 AgustaWestland joined Bell for the tiltrotor’s development. At this time four test aircraft have been produced with one prototype aircraft conducting flight test operations at Bell’s facility in Arlington, TX and another prototype aircraft conducting flight test operations at AgustaWestland’s facility in Cameri, Italy. The remaining two aircraft have been
delivered to the facility in Italy and will be used in support of test and evaluation efforts beginning in 2011 and 2012 (Dubois and Huber, 2011). The design of the BA09 is primarily based on the technology and test results from operations of the XV-15 and V-22 aircraft.

**HELICOPTER AND AIRPLANE MODES OF OPERATION**

As a fixed wing student pilot, the student is first introduced to the world of basic aerodynamics and what flight control surfaces allow the aircraft to be controlled on the ground and in forward flight. They are told that the rudder controls the aircraft around the vertical axis resulting in yaw control, the elevator controls the aircraft around lateral axis for pitch control and the ailerons control the aircraft the around the longitudinal axis and allow the aircraft to roll. The flaperons, also referred to as flaps, change the wing’s lift and drag characteristics and are typically used by the pilot during their approach and landing.

As shown in figure 1, what is truly unique about the BA09 is that the aircraft has no rudder for yaw control about the vertical axis. Also, the left-hand and right-hand wings have no ailerons, but instead they each have only a single flaperon control surface. Let’s take a closer look and see how this is possible. First, we will need to discuss the basics on how a standard helicopter is able to be flown and controlled by the pilot.

(Courtesy of Wikimedia)

*Figure 1. Bell/Agusta BA609 Test Aircraft*
A standard helicopter has three basic controls in the cockpit that used by the pilot in order to control it during flight. The cyclic stick is centered in front of each pilot’s seat that extends up from the floor and is used to control the aircraft around the longitudinal and lateral axis. It basically controls the tilt of the main rotor disc. The anti-torque pedals, which are sometimes referred to as rudder pedals, are operated by the pilot’s feet and allow the aircraft to be controlled about the vertical axis. The collective lever is located to the left of the pilot and it serves two purposes which are for vertical ascents and descents and it also incorporates a means to control the engine’s power output. As the lever is raised and the aircraft ascends the aircraft requires more power and as the aircraft descends then less power is required. On helicopters powered by reciprocating engines, the engine power is manually controlled by using a twist grip on the pilot’s collective lever. (Schafer, 1980) There are several different systems that are used with helicopters powered by turbine engines that adjust the engine’s power based on the position of the collective lever, atmospheric conditions and load demanded by the aircraft. The goal is to maintain a rotor RPM (Revolutions Per Minute) of 100 percent. This RPM varies from one rotorcraft to another and is based on the rotor blade dimensions and design of the aircraft. The rotor speed for the BA609 aircraft in helicopter mode is 569 RPM while the rotor speed in airplane mode is 478 RPM (Gerzanics, 2008).

When the BA609 is in helicopter mode and the pilot wants to achieve a roll around the longitudinal axis, they will move the cyclic stick to the left or right and the aircraft will roll as a result of differential collective pitch. The collective pitch on one of the rotors will increase more while the collective pitch on the other rotor increases to a lesser degree and basically what that means is that one rotor is providing more lift than the opposite rotor (Figure 2).
The pitch, yaw and thrust inputs are accomplished in a similar fashion as compared to a tandem rotor helicopter except that the rotor orientation on the BA609 is configured laterally. In order to pitch the aircraft about the lateral axis using the cyclic in the forward or aft directions, both the left and right rotor discs tilt in the desired direction. To turn the aircraft about the vertical axis using the rudder pedals, opposite inputs are made to the left and right rotors that result in the corresponding rotor discs tilting in opposite directions. In order to climb the power lever (as now called in the BA609 versus a collective lever) is raised and it results in the simultaneous and the same amount of pitch increase in both of the rotor blades that allows the aircraft to vertically ascend. Accordingly, by lowering the power lever the pitch is simultaneously decreased for all rotor blades and the aircraft vertically descends.

When the BA609 is in airplane mode with the left and right nacelles at zero degrees the pilot commands the aircraft to rotate about the lateral axis using the elevator and moving the cyclic stick forward or aft. When the pilot wants to roll the aircraft about the longitudinal axis using left or right cyclic, it is accomplished by using the flaperons. In order to yaw the aircraft about the vertical axis, differential collective pitch is used and the need for a rudder is eliminated. A larger amount of thrust (more pitch) is obtained on one of the rotors as compared to the opposite rotor. Thrust is obtained by raising the collective lever which increases the pitch equally on both the left and right rotors (Figure 3).

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Figure 3. BA609 Primary Controls in Airplane Mode

When the aircraft is flying with the nacelles at an angle between the airplane and helicopter modes, a combination of the controls must be used simultaneously. This is accomplished by
using complex flight control algorithms that are within the software of the three FCC’s (Flight Control Computers). Next, we will discuss the primary flight control system and what major components are used to operate and control the rotors and flight control surfaces during flight.

**ROTOR AND CONTROL SURFACE COMPONENTS**

Fly-by-wire aircraft designs for the flight control systems on the V-22 and BA609 are similar by the fact that they are both designed to have triple redundancy. What this basically means is that if a component has failed or has been determined to not be operating within the prescribed limits that are being monitored by the three FCCs, it will automatically be deactivated and one of the remaining components will take its place for control or operation. This increases the reliability of the overall system and safety margin for operating the aircraft.

The major components necessary for control and operation are the FCCs, rotor actuators and control surface actuators. In order to ensure the necessary reliability, enormous amounts of testing are conducted. During the early stages of developing the aircraft, over 1,000 hours of hydraulic system operational testing were completed before the rotors actually turned on the first BA609 aircraft. The operational testing was conducted in what is called the Bell Xworx Vehicle Software Management Integration Lab (VMSIL) located at the Bell Helicopter facility located in Arlington, Texas. Any software changes made during the flight test or operational phases again require verification using the VMSIL and then on the aircraft before the software will be released for remainder of the aircraft (Fenny and Schultz, 2005).

As previously stated, there are three FCCs that receive input signals following movement of the cyclic stick, power lever or rudder pedals by the pilot. There are also three separately isolated hydraulic systems that correspond to the number 1, number 2 and number 3 FCCs. The elevator is operated by three hydraulic actuators. This is also true for the left-hand and right-hand flaperon control surfaces. Each of the single actuators is also controlled by a different FCC and a different hydraulic system that again makes the systems triple redundant.

For controlling the pitch of the rotor blades, each of the rotor systems uses two actuators that are referred to as the collective and longitudinal triplex actuators. This is a major difference when compared to the V-22 design that uses three duplex actuators for controlling each rotor assembly. As shown in figure 4, each of the actuators for the BA609 contains three actuators that are housed within one assembly and this is where the term triplex originates.

![Cross Sectional View of Longitudinal and Collective Actuators](image-url)
CONVERSION MODE OF OPERATION

One of the most unique characteristics of the BA609 that allows the aircraft to transition between the helicopter and airplane modes is the converting of the left hand and right hand nacelles. This is what truly places the aircraft within the powered-lift category and allows the aircraft to operate like a helicopter and then fly at forward airspeeds comparable to a twin engine turboprop aircraft. When the aircraft is converting between the two modes, both the helicopter and airplane controls are being simultaneously used at the same time. The actual rotation of the nacelles, also referred to as pylons, is accomplished by using a hydro-mechanical actuation system that is called the Pylon Conversion System (PCS). The nacelles are rotated by using a switch that is mounted on the power lever. By pushing the switch forward the nacelles will come down and by pulling it aft the nacelles will come up. The normal speed of rotation for the nacelles is 2 degrees per second and there is an emergency mode that only allows the nacelles to be rotated up at 8 degrees per second. This can be accomplished by using additional effort and overcoming a detent in the aft position of the switch.

The system consists of one conversion actuator (Figure 5) for each nacelle and a mechanical cross shaft that connects the two actuators between the two nacelles. The mechanical cross shaft system is referred to as the Interconnect Drive Train (IDT). The provision for the IDT was incorporated in case one of the conversion actuators fails to properly operate and then it can be manually controlled by the opposite conversion actuator. The IDT is made up of aluminum torque tubes that have U-joints and sliding splined shafts. These design features allow for the bending and temporary misalignments that can take place during flight and are typical for standard rotorcraft designs.

![Figure 5. BA609 Pylon Conversion Actuator](image)

Each conversion actuator incorporates a primary brake and a backup brake that are hydraulically operated. They are used internally to the actuator gearbox to prevent rotation of the telescoping
ball screw and hold the nacelles at the selected position. Each of the conversion actuators has a quantity of three resolvers that provide pylon position information to the FCCs. Once again, this is in support of triple redundancy.

The PCS allows the nacelles to be rotated a total of 95 degrees, from 5 degrees aft of being vertical (helicopter mode) to being horizontal (airplane mode). One of the reasons that the nacelles are allowed to rotate aft of vertical is so that the aircraft can be slowed down through the use of aerodynamic braking following a run-on landing. Run-on landings are accomplished similar to fixed wing aircraft and done when the aircraft gross weight and/or ambient conditions do not allow a vertical landing to take place. Of course the nacelles are kept at an angle above 45 degrees during a run-on landing in order to prevent the rotor blades from contacting the ground (Fenny and Hart, 2000).

**HYDRAULIC SYSTEM**

The hydraulic systems are primarily used to provide pressure for operation of the control surface actuators, rotor actuators, pylon conversion actuators, and landing gear actuators. The hydraulic system is similar to the V-22 in that there are three separate systems and all of the pressure and return lines used for distribution are made of titanium tubing. One major difference is the fact that the V-22 hydraulic systems operate at 5,000 pounds per square inch (psi) and the BA609 hydraulic systems operate at 3,000 psi. A decision was made during the initial design planning stages to use the 3,000 psi systems due to two factors. One reason was that an extensive amount of pre-existing data was already available concerning hydraulic component reliability for civil aircraft. The second reason was the availability of compatible ground carts and support equipment at civil airports. The standard for civil aircraft is 3,000 psi hydraulic systems and the introduction of a 5,000 psi system would have been very costly and require the introduction of new ground carts and support equipment specifically for use by the BA609 aircraft.

The preferred hydraulic fluid used for the BA609 hydraulic systems is manufactured in accordance with specification MIL-PRF-87257 with an optional fluid per MIL-PRF-83282. The MIL-PRF-87257 fluid was chosen due to the increased safety advantages over other fluids typically used. It has a lower operating temperature and is more flame retardant. Most civil helicopters use hydraulic fluid per the MIL-H-5606 specification and many commercial airplanes use Skydrol PE-5 hydraulic fluid as compared to the newer military airplanes that have shifted and are using hydraulic fluid per the MIL-PRF-83282 specification. The production BA609 aircraft will be delivered with the MIL-PRF-87257 fluid and the operators can then choose to replace it with fluid adhering to either the MIL-PRF-83282 or MIL-H-5606 specifications. Seals are installed within the aircraft’s three hydraulic systems that are compatible with any of the three specifications (Fenny and Schultz, 2005).

**CONCLUSION**

The BA609 aircraft is a highly anticipated concept with its ability to take off vertically and fly in airplane mode at a maximum cruise speed of 275 knots and it has flown up to 333 knots as part of flight test demonstrations. It will have a maximum takeoff weight of 16,800 pounds, a useful load of 5,500 pounds and be able to fly up to 25,000 feet with a pressurized cabin that can handle up to nine passengers for the standard commercial configuration (AgustaWestland, 2011).
Several civil versions that are being marketed include configurations that support air medical and search and rescue in addition to corporate and commercial variations. Government configurations include search and rescue, medical evacuation and emergency medical service. The ideas of using the aircraft for Homeland Security operations and surveillance have also been discussed.

According to the International Civil Aviation Organization (ICAO, 2004), “The powered lift aircraft will increase our airspace system capacity through simultaneous, non-interfering operations by fixed-wing and vertical flight aircraft”. The aircraft can also reduce runway and airport occupancy congestion that alone costs the U.S. economy billions of dollars each year.

No new skills are required by the Aircraft Maintenance Technician (AMT) to maintain the BA609 but instead there is an increase in the overall number of skills needed to maintain the aircraft as compared to traditional helicopters. The increase in the number of skills is mainly due to the presence of composites, fly-by-wire technology, digital avionics and cabin pressurization. As our technology continues to advance, so must the technical capabilities of the AMT.
REFERENCES


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