Supplementary materials for the paper: "A Benchmarking Platform and a Control Allocation Method for Improving the Efficiency of Coaxial Rotor Systems"

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I. Supplementary Figures and Discussions

The preliminary testing consisted of a command swap from 40% to 95% of throttle divided into 20 equally spaced points. The testing results for all rotors are shown in Fig. 1. The plots shows the main quantities of interest for this work, namely, thrust T, torque τ, mechanical η_m and electrical η_e efficiencies and rotor speed ω.

The results from the second preliminary experiment are presented in Fig. 2. The results from the lower rotor are plotted together with the results from the isolated upper rotors to contrast any differences. For the rotors with propellers of 22 and 16.2 inches in diameter, no significant differences are noticeable. This indicates that the interference on the measurements by the structure downstream to the slipstream of the lower rotor is minimal and can be assumed as negligible. For the rotor with 11 inches in diameter, however, the difference in readings is significant. Specifically, thrust measurements for the lower rotor are always smaller than that of the isolated rotor. The most likely cause for such difference is the relative size between the propeller and downstream structure. The 11 inches propeller is the smaller one tested, and it makes sense that the amount of flow blocked by the sensor structure is much more significant for this case than for the other two larger propellers. In turn, this flow blocked by the sensors cancels some of the pulling force generated by the rotor, resulting in lower thrust readings.

As an example that illustrates the general behavior of a coaxial rotor system, Fig. 3 shows the thrust, torque, mechanical, and electrical efficiency map across the actuation domain for the rotor set with 22 inches propeller, for $z/D = 0.7$. There are some interesting observations to make over Fig. 3. First is the clear drop in total thrust on the right corner at Fig. 3 a). As the upper rotor throttle increases, the thrust of the lower rotor decreases, causing a sag on the thrust mesh plot. Such behavior is not, however, as significant on the left side. Second, and perhaps more interesting, note how on the right side of Fig. 3 d) there is a region of higher efficiency. Again, this region is not repeated on the left side. Both of these observations imply that the behavior of the coaxial system is not symmetric with respect to the line of equal commands sent to both rotors. Additionally, Fig. 3 d) indicates that the line of equal commands may not pass through this region of higher efficiency. This is important because the current standard for the control allocation of coaxial multirotor vehicles is to send equal commands to both rotors to achieve an arbitrary, static, thrust goal for hovering [1], [2].

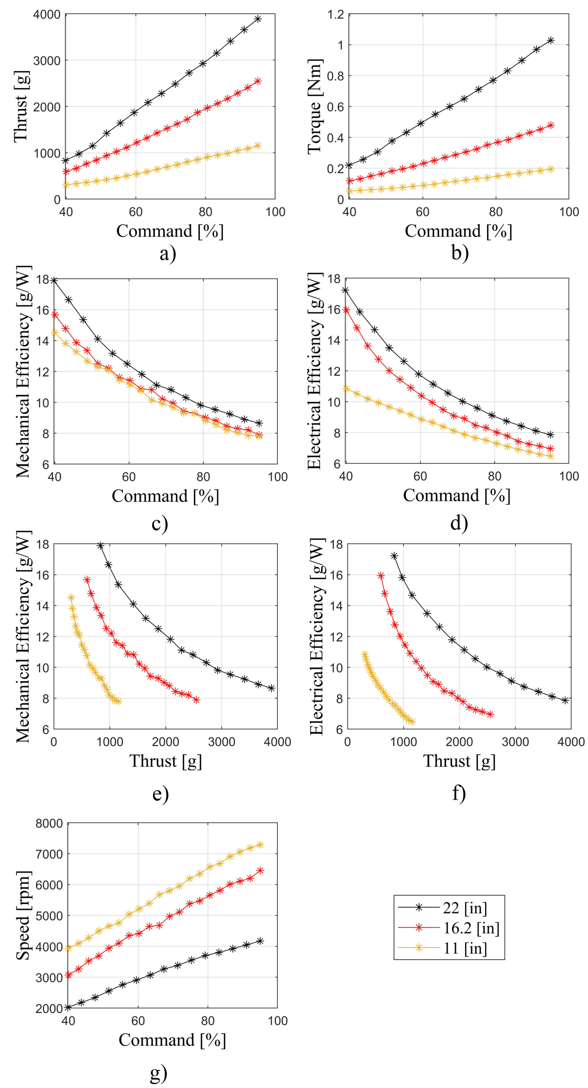

Fig. 1. Results from the first preliminary experiment, i. e., for isolated rotors, for all three rotors considered. a), b), c), d), and g) shows how the relevant quantities vary with respect to motor commands. Meanwhile, e) and f) shows the variation of mechanical and electrical efficiency with respect to thrust.

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