A nudged hybrid analysis and modeling approach toward airport digital twinning for real-time wake vortex prediction

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Every aircraft generates a wake of turbulent air and disturbance as it flies, caused by a pair of tornado-like counter-rotating vortices (called wake vortex) that trail from the tips of the wings. Due to the hazards posed by the wake vortices left behind by a taking off or landing aircraft, serious precautions are to be considered. For example, the operational minimum aircraft separation for different weight class configurations, adopted by the air traffic control, varies from 2.5 to 6 nautical miles. However, when deciding the separation distance following those guidelines, the weather conditions and associated transport and decay of WVs are not often taken into account. This was not a serious issue a couple of decades ago, but with the significant increase of the air traffic and a push for remote towers for cost effective and safe operation, major airports around the world are feeling the pressure. In this regard, digital twinning of airports appear like a potential solution.

We put forth a long short-term memory (LSTM) nudging framework for the enhancement of reduced order models (ROMs) of fluid flows utilizing noisy measurements for air traffic improvements. Toward emerging applications of digital twins in aviation, the proposed approach allows for constructing a real-time predictive tool for wake vortex transport and decay systems. We build on the fact that in realistic application, there are uncertainties in initial and boundary conditions, model parameters, as well as measurements. Moreover, conventional nonlinear ROMs based on Galerkin projection (GROMs) suffer from imperfection and solution instabilities, especially for advection-dominated flows with slow decay in the Kolmogorov n-width. In the presented LSTM nudging approach, we fuse forecasts from a combination of GROM predictions and uncertain state estimates, with sparse Eulerian sensor measurements to provide more reliable predictions in a dynamical data assimilation framework. We illustrate our concept by solving the two-dimensional vorticity transport equation and investigate the effects of measurements noise and state estimate uncertainty on the performance of the proposed approach. We also demonstrate that it can sufficiently handle different levels of temporal and spatial measurement sparsity, and offer a huge potential in developing next-generation digital twin technologies for aerospace applications [1].

This material is based upon work supported by the U.S. Department of Energy, Office of Science, under the Advanced Scientific Computing Research program (award Number DE-SC0019290). O.S. gratefully acknowledges the U.S. DOE Early Career Research Program support.

References

[1] Ahmed, S. E., Pawar, S., San, O., Rasheed, A., & Tabib, M. (2021). A nudged hybrid analysis and modeling approach for realtime wake-vortex transport and decay prediction. *Computers & Fluids*, *221*, 104895.