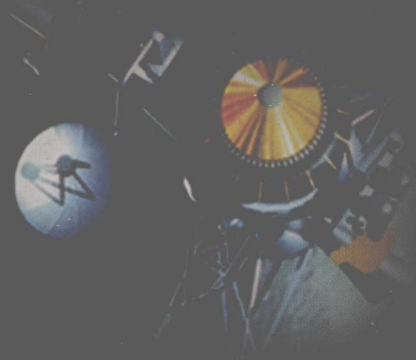
F.C. Campbell



MANUFACTURING TECHNOLOGY FOR AEROSPACE STRUCTURAL MATERIALS

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Manufacturing Technology for Aerospace Structural Materials

F.C. Campbell

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Preface

This book is intended for anyone wishing to learn more about the materials and manufacturing processes used to fabricate and assemble advanced aerospace structures. The remarkable performance characteristics of modern aerospace vehicles are, to a large degree, a result of the high performance materials and manufacturing technology used in both the airframes and propulsion systems. To obtain continual performance increases, designers are constantly searching for lighter, stronger and more durable materials.

Chapter 1 gives a brief overview of the structural materials that are used in aerospace structures. The next five chapters are then devoted to the important metals, namely aluminum, magnesium, beryllium, titanium, high strength steels and superalloys.

Aluminum alloys (Chapter 2) have been the main airframe material since they started replacing wood in the early 1920s. Even though the role of aluminum in future commercial aircraft will probably be somewhat eroded by the increasing use of composite materials, high strength aluminum alloys are and will remain important airframe materials.

Although both magnesium and beryllium (Chapter 3) are extremely lightweight materials, they both have serious drawbacks that limit their applications. The biggest obstacle to the use of magnesium alloys is its extremely poor corrosion resistance. Beryllium is also a very lightweight metal with an attractive combination of properties. However, beryllium must be processed using powder metallurgy technology that is costly, and beryllium powder and dust are toxic, which further increases its cost through the requirement for controlled environments.

Titanium (Chapter 4) is often used to save weight by replacing heavier steel alloys in the airframe and superalloys in the low temperature portions of gas turbines. Titanium is becoming even more important as an airframe material due to its outstanding resistance to fatigue, its high temperature capability and its resistance to corrosion.

While high strength steels (Chapter 5) normally account for only about 5–15% of the airframe structural weight, they are often used for highly critical parts such as landing gear components. The main advantages of high strength steels are their extremely high strengths and stiffness. This can be extremely important in landing gear applications where it is critical to minimize the volume of the gear components.

Superalloys (Chapter 6) are another enabling material for modern flight where they are used extensively in the jet turbine engines. Some superalloys are capable of being used in load bearing applications in excess of 80% of their incipient melting temperatures while exhibiting high strength, good fatigue and creep resistance, good corrosion resistance and the ability to operate at elevated temperatures for extended periods of time.

Chapters 7 through 10 deal with the important field of composite materials. Chapter 7 covers polymer matrix composites. This is followed by Chapter 8 on Structural Adhesives and Cocured Structure. Metal Matrix Composites and Ceramic Matrix Composites are covered in Chapters 9 and 10 respectively.

The advantages of high performance polymer matrix composites (Chapter 7) are many, including lighter weight; the ability to tailor lay-ups for optimum strength and stiffness; improved fatigue life; corrosion resistance; and with good design practice, reduced assembly costs due to fewer detail parts and fasteners. The specific strength (strength/density) and specific modulus (modulus/density) of high strength fiber composites, especially carbon, are higher than comparable aerospace metallic alloys. This translates into greater weight savings resulting in improved performance, greater payloads, longer range and fuel savings.

Adhesive Bonding and Cocured Structure (Chapter 8) covers how parts can be combined into a single cured assembly during either initial cure or by secondarily adhesive bonding. Large one piece composite structures have demonstrated the potential for impressive reductions in part counts and assembly costs.

Metal matrix composites (Chapter 9) offer a number of advantages compared to their base metals, such as higher specific strengths and moduli, higher elevated temperature resistance, lower coefficients of thermal expansion and, in some cases, better wear resistance. On the down side, they are more expensive than their base metals and have lower toughness. Due to their high cost, commercial applications for metal matrix composites are limited.

Similar to metal matrix composites, there are very few commercial applications for ceramic matrix composites (Chapter 10) due to their high costs and concerns for reliability. Carbon–carbon has found applications in aerospace for thermal protection systems. However, metal and ceramic matrix composites remain an important material class, because they are considered enablers for future hypersonic flight vehicles.

Assembly (Chapter 11) represents a significant portion of the total airframe manufacturing cost, as much as 50% of the total delivered airframe cost. In this chapter, the emphasis is on mechanical joining including the hole preparation procedures and fasteners used for structural assembly. Sealing and painting are also briefly discussed.

This book is intended for the engineer or student who wants to learn more about the materials and processing used in aerospace structure. It would be useful to designers, structural engineers, material and process engineers and manufacturing engineers involved with advanced materials. A first course in Materials Science would be helpful in understanding the material in this book; however, a brief review of some of the fundamentals of materials science is included as Appendix B. There is also an Appendix C, which gives a brief explanation of some of the mechanical property terms and environmental degradation mechanisms that are encountered throughout this book.

The reader is hereby cautioned that the data presented in this book are not design allowables. The reader should consult approved design manuals for statistically derived design allowables.

I would like to thank a number of my colleagues for reviewing the chapters in this book, in particular Dr J.A. Baumann, D.R. Bolser, D.M. Furdek, T.L. Hackett, N. Melillo, and Dr K.T. Slattery. In addition, I would like to acknowledge the help and guidance of Dr Geoff Smaldon, Elsevier Advanced Technology, and Priyaa H. Menon, Integra Software Services Pvt. Ltd, and their staffs for their valuable contributions.

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Chapter 1

Introduction

The remarkable performance characteristics of a modern fighter aircraft (Fig. 1.1) are, to a large degree, a result of the high performance materials used in both the airframe and propulsion systems. A commercial aircraft will fly over 60 000 h. during its 30-year life, with over 20 000 flights, and will taxi over 100 000 miles.[1] To obtain continual performance increases, designers are constantly searching for lighter and stronger materials. Reducing material density is recognized as the most efficient way of reducing airframe weight and improving performance. It has been estimated that reductions in material density are about 3 to 5 times more effective than increasing tensile strength, modulus or damage tolerance.[2] For gas turbine jet engines, advances in materials have allowed significantly higher operating temperatures, which result in increases in thrust levels, again increasing performance.

Over the next 20 years, it has been forecast that there will be a significant increase in the demand for air travel, especially in the large population centers in Asia. It is possible that the number of air travelers will double with the demand for new aircraft increasing between 13 500 and 17 000, with yearly deliveries between 675 and 850 aircraft, at a total estimated value of approximately 1.25 trillion dollars.[3]

Airframe durability is becoming a greater concern since the life of many aircraft, both commercial and military, are being extended far beyond their intended design lives. Will the B-52 bomber, which first flew in 1954, become the first 100-year airframe? Even for an aircraft with "only" a 30-year lifetime, it has been estimated that the cost of service and maintenance over the 30-year life of the aircraft exceeds the original purchase price by a factor of two.[1]

Since the early-1920s, airframes have been built largely out of metal, aluminum in particular has been the material of choice. When high performance composites (i.e., first boron and then carbon fibers) started being developed in the mid-1960s and early-1970s, the situation started changing. The earliest developers, and users, of composites were the military. The earliest production usage of high performance composites were on the empennages of the F-14 and F-15 fighter aircraft. Boron/epoxy was used for the horizontal stabilators on both of these aircraft, and for the rudders and vertical fins on the F-15. In the mid-1970s, with the maturity of carbon fibers, a carbon/epoxy speedbrake was implemented on the F-15. While these early applications resulted in significant weight savings (~20%), they accounted for only small amounts of the airframe structural weight.

However, as shown in Fig. 1.2, composite usage quickly expanded from only 2% of the airframe on the F-15 to as much as 27% on the AV-8B Harrier by the early-1980s. Significant applications included the wing (skins and substructure), the forward fuselage, and the horizontal stabilator, all fabricated from carbon/epoxy. While the amount of composites used on the AV-8B was somewhat on the high side, most modern fighter aircraft contain over 20% composite

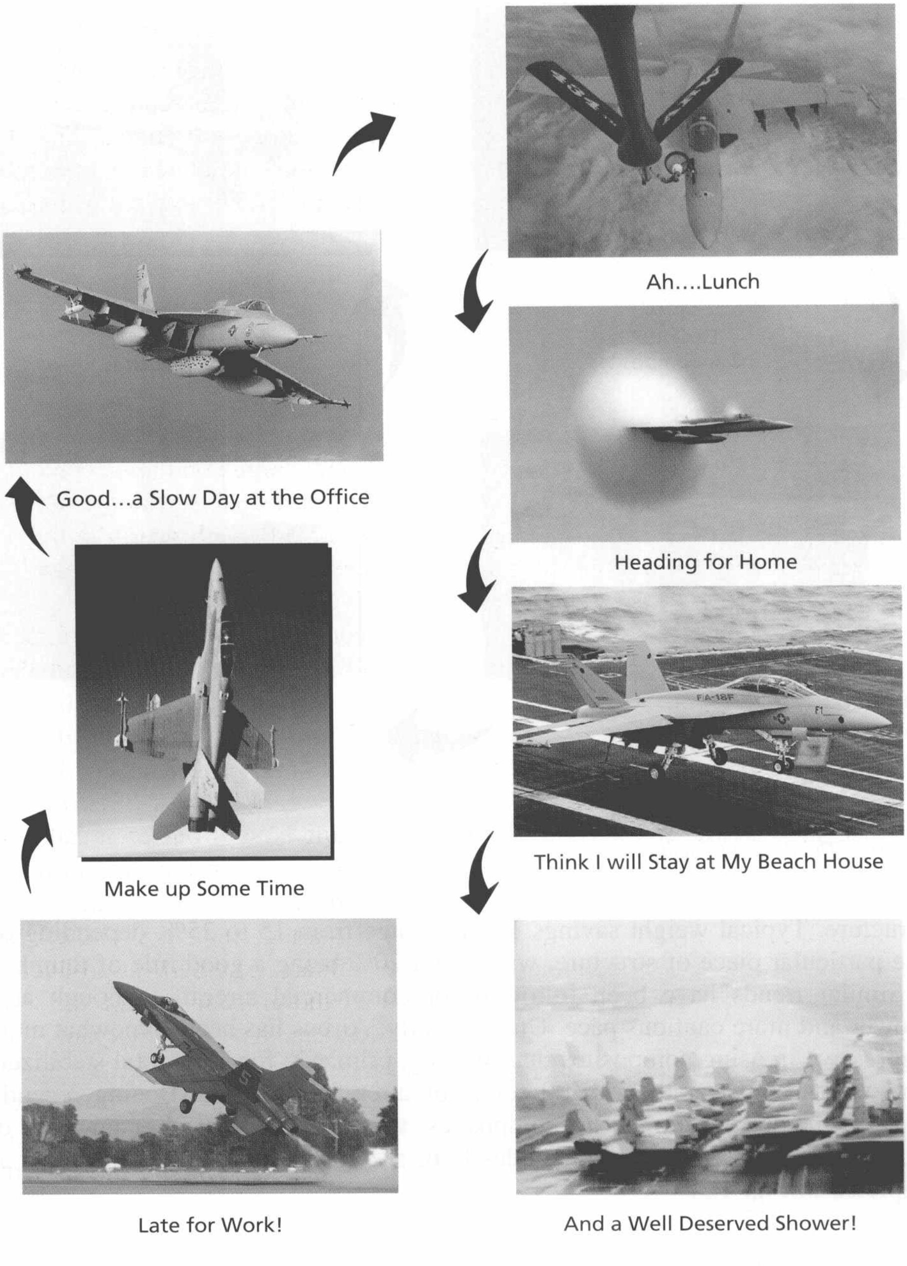

Fig. 1.1. F/A-18 Fighter Aircraft
Source: U.S. Navy & The Boeing Company