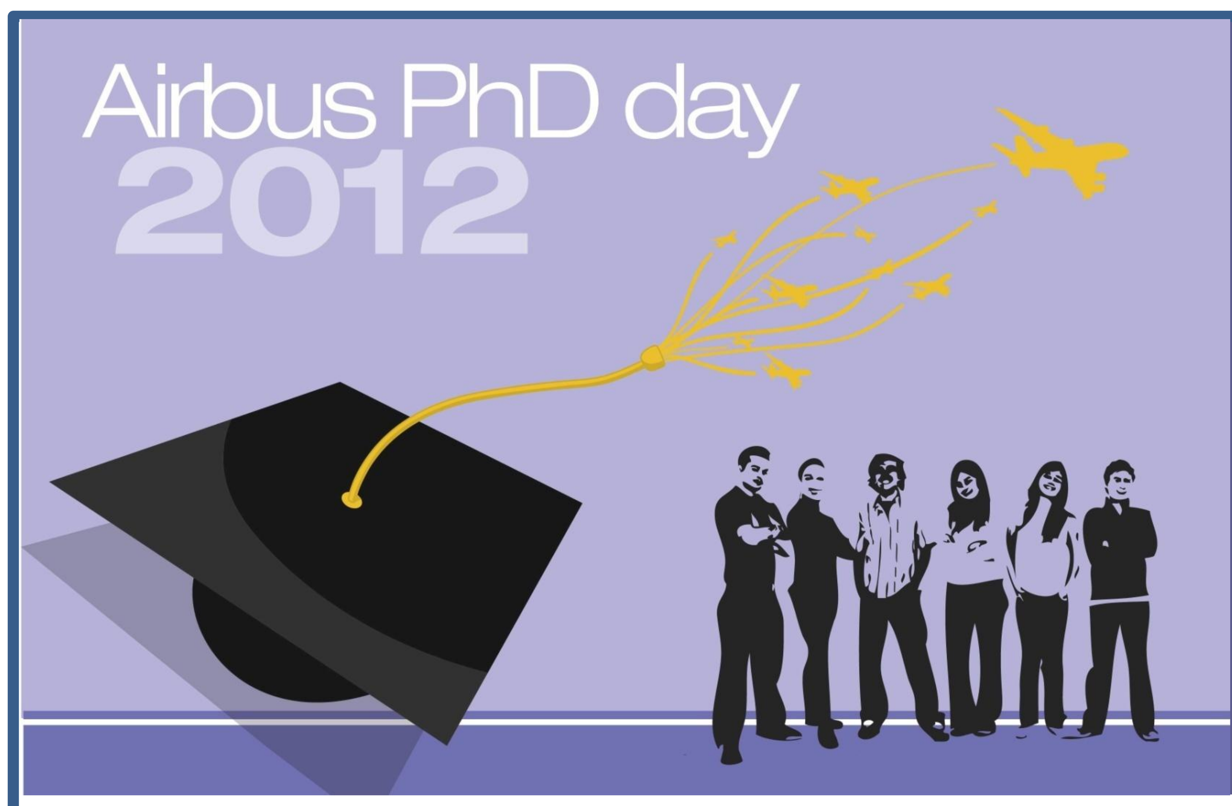

Aerodynamic Models for Flight Simulation

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Motivation/Industrial Relevance

The flight testing of aircraft is one of the most expensive and critical parts of the design process. Using computer simulations with CFD allows this to be carried out earlier in the design phase and at much lower cost. This work looks to study the aerodynamic models available and assess these for adequacy for the simulation of manoeuvres typical of Airbus aircraft.

Frequency Domain Methods

Frequency domain methods allow rapid solution of periodic unsteady problems such as those encountered in flutter and flight dynamics analyses. The time dependent equation:

$$\frac{d\mathbf{W}(t)}{dt} + \mathbf{R}(t) = 0$$

is transferred to the frequency domain whereby after manipulation, the equations to solve are:

$$\begin{pmatrix} \frac{\partial \mathbf{R}}{\partial \mathbf{W}} & \omega n \mathbf{I} \\ -\omega n \mathbf{I} & \frac{\partial \mathbf{R}}{\partial \mathbf{W}} \end{pmatrix} \begin{pmatrix} \hat{\mathbf{W}}_{a_n} \\ \hat{\mathbf{W}}_{b_n} \end{pmatrix} = - \begin{pmatrix} \frac{\partial \mathbf{R}}{\partial \mathbf{x}} & \frac{\omega n \partial \mathbf{R}}{\partial \dot{\mathbf{x}}} \\ \frac{-\omega n \partial \mathbf{R}}{\partial \dot{\mathbf{x}}} & \frac{\partial \mathbf{R}}{\partial \mathbf{x}} \end{pmatrix} \begin{pmatrix} \hat{\mathbf{x}}_{a_n} \\ \hat{\mathbf{x}}_{b_n} \end{pmatrix}$$

for Linear Frequency Domain (LFD) method and:

$$\frac{d\mathbf{W}_{hb}}{dt} + \omega \mathbf{D}\mathbf{W}_{hb} + \mathbf{R}_{hb} = 0$$

for Harmonic Balance (HB). Each are solved by a linear solver with an effective preconditioner also developed in this work. The above two methods are implemented in the DLR TAU code with LFD having been run on a very large Airbus test case. Typical speed up for each of the methods is shown in the below table where the number after HB is the number of retained harmonics and implicit LFD is using a fully implicit method to solve the LFD problem.

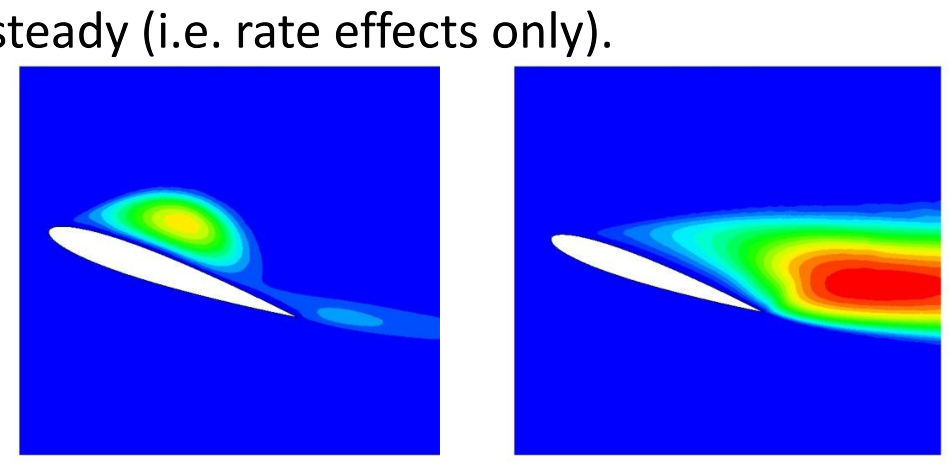
Method	HB-1	HB-3	LFD	Implicit-LFD
Speed up	16.26	10.37	27.99	124.2

Dynamic Derivatives

The tabulated aerodynamic data is static and for manoeuvres where rate effects begin to be significant, it is necessary to modify the static data to account for these. Dynamic derivatives modify the forces and moments by:

$$C_j = C_{j_0} + \bar{C}_{j_\alpha}\alpha + \bar{C}_{j_q} q \frac{c}{2U_\infty}$$

where the "j" subscript indicates the force or moment. The bar terms are dynamic derivatives obtained from forced periodic oscillations. There is no accounting for history effects in this model and as such it is quasi-steady. However, for most manoeuvres of interest the rates are low and history is insignificant. The effect of history on turbulent terms is shown below for a dynamic stall case, with the left image accounting for history effects (URANS) and the right image being quasi-steady (i.e. rate effects only).



Objectives

- Extend frequency domain methods in TAU
- Assess tabular aerodynamic models
- Assess dynamic derivative models
- Study alternative models

Tabular Models

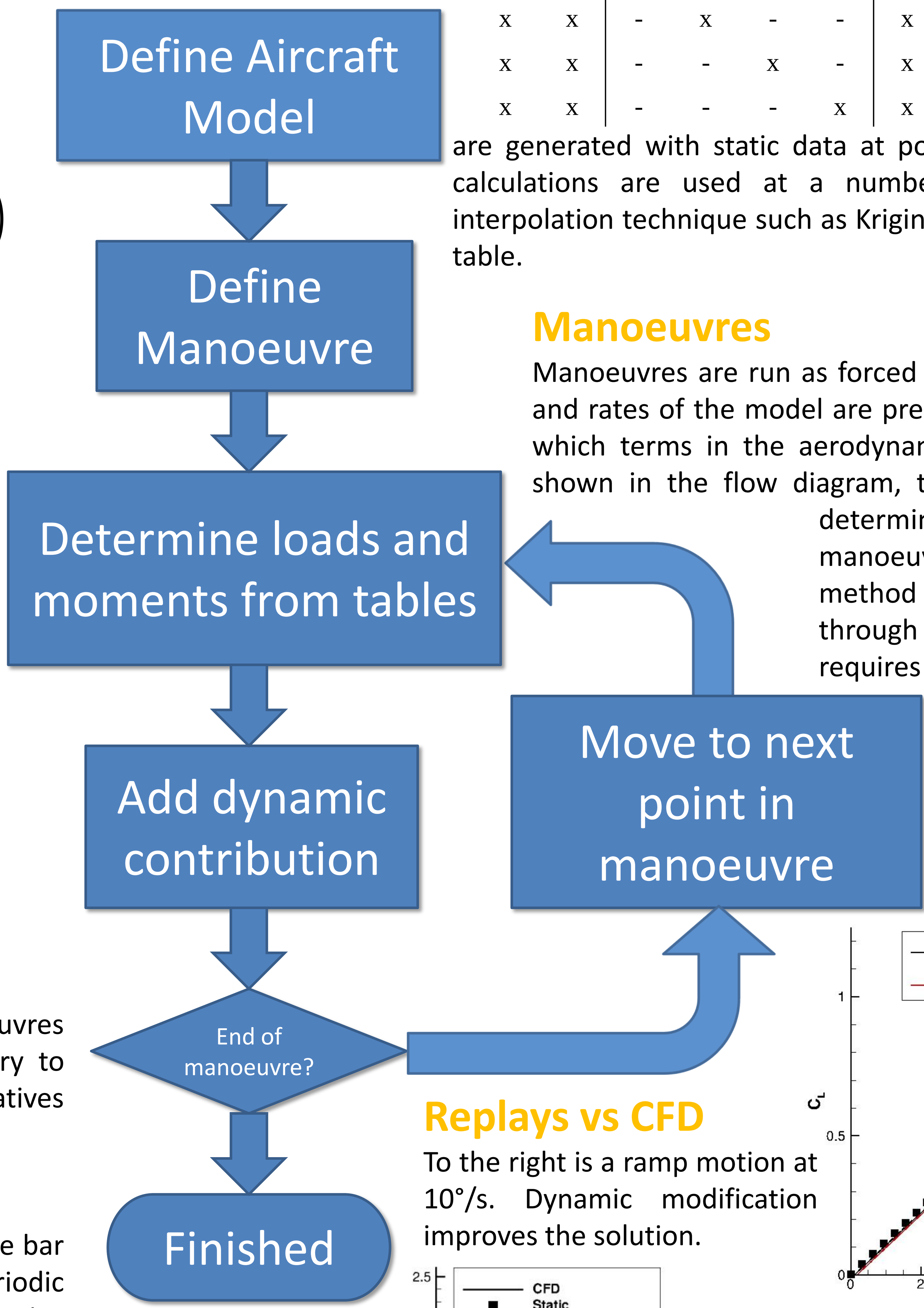
Tabular aerodynamic models are a quick and easy way of determining the loads and moments of an aircraft for a given manoeuvre. Tables similar to

M	α	β	δ_{ele}	δ_{ail}	δ_{rud}	C_L	C_D	C_Y	C_l	C_m	C_n
x	x	x	-	-	-	x	x	x	x	x	x
x	x	-	x	-	-	x	x	x	x	x	x
x	x	-	-	x	-	x	x	x	x	x	x
x	x	-	-	-	x	x	x	x	x	x	x

are generated with static data at points marked with "x." CFD calculations are used at a number of the points with an interpolation technique such as Kriging to populate the rest of the table.

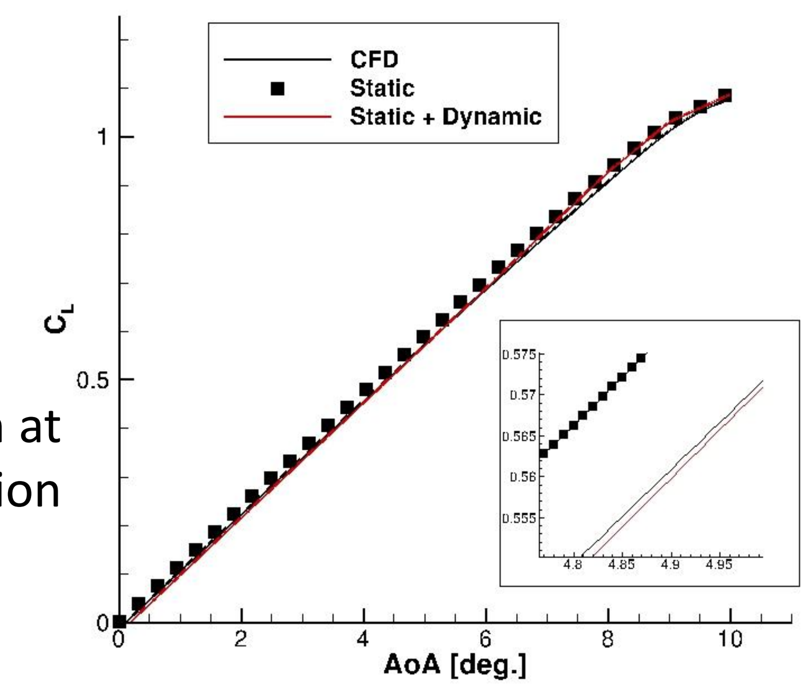
Manoeuvres

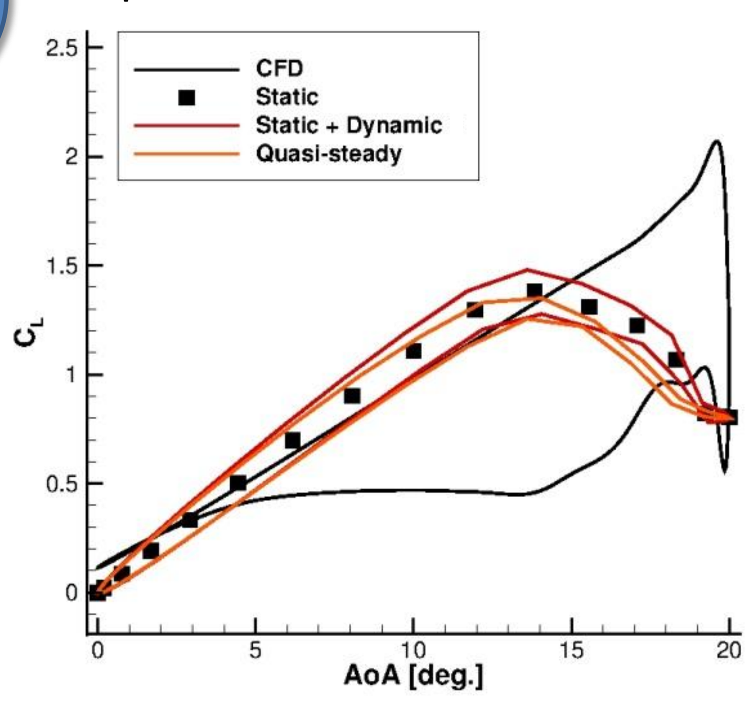
Manoeuvres are run as forced motions whereby the angles and rates of the model are prescribed a priori to determine which terms in the aerodynamic tables are required. As shown in the flow diagram, the loads and moments are determined for each step in the manoeuvre until completion. This method of "flying" the model through the tables is very rapid and requires little computational effort.



Replays vs CFD

To the right is a ramp motion at 10°/s. Dynamic modification improves the solution.





To the left is a dynamic stall case where there is poor agreement with the time-accurate CFD solution but this is expected due to history effects. It is necessary to gain an understanding of when these models are no longer fit for purpose.

Progress

In the project so far, the frequency domain methods have been implemented in TAU and the assessment of the tables and dynamic derivative models is well under way. Two conference presentations have been created from this work and one journal publication under review. Each of these can be accessed at www.cfd4aircraft.com or

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