# Applied Dynamics

## Introduction

The research activities of the “Applied Dynamics Laboratory” (*ADL*) started in 1986, with the following main objectives:

- Develop *theoretical methods*, *computer tools* and *experimental techniques*, to solve structural problems in *nuclear power station* components;
- 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 were solved, such as nonlinear vibrations in steam-generators, flow-induced vibrations of nuclear fuel, as well as stability problems in rotating machinery. The second objective has been pursued by starting in 1990 a series of projects with (and for) the portuguese power supplier “Electricidade de Portugal (EDP)”, 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 heat-exchangers, as well as structural identification problems.

From the previous statements, one may conclude that the *ADL* is mainly concerned with the following scientific fields: *structural dynamics, flow-induced vibrations, nonlinear dynamics, vibro-acoustics, experimental methods, signal processing and system identification.* As a spin-off from the research activities at *ADL*, teaching has been actively pursued on *structural dynamics* and *acoustics* — ranging from university level curses in Portugal (Coimbra, Lisbon) to several post-graduation short curses abroad (Paris, Dublin). Also, student training and university thesis (Graduation, MSc and PhD) have been successfully supervised at *ADL*, for both portuguese and foreign students.

During 1998, several research projects were pursued — namely, “Rotor-flow interaction”, “Remote impact identification”, ”Experimental modal analysis”, “Nonlinear modeling and dynamics”, as well as a PhD thesis on the “Identification and simulation of complex systems using stochastic optimization methods”. Furthermore, we started two new projects, concerning the “Dissipative Phenomena in Two-Phase Flow” and the “Optimization of Acoustic Baffles in Heat Exchangers”. These projects are almost entirely founded by external partners. Research results have been published in wide-audience journals and international meetings.

## Research Team

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|---|---|
| Researchers – | 1 ( PhD) |
| Research Students – | 4 (1 PhD and 1 MSc students, 2 Graduate students) |
| Undergraduate Students – | 3 (*) |
| Technicians – | 1 |

(*) These students were funded using resourses from ADL contract work.

## Publications

| | |
|---|---|
| Journals – | 2 + 2 in press |
| Proceedings – | 2 |
| Special Publ. – | 1 (Lecture notes) |
| Reports – | 6 |

$10^3$ PTE

| **Expenditure:** | **5 316** |
|---|---|
| Missions: | 2 601 |
| Other Expenses: | 1 972 |
| Hardware & Software: | 547 |
| Other Equipment: | 196 |

$10^3$ PTE

| **Funding:** | | **3 777** |
|---|---|---|
| External Projects: | 1997 | -473 |
| | 1998 | 4 250 |

# REMOTE IMPACT IDENTIFICATION

## Remote Identification of Impact Forces on Multi-Supported Tubes

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**Abstract**
Flow-induced vibration of heat-exchanger tube bundles and nuclear fuel is an important issue, concerning both component life and plant availability. Predictive methods have been developed to analyze the vibratory responses and wear, for realistic multi-supported configurations and flow excitations. There is a need for identification techniques that enable the diagnostic and field monitoring of tube-support interaction under real operating conditions, using information from motion transducers located far from the impact locations. This is a very difficult problem, due ill-conditioning of the inverse problem, and also to the severe noise contamination of the measurements. In three papers, we successively have developed techniques, based on response measurements at remote locations, for the experimental identification of the flexural wave-guide propagation parameters and for recovering the impact forces.
Numerical simulations and experiments were presented, for *isolated impacts (1)* as well as when the tubes display very *complex rattling* motions *(2)*. Recently, we have developed a new technique to deal with multi-supported systems. An iterative multiple-identification method is introduced, which operates in an alternate fashion between the time and frequency domains. This technique proved to be effective in isolating the impact forces generated at each gap support *(3,4)*. Experiments show a good agreement between direct force measurements and the remotely identified impact forces. Currently, we are developing algorithms for the blind identification of the impact forces, which use constrained inversion techniques for the identification, without using any specific information concerning the physical properties of the propagation path *(5)*.

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*(1) Journal of Sound and Vibration, Vol. 215, pp. 1015-1041 (1998).*
*(2) Journal of Sound and Vibration, Vol. 215, pp. 1043-1064 (1998).*
*(3) Paper presented at the ASME Pressure Vessel and Piping Conference, S. Diego, USA, July 1998. To appear in ASME Journal of Pressure Vessel Technology.*
*(4) Commissariat à l'Energie Atomique, Report CEA/DMT/98-27/A (1998).*
*(5) Paper accepted for presentation at the SMIRT conference, Seoul, Corea, August 1999.*

# EXPERIMENTAL MODAL IDENTIFICATION

## Program ALADIN

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**Abstract**

An essential step in the diagnosis of most vibratory problems is the modal analysis of the vibrating structures or machine components. Very often, theoretical methods (such as the finite element method) must be complemented — or even replaced — by the experimental identification of the system modes. This is a common problem, because important structural data or end-conditions, which are essential for analysis, are unknown or ill-defined. Hence, specific methods and software must be developed to cope with the need for experimental modes.

Program *ALADIN* has been developed under contract for the portuguese power supplier EDP/CPPE. The computer code was developed, several identification algorithms were implemented, using both time-domain and frequency-domain vibratory data. The bulk of programming was performed during 1996/7. However, debug work, documentation *(1,2)* and experimental validation was achieved in 1998. A working version of the program was delivered to EDP/CPPE, for field tests and user training. Currently, *ALADIN* is being used with success by EDP/CPPE engineers for modal identification of their power-station machinery.

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*(1) Instituto Tecnológico e Nuclear, Report ITN/ADL-Jun98-1 (1998).*

*(2) Instituto Tecnológico e Nuclear, Report ITN/ADL-Jun98-2 (1998).*

# ROTOR-FLOW INTERACTION

## Theoretical Modeling of the Nonlinear Motions of Immersed Rotors

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**Abstract**

Rotor vibration under moderate fluid confinement is an interesting problem, in connection with several important practical applications, such as immersed pumps (of fast-breeder reactors) and oil drilling machinery. For the geometries under consideration here — with a moderate reduced gap — inertial effects are very important to the rotor-flow dynamics. This behavior contrasts with small-gap configurations, such as found in bearings and seals, where dissipative effects are dominant. In previous papers, the authors presented simplified theoretical models for both centered and eccentric systems, as well as extensive experiments on such systems. In those theoretical works, rotor dynamics were modeled using flow equations which were linearised on the gap-averaged fluctuating quantities.

More recently, a fully nonlinear model was developed for the specific case of high-amplitude planar motions *(1)*. This nonlinear approach has been further extended to cope with nonlinear orbital motions, using a rather involved theoretical formulation *(2,3)*. Preliminary experiments showed that the nonlinear terms of the flow enable better predictions of the rotor-dynamics at high spinning velocities, when approaching and beyond the instability boundaries. These very encouraging results apply to both planar and orbital nonlinear motions. New experiments, with a different flow configuration and a better experimental set-up, are currrently being completed, in order to fully assert the validity of the new theoretical models.

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*(1) To appear in Journal of Fluids and Structures.*

*(2) Paper presented at Jornadas de Matemática, Instituto Politécnico de Lisboa, October 1998.*

*(3) Paper submitted for presentation at the ASME Pressure Vessel Conference, Boston, USA, August 1999.*

## Current Work

# Identification and Simulation of Complex Systems

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**Abstract**
At the present time, a number of methods exist to identify the physical parameters of linear and non-linear systems. Concerning non-linear problems, these methods range from Volterra/Wiener series to parametric methods of the ARMA (Auto-Regressive Moving-Average) type. Most of these methods are very time-consuming and/or do not easily enable physical insight. Therefore, in the context of a PhD thesis, we started at *ADL* a project in this field, which is important to tackle many problems in applied dynamics. Specifically, we are focused on very some promising nature-inspired identification and simulation techniques — neural networks and genetic methods — coupled with stochastic optimization methods such as simulated annealing.
During 1998 we concentrated on the physical modeling of a specific nonlinear problem of practical interest, suitable for testing the performance of various identification techniques. We started developing simplified analytical models for the nonlinear dynamics of squeeze-films subject to the vibratory motions of perforated plates. This unsolved problem is relevant for predicting the impacting behavior of nuclear fuel bundles, under severe excitations. At the present time, we have already obtained an analytical solution suitable for plates with regular perforations *(1)*. An experimental set-up is being designed to validate our theoretical efforts.

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*(1) Instituto Tecnológico e Nuclear, Report ITN/ADL (in print).*

# Optimization of Acoustic Baffles in Heat Exchangers

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**Abstract**
A couple of years ago we solved severe problems in the 250 MW units at a portuguese power plant (Setúbal), which were plagued by abnormal vibrations and noise arising in the oil-fired boilers at specific burning regimes and flow rates. Field tests enabled the diagnosis of a transverse acoustic mode instability, in the boiler re-heater — which was experimentally confirmed by computations. Although the details of the coupling mechanism are not always clear, it is usually believed that energy is extracted from the steady flow as a result of the coupling between periodic shedding induced by the tubes and the modal acoustic fluctuations, most often in connection with modes which are transverse to both the tubes and the main flow. Several criteria exist to predict the possible occurrence of acoustic instabilities in tube banks. Typically, such problems are solved by installing acoustic baffles inside the tube banks. Indeed, these passive devices may prevent acoustic instabilities without costly hardware modifications.
The popular view is that acoustic baffles are effective because they "break" the acoustic pressure field — which imply significant changes in the acoustic modal frequencies and a detuning effect. However, when attempting to fix acoustic problems in operating units using only a few baffles, these are often ineffective. Indeed, for realistic bank configurations, finite element computations show that most acoustic modal frequencies are not significantly changed when typical staggered baffles are installed. Therefore, we believe that the effectiveness of a given baffle configuration is mainly dependent on how such device decreases the coupling between flow excitation and the acoustic pressure field. The mechanisms of acoustic energy transfer and dissipation in heat exchangers are quite complex. Presently we are developing a theoretical-numerical method to chose optimal baffle configurations, among a set of options, using simple physical assumptions and a stochastic optimization technique. This approach already produced encouraging results *(1)*.

*(1) Submitted for presentation at Internal Conference on EAHE, Prague, August, 1999.*