Conceptual Design and Mission Selection for a Large Civil Compound Helicopter

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Abstract

A conceptual design study of a large civil compound helicopter is presented. The objective is to determine whether there is a range of missions for which a compound helicopter performs better than either a conventional helicopter or a tiltrotor. The designs are generated and analyzed using conceptual design software and are further evaluated with a comprehensive rotorcraft analysis code. Costs and environmental metrics are used to determine the suitability of a design for a given mission. Plots of various trade studies and parameter sweeps as well as comprehensive analysis results are presented.

MOTIVATION

With passenger airline delays reaching all-time highs due to increasing airport congestion, vertical and short takeoff and landing (V/STOL) aircraft are uniquely equipped to increase airport throughput without significant runway improvements or expansion.[1] To fill this need, conventional helicopters are well suited to short trips on the order of 100 nm, while tiltrotors are likely best suited to longer trips on the order of 1,000 nm. The focus of this study is to determine whether a third configuration—a slowed-rotor compound helicopter—can be a better choice than either a conventional helicopter or a tiltrotor for an intermediate distance.

This study is not intended to design a prototype compound helicopter, but rather to suggest designs that are best capable of meeting given mission constraints. These designs will necessarily contain assumptions about future technology improvements in both aircraft and infrastructure. The impact of these assumptions is outside the scope of this study, but will likely be addressed by future research.

BACKGROUND

While compound helicopters have never been produced for civilian passenger transportation, various prototypes have been produced for military applications. The most notable of these is the Lockheed AH-56 Cheyenne.[2] The Cheyenne was developed in the late 1960s for the US Army as an attack helicopter, but the program was canceled after only 10 had been built. With a top speed of 212 kt, the Cheyenne could reach higher speeds than its conventional helicopter counterparts.

Compound helicopters are able to achieve these higher speeds in two ways. In a conventional helicopter, forward speed is limited by retreating blade stall, which can drastically reduce lift at high speeds. Compound helicopters eliminate this problem by using a wing to supply the majority of lift at high speeds. Additionally, the compound uses one or more propellers to provide the thrust needed to reach high speeds. To reduce compressibility drag experienced on the advancing side of the main rotor at cruise speeds, the rotor may be slowed to lower the advancing tip speed.

This study is focused on design of a rotorcraft in the payload range of approximately 20,000 lb. While no compound helicopter of this size has been produced, there are prominent examples of conventional helicopters and tiltrotors in this size range. The Bell-Boeing V-22 Osprey is a tiltrotor with a payload of 20,000 lb, and both the Mil Mi 26 Halo and Sikorsky CH-53E Super Stallion are conventional helicopters with payloads over 30,000 lb.[3,4,5] None of these rotorcraft is a passenger transport, but they provide good bases for comparison.

A previous NASA study focused on designing a notional heavy lift passenger transport capable of transporting 120 passengers at a cruise speed of 350 kt at 30,000 ft altitude with a range of 1,200 nm.[6] This study examined three configurations: a tiltrotor, a tandem compound, and an “advancing blade concept.” In this case, the tiltrotor provided the best characteristics for the design mission; however, the study only looked at a single design mission, so it is possible that a

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compound design would perform better given different mission constraints. This study produced the Large Civil Tiltrotor (LCTR) design, which was followed by a refined version, the LCTR2, designed to carry 90 passengers 1,000 nm at 300 kt and 28,000 ft altitude.[7]

Another study focused on optimizing a compound helicopter design weighing 100,000 lb, cruising at 250 kt and 4,000 ft altitude.[8] This study ran sweeps of disk loading, blade loading, and wing loading to determine the effects of these parameters on aircraft performance. More recent conceptual design studies have used both conceptual design and comprehensive analysis software packages to design slowed-rotor compound helicopters in the 30,000 to 40,000 lb range.[9,10]

APPROACH

To determine the competitive domain of the compound helicopter, three designs were created: a conventional helicopter, a compound, and a tiltrotor. Each is capable of carrying the same payload of 90 passengers, or 19,800 lb. All three designs also use the same fuselage geometry so that passenger accommodation is consistent. Aside from the fuselage and payload specification, the three aircraft designs are independent. Each has a unique design mission that maximizes the efficiency of the particular design.

The primary design evaluation tool used for this study was NASA Design and Analysis of Rotorcraft (NDARC).[11] NDARC uses low-fidelity models typical of the conceptual design phase to perform its analysis. The software analyzes the performance of a rotorcraft design by breaking it down into components, such as rotors, wings, and engines, and determining the drag, lift, weight, and other characteristics of each. The overall aircraft performance is then determined by summing values for the various components. NDARC is also capable of sizing a rotorcraft to satisfy a set of mission and performance requirements. Using an iterative solver, it takes an input design and re-sizes the components so that the final design meets the required specifications. For a more in-depth description of NDARC, see Ref. 11.

For more detailed analysis, the comprehensive rotorcraft analysis tool CAMRAD II was used.[12] CAMRAD II uses multi-body dynamic, finite element, and aerodynamic models to provide detailed analysis of rotorcraft performance for given flight conditions. The results of the CAMRAD analysis can then be used as input to NDARC to obtain a more accurate sizing and mission analysis.

Since airlines or other operators will likely be primarily concerned with costs, the various designs were evaluated from a monetary standpoint. Initial purchase price of aircraft tends to correlate well with empty weight, so the airframes designed for this study are as lightweight as possible.[13] Because fuel makes up a large fraction of an aircraft's direct operating cost, the designs were also targeted at fuel-efficient operations.

Another factor considered in evaluating the different designs was environmental performance. Many industrialized countries have signed the Kyoto Protocol, which limits emissions of greenhouse gases with the intent of bringing emissions down to their pre-1990 levels; however, it is uncertain how the Kyoto requirements will affect aviation.[14] In Europe, the preliminary effects will be seen beginning early in 2012. Under the European Emissions Trading Scheme (ETS), airlines will be limited in the amount of carbon dioxide they can emit; if they exceed their limits, they will need to purchase carbon credits at the current market rate.[15] While carbon dioxide is currently the only aircraft emission regulated in Europe, others, such as nitrous oxide, may soon follow. Since it is still unclear how emissions caps will affect direct operating costs, this study used a separate metric to evaluate the environmental performance of the candidate designs.

With the metrics determined, trade studies and parameter sweeps were used to determine an optimal design for each of the three rotorcraft configurations. Major parameters varied included disk loading, wing loading, rotor tip speed, and number of rotor blades. After using NDARC to find promising designs, CAMRAD II was used to generate refined performance models. Using these updated performance models, NDARC outputs were then used to calculate costs and emissions. These cost and emissions data were in turn used to determine which design was best suited for a given mission in terms of either direct operating cost, purchase cost, or environmental performance.

RESULTS

Initial results have been generated for all three configurations and parameter sweeps have been run in NDARC on all three. Most of the final results will be generated later this year to be included in the final paper. The figure shows how sweeping wing loading and disk loading on the tiltrotor configuration affects both empty weight and fuel burn.

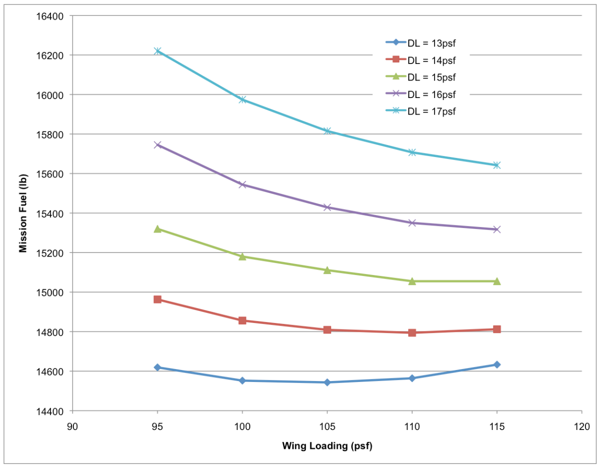

Figure 1. Tiltrotor fuel burn as a function of wing loading and disk loading

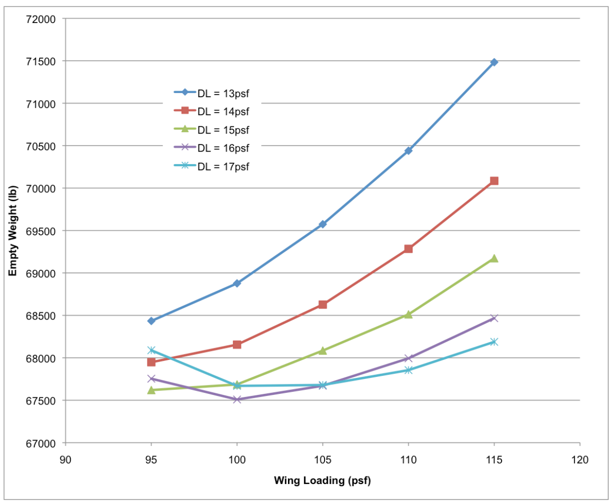

Figure 2. Tiltrotor empty weight as a function of wing loading and disk loading

Similar plots will be generated for both the compound and the conventional helicopter configurations. These plots use preliminary data, so they are only representative of the expected final results. The bulk of the work to be presented in this paper will be completed in the second half of 2011. The final paper will include trade studies and plots for all three configurations. Comprehensive analysis results from CAMRAD II and plots of environmental metrics will also be presented.

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