Aerospace Europe Conference 2023
Joint 10th EUCASS – 9th CEAS Conference

Abstract #XXX
Preferred Topics: *AEROFLIPHY / FDGNCAV*
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Type: Oral
Status of corresponding author: Regular

Title
Optimal control of a combat aircraft with thrust vectoring during take-off

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Abstract
In this work we explore the benefits of thrust vectoring in reducing the take-off distance of a combat aircraft. The early stages of the design of a new aircraft are a multidisciplinary challenge in which numerous aircraft configurations of different nature are compared. To assess the aircraft's pure performance and handling qualities, the optimal control method is proposed herein to avoid the need to formulate ad-hoc Flight Control Laws (FCL) to simulate the aircraft in these preliminary design phases. This becomes even more relevant for combat aircrafts, usually open-loop longitudinally unstable, where a tentative FCL design might not fully exploit the capabilities of the plant and lead to deceiving design conclusions.

The optimal control method consists in finding the time histories of a system's control variables that minimize a given functional [1]. In this work, we solve the optimal control equations that model the longitudinal motion of an aircraft during a take-off in the spatial domain, and use the final altitude as the fitness function. This quantity is adopted in contrast to the take-off distance since it guarantees the control of the aircraft on the initial climb. The two-dimensional aircraft model includes an unstable non-linear aerodynamic model (typical of a high maneuverable combat aircraft), an engine model with thrush vectoring, and a landing gear suspension model to reproduce the reaction forces on the runway. The engine model implements a thrust loss effect due to nozzle deflection that typically characterizes these systems. All control variables are limited in position and rate, and their smoothness can be tuned with the addition of penalization terms in the fitness function. Furthermore, practical constraints are considered, such as the clearance of the aircraft body with the runway.

We conclude that, without thrust vectoring, the aircraft is limited by its capability to rotate at very low speed to build up a large angle of attack and take benefit of the maximum lift available. Conversely, when thrust vectoring is active, performance is limited by the risk of tailstrike, that restricts the maximum rotation angle. Overall, we find that the take-off distance is improved by roughly a 40% and, on the other hand, the penalty in acceleration time due to thrust misalignment and thrust loss is negligible. The optimal control method contributes to understand how to actively exploit the thrust vectoring capability on a take-off, to introduce a pitch up moment that drives the rotation, followed by a pitch down moment that stops the rotation and prevents contact with the asphalt.

References
[1] Vinayagam, A. K., and N. K. Sinha. "Optimal aircraft take-off with thrust vectoring." The Aeronautical Journal 117.1197 (2013): 1119-1138