Construction of a Tilt Rotor Drone for Implementation of Transition with Reduced Power Consumption

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Summary

This honors capstone aimed to implement the findings of the M-Tilt study of transition from vertical to horizontal flight in tilt rotor VTOL (Vertical Take-Off and Landing) drones by creating a prototype tilt rotor aircraft. The study found through testing and simulation that reducing the overall transition time reduces the overall energy consumption, but it also increases the maximum peak power draw. Furthermore, the shape of the transition profile can have the same effect. Therefore, there is no one optimal transition method that minimizes overall and peak power usage, but rather there exists a trade that must be considered for tilt rotor aircraft design. This poster discusses the study, as well as the prototype construction and challenges faced.

Introduction

Vertical takeoff and landing (VTOL) aircraft have a variety of uses as they are able to loiter over an area, take off and land from confined spaces, and demonstrate the range and speed of a fixed-wing aircraft.

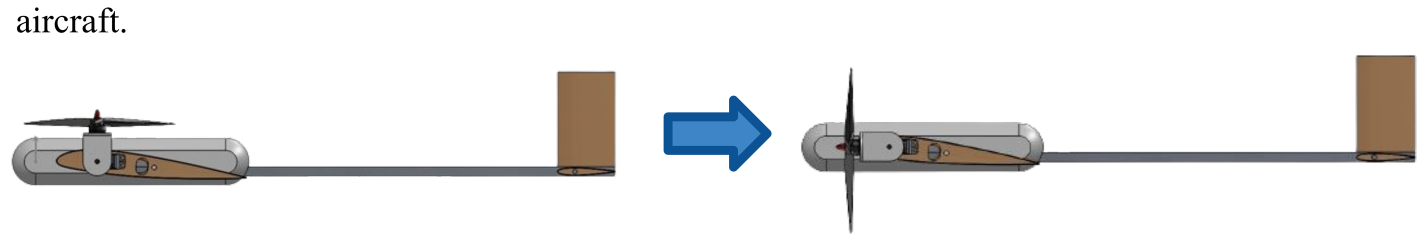


Figure 1. Vertical and Horizontal Flight Configuration of Tilt Rotor Drone

One common configuration is the tilt rotor (Figure 1), which has wingtip mounted propellers which rotate about the wing from vertical to horizontal, providing upward or forward thrust.

At present, such VTOL drones are inefficient during their transition from vertical to horizontal flight since the motors require a large amount of power to provide enough thrust to safely change flight modes. M-Tilt investigated this problem by recreating the tilt rotor drone transition phase through the use of a tilt rotor wing test article, as well as a full aircraft simulation. Multiple transition profiles were analyzed with the goal of minimizing overall power consumption and peak power consumption.

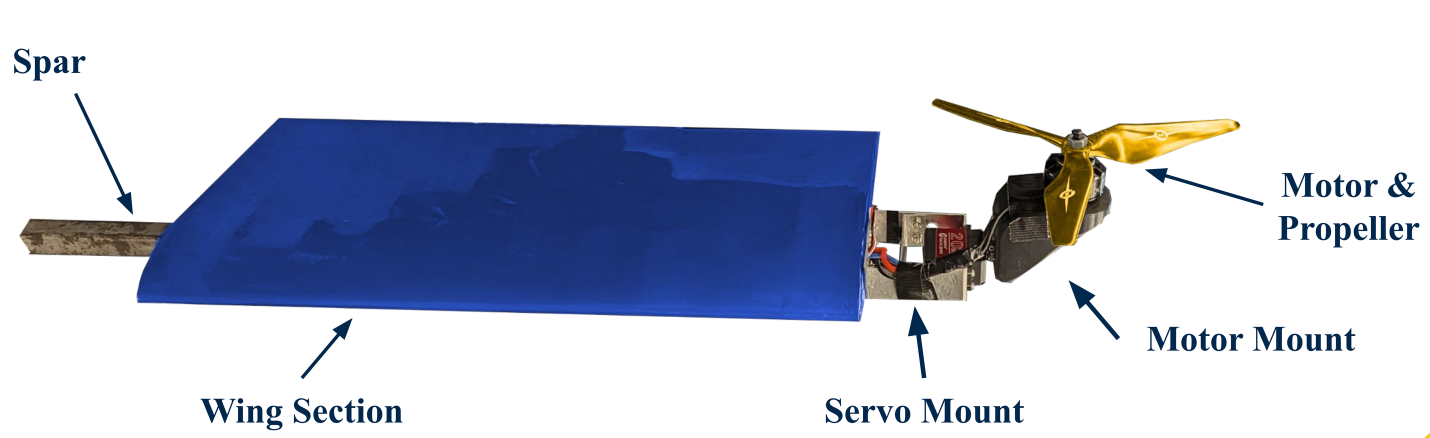
The prototype drone has requirements of a fixed weight of 10 Newtons (N) and a thrust-to-weight (T/W) ratio of 1.4. These requirements subsequently drove the design of the M-Tilt test article described in the following section. The cad model of the prototype is used in Figure 1.

M-Tilt Test Article

The M-Tilt tilt rotor wing test article replicates one-half of the prototype drone. Key details of this test article are listed below.

- Wing section spans 19in with a NACA 24012 airfoil cross section with a chord of 10in and a wingtip tilting mechanism
  - Wing dimensions and airfoil shape determined based on the prototype weight requirement, derived performance requirements, and hardware constraints
- Tilting mechanism made with servo, motor, aluminum bracket, and 3D-printed motor mount
- Servo rotates motor from 90° to 0° to transition from vertical flight to horizontal flight

The test article did not have its own weight or T/W requirements as it was only designed for use in the University of Michigan 5- by 7-foot wind tunnel.



Preliminary Testing & Analysis

Preliminary testing and analysis of the test article components was done in order to properly characterize their performance for implementation into a full aircraft simulation. This was done in three phases detailed below.

Phase 1 - Propulsion System Characterization
- Achieved requirement of 7 N maximum thrust for one-half aircraft using an EMAX MT-3110 motor, a 3-bladed propeller, and a 3S or 4S LiPo battery

Phase 2 - Dynamic Thrust Characterization
- Characterized propulsion system power as a function of thrust and efficiency as a function of freestream velocity using the University of Michigan 2- by 2-foot wind tunnel

Phase 3 - Wing Characterization
- Tested wing section in 5- by 7-foot wind tunnel to measure actual lift, drag, and moment for input into the full aircraft simulation

Full Aircraft Simulation

The preliminary testing data was utilized in the creation of a Simulink model that can replicate the conditions and forces of the prototype drone during transition. In this model, different servo tilt profiles can be simulated and the corresponding thrust output, power consumption, and altitude change can be examined. Shown in Figure 2 shows the servo angle vs time for 3 different profiles (**linear**, **cosine**, **exponential**) as well as the corresponding power consumption. It is clear that different transition profiles have varying max power peaks and all consume different amounts of total power.

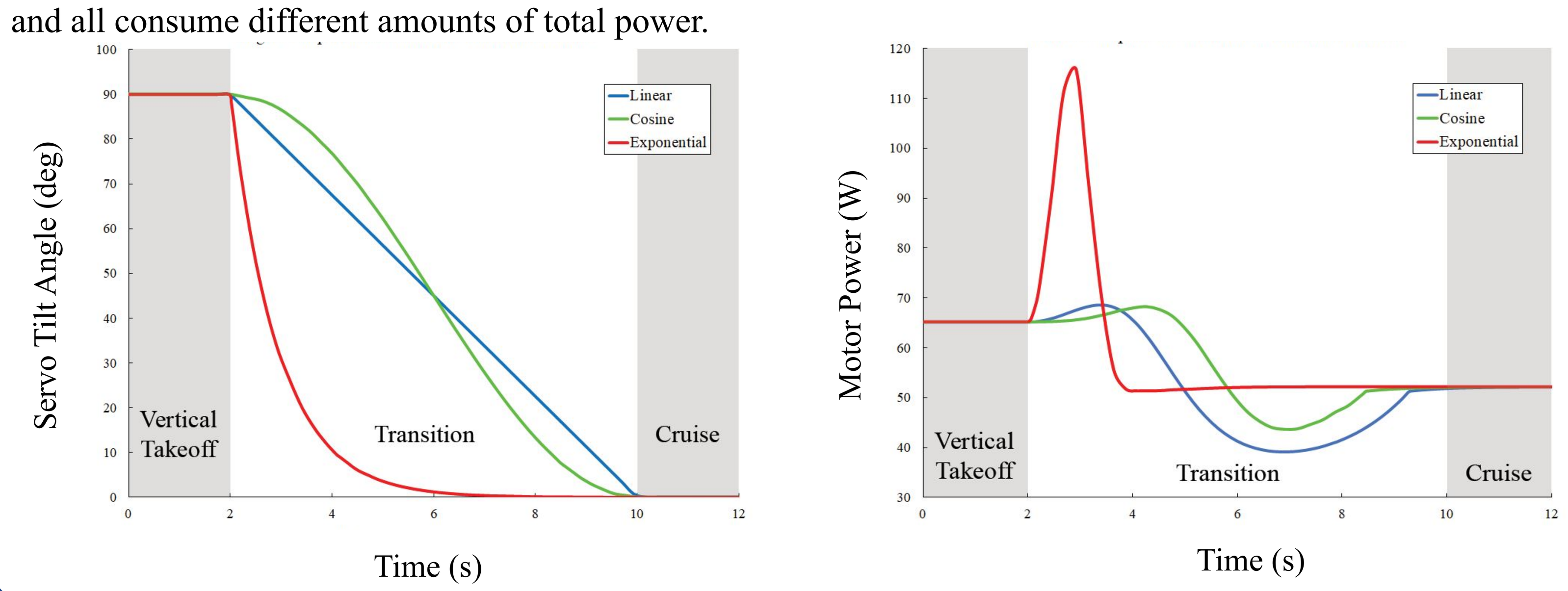


Figure 2. Various Transition Profiles and Estimated Performance

Validation Testing

With the results from the full aircraft simulation, a fully integrated tilt rotor test article was placed in the 5- by 7-foot wind tunnel to validate the simulation results.

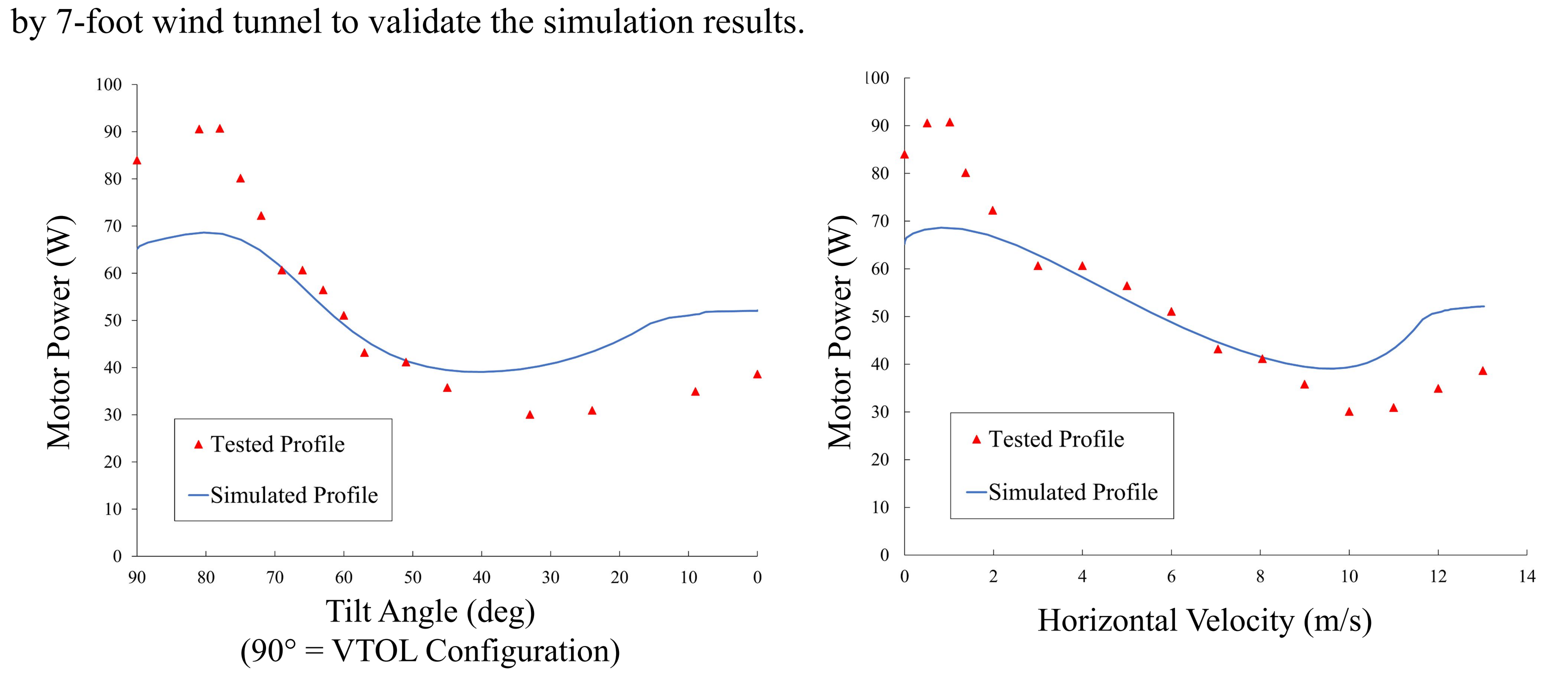


Figure 3. Experimental Data Hows Higher Peak Power for Linear Transition Profile

- Test data shows that the peak power for a linear transition is 92 W, which is 30% higher than what was predicted during the simulation. The test data also shows that the full aircraft simulation overestimates power requirements as the aircraft approaches horizontal flight.
- Overall, the aircraft simulation was validated by the test data as the collected data follows the expected trends and values.

Tilt Rotor Prototype

As mentioned in the Introduction, the tilt rotor prototype drone has requirements of a 10 N weight and a T/W of 1.4. Below is a summary of the actual finished prototype.

Weight: 17.36 N (3.90 lbs)
T/W: 1.325
Airfoil: NACA 24012
Wing Dimensions: 19 inch span, 10 inch chord
Tilting Mechanism: Integrated into the wing with a torque bar support structure (Figure 4)
Propulsion: EMAX MT-3110 motor, a 3-bladed propeller, and a 4S LiPo battery

The image below shows the interior of the wing and labels the key features of the structure and tilting mechanism. The full drone is not pictured as it will be on display with this poster!

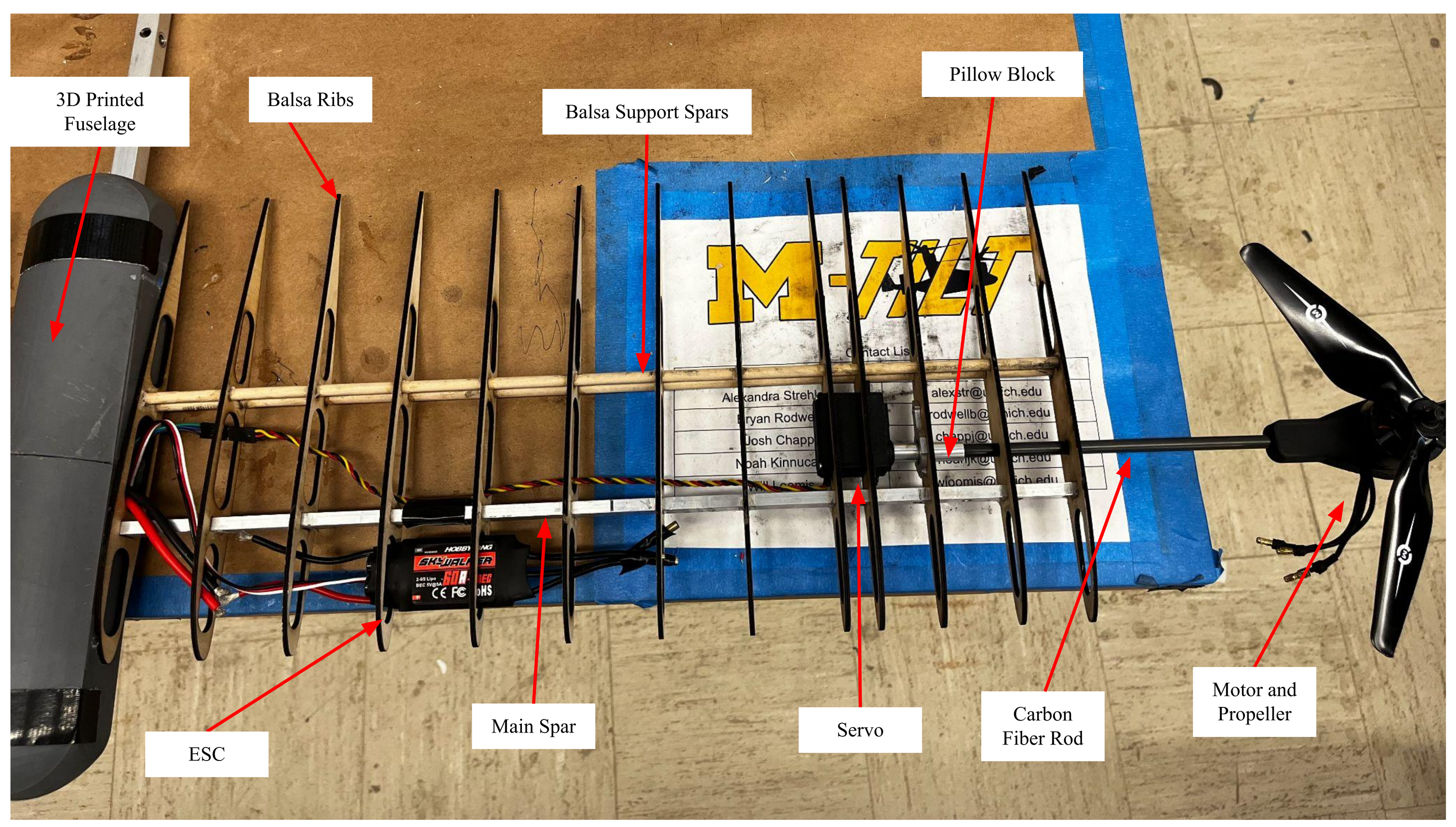


Figure 4. Interior of Prototype Drone Wing

Challenges Faced

Unfortunately, there were some challenges that prevented the flight of this prototype. They are numbered below.

1. The implementation of open-source software proved to be challenging due to unforeseen issues with the flight controller.
2. Limited experience with construction processes of small aircraft such as Monokoting.

Results & Future Work

In Conclusion, the M-Tilt team was able to conduct hands on testing which resulted in a simulation that can model any given tilt angle profile. Preliminary results of this simulation show that longer transition profiles reduce the spike in power consumption during transition, but they also lead to increased overall power consumption. Furthermore, the shape of the profile demonstrates similar effects. Continued study is necessary to determine the proper trade between these behaviors, as well as the optimally transition profile. The prototype was unsuccessful at flying; however, significant progress was made and can be built upon in the future. If given more time, the following future steps would be taken:

1. The M-Tilt team will continue with phase 4 and validating the power consumption of studied profiles, determining the optimal one.
2. The prototype will be improved using carbon fiber spar and fuselage design.
3. The prototype flight software will be troubleshooted (or developed in house).
4. A second iteration of the prototype will be constructed with improvements in design and quality due to experience.