

Executive Summary

*“I, as Aeneas our great ancestor
Did from the flames of Troy upon his shoulder
The old Anchises bear, so from the waves of Tiber
Did I the tired Caesar.”*

Cassius in Shakespeare’s Julius Caesar, Act I Sc. 2

The UM-911 Aeneas is a multi-role urban disaster rescue vehicle designed in response to the American Helicopter Society’s Annual Student Design Competition. The Request For Proposals (RFP), sponsored by Sikorsky Aircraft and NASA, identified the need for a hovering aerial vehicle capable of evacuating people from high-rise buildings in the event of an emergency. Aeneas features a single-helicopter multiple-module design philosophy, enabling the same rotorcraft to perform different missions specified by the RFP when equipped with the appropriate mission module. Throughout the design of Aeneas, emphasis has been placed on maximizing the safety and controllability of the rescue system, even when operating in the most challenging emergency situations. The heavy lift capability, minimum reconfiguration time and unparalleled safety makes Aeneas the ideal choice for emergency rescue operations.

Mission Requirements and Design Objectives

The RFP specifies different mission requirements as part of the standard rescue vehicle package. Broadly speaking, the rescue operation consists of two main parts, evacuating victims trapped on the upper floors of a high-rise, and containment and suppression, if possible, of the fire (or other disaster situations). The primary goals specified by the RFP included the ability to evacuate at least 1,200 from rooftops, and at least 800 people from windows, in one hour, capability to fight fires at any floor of the building using an on board water source or ground based water pumps, and the capability to deploy 15 firemen at a time on the rooftops. These missions were to be co-ordinated by a sophisticated command and control platform with access to real-time data on the fire, building and city maps. The requirements imply the need for a multi-role system, with an advanced flight control system, capable of operating in urban canyons.

Configuration Selection

Aeneas is an optimally designed configuration capable of satisfying the unique requirements of this multi-mission operation. One of the initial challenges faced by the design team was to decide whether multiple rotorcraft configurations, tailor-made for each of the specific missions, were necessary. It was felt that a multi-role rotorcraft equipped with mission specific modules would result in lower production and acquisition costs. Furthermore, the RFP requirement of “system reconfigurability” was interpreted to mean that the same rotorcraft should be capable of performing all the defined missions. The optimum configuration was, therefore, arrived at after carefully choosing a fundamental set of critical design parameters based on the specific needs of a generic rescue mission. All the potential candidate configurations were carefully evaluated for each of the missions specified by the RFP. The results of the configuration evaluation study suggested that a co-axial rotor configuration was the most promising candidate for all the missions

defined by the RFP. A co-axial rotor configuration is the most geometrically compact design for a given payload capability and can, therefore, more easily operate in congested urban areas. A single rotor – tail rotor configuration requires a long tail boom to increase the moment arm of the tail rotor. The presence of a tail rotor is also a safety issue in a mission where one expects the movement of people around the helicopter. Tandem and tilt-rotors are not as compact as co-axials because of the horizontal separation between the rotors. The downwash from tilt-rotors is comparatively large, and could cause hazardous conditions both for the rotorcraft and people around it from flying debris. An intermeshing rotor or synchropter design was a close second to the co-axial configuration. However, the synchropter was felt to be a sub-optimal design for the following reasons. The rotor shafts have to be tilted, which means that the rotors must be set higher up on the mast to provide adequate clearance between the rotor tips and the ground to increase safety. The existing synchropter designs are two-bladed, and increasing the number of blades results in greater complexity of the design. Constraining the design to a two-bladed rotor placed restrictions on the minimum rotor radius that could be achieved for a given payload. Taking into consideration the primary mission requirements and associated flight environments, a co-axial configuration was decisively chosen.

Design Approach

Aeneas design was carried out in conjunction with the ENAE634 – Helicopter Design course at the University of Maryland in Spring 2003. No commercial codes were used in the design process. The study was performed entirely using tools developed during the course. The rotor dynamics analysis was performed using the University of Maryland Advanced Rotorcraft Code (UMARC), which was modified for trailing edge blade flaps. The graphics were developed using I-DEAS CAD software.

Aeneas – Design Features

Aeneas rescue system comprises of a heavy lift, co-axial helicopter, and an array of subsystems tailored for different missions. The helicopter has a gross takeoff weight of about 22,230 lbs. This heavy-lift capability was necessary to limit the number of independent systems required to perform the mission. The evacuation missions will be carried out using a versatile underslung pod. The compact firefighting subsystems can be installed on both the helicopter, as well as on the pod, enabling engagement of fires in narrow urban canyons. The schematic of Aeneas with its different subsystems is shown in Foldout 1.

Analysis of the Thermal Environment

The design team worked actively with the faculty of the Department of Fire Protection Engineering at the University of Maryland. With their advice, the team was able to develop a realistic picture of the aerodynamic and thermodynamic environment around a burning building. This analysis proved extremely valuable in determining the no-fly zones around the building, and the feasibility of rooftop and window extraction missions when the fire occurs at different heights above the ground. Based on this analysis, a simple fire modeling database was proposed, for the disaster command and control module, to aid in the decision making process of the flight management of vehicles.

Aeneas: Co-Axial Helicopter

Aeneas features an advanced swashplateless, three-bladed, bearingless, co-axial main rotor, a state-of-the-art MR landing gear, a cutting edge flight control system with simple operator interface, sophisticated avionics suite and a three engine configuration to ensure sufficient power for hovering at high effective density altitudes. The primary design features are:

Co-axial rotor configuration — The co-axial configuration is the most compact hovering vehicle system for a given payload capability enabling Aeneas to operate in narrow urban canyons. The absence of the tail rotor improves operational safety in ground operations. This is critical because a disaster rescue operation is usually carried out amidst widespread panic and mass movement of people around the helicopter. The rotor design is optimized for hover and low-speed forward flight. The rotor diameter is 52.35 ft. This is the most compact rotor possible for a vehicle of this weight class, without incurring severe downwash and induced power penalties.

Swashplateless control — Aeneas uses actuated trailing edge flaps on the blades for primary flight control. The swashplateless design eliminates the need for pitch linkages, resulting in an aerodynamically clean and mechanically simple rotor. Absence of failure prone, mechanical linkages enhances the reliability of the system and improves the Mean Time Between Failures (MTBF). In addition to primary control, the trailing edge flaps can be used for Individual Blade Control (IBC) providing vibration reduction. The present swashplateless concept uses recently developed piezo-hydraulic, compact, hybrid actuators to control the trailing edge flaps, in conjunction with a neural-network based adaptive controller perfected for individual blade control with a dissimilar rotor. The blades have an indexing angle of 20° and a low torsional frequency. Two trailing edge flaps per blade and two actuators per flap provide high redundancy in case of failure.

Magneto-Rheological landing gear — Aeneas is expected to land on unprepared landing sites during emergency operations. In addition, the takeoff weight is dependent on the type of mission performed. A semi-active landing gear uses a magneto-rheological fluid that has adaptive damping characteristics, and will absorb landing impact loads more efficiently decreasing susceptibility to structural fatigue failure, dynamic stresses and passenger discomfort.

Autonomous flight control system — Aeneas features a full authority, triple redundant, digital, Fly-By-Light (FBL) Flight Control System (FCS). The Autonomous FCS provides response shaping, stability augmentation and integrated flight and engine control that enhances operational safety in urban canyons. Mission specific auto-navigation relieves the pilot workload considerably, and enables a *trained operator* to fly the vehicle inside *urban canyons*.

Sophisticated avionics suite — Aeneas is required to hold hover position within one foot in all directions. The flight control system is assisted in this task by fast, responsive, high resolution inertial and position sensors. The instruments include a Zero-lock Laser Gyro and a Global Positioning System (GPS) which, when augmented with Differential GPS (DGPS) corrections, can provide very accurate position information to less than one foot.

Simple operator interface — Aeneas provides Multi-Function Displays (MFDs) capable of displaying different information depending on the pilot proficiency and mission performed. This enables a *trained operator* to fly the vehicle with considerable ease, when assisted by the automatic flight control system.

Three engine configuration — Rescue missions require the helicopter to hover for extended periods of time. One engine inoperative (OEI) condition is critical while operating in urban canyons and loading passengers from building windows. In addition, all these missions need to be performed in “a hot day in Denver” conditions. Aeneas was, therefore, designed with three engines. In the event of an engine failure, Aeneas is capable of sustained hover with two engines operating at intermediate power, ensuring successful completion of the mission.

Aeneas: Modular Subsystems

The capabilities of the helicopter subsystem are complemented by a highly modular, versatile array of mission specific subsystems. Considerable efforts were taken in the module design to ensure multi-mission capability with minimum reconfiguration. The subsystems are described in brief detail below.

Aerial Rescue Kit (ARK)

The primary module is the Aerial Rescue Kit (ARK), an underslung pod of dimensions 18.5 ft×9.3 ft×6.5 ft, designed to carry 40 passengers and one operator. The ARK is designed for a gross weight of 10,000 lbs. Structurally, the module is capable of resisting a limit load of 3.5g (35,000 lbs). The ARK is built from three modular sections for ease of manufacture and reconfigurability. The main design features of the ARK are:

Control with thrust fans — The ARK has three fans, two on the side and one on top, which provide precise longitudinal, lateral and yaw control. The thrust fans assist in positioning the box vertically below the helicopter in forward flight, enabling Aeneas to maneuver within urban canyons. The fans also serve to orient the box for precise landing on the rooftops and position the ARK alongside the building face during evacuation through windows. The thrust fans can be used to eliminate the oscillations arising from gusts and other unsteady aerodynamic effects within urban canyons.

Independent flight control system — The ARK is equipped with an advanced flight control system (FCS), similar to the FCS in the helicopter, to control the thrust fans. A continuous two-way data transfer between the ARK FCS and the helicopter FCS enables it to position the ARK vertically below the helicopter at all times.

Crash-worthy seats — Safety of the passengers was the primary concern throughout the design of Aeneas. The ARK provides seating arrangement to its passengers, ensuring enhanced operation safety. The seats can be folded easily to increase the standing floor space to accommodate 15 fully equipped firemen.

Heavy duty cables — The ARK is supported by the helicopter through high strength, lightweight, abrasion resistant Kevlar cables. The torque-balanced, double braid construction minimizes the oscillations of the ARK in the torsional mode.

Oleo-pneumatic undercarriage — The ARK is provided with landing gears to minimize passenger discomfort and structural fatigue during rough landings on unprepared landing sites.

Quick installation and reconfiguration — The installation and reconfiguration times are critical in emergency response situations. The ARK can be installed on the helicopter within 5 minutes, and can be reconfigured for different missions within 20 minutes.

Aerial Firefighting System

Aeneas is designed as an aerial firefighting system capable of engaging fires at any floor of a high-rise building using both on-board water tanks and ground based water systems. The on-board tank is capable of carrying 800 gallons of water and 40 gallons of additives. In addition, Aeneas can lift and direct a 5 inch water hose at any floor of the building. The main features of the firefighting module are:

Impulse nozzle water cannon — While fighting fires with an on-board water tank, Aeneas uses an impulse water cannon. These cannons require only about 10% of the water required by a conventional spraying system to control the fire. Aeneas' on-board water tank can fight fires for longer periods without the need for refilling the tank.

Conventional nozzle — In addition to the impulse nozzle, a conventional nozzle capable of delivering up to 2000 gallons per minute is installed on Aeneas. This nozzle is used with the ground based water pumps. A 5 inch hose connects the nozzle to the ground based pump, and this arrangement enables Aeneas to fight fires without the need for refilling.

Aeneas: An Ideal Disaster Response Package

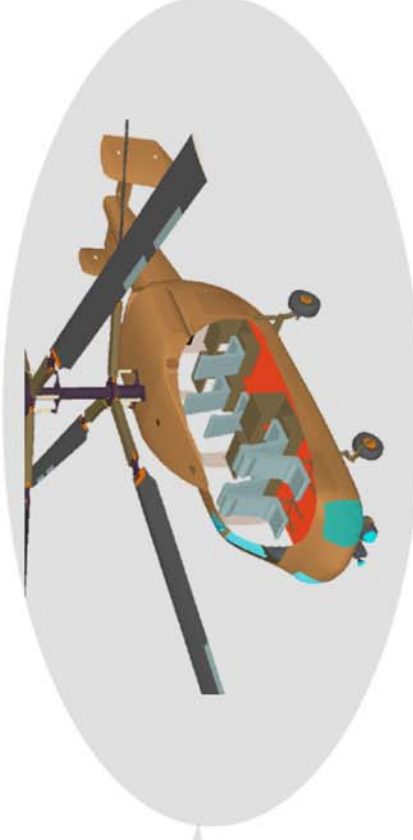
Minimizing the number of systems required to carry out all the RFP specified missions simultaneously was the primary design objective. The mission strategy, the vehicle payload, and size were all chosen to maximize the utilization of available resources. Preliminary analyses of various mission scenarios was carried out to determine the minimum number of systems required to perform all the missions simultaneously. Based on the study, it was determined that a minimum of 10 helicopters with appropriate subsystems were necessary to successfully carry out all missions goals within the prescribed time limit on a representative 100 story building. Of the ten systems, three each are required to perform the rooftop and window evacuations, one for deploying firemen onto rooftops, two for aerial firefighting (assuming self contained water tank firefighting), and one for the aerial disaster command and control platform. The final number of systems was chosen based on an optimization study of different parameters such as the number of people to be evacuated, and restrictions on multiple systems operating simultaneously around the building.

A preliminary estimation shows the acquisition cost of the helicopter system to be around 10 million US dollars. The cost is comparable to existing helicopters of similar payload capability.

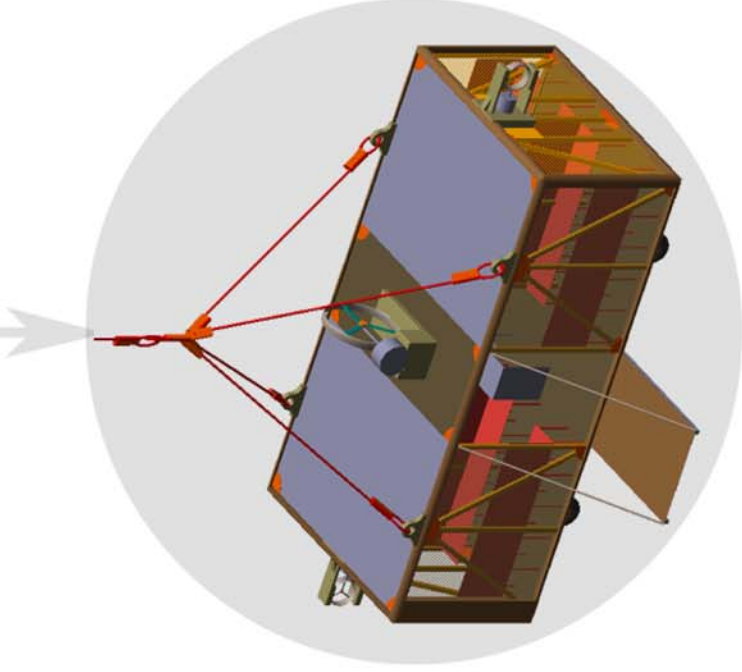
Conclusions

Aeneas offers the prospective customer a reliable and efficient rescue system that is responsive to the unique requirements of a disaster control operation. The incorporation of the latest technologies improves the performance with considerable reduction in maintenance and operating costs. Aeneas has been carefully designed to meet all the design requirements and expectations of the RFP to provide unsurpassed performance when the situation demands it.

Aeneas - Urban Disaster Response System



Command and Control Module



Aerial Rescue Kit



Self Contained Firefighting Module