"COMPUTING FLUID STRUCTURE INTERACTION PROBLEM WITH COUPLED SPECTRAL METHODS "

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Abstract:
This paper deals with fluid-structure interactions (FSI), involving a blade profile. An external excitation at a fixed frequency is applied to the structure, and the effect of the fluid on the damping is studied by analyzing Frequency Forced Response (FFR). In order to predict the dynamic behavior of such system, a fully coupled numerical methodology is developed. On the one hand, to compute the time periodic aerodynamic field, a numerical approach the Time Spectral Method (TSM [Sicot (2009)]) or an analytical model (theory of Theodoresen [Theodorsen (1935)]) is used. On the other hand, the Harmonic Balance Method (HBM [Grolet and Thouverez (2012)]) allows the computation of the periodic response for the nonlinear mechanical structure under external/fluid loading. These two spectral approaches will be coupled in order to reach directly the periodic steady state solution.

Keywords: *vibrations, Fluid Structure Interaction (FSI), nonlinear dynamics, Time Spectral Method (TSM), Harmonic Balance Method (HBM)*

1 Introduction

This model is applied to compute the pitching (α) and pumping (h) motion of the NACA 64A010 airfoil, described in [Isogai (1979)]. The equation of motion is given by (1). α is imposed and the response on h is observed. L represents aerodynamic effects of fluid on the system. It corresponds to the lift. M, C_h and K_h are respectively coefficients of masse, damping and rigidity. $S_\alpha = Mbx_\alpha$ with b the airfoil semichord and x_α the distance of center of gravity behind midchord.

$$M\ddot{h} + C_h\dot{h} + K_h h + S_\alpha\ddot{\alpha} = -L \tag{1}$$

2 Time Spectral Method Validation

To compute the time periodic aerodynamic field, the Time Spectral Method (details of the TSM in [Sicot (2009)]), implemented in the Onera's elsA solver, is used for a fast and efficient resolution. This method relies on a time-integration scheme that turns the resolution of the turbulent Navier-Stokes problem into the resolution of several coupled steady state problems computed at different instants samples of the time period of the movement.

The Theodorsen approach (entirely explained in [Theodorsen (1935)]) can also supply the instationnary lift effort L. Several hypotheses are done such as thin profile, single-harmonic movement, attached boundary-layer, incompressible flow and perfect fluid.

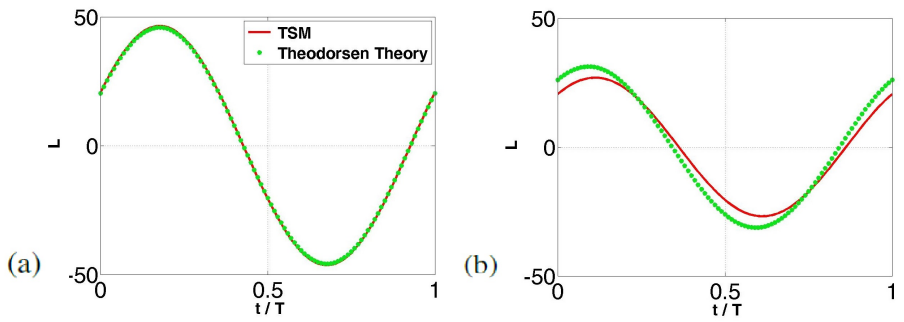

Figure 1: Evolution of the lift during one period for a frequency of 1 Hz (a) or 125 Hz (b).

These two approaches are compared for an imposed movement. Results plotted on figure 1. It shows that the more the frequency increases, the more the fluid behaves as unsteady and therefore Theodorsen's model becomes unsuitable.

3 Frequency Forced Response

A cubic non-linearity is added to equation (1), in order to take into account a rigidification effect of support, which leads to the equation :

$$M\ddot{h} + C_h\dot{h} + K_h h + K_{nl}h^3 + S_\alpha\ddot{\alpha} = -L \tag{2}$$

The solution of this nonlinear dynamic problem is sought here under a truncated Fourier series which coefficients are given thanks to the Harmonic Balance Method [Grolet and Thouverez (2012)] by the resolution of a nonlinear algebraic problem.

HBM and the Theodorsen analytical model are fully coupled such that at each iteration, the model supplies the lift L which is used by HBM as an excitation on the structure and conversely, HBM supplies the displacement field which will be used to estimate de lift by the Theordosen's model. This strategy has the advantage that all computations take place in the spectral domain, allowing thus to find the steady-state behavior of the fluid and the structure without computing any transient state.

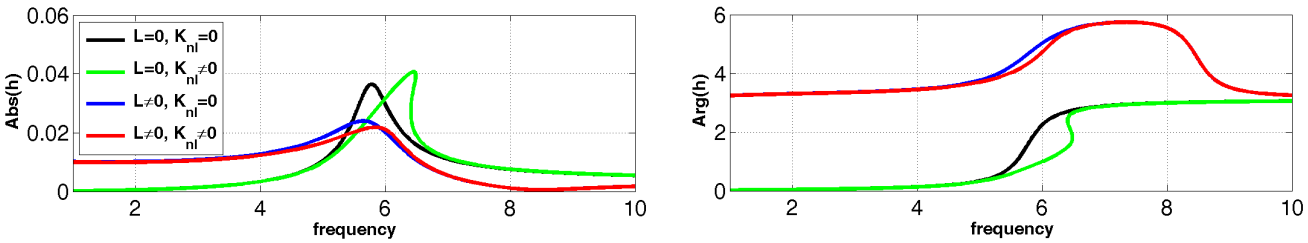

Figure 2: Frequency response of the system (magnitude diagram above, phase diagram below).

Figure 2 presents frequency responses with or without the lift and the cubic non-linearity. h is expressed in millimeter and the frequency in Hertz. It highlights the lift influence on the behaviour of the blade, especially on the non-linear effect and the damping. Non-linearity amplifies the maximum and deforms the response curve. Aerodynamic excitation without the non-linearity damps the response. Aerodynamic excitation with the non-linearity increases slightly the damping and shifts the maximum response.

This coupled methodology has an interest provided that aerodynamic efforts are correct. Their theoretical evaluation, with the Theodorsen model, bases on several hypotheses. As a result, a numerical approach with elsA allows to take into account more phenomena (non-attached boundary-layer, compressible flow and viscous fluid). Therefore, the objective is to develop this coupled approach with a numerical evaluation of aerodynamic forces.

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