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:

- 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 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 (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.

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 and system identification.* As a spin-off from our research activities, 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, for both portuguese and foreign students.

Among the above-mentioned scientific fields one should stress those features which give our group a distinct profile from others working in structural dynamics in Portugal. Those features are:

– A proven expertise and scientific output in problems connected with flow-excited systems and nonlinear vibrations;
– A complementary theoretical/numerical and experimental approach for each and every problem tackled at ADL.

There are no nuclear power stations in Portugal. However, past experience proved beyond doubt that the Applied Dynamics Laboratory is an active contributor at international science level, as well as a versatile problem-solving unit for domestic industrial partners. Therefore, the previously stated objectives remain our motivation and driving force. In spite of ADL extremely scarce permanent staff, we managed to attract motivated students and scientific collaborators from other institutions, which are essential for our activities. Beyond the close partnership with CEA, our work has been developed in collaboration with other Universities and Research laboratories, both in Portugal (IST, UNL, FCL, INESC, IPS, IPL, ENIDH) and abroad — France (ESPCI, Paris), Ireland (Trinity College, Dublin), England (Southampton University) and Greece (University of Tessalonika).

As in previous years, several research projects were pursued at ADL during 2000, most of them being funded by research contracts. We recently concluded the project **"Remote impact identification"** (CEA funding), which provided many interesting results. We pursued several other projects: **"Optimisation of rotor balancing"** (EDP funding), "**Structural identification of machinery under working conditions**" (Praxis XXI funding), "**Modelling of vibration-controlled encapsulation**" (PROENOL funding), "**Simulation and identification of complex dynamic systems**" and "**Dynamical modelling of nonlinear systems".** Funding for the last mentioned two projects has been recently granted under the Sapiens programme.
The average time-scale of ADL projects is 2~3 years. Several PhD thesis are being prepared in connection with them.

Research Team

Researchers

José Antunes, PhD, Researcher (**Group Leader**)

Technicians

- Álvaro Anastácio (Technician)

Visiting researchers/students

- Luis Henrique, Assistant Professor, IPP, Porto, **PhD** student (UNL)
- Martins Paulino, MSc, Invited professor, ISEL, Lisbon, **PhD** student (UNL)
- Miguel Moreira, MSc, Assistant professor, IPS, Setúbal, **PhD** student (IST)
- Octávio Inácio, MSc, Invited professor, IPP, Porto, **PhD** student (Southampton University)
- Rui Sampaio, MSc, Assistant Professor, ENIDH, Lisbon

Publications

Journals:	3
Conf. Communications:	7
Internal Reports:	5

Funding

	$\times 10^3$ PTE
Research Projects: [(a)]	7276
TOTAL:	7276

(a) $\times 10^3$ PTE

- Adaptative Noise Reduction for Industrial Applications (ANRIA) (PRAXIS/P/EEI/13176/98) (Oct. 1999-2001) (ITN/2800 × 10^3 PTE)
  Project Co-ordinator: **C. Martins** (INESC), Partners: ITN (**José V. Antunes**), ENIDH (R. Sampaio), INESC (M. Piedade), INETI (E. Ataíde),.. 1120
- Optimisation of Rotor Balancing (Contract ITN/EDP) (Dec.1999-Dec.2001) (ITN/ 8000 × 10^3 PTE)
  ITN/Co-ordinator**: José V. Antunes**, Partners: ISEL (M. Paulino), EDP (J. Soares), UNL (F. Urgueira) 1600
- Modelling of Vibration-Controlled Encapsulation (Contract ITN/PROENOL) (ITN/1500 × 10^3 PTE) (Oct. 1999 - Oct. 2000)
- ITN/Co-ordinator**: José V. Antunes,** Partners: ENIDH (R. Sampaio), IPS (M. Moreira), Proenol (M. Fátima) 1500
- Remote Identification of Impacts (Contrat SAV 25134/VCH) (1998-Nov. 2000) (ITN 9000 × 10^3 PTE)
  ITN/Co-ordinator**: José V. Antunes**, Partners: CEA/Saclay... 3056

Remote Identification of Impacts

J. Antunes, M. Paulino[1], P. Izquierdo[2], T. Grunenwald[2]

Objectives

Our aim is to develop methods for the identification of impact phenomena inside critical components through signal processing of vibratory measurements from transducers at remote locations. This is to avoid placing force transducers under severe environmental conditions (space, temperature, radiation). This study is of particular significance for condition-monitoring of wear-prone components, such as heat-exchangers, and also as a tool for the analysis of ageing industrial facilities. The later aspect is of particular relevance for nuclear power facilities. This is a very difficult problem, because the interesting signals are often immersed in high noise contamination from many sources.

Results

Our past work in this field mainly concerned about wave-propagation modelling techniques. During 2000 we further explored how the so-called "blind" identification methods can be usefully applied to the remote identification of spiky impact forces. These methods were originally developed in very different fields (geophysics and communications) to enable the identification of impulsive signals *without any information on the dynamics of the propagation path*. Blind deconvolution techniques seem extremely interesting for the problem of impact identification, because they avoid any explicit modelling of the system.

We extended the Wiggins/Donohe blind deconvolution algorithm (the so-called minimum entropy method), to enable the effective use of simultaneous response measurements. This technique uses higher-order statistics of the multiple data in order to enable the identification of the impulsive sources. The developed identification method was validated experimentally, with effective results in many practical cases (see reference 1). However, under heavy background noise, a certain degradation is unavoidable. Blind identification techniques may be of particular significance when dealing with complex structures.

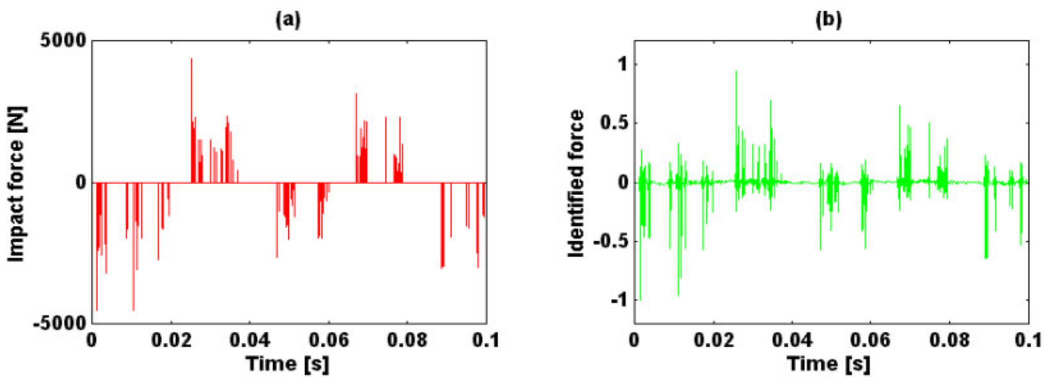
An international prize was awarded by the American Association of Mechanical Engineers (ASME) in 2000 to distinguish some of our published results in this project (Paulino, M., Antunes, J., Izquierdo, P., Remote Identification of Impact Forces on Loosely Supported Tubes: Analysis of Multi-Supported Systems, *ASME Journal of Pressure Vessel Technology* **Vol. 121** (1999) pp. 61-70).

Published (or in press) work

[1] Antunes, J., Izquierdo, P., Paulino, M., Blind Identification of Impact Forces from Multiple Measurements, ASME International Mechanical Engineering Congress, Orlando, November 5-10, 2000, *International Journal of Nonlinear Science and Numerical Simulation*, in press.

Further work

Although our CEA contract is now completed, we intend to further pursue this fascinating subject, as time allows, in order to clarify several pending important issues (namely: impact scaling, optimal inverse filter length, identification of simultaneous impacts).



Blind identification of an impact force from the system response at a remote location:
(a) Exact impact force; *(b)* Identified force.

[1] Instituto Superior de Engenharia de Lisboa (ISEL).
[2] Commissariat à l'Energie Atomique (CEA), Saclay, France.

Optimisation of Rotor Balancing

J. Antunes, M. Paulino[1], J. Soares[2]

Objectives

Balancing is one the most common and important tasks currently performed on all rotating machinery. Because the traditional way of rotor balancing (using influence coefficients and many test runs) is very time-consuming and costly, our aim is to optimise these operations. Therefore, we depart from standard procedures and are developing a new method which will enable balancing of flexible rotors at a fraction of the cost and time. If successful, our approach will be of great interest in many industrial facilities. However, this is definitely not an easy task. This project has been recently started under contract for the portuguese power supplier (EDP/CPPE), with an expected duration of two years. A PhD thesis was started in connection with this project.

Results

Following preliminary work to convince the portuguese power supplier EDP/CPPE that better methods should be attempted, we pursued during 2000 a innovative balancing technique developed at ADL, for which encouraging preliminary simulation results have been obtained. A test rig has now been designed and built, in order to test the performance and weaknesses of our approach [1-3]. If successful, the new balancing method will later be tested on a power plant.

Internal Reports

[1] Antunes, J., Paulino, M., Optimal Balancing of Flexible Rotors: 1 - Theoretical Analysis Using the Method of Influence Coefficients and Some Important Generalisations, ITN/ADL Report, December 2000.

[2] Paulino, M., Antunes, J., Soares, J., Optimal Balancing of Flexible Rotors: 2 – Experimental Laboratory Validation of Methods Based on Influence Coefficients, ITN/ADL Report, December 2000.

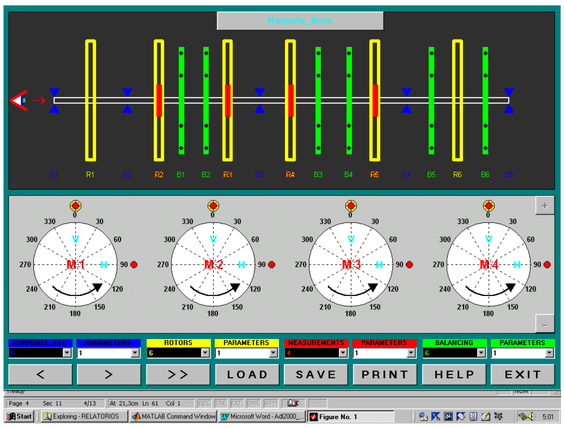
[3] Antunes, J., Paulino, M., Optimal Balancing of Flexible Rotors: 3 - Theoretical Development of a New Optimised Modal Method, ITN/ADL Report, December 2000.

Further work

The contract work for the next couple of years will consist in improving and experimentally validate our current ideas, both in laboratory and in field tests. Furthermore, if successful, our approach will be converted in a user-friendly computer program for field balancing.

(a)

(b)



Development of balancing procedures at ADL:
(a) Acquisition system and experimental rig; *(b)* Balancing program SPIN.

[1] Instituto Superior de Engenharia de Lisboa (ISEL)
[2] Electricidade de Portugal (EDP/CPPE)

Structural Identification of Machinery under Working Conditions

C. Martins[1], J. Antunes, R. Sampaio[2], M. Piedade[1], E. Ataíde[3]

Objectives

Modal identification of machinery is usually performed by testing components under controlled conditions. Therefore, measurement of the test forces and vibratory responses are usually achieved when the plant is not working. If vibratory problems arise, production must be stopped in order to diagnose what is going wrong. Because this is obviously very costly, the aim of this project is to develop new methods of modal testing without the need to stop the machinery. A working plant is an extremely noisy environment, so this is a difficult problem. This project, in collaboration with INESC, ENIDH and INETI institutes, is funded under the Praxis XXI research programme.

Results

A laboratory test model has been designed and build (reference 1), enabling the experimental validation of various signal processing techniques developed by the partners in this project. The signal cleaning/separation methods developed at ADL are based on signal modelling and extrapolation techniques, in order to extract the useful signals from the measurements contaminated by environmental noises. During 2000 we focused on several signal identification techniques, including Pisarenko decomposition, cepstral methods and nonlinear iterative signal reconstruction. These are currently being tested under experimental conditions.

Internal Report

[1] Sampaio, R., Antunes, J., Vibratory Experiments on ADL/PRAXIS Test Model, ITN/ADL Report, March 2000.

Further work

Future work will address development of new algorithms for signal separation from single and multiple transducers, and experimental testing of the signal cleaning methods under laboratory and field conditions.

[1] INESC, Lisbon.
[2] Escola Nautica Infante D. Henrique (ENIDH), Lisbon.
[3] INETI, Dep. Electronics, Lisbon.

Simulation and Identification of Complex Dynamic Systems

J. Antunes, M. Moreira[1], H. Pina[2]

Objectives

Complex dynamical systems, which present high-order dynamics and/or a nonlinear behaviour still present considerable challenges for both simulation and identification purposes. Nature-inspired computation methods, such as simulated annealing or genetic methods show considerable promise to deal with such problems.

The aim of this project is to apply stochastic optimisation methods to dynamical problems of interest to industrial components. As a test problem, we chose to work on rotor-flow coupled vibrations, which is a problem with strong nonlinear effects. Our group has considerable experience in this area.

This is a project in collaboration with two portuguese engineering schools, IST and IPS, in the framework of a PhD thesis. It has recently been funded under the Sapiens programme.

Results

During 2000 we extended our previous formulations of rotor-flow dynamics in order to deal in a more adequate manner with nonlinear and dissipative flow effects [1, 2]. These new formulations have been confronted with experimental results with reasonable success [3]. Furthermore, an automatic method for generating a system of nonlinear ODEs from the original Navier-Stokes equations, using a Galerkin/spectral approach, has been developed with success for planar vibrations of immersed rotor systems [4].

Published (or in press) work

[1] Moreira, M., Antunes, J., Pina, H., A Theoretical Model for Nonlinear Orbital Motions of Rotors Under Fluid Confinement, *Journal of Fluids and Structures* **14** (2000) 635-668.

[2] Moreira, M., Antunes, J., Pina, H., An Improved Model for Rotors Subject to Dissipative Annular Flows", *7th International Conference on Flow Induced Vibrations (FIV 2000)*, Lucerne, 19-21 June 2000. (Accepted for publication in *Journal of Fluids and Structures*).

[3] Moreira, M., Tissot, A., Antunes, J., Experimental Validation of Theoretical Models for the Linear and Nonlinear Vibrations of Immersed Rotors, *International Journal of Rotating Machinery,* Vol. 7, pp. 1-14, 2000. Also in *8th International Symposium on Transport Phenomena and Dynamics of Rotating Machinery (ISROMAC-8)*, Honolulu, March 26-30, 2000.

[4] Moreira, M., Antunes, J., Pina, H., A Symbolic-Numerical Method for Nonlinear Rotor Dynamics Under Fluid Confinement, *ASME International Mechanical Engineering Congress*, Orlando, November 5-10, 2000. (Accepted for publication in *International Journal of Nonlinear Science and Numerical Simulation*).

Further work

Future work will focus on further theoretical aspects of this nonlinear system, including limit cycles and bifurcations, dimension-reduction techniques, as well as flow computation schemes based on stochastic techniques.

Experimental validation of rotor-dynamic predictions.

[1] Instituto Politécnico de Setúbal (IPS).
[2] Instituto Superior Técnico (IST), Lisboa.

Dynamical Modelling of Nonlinear Systems

J. Antunes, L. Henrique[1], L. Borsoi[2], V. Gibiat[3], O. Inácio[1]

Objectives

This on-going project of fundamental nature is an international co-operative effort to develop theoretical methods and numerical techniques to deal with strongly nonlinear dynamical problems. From our experience, techniques developed in music acoustics can be and have been adapted with success to control vibrations in industrial facilities. This is a field with great potential for the development of effective simulation and identification techniques.
Indeed, control and understanding of self-excited regimes are the main objectives when musical instruments are addressed. In contrast, one is only happy to avoid vibratory and acoustic instabilities in industrial problems. Therefore, the level of physical understanding demanded by sound production instruments is usually higher than in typical industrial problems. A PhD thesis was started in connection with this project, which has recently been funded under the Sapiens programme.

Results

During 2000 we refined our computational method for simulating the dynamics of a paradigmatic nonlinear system — the bowed string — which present a number of difficulties also encountered in industrial problems (friction forces, self-excited vibrations). Our simulation technique, based on a nonlinear modal approach, can now deal effectively with multiple contact points, as well as other difficulties.

Extensive computations have been performed, enabling a clear visualisation of the frictional bow/string interaction forces, as well as many periodic and some chaotic motion regimes [1-3]. This is a system with extremely rich dynamics.

Published (or in press) work

[1] Antunes, J., Tafasca, M., Borsoi, L., Simulation des Régimes Vibratoires Non-linéaires d'une Corde de Violon, *Revue Française de Mécanique*, pp. 193-202, Septembre 2000. Also in *Symposium sur Analyse Vibratoire Non-Linéaire sur Base Modale,* Paris, 25-26 Janvier 2000.

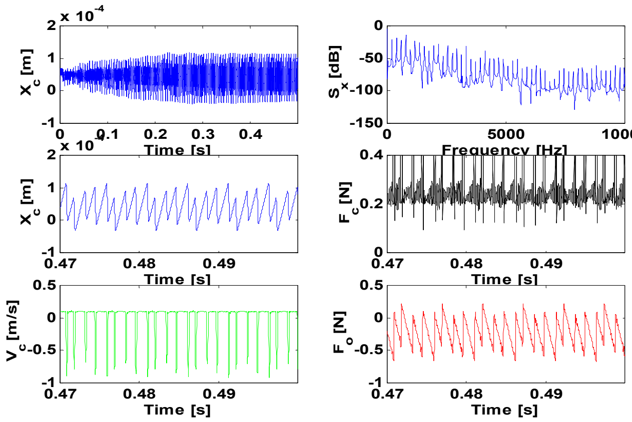
[2] Antunes, J., Tafasca, M., Henrique, L., Simulation of the Bowed-String Dynamics: Part 1 – A Nonlinear Modal Approach, *5ème Conférence Française d'Acoustique (CFA 2000)*, Lausanne, 3-7 Septembre 2000.

[3] Tafasca, M., Antunes, J., Henrique, L., Simulation of the Bowed-String Dynamics: Part 2 – Parametric Computations", *5ème Conférence Française d'Acoustique (CFA 2000)*, Lausanne, 3-7 Septembre 2000.

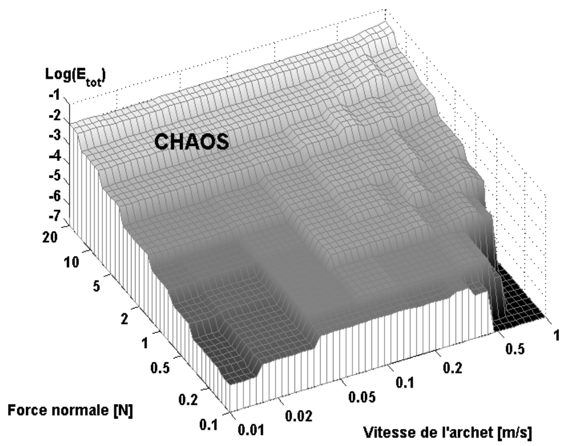
Further work

Future work will include the experimental validation of the above-mentioned techniques for system simulation. Similar techniques will be developed for wind instruments, in the framework of the above mentioned research contract.

(a)



(b)



Numerical simulations of the bowed string:
(a) Sample computation of a multiple stick-slip Helmholtz regime;
(b) Motion energy as a function of the bowing parameters.

[1] Instituto Politécnico do Porto (IPP).
[2] Commissariat à l'Energie Atomique (CEA), Saclay, France.
[3] Ecole Nationale Supérieure de Physique et Chimie (ESPCI), Paris.