Evaluating and Augmenting Fuel-Saving Benefits Obtained in Aircraft Formation Flight
by
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Abstract:

Each year, a substantial amount of money is spent on aviation fuel. To mitigate this, regulatory boards are requiring aircraft manufacturers to improve aircraft operating efficiencies through various aerodynamic, structural, and propulsive enhancements. These enhancements, which may include replacing aircraft structures with high performance composite materials to reduce weight or installing new engines to improve fuel economy, are feasible but not cost-effective. This research seeks to inexpensively enhance the aerodynamics of existing aircraft by (i) flying them in extended formations to obtain fuel savings, and (ii) employing unconventional trimming techniques to augment the fuel savings achieved in formation flight.

Studies have shown that when an aircraft flies, it generates wake vortices, which induce a non-uniform wind distribution in its wake. A trail aircraft, placed in the wake of a lead aircraft's vortices, experiences this non-uniform wind distribution with varying directions and magnitudes depending on the location within the wake. It has been demonstrated that there is a "sweet spot" within the wake of a leader in which a trail can experience upwash that leads to reduced drag. Through this mechanism, aircraft can save significant amounts of fuel by flying at the sweet spot of the lead aircraft's wake. As a result of this potential benefit, multiple agencies such as the Air Force Research Laboratory (AFRL), the Defense Advanced Research Projects Agency (DARPA), and NASA have renewed interest in aircraft formation flight as a fuel-saving initiative.

This research develops two metrics for obtaining the sweet spot and evaluating the benefits to the trail aircraft at the sweet spot: a static and a dynamic analysis. The static analysis is similar to wind tunnel tests in that the aircraft are statically placed in formation in the absence of trim. Induced aerodynamic forces and moments on the trail aircraft are recorded as the trail varies its position within the wake of the vortex-generating lead aircraft. The relative location of maximum lift-to-drag ratio is then denoted the static sweet spot. The dynamic study is analogous to actual flight tests in which the two aircraft are trimmed and the control surface deflections and thrust values are tracked. In the case of the dynamic analysis, the relative location of minimum thrust is the dynamic sweet spot.

The static and dynamic analyses are simulated for aircraft formations with different relative lead-trail sizes and varying trail aircraft configurations such as flying-wing and conventional aircraft. Results demonstrate that the sweet spot locations and associated fuel-saving benefits are dependent on the weight of the leader and the relative sizes of the aircraft pair in the formation. In addition, it is shown that the trail aircraft experiences large induced aerodynamic moments and requires non-zero drag-inducing control surface deflections to trim at the static sweet spot. Thus, alternative lateral trimming methods, such as internal fuel transfer and differential thrusting, are investigated. These techniques are shown to reduce the need for the control surface deflections required at the static sweet spot and decrease the thrust required to trim by over four percent.

This study demonstrates that formation flight, especially when combined with unconventional trimming methods, results in significant thrust reductions and thus, fuel savings for a trail aircraft. Considering how much money is spent on fuel, the potential impact of each percentage savings in fuel translates to savings in millions of dollars, attainable by both the military and commercial aerospace sectors.