Nonlinear reduced order model for vertical sloshing by employing neural networks

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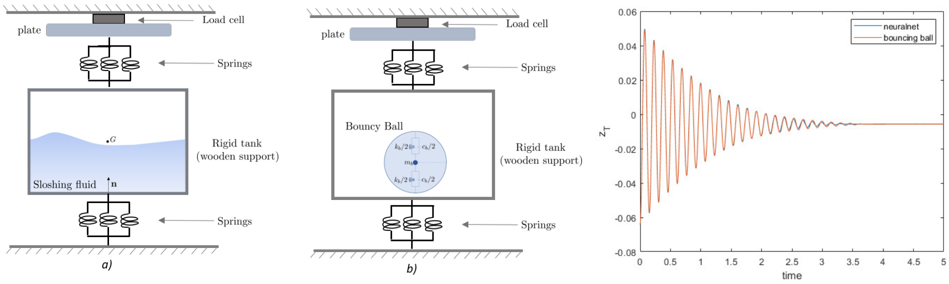
Abstract. The aim of this work is to provide a reduced order model to describe the dissipative behaviour of nonlinear vertical sloshing (involving Rayleigh-Taylor instability) of the fuel inside wing tanks by means of Feed-Forward Neural Network (FFNN). A 1 DoF system is taken into account as representative of fluid structure interaction problem. So far, sloshing has been replaced by an equivalent mechanical model (EMM), namely a boxed-in bouncing ball with parameters suitably tuned with available experiments. The network was trained by using a large design of experiment (DOE), consisting of several virtual experiments with different values of oscillation amplitude and frequency. Indeed, the vertical sloshing forces are highly nonlinear and dependent on the amplitude of oscillation and its frequency content. The obtained FFNN Input-Output model has been included in a Matlab Simulink® environment for closed loop fluid structure interaction simulations showing promising performances.

Introduction

The sloshing phenomenon is caused by the movement of a two-phase fluid inside the tanks. When a tank is accelerated with respect to its equilibrium condition, the resulting internal dynamics of the fluid generates a variation of the pressure field on the internal tank walls. This load causes structural vibrations which produce further perturbations on the tank as well. In this way, the dynamics of sloshing is in turn able to influence the structural dynamics. In particular, the nonlinear sloshing behavior is one of the subject of the European project H2020 SLOWD - SLOshing Wing Dynamics [1] which generally aims at characterizing the internal fluid-structure coupling. The project mainly focuses on the characterization of vertical sloshing, *i.e.* that featured by the so-called Rayleigh-Taylor instability. This type of sloshing provides a significant increase in the damping of the structural time response due to the impacts between the fluid and tank walls. The capability to model this further contribution on structural response given by sloshing may provide positive effects on aircraft design.



(a) Equivalent Mechanical model for vertical sloshing (b) Vertical displacement of the tank

Figure 1: EMM for vertical sloshing (a) and vertical displacement of the tank by EMM (red) and FFNN (blue) (b).

Proposed approach

In this activity the nonlinear sloshing operator is provided with a neural network model to return the vertical sloshing forces caused by the vertical motion of the tank. The use of neural network is getting attention in providing ROM for fluid structure interaction as it was already done for external aerodynamics in Ref. [2]. The proposed model is still in its preliminary stage since it makes use of data from the equivalent mechanical model, *i.e.* the bouncing ball model in Fig. 1(a). Nevertheless, the proposed approach will be exploited also with different data provider, like CFD simulations and experiments. After the network training stage, the neural network block has been embedded in a 1DoF fluid structure interaction environment providing promising results. Indeed, the damping characteristics provided by FFNN are able to fit the simulations provided by EMM, see Fig. 1(b). It is worth to notice that this FFNN model can be generalized for complex structural systems.

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