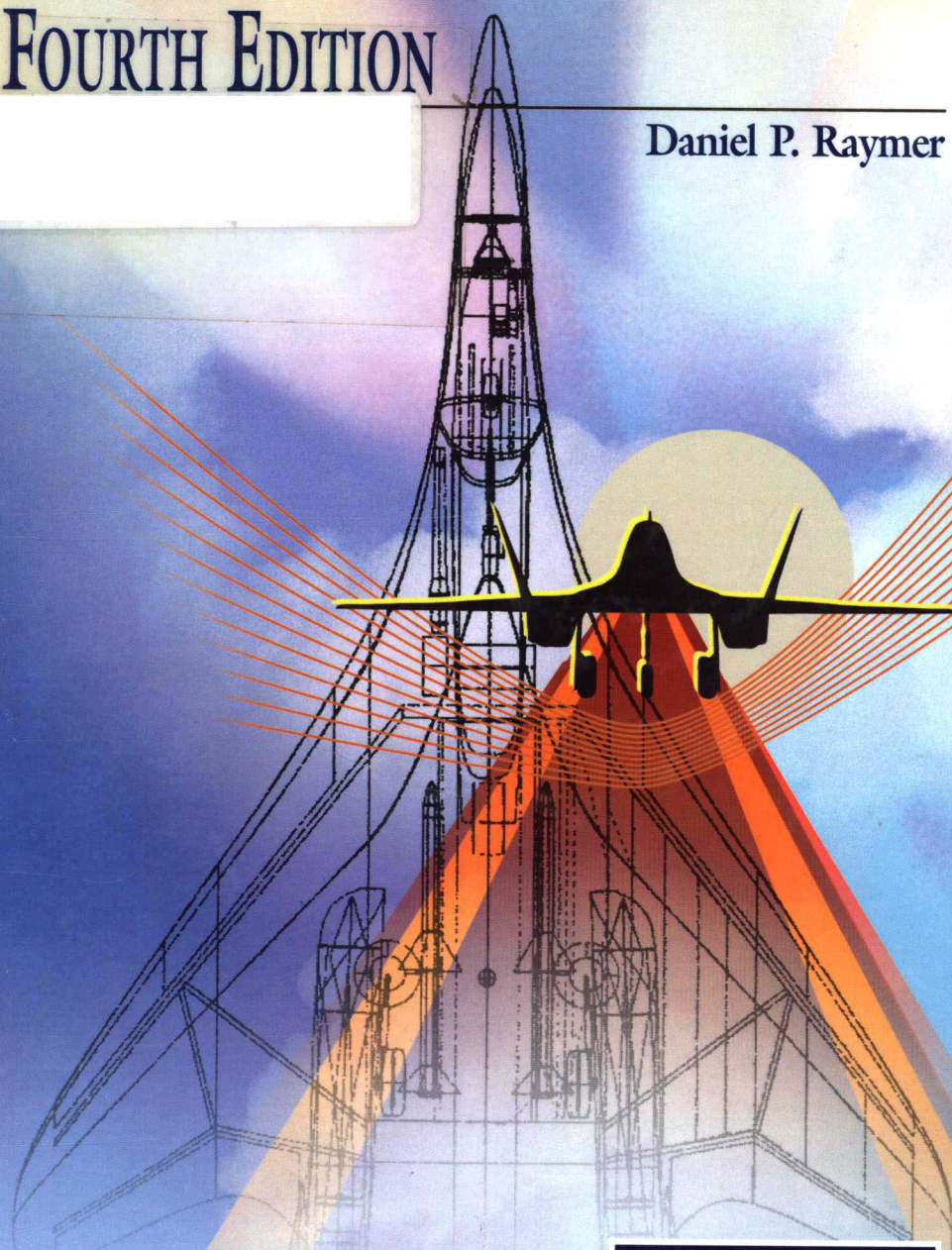


# AIRCRAFT DESIGN: A CONCEPTUAL APPROACH FOURTH EDITION

Daniel P. Raymer



AMERICAN INSTITUTE OF  
AERONAUTICS AND ASTRONAUTICS

**AIAA EDUCATION SERIES**  
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# **Aircraft Design: A Conceptual Approach Fourth Edition**

**Daniel P. Raymer**  
Conceptual Research Corporation  
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**Aircraft Design:  
A Conceptual Approach  
Fourth Edition**

**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, David Schmidt, Bruce Reese, William Heiser, and Gordon Raymer (test pilot, aeronautical engineer, and my father).**

**Thanks also to Rockwell North American Aircraft Operations, SAAB Aircraft, and Lockheed Martin for permission to use various illustrations. All other artwork is original, in the public domain, or copyrighted by AIAA.**

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## Foreword

We are delighted to present the Fourth Edition of *Aircraft Design: A Conceptual Approach* by Daniel Raymer. The first three editions have been very well received and widely used in the aerospace community. This new edition has updated the material and expanded the coverage, and we anticipate that it will be equally well and even better received. The current volume has 23 chapters and six appendices in more than 800 pages. A key feature of this and the earlier volumes is the encyclopedic scope of the coverage. In addition, every topic necessary to the understanding of aircraft design such as aerodynamics, structures, stability and control, propulsion, etc. is discussed from the point-of-view of the designer, not the specialist in a given topic area.

Daniel Raymer is uniquely qualified to write this book because of his broad expertise in the area. His command of the material is excellent, and he is able to organize and present it in a very clear manner. Clearly, his extensive industrial experience provides the background and perspective needed for the author of a successful design textbook.

The AIAA Education Series aims to cover a very broad range of topics in the general aerospace field, including basic theory, applications and design. A complete list of titles can be found at [www.aiaa.org](http://www.aiaa.org). The philosophy of the series is to develop textbooks that can be used in a university setting, instructional materials for continuing education and professional development courses, and resources that can serve as the basis for independent study or as working references. Suggestions for new topics or authors are always welcome.

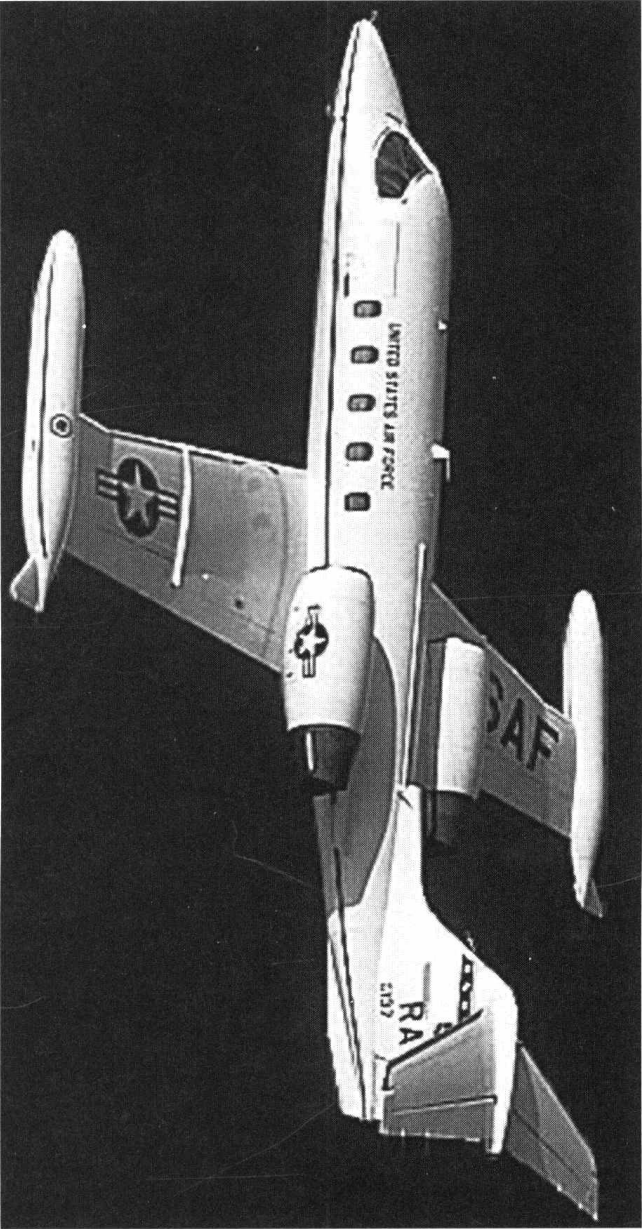
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**Author with display model of his Advanced Supercruise Fighter Concept (Ref. 13).  
Photo courtesy of Rockwell International North American Aircraft Operations.**





Learjet (USAF C21-A) (U.S. Air Force photo).

## Preface

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

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

Aircraft design obviously depends on the reliable calculation of numbers; however, in the end the only thing that actually gets built is the drawing. Its creation is not a trivial task of drafting based upon the analysis results, but rather it is a key element of the overall design process and ultimately determines the performance, weight, and cost of the aircraft. Bluntly stated, if you don't have a good drawing, you don't have an aircraft design.

It is difficult to visualize and draw a new aircraft that has a streamlined aerodynamic shape and an efficient internal layout and yet satisfies an incredible number of real-world constraints and design specifications. This is a rare talent that takes years to cultivate. Although to some extent good designers are "born, not made," the proven methods and best practices of aircraft configuration layout can be taught, and are covered here in the first half of this book.

It is also true that a nice aircraft drawing is nothing without the analytical results to support it, and it will be a much nicer drawing if clever optimization methods are employed to make it better. So, a good designer or design team must find an appropriate balance between layout and analysis. To provide such balance, the second half of this book covers analysis and optimization methods that will tell you if the design works, if it meets its design requirements, and how you can make it better in the next drawing.

One of the most important lessons that a student of aircraft design must absorb is that design is an iterative process. One does not draw a neat-looking concept, analyze its range and performance, and stop there. You must use design judgment and computational analysis to identify all possible areas for improvement and optimization of your concept, and then draw it again . . . and again, and maybe again!

The specific analysis techniques presented in the book are simplified to permit the student to experience the whole design process in a single course. No textbook can contain the methods actually used in industry, which tend to be proprietary and highly computerized. However, the methods presented here are sufficient, and give reasonable results for most categories of aircraft. In fact, they are

good enough to be used to check the results of the sophisticated computerized methods, and if they are far apart, the computer results are probably wrong!

The Aircraft Conceptual Design Web site at [www.aircraftdesign.com](http://www.aircraftdesign.com) includes examination questions for the book, advice to students and would-be inventors, sample aircraft design layouts, free design software, tips for the use of the design software RDS-Student (based on methods in this book), and information on aircraft design short courses. All are welcome!

I, and the AIAA, would like to thank the many people who have offered constructive suggestions for this new edition, as well as the 30,000 students and working engineers who have made this book an AIAA best seller. Writing this book has been an educating and humbling experience. It is my sincere wish that it helps aspiring aircraft designers to “learn the ropes” more quickly.

**Daniel P. Raymer**

March 2006

## Author's Note Concerning Use of Metric Weight Units

Metric (SI) units are more universal and technically consistent than British "Imperial" units (fps) and also reduce the possibility of stupid errors in aircraft calculations. However, one must still decide exactly which metric unit multipliers to use. Should masses be defined in grams or in kilograms? Should times be in seconds or in hours, or used as needed to make the numbers "nice." These decisions change the numbers, and unfortunately, different companies use slightly different combinations of unit multipliers and times. To maximize consistency with prior literature, the metric unit terms used in *Jane's All the World's Aircraft* (Ref. 1) and in Stinton's *The Design of the Aeroplane* (Ref. 28) were employed in this book. Values in this book are presented first in British units, and then in metric units enclosed in braces { }.

A key issue and the source of much confusion is the treatment of "weight" in metric units. Weight by definition is a force, not a mass. However, pilots and working engineers describing the weight of the Airbus A340 would say 126,000 kg, not 1,235,682 kN. What those pilots and engineers really mean is, "the Airbus exerts a weight force equivalent to that exerted by a 126,000 kg mass in a 1-g gravitational field." This book follows this common practice—don't let it confuse you! When doing an analysis such as calculating lift force and equating it to weight, the weight of 126,000 kg must first be converted to proper force units (Newtons) by multiplying by the 1-g acceleration constant ( $g = 9.807 \text{ m/s}^2$ ).

This verbal equating of weight with force in a 1-g gravitational field is carried over to the definitions of ratios such as wing loading ( $\text{kg/m}^2$ ) and power loading ( $\text{kg/kW}$ ). Because of this, the values of these ratios as given in the tables are not technically correct when applied to the various equations that use them. The mass terms must be converted to force by multiplying by  $g$ . Thus, a wing loading given in "pilot talk" as  $586 \text{ kg/m}^2$  must be converted to  $5746.9 \text{ N/m}^2$  to apply in equations relating lift to weight (for example, see Table 5.5).

The values given for thrust-to-weight ratio (T/W) do not require conversion. In traditional British-unit practice, the thrust is given in lbs-force, and the weight is given in lbs-mass (exerted force assuming a 1-g field), so that the ratio is non-dimensional and the same as the desired SI units of Newtons/Newton. A T/W greater than one means the aircraft can accelerate straight up, regardless of the units in which it was designed!



X-15 rollout (U.S. Air Force photo).

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