Electric VTOL preliminary design and wind tunnel tests

Summary

Electric vertical takeoff and landing aircraft have the potential to transform the transportation industry. They fly over traffic directly to their destination, drastically reducing commuting time. Electric motors and batteries developed for electric cars power them, and propellers and ducted fans generate the thrust required for vertical and horizontal flight. Although many start-ups and many established companies are designing and testing their prototypes, there is little academic published data. Most designs are kept secret to shield them from the competitors.

The goal of this research is to investigate the broad field of eVTOL design and focus on one of its aspects, the retraction of the lift+cruise takeoff propellers inside the fuselage to reduce drag. First, an analytical toolset of equations is collected to evaluate eVTOL performances. Next, VTOL configurations from the 1950s up to the present day are presented, and the three main eVTOL configurations are compared, assessing the performances of a prototype for each one of them. Then, the power sources available are presented, discussing batteries, fuel cells, and hybrids. Finally, the propeller retraction system is investigated building and testing in the wind tunnel a model. Two exotic eVTOL designs are also discussed. The eVTOL for the exploration of Titan highlighted the effects of gravity and the density on its performances. The supersonic eVTOL showed the procedure to derive power source requirements from an existing design.

This work successfully highlights the crucial aspects of eVTOL design. The eVTOL range depends not only on the specific energy of the batteries but also on the lift to drag ratio and on the battery-mass ratio. Efficient hover requires a large disk actuator area, and coaxial rotors and ducted fans are valid alternatives to the standard rotor. EVTOL wing can be designed for an efficient cruise with no takeoff and landing distance requirements as conventional airplanes have.

The configuration comparison showed that each configuration is best suited to a different mission. Multirotors are efficient in hover and best suited to short-range missions. Vectored thrust eVTOLs are efficient in cruise and best suited to long-range missions. Lift plus cruise eVTOLs are a compromise, but they are slowed down by the drag of the lift propellers.

The power sources were analyzed, evaluating their specific energy and specific power. The high efficiency of the battery and the factors affecting its life are discussed. The specific fuel consumption of the fuel cells is computed. Hydrogen storage is crucial to the fuel cell system specific energy. Cryogenic liquid storage

offers the best gravimetric efficiencies, but it poses the biggest challenges. Metal-hydrides and other chemical compounds are options with lower gravimetric efficiencies than compressed hydrogen. The structural analysis of a compressed hydrogen tank was performed, evaluating its gravimetric efficiency. Hybrids were discussed, including internal combustion engine plus battery, gas turbine plus battery, and fuel cell, battery, and supercapacitor.

The lift propellers retraction system is investigated, building a model based on the Mini Talon drone and testing it in the wind tunnel. The drag reduction measured is around 30%, and this value is used to estimate the performances of a passenger eVTOL and a surveillance drone employing it. The Kitty Hawk Cora data is used to evaluate the passenger eVTOL performances with the retraction system, and the range and the cruise speed found were higher than the baseline. The advantages for a surveillance drone are limited because it is designed to watch over its target area for as long as possible, and an increase in flight speed has minor advantages.