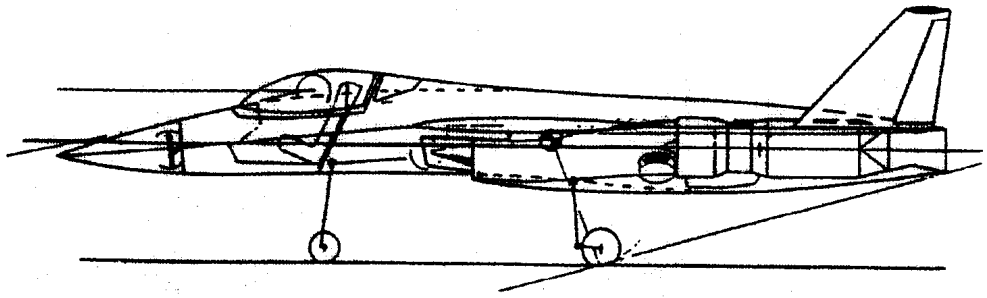

DANIEL P. RAYMER

Aircraft Design: A Conceptual Approach

AIAA Education Series

J.S. PRZEMIENIECKI / SERIES EDITOR-IN-CHIEF

Aircraft Design: A Conceptual Approach

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DISCLAIMER: The Author and the AIAA do not guarantee the accuracy of the information provided in this book, and it should not be referenced as an authoritative source for aircraft design data or methods.

DEDICATION

This book is dedicated to all who taught me, especially Lester Hendrix, Richard Hibma, Louis Hecq, Harry Scott, Richard Child, George Owl, Robert Maier, Ed McGachan, Doug Robinson, Steve White, Harvey Hoge, Michael Robinson, George Palmer, Henry Yang, Robert Swaim, C. T. Sun, Dave Schmidt, Bruce Reese, William Heiser, and Gordon Raymer (test pilot, aeronautical engineer and my father).

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FOREWORD

As one of its major objectives, the AIAA Education Series is creating a comprehensive library of the established practices in aerospace design. *Aircraft Design: A Conceptual Approach* by Daniel P. Raymer provides an authoritative exposition of aircraft conceptual design. The great demand for the first edition of this new authoritative text on aircraft design has prompted the author to update and enlarge the text content into a second edition. In particular, Chapters 8 (Special Considerations in Configuration Layout), 13 (Propulsion), 17 (Performance and Flight Mechanics), and 21 (Conceptual Design Examples) have been extensively enlarged to cover some of the latest developments. The author's extensive experience with several aircraft companies supports the broad cross section of different views and approaches discussed in this comprehensive volume.

This textbook offers aircraft designers, design managers, and design instructors an industry perspective on the new aircraft concept development process, which basically consists of two major activities: design layout and design analysis. The whole process is described in a very comprehensive manner, tailored to serve as a college design textbook. However, only an elementary knowledge of mathematics is required to make full use of the text, for the book focuses on industry design practice rather than theoretical definitions. A simplified but complete set of first-order analytical methods is presented. The text covers every phase of conceptual design: configuration layout, payload considerations, aerodynamics, propulsion, structure and loads, weights, stability and control, handling qualities, performance, cost analysis, tradeoff analysis, and many other topics.

This latest text in the AIAA Education Series offers students, teachers, and practicing designers a unique source of information on current design practice in the U.S. aircraft industry—its science and art. To write a textbook on aircraft design is indeed a formidable task. Raymer has succeeded in creating a balanced text in which all the necessary topics needed to understand the design process are clearly described.

For many years *Aircraft Design: A Conceptual Approach* will be a valuable textbook for all who struggle with the fundamentals and intricacies of aircraft design.

J. S. PRZEMIENIECKI
Editor-in-Chief
AIAA Education Series

AUTHOR'S NOTE

There are two equally important aspects of aircraft design: design layout and design analysis. These very different activities attract different types of people. Some people love playing with numbers and computers, while others can't stop doodling on every piece of paper within reach.

This book was written to fill a perceived need for a textbook in which both aircraft analysis and design layout are covered equally, and the interactions between these two aspects of design are explored in a manner consistent with industry practice.

This book is not intended to be definitive on the subject of aircraft analysis. The analysis techniques presented are simplified to permit the student to experience the whole design process in a single course, including the key concepts of trade studies and aircraft optimization.

No textbook can contain the methods actually used in industry, which tend to be proprietary and highly computerized. When the student goes into an industry or government design job, the more sophisticated methods of his or her chosen specialty will be better understood in the broader context of the whole of design as presented here.

One key area in which this book differs from prior aircraft design books is in the chapters on aircraft configuration layout. The actual development of the aircraft design drawing is not a trivial task of drafting based upon the analysis results, but rather is a key element of the overall design process and ultimately determines the performance, weight, and cost of the aircraft.

The ability to visualize and draw a new aircraft that has a streamlined aerodynamic shape, an efficient internal layout, yet satisfies an incredible number of real-world constraints and design specifications is a rare talent that takes years to cultivate. While to some extent good designers are "born, not made," a number of concepts and techniques in aircraft configuration layout can be taught, and are covered here.

Writing this book has been an educating and humbling experience. It is my sincere wish that it help aspiring aircraft designers to "learn the ropes" more quickly.

This second edition of *AIRCRAFT DESIGN: A Conceptual Approach* offers several new subjects, including production methods, post-stall maneuver, an update on VSTOL, and a brief introduction to engine cycle analysis. Also, typographical and technical errors from the first edition are corrected.

A key difference in the second edition is Chapter 21, the Conceptual Design Examples. These are reworked to better serve as examples for the chapters of the book. The second example illustrates the use of RDS, a PC-based design, sizing and performance program now available from AIAA. RDS uses the methods in this book, and permits rapid design, analysis, and trade studies.

AIAA and the author would like to thank the many people who have offered constructive suggestions for this second edition, as well as the more than 7000 students and working engineers who made the first edition an AIAA best seller.

Display model of an Advanced Supercruise Fighter Concept (Ref. 13). Photo courtesy of Rockwell International North American Aircraft Operations.

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1
DESIGN—A SEPARATE DISCIPLINE

1.1 WHAT IS DESIGN?

Aircraft design is a separate discipline of aeronautical engineering—different from the analytical disciplines such as aerodynamics, structures, controls, and propulsion. An aircraft designer needs to be well versed in these and many other specialties, but will actually spend little time performing such analysis in all but the smallest companies. Instead, the designer's time is spent doing something called "design," creating the geometric description of a thing to be built.

To the uninitiated, "design" looks a lot like "drafting" (or in the modern world, "computer-aided drafting"). The designer's product is a drawing, and the designer spends the day hunched over a drafting table or computer terminal. However, the designer's real work is mostly mental.

If the designer is talented, there is a lot more than meets the eye on the drawing. A good aircraft design seems to miraculously glide through subsequent evaluations by specialists without major changes being required. Somehow, the landing gear fits, the fuel tanks are near the center of gravity, the structural members are simple and lightweight, the overall arrangement provides good aerodynamics, the engines install in a simple and clean fashion, and a host of similar detail seems to fall into place.

This is no accident, but rather the product of a lot of knowledge and hard work by the designer. This book was written primarily to provide the basic tools and concepts required to produce good designs which will survive detailed analysis with minimal changes.

Other key players participate in the design process. Design is not just the actual layout, but also the analytical processes used to determine what should be designed and how the design should be modified to better meet the requirements. In a small company, this may be done by the same individuals who do the layout design. In the larger companies, aircraft analysis is done by the sizing and performance specialists with the assistance of experts in aerodynamics, weights, propulsion, stability, and other technical specialties.

In this book, the design layout techniques are discussed primarily in Chapters 4–11, while the analysis and optimization methods are presented in Chapters 12–19.

1.2 INTRODUCTION TO THE BOOK

This book describes the process used to develop a credible aircraft conceptual design from a given set of requirements. As a part of the AIAA

Education Series, the book is written primarily for the college student. Every effort has been made to achieve a self-contained book.

In an aircraft company, the designer can ask a functional specialist for a reasonable initial tire size, inlet capture area, weight savings due to the use of composites, or similar estimates. Such specialists are not available at most universities. This book thus gives various "rule-of-thumb" approximations for initial estimation of design parameters.

The book has 21 chapters, and approximately follows the actual design sequence. Chapters 2 and 3 provide an overall introduction to the design process. Chapter 2 discusses how the conceptual design process works, and how it fits into the overall process of aircraft development. Chapter 3 presents a "first-pass" design procedure to familiarize the reader with the essential concepts of design, including design layout, analysis, takeoff-weight estimation, and trade studies.

In Chapters 4–11 the techniques for the development of the initial configuration layout are presented. These include the conceptual sketch, initial sizing, wing geometry selection, lofting, inboard layout, and integration of propulsion, crew station, payload/passenger compartment, fuel system, landing gear, and considerations for observability, producibility, and supportability. While the text implies that the design is done on a drafting board, it should be understood that in major aircraft companies today most aircraft design work is done on a computer-aided design system. However, the same basic design techniques are used whether on a drafting table or computer scope.

Chapters 12–19 address the analysis, sizing, and optimization of the design layout. Various chapters discuss aerodynamics, weights, installed propulsion characteristics, stability and control, performance, cost, and sizing. Optimization based upon design requirements is introduced in a section on trade studies.

These methods are simplified to allow rapid design analysis by students. No college textbook can contain the methods actually used by major aircraft companies, which tend towards highly sophisticated computer programs operated by specialists. Simplified analysis methods allow the student more time to experience the all-important optimization and iteration process.

Chapter 20 presents an overview of VTOL aircraft design. This material builds upon the methods for conventional aircraft design. However, VTOL introduces additional considerations that affect the design layout and analysis.

The last chapter, 21, contains two complete design project examples which use the methods presented in the previous chapters. These are provided instead of numerous example calculations throughout the text to illustrate how the different aspects of design fit together as a whole.

The appendices contain information useful in conceptual design, such as conversion tables, atmosphere and shock tables, and data on airfoils and engines. Also included is a summary of the current civil and military design requirements and specifications, which have been taken primarily from Federal Aviation Regulations (FAR) and Military Specifications (Mil-Specs).

2
OVERVIEW OF THE DESIGN PROCESS

2.1 INTRODUCTION

Those involved in design can never quite agree as to just where the design process begins. The designer thinks it starts with a new airplane concept. The sizing specialist knows that nothing can begin until an initial estimate of the weight is made. The customer, civilian or military, feels that the design begins with requirements.

They are all correct. Actually, design is an iterative effort, as shown in the "Design Wheel" of Fig. 2.1. Requirements are set by prior design trade studies. Concepts are developed to meet requirements. Design analysis frequently points toward new concepts and technologies, which can initiate a whole new design effort. However a particular design is begun, all of these activities are equally important in producing a good aircraft concept.

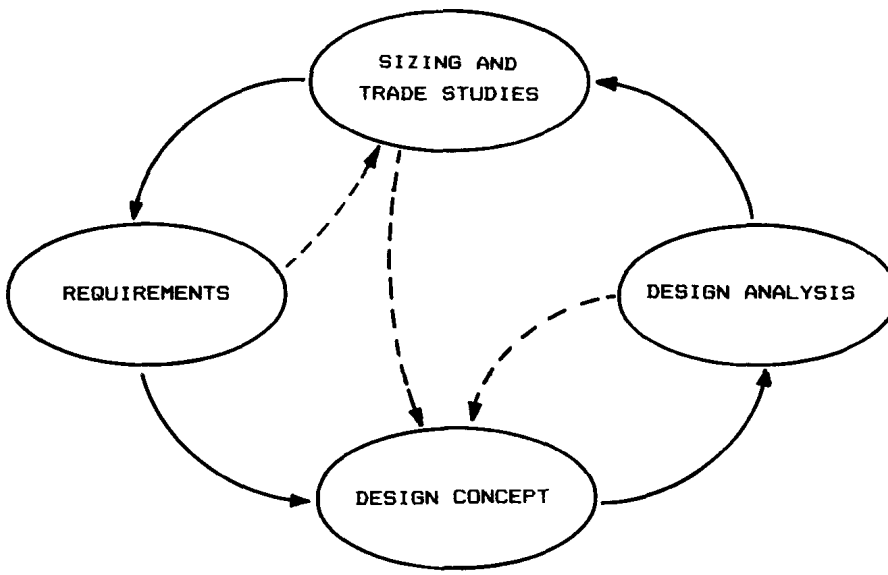

Fig. 2.1 The design wheel.

2.2 PHASES OF AIRCRAFT DESIGN

Conceptual Design

Aircraft design can be broken into three major phases, as depicted in Fig. 2.2. Conceptual design is the primary focus of this book. It is in conceptual design that the basic questions of configuration arrangement, size and weight, and performance are answered.

The first question is, "Can an affordable aircraft be built that meets the requirements?" If not, the customer may wish to relax the requirements.

Conceptual design is a very fluid process. New ideas and problems emerge as a design is investigated in ever-increasing detail. Each time the latest design is analyzed and sized, it must be redrawn to reflect the new gross weight, fuel weight, wing size, engine size, and other changes. Early wind-tunnel tests often reveal problems requiring some changes to the configuration. The steps of conceptual design are described later in more detail.

Preliminary Design

Preliminary design can be said to begin when the major changes are over. The big questions such as whether to use a canard or an aft tail have been resolved. The configuration arrangement can be expected to remain about as shown on current drawings, although minor revisions may occur. At some point late in preliminary design, even minor changes are stopped when a decision is made to freeze the configuration.

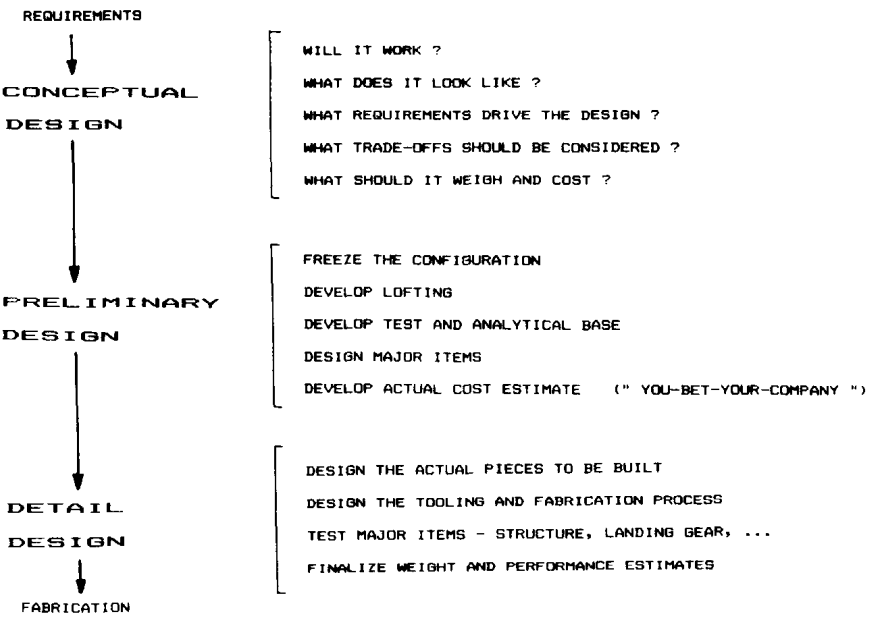

Fig. 2.2 Three phases of aircraft design.