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Installation Effect on Hover Propeller Performance

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Abstract

For many hovering air vehicles, a tractor propeller is installed above the vehicle, while all its supports, engines, etc., are located below the propeller disk. The current paper describes the influence of the installation immersed in the propeller wake over the air vehicle performance. These components interact with the propeller wake/down-wash and affect the propeller performance. The propeller wake interacts with these components and produces vertical drag, which increases the required total thrust of the propeller. Understanding the interaction between the installation and the propeller is required for reliable performance estimation of the entire air vehicle.
Through simple momentum consideration, these interactions are modeled, providing thrust and power bookkeeping procedures. The suggested method requires mainly the non-installed/isolated propeller performance which in most cases is given by the propeller manufacturer. In other cases, this isolated performance can be estimated through analysis. In addition, the model requires the drag area of the installation immersed in the propeller wake and its axial position - the distance between the installation and the propeller disk. By these parameters, one can estimate the required power by the propeller which produces the specified required net thrust.
The suggested model enables estimating the installation influence in a relatively simple way. The main gaps to complete in the bookkeeping procedure are the propeller thrust and induced-power isolated-to-installed ratios. These two ratios are a function of two non-dimensional parameters: drag-area to disk-area and installation-distance to propeller-diameter ratio.
Using a test campaign, the two required isolated-to-installed ratios (power and thrust) are found and an empiric model is substantiated. The experiments use both an isolated propeller and a set of axisymmetric disks, positioned in various locations behind the propeller. The empirical model was substantiated by testing a range of propeller diameters, ring sizes, and installation locations. After normalizing all data, the data exhibits specific trends which enable, through curve fitting, an empirical model. Using this model allows one to conduct the full thrust/power bookkeeping, enabling a relatively simple estimation of the installation effect.
The empiric model exhibits a good comparison to the thrust isolate-to-clogged ratio. For the induced-power model, the comparison is less accurate although the trends are captured in a good manner. Induced power cannot be measured directly and has to be estimated. The induced power is calculated by subtracting an estimated parasite power (due to cross-sectional drag) from the measured shaft power. This causes some degradation in the accuracy of the results. Still, the resulting model is practical and gives reasonable estimations.
To demonstrate the model's correctness, test validation was conducted using a separate test campaign. This additional test uses non-axisymmetric disks, rather than the axisymmetric disks, which were used in the main campaign. By installing non-axisymmetric obstacles in the propeller wake, the measured thrust and power can be compared to the suggested model using the same parameters. After simple processing, the test results exhibit a good comparison to the empiric model. This proves that the model can be used for general installation, rather than axisymmetric disturbances. In the non-axisymmetric installation, the thrust behavior exhibits better agreement with the model while the induced power is captured less accurately. This repeat the basic empiric model accuracy trend - better agreement of the thrust compared to the induced-power model.
The presented installation effect estimation is very practical. With few parameters concerning the isolated propeller and the installation properties, one can evaluate at a good accuracy the propeller installed performance. This can be used not only for small-scale propellers but also for other scales with the relevant normalized parameters. Moreover, the suggested procedure can be improved by additional test data, hence improving the empirical model's correctness.