NDARC — A Tool for Synthesis and Assessment of Future Vertical Lift Vehicles

Conceptual design capability is needed in government laboratories in order to assess how technology will affect future systems and to support decisions regarding investment for technology maturation. Conceptual design is required in industry to define new aircraft and support aircraft development. With the current intense interest in innovative propulsion concepts for vertical lift vehicles, these requirements are even stronger. NASA has developed a tool to meet these requirements: NASA Design and Analysis of Rotorcraft (NDARC).

Following an extensive investigation of advanced heavy-lift rotorcraft, the growing importance of analyzing non-conventional aircraft was recognized, and in 2007 NASA Ames Research Center embarked on development of a new rotorcraft sizing code. The definition of the code requirements benefited substantially from the experiences and computer codes of the advanced design office of the U.S. Army Aeroflightdynamics Directorate (AFDD) at Ames. NDARC Version 1.0 was released in May 2009, together with a theory manual and an input manual. Release 1.8 (February 2014) was a major upgrade to NDARC capability that implemented expansion of the propulsion system model to support assessment of environmentally-friendly designs.

NDARC is an aircraft system tool that performs design and analysis tasks. The design task sizes the vehicle to satisfy a set of design conditions and missions. The analysis tasks include off-design mission analysis and flight performance calculation for point operating conditions. The aircraft size is characterized by parameters such as design gross weight, weight empty, component dimensions, drive system torque limit, fuel tank capacity, and engine power.

To achieve flexibility in configuration modeling, NDARC constructs a vehicle from a set of components, including fuselage, wings, tails, rotors, transmissions, and engines. For efficient program execution, each component uses a surrogate model for performance and weight estimation. Higher fidelity component design and analysis programs as well as databases of existing components provide the information needed to calibrate these surrogate models, including the influence of size and technology level. The reliability of the synthesis and evaluation results depends on the accuracy of the calibrated component models.

NDARC initially modeled conventional rotorcraft propulsion systems, consisting of turboshaft engines burning jet fuel, connected to one or more rotors through a mechanical transmission. The latest software release represents a major enhancement to the propulsion modeling in NDARC, and has greatly expanded the configurations that can be analyzed, including green aircraft. The NDARC propulsion system representation now includes electric motors and generators, rotor reaction drive, turbojet and turbofan engines, fuel cells and solar cells, batteries, and fuel (energy) used without weight change.

Within NDARC, the components needed to construct the propulsion system model are characterized as transferring power by shaft torque (“engines”), producing a force on the aircraft ("jets"), or generating energy for the aircraft ("chargers"). Engines and rotors are connected to a mechanical drive train. The "engines" category includes turboshaft and reciprocating engines, compressors, motors, generators, and generator-motors. The "jets" category includes turbojet and turbofan engines, and reaction drive systems for rotors. The "chargers" category includes fuel cells and solar cells. Each engine, jet, and charger is associated with a fuel type and a fuel tank system. Fuels are characterized by whether the quantity stored and used is measured in weight (jet fuel, gasoline, diesel, hydrogen) or energy (batteries, capacitors, flywheels).

Many propulsion architectures can be constructed from these components. The conventional helicopter has rotors and turboshaft engines connected to the drive train, with a tank for jet fuel. An electric rotorcraft has rotors and electric motors connected to the drive train, with a battery. A hybrid configuration has both engines (burning fuel) and motors (using electricity) connected to the drive train. An electric rotorcraft can have a system to charge the battery, such as a turboshaft engine (burning jet fuel) connected through a transmission to a generator (turbo-electric configuration); or a fuel cell (burning hydrogen or a hydrocarbon fuel); or a solar cell.

Variations in the number and distribution of the rotors, engines, motors, generators, and other components lead to a large range of potential propulsion system and aircraft configurations. NDARC can analyze aircraft with combinations of rotors, wings, and tilting and swiveling components. NDARC can also model fixed-wing jet or propeller-driven aircraft.

At the August 2014 workshop hosted by the AHS and AIAA (Transformative Vertical Flight Concepts Joint Workshop on Enabling New Flight Concepts through Novel Propulsion and Energy Architectures), a presentation by Carl Russell and Wayne Johnson on NDARC caught the attention of many aviation enthusiasts from non-rotorcraft backgrounds. In the 5 years since the first release of NDARC, the number of organizations using NDARC has grown to more than 50, and a 5-day training class held in April 2014 attracted 47 participants.

NASA will continue applying the software to advanced propulsion concepts and aircraft configurations. The NDARC user community is expected to expand and provide more validation data and suggestions for architecture refinement. Plans are to integrate NDARC into a design environment with tools for other disciplines (including acoustics, aerodynamics, and handling qualities), with the goal of developing an optimization capability for a complete aircraft.

The NASA Fundamental Aeronautics Program and the Rotary Wing Project continue to fund the development of NDARC. The software is available to U. S. companies, laboratories, universities, and individuals and is distributed by the Software Release Authority at NASA Ames Research Center. The software distribution package includes source code, manuals, and test cases. A wiki has been established for NDARC, providing tutorials and PC executables. NDARC can be used on Windows, Macintosh, and Linux systems. Contact wayne.johnson@nasa.gov for information on a Software Usage

Agreement.

In summary, NDARC is a conceptual/preliminary design and analysis computer program for rapidly sizing and conducting performance analysis of new vehicle concepts with particular emphasis on vertical lift configurations. NDARC has a modular code base, facilitating its extension to new concepts and the implementation of new computational procedures. The code is general enough to treat the innovative concepts now being imagined, proposed, studied, and built.