Applied Dynamics

José Antunes

The activities at Applied Dynamics Laboratory (ADL) are devoted to research in nuclear engineering, with an emphasis in the vibratory and acoustic behaviour of mechanical components. Our group started in 1986, with the following objectives: (1) Develop theoretical methods, computer tools and experimental techniques, to solve structural problems in nuclear power station components; (2) Use this state-of-the-art know-how, in order to solve structural problems arising in Portuguese power plants and other industrial facilities.

The first objective has been pursued through extensive international collaboration with our main scientific partner - the French Commissariat à l'Energie Atomique (CEA) / Département de Mécanique et Technologie (DMT). More than one decade of fruitful collaboration is attested by a significant number of published results. Important problems have been solved, such as nonlinear vibrations in steam-generators, flow-induced vibrations of nuclear fuel and stability problems in rotating machinery. Furthermore, new identification techniques have been developed and applied with success to nonlinear dynamical systems.

The second objective has been pursued by starting in 1990 a series of projects with (and for) the Portuguese power supplier Electricidade de Portugal / Companhia Portuguesa de Produção de Electricidade (EDP/CPPE), stemming from actual structural problems in power plants (Sines, Setúbal): These projects enabled us to model and solve vibratory problems arising in rotating machinery, vibro-acoustical problems in boilers and heat-exchangers, as well as structural identification problems. Several computer codes have been developed in connection with these projects.

In recent years we also developed research projects of more fundamental nature, mainly funded through the Portuguese Science Foundation (FCT) research programmes. These projects have been developed in partnership with several Portuguese institutions (Faculdade de Ciências de Lisboa, Instituto Politécnico do Porto, Instituto Politécnico de Setúbal, Instituto Superior Técnico, Universidade Nova de Lisboa), as well as the Université de Paris, Trinity College Dublin and Southampton University. This work, developed in the context of fundamental physics – in particular addressing problems in music acoustics, optimization and structural geology – is centred in modelling nonlinear dynamics and flow-structure phenomena. The methods developed transcend the context of these projects and may be adapted to solve several aspects of industrial problems.

The Applied Dynamics team is mainly concerned with the following scientific fields: structural dynamics, flow-induced vibrations, nonlinear dynamics, vibro-acoustics, experimental methods, signal processing, system identification, structural and acoustical optimization. As a spin-off from our research activities, teaching has been actively pursued on structural dynamics and acoustics - ranging from university level courses in Portugal (Coimbra, Lisbon) to several post-graduation short courses abroad (Paris, Dublin, Cargèse). Also, student and post-doc training, as well as several university thesis (MSc and PhD) have been successfully supervised, for both Portuguese and foreign students. An extensive book on fluid-structure dynamics and acoustics, co-authored by two researchers from CEA and ITN/ADL was internationally published during 2006 and another volume on flow-induced vibrations is currently under completion, to be released early in 2009.

Among the above-mentioned scientific fields one should stress those features which give this small group a distinct profile from others working in structural dynamics in Portugal. Those features are: (1) a proven expertise and output in flow-excited systems and nonlinear vibrations; (2) a complementary theoretical/experimental approach for every problem.

Most of the research projects pursued at ADL have been based on both industry and academic research contracts. Research activities at ADL were internationally recognized by two prizes from the American Association of Mechanical Engineers (ASME).

Research Team

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Flow-Induced Vibrations of Tubular Nuclear Components

J. Antunes, X. Delaune[1], P. Piteau[1], L. Borsoi[1]

Objectives

Flow turbulence excitation is a well-known source of structural vibrations, often leading to failures due to fatigue or wear problems. In the context of nuclear facilities, such problems must be addressed with a particular care, for obvious safety reasons, but also due to the increased difficulties of problem-fixing in a radiation-active environment. At ITN/ADL, in close cooperation and under contract with CEA-Saclay, we gained a significant expertise in this area, both theoretically and experimentally. This long-ranging project, now starting its third year, is aimed at the development of up-to-date software to compute the flow-induced vibrations of nuclear components such as fuel rods or steam-generator tubes, due to the turbulence of both axial and transverse flows. Nonlinear vibro-impact and rubbing phenomena between the tubular components and their supports (accounting for gaps and pre-charges) are incorporated in the nonlinear time-domain computational models, in order to enable realistic predictions. Such computations supply the dynamical row data necessary for designing the multi-supported rods and tubes.

Results

During 2006 and 2007, two successive versions of our computer program were developed, the later version incorporating substantial improvements on the time-domain turbulence model, in order to accommodate the important case of local excitations due to non-uniform flow velocity profiles. Substantial original developments have been produced, in order to generate consistent sets of uncorrelated random point-forces to simulate the action of partially correlated turbulence force fields. Our effective computational strategy leads to mathematically exact results if the excitation profile is uniform, or to a negligible error for localized excitations (Figure 1). Furthermore, we proved that the system modal excitations are uncorrelated for uniformly distributed flows, but become strongly correlated for localized flows (Figure 2). Such results are significant when addressing turbulence-excited vibratory responses. A conference paper on these findings has been accepted for presentation and a journal paper is currently being prepared. During 2008, turbulence-excitation issues will be further refined, and the problem of identification of gap-support nonlinearities from remote response measurements will be addressed.

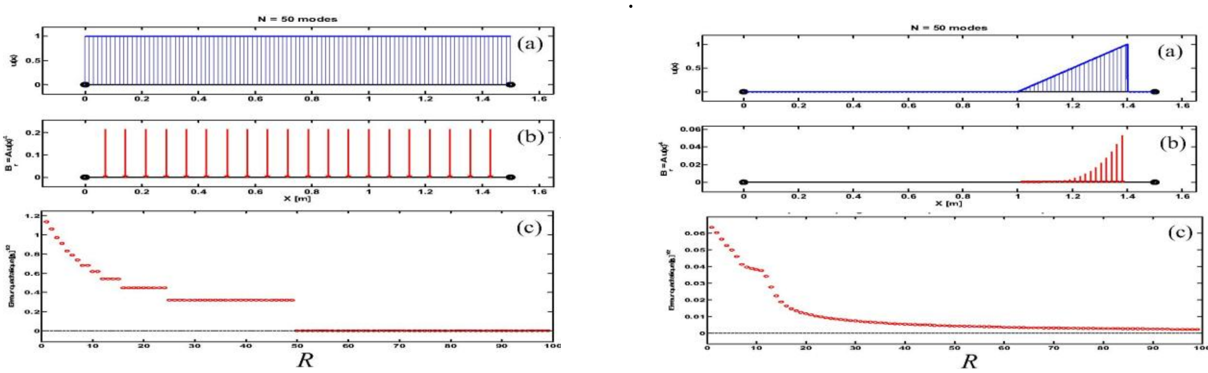

Fig. 1. Uniform and localized velocity profiles – Convergence of the modal excitations as the number of equivalent excitation point-forces increases.

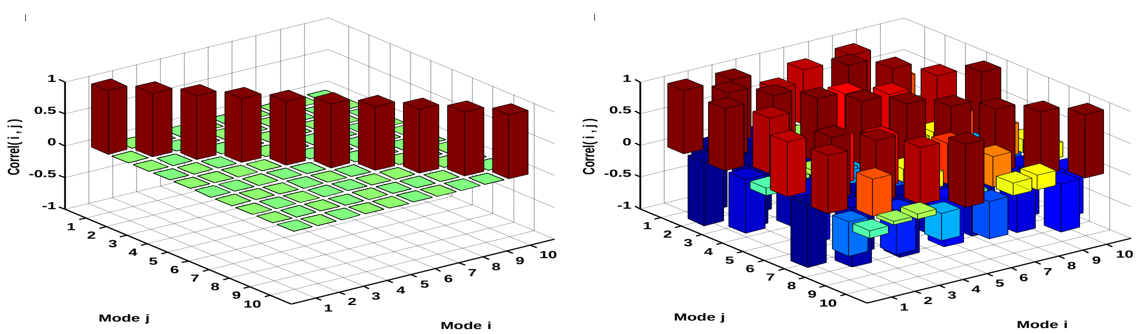

Fig. 2. Uniform and localized velocity profiles – Correlation matrices between the turbulence-generated modal forces.

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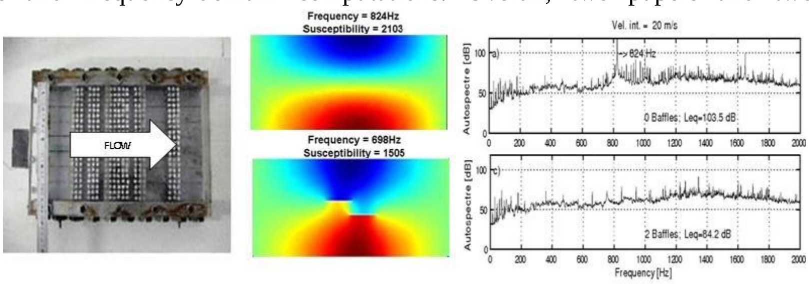
Optimization of the Noise Reduction in Tubular Heat Exchangers

M. Moreira, J. Antunes,V. Debut, H. Pina[1], J. Paulino

The interaction between a gaseous flow and the tube banks of heat exchangers can lead to the self-excitation of acoustic resonances. These lead to high-amplitude pressure fluctuations inside the equipment, with the consequent vibratory excitation of structural elements. When the frequencies of the excited acoustic modes near-coincide with the modal frequencies of tubes, high vibratory levels can seriously affect the system integrity. This problem only arises in gaseous heat exchangers, since the typical sound speed in liquids lead to acoustical frequencies typically beyond those of the structural component vibrations. To the present date, in spite of the industry concern by this problem, the physical mechanisms of sound excitation of by cross-flows within tubular banks are not yet fully understood, therefore the available criteria for predicting such flow-acoustic instabilities are not trustfully. Typically, this problem is solved by inserting plates inside the tubular banks (so-called acoustic baffles), in order to inhibit the acoustical instabilities by modifying the acoustic field. However the physical mechanism that renders a given baffle configuration effective or not is still insufficiently known and controversial. The objective of this three years project, funded by a FCT/POCTI grant, is to increase our understanding of the relevant physical mechanisms of aero-acoustic instabilities, and to develop techniques for optimizing the acoustic baffle configurations.

Following the theoretical work developed in previous years, wind tunnel experiments have now been conducted to validate a simplified numerical model of the vortex-excited acoustic field coupled with efficient global optimization methods (simulated annealing and genetic techniques) for the optimal configuration of a given number of acoustic baffles. These experiments suggested an improved form for the optimized functional, results which are currently under publication. Also, additional analytical and experimental work has been developed and published on a closely related problem of industrial interest – the acoustic self-excitation of corrugated pipes under axial flow – leading to an interesting nonlinear phenomenological aero-acoustic model of such systems, time-domain numerical simulations and frequency-domain computations. Overall, two papers and two conference communications were produced from our recent work in this field. Physical understanding of the complex phenomena will be further acquired in the future, by developing suitable CFD computing tools.



Theoretical and experimental results on the aeroacoustic noise induced by wind-tunnel flow across the tube bundles of a power station re-heather model : (1) Reduced scale test model; (2) Acoustical pressure mode shapes of the unstable mode respectively without and using two optimized baffles; (3) Corresponding measured noise spectra.

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Dynamical modelling of nonlinear vibratory and acoustical systems

J. Antunes, O. Inácio, M. Wright[1]

This research started some years ago as a POCTI funded project, an international cooperative effort to develop theoretical methods and numerical techniques for dealing with strongly non-linear dynamical problems, such as involving impacts and friction phenomena. The main objective was the development of modeling techniques for nonlinear multi-modal structures. These techniques have been applied to a paradigmatic problem in nonlinear physics – bowed instruments – but it is mostly triggered by industrial problems of the same nature.

In previous years we developed efficient numerical techniques to predict the nonlinear dynamics and interaction forces of friction self-excited systems. Such detailed computations have been complemented by a strong focus on the linearized analytical models of friction-excited systems. We addressed the case of friction-excited bars and derived a single relevant parameter which controls self-excitation as a function of the contact normal force, sliding velocity and the Coulomb friction law. We then performed extensive parametric analysis from efficient eigenvalue computations of the linearized model, leading to dynamical charts which enable a more clear understanding of the nonlinear limit-cycle regimes. Three papers have been produced from the results obtained.

These techniques where recently extended to the case of bowed strings, with many results published during 2007, and also started theoretical developments to tackle the difficult theoretical problem of predicting the linear instability of friction-excited shells, which is particularly relevant for the understanding of brake squeal phenomena, an effort which will be pursued during the next year. A PhD thesis encompassing our findings of the last years is to be presented at Southampton University early in 2008.

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