PREFACE

The use of slender or thin-walled construction in aeronautical, space, civil, maritime and offshore structures, necessitates the need to consider their stability under compressive loads. A number of case histories exist which attribute structural failure to buckling. These include the collapse of silos, bridges still under construction, oil platforms and structural failure of aircraft operating beyond their design ultimate loads. In most cases, the desire to utilise this form of construction arises from the need to minimise weight. This is the primary objective in the development of aircraft structures where a light airframe leads to reduced payload costs which, in turn, minimises environmental impact. The emergence of carbon-fibre composites, with their superior specific weight and stiffness, has greatly contributed to the development of even lighter structures. New generations of aircraft are utilising an increased level of this material in their primary structure and the possibility of developing postbuckling primary composite aerostructures paves the way for the development of very lightweight airframes. Composites also have the added advantage that they do not corrode and have excellent fatigue properties compared to metals.

This book brings together a number of established researchers in the field of structural stability and presents the state-of-the-art. An emphasis is placed on the structural stability of composite structures. Despite their obvious advantages, their anisotropic nature, coupled with a relatively weak through-thickness strength, present numerous challenges to the structural analyst. It will be shown that more sophisticated tools are required to characterise their structural response. The results of a number of experimental programmes are also presented which enhance our understanding of stability phenomena and serve as a valuable database for validating numerical and analytical models.

In the design of plate structures, it has been known for decades that a metallic plate, suitably supported along its edges, may be designed to carry load beyond initial buckling. Further demonstrations followed whereby thin-skinned panels, with stiffeners attached, were shown to be capable of sustaining load beyond initial skin-buckling. In the 1980s a number of papers were published highlighting the same postbuckling load-carrying capability in thin-skinned composite structures with stiffeners co-cured, co-bonded or secondary bonded onto the skin. Most of these experimental studies were conducted under uniaxial loading and a number of numerical studies, using the finite element method (FEM), were undertaken to predict their structural response.

Chapter 1 builds on this experimental database by presenting the results of a new experimental programme where curved stiffened composite panels, which are arguably more representative of wing or fuselage sections, are loaded in compression until failure. Torsion boxes, constructed from two of these stiffened panels, mounted on aluminium side panels, are also tested in compression, torsion and combined loading. This work formed part of a large European Union funded programme. In Chapter 2, experimental results on stiffened cylindrical shells under loading conditions similar to those used on the boxes in Chapter 1 are presented. Indeed, this work also formed a part of the same research programme and together these two chapters present a wealth of experimental results which yield valuable insight into the postbuckling response of thin-skinned composite structures and may be used reliably in the validation of analytical or computational models.

In Chapter 3, the observed phenomenon of 'mode-jumping', where highly postbuckled structures undergo secondary instabilities beyond initial buckling, is discussed and the difficulties that this poses to standard nonlinear finite element solution schemes are highlighted. A numerical methodology is proposed which combines aspects of quasi-static implicit and pseudo-transient schemes. This is shown to be robust and capable of predicting mode-jumping with good accuracy.

The central aim of Chapter 4 is to provide less conservative guidelines for the design of imperfection-sensitive composite shell structures. A similar experimental procedure to Chapter 2 is followed whereby geometric imperfections are measured on a set of composite shells which are subsequently tested in compression and combined compression-torsion loading. These measured imperfections are used to determine a manufacturing-process-specific imperfection signature for the shells.

Chapter 5 also deals with stiffened composite structures. A number of curved stiffened panels, with different lay-up, dimensions and material system to the ones presented in Chapter 1, are tested in uniaxial compression. The challenges presented to numerical analysis support the concerns raised in Chapter 3 and a nonlinear finite element solution strategy, using commercially-available finite element software, is presented. Collectively, the first five chapters attest to the interest in characterising the structural behaviour of thin-walled stiffened structures which predominate most advanced composite airframe construction.

The anisotropy associated with composite materials is hardly ever exploited and is often seen as a hindrance in the design of composite structures. This is partly due to the added analytical complexity which must be dealt with even at a preliminary design stage. In Chapter 6, buckling and postbuckling formulae are derived for anisotropic plates and shells which demonstrate the structural efficiency that may be gained by utilising this anisotropy. These expressions are particularly useful at a preliminary design stage prior to the use of numerical methods for detailed analysis and design. The use of genetic algorithms and a finite-strip buckling analysis program to optimise the buckling load of stiffened composite panels is presented in Chapter 7.

Tubes and pipelines find widespread use in engineering applications across scales ranging from millimetres to kilometres. Their susceptibility to local buckling, when subjected to bending or external pressure loads, is demonstrated through the non-linear finite element method in Chapter 8. Both metallic and composite tubes and pipelines are considered and the problem of delamination in composite tubes under external pressure is discussed at some length.

Chapter 9 presents a mixed variational finite element formulation for the modelling of imperfection-sensitive spherical caps subjected to an external pressure load. The results obtained from the numerical modelling are validated using a comprehensive experimental programme where initial geometric imperfections on thin membrane polymer caps were measured prior to loading.

The use of sandwich construction, where metallic (or, indeed, composite) face sheets are bonded onto a softer core, are being increasingly utilised in the design of advanced lightweight structures. Chapter 10 deals with the complex global and local instabilities which may arise in such structures. Instabilities in these types of structures are also investigated in Chapter 13.

In Chapter 11, boundary element method (BEM) formulations for the analysis of the buckling and postbuckling of plates and shells are explained. This provides an alternative numerical approach to the more established traditional one of using the finite element method. A special feature of the BEM presented, is its ability to model nonlinear problems and still retain its boundary only modelling philosophy.

Chapter 12 presents a progressive failure analysis of compression-loaded composite structures where a novel approach for accounting for fibre microbuckling, a highly localised instability which leads to structural failure, is presented. Highly localised instabilities in cellular materials, at the micro and meso levels, are modelled in Chapter 13 using detailed finite element analysis. This chapter shows how instabilities at the micro level propagate to create instabilities at higher levels leading to structural failure at much larger length scales.

In developing this book, we have endeavoured to ensure that enough introductory material was included in each chapter to make it accessible to a wider readership. Engineering graduates new to this field can gain an overview of our current understanding of structural stability and the strategies being adopted to model this behaviour. Researchers, academics and practicing engineers who are familiar with these issues will find it useful as a comprehensive reference text encompassing the latest developments in the field.

We are eternally grateful to all contributors who have displayed great enthusiasm for this book. Their prompt response to our numerous e-mails and phone calls over the past couple of years, the willingness of some to meet us and discuss their chapter contributions whenever they were passing through London, or indeed, when either of us were crossing their paths in other parts of the world is deeply appreciated.

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