Conceptual Design of Vertical Lift Aircraft with Future Propulsion System Architectures

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AHS International and AIAA
Transformative Vertical Flight Concepts Joint Workshop on
Enabling New Flight Concepts through Novel Propulsion and Energy Architectures

Arlington, Virginia
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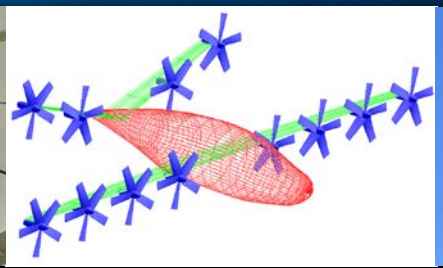


Design Tools

- **Aircraft design capability is required to support research in a government laboratory**
  - Technology impact assessments
    - Show how technology will affect future systems
  - System level context for research
    - Support level of investment for technology maturation
  - Concept exploration, decision, and refinement

- **Must conduct quantitative evaluation and independent synthesis for wide array of aircraft configurations and concepts**

- **Many different tools available**
  - Choice of tool dependent on many factors, including validation, fidelity, familiarity, etc.

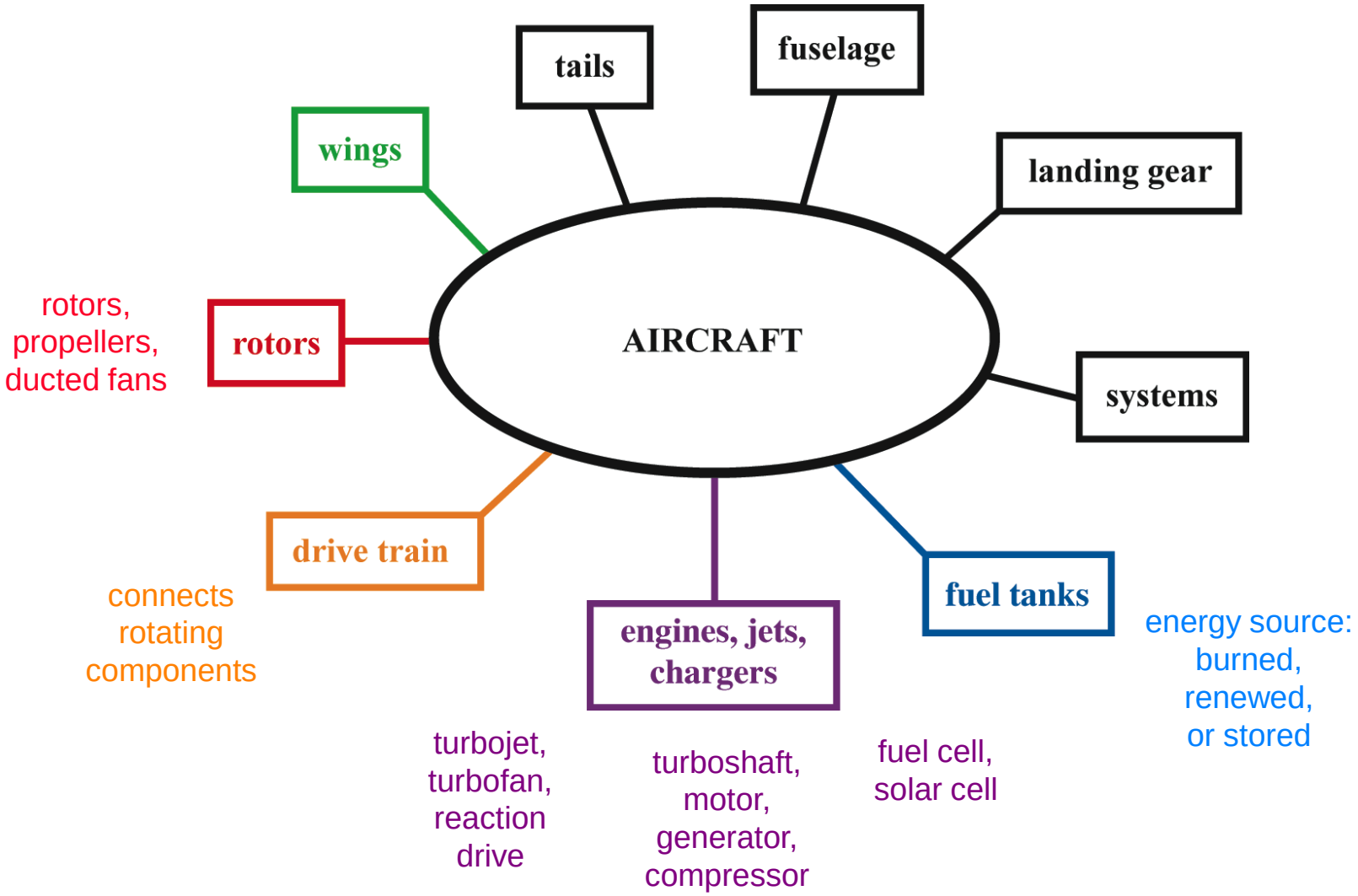
NASA Design and Analysis of Rotorcraft (NDARC)

- **Conceptual/preliminary design computer program**
  - Design task sizes aircraft for set of design conditions and missions
  - Analysis task for fixed aircraft, and for off-design missions and point operating conditions
- **Initial release May 2009**
  - Distributed to 50+ organizations as of August 2014
- **Release 1.8 (February 2014) implemented expansion of propulsion system model**
  - Support development and assessment of environmentally-friendly designs

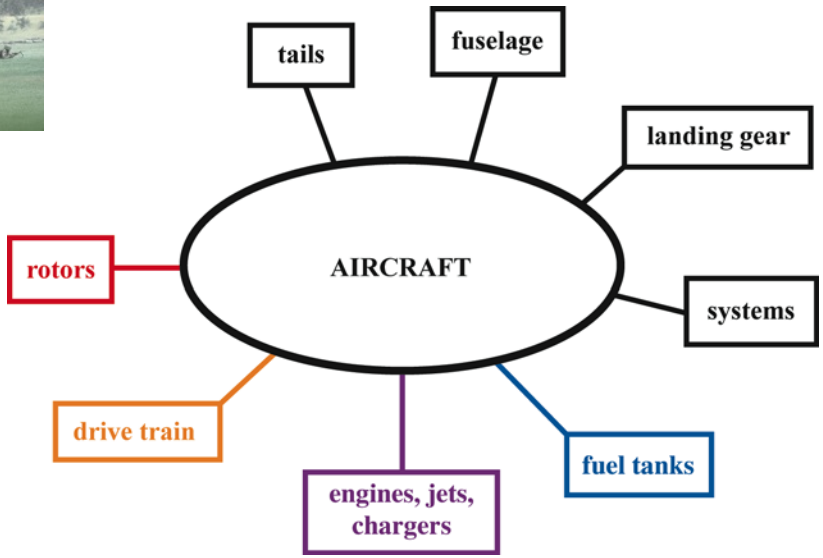
Key Attributes of NDARC

- **General aircraft and propulsion system architecture**
  - Aircraft model built from set of components
- **Surrogate models of component performance and weight**
  - Allows for very short runtime and rapid concept iteration
  - Requires calibration of the models
- **Run standalone or within design environment**
  - Input and output processing tools

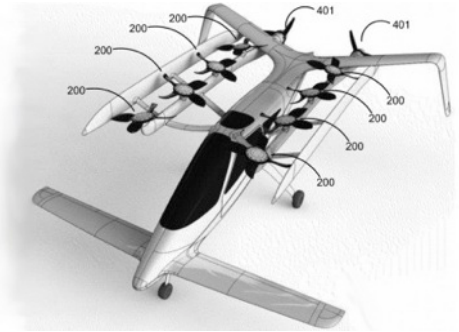
NDARC Components

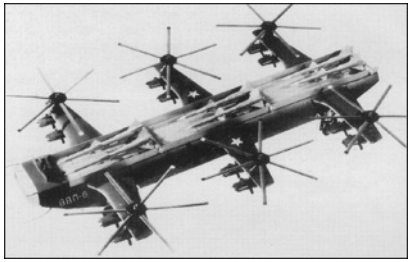


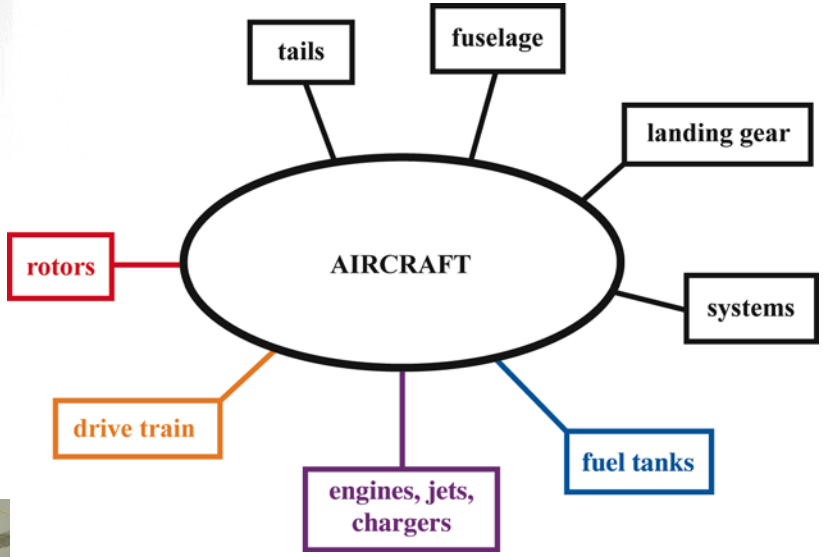
Aircraft with Rotors

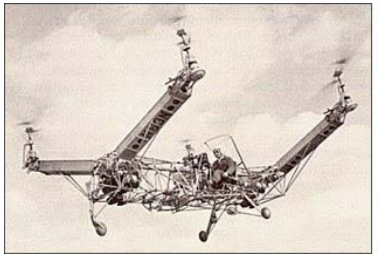


Lots of Rotors

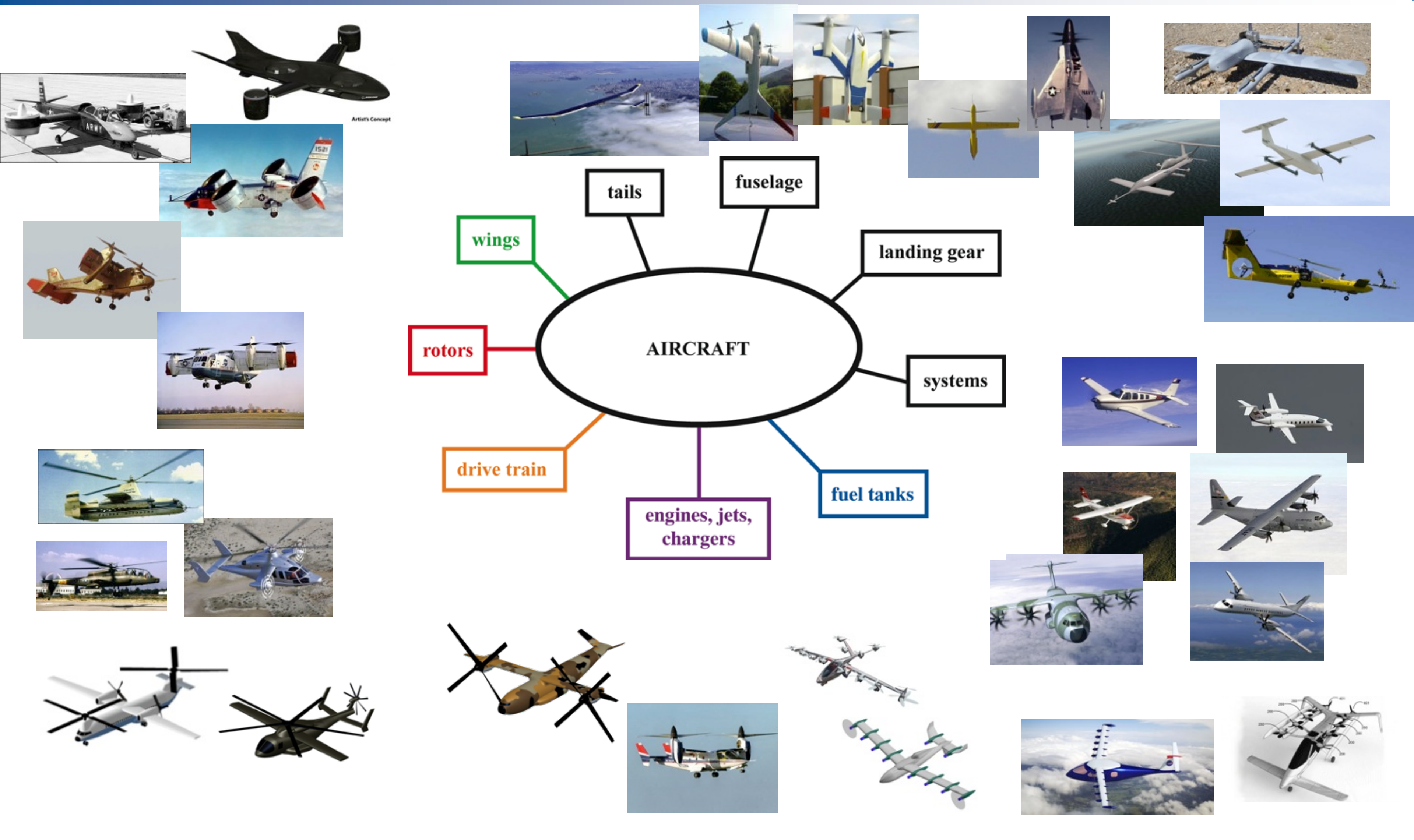




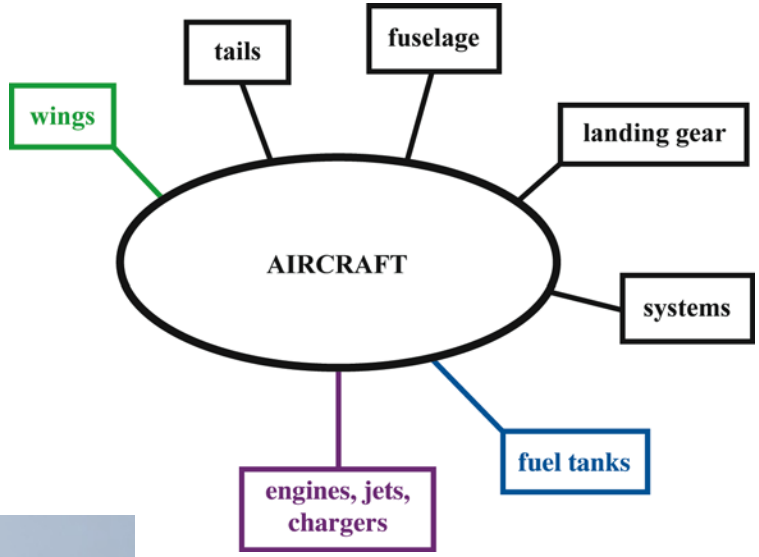




Rotors and Wings



Aircraft without Rotors



Fixed Geometry











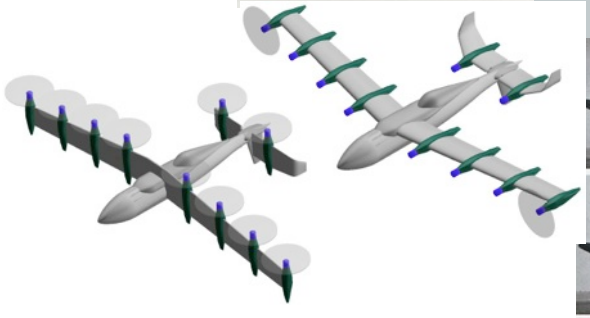









Tilting and Swiveling Components



Components for Propulsion Representation

Engine Group
Turboshaft engine
- convertible — jet
- convertible — reaction

Reciprocating engine
Compressor
Compressor-reaction
Motor
Motor + fuel cell
Generator
Generator-Motor

Transfers power by shaft torque

Connected to drive train

Jet Group
Turbojet / turbofan
- convertible — reaction

Reaction drive
Simple force

Produces force on aircraft

Charge Group
Fuel cell
Solar cell

Generates energy for aircraft

Fuel Tank
Weight
- jet fuel
- gasoline
- diesel
- hydrogen

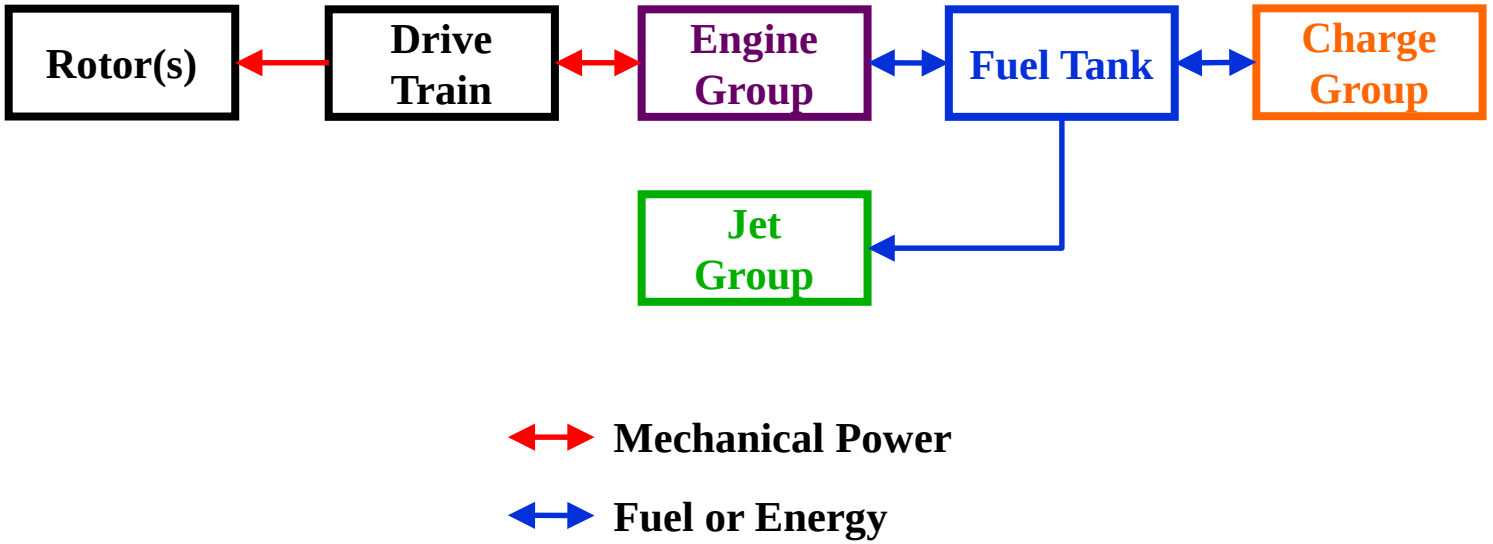
Energy
- battery
- flywheel
- capacitor

Associated with components that use fuel

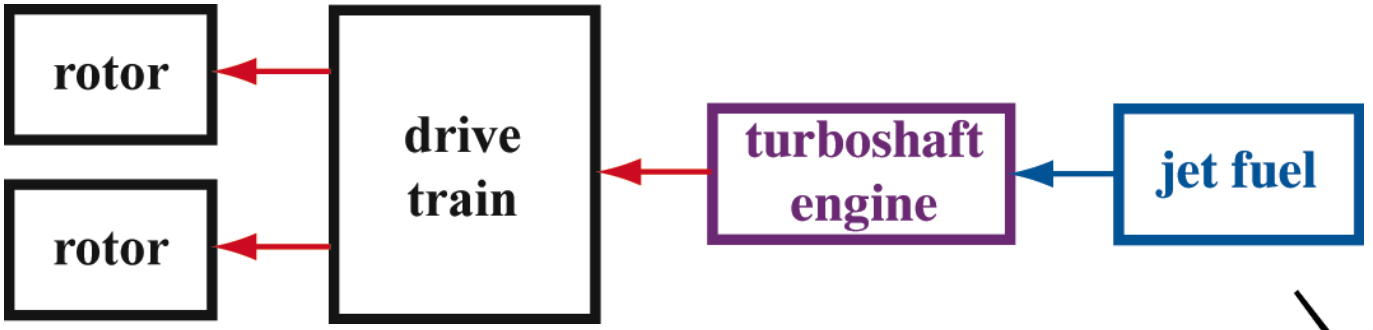
Quality of the results depends on the accuracy of the calibrated model for each component

Basic Propulsion Architecture

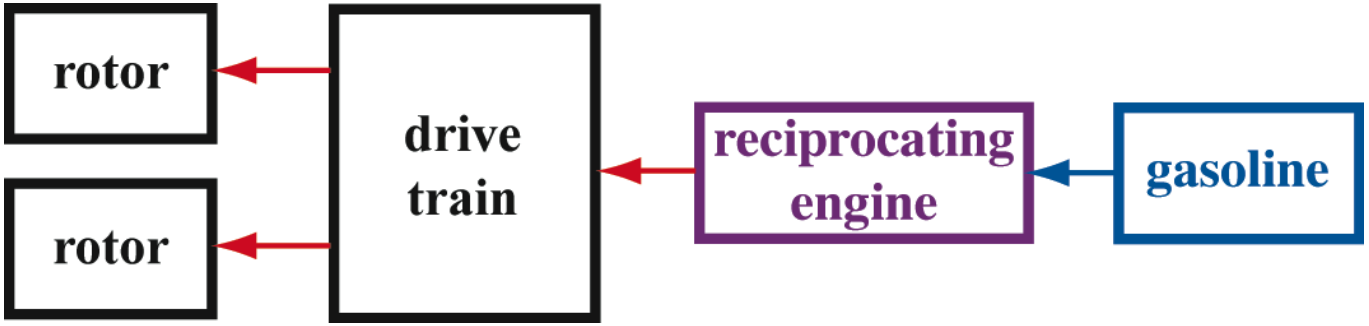
- Can have one or more complete or partial sets of propulsion components
- Components can be linked to multiple groups
- Power or energy can flow into or out of a group



Turboshaft



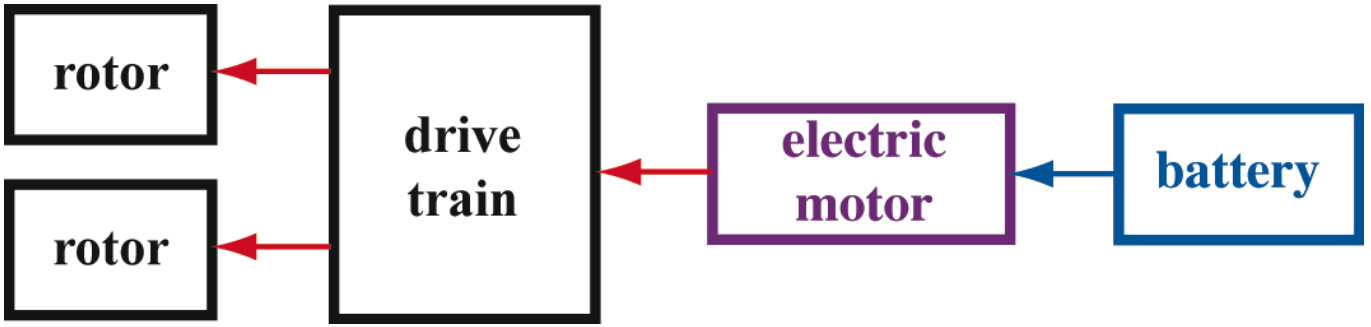
Reciprocating Engine

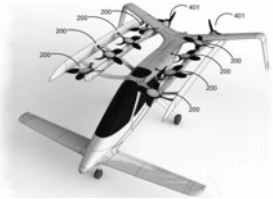


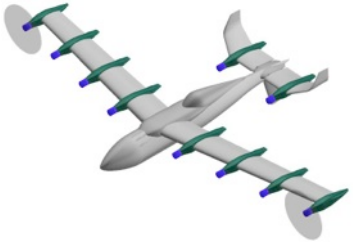
Turbojet / Turbofan

turbofan engine ← jet fuel

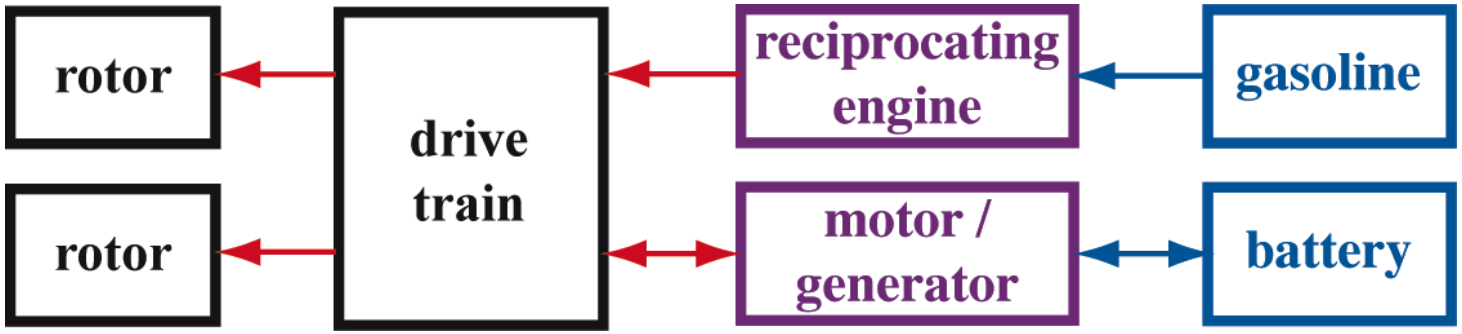
Electric Motor



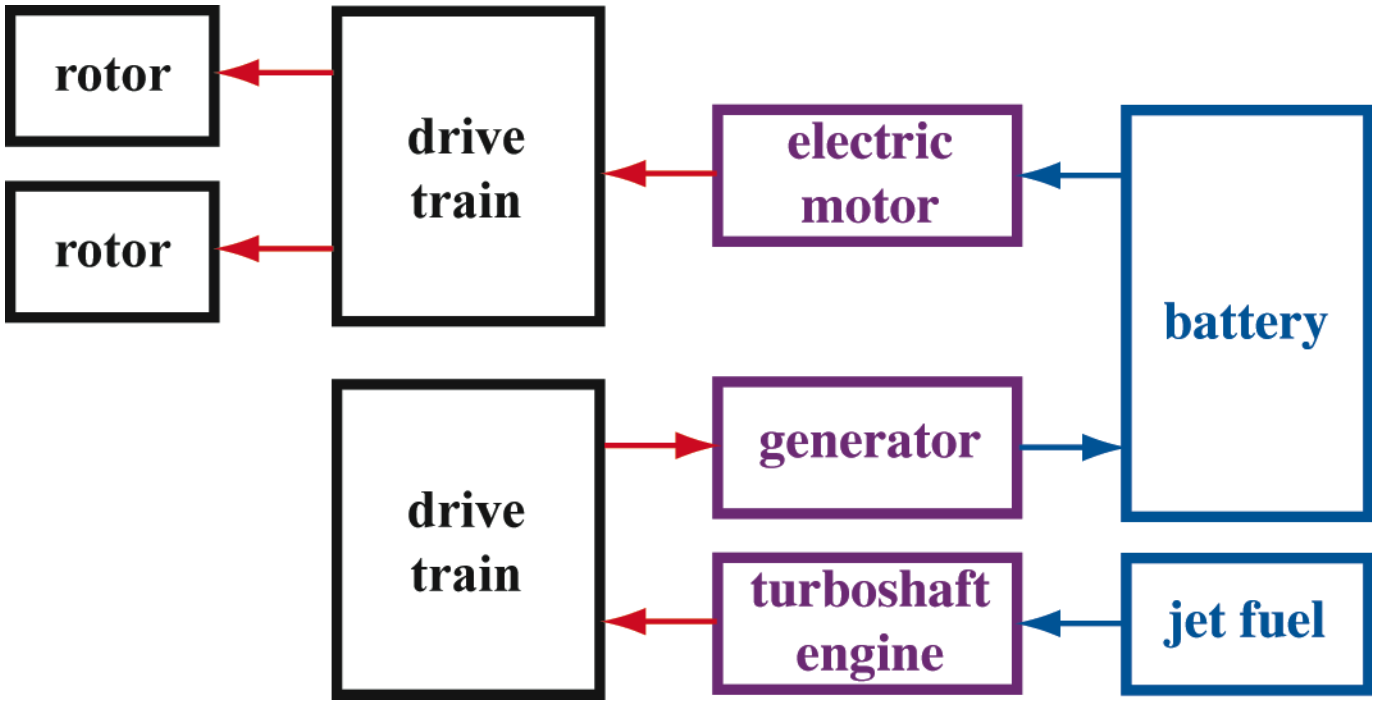




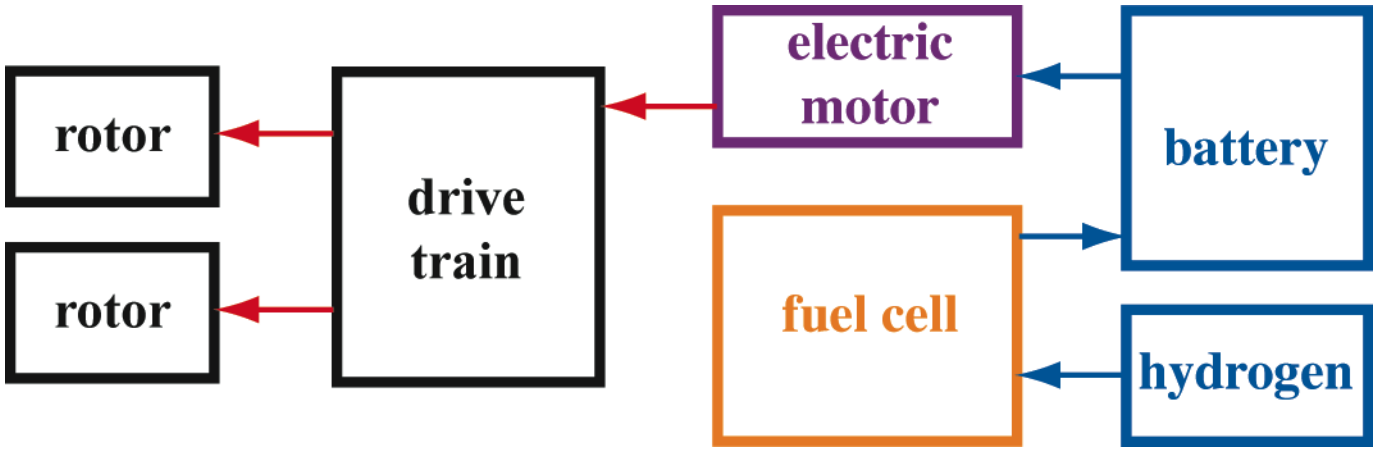
Hybrid


rotor
rotor
drive train
reciprocating engine
motor / generator
gasoline
battery

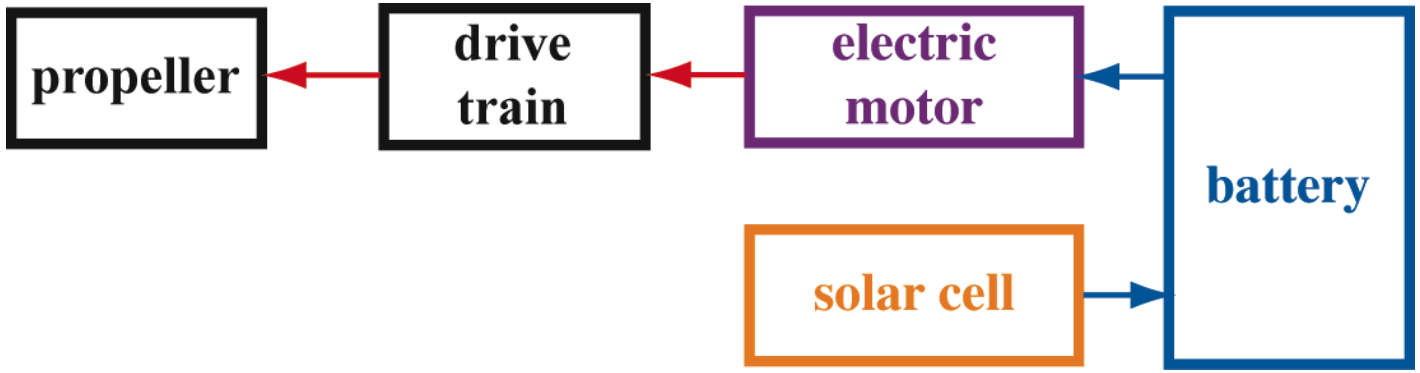
Turbo-Electric



Fuel Cell

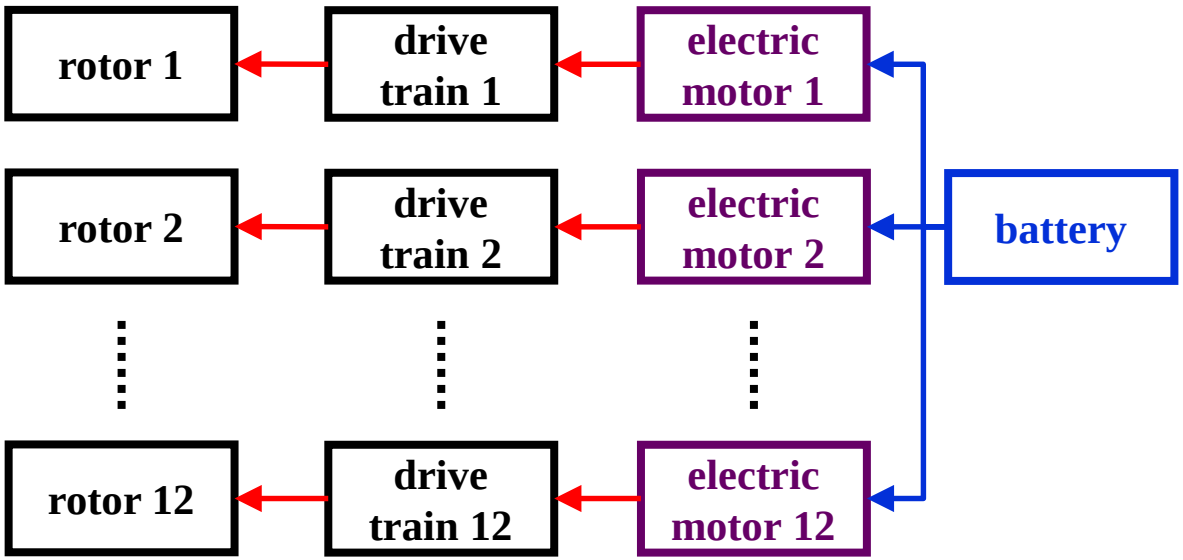

rotor
rotor
drive train
electric motor
fuel cell
battery
hydrogen

Solar Cell



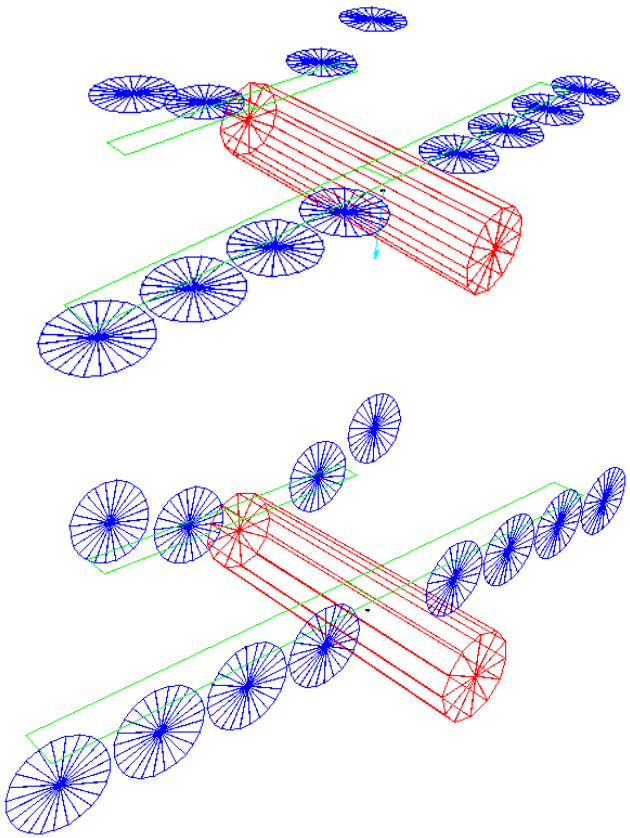
Distributed Propulsion Example

- Similar to Joby S2 – 12 tilting rotors
- Need to increase maximum number of rotors allowed (minor source code change)
- Can easily model more rotors by copying existing ones



Distributed Propulsion Example

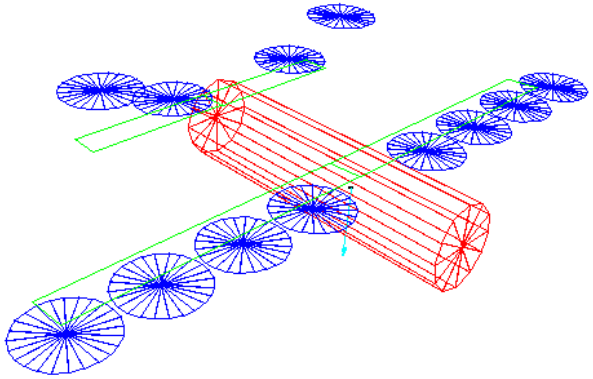
- **Achieve 6-variable trim in cruise and hover**
- **Can still trim in hover with a failed motor**
- **Need refined component models**



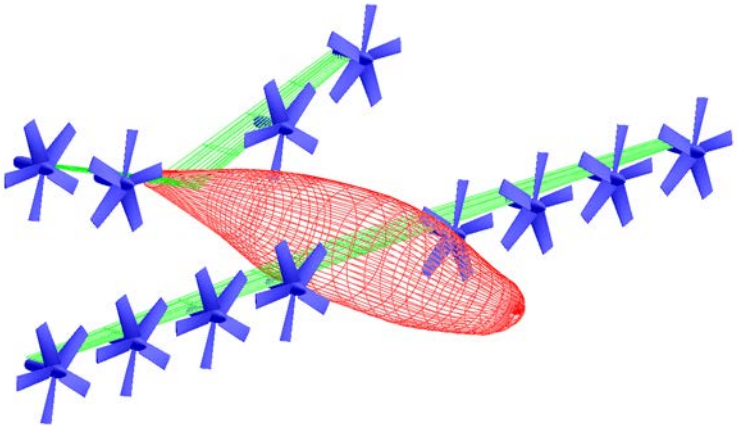
Model verification sketches output by NDARC

Integration with OpenVSP

- Allows rapid generation of more refined aircraft geometry
- Enables CFD analysis to refine performance estimates



NDARC sketch



OpenVSP representation

Future Plans for NDARC

- **Continue applying the software to advanced propulsion concepts and aircraft configurations**
  - Expand the NDARC user community
  - Refine and enhance the architecture based on experience
- **Improve calibration of the component models**
  - Collect data on existing advanced propulsion components
  - NASA SBIRs improving databases of existing technology
- **Integration of NDARC into a design environment with multiple tools**
  - OpenMDAO – optimization framework
  - OpenVSP – vehicle sketch tool
  - NPSS – propulsion modeling
  - DEN – NDARC input/output processing tool

Concluding Remarks

- **Described aircraft and propulsion system architectures in the rotorcraft conceptual design code NDARC**
  - General enough to treat the innovative concepts being imagined, proposed, studied, and built
  - Multirotor example demonstrates that the code can successfully model advanced configurations
- **Propulsion system can include**
  - Motors, generators, fuel cells, reaction drive, convertible engines
- **Energy source can be**
  - Burned (jet fuel, gasoline, diesel, hydrogen)
  - Renewed (solar cells)
  - Stored (battery, flywheel, capacitor)
- **Component models permit representation of current as well as future technology**

How to Request NDARC

- **Software is available to US companies, laboratories, universities, and individuals**
- **Distributed by Software Release Authority at Ames Research Center**
- **Contact wayne.johnson@nasa.gov for information on Software Usage Agreement**

Documentation

- 25 open papers and reports on NDARC development and applications
- Key development documentation:
  - Johnson, W. "NDARC. NASA Design and Analysis of Rotorcraft." NASA TP 2009-215402, December 2009.
  - Johnson, W. "NDARC — NASA Design and Analysis of Rotorcraft. Theoretical Basis and Architecture." American Helicopter Society Specialists' Conference on Aeromechanics, San Francisco, CA, January 2010.
  - Johnson, W. "NDARC — NASA Design and Analysis of Rotorcraft. Validation and Demonstration." American Helicopter Society Specialists' Conference on Aeromechanics, San Francisco, CA, January 2010.
  - Johnson, W. "Propulsion System Models for Rotorcraft Conceptual Design." American Helicopter Society 5th Decennial Aeromechanics Specialist's Conference, San Francisco, CA, January 2014.
  - "NDARC Theory Manual, Release 1.8" and "NDARC Input Manual, Release 1.8." February 2014.


NASA