Executive Summary

Introduction

The Raven is a dedicated Search and Rescue (SAR) helicopter that was designed in response to the 2001 AHS International Request For Proposal (RFP) for 'Advanced Rotor Control Concepts'. The objective of this student design competition, which was cosponsored by Boeing, was to develop a conceptual design of a modern civil SAR VTOL rotorcraft that incorporates new and innovative methods for controlling the pitch of the rotor blades. The primary challenge outlined in the RFP was the development of an advanced, high performance, rotor control mechanism that is not only affordable, but also capable of being developed to meet flight safety qualification and airworthiness requirements. It is anticipated that launch of the configuration will lead to delivery of the first aircraft in the year 2015 and therefore the new system is to provide dramatic improvements in performance over existing SAR configurations.

Mission Requirements

The primary mission of the Raven is to provide search and rescue service in IFR conditions out to a range of 300 nautical miles. The mission details are loosely based upon the mission flown in the "The Perfect Storm" and include fly-out, loiter, perform a rescue of two people and return to base, with two flight crew and two pararescuers onboard. The adverse conditions in which the rescue is to be performed include crosswinds gusting up to 45 knots, with large 60 knot headwinds specified during the return segment. The design is further constrained by a stringent One Engine Inoperative (OEI) requirement that stipulates a OEI Hover-Out-of-Ground-Effect (HOGE) capability at 60% fuel and full payload capacity, using no more than emergency power at sea level, ISA+20°C conditions.

Optimum SAR Configuration

The Raven was developed to be responsive to the unique requirements of search and rescue missions and presents an optimum SAR design solution. An optimum configuration was arrived at by developing a set of fundamental design drivers that were based upon mission requirements and operator suggestions. This approach allowed the key SAR design requirements to be highlighted at an early stage, allowing the team to focus its efforts on the issues that most heavily impact upon SAR mission success. A comprehensive configuration study was undertaken based on these drivers, to enable the best configuration to be selected from a large number of potential SAR candidates. In order to downselect the most promising candidates, their relative 'goodness' was established by a measure of both design attributes and performance, with attributes assessed on a qualitative basis and performance on a quantitative one. The results of the qualitative analysis concluded that a helicopter configured with a fan-in-fin anti-torque system would provide the best SAR design solution to the specified mission requirements. In fact, during the trade studies a new measure of SAR mission effectiveness was developed to ensure that the best configuration was indeed selected. This enabled a direct comparison to be made of the SAR potential of the three primary configuration types; helicopter, tiltrotor, and compound. The resulting quantitative analysis once again concluded decisively in favor of the helicopter, which was able to outperform the tiltrotor and compound configurations in virtually all aspects of the mission.

Raven Design Features

The Raven is a twin engined, SAR helicopter with a fan-in-fin anti-torque system. It incorporates high value technologies in the main rotor, airframe, flight controls and crew station that enable it to offer the customer unsurpassed mission performance. The primary design features of the Raven are displayed in the foldout on page xii and are discussed in greater detail below.

Swashplateless Main Rotor

The advanced swashplateless, five bladed, bearingless main rotor system of the Raven was designed to offer a safe, reliable and efficient means of providing pitch control to the rotor blades. The system, which was the result of a comprehensive design study into swashplateless technologies, uses trailing edge moment flaps to generate the required pitch inputs and provides an optimum design solution in terms of reliability, performance and cost effectiveness. The salient design features of the main rotor are summarized below:

- The swashplateless control system consists of trailing edge moment flaps embedded into torsionally soft rotor blades and actuated by a revolutionary smart material known as magnetic shape memory alloy.
- The blade design incorporates advanced airfoil sections and optimized blade tips to enhance performance in both hover and forward flight. Furthermore, the blades are indexed at the root to minimize flap deflections in hover and forward flight, resulting in much improved drag characteristics.
- Each blade incorporates twin trailing edge flaps that are both capable of providing primary control should the other fail. A redundant system was developed in order to minimize future certification costs and ensure a high level of system reliability.
- There are two flap actuators in each blade (one per flap) located behind the main spar. This design improves the weight distribution of the blade by locating smaller flap actuators at multiple spanwise locations.
- The actuators are designed from a magnetic shape memory alloy which is capable of providing the desired flap deflections and frequency throughout the entire flight envelope.
- Each actuator is readily accessible through access ports that have been designed into the blades. Additionally, the design incorporates the ability for manual blade folding to enhance mission flexibility and minimize hangar space.
- The hub design is bearingless, which produces a clean aerodynamic surface and results in low hub drag. Furthermore, simple dual operation compression pitch springs are incorporated into the hub design, in place of conventional pitch links, to accommodate the low blade torsional frequency requirement of the moment flap design.
- To transition the required power from the fixed frame to the blades, a contactless slip-ring was incorporated into the design, ensuring reliable and frictionless electrical transfer.
- Flap actuation is controlled via the Flight Control System (FCS), which obtains feedback from sensors integrated into the blades. The status of the actuators and flaps are monitored by the HUMS, which ensures that the flaps are operating correctly and provides data to the pilot in the event of a failure.
- Active vibration and noise reduction is incorporated into the design by introducing higher harmonic pitch inputs at the embedded trailing edge flaps. A benefit of using flaps for primary control is that vibration and noise can be reduced without requiring additional features to be added to the existing system. Due to a large reduction in vibratory loads, the maintenance requirements of the Raven are expected to be significantly reduced.

- The swashplateless control system integrated into the Raven, which includes the on-blade actuators, cables, balance weights, additional blade structure (to stiffen the ribs around the actuators) and springs at the hub, is approximately 50% lighter than a conventional swashplate design. Furthermore, the design reduces operating costs by doing away with maintenance intensive hydraulic systems.

Crew Station

The Raven incorporates high value technologies in human factors engineering to allow it to interface seamlessly with the crew. The cockpit and cabin stations were specifically designed to enhance the SAR mission performance of the crew through improved situational awareness and reduced workload. The salient design features of the crew station are summarized below:

- The cabin is designed with large doors to facilitate rapid ingress and egress. Furthermore, the Raven incorporates an oversized fuselage to ensure ample space is available for efficient crew operations and extensive SAR/EMS equipment.
- An advanced digital 'glass' cockpit with large multi-function displays is provided to reduce crew workload and enhance mission flexibility. Crew workload is further reduced via the cockpit management system, automatic GPS search patterns, and cabin crew hover control.
- The large multi-function displays, powerful searchlight, FLIR and helmet mounted displays all serve to increase the situational awareness of the crew throughout the entire SAR mission.
- The crew stations were designed after extensive consultation with SAR pilots, pararescuers and crew station design experts to ensure the unique requirements of SAR missions were thoroughly addressed.

Flight Control System

The Flight Control System (FCS) for the Raven is a triple redundant, digital, Fly-by-Wire (FBW) system that ensures a predictable response, enabling helicopter pilots to fly the vehicle without requiring special training. The salient design features of the FCS are summarized below:

- The FCS maximizes safety and reliability by partitioning flight-critical and mission-critical control laws into a Primary Flight Control System (PFCS) and Automatic Flight Control System (AFCS).
- The PFCS has three separate redundant processors resulting in large improvements in safety and reliability. Other safety and reliability design features include redundancy in system processing, minimization of sensor inputs, reduced control law complexity, and isolation of the AFCS in the event of multiple system faults.
- The AFCS was designed with several features and modes to assist the flight crew to accomplish the mission by reducing workload and improving performance. In addition to stability augmentation functions, the AFCS will provide the pilot with the ability to switch to pure attitude command for operations in degraded visual conditions.
- The Flight Control Computers (FCCs) provide digital algorithms for fault detection as well as reconfiguration routines that provide redundancy management capability.
- Similar flight control systems in the RAH-66 Comanche have demonstrated a flight safety reliability of 0.9999998 for a one hour mission, fault detection of 97% and isolation of 96% effectiveness.

- The Raven was designed to the bandwidth and phase delay requirements depicted in ADS-33E-PRF (for utility helicopters) to ensure optimum handling qualities.

General Configuration

The Raven incorporates many other innovative design features that help to improve system performance and reduce costs. The primary design features of the Raven include:

- A fan-in-fin anti-torque system which enhances safety in-flight and on the ground by housing the rotor in a shroud. Furthermore, the design is offloaded by the vertical fin in forward flight which reduces dynamic strains, resulting in reduced maintenance costs. An added feature of the design is the asymmetrically spaced blades which reduce noise.
- A hybrid composite/metal airframe which offers superior crashworthiness and corrosion resistance whilst facilitating ease of construction and repairability.
- A retractable undercarriage which minimizes drag, thereby enhancing cruise performance.
- A retractable FLIR and searchlight, which also serve to minimize drag and enhance cruise performance (special consideration was given to reducing the drag of the SAR equipment to limit the impact on mission performance).
- Extensive medical/EMS equipment to enable critically injured patients to be treated as soon as the rescue is performed, instead of making them wait until the vehicle returns to a hospital.
- Advanced, lightweight, high performance engines, with a high emergency rating and low cruise specific fuel consumption.
- A split-torque transmission which enhances reliability and reduces repair times by elimination of complex planetary gearing.
- Advanced, lightweight avionics and equipment that incorporate MicroElectroMechanical Systems (MEMS) technology.
- Remove and replace modular avionics with robust avionics modules installed in highly accessible and easily opened avionics bays.
- An advanced diagnostic and prognostic system to assist maintenance personnel in isolating aircraft faults and diagnosing problems. A Health and Usage Monitoring System (HUMS) is also integrated into the design, enhancing maintenance predictability.

System Performance and Affordability

The Raven provides significant improvements in performance and operating costs over existing SAR rotorcraft. The salient performance, cost and general design characteristics of the Raven are summarized in Table 1 (displayed on page xi).

Conclusion

The Raven SAR design solution, as presented, offers prospective customers a revolutionary rotor control system that is affordable, reliable and easy to maintain. Furthermore, it is responsive to the unique demands of SAR operators by offering unsurpassed mission performance at an affordable price. The end result is a vehicle that meets or exceeds all of the performance requirements and expectations specified in the RFP. The Raven provides an innovative SAR design solution in a safe and reliable package that is capable of meeting all of the demands of current and future customers well into the 21st century. Put simply, the Raven is the perfect helicopter for the perfect storm.

Methodology and Approach

The design of the Raven by the Terp Works (University of Maryland) team was conducted in conjunction with the Spring 2001 helicopter design course (ENAE634), from February to May 2001. The design course was aimed at providing the team members with a fundamental understanding of design related issues in rotorcraft design. To this end, no commercial design codes were employed in the preliminary design stage, with in-house analysis tools being developed to gain insight into the primary issues involved. This design approach enabled us to develop some unique tools that are specially adapted to the SAR mission requirements expressed in the RFP. The performance analysis was based on a specially developed servo-flap rotor model (undergoing elastic flap and elastic twist) and the recently modified comprehensive code UMARC was used for further detailed design. The rotorcraft was modeled with IDEAS CAD software.

Note: The foldouts that are referred to throughout the report are located at the end of the relevant sections.

Table 1 – Raven Performance, Cost & General Design Specifications

General Details	
Designation	TW-258 Raven
Type	Twin turboshaft SAR helicopter
Accommodation	4 crew / 2 passengers
Acquisition cost	US $ 4.35 million (2000)
Direct operating cost[1]	US $ 423 per flight hour (2000)

Weights & Loadings	
Design gross weight	8330 lb (3778 kg)
Maximum takeoff weight	8680 lb (3937 kg)
Empty weight	4323 lb (1961 kg)
Fuel weight	1710 lb (776 kg)
Payload weight[2]	1432 lb (650 kg)
Disk loading, maximum	7.1 lb/ft^2 (34.7 kg/m^2)

Main Rotor Specifications	
Diameter	39.2 ft (11.9 m)
Number of blades	5
Chord	1.08 ft (0.329 m)
Tip speed[3]	695 – 725 ft/s (212 – 221 m/s)
Twist	-12.5 deg (linear)
Sweep (leading edge)	25 deg (from 90% radius)
Anhedral	8 deg (from 95% radius)
Shaft tilt	4 deg (forward)
Root cutout	30%
Airfoil sections	RAE9648 (root - 60%) VR-12 (60% - 90%) SSC-A09 (90% - tip)

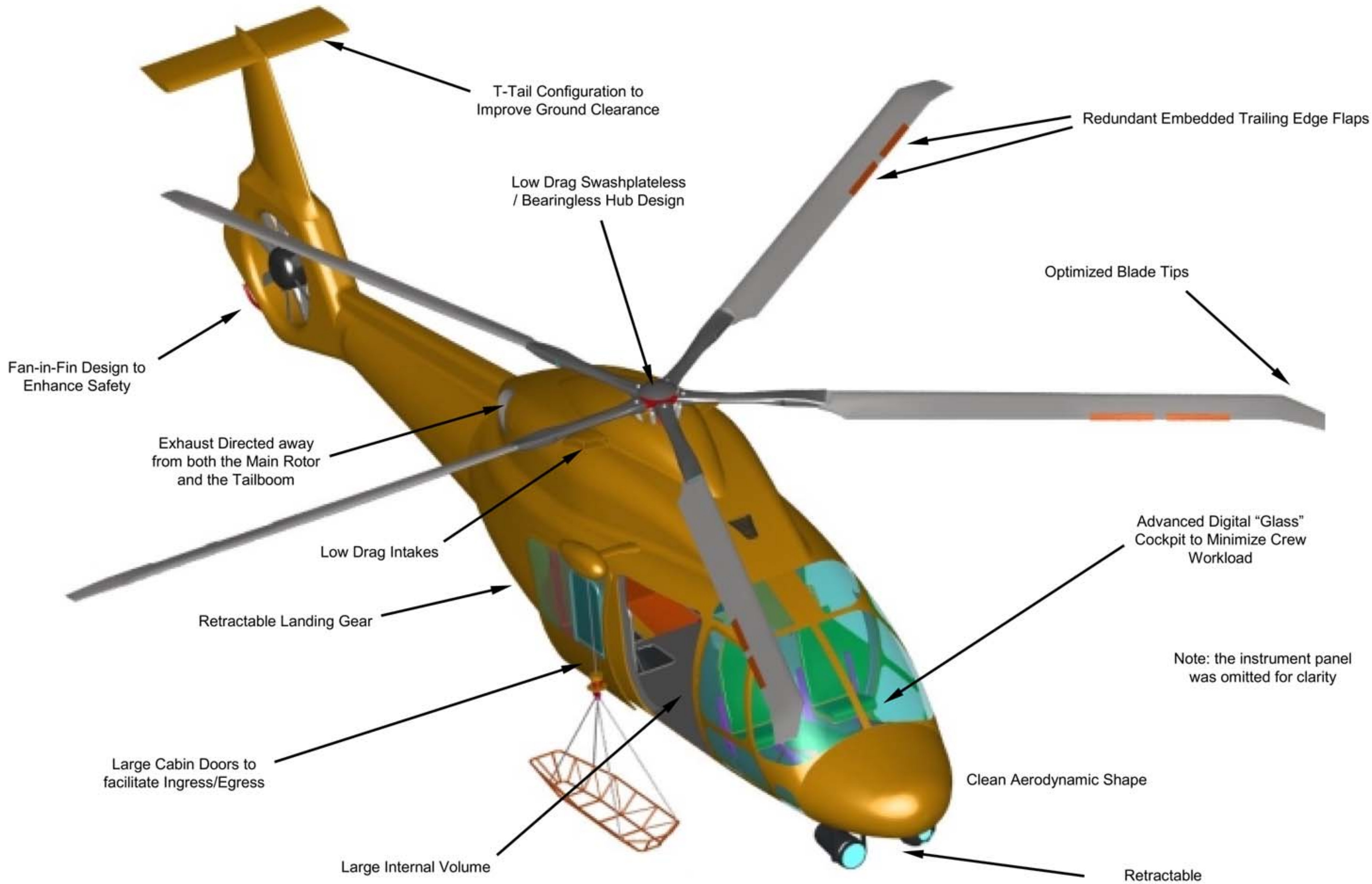
Fan-in-fin Specifications	
Diameter	3.7 ft (1.1 m)
Number of blades	8
Blade chord	0.39 ft (0.12 m)
Rotational speed	3320 RPM
Twist	-7 deg
Blade spacing	35/55 deg
Root cutout	38%
Airfoil sections	OAF102 / OAF117 / OAF128

Performance Specifications	
Nominal cruise speed (@ 500ft)	160 knots (296 km/hr)
Maximum cruise speed (@ SL)	170 knots (315 km/hr)
HOGE ceiling[4]	12730 ft (3880 m)
HIGE ceiling[4]	15327 ft (4672 m)
OEI, HOGE ceiling[5]	4224 ft (1287 m)
VROC[4], maximum	3071 ft/min (936 m/min)
Climb rate[6], maximum	2900 ft/min (884 m/min)
Range[7], maximum	776 nm (1437 km)
Endurance[8], maximum	5.7 hrs

Engine Specifications	
Number of engines	2
Emergency power	1082 hp (807 kW)
Takeoff power	866 hp (646 kW)
Intermediate rated power	800 hp (597 kW)
Maximum continuous power	685 hp (511 kW)

Dimensions	
Length (overall, rotors turning)	44.5 ft (13.6 m)
Height (overall)	13.9 ft (4.24 m)
Fuselage width (maximum)	6.5 ft (1.98 m)
Horizontal stabilizer span	6.5 ft (1.98 m)
Wheelbase	24.1 ft (7.34 m)
Wheeltrack	6.4 ft (1.95 m)
Cabin width (maximum, internal)	5.5 ft (1.68 m)
Cabin length (internal)	8.9 ft (2.71 m)
Cabin height (internal)	5.7 ft (1.74 m)
Cargo compartment volume	130 ft^3 (3.68 m^3)
Cabin door height	5.1 ft (1.55 m)
Cabin door width	4.5 ft (1.37 m)

[1] – Direct operating costs include fuel, flight crew and maintenance only
[2] – Including MEP weight
[3] – Hover and cruise setting
[4] – ISA, takeoff power
[5] – ISA, emergency power
[6] – ISA, maximum continuous power
[7] – Standard reserves at 500 ft PA, ISA+15°C
[8] – Standard reserves at 500 ft PA, ISA



RAVEN HIGHLIGHTS