Executive Summary

Introduction

The Calvert, a high-speed multirole personal transport helicopter, has been designed in response to the 1999 American Helicopter Society Student Design Competition (sponsored by Bell Helicopter). The Request For Proposal (RFP) identified the need for a small civil transport aircraft to replace existing "general aviation" helicopters and small turbine-engined helicopters. The primary goal for this design is to produce an aircraft capable of vertical flight that provides significant gains in performance (in terms of speed and range) over existing helicopters in its class, at a minimal increase in cost over these aircraft. To meet this goal, special attention was to be paid to aspects of cost-effective manufacturing, ease of maintenance and overall value. The RFP stipulated a production run of 300 aircraft at a rate of 60 aircraft per year.

Mission requirements and design objectives

The RFP specified a cruise speed of 180 knots and a range of 540 nautical miles while carrying 4 to 6 people and their baggage. The Calvert exceeds the requirements with a cruise speed of 180 knots and a range (dry-tank) of 548 nm while carrying 4 passengers at 4000 ft ISA. Significantly, it also provides the capacity to carry 6 people at a reduced cruise speed of 160 knots, and with a range of 552 nm. At the production rate stipulated in the RFP, a preliminary cost analysis indicated a purchase price of the Calvert at US$ 1.84 Million. In comparison, BO-105, a twin-engined helicopter in the same weight category, is priced at US$1.9M (1993). The Calvert achieves a significant increase in cruise speed (60%) and range (70%) at a similar price to the BO-105 by synergizing technological advancement with cost-effectiveness and mission adaptability. The compounding features in the Calvert (the wing and pusher propeller) are simple in construction, have weights comparable to a standard helicopter (tail rotor group), are inexpensive, and are proven technologies, and thus provide the Calvert with superior performance with little cost penalty. These factors make the Calvert a potent solution to fulfill the requirements indicated by the market study.

Aircraft configuration trade-off study

An extensive study of various aircraft configurations was conducted. The compound helicopter and tilt rotor/wing emerged as feasible candidates, whereas the coaxial-ABC helicopter, Verticraft, and Autogyro, among others, were eliminated due to their technological risk and poor overall value for the specified mission. Trade studies indicated that a compound helicopter with both thrust and lift compounding offered a considerably less expensive solution than a tilt rotor/tilt wing for the selected mission profile and an enhanced mission flexibility to replace conventional helicopters in low-speed missions. A detailed trade-off study incorporating performance, weights and cost resulted in the choice of a lift compounding of 40% of aircraft gross weight using a high-wing, and a thrust compounding of 80% of aircraft drag using a pusher propeller. Trade-offs involving the rotor and anti-torque device also resulted in the choice of an intermeshing rotor for a compact design. The final configuration selected had several advantages: the capability for high speed flight without encountering stall or compressibility limits, a compact fuselage, a low equivalent drag area, minimized transmission losses, a low apron footprint, low vibration levels (meets ADS-27 limit) and low noise signatures due to reduced tip speed in cruise.

Calvert: design features

The Calvert is a compound helicopter with a wing, a pusher propeller and intermeshing main rotors. The design of the entire aircraft was propelled towards maximizing value to the customer. The high-speed and long range capability of the aircraft are offered while paying special attention to reduced manufacturing, material and operational costs.

- The Calvert uses lift compounding by a wing to offload the rotor, delaying the onset of stall. The offloading factor of 40% was chosen to minimize the weight and hover download penalty while providing the rotor with enough control authority to operate well within stall limits at a cruise speed of 180 knots.
- A variable pitch pusher propeller is used to provide 80% of the forward thrust required by the aircraft in cruise so as to minimize the shaft tilt and fuselage angle of attack variation. The propeller was designed to provide the required thrust with the smallest diameter and weight penalty and with a relatively high propulsive efficiency of 82%.
- A variable RPM configuration is used for the main rotors. The rotational speed of the main rotor is 400 RPM in hover, and is reduced to 346 RPM in cruise. This reduction ensures the advantages of maintaining good autorotation and stall characteristics at low speeds, while avoiding compressibility effects on the advancing rotor at cruise speeds. The choice of RPM was also motivated by the dynamic properties of the rotor to ensure aeroelastic stability in the entire operating range of the aircraft.
- The Calvert is powered by two scalable IHPTET engines (for safe OEI operation capability) that will be developed in parallel with the aircraft. The engines will be equipped with capability to maintain a good fuel efficiency over a range of RPM, and a FADEC system to ensure optimum engine settings. The FADEC also regulates the output shaft speed of the engine with forward speed.
- The transmission of the Calvert is designed to operate over the range of RPM prescribed while minimizing weight. It accepts inputs from the two engines through a spring clutch, and distributes power to the two main rotor shafts and the propeller shaft at varying RPMs and power requirements. To minimize fatigue loads on the transmission housing, the rotor loads are transferred into the fuselage through a unique independent truss support referred to as a standpipe.
- An intermeshing rotor configuration is used for the main rotors. This maximizes the lifting efficiency of the main rotors while providing a compact fuselage without the use of an anti-torque device. Care was taken to minimize the drag penalty for this configuration.
- A compact teetering door-hinge hub design is used for the main rotors. The hub is enclosed in a hub cap to reduce drag. The pitch links, swashplate and upper controls are enclosed inside pylons with fairings cambered outboard to prevent drag buildup
- The design of this high-speed aircraft includes several drag reduction features such as a compact fuselage and cabin space optimized for drag reduction, a compact retractable landing gear design, engine and transmission deck enclosed in an aerodynamic fairing, and compact hub design.

• Several advanced active technologies are proposed for the Calvert, including a piezostack driven servo-flap for vibration suppression, an SMA-activated inflight tracking tab, active interior noise control with a trim panel for noise cancellation, an advanced, fully integrated prognostics and health management (PHM) system for condition monitoring, and a FADEC system to monitor engine settings with forward velocity.
• Manufacturing and maintainability issues were some of the primary drivers for the design of the Calvert. The airframe uses a composite-over-metal-frame construction for reduced parts count and manufacturing costs, enhanced crashworthiness, repairability, and inspectability. A unique assembly process involving three jigs that double as construction and assembly jigs will be used. The materials and construction techniques for each of the components reflect an enhanced manufacturability.
• An integrated solid modeling of the entire aircraft was conducted. This ensures ease of data transfer from design to production stages in the virtual factory and incorporating maintenance, manufacturing, and materials into the preliminary design process, thus reducing the cycle time for production.
• The enhanced marketability of the Calvert comes from its adaptability for use in different missions. The aircraft is capable of flying at 180 knots over a range of 548 nm with 4 passengers, or at 160 knots over a range of 552 nm with 6 people. The Calvert, with only slight modifications, is also highly suitable for search and rescue, surveillance, and short-haul heavy lift operation. This adaptability is likely to increase production rates and reduce aircraft cost.

Methodology and approach

The design of the Calvert was conducted in conjunction with the spring 1999 Helicopter Design Course in the Aerospace Engineering Department. The course was aimed at providing students a fundamental understanding of design issues in engineering and particularly aircraft design. To this end, no commercial codes were used for the primary design. In contrast, the entire design and analysis of this aircraft was conducted using codes developed in-house. The analysis was conducted at varying levels of complexity, the first order models being adapted from Dr. Tishchenko's lecture notes [TNC99] for simplicity and insight. The performance analysis was based on a rigid blade model with a uniform inflow, and successfully captured the interdependent effects of the wing, propeller and intermeshing rotor. The modeling of the aircraft was conducted using IDEAS, and the key aspects of aircraft operation such as spinning of the rotors, blade flapping, propeller, and drivetrain operation were simulated to ensure safety.

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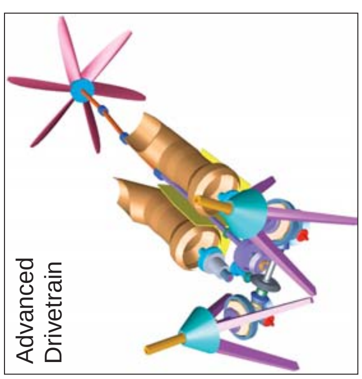
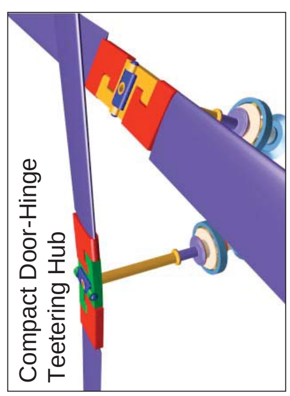
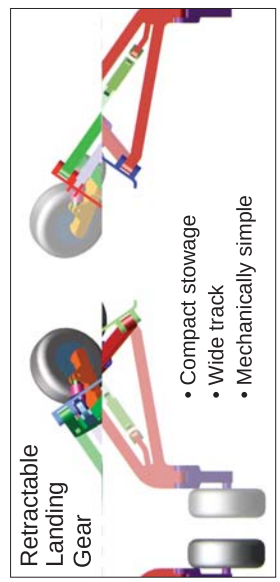
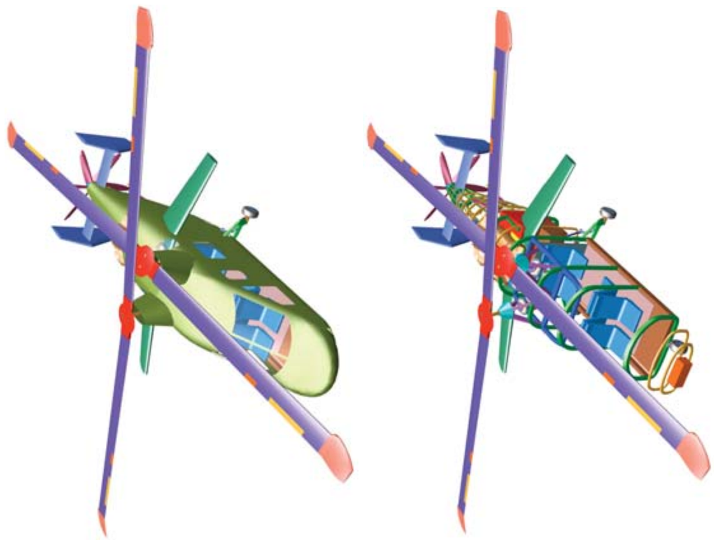
THE CALVERT









- Thrust and lift compounded synchropter
- 540 nm range at 180 kts
- Multi-mission adaptability
- Variable RPM engine and main rotor
- Low vibration and noise signatures
- Low Manufacturing and purchase cost
- Low drag hub and fuselage
- Advanced active systems

Parameter	Units	4 Passengers	6 Passengers
PERFORMANCE			
Max. Cruise Speed	*kt*	***180***	*160*
Range@ Max. Cruise Speed	*nm*	***548***	*552*
Speed for Best Range	kt	140	142
Max. Range	nm	584	580
Cruise Altitude	ft	4000	4000
Never Exceed Speed	kt	210	190
WEIGHTS			
Take-off Weight	lb	5067.7	5486.4
Empty Weight	lb	2926.6	same
Payload	lb	2141.1	2559.8
Maximum Fuel Weight (Usable)	lb	1233.8	same
COST			
Purchase Cost	*US $(1999)*	***1.84 M***	*same*
DOC/air-seat mile	US $(1999)/mi	0.604	0.39
POWERPLANT			
# of Engines		2	same
Max. Continuous Power (MCP)	hp(each engine)	525	same
Take-off Power	hp(each engine)	656	same
TRANSMISSION			
Max. Continuous	hp	1070	same
Contingency (2min)	hp	1320	same
Intermediate (30 min)	hp	678	same
MAJOR DIMENSIONS			
Main Rotor Diameter	ft	34.43	same
Main Rotor Blade Chord	ft	1.04	same
Main Rotor Disk Loading	lb/ft^2	2.72	2.95
Wing Span	ft	14.93	same
Propeller Diameter	ft	6.23	same

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Figure 0.1: Calvert Highlights 4

Figure 0.1: Calvert highlights.