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# A NUMERICAL STUDY OF FREQUENCY AND AMPLITUDE EFFECTS IN FLOW AROUND AN OSCILLATING NACA AIRFOIL

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Accurate prediction of airfoil performance metrics (lift and drag coefficients) at the design stage of stationary and rotary wings is vital in order to maximise flight efficiency and also for flight controls and avionics. To date, a large number of papers was published, where oscillating (heaving, pitching) airfoils were studied (see for example Yu et al. 2010, Yang et al. 2004, Kang et al. 2009, Lewin et al. 2003). Majority of this research is conducted at low to moderate Re number, oftentimes with focus on Unmanned Aerial Vehicles (UAVs), while some applications require understanding of flow around existing and new airships in design stage destined to fly at in highly turbulent low (chord based Re number > $10^6$).

One of such areas of application is flow over a stabiliser of an airship able to perform a wide range of manoeuvres (i.e. helicopter). The flight path can lead to fluctuations of lift and drag on the stabiliser. For flight controls, an accurate pitch angle setting on the stabiliser must be set to maintain trim of the airship. Often, at the design stage, it is assumed that the lift vs. angle of attack and drag vs. angle of attack characteristics of an airfoil during flight are going to be linear, while in reality oscillations lead to hysteresis.

At the Institute of Turbomachinery a numerical study of pitching oscillation was performed for a NACA 0016 profile, where oscillation frequency, amplitude and initial angle of attack were varied. Alongside, several tests, including dynamic mesh deformation, were made to establish an appropriate methodology to study such phenomena. Figure 1 shows the comparison between various approaches.

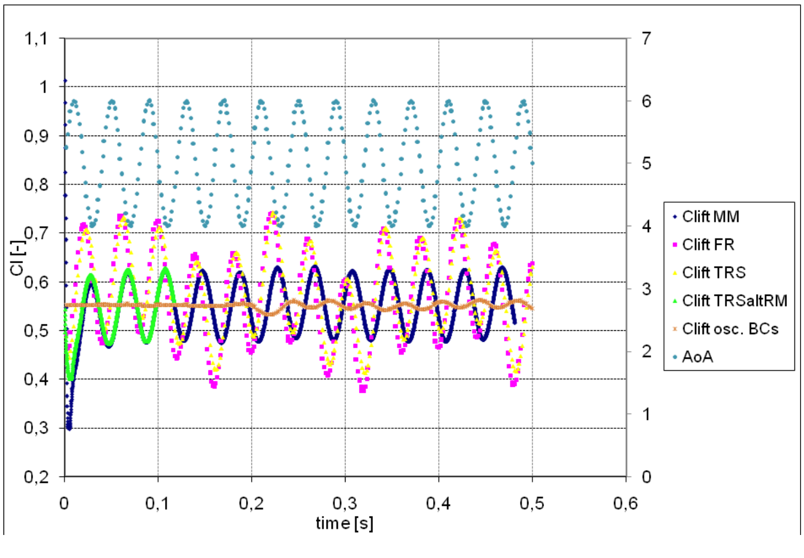


*Fig. 1. Time history of lift coefficient for 5 of the tested model rotation methods*

The work was divided into two parts – computing a steady-state flow past the airfoil for a number of angles of attack (point 1 on the list below), and transient simulations for time-dependent flow with forced oscillations of the airfoil (point 2 on the list). The following configurations were tested (Ma = 0.33 and Re = 7.13x10$^6$ in each case):

1) Static polar : ($\Delta\alpha = 0°$)

sweep on α : 0°, 5°, 10°, 15°, 17.5°, 20°, 22.5°, 25°

2) Time-dependent dynamic polar:

| a) | b) | c) |
|---|---|---|
| αi = 5° | αi = 5° | αi = 10° |
| Δα = 1° | Δα = 0.2°, 0.5°, 1°, 2° | Δα = 1° |
| f = 2, 5, 10, 15, 20, 25 Hz | f = 5 Hz | f = 2, 5, 10, 15, 20, 25 Hz |

The influence of each parameter on the airfoil's aerodynamic characteristics is established, fast Fourier Transform is performed in order to gain insight into frequency domain. Figure 2 presents an example analysis performed for one of the cases studied.

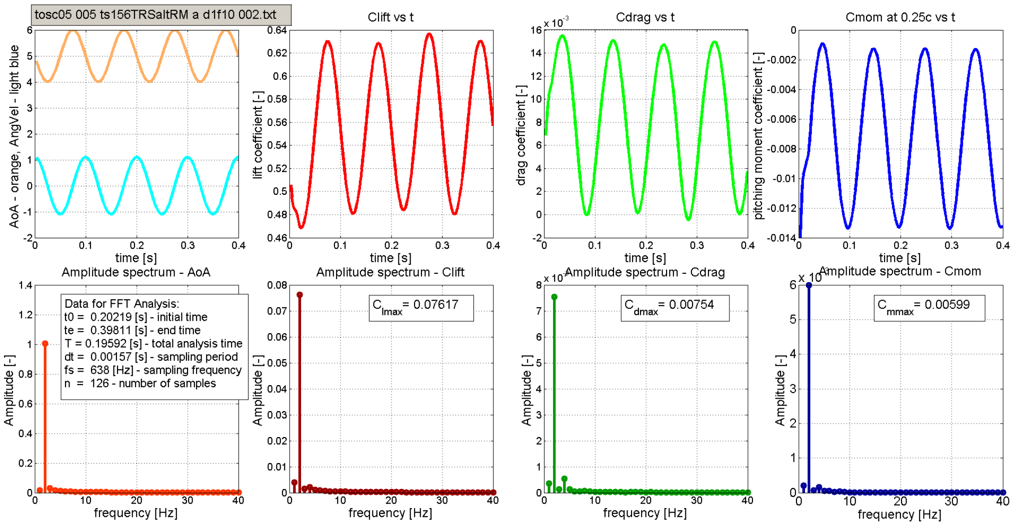


*Fig. 2. Time-dependent simulation of forced oscillations of the airfoil. Cl, Cd, Cm histories along with FFT analysis for last two cycles are presented ($\alpha_i = 5°$, $\Delta\alpha = 1°$, $f = 10$ Hz)*

CFD campaign results show the type of hysteresis between aerodynamic coefficients and angle of attack during forced airfoil oscillations.

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