Modelling of the Noise Shielding Research Aircraft UAV in MATLAB using Kirsten Wind Tunnel Data

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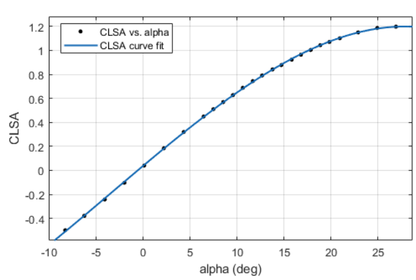
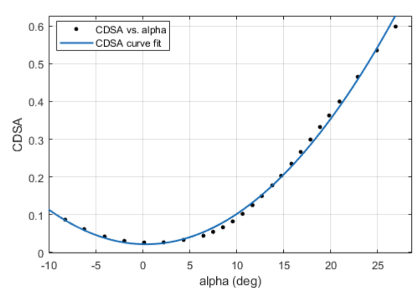
Kirsten Wind Tunnel data for the Noise Shielding Research Aircraft (NRSA) UAV was used to create a MATLAB/Simulink model of the aircraft. The noise shielding research aircraft was the product of a senior capstone design project in the year of 2010, and is currently being refurbished as part of a 2023 capstone project. Wind tunnel data from tests carried out in the KWT has been made available to students working on the aircraft. This report will outline the use of the KWT data to develop a model of the aircraft in MATLAB. Curve fits were performed on CL vs. Alpha, CD vs. Alpha, CY vs. Beta, and CR vs Beta. Lookup tables were implemented for CM and CN. The CM lookup table had a dependency on both alpha and beta. The engine was modelled by curve fitting thrust vs. RPM data. When building the model in MATLAB, it was assumed that the control input was proportional to engine RPM. Due to a lack of physical data on the aircraft, such as measured moments of inertia, and accurate locations of the CG and AC, the simulator model did not perfectly reflect the flight characteristics of the real aircraft.

1. Method for developing the equations of motion

Reduced data from several alpha-sweep and beta-sweep Kirsten wind tunnel runs were used generate curve fits of force and moment polars that could be implemented in a MATLAB function. All runs had a q of 12.5 psf and featured an identical aircraft configuration, except for varied control surface deflections. All force coefficients were represented in the stability frame, while the moment coefficients were represented in the body frame. The figure below shows the 3rd order polynomial that was fit to CL vs. Alpha, and the second order polynomial fit to CD vs. Alpha.



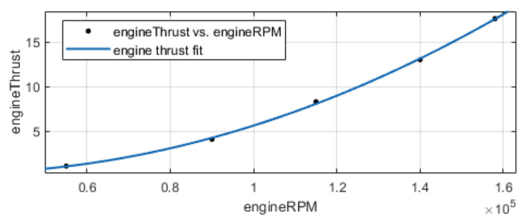


The horizontal stabilizer's effect on the total lift was included in the model by analyzing a run with a 6-degree elevator deflection. The difference in lift on the body of the aircraft compared to a neutral elevator was normalized to this 6-degree deflection. This value can then be multiplied by any elevator deflection and added onto the neutral elevator lift curve, to determine the change in lift due to elevator inputs. This is not a perfect way to model the effects of the elevator on the lift of the aircraft but could be improved by analyzing several more runs with various positive and negative elevator deflections. The coefficients of side force and rolling moment were similarly determined using a curve fitting method.

When analyzing the wind tunnel data, it became apparent that pitching moment coefficient was coupled with both alpha and beta. For this reason, lookup table functions were programmed. Using a MATLAB mesh grid, a 2-D array of pitching moment values corresponding to a sweep of beta from -30 to 30 degrees, and a sweep of alpha from -8 to 26 degrees was formed. The pitching moment coefficient can be determined for any combination of alpha and beta in this range by performing a 2-D interpolation on the grid. The same method was used to determine the Rolling Coefficient at any combination of alpha and beta. During data reduction, the wind tunnel crew reduces the data such that final moments are output as the moments about the CG of the aircraft. For this reason, a moment transfer from AC to CG was never performed.

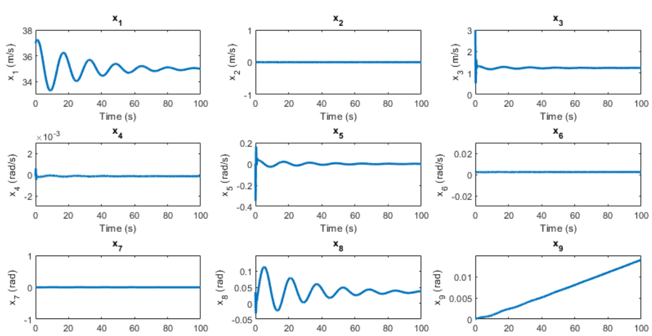
The effects of control surfaces on the moment coefficients were determined by analyzing KWT runs that were performed with control surface deflections. The elevator's effect on pitching moment, and the aileron's effect on rolling moment were considered. The rudder's effects on roll and yaw were both considered. These effects were determined by calculating the difference in each coefficient between the surface-deflected and surface-neutral runs. These values were then normalized by the deflection of the surface to give $\frac{\delta CR}{\delta aileron}$, $\frac{\delta CR}{\delta \text{rudder}}$, $\frac{\delta \text{CN}}{\delta \text{rudder}}$, and $\frac{\delta \text{CM}}{\delta \text{elevator}}$. These values can then be used to determine the change in each moment due to any control surface deflection.

The engine on the Noise Shielding Research Aircraft is a small turbojet jet engine. This system was modelled by curve fitting engine data, and implementing the curve fit into the aircraft model MATLAB function. The curve fit is shown below. It was assumed that the throttle input *u1* was proportional to the RPM. It was also assumed that the throttle leveled off 158000 RPM, the highest datapoint on the plot.



Results and Conclusion

The model was trimmed and linearized about a 35 m/s steady, level flight operating point. A simulation was run with an initial $\Delta x_1 = 2$ and $\Delta x_3 = 2$ in order to excite the longitudinal modes of the aircraft. The resultant state trajectories are shown below. The phugoid mode response is most obvious in x_3 and x_8 while the short period response appears subtly in x_3 before it is quickly damped out. Note that the heading angle also slightly drifts, by about 0.015 radians over the course of 100 seconds.



This model successfully implements the NRSA aircraft dynamics, however, it currently suffers from loss of fidelity due to lack of complete data on CG locations and detailed moments of inertia. It also does not account for the effect of angular rates on the moment coefficient, in the form of a $\frac{\delta CM}{\delta x}$ matrix. The model also has not been implemented in Simulink, so no nonlinear analysis has been performed.

Appendix A. The Noise Shielding Research Aircraft