CHAPTER 1
INTRODUCTION

1.1 INTRODUCTORY REMARKS

Analysis and prevention of buckling in aircraft structures has been a concern to the aeronautical engineers ever since the invention of the aeroplane. Although Euler (15) solved the problem of buckling in eighteenth century its application became significant when engineers started using slender members of metal in aircraft construction. Since then there have been considerable developments both in theoretical abilities to analyse buckling problems as well as in the types of construction adopted in aircraft structures. A wide variety of problems has been solved by eminent scientists and solution methods ranging from classical differential equation to modern Finite Element Techniques have been established. These developments were necessitated by the evolution of stressed skin concepts and composite materials design philosophies changed from merely preventing buckling to design and optimize for maximum buckling strength. The advent of computers and software made it possible for the designers to consider buckling as a major design consideration. The use of composite materials has posed new challenges for research.

1.2 COMPOSITE STRUCTURES

Composite structures which are made up of more than one material have found widespread application in various fields of engineering such as aerospace. Since lamination
allows the designer to tailor the directional strength and stiffness of the material to suit the loading conditions of the structural element, laminated composite plates have received wider attention. Due to the inherent capability to tailor the mechanical properties of these materials many unique design features such as high strength to weight ratio, high specific stiffness, improved performance increased service life, reduced system maintenance and active controlled configuration of the structures can be utilized. The term "composite" (47) has various meanings in literature. It is often used to denote layered plates where each layer is made up of anisotropic material whereas "sandwich" construction typically is used to describe a plate having a core material which separates relatively thin face sheets of higher modulus material. In the present work "composite" is made up of layers (or laminates or plies) each ply being composed of straight parallel fibres (e.g. Glass, Boron, Graphite etc) embedded in and bonded together by a matrix material (eg Epoxy resin). Each layer is assumed to be a homogeneous orthotropic material having a value of \( E \) considerably greater in the longitudinal direction (\( E_L \)) than in the transverse direction (\( E_T \)) but the longitudinal axis of adjacent laminae are generally not parallel.

1.3 DESIGN PRACTICE

In the design of aerospace structures a variety of problems involving buckling is encountered. Table 1.1. shows a
The engineer is primarily concerned with ensuring that the structure does not fail by any form of buckling. The usual method in a design office is basically based on data sheet approach. In the following sections typical problems of instability in aircraft structures are discussed.

**COLUMNS**

Thin walled curved/straight open section tubes are used in aircraft structures as a reinforcing member in ribs, floor supports, control systems etc. These are mostly tubes made from the sheet metal with open sections. Buckling failure of these members may be due to local, flexural, torsional or coupled modes. Generally local modes are kept higher than the overall modes. Other problems commonly encountered are columns on multiple elastic supports, compound columns and beam columns. These columns do buckle at very low values of stress but the structural engineer was able to exploit the enormous "post buckling strength" (sometimes four to five times that of initial buckling strength).

**PLATES**

The flanges of spars, bulkheads and webs of spar etc. loaded in compression and shear are treated usually as plates. The well known classical theory of buckling leads to typical formula.

\[ \sigma_{cy} = KE \left( \frac{t}{b} \right)^2 \]  

(1.1)
where \( K \) is the coefficient depending on support conditions and the nature of loading.

Again the buckling of panels are in any one of the following modes.

1. Local buckling
2. Buckling of Skin between supports
3. Buckling of Skin and Stiffener
4. Inter rivet buckling
5. Wrinkling
6. Crippling

In general the panels are generally subjected to both compression and shear.

**SHELLS**

Fibre reinforced shells such as cylindrical panel is a typical structural component which is used in aerospace structure such as Ariane 4 interstage. Buckling of shells is a grey area. Leissa (47,48) has given a comprehensive survey on the work done in the past on buckling of cylindrical shell panels. The discrepancies which exist between experimental findings and theoretical predictions are very large. Hence efforts are being devoted for understanding the problem of composite shells. Moreover the shells are imperfection sensitive structures and the buckling very much depends on these imperfections and sometimes "snap through" buckling occurs. In addition all metallic material used in aircraft construction exhibit plasticity.
1.4 METHOD OF SOLUTION AND SOFTWARE

There are three different situations in which nonlinear analysis is required.
The structure loses stability at limit point
The structure loses stability at bifurcation point
The structure loses stability at bifurcation point but imperfection sensitive,

Formulation and discretization of nonlinear structural analysis problems lead to a set of nonlinear algebraic equations of the form

\[ F(q, \lambda) = 0 \]  

(1.2)

where \( \lambda \) is a load parameter and \( q \) a solution vector. These problems can be handled by a) eigenvalue approach b) beam-column approach. Eigen value problem assumes that there is no imperfection and at buckling load structure jumps from unstable configuration to stable configuration. Wilson's Subspace Iteration is used to solve such problems. On the other hand beam-column approach traces the load deflection path taking into account the initial imperfection. The solution procedure is based on the minimization of total potential energy implementation in conjunction with an iterative method such as Newton-Raphson or Riks/Wempner method(68).

1.5 OBJECTIVES AND SCOPE OF THE INVESTIGATION

1. To derive the equations for a thin-walled curved beam of open cross section
2. To develop a simple finite element model by modelling the
curved beam with straight elements to solve the buckling of thin-walled curved beams of open cross section made of composite materials.

3. To develop flexural and geometric stiffness matrix for composite plates using 16 BFS element and to solve for buckling of composite plates.

4. To solve for buckling of composite axi-symmetric shell using degenerated shell element.

5. To determine the optimal configuration of a composite shallow shell on any ground plan subjected to any type of loading using Boundary Integral Element Method.

6. To develop the software for buckling of thin-walled curved beams, plates and shells made of composite materials.

1.6 OUTLINE OF CONTENTS

Chapter 2 deals with the important characteristic behaviour and modelling of composite materials and the properties of some composites are tabulated.

Chapter 3 discusses the curved beam equations derived using the principle of virtual work.

Chapter 4 describes various finite element models used for solving curved beams.

Chapter 5 presents the static analysis of thin-walled curved beam of open cross section made of composite materials.

The buckling analysis results for thin-walled curved beam is presented in Chapter 6.
Finite Element Static analysis of layered composite plates is discussed in Chapter 7.

Various geometrically nonlinear formulations of layered composite materials are presented in Chapter 8.

The results of buckling of layered composite plates are given in Chapter 9.

The finite element formulation for static analysis of the degenerated axisymmetric shells of revolution is given in Chapter 10. The shape functions for cubic elements are also given. Some numerical problems are solved and compared with the available results.

Chapter 11 discusses finite element formulation of layered axisymmetric shells (made of composite material) of revolution. Some numerical examples are solved.

Chapter 12 details the formulation of geometric stiffness matrices for the above shells of revolution for buckling analysis. Some numerical problems are solved and compared with closed form solution.

Chapter 13 discusses the Boundary Integral Element method to obtain the optimal configuration of shallow shells on any ground plan subjected to any type of loading.

In chapter 14, based on the results obtained conclusions are arrived at and suggestions and recommendations for further work in the field are given.

Appendix A explains the procedure for the calculation geometric properties of thin-walled curved beam of open cross section made of composite materials.
The incremental matrices $[K]$, $[N1]$ and $[N2]$ for geometric nonlinear analysis of plates are derived in Appendix B. Derivation for transformation matrix to get local displacement derivatives from global displacement derivatives in case of shells is given in Appendix C. The detailed formulation of BIE for obtaining the optimal configuration of shallow shell on any ground plan subjected to any type of loading is presented in Appendix D. The computer program and the relevant input data for solution of beam column and buckling problems of thin-walled beams of open cross section made of composite material are explained in Appendix E. Appendix F discusses the program for carrying out static and buckling analysis of layered composite plates and the program for axisymmetric shells is explained in Appendix G. The program for obtaining the optimal configuration of funicular shells by BIE is given in Appendix H.

1.7 SUMMARY

In this chapter the development of theories of buckling of composite structures has been discussed. The objectives and scope of the investigation as well as outline of contents are presented.
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<thead>
<tr>
<th>TYPE OF PROBLEM</th>
<th>LOADING</th>
<th>TYPICAL COMPONENTS</th>
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<tr>
<td>1. Columns</td>
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<tr>
<td>Thin-walled open</td>
<td>Compression</td>
<td>Truss Member</td>
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<td>section tubes</td>
<td>Transverse load</td>
<td>Control rods</td>
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<td>Internal and</td>
<td>Undercarriage components</td>
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<td></td>
<td>external pressure</td>
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<td>2. Compound columns</td>
<td>compression</td>
<td>Hydraulic jacks</td>
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<td>3. Columns on elastic</td>
<td>Compression</td>
<td>Edge members</td>
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<td>supports</td>
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<td>of large cutouts</td>
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<td>4. Plates</td>
<td>Compression shears</td>
<td>Flanges, spar webs etc</td>
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<td>5. Stiffened panels</td>
<td>Compression shear</td>
<td>Wing and Fuselage skins</td>
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<td></td>
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<td>shear walls</td>
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<td>6. Shells</td>
<td>Pressure Axial</td>
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