Exploration of Configuration Options for a Large Civil Compound Helicopter

Carl Russell and Wayne Johnson
Aeromechanics Branch
National Aeronautics and Space Administration
Ames Research Center, Moffett Field, California
carl.russell@nasa.gov, wayne.johnson@nasa.gov

Summary

Multiple compound helicopter configurations are designed using a combination of rotorcraft sizing and comprehensive analysis codes. Results from both the conceptual design phase and rotor comprehensive analysis are presented. The designs are evaluated for their suitability to a short-to-medium-haul civil transport mission carrying a payload of 90 passengers. Multiple metrics are used to determine the best configuration, with heavy emphasis placed on minimizing fuel burn.

INTRODUCTION

Vertical and short takeoff and landing (V/STOL) aircraft are uniquely equipped to increase airport throughput without causing increased flight delays or requiring significant improvements at airports.[1,2] Short-haul regional flights represent the likely target market for large V/STOL passenger aircraft. For design missions with a range on the order of 1,000 nm, the NASA Heavy Lift Rotorcraft Systems Investigation showed that while a tiltrotor configuration provides the best vertical takeoff solution, a compound helicopter is a promising alternative meriting further investigation.[3]

A more recent study examined whether a compound helicopter would perform better than either a conventional helicopter or a tiltrotor for a 500 nm design mission and found that the tiltrotor still retained a lower empty weight, installed engine power, and fuel burn than the compound.[4] One limitation of that study was that while there are many configuration options for a compound helicopter, the analysis focused on a single concept. The current study more fully explores the compound helicopter design space. Using a consistent set of assumptions and design methodology, multiple configurations are examined in an effort to determine the advantages and disadvantages of different compounding methods.

To assess the different configurations, multiple compound helicopter designs are created using NASA's rotorcraft design code NDARC. Detailed rotor performance analysis is then carried out with the CAMRAD II comprehensive rotorcraft analysis code. Each aircraft design is capable of carrying a payload of 90 passengers, or 19,800 lb. The designs use the same fuselage geometry so that passenger accommodation is consistent, and they use the same engine performance model. Aside from the fuselage, payload, and engine specifications, the aircraft designs are independent.

BACKGROUND

Conventional helicopters are limited to flight speeds of approximately 200 kt because retreating blade stall severely limits lift and propulsive thrust at higher speeds. There are multiple methods of compounding a helicopter to achieve flight speeds well above this limit. With lift compounding, a wing is added to the aircraft to unload the main rotor. Thrust compounding adds a propulsor, such as a propeller or jet engine to provide the necessary thrust for high speeds. Compressibility drag on the advancing side of the main rotor limits forward speed as well, so as the advancing tip Mach number approaches sonic conditions, the rotational speed of the rotor must be reduced.

APPROACH

Configurations

The compound helicopter studied in Ref. 4 was fully compounded, with a slowed single main rotor and tail rotor, and auxiliary propulsion provided by two propellers mounted on a large wing. This design provides the baseline for comparisons for the current study and will be referred to as CH90 in this paper. In addition to the baseline, the following compound helicopter configurations are studied:

1. **Tandem Compound (TC90):** Two counter-rotating lifting rotors in a tandem configuration with auxiliary propulsion provided by two wing-mounted propellers. A large high-aspect ratio wing provides supplemental lift in cruise.
2. **Swiveling Tail Rotor Compound (SC90):** Similar to the baseline CH90 configuration, but instead of using wing-mounted propellers for auxiliary propulsion, the tail rotor swivels to become a propeller in cruise.

In addition to the baseline and the two above configurations, multiple wing sizes are examined with varying amounts of lift carried on the wing. The wing size ranges from that of the baseline, where 80 percent of the aircraft weight is carried on the wing, down to no wing at all, where the main rotor carries all of the lift.

Computational Methods – Sizing

All of the sizing and design tasks are carried out using NASA's rotorcraft design code NDARC. NDARC is a conceptual/preliminary design and analysis code for rapidly sizing and conducting performance analysis of new rotorcraft concepts.[5,6,7] NDARC has a modular code base, facilitating its extension to new concepts and the implementation of new computational procedures. NDARC version 1.6 was used in this design activity.

Computational Methods – Comprehensive Analysis

Performance analyses for rotor optimization is conducted with the comprehensive rotorcraft analysis CAMRAD II.[8] CAMRAD II is an aeromechanics analysis of rotorcraft that incorporates a combination of advanced technologies, including multibody dynamics, nonlinear finite elements, and rotorcraft aerodynamics. The trim task finds the equilibrium solution for a steady state operating condition, and produces the solution for performance, loads, and vibration. The aerodynamic model includes a wake analysis to calculate the rotor non-uniform induced velocities. CAMRAD II has undergone extensive correlation of performance and loads measurements on helicopters.[9-16]

Design Process

The iterative design process used for this study is illustrated in Fig. 1. Tasks of the design process utilizing NDARC are contained in the heavier square boxes, while tasks using CAMRAD II are contained in the lighter rounded boxes.

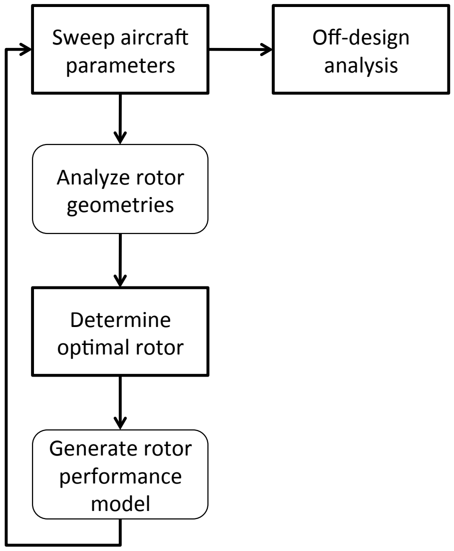

Figure 1. Iterative design process

The process for each of the different configurations is substantially the same, and the steps are outlined below.

1. <u>Sweep aircraft parameters</u>
   Aircraft characteristics such as wing loading, disk loading, and number of rotor blades are varied in NDARC using a representative rotor model, resulting in a baseline configuration.

2. <u>Analyze rotor geometries</u>
   Different rotor geometries are simulated in CAMRAD II at the design flight conditions to develop a set of candidate rotors.

3. <u>Determine optimal rotor</u>
   Performance characteristics of the candidate rotor designs are used in NDARC to determine the best rotor for the design mission.

4. <u>Generate rotor performance model</u>
   Using the optimal rotor geometry, various flight conditions are simulated in CAMRAD II to generate a math model of the rotor power consumption.

5. <u>Sweep aircraft parameters 2</u>
   With the rotor performance model determined, aircraft characteristics are swept again to arrive at a revised optimal configuration. If necessary, steps 2-4 can be repeated as many times as desired. For this study, the loop is only completed once for each aircraft.

6. <u>Off-design analysis</u>
   Once the aircraft configuration is determined, NDARC can be used to analyze different operating conditions and missions.

RESULTS

Table 1 summarizes key parameters for the preliminary designs that have been generated. The baseline compound helicopter is shown in Fig. 2, and a representative tandem compound design is shown in Fig. 3.

Initial results suggest that the tandem compound performs significantly better than the baseline configuration in minimizing empty weight, installed power, and fuel burn. The tandem compound has significantly reduced hover download compared with the baseline, since the wing is almost entirely outside the rotor wake. Also, splitting the lift between two large rotors allows for a lower disk loading, resulting in lower induced power for hover. Finally, there is no power lost to anti-torque in hover, since the moments from the counter-rotating lift rotors cancel each other.

The swiveling tail rotor design also performs better than the baseline in the preliminary results. The difference can be attributed to the reduced empty weight achieved by eliminating the rotors on the wing as well as their associated gear boxes and drive shafts.

In addition to summaries and drawings of the various configurations, the final paper will present the results of the parameter sweeps to show how characteristics such as wing loading, disk loading, and wing lift share affect the final designs. The results of the rotor optimization task will also be presented. Based on the final results, suggestions will be made on what type of compound helicopter is best suited to the short-haul passenger transport mission studied.

Table 1. Design summary for three compound helicopter configurations (preliminary results)

	CH90	TC90	SC90
Payload (90 pax), lb	19,800	19,800	19,800
Overall length, ft	122.9	167.2	121.6
Overall width, ft	105.4	106.6	101.4
Max takeoff weight, lb	115,040	94,065	106,437
Empty weight, lb	65,178	50,851	58,496
Mission fuel, lb	13,626	9,692	12,825
Engine max rated power, hp	4×7,817	4×4,388	4×7,223
Design mission cruise speed, kt	227	222	229
Main rotor disk loading, lb/ft^2	15.0	10.0	15.0
Main rotor solidity	0.123	0.0817	0.123
Main rotor design C_W/σ	0.151	0.151	0.151
Main rotor radius, ft	46.1	36.1	44.3
Main rotor V_{tip}, hover, ft/s	650	650	650
Main rotor V_{tip}, cruise, ft/s	450	475	450
Main rotor number of blades	7	4	7
Wing lift share in cruise	80%	80%	80%
Wing span, ft	105.4	106.6	101.4
Wing loading, lb/ft^2	90.0	90.0	90.0

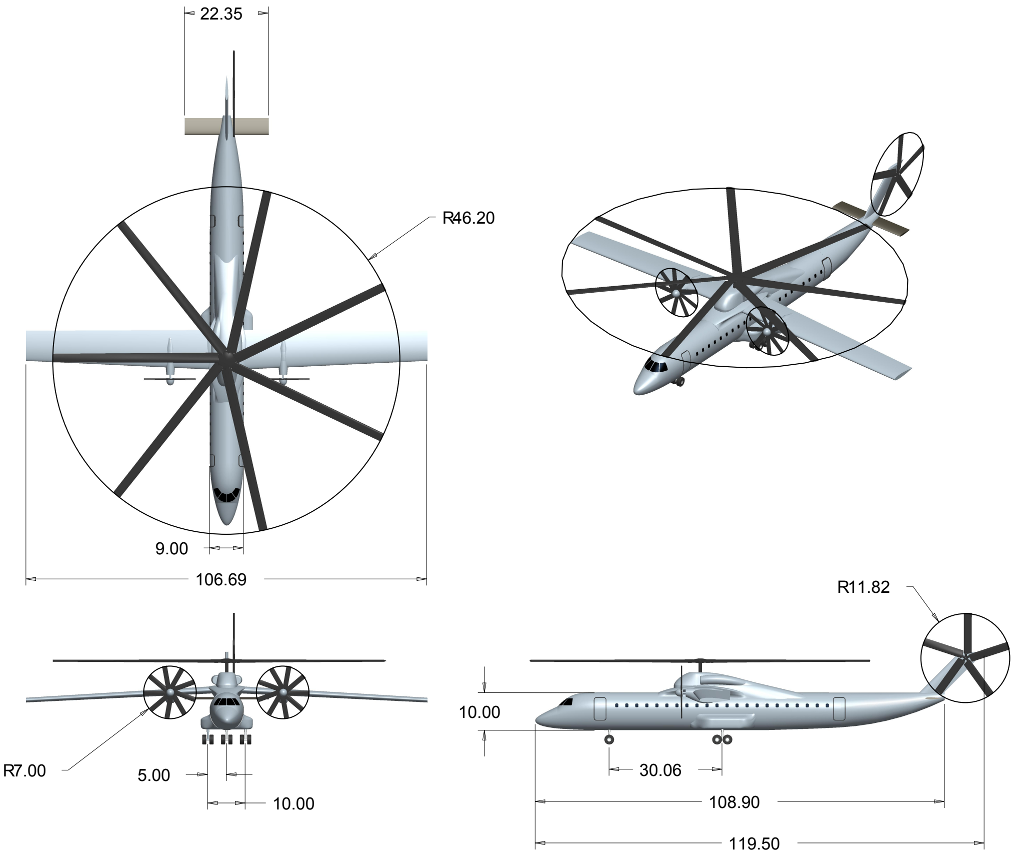

Figure 2. Illustration of the baseline compound helicopter, CH90

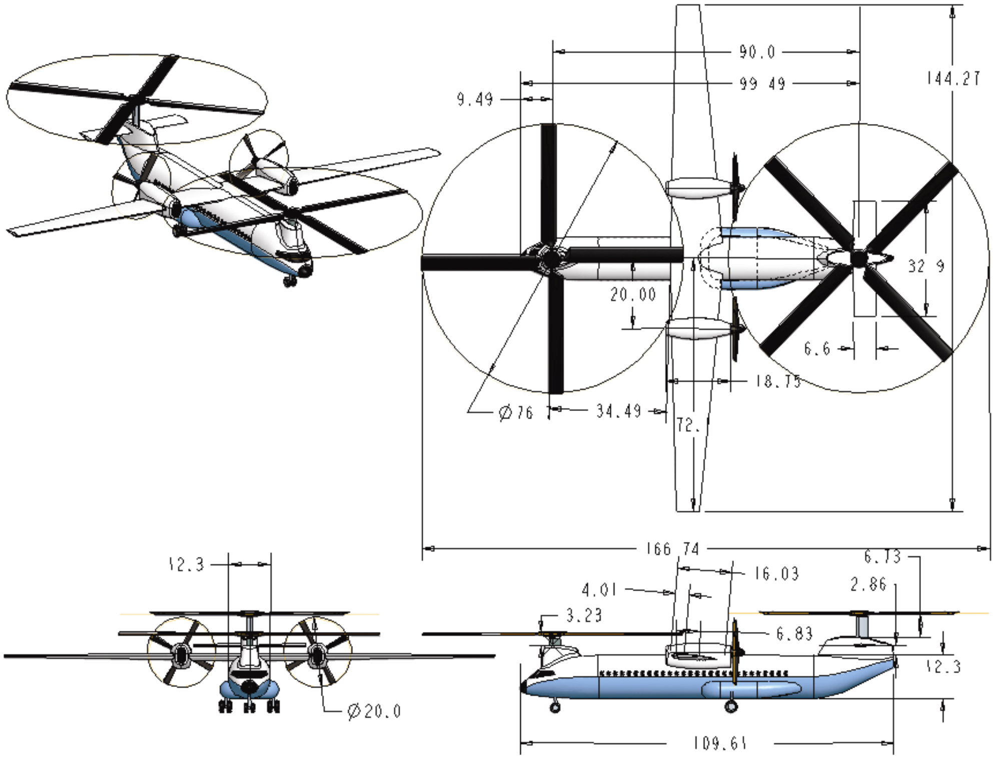

Figure 3. Illustration of a tandem compound example (reproduced from Ref. 3)

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