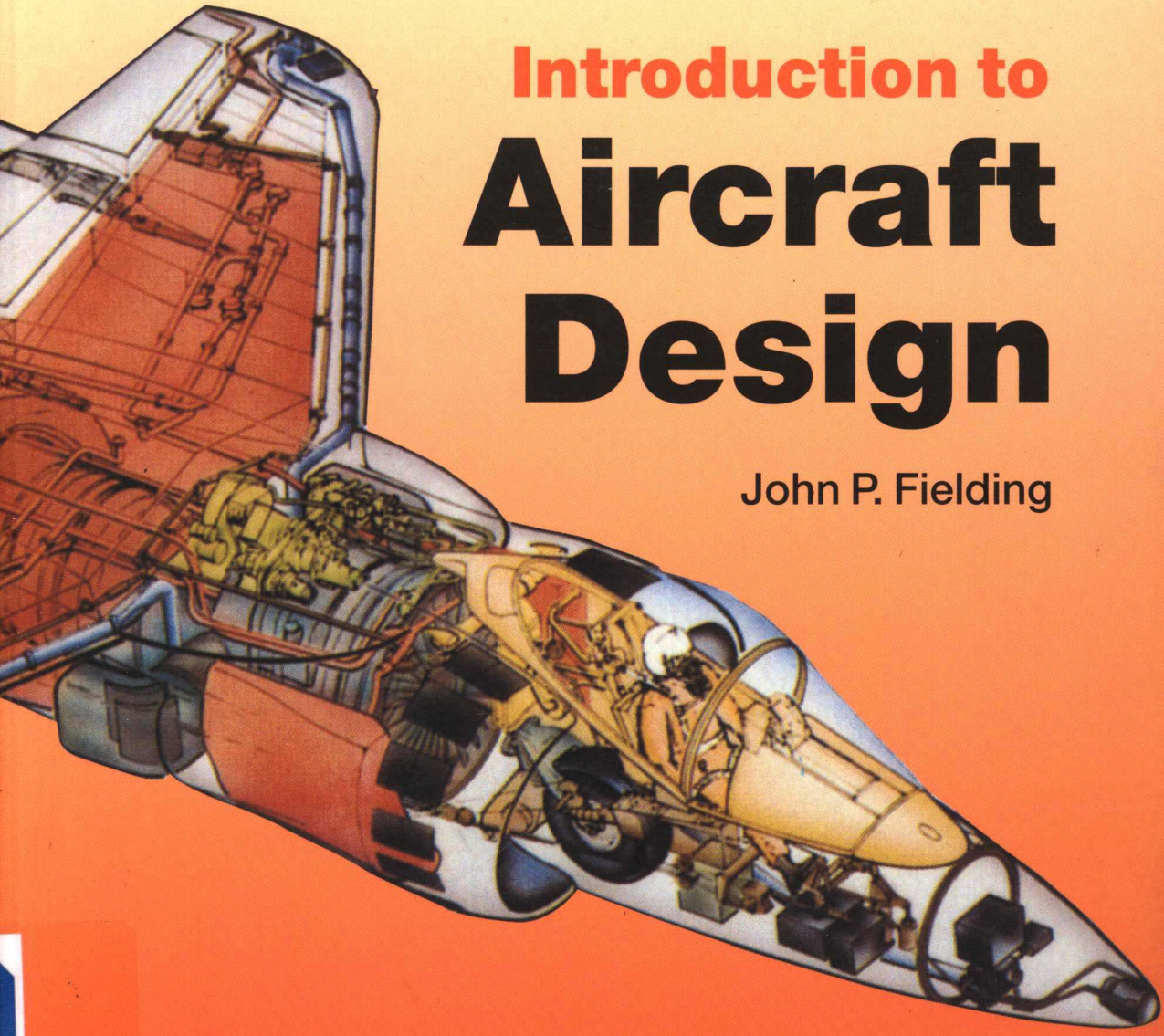
Introduction to Aircraft Design

John P. Fielding



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JOHN P. FIELDING

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Introduction to Aircraft Design

This book provides an accessible introduction to the fundamentals of civil and military aircraft design.

Giving a largely descriptive overview of all aspects of the design process, this well-illustrated account provides an insight into the requirements of each specialist in an aircraft design team. After discussing the need for new designs, the text assesses the merits of different aircraft shapes from micro-lights and helicopters to super-jumbos and V/STOL aircraft. Following chapters explore structures, airframe systems, avionics and weapons systems. Later chapters examine the costs involved in the acquisition and operation of new aircraft, aircraft reliability and maintainability, and a variety of past aircraft projects to see what conclusions can be drawn. Three appendices and a bibliography give a wealth of useful information, much not published elsewhere, including simple aerodynamic formulae, aircraft, engine and equipment data and a detailed description of a parametric study of a 500-seat transport aircraft.

Introduction to Aircraft Design is a useful text for undergraduate and graduate aeronautical engineering students and a valuable reference for professionals working in the aerospace industry. It should also be of interest to aviation enthusiasts.

PROFESSOR J. P. FIELDING, MSc., PhD., CEng., MRAes., MAIAA With 12 years industrial experience as both an engineering apprentice and design engineer working on the BAe 748, 146 and Nimrod Aircraft, John Fielding joined Cranfield University in 1975 as the first ARB Research Fellow. Subsequently promoted to lecturer and senior lecturer, he is now Professor of Aircraft Design, head of the Air Vehicle Technology Group, and is responsible for four Master's courses and the PhD studies of some 100 postgraduate students.

Whilst his personal research, teaching, and consultancies are in the areas of aircraft design, reliability and maintainability, he is the College of Aeronautics' Business Manager for Continuing Professional Development. A well-known lecturer in aircraft design, Professor Fielding has given lecture courses in the Netherlands, the People's Republic of China, Indonesia, Belgium, South Africa, Poland and the USA and has published more than 60 technical papers.

Since 1991, Professor Fielding has been visiting Lecturer at the University of Texas, and is external examiner at City and Limerick Universities in the UK. He is on the editorial board of two Aeronautical Journals, and is a member of the technical committee of the American Institute of Aeronautics and Astronautics.

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Dedication

This book is dedicated to the late Prof. David Keith-Lucas, C.B.E, and Prof. Denis Howe, both of whom were the author's immediate predecessors as Professor of Aircraft Design at the College of Aeronautics, Cranfield University, The author gained much of his knowledge of aircraft design, much encouragement and good role-models from these elder-statesman of aircraft design education.

Preface

This book acts as an introduction to the full breadth of both civil and military aircraft design. It is designed for use by senior undergraduate and post-graduate aeronautical students, aerospace professionals and technically-inclined aviation enthusiasts.

The book poses and answers pertinent questions about aircraft design, and in doing so gives information and advice about the whole aircraft design environment. It asks why we should design a new aircraft and gives examples of market surveys and aircraft specifications. It then answers the question 'why is it that shape' and gives the rationale behind the configurations of a wide range of aircraft from micro-lights and helicopters to super-jumbos and V/STOL aircraft, with many others in-between. Having examined the shape, the book then examines and describes what is under the skin in terms of structure, propulsion, systems and weapons. Later chapters answer questions about aircraft costs and conceptual design and draw lessons from past projects and then look into the future. A major part of the book answers the question 'what help can I get?' It is a combination of bibliography, lists of data sheets, computer tools and 100 pages of appendices of design data vital to aircraft conceptual designers (most of it previously unpublished).

The book concentrates on fixed-wing civil and military aircraft, with some reference to light aircraft and rotorcraft, but does not address the design of sailplanes, airships, flying boats or spacecraft. While these are fascinating and important subjects it was decided that the current scope of the book is sufficiently wide and further extension would make it unwieldy, although information about references which address the design of aircraft in the excluded categories is provided.

Much of the material has been developed for use in Preliminary and Masters' courses in aircraft design at Cranfield University. Many of the examples and illustrations have been produced as part of Cranfield's unique Group Design Project programmes. With the Cranfield method, conceptual design is done by the staff, thus enabling the students to start much further down the design process. They thus have the opportunity to get to grips with preliminary and detail design problems and become much more employable in the process. This method also allows students to use modern design tools such as CAD, finite elements, laminate analysis and aerodynamic modelling. The group design project is undertaken by all the aerospace vehicle students and is a major feature of the M.Sc. course, accounting for almost half of the final assessment. Each year the students work in a team on the design of a project aircraft. A substantial part of the airframe, a system, an installation or some

performance aspect is allocated to each student at his or her own responsibility. The aircraft chosen as the subject for the work are representative of types of current interest to industry. They usually incorporate some feature which extends the bounds of existing practice, as an applied research activity. This excites the interest, enthusiasm and ingenuity of the students and forces the staff to keep up to date. Civil and military aircraft are investigated in alternate years, so that the whole of the industry is catered for. Recent examples of design projects included large and small business-jets, a number of medium-sized jet transports and a 500-seat short-haul airliner. The latter aircraft is described in Chapter 10 and Appendix B of this book. Military aircraft have also been designed, including basic and advanced trainers, close-air support aircraft, an advanced tactical fighter, V/STOL supersonic strike aircraft and military transports.

There are many textbooks available that cover the conceptual design phase and others that provide the more specific information appropriate to the detailed design phase. This book has been written to fill the gap between these two stages, utilizing the experience gained from all the projects carried out at Cranfield and from other industrial projects.

Acknowledgements

The author would like to acknowledge the assistance of current and past students and staff of the College of Aeronautics at Cranfield University. Particular thanks are due to Mrs D. Boyles, Mrs C. Pratt and Miss K. Pointon for doing numerous versions of word-processed text. Professor M. J. Rycroft performed valuable proofreading and made suggestions for improvements, as series Editor of the Aerospace Series of the Cambridge University Press.

The book contains some 200 illustrations and large amounts of data. Much of this has come from the author's and colleagues' work at Cranfield University, but many other organizations have helped. The following individuals, companies and organizations have provided data, drawings and photographs.

Airbus Industrie: Figs 3.4, 3.5, 3.10, 5.13, 6.12, 8.1, A9.2, A9.8, A9.11, A9.12, A9.13.
American Society of Mechanical Engineers: Fig 4.5.
Boeing Commercial Airplane Company: Figs 2.1, 2.2, 2.3, 2.4, 2.5, 3.11, 8.6.
British Aerospace PLC: Figs 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 6.13, 7.2, 7.3, 8.17, 8.18, 8.19, 11.1.
A British airline: Figs 8.13, 8.14, C2.1.
Davey, Bernard, Air Cargo Research Team: Fig 11.14.
Denel Ltd South Africa: Fig 4.14.
Dunlop Aerospace Ltd – data used in Tables A8.1 and A8.2.
EMBRAER, Brazil: Fig 8.15.
European Space Agency: Fig 11.12.
Fairchild Aircraft Company: Figs 4.9, 6.11.
Flight International Magazine – some of the data used in Tables A4.1–A4.11.
Fokker Aircraft: Figs 5.5, A9.6, A9.7, A9.9, A9.10.
Jane's All the World's Aircraft: some of the data used in Tables A4.1–A4.11.
Ministry of Defence, UK: Figs 8.10, 8.11, 8.12, A9.1 and A9.4.
Northrop Ltd: Fig 11.8.
SAAB Aircraft Company: Figs 3.7 and A9.5.
Salamander Books: Fig 11.4.
Solar Wings: Figs 3.15.
Normal Wijker: Fig 1.3.

Contents

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1

Introduction

1.1 Why another aircraft design book?

Aircraft design is a complex and fascinating business and many books have been written about it. The very complexity and dynamic nature of the subject means that no one book can do it justice.

This book, therefore, will primarily act as an introduction to the whole field of aircraft design leading towards the subjects summarized in Fig. 1.1. It will not attempt to duplicate material found in existing design books, but will give information about the whole aircraft design environment together with descriptions of aircraft and component design. It also presents otherwise unpublished data and design methods that are suitable for aircraft conceptual, preliminary and detail design activities.

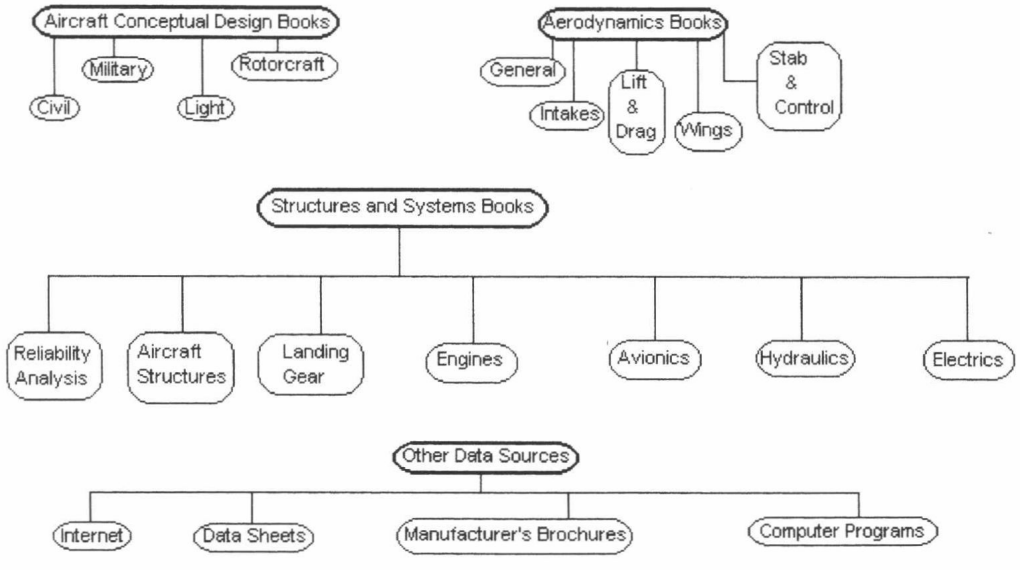

Fig. 1.1 Aircraft design data sources.

1.2 Topics

The following chapters are arranged as a series of questions about aircraft design, the answers to which give largely descriptive overviews of all aspects of aircraft design. This will provide an introduction into the conflicting requirements of aircraft design specialists in a design team, with a view to improving understanding, and the integration of a sound overall design.

The book is divided into chapters which answer a number of significant design questions.

The question 'why design a new aircraft?' is answered in Chapter 2 which shows the derivation of aircraft requirements for civil and military aircraft from market surveys, and gives examples of operator-derived specifications.

Chapters 3 and 4 answer the question 'why is it that shape?' with an initial discussion of aircraft wing and tail shapes, followed by descriptions of the configurations of a wide range of civil and military aircraft types.

The question 'what's under the skin?' is answered in Chapters 5, 6 and 7, which deal with structures and propulsion, airframe systems, avionics, flight controls and weapons, respectively. These chapters describe the interiors of aircraft, ranging from structures to weapon systems via airframe systems, avionic systems and landing gears.

In Chapter 8 the crucial areas of acquisition and operating costs are discussed and some prediction methods are described and the importance of good reliability and maintainability are stressed in order to answer the question, 'why do aircraft cost so much.'

The answer to the question 'what help can I get?' is provided in Chapter 9 which contains a bibliography of the most important current aircraft design books. It is followed by a description of some of the computer design analysis and computer-aided design (CAD) tools that are available. A summary of relevant data sheets is also given.

Chapter 10 draws together the information produced at the end of the conceptual stage and leads on to the preliminary and detail design stages in order to explain 'what happens next'. The question 'what can go wrong' is answered in Chapter 11 in which many unsuccessful or partially successful projects are examined and conclusions drawn from them.

The aircraft designer is bedeviled by lack of design data. Appendix A pulls together information that is not generally available, and includes simple aerodynamic and structural design formulae. It also provides a US/British translation list for aeronautical terms.

Appendix B presents a parametric study design example which describes the author's parametric study of a 500-seat transport aircraft. Appendix C considers reliability and maintainability targets by discussing targets for civil and military aircraft and describing a method to be used for the prediction of dispatch reliability.

1.3 The design process

There are a number of generally accepted stages in the design, development, manufacture and operation of aircraft, each with associated design methods and data requirements. These are shown schematically in Fig. 1.2, which also shows how the modern practice of concurrent engineering has reduced the overall timescale from conception to service.

Figure 1.3 gives some idea of how a designer's prejudice may affect his or her design to the detriment of others. It is an exaggeration, but not much of an exaggeration!!

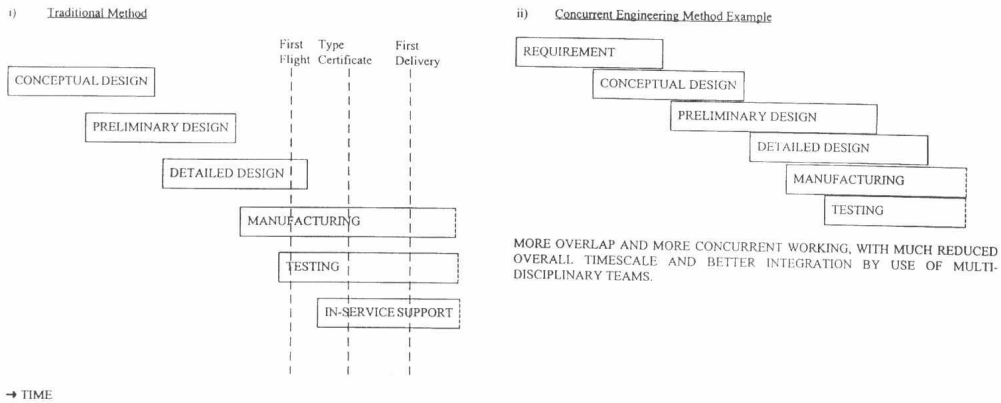

Fig. 1.2 Comparison of traditional and concurrent design approaches.

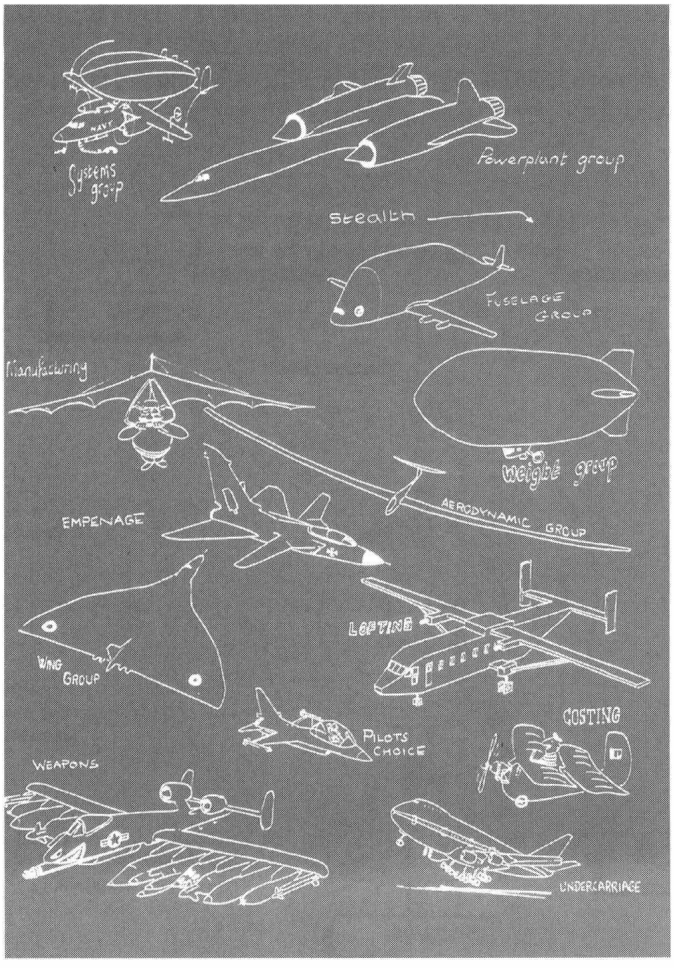

Fig. 1.3 Different specialist's views of an ideal aircraft.

The most crucial stage of any design process is to arrive at the correct set of requirements for the aircraft. These are summarized in design specifications for the particular aircraft type. Typical examples of design specifications are shown in Chapter 2. They are augmented by a large number of airworthiness requirements for civil aircraft or Defence Standards for military aircraft. These are distillations of decades of successful (and unsuccessful!) design, manufacturing and operational experience. Fig. 1.4, adapted from Haberland *et al.* [1], shows a very helpful illustration of what may happen after the issue of the design specifications, and illustrates the iterative design process that is not apparent in the simplified illustration in Fig. 1.2.

A converging iterative spiral of design stages, ending in the detail design, and ultimately manufacture and operation of the aircraft can be seen in Fig. 1.4.

It is a truism that 99% of the decisions which affect aircraft success are made on 1% of the facts available during the conceptual design phase. Very coarse methods have to be used which are then refined by progressively more accurate methods as the design evolves. This is true if the spiral is convergent, but there are occasions where the spiral is divergent and the design must be abandoned, and started again, unless significant modifications are made to the design.

Figure 1.5 shows the author's usual design procedure for conceptual design and the start of preliminary design process.

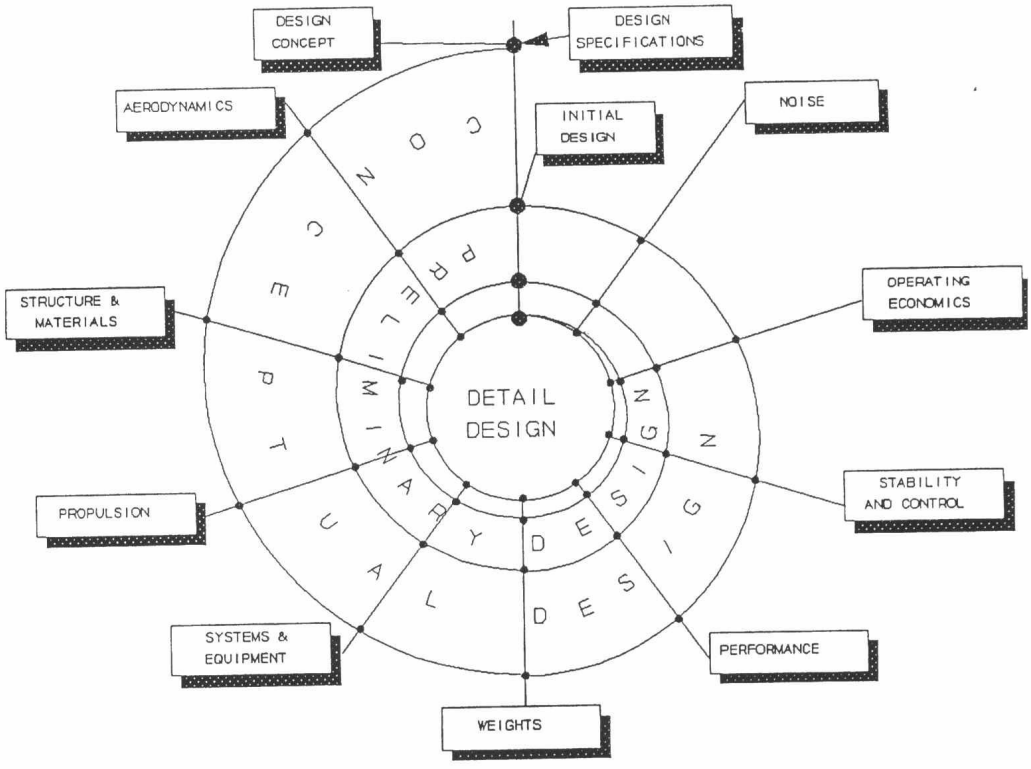

Fig. 1.4 The design spiral.

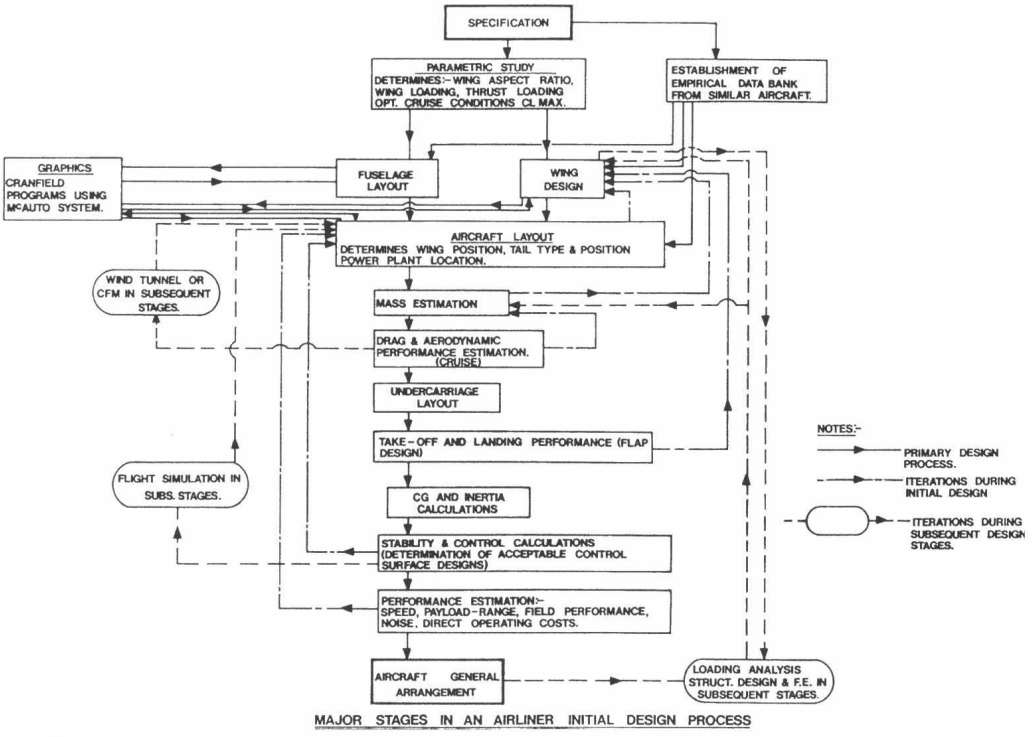

Fig. 1.5 Major stages in an airliner initial design process.

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