Up, Up and Away!

Using CFD tools to develop a Real-Time Flight Model

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The traditional development of aircraft of any type usually goes through a long design process until the first full-scale prototype is built to test flight behavior. Such an approach is extremely costly considering the capital investment required for large passenger liners. Considering the challenges faced by the recent development of the Airbus A380 and Boeing 787 Dreamliner, manufacturers and component suppliers are understandably under increased pressure to deliver right, on time, every time.

There is therefore a need to streamline the development process and improve the prediction accuracy in flight behaviors in real-time flight simulators. Dr. Olivares and his team at the National Institute for Aviation Research (NIAR) of the Wichita State University set out to develop a method to increase the prediction accuracy of flight behaviors with the real-time flight simulator, MIURA. Conventional aerodynamic calculations used by the simulator were not accurate enough, especially predicting stall and other effects such as propeller performance or the wing-fuselage interference. The NIAR team conducted several simulations with Mentor Graphics' FloEFD™ Simulation Software on their test model, a push propeller UAV (Figure 1), in order to get more accurate data to feed into the simulator for a better prediction of flight characteristics as well as to validate the FloEFD results with wind tunnel measurements.

The goal of the NIAR research team is to better predict, not only the aerodynamics, but also take into account more models, (such as the controls and electrical systems), in the virtual engineering environment while also collecting data throughout the flight envelope and feed that back into stress simulations of the aircrafts structure. This article is based on the presentation given by Dr Olivares at the COE 2015 Annual PLM Conference & TechniFair in April 2015.

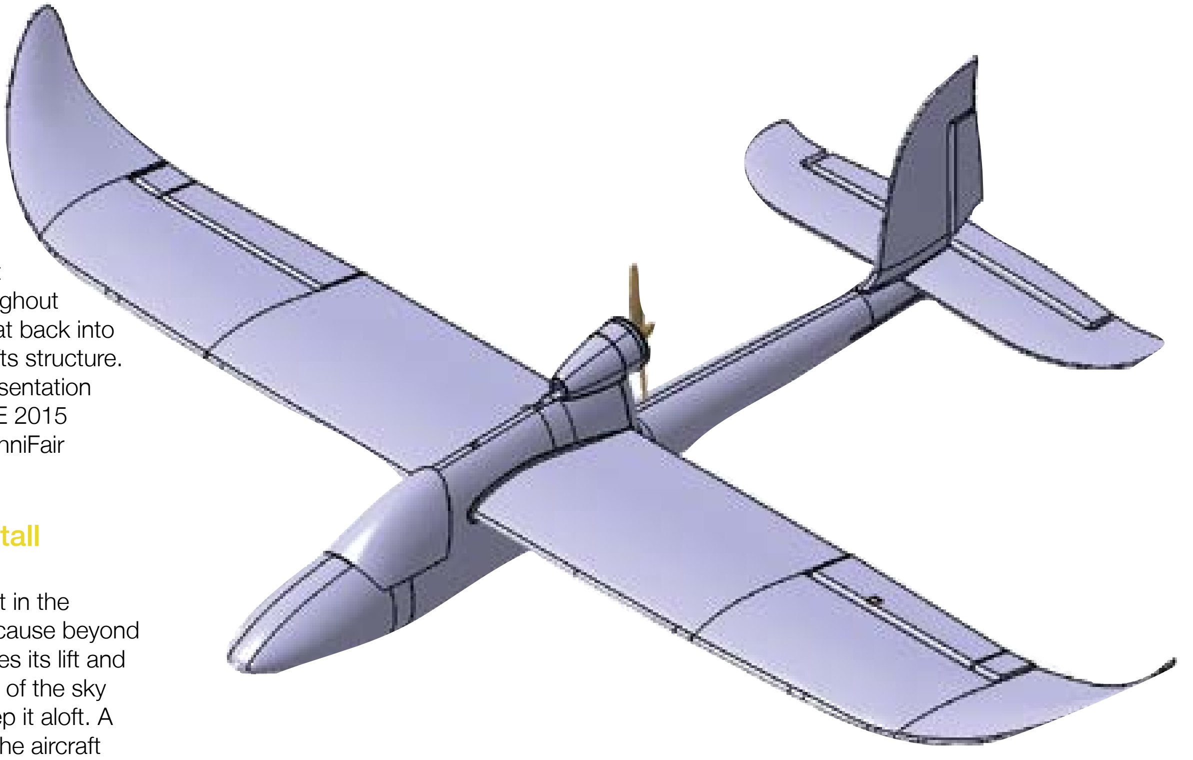

Figure 1. The NIAR push propeller UAV CATIA V5 model..

Aerodynamic Surface Stall Prediction

Stall prediction is a critical point in the aerodynamics of an aircraft because beyond the point of stall the aircraft loses its lift and maneuverability and will fall out of the sky since no lift is generated to keep it aloft. A trained pilot is able to recover the aircraft after stalling but not without a large loss in elevation. Stalling maneuvers such as those seen at airshows with fighter jets or acrobatic aircrafts, are tested by test pilots in new aircraft prototypes. The standard development process of an aircraft includes initial aerodynamic calculations starting with the selection of an airfoil. The aerodynamic parameters of airfoils however are based on a 2D profile which behaves differently to a 3D wing. There are analytical methods to predict the 3D behavior based on the 2D profile data, but this method often lacks accuracy compared to wind tunnel measurements or 3D CFD calculations. The MIURA prediction of the 3D wing and the comparison of the 2D and 3D experimental data are shown in Figure 2. It can clearly be seen that the default prediction of the stall behavior of MIURA is at a much lower lift coefficient (CL) and lower angle of attack. In a simulation the aircraft would stall at a

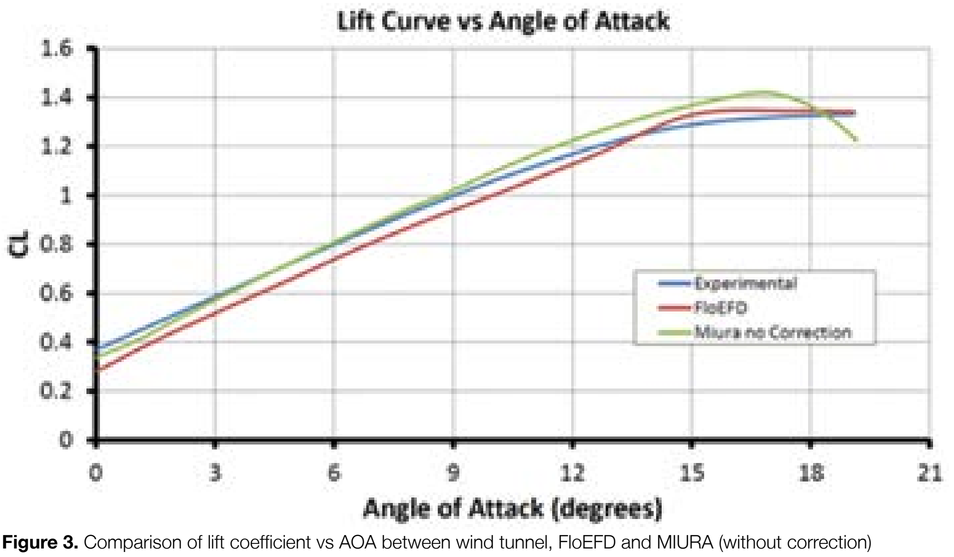

Figure 3. Comparison of lift coefficient vs AOA between wind tunnel, FloEFD and MIURA (without correction)

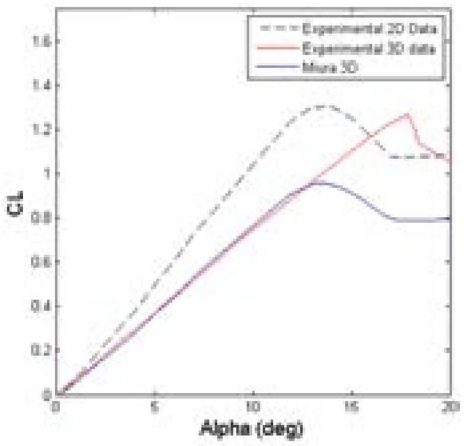

Figure 2. MIURA results without correction for stall prediction.

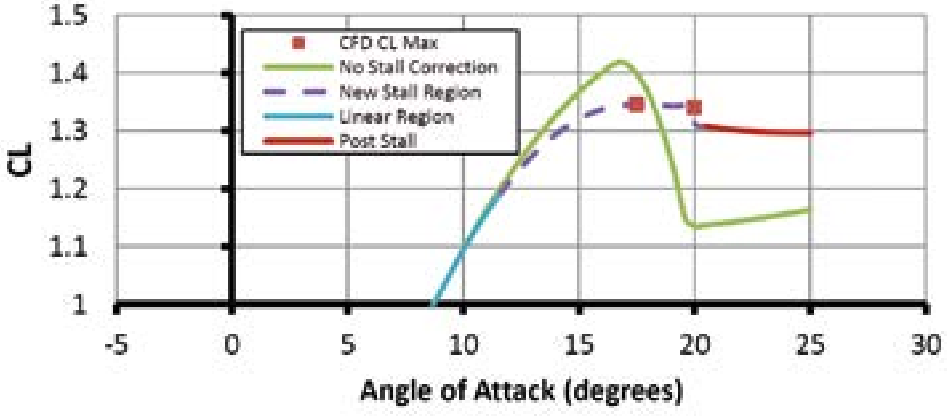

Figure 4. Lift coefficient vs. AOA showing effect of stall correction for MIURA

much smaller angle and lower lift compared to the reality. The NIAR team built a 3D wing as an extrusion of the 2D airfoil SD7062 and measured its aerodynamic performance in the closed loop Beech Wind Tunnel at the Wichita State University (WSU). They then conducted a FloEFD simulation at a range of angles of attack (AOA).

The results from the experiment, FloEFD and MIURA (without correction) are shown in Figure 3 and shows that FloEFD has the same lift curve slope and stall pattern as the wind tunnel data. MIURA on the other hand captures the initial slope but over - predicts the stall at 17° AOA.

The vital parts of the lift curve that MIURA must correct are after the linear section so as not to over-predict the lift and drop too strongly after the maximum lift. In order to do that, MIURA enables the user to input the CLmax and an additional point after that, and consequently calculates the post-stall again on its own (Figure 4).

This method leads to a drastically improved stall behavior (Figure 5). The corrected MIURA calculation fits the stall behavior of the experimental data much better than the uncorrected calculation.

Propeller Performance

Since the polars used in airfoils also apply for the propeller blades, the same problem affects the propeller performance and can be seen in the thrust and power coefficient vs. advance ratio of the propeller diagrams shown in Figure 6.

This is especially true in the crucial take-off and climb phase where the curves differ drastically and would result in extremely different flight behavior by the simulator.

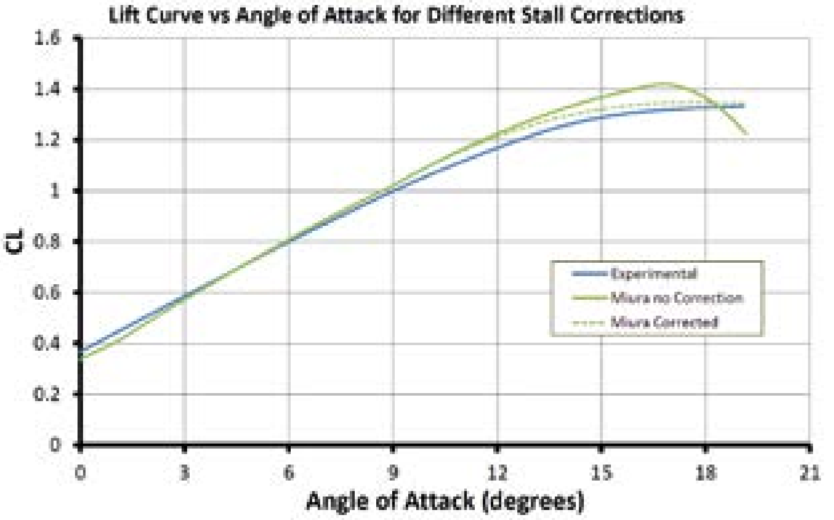

Figure 5. Lift coefficient vs. AOA showing the corrected MIURA results compared to the experiments

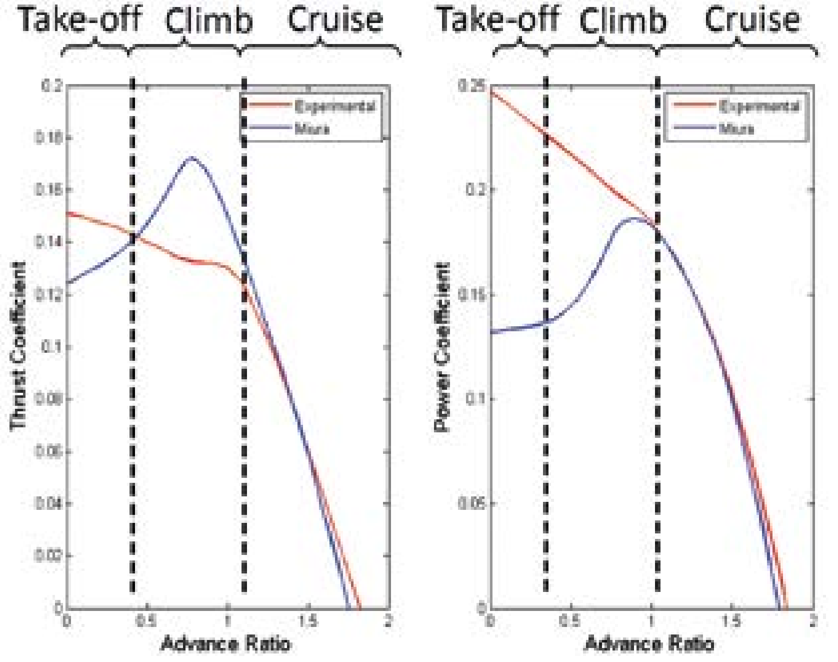

Figure 6. Thrust and power coefficient prediction of MIURA compared to experimental data

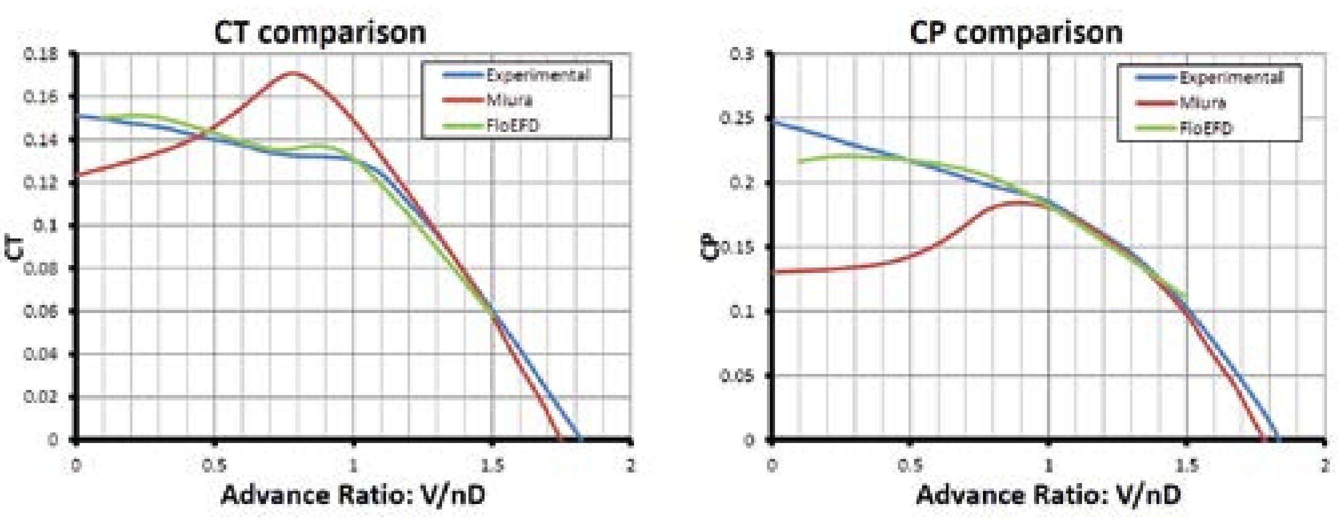

Figure 7. Thrust and power coefficient (CT and CP respectively) comparison between wind tunnel, FloEFD and MIURA (not corrected)

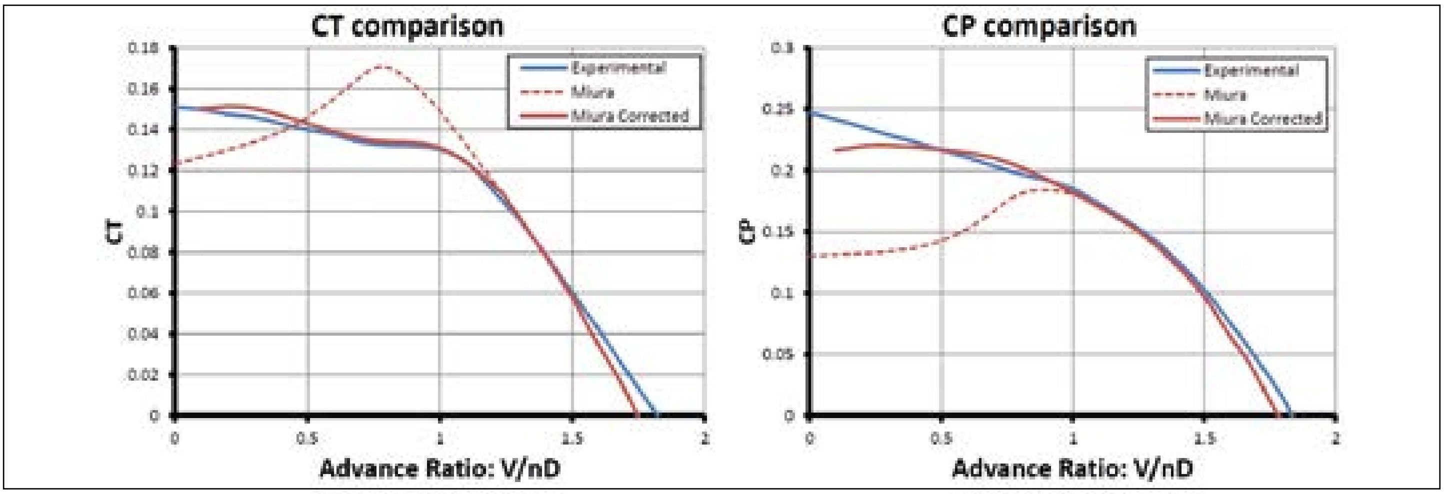

Figure 8. Corrected MIURA results for thrust and power coefficient compared to not corrected results and experimental data

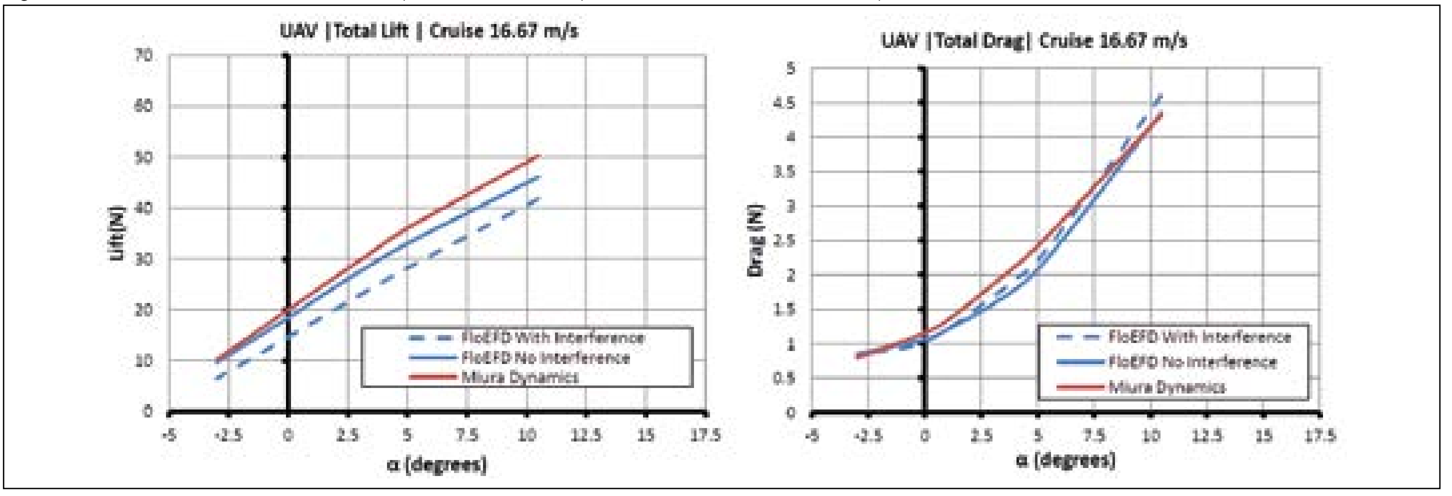

Figure 9. Lift and drag vs. AOA for not corrected MIURA results compared to FloEFD results with and without interference

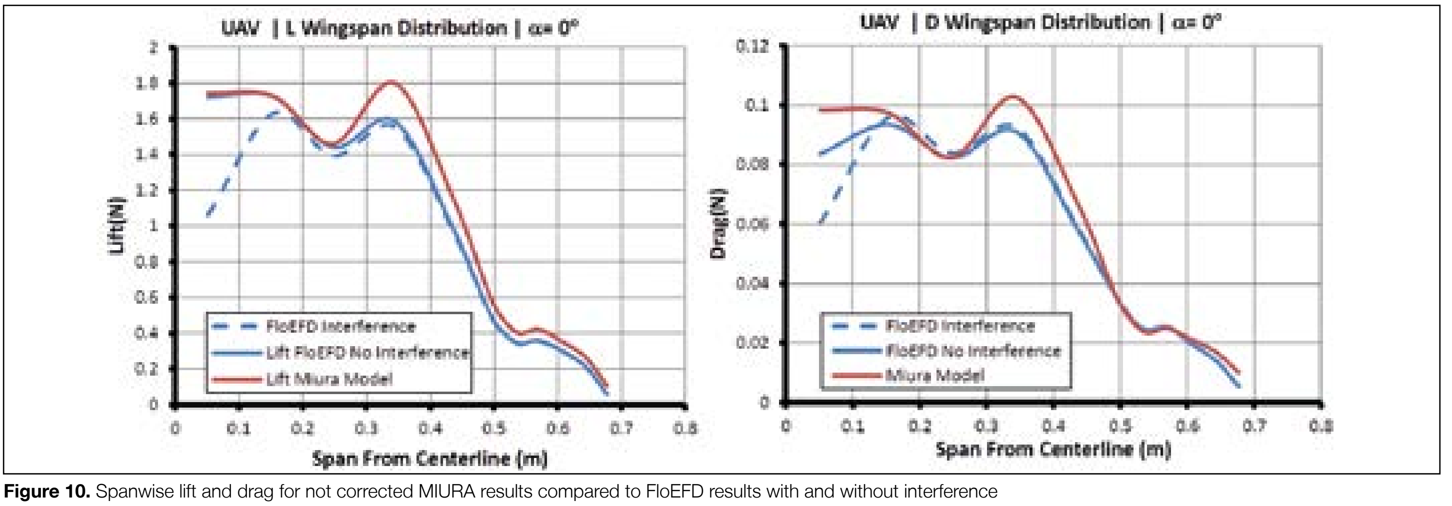

Figure 10. Spanwise lift and drag for not corrected MIURA results compared to FloEFD results with and without interference

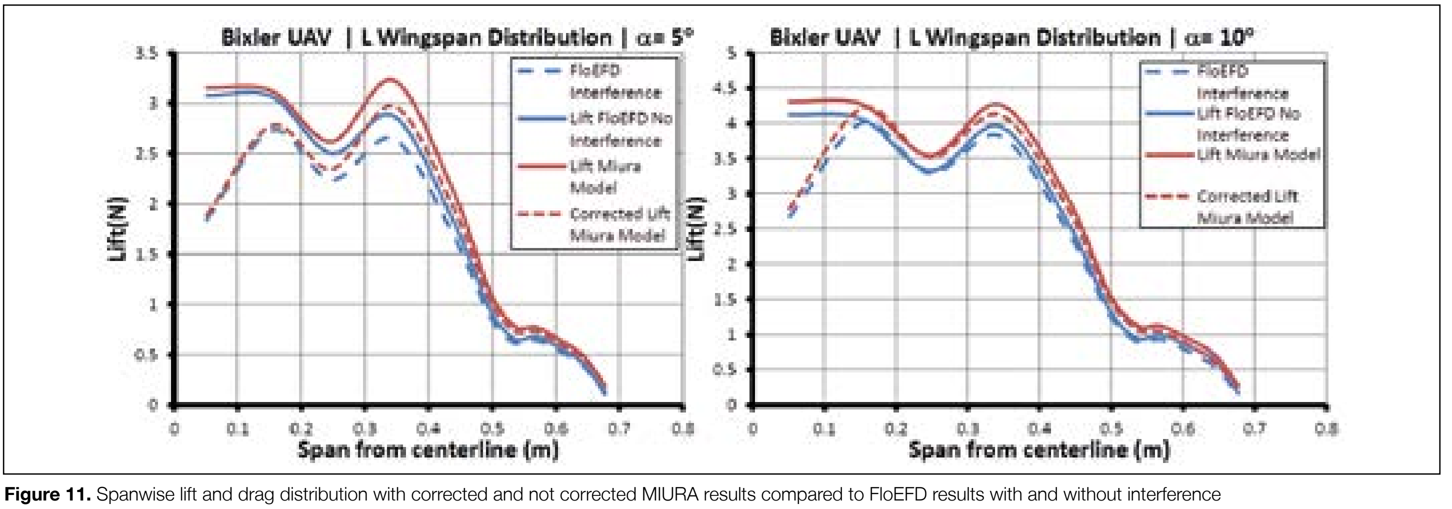

Figure 11. Spanwise lift and drag distribution with corrected and not corrected MIURA results compared to FloEFD results with and without interference

“The four distinctive features that make FloEFD the best candidate for this kind of application are its CAD embedded approach, the Immersed Body Meshing technology, the parametric study, and the solver accuracy”

Gerardo Olivares Ph.D, National Institute for Aviation Research

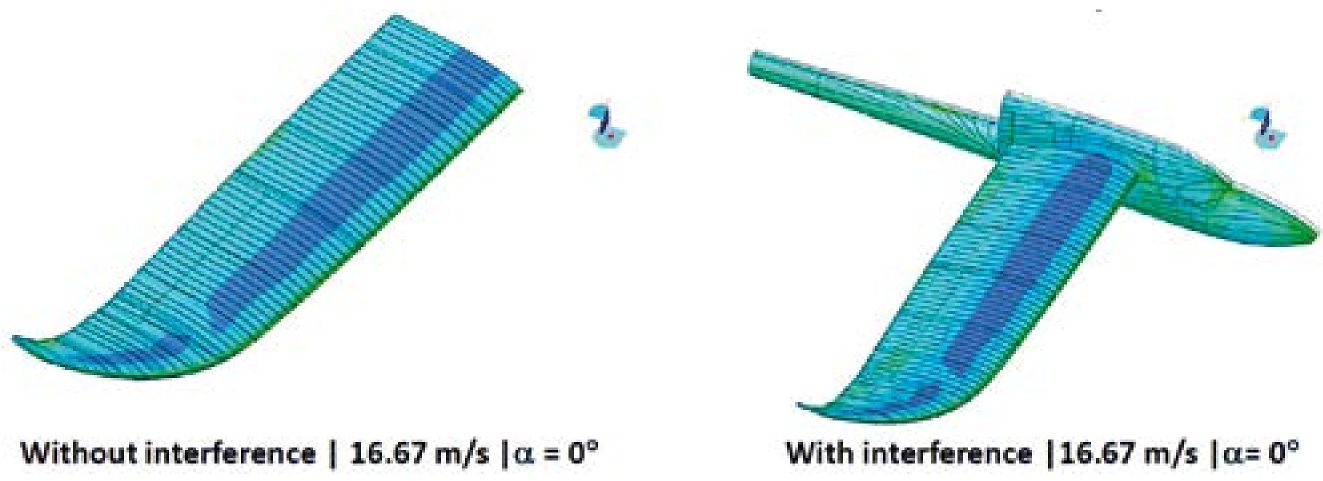

Figure 12. Pressure surface plot showing the influence with and without wing-fuselage interference

The NIAR team used one propeller from the NACA Report No. 594, “Characteristics of six propeller including the high speed range” and again measured in the wind tunnel and simulated with FloEFD then compared with the prediction of the uncorrected MIURA calculations (Figure 7).

It can be seen that the Blade Element Theory approach of MIURA works well for the power coefficient prediction above an advance ratio of 1, and for the thrust coefficient above an advance ratio of around 1.2. The NIAR team introduced correction points for the advance ratio smaller than 1, with a “Joint Point” at 1 so the interpolation of the corrected curve would utilize the results of the FloEFD simulation to achieve a higher accuracy (Figure 8).

Interference Effects

In order to analyze the interference effects of a 3D wing intersection with the fuselage of the UAV, the aircraft was 3D scanned and a CAD model generated. The CATIA model was again simulated in FloEFD, once with only the wing and once with wing and fuselage joined together. The two different scenarios were analyzed and compared with the MIURA calculations. The lift and drag vs. AOA curves shows little deviation between MIURA and FloEFD with no interference (only the wing) but larger deviation if the interference is taken into account (Figure 9).

By taking a closer look at the spanwise distribution of lift and drag, a strong difference can be detected between wing only (no interference) and wing and fuselage (with interference) (Figure 10). FloEFD was able to predict the difference between both cases and therefore the correction of the MIURA model will improve the accuracy (Figure 11).
The interference is clearly visible and in an aircraft surface plot of the pressure, the change in the distribution can be seen close to the wing-fuselage intersection (Figure 12).

Conclusion

Dr. Olivares and his team were able to improve the simulator flight characteristic drastically with the help of the CATIA V5 embedded FloEFD simulations. The improved accuracy of stall prediction, propeller performance and interference effects enabled his team to conduct the first steps to develop a Virtual Engineering Method that is superior to the Traditional Engineering Method with regards to product development time (Figure 13) and costs.

References

[1] A. Barragan, J. M. Gomez, H. Solano, G. Olivares, “Comparison of a Simplified Real Time Aerodynamic Model with a 3D CFD Model of a UAV”, COE 2015, North Charleston (SC, USA), 28th April 2015

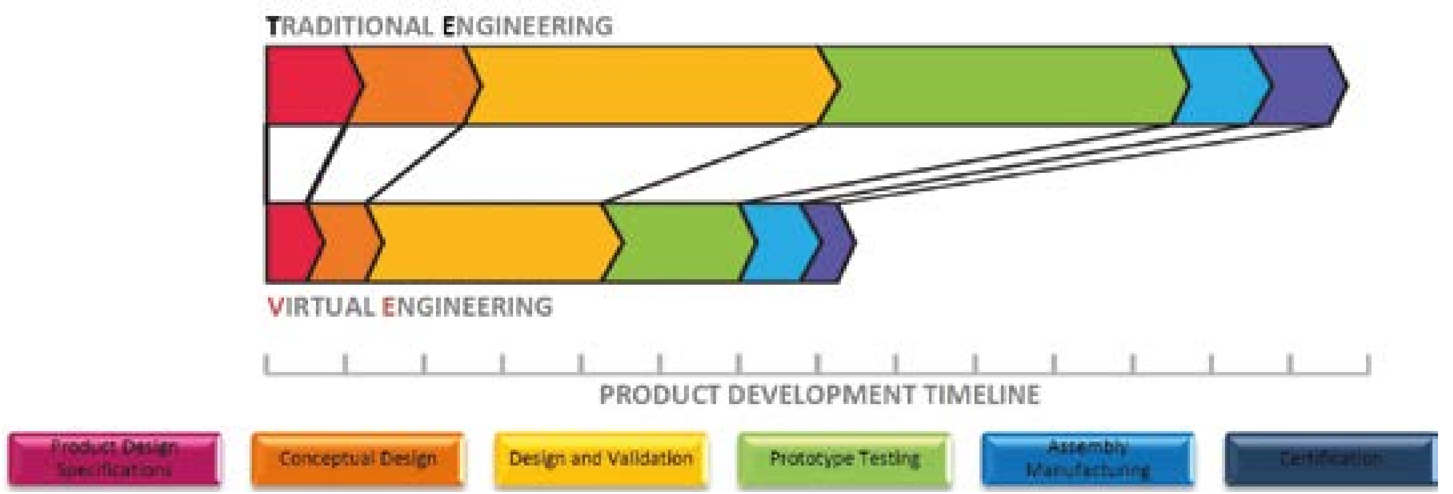

Figure 13. Advantages of the Virtual Engineering Method for the product development timeline