Chapter 27
Around the World in 80 Courses

David Ewins

Abstract This paper summarises the genesis and evolution over 30 years of a series of short courses on Analytical and Experimental Structural Dynamics. In total, more than 120 of these courses have been presented in more than 20 countries. In the early days, the courses were specifically focussed on teaching the basic techniques and applications of the then-new subject of Modal Testing (or Experimental Modal Analysis). Later came the need for more advanced and complex capabilities in some of the more demanding tasks, and especially in the more challenging applications to which the modal test results were to be subjected. The major changes in information technology that have taken place in this 30-year period have resulted in some significant changes in the style and content of the courses. Most recently, the 'courses' have turned more towards developing a full integration of the experimental, numerical an theoretical skills that combine to make the complete Structural Dynamicist – that rare individual who knows, above all, that solving problems in structural dynamics hinges on being able to ask the right questions. The answers can usually be found in text books and scientific papers. Not so the questions. Learning how to formulate these requires practice and experience and this is best passed on in courses.

Keywords Courses • Structural dynamics • Philosophy • Modal analysis • Education

27.1 Genesis

The 'birth' of Experimental Modal Analysis coincided with another phenomenon which has become very familiar to most engineers: that of the Short Course. Not surprisingly, then, short courses (1–5 days) on Modal Analysis or Modal Testing have become very popular and an effective way of bridging between the classical Vibrations courses taught to most undergraduates and the real world of actual engineering structures: namely, the need to measure how they vibrate and to predict and control such behaviour.

The particular suite of courses that are the subject of this paper grew out of research some 50 years ago which addressed the complexities of vibration of real engineering structures which, as is mostly the case, were actually an assembly of several components, often of disparate form and composition, that constituted machines vehicles or other structures. Specifically, interest was focussed on two industrial applications where vibration represented (and still does) a major concern as regards reliability and integrity of critical engineering products. One was machinery installed on board a ship (Fig. 27.1) where the transmission of vibration and sound throughout the vessel and thence radiated into the surrounding sea was a major concern and the other was concerned with the integrity of a store mounted on the side of helicopter (Fig. 27.2). In both these applications, some form of mathematical model was required in order to describe the various structural dynamic features in such a way as to be able to control then and thus to contain them within acceptable limits. In the period of those projects (the 1960–1970s), mathematical models were hard to come by, and very limited in capacity when created. As a result, it was more commonplace to rely on measured data to describe the required vibration properties, even though this is inaccurate and incomplete. At least it represented how the actual structure was really behaving. In effect, the methodology adopted in those

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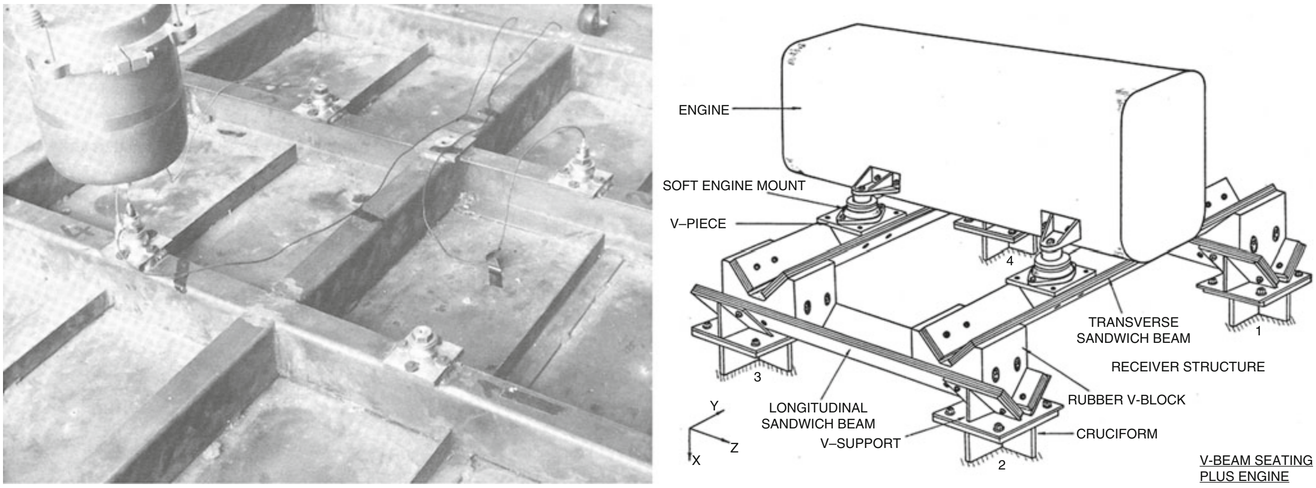

Fig. 27.1 Early attempts to analyse the dynamics of a highly complex structural assembly of shipboard equipment

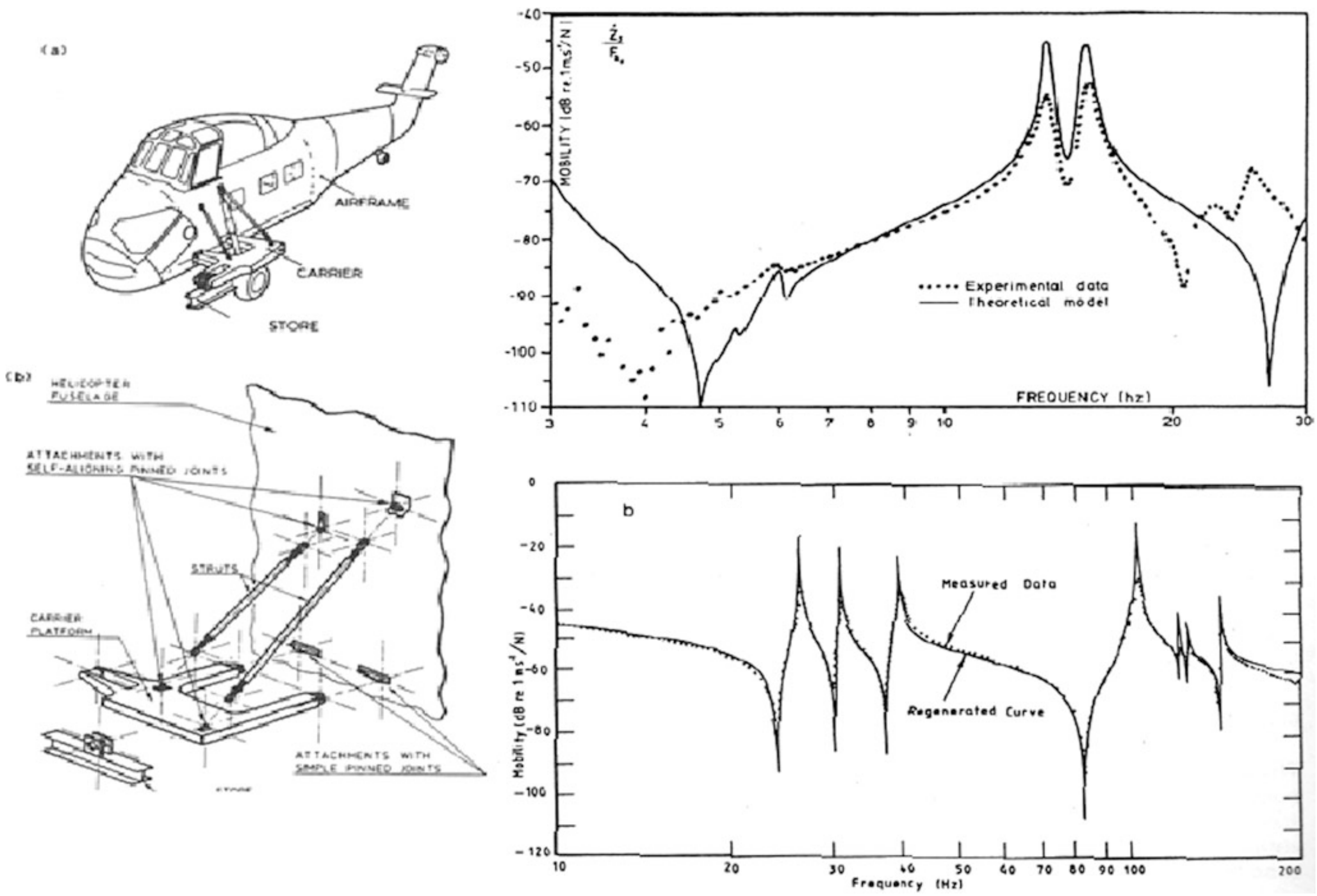

Fig. 27.2 Combined theoretical-experimental generated mode of helicopter dynamic response analysis

days was to construct simple mathematical models from theory wherever possible and to formulate mathematical models from measured data where the necessary theoretical descriptions were unavailable. This approach to the engineering needs, in effect, gave birth to modal testing, or experimental modal analysis that is so widely practiced today, although it was often referred to as the 'impedance method' approach rather than experimental modal analysis that quickly became the norm.

27.2 First-Generation Courses on Modal Testing

There was a need for courses that could combine the classical theoretical treatment of vibration of systems and structures, with the corresponding measurement techniques that were usually undertaken as they represented the only way of gaining any useful insight into the critical characteristics of many engineering structures. The first such offering by the author was presented in Shanghai, in 1982, unknowingly foretelling the international ("around the world") nature of the many subsequent courses that have now been visited on some 20 countries spanning six of the seven continents. The first 'deliberate' Modal Testing course was given in the USA in 1983, followed by others the following year, also in the USA. The first course in the UK was not until 1985.

The history of the individual courses of is not of interest here. Rather, the structure and format is relevant as it evolved through experience is perhaps worth mention because it became the foundation for teaching the subject today – three decades on. The main ingredients were: (i) Theory of SDOF and MDOF systems, with a strong emphasis on **both** the free vibration (modal) behaviour and the forced vibration (FRF) characteristics; (ii) Measurement and testing techniques, as applied to real engineering structures, and (iii) Analysis techniques, primarily for extracting useful information about the makeup of the structures based on measurements of its dynamic behaviour. These three key fundamental tools were supplemented by a synthesis process that sought to combine the theoretical and experimental descriptions of a structure's dynamics into a single model, for subsequent use and, lastly, by a number of applications to which the assembled model can be put to the benefit of the designer or user of the structure(s) itself.

All this information was collected for presentation first as a book [1], whose chapters simply follow this list of five main themes, and as a typically 3-day course in which the subject matter is delivered, slice by slice (not chapter by chapter) in such a way that the interdependence of the different parts of the process of modelling, measurement and interpretation is emphasised. Typically, the sequence would be:

Theory-1; Measurements-1; Theory-2; Measurements-2; Analysis-1; Theory-3; Analysis-2; Synthesis (Modelling); Applications; ..Advanced methods (as dictated by the persistent discrepancies between theory and practice). . .

. . . supplemented with demonstrations and exercises to illustrate the main points through practical examples. Suddenly, three days have passed!

27.3 Underlying Philosophy of Models for Structural Dynamics

As mentioned above, the destination of most of these studies was almost always the construction of some form of mathematical model that would allow the user to extend their knowledge of how the structure would vibrate under different circumstances – both under different loading (excitation) conditions and/or when selected physical changes had been made to the original structure by adding mass, or stiffness or damping, for example. It is appropriate now to describe what is meant by 'mathematical model', and in particular from the perspective of the teacher of the subject who wants to instil in the pupil the necessary understanding and philosophy of the concepts involved essential to understand the physics as well as the maths. In general, a mathematical model is defined by a set of equations which describe the dynamic behaviour of the subject structure. Not surprisingly, there is more than one type of model and three different versions are in regular use in structural dynamics: (i) Spatial, (ii) Response and (iii) Modal. A **spatial model** is one which describes the structure's relevant properties in terms of their distribution in space: i.e. the geographic distribution of mass, stiffness and damping and the interconnections of these elements at and between junctions. It is what the structure 'looks like' and we can influence this directly by changing individual masses thicknesses, etc. etc. A **response model** is one which describes the structure's dynamic properties in terms of set of response characteristics – most commonly, the FRF properties, but any other formal response characteristic will suffice. The response model describes how the structure 'behaves' in a response sense, and is a direct measure of the performance of the structure from a vibration perspective. The response is what we want to be able to predict and to control but we cannot adjust this quantity directly: we can only change the spatial model elements. So, the relationship between the spatial and the response models is what most structural dynamics analysis is all about. The third type of model is the **modal model,** a 'virtual' model which is an intermediate form sitting between the spatial and the response models and providing a very convenient means of communicating between these two 'real' models. These three models are illustrated in Fig. 27.3. The usual 'Analysis' activity in Structural Dynamics seeks to predict the response behaviour of the subject structure by defining its spatial model and solving the equations of motion to a given input excitation loading. The usual 'Test' activity consists of measuring response characteristics of a test structure and seeking to infer from these measurements the underling spatial model properties with a view to changing these in order to bring about an improvement in the response behaviour. The modal model provides a very efficient way of communicating between these two primary models.

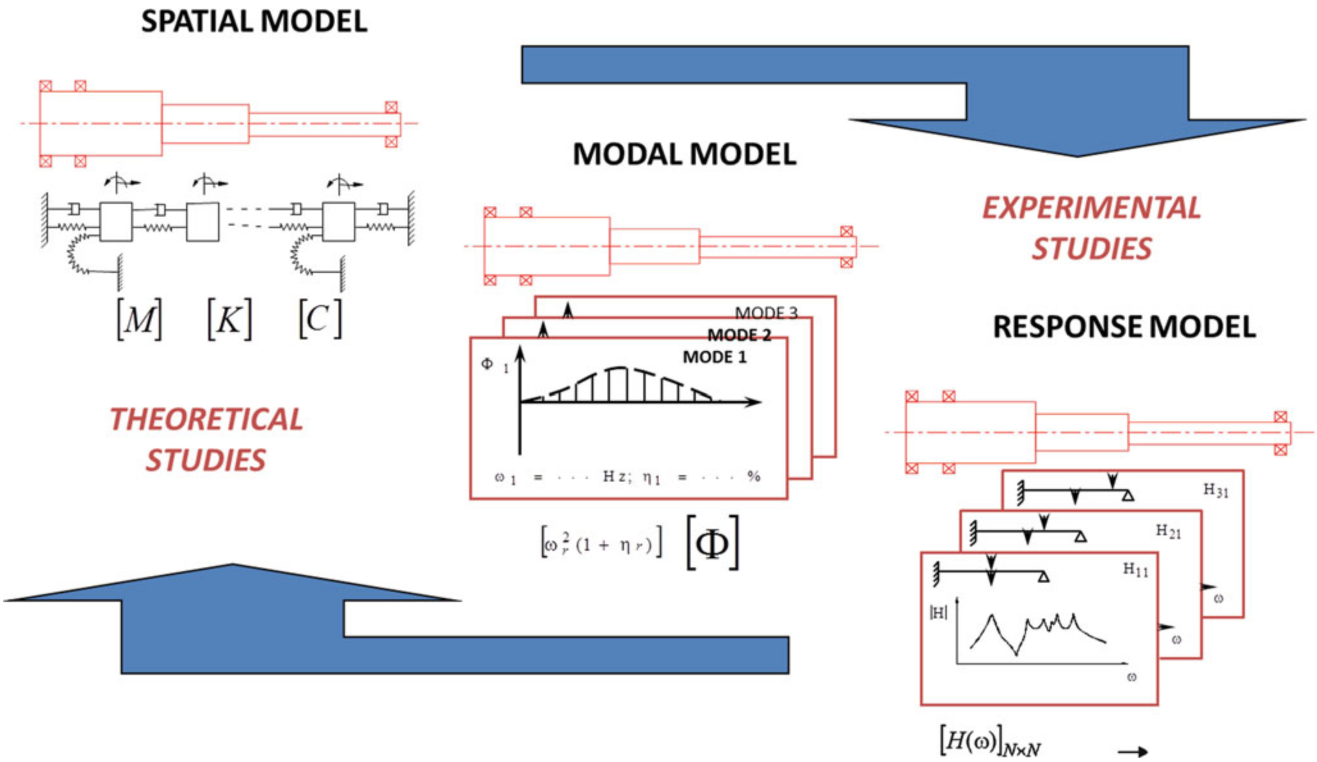

Fig. 27.3 Types of model used for structural dynamic studies

A full grasp of this underlying philosophy is essential to the student of structural dynamics who seeks to design and maintain machines, vehicles and structures which are subjected to dynamic loads.

27.4 Future Needs and Trends for Next-Generation Courses in Structural Dynamics

The preceding paragraphs describe the aims and the form of a suite of courses that have been delivered for more than 20 years. What next? The underlying subject matter that needs to be taught and (more importantly) learned has not changed much. There are some more advanced topics but essentially, the basics are still the same. Perhaps what is changing is the context in which the material needs to be taught (and learned). In fact, what started out as a course for Modal Testing (or EMA) has now evolved into one on the broader, and complete, subject of Structural Dynamics

The conventional wisdom is that what is needed is an improved modelling capability. We need better (more reliable, cheaper) models with which to design and to maintain through monitoring and diagnostics engineering products with greater reliability and resilience to the dynamic loads that are imposed on all machines and vehicles. At first sight, this approach suggests that the future is in 'Analysis' with less emphasis on 'Test'. However, it is not as simple as that! There are three primary skills (tools) which are distinct but mutually interdependent: (i) Theoretical Modelling, (ii) Numerical Analysis and (iii) Experimental Measurement. Modern structural dynamics requires an integration of all three. Figure 27.4 shows the trio of basic skills. Alongside, Fig. 27.4 shows how the three basic skills are used in combinations to provide the technologies of (a) Simulation, (b) Identification and (c) Validation which together provide the capabilities required to address and resolve most structural dynamics problems encountered today. This construction is more complex than the simpler 'Test' versus 'Analysis' scenarios that are often cited, and is thought to be more realistic of the real situation. It is important here to note the central role played by experimental measurement activities.

In the identification process, ***experiments*** are the basis for observing, understanding and thereby modelling the increasingly complex physics that we need to describe in our models. At the other end of the design process, ***tests*** are the means of checking or 'validating' the predictions that are the result of simulations (modelling plus computation). Even later in the life cycle of these products, ***measurements*** are the basis for monitoring and diagnostics that will keep the products in effective service throughout their life. A full set of experimental procedures is shown in Fig. 27.5: clearly experimental methods will continue to play an essential role in structural dynamics and so need to be embedded in modern courses on the subject.

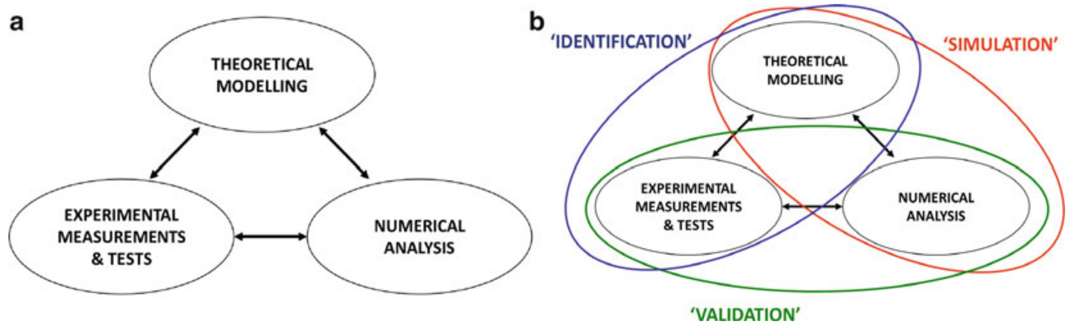

Fig. 27.4 (**a**) The three basic skills required for structural dynamics studies and (**b**) the three main procedures that are carried out

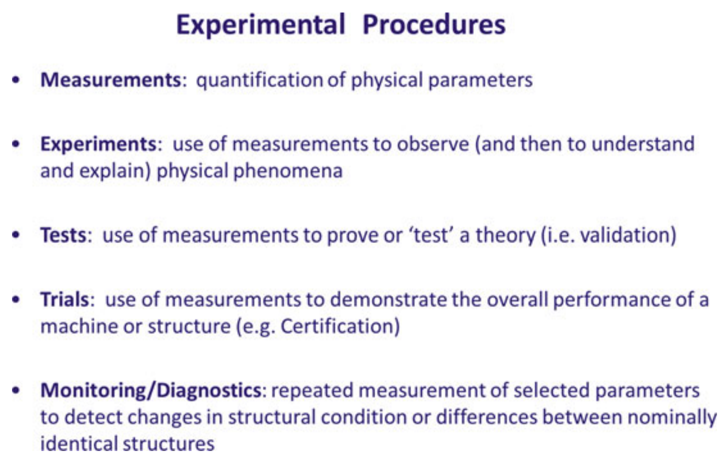

Fig. 27.5 The different types of experimental measurement activities involved in structural dynamics

27.4.1 Subtleties and the Questions

The future need is for ***valid*** models. 'Valid' means 'good enough' – not perfect, not too good, but good enough. This requires a definition of what is good enough followed by methods to test if a model is good enough and, if not, then to improve/update it so that it is good enough – i.e. how to **validate** it.

At this stage, it is important to consider more thoroughly the different types and sources of deficiency that determine whether a model is valid or not. There are essentially two types of deficiency to be considered. The first arises from the use of inaccurate data in the modelling procedure: incorrect values of the various parameters that comprise the model, perhaps resulting from errors in measured data or assumed data. The second, and more serious deficiency, is the omission of parameters that are relevant but which may be assumed to be unimportant or, simply, ignored. Such omissions can be of physical elements themselves, or the degree of complexity with which individual elements are described. A classic example of this latter situation is the oversimplification of a non-linear characteristic by a simple linear representation. A model which is deficient in this way, by incompleteness of the parameter set, is more seriously limited in its usefulness and cannot generally be validated. Both of these limitations – often referred to as Variability and Uncertainty – must be addressed and corrected. These are the subject of validation and verification, respectively.

These issues may seem to be subtleties, but they can differentiate between models which are fit for purpose – good enough – for the increasingly stringent demands placed on structural dynamics analysis today, and those which are not good enough. The means to answer these questions are to be found in the theoretical and experimental tools mentioned above. The ability to ask the right questions comes from experience and effective teaching of the subject. Verified? Validated? Uncertainty? Variability? Linear or Nonlinear?

Reference

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