The Aerospace Business

Management and Technology

Wesley Spreen

ROUTLEDGE

The Aerospace Business

This textbook provides a detailed overview of industry-specific business management and technology management practices in aerospace for relevant bachelors and MBA programs.

The Aerospace Business: Management and Technology sequentially addresses familiar management disciplines such as production management, labor relations, program management, business law, quality assurance, engineering management, supply-chain management, marketing, and finance, among others. In this context it analyzes and discusses the distinctive perspective and requirements of the aerospace industry. The book also includes subjects of special interest such as government intervention in the sector and strategies to deal with the environmental impact of aircraft. As each chapter deals with a separate management discipline, the material reviews the historical background, technical peculiarities, and financial factors that led the aerospace industry to evolve its own distinct practices and tradition. Theoretical bases of the practices are explained, and the chapters provide actual examples from the industry to illustrate application of the theories. The material is compiled, organized, and analyzed in ways that often provide original perspectives on the subject matter.

University students, particularly in programs oriented towards aviation and aerospace management, will find the book to be directly applicable to their studies. It is also extremely appropriate for aerospace MBA and executive MBA programs, and would suit specialized corporate or government training programs related to aerospace.

Wesley Spreen's professional career in the aerospace industry includes executive and managerial jobs at Boeing, Lockheed, General Dynamics, Textron, and the US Air Force. At Lockheed he was managing director of the F-16 international coproduction consortium, which at the time was the largest cooperative industrial program in the history of the aerospace industry. At Boeing he was Director of International Marketing and Sales for the company's helicopter division.

The Aerospace Business

Management and Technology

Wesley Spreen

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

First published 2020
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

and by Routledge
52 Vanderbilt Avenue, New York, NY 10017

Routledge is an imprint of the Taylor & Francis Group, an informa business

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record has been requested for this book

ISBN: 978-0-367-28059-8 (hbk)
ISBN: 978-0-367-28058-1 (pbk)
ISBN: 978-0-429-29945-2 (ebk)

Typeset in Bembo
by Deanta Global Publishing Services, Chennai, India

To my daughters Janette and Elizabeth, perfectly described by John Milton in *Paradise Lost*:

Grace was in all her steps, heaven in her eye, in every gesture dignity and love.

Full disclosure

In any book of this scope there is often insight to be gained by comparing history and management practices at different companies and in different geographical regions. The author has made every attempt to be objective and impartial in these comparisons. However, he is a former executive of Lockheed and Boeing, and his views have no doubt been influenced by those experiences. Geography is destiny. On the other hand, he has spent more than 11 years in residence in Europe, working closely with European aerospace entities that were often Airbus members, and he has vast respect for the ideals, the accomplishments, and the managerial competence of that undertaking.

In Canada, Brazil, Japan, China, India, Russia, Korea, and elsewhere in the world we are all colleagues in the industry, and we have much to learn from each other.

Contents

Abbreviations and acronyms

A&D	Aerospace and Defense
AAQG	American Aerospace Quality Group
AC3B	Airworthiness Certification Criteria Control Board
ACARE	Advisory Council for Aviation Research and Innovation in Europe
ACWP	actual cost of work performed
AD	airworthiness directive
AECA	Arms Export Control Act
AFP	automatic fiber placement
AFPD	Air Force Policy Directive
AHM	aircraft health monitoring
AIA	Aerospace Industries Association
AIG	American International Group
APT	automatically programmed tool
APU	auxiliary power unit
ASB	alert service bulletin
ASD	Aerospace and Defence Industries Association of Europe
ASTM	American Society for Testing and Materials
ASU	Aircraft Sector Understanding
ATE	automated test equipment
ATR	Avions de Transport Régional
AVIC	Aviation Industries of China
AWACS	Airborne Warning and Control System
AWJ	abrasive water jet
BAFO	Best and Final Offer
BCWP	budgeted cost of work performed
BCWS	budgeted cost of work scheduled
BGA	business and general aviation
BIS	Bureau of Industry and Security
BLS	Bureau of Labor Statistics
BNDES	Banco Nacional de Desenvolvimento Econômico e Social
BWB	blended wing and body
BXA	Bureau of Export Administration
CAA	Civil Aeronautics Authority

CAA	Civil Airworthiness Authority
CAA	Civil Aviation Authority
CAAFI	Commercial Aviation Alternative Fuels Initiative
CAB	Civil Aeronautics Board
CAEP	Committee on Aviation Environmental Protection
CAPEX	capital expenditure
CAST	China Aerospace Science and Technology Corporation
CATIA	computer-aided three-dimensional interactive application
CCB	change control board
CCL	Commerce Control List
CDR	Critical Design Review
CDRL	contract data requirements list
CER	cost estimating relationships
CFE	customer-furnished equipment
CFE-CGC	Confédération Française de l'Encadrement – Confédération Générale des Cadres
CFIUS	Committee on Foreign Investment in the United States
CI	configuration item
CIEEMG	Commission interministérielle pour l'étude des exportations de matériel de guerre
CIP	component improvement program
CIS	Commonwealth of Independent States
CNC	computerized numerically controlled
CO_2	carbon dioxide
COFACE	Compagnie Française d'Assurance pour le Commerce Extérieur
COMAC	Commercial Aircraft Corporation of China
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
COTS	commercial off-the-shelf
CPM	Critical Path Method
CPMIEC	China Precision Machinery Import Export Corporation
CR	change request
CTC	cost-to-complete
DCAA	Defense Contract Audit Agency
DFARS	Defense Federal Acquisition Regulation Supplement
DOC	Department of Commerce
DoD	Department of Defense
DPD	digital product definition
DSCA	Defense Security Cooperation Agency
DSU	Dispute Settlement Understanding
DTI	Department of Trade and Industry
EADS	European Aeronautics, Defence and Space Company
EAQG	European Aerospace Quality Group
EAR	Export Administration Regulations
EASA	European Union Aviation Safety Agency

ECA export credit agency
ECAC European Civil Aviation Conference
ECN engineering change notice
ECO engineering change order
ECO export controls organization
ECP engineering change proposal
ECR engineering change request
EDC Export Development Canada
EETC enhanced equipment trust certificates
EPNdB effective perceived noise in decibels
EPROM erasable programmable read-only memory
ESA European Space Agency
ETS emissions trading system
EU-ETS European Emissions Trading System
EVM earned value management
FAA Federal Aviation Administration
FACE Future Airborne Capability Environment
FAR Federal Acquisition Regulation
FAR Federal Airworthiness Regulation
FASB Financial Accounting Standards Board
FIRRMA Foreign Investment Risk Review Modernization Act
FMS foreign military sales
FO *force ouvrière*
FRR Flight Readiness Review
FT Fischer–Tropsch
GA General Aviation
GAMA General Aviation Manufacturers Association
GAO Government Accountability Office
GARA General Aviation Revitalization Act
GATT General Agreement on Tariffs and Trade
GDP Gross Domestic Product
GE General Electric
GFE government-furnished equipment
GHG greenhouse gas
GOCO government-owned contractor-operated
GPA Guinness Peat Aviation
HALE high altitude long endurance
HEFA Hydroprocessed Esters and Fatty Acids
HSM high-speed machining
IAE International Aero Engines
IAI Israel Aerospace Industries
IAM International Association of Machinists
IAQG International Aerospace Quality Group
IASB International Accounting Standards Board
ICA instructions for continued airworthiness

ICAO	International Civil Aviation Organization
ICD	interface control documentation
IFE	in-flight entertainment
ILFC	International Lease Finance Corporation
IMP	integrated master plan
IMS	integrated master schedule
IPCC	Intergovernmental Panel on Climate Change
IPS	integrated product support
IPT	integrated product team
ISO	Organization for Standardization
ITAR	International Traffic in Arms Regulation
ITC	International Trade Commission
ITT	invitation to tender
JAA	Joint Aviation Authorities
JSF	Joint Strike Fighter
KAI	Korean Aerospace Industries
KIS	keep-it-sold
LASU	Large Aircraft Sector Understanding
LCA	large civil aircraft
LLP	life-limited parts
LRU	line replaceable unit
MALE	medium altitude long endurance
MBD	model-based definition
MCR	Mission Concept Review
MDR	Mission Definition Review
MRB	material review board
MRCA	Multi-Role Combat Aircraft
MRO	maintenance, repair, and overhaul
MTT	Moscow Institute of Thermal Technology
MWI	manufacturing work instruction
NAICS	North American Industrial Classification System
NAMMA	NATO Multi-Role Combat Aircraft Development and Production Management Agency
NAMMO	NATO MRCA Management and Production Organization
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NC	numerically controlled
NCR	non-conformance report
NDI	non-destructive inspection
NDIA	National Defense Industrial Association
NEC	nowhere else classified
NETMA	NATO Eurofighter and Tornado Management Agency
NextGen	Next Generation Air Transportation System
NLRB	National Labor Relations Board
NORC	Naval Ordnance Research Calculator

NORINCO	China North Industries Corporation
NOx	Generic Nitrogen Oxide Pollutants
NRCC	Nuclear Regulatory Commission Controls
NTSB	National Transport Safety Board
OBS	organizational breakdown structure
OCCAR	Organisation Conjointe de Coopération en matière d'Armement
ODTC	Office of Defense Trade Controls
OECD	Organization for Economic Cooperation and Development
OEM	original equipment manufacturer
OMS	Open Mission Systems
ORR	Operational Readiness Review
OT&E	Operational Test and Evaluation
P&W	Pratt and Whitney
P2F	passenger to freighter
PBP	performance-based payments
PDP	predelivery payments
PDR	Preliminary Design Review
PERT	Program Evaluation Review Technique
P_{go}	probability that the program will occur
PM	program manager
PMA	Part Manufacturer Approval
PMP	program management plan
ppm	parts per million
PRR	Production Readiness Review
P_{win}	probability of win
QEC	quick engine change
QMS	quality management system
RFI	request for information
RFP	request for proposal
RFQ	request for quotation
RFT	request for tender
RMA	reliability, maintainability, availability
RNAV	area navigation
RNP	required performance navigation
RPV	remotely piloted vehicle
SADI	Strategic Aerospace and Defense Initiative
SAE	Society of Automotive Engineers
SAR	System Acceptance Review
SARPs	Standards and Recommended Practices
SB	service bulletin
SCM	subcontract management
SCM	Subsidies and Countervailing Measures
SDR	System Design Review
SECBAT	Société d'Étude et de Construction de Breguet Atlantic

SEMP	systems engineering management plan
SEP	systems engineering plan
SIC	Standard Industrial Code
SIP	Synthesized Iso-Paraffins
SJAC	Society of Japanese Aerospace Companies
SM	Single Manager
SMP	subcontract management plan
SOO	statement of objectives
SOPs	standard operating procedures
SOW	statement of work
SPEEA	Society of Engineering Employees in Aerospace
SPF	superplastic forming
SRD	system requirements document
SRR	System Requirements Review
SRU	shop replaceable unit
STOVL	short takeoff vertical landing
TC	Type Certificate
TCTO	time compliance technical order
TO	technical order
TRR	Test Readiness Review
UAC	United Aircraft Corporation (Russia)
UAS	unmanned aerospace system
UAV	unmanned aerospace vehicle
UAW	United Auto Workers
UCAV	unmanned combat aerospace vehicle
UCI	Unmanned Aircraft Systems Control Initiative
UNFCCC	United Nations Framework Convention on Climate Change
UTAS	United Technologies Aerospace Systems
VOC	volatile Organic compounds
VTOL	vertical takeoff and landing
WBS	work breakdown structure
WIP	work-in-process
WTO	World Trade Organization
WTW	well-to-wake

1 Introduction

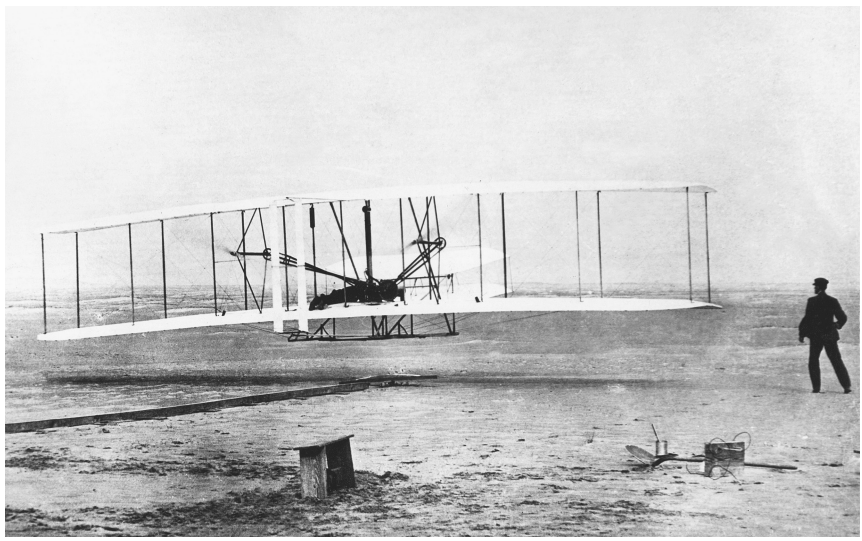

Figure 1.1 The beginning of a new industry.

It put a man on the moon. The aerospace industry is exceptional in many respects. It is a technological crown jewel that synthesizes much of the most advanced scientific and engineering knowledge of modern civilizations. It produces products that, even to technologically jaded citizens of the twenty-first century, are breathtaking in their appearance and capabilities.

The structure and characteristics of the industry are described in detail in Chapter 2, but a few summary statistics published by the Aerospace Industries Association (AIA) provide insight into the economic importance of the industry in the USA:

- The US Aerospace & Defense (A&D) industry supports 2.4 million jobs in the USA in 2016, representing approximately 2% of the nation's total employment base and 13% of the nation's manufacturing workforce.

- End-use manufacturers of A&D systems accounted for 35% (845,000) of the industry's total jobs, while the supply chain accounted for the remaining 65%, or 1.6 million jobs.
- In 2016, the US Aerospace & Defense industry generated $872 billion in sales revenue.
- End-use manufacturers of A&D systems accounted for 52% of total sales, while the industry's supply chain accounted for the remaining 48% of sales.
- A&D generated $307 billion in value-added products and services, which accounted for 1.8% of US Gross Domestic Product.
- A&D is the nation's leading net exporting industry and generated a record trade balance of $90 billion in 2016.
- A&D accounts for 10% of total US exports in goods, and is the nation's second-largest exporting industry.

The Aerospace and Defence Industries Association of Europe (ASD), the European equivalent of AIA, publishes some similar data:

- Total turnover for the A&D industry in Europe for 2016 was €220.2 billion.
- Total employment in 2016 was 843,400.
- The industry generated €20 billion in research & development (R&D) in 2016.
- European A&D exports in 2016 were €123 billion.

Distinguishing characteristics of the aerospace industry

This book will look in detail at some of the fundamental ways in which the aerospace industry is managed differently from other industries. Before proceeding to that detailed study, it is worthwhile to consider a few of the **intangible** characteristics that differentiate aerospace from its industrial peers:

- Aircraft and space vehicles are perhaps the ultimate technological icons of our civilization. The industry represents a single-point confluence of many of the most advanced technical achievements of our species.
- Aircraft and rockets are big, visible, noisy, and in the aesthetic of some observers, awesome to behold.
- They are extremely expensive to acquire and to operate.
- The complexity of aerospace design and manufacture is probably unmatched by any other industry.
- Since its advent, the industry has been a symbol of national prestige and military hegemony.
- The industry is intrinsically international in outlook and structure. In many ways it represents the most sophisticated manifestation of large-scale technological cooperation among nations.

- The industry and its products are inherently exposed to risk of large-scale catastrophic occurrences, resulting in application of rigorous international and national safety standards and regulations.
- The products of the industry are characterized by a dichotomy of civil or military applications. The two segments often overlap, eliciting the attention and direct involvement of governments and international organizations.
- The increasing volume of air transportation combined with public concern about rising emissions seem to be leading to an environmental dilemma that will eventually have to be resolved by government involvement, technological improvements, and societal change.

The structure of this volume

In many respects, the aerospace industry is managed in the same ways as other manufacturing industries. In other ways, aerospace management methods have evolved in ways that are distinctly different. The objective of this book is to identify the distinct management methods of the industry, to understand how they came to evolve, and to study how they are applied.

To accomplish this, we will proceed by sequentially focusing on the traditional disciplines familiar to any student of management.

In Chapter 2 we will examine the **general structure of the aerospace industry**, starting by studying its historical evolution. We will survey the many specialized products and industry sectors that make up its horizontal segmentation, and will pay special attention to the military–civil dichotomy that divides the industry into halves of roughly equivalent size. We will see how the industry is distributed geographically within Europe, the USA, and elsewhere, and will discuss the industry's vertical stratification and its value chain, beginning with raw material suppliers and proceeding to the giant integrated aircraft manufacturers at the top of the pyramid.

Chapter 3 deals with the **aerospace workforce and labor relations**. It analyzes the geographical distribution of the workforce in North America, Europe, and Asia, and looks at government initiatives to foster its growth. It follows the history of organized labor in the industry, and considers political controversies caused by redistribution of aerospace jobs as a result of international collaborative ventures.

Chapter 4, on **aerospace law, international accords, and contracting procedures**, is a summary of the context and application of laws and international agreements applying to the aerospace industry, including government airworthiness regulations and agencies, civil liabilities and tort law governing civil and military aircraft, export control licensing, and international limitations on government subsidies. A section on aerospace contracting methods is also included.

Chapter 5 addresses **government financial support of aerospace**. It reviews the history of government nationalization and subsequent privatization

of aerospace industries, international agreements intended to curtail market distortions caused by government loans and subsidies, and an overview of the long-term Euro–American dispute involving perceived unfair subsidies to Boeing, Airbus, Bombardier, and Embraer.

Chapter 6 covers the unique history of **international cooperation in aerospace**, including **joint ventures, teaming, and industrial offsets**. It analyzes the motivation for international cooperation and the structural arrangements that aerospace firms use to work together internationally, and includes a study of economic benefits and political controversy surrounding industrial offsets.

Chapter 7 explores **aerospace accounting and financial management**, and contains explanation and analysis of unconventional financial methods and accounting treatments used in the industry. These practices are often a result of inordinately large capital investments and extended time intervals between program launch and breakeven. The chapter studies financing strategies used in the industry, including arrangements with risk-sharing partners. Financial practices in both the civil and military sectors are discussed and accounting concepts used by Airbus and Boeing are compared and contrasted.

Chapter 8 is a treatment of **aerospace systems engineering and technology management**. It is a detailed review of how the aerospace industry developed the concept of systems engineering, what the concept accomplishes, and how the discipline has been defined and applied to control technology during the phases of design, production, and post-delivery. Procedures used for change management and configuration control are described in detail.

Chapter 9 describes practices the industry has developed for **management of aerospace programs**. Beginning with a definition of an aerospace program, the chapter recounts the early history of the need for a management system to control the growing design and production complexity in the industry. Basic tenets of the program management concept are explored, and standard aerospace program management practices are explained. Illustrative examples are provided, including management structures of major joint international programs.

Chapter 10 addresses **aerospace production management**, and traces the evolution of aerospace production methods, including innovative technologies originally developed specifically for aerospace applications. Recent aggressive initiatives to improve efficiencies by introducing lean manufacturing methods are described. Concepts for scheduling and control are discussed, including the use of work breakdown structures. The flow of planning, control, and implementation in the factory are traced in detail.

Chapter 11, on the subject of **management of aerospace quality assurance**, includes a discussion of the concept of cost of quality in the aerospace industry, and follows the historical development of international aerospace quality standards. A detailed explanation is provided of AS/EN 9100, the principal quality standard that currently defines industry requirements. Procedures for managing the disposition of non-conforming material are defined.

Chapter 12 studies **aerospace supply chain management**, and looks at the aerospace supplier network that accounts for the majority of the value of new aircraft. Alternative methods for organizing the supply chain are analyzed and compared. Historical experiences by Boeing and Airbus are described and discussed. Subcontract management and control practices are surveyed.

Chapter 13 explores the distinctive practices involved in **aerospace marketing**. The entire sales process is traced from beginning to end, with a discussion of unique circumstances that characterize the product and the industry. Different processes for civil and military markets are compared. Considerations for international marketing are surveyed, including industrial offsets and international alliances.

Chapter 14 is an overview of **maintenance, repair, and overhaul (MRO)** of aircraft. This sector involves services performed on aircraft in service, and thus differs from much of the other material in this book, which principally addresses activities related to management, design, and production of aerospace products. The chapter describes the principal categories of MRO work, classifications of aerospace parts inventories, management of technical data, maintenance of airborne software, and the distinctions between civil and military MRO activities.

Chapter 15 considers **environmental challenges facing the aerospace industry** in the context of rising global concern over greenhouse gasses and other emissions. Aviation is currently a relatively small contributor to gasses, but increasing air travel and decreasing emissions from other sources may result in a dramatic rise in aviation's future share of the total. The chapter studies trend data and international environmental conventions addressing aviation and surveys solutions being developed by the aerospace industry, including alternative biofuels, electric and hybrid aircraft, hydrogen fuel, aerodynamic improvements, and carbon trading schemes. Noise emissions and sound-reduction technologies are also discussed.

2 Structure of the aerospace industry

Overview of the industry structure

Classification systems are inherently arbitrary, but the aerospace industry lends itself to division into major segments based upon the types of products produced. The firms in these segments share common affinities, and governments and economic observers use the segments as practical means of classifying firms and measuring market activity.

The US Department of Commerce (DoC) uses Standard Industrial Classification (SIC) codes to categorize the industrial activity of all firms in the USA. In this system, the SIC codes are four-digit classifications that are subcategories of three-digit industry groups of a broader nature. The DoC considers most aerospace activity to fall within industry groups 372, **Aircraft and Parts**, and 376, **Guided Missiles and Space Vehicles and Parts**. The specific SIC codes are shown in Table 2.1. Also shown are corresponding North American Industrial Classification System (NAICS) codes that have recently come into use by the US Office of Management and Budget.

These broad categories are further refined in other systems of classification, notably by the industry itself. The following breakdown by major product categories and subcategories is typical of efforts to identify specific segments.

Note that this particular classification includes engines, but does not include aerospace electronics, commonly called avionics, or other items of aerospace equipment such as landing gear, hydraulics, control systems, electrical systems, environmental control systems, and aircraft interiors. The value of

Table 2.1 US Department of Commerce and US Office of Management and Budget codes for aerospace industry segments

SIC	*Industry sector*	*NAICS*
3721	Aircraft	336411
3724	Aircraft engines	336412
3728	Aircraft parts	336413
3761	Guided missiles and space vehicles	336414
3764	Space vehicle propulsion units	336415
3769	Guided missile and space vehicle parts	336419

Table 2.2 Aerospace market segments identified by *Aviation Week & Space Technology*

Aerospace industry product categories	
Category	*Products*
Military fixed wing aircraft	Attack
	Bombers
	Cargo/transport/refueling
	Early warning
	Electronic warfare
	Fighters
	Observation
	Patrol anti-submarine
	Reconnaissance
	Research/test Bed
	Training
	Utility
Commercial fixed wing aircraft	Narrow body turbofans
	Wide body turbofans
	Turboprops
Rotary wing aircraft	Naval
	Scout/attack
	Tiltrotor
	Training
	Transport
	Utility
Business and general aviation aircraft	Turbofan
	Turboprop
	Reciprocating engine powered
Gas turbine engines	
Unmanned aerial vehicles and drones	
Space launch vehicles	Manned systems
	Unmanned systems
Missiles	Air-to-air
	Air-to-surface
	Anti-armor
	Anti-ballistic
	Anti-ship
	Anti-submarine
	Surface-to-air
	Surface-to-surface

these product lines is a significant part of the overall aerospace market, and although the firms sometimes classify themselves as members of other sectors such as the electronics industry, they also have a strong identity as part of the aerospace market.

In addition to the manufacturing sectors described above, the aerospace industry is generally considered to encompass a broad range of services that are substantial in terms of revenue and numbers of people employed.

Table 2.3 Aerospace industry segments as classified by the US Office of Management and Budget

Standard Industrial Classifications Applicable to the Aerospace Industry

3721 Aircraft
- **37211** Military aircraft
- **37215** Civilian aircraft
- **37217** Modification, conversion, and overhaul of previously accepted aircraft
- **37218** Aeronautical services on complete aircraft, NEC

3724 Aircraft engines and engine parts
- **37241** Aircraft engines for military aircraft
- **37242** Aircraft engines for civilian aircraft
- **37243** Aeronautical services on aircraft engines
- **37244** Aircraft engine parts and accessories

3728 Aircraft parts and auxiliary equipment, NEC
- **37281** Aircraft parts and auxiliary equipment, NEC
- **37282** Aircraft propellers and helicopter rotors
- **37283** Research and development on aircraft parts

3761 Guided missiles and space vehicles
- **37611** Complete guided missiles (excluding propulsion systems)
- **37612** Complete space vehicles (excluding propulsion systems)
- **37613** Research and development on complete guided missiles
- **3761**4 Research and development on complete space vehicles
- **37615** All other services on complete guided missiles and space vehicles

3663 Radio and television communications equipment
- **36631** Communication systems and equipment, except broadcast

3764 Space propulsion units and parts
- **37645** Complete missile or space vehicle engines and/or propulsion units
- **37646** Research and development on complete missile or space vehicle engines and/or propulsion units
- **37647** Services on complete guided missile or space vehicle engines and/or propulsion units, NEC
- **37648** Missile and space vehicle engine and/or propulsion unit parts and accessories

3769 Space vehicle equipment, NEC
- **37692** Missile and space vehicle engine and/or propulsion unit parts and accessories
- **37694** Research and development on missile and space vehicle parts and components, NEC

3669 Communications equipment, NEC
- **36691** Alarm systems
- **36692** Traffic control equipment
- **36693** Intercommunication equipment

3812 Search, detection, navigation, guidance, aeronautical and nautical systems, instruments, and equipment
- **38121** Aeronautical, nautical, and navigational instruments, not sending or receiving radio signals
- **38122** Search, detection, navigation, and guidance systems and equipment

3829 Measuring and controlling devices, NEC
- **38291** Aircraft engine instruments, except flight

Note: NEC = Not elsewhere classified.

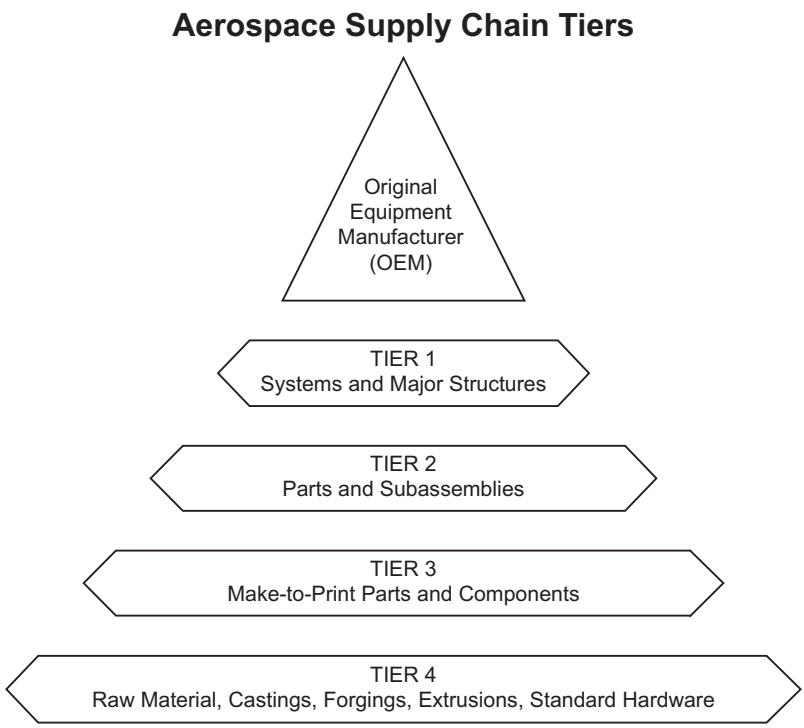

Figure 2.1 The hierarchical structure of the aerospace industry.

Examples are the aircraft maintenance, repair, and overhaul sector, known as MRO, and the satellite services component of the space sector. These service activities will be included in our broader overview.

Another means of describing market segments involves stratifying the market into vertical tiers. With this approach, the **original equipment manufacturer (OEM)**, or **prime contractor**, who contracts to deliver the completed aerospace product to the final customer, is at the top of the hierarchy. Below the OEM are subordinate tiers of suppliers that feed intermediate products into the manufacturing process. Buying and selling activities occur at each transition from one tier to the next. The industry's supply chain is discussed in detail in Chapter 12.

This chapter will attempt to identify and describe principal segments of the aerospace market, considering the natural delineations of the technical differences between products, such as airliners, missiles, and spacecraft. At the same time, the major market dichotomy between military aerospace and civil aerospace will be considered. Aerospace activities by geographical regions will also be noted.

Chapter 3, which addresses the aerospace workforce, will show that the industry worldwide currently creates jobs for more than a million direct

Table 2.4 Aerospace production is concentrated in a small number of countries

Aerospace industry revenue ($ billions)	
Country	*2017 Revenue*
USA	408
France	69
China	61
UK	49
Germany	46
Russia	27
Canada	24
Japan	21
Spain	14
India	11
Brazil	9

Source: Statistica.

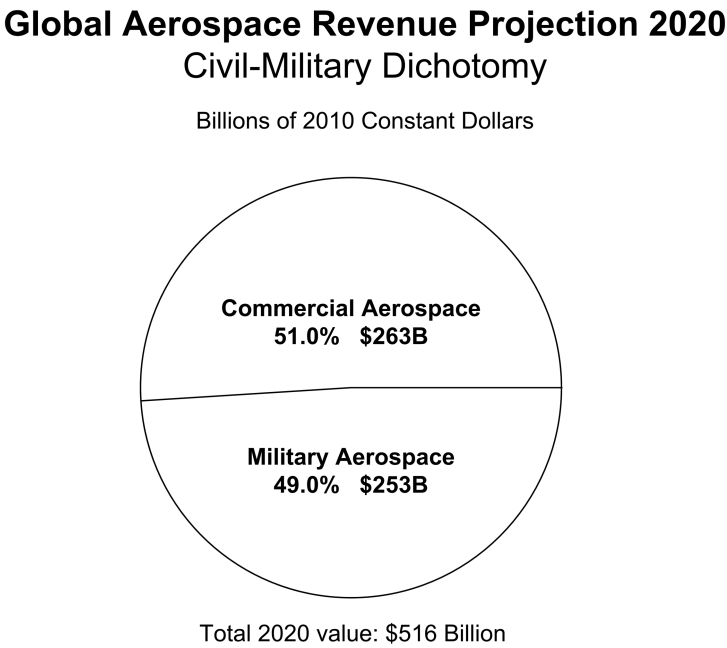

Figure 2.2 The approximately equal shares of military and commercial aerospace.

Note: this total value is less than shown in Table 2.4 due to exclusion of some industry activities.
Source: Deloitte & Touche LLP.

employees. If jobs indirectly created by the industry are included, this number increases by several multiples.

Measurements of revenue of the industry vary according to composition of statistical data, but the credible economic reporting firm Statistica showed revenue of $739 billion in 2017 for the 11 largest aerospace producing countries.

How do the various market segments compare in terms of size and economic importance?

At the top level, the biggest dichotomy in the industry is the division between civil and military equipment. The relative proportions of this dichotomy vary from country to country and from subsector to subsector, but for aggregate worldwide aerospace production we find that roughly half of annual revenues are military in nature.

For the important subsector of completed aircraft deliveries, approximately 75% of annual sales are civil aircraft, and the largest component of civil aircraft production consists of large airliners and mid-sized regional transports. Business aircraft is the category with the second-biggest revenue total.

From the perspective of the value chain that produces the finished products, the largest revenue shares belong to the large prime contractors or OEMs. The indicated shares vary according to how the data is compiled, but the OEM revenue share is approximately 60% of total industry output. Looking farther down the value chain, the propulsion industry has the largest share among subcontractors at about 10%, followed by other contributors.

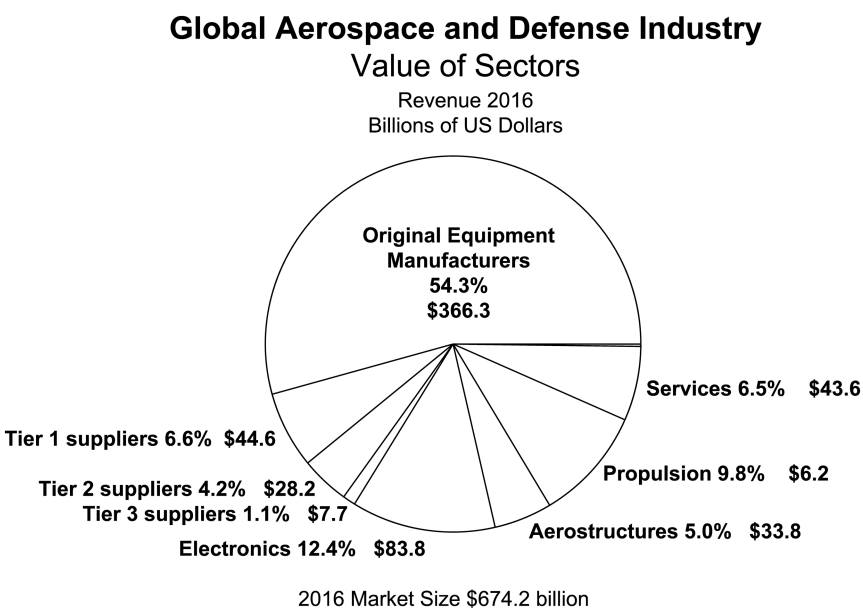

Figure 2.3 Original equipment manufacturers' domination of defense aerospace.

Source: Deloitte.

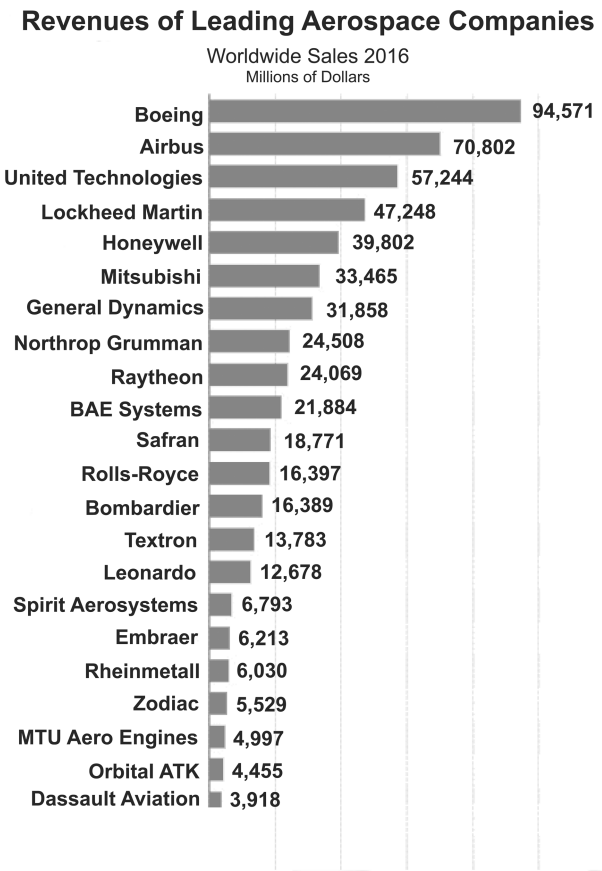

Figure 2.4 A few very large producers control a big share of the industry.

Source: Statistica.

Military aircraft

The military aircraft segment of the aerospace market has several striking characteristics. First, in terms of value it is highly concentrated among a few countries, principally the USA, the European Union, Russia, Japan, and China. Secondly, it is highly diverse, encompassing a vast array of specialized systems.

The general category of military aircraft is very broad and somewhat imprecise. Some military types, particularly transports and utility helicopters, have been certified by civil airworthiness authorities and are sold in commercial markets in slightly modified configuration.

The mix of military aircraft types varies dramatically among countries, reflecting their military threats and requirements. Some specialized military

aircraft types are typically limited to countries with diverse requirements and large defense budgets.

Virtually all nations of significant size operate fighters, generally defined as armed fixed wing aircraft with combat capability. For comparative purposes, Table 2.5 is a snapshot of international fighter aircraft inventories during the last decade. Although the highest numbers are in large, economically important countries, we also see large fleets in nations located in historic conflict zones. The numbers do not reflect qualitative differences in aircraft. Most of the North Korean aircraft, for example, are obsolete models from the 1950s and 1960s.

The mix of military aircraft types operated by national armed forces varies dramatically from country to country. At one extreme are the small number of countries with strategic military roles, notably the USA, Russia, and China, who possess heavy bombers, intercontinental ballistic missiles, aerial refueling tankers, airborne early warning radars, and other strategic aeronautic systems. Typical more-or-less industrialized nations generally operate a more limited variety of aircraft, principally limited to fighters, medium transports, trainers, and helicopters. The poorest nations likewise attempt to maintain small inventories of fighters, transports, trainers, and helicopters, but they are often out of date and of limited quantity.

Table 2.5 Estimated international inventories of fighter aircraft during the last decade

National inventories of fighter aircraft

Fixed wing aircraft with combat capability

Country	*Quantity*	*Date*
1 USA	3,318	2011
2 Russia	1,900	2008
3 China	1,500	2014
4 India	1,080	2011
5 Egypt	900	2011
6 North Korea	661	2011
7 Pakistan	502	2006
8 Turkey	465	2014
9 South Korea	458	2012
10 Germany	423	2014
11 Israel	420	2011
12 Iran	407	2006
13 Libya	385	2014
14 Japan	374	2011
15 Taiwan	360	2014
16 Syria	335	2005
17 Italy	320	2011
18 Greece	308	1999
19 France	306	2009
20 Saudi Arabia	287	2006

Source: Forecast International.

Of the many companies that constitute the aerospace industry, a relatively small number have the technical and financial resources necessary to design and manufacture modern military aircraft. Figures 2.5, 2.6, and 2.7 identify these companies and the types of aircraft they make.

Figure 2.5 conveys the impression that the Russian and Chinese aerospace industries are negligible presences in the international market for combat aircraft. However, Russia has a long and impressive history of designing and building highly capable aircraft of the type. Following the near-collapse of the Russian aerospace industry after the disintegration of the Soviet Union, the industry has been reorganized and refinanced, and is once again starting to emerge in international markets. China also has reorganized its military aerospace industry and is experimenting with indigenously designed advanced fighters.

The large and important military transport market is dominated by Lockheed Martin, Airbus, and Boeing, who historically have built heavy commercial transports. The less valuable market for smaller transports is more diversified.

The military helicopter market consists primarily of transports of various sizes, but also includes armed attack helicopters and specialized types for missions such as reconnaissance, search and rescue, minesweeping, antisubmarine warfare, and so on. The supply side of the market is characterized by many international suppliers and is highly competitive. This is a segment of the military aerospace market in which Russian industry has retained a formidable presence.

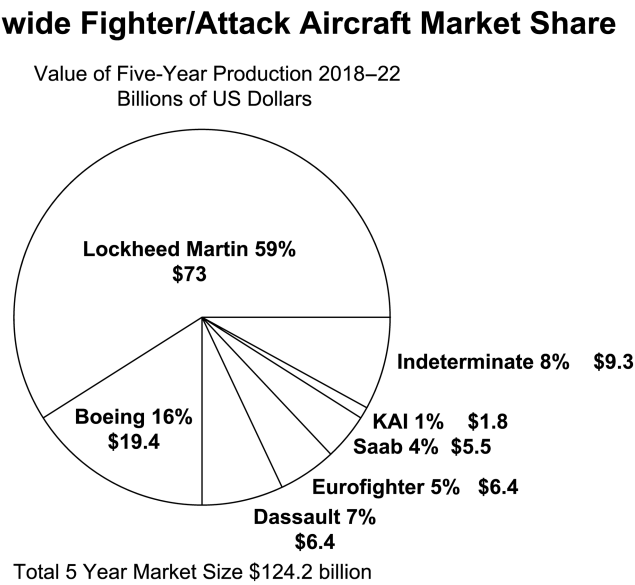

Figure 2.5 The limited field of combat aircraft manufacturers.

Source: *Aviation Week & Space Technology*.

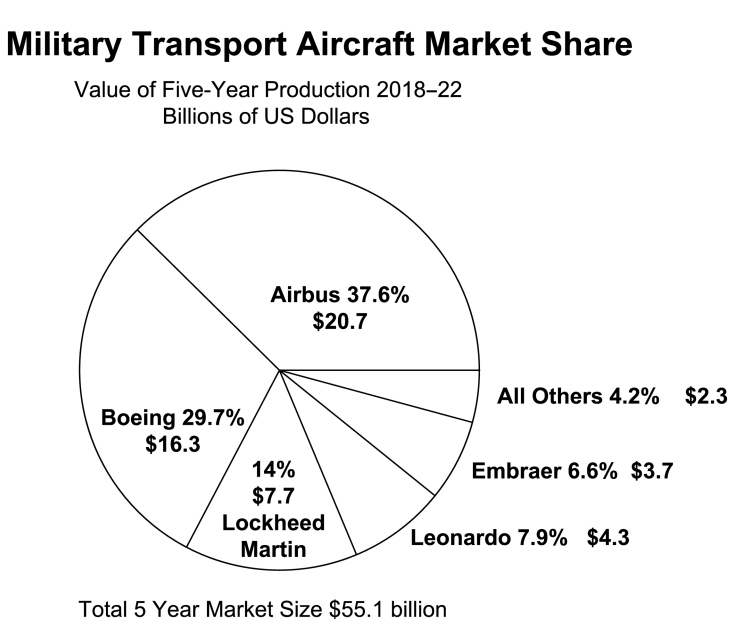

Figure 2.6 Airbus, Boeing, and Lockheed Martin dominate the market for military transports.
Source: *Aviation Week & Space Technology*.

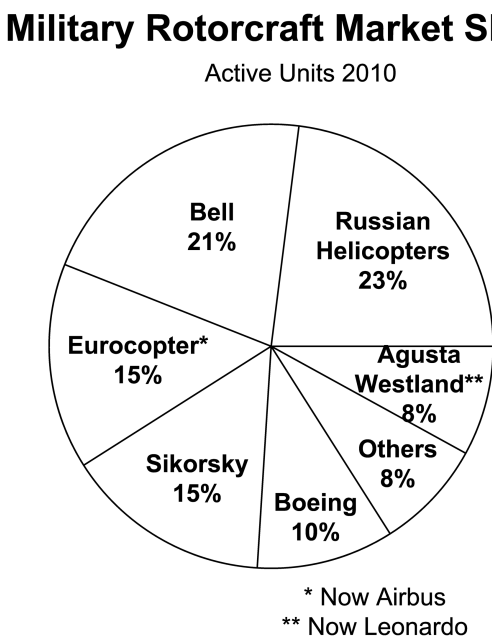

Figure 2.7 Military helicopters: manufacturers' market shares.
Source: Frost and Sullivan.

Large civil transport aircraft

This is the most concentrated segment of the aerospace industry, dominated entirely by Boeing and Airbus. In terms of value it is also by far the most important component of the civil aerospace industry. The historical Soviet manufacturers of civil airliners, Tupolev, Antonov, and Ilyushin, have struggled to compete in the post-Cold War-free markets, but perhaps will eventually recreate themselves and reemerge. Likewise, the Chinese civil aircraft industry, which historically has been absent from international markets, has been targeted by the Chinese government for development, and has launched several airliner programs intended to compete in international markets.

In recent years the competition between Boeing and Airbus has been intense as the companies have battled for domination throughout the world. This competition has been an unqualified benefit to aircraft buyers, who enjoy the advantages of highly competitive markets: lower prices, improved products, and improved service.

In recent years, total deliveries of these large aircraft have exceeded 1,200 units. The market is notoriously cyclical, and demand is derived entirely from passenger demand for airline transportation and by air freight requirements, which in turn are largely driven by cyclical economic factors. Rates of retirements of older aircraft also affect demand for new aircraft. In spite of the cyclical nature of orders, both companies commonly have backlogs of several years of undelivered aircraft, so recent delivery trends have tended to be stable.

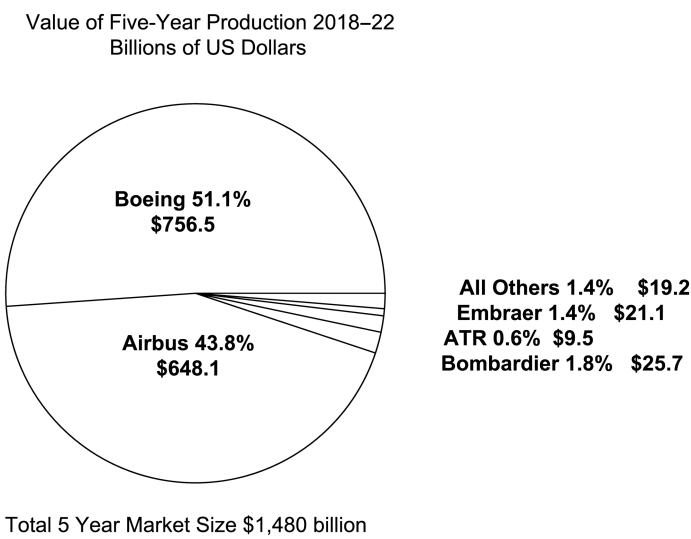

Figure 2.8 The duopoly of large commercial aircraft manufacturers.

Source: *Aviation Week & Space Technology*.

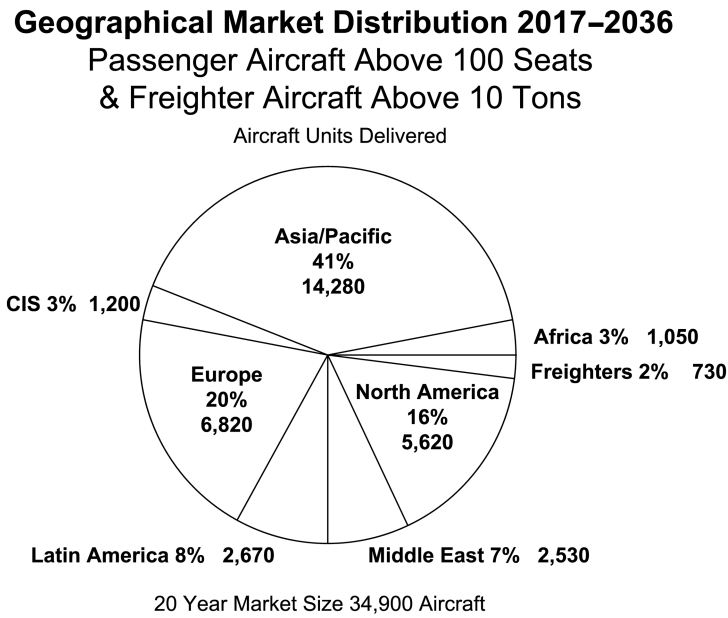

Figure 2.9 Most airliners are delivered to Asia, Europe, and North America.
Source: Airbus.

The market for large commercial aircraft is quintessentially international, reflecting the geographically dispersed nature of the airline industry. Forecasts of market demand for the next 30 years indicate that almost 80% of purchases will come from Asia, Europe, and North America.

Twenty-year forecasts indicate that the market will continue to grow substantially, as demand increases and approximately 13,000 older aircraft are retired from service. Airbus estimates that the overall market will absorb approximately 35,000 new aircraft deliveries. Boeing estimates are similar.

Regional airliners

One of the most dramatic developments in the civil airline industry in recent decades has been the growth and evolution of regional airlines, sometimes called commuter airlines. Regional airlines are generally defined as operators that provide scheduled air service over relatively short distances between smaller cities, in aircraft of fewer than 100 seats. The growth of these airlines has resulted in burgeoning demand for suitable aircraft.

Initially regional airliners were exclusively turboprops, which are cheaper to produce and are highly efficient over short-range, low-altitude routes. In the 1980s, more than 95% of regional airliners in service were

turboprops. Subsequently larger jets displaced turboprops in much of the regional market.

The rapid transition to jets from turboprops appeared to end by 2002, by which time approximately half the regional airliners in service were jets. Of the illustrious historical producers of regional turboprops such as Fokker, British Aerospace, Fairchild, and Dornier, the only remaining major producers are Bombardier and the European consortium Avions de Transport Régional, or ATR.

Contributing to the overall health of the market, the average size of regional aircraft has grown, adding value for producers. Paradoxically, in spite of the strong growth of the market, the number of major suppliers has diminished. Three long-time suppliers of regional jets, Fokker, BAE Systems, and Fairchild Dornier, have either withdrawn from the market or have ceased operations. The regional jet market is now dominated by Embraer and Bombardier.

However, new competitive entrants are emerging in the form of Russia's Sukhoi, Japan's Mitsubishi, and Commercial Aircraft Corporation of China, Ltd. (Comac). Sukhoi and Comac have introduced the Russian Regional Jet and the ARJ21, respectively, both of which are in limited initial service. Mitsubishi is close to introduction of its Mitsubishi Regional Jet, and Comac is also in final development of the C919.

Market projections by Embraer and Bombardier vary somewhat, but are consistent in their conclusion that the market will continue to experience strong growth. The consensus is that sales for the next 20 years will approach $200 billion.

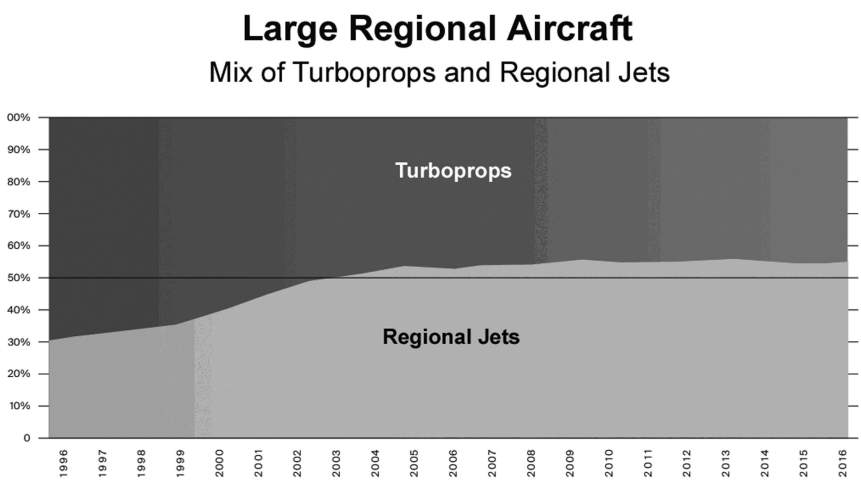

Figure 2.10 Market shares of regional jets and turboprops have stabilized in recent years.

Source: Flightglobal Fleets Analyzer.

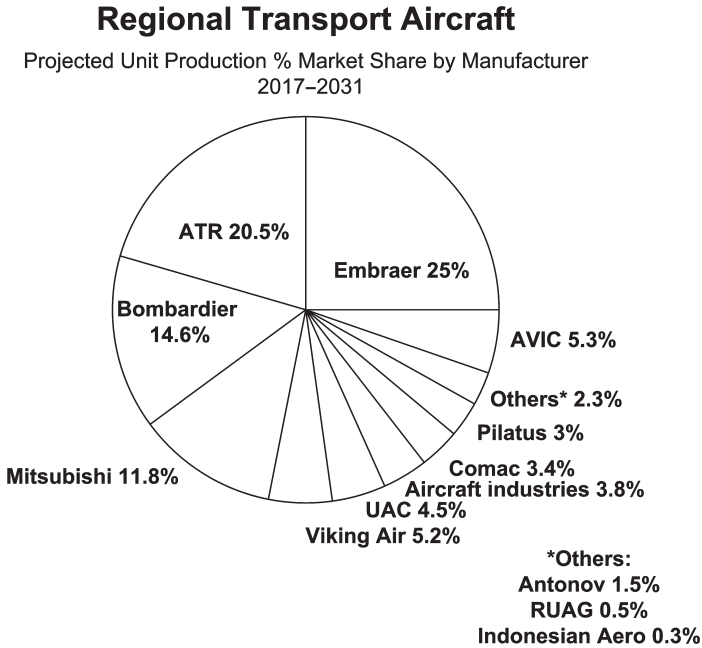

Figure 2.11 Current domination by ATR, Bombardier, and Embraer is threatened by emerging entrants.

Note: Sukhoi is part of UAC.
Source: Forecast International.

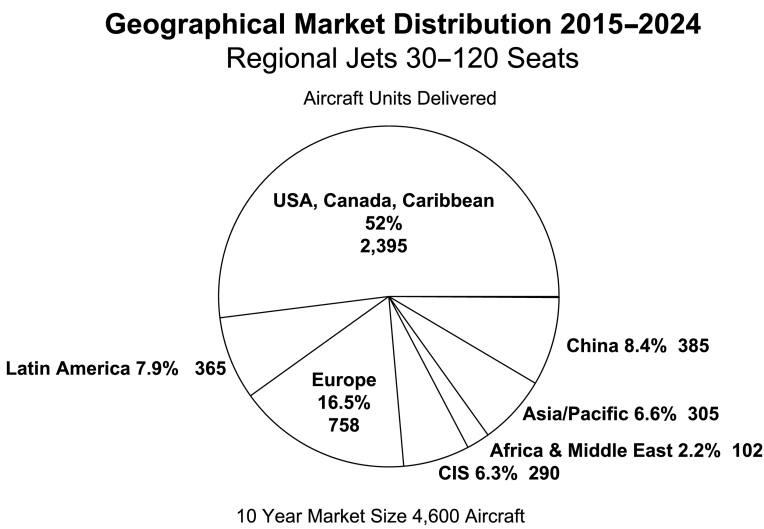

Figure 2.12 North America is by far the largest geographical market for regional jets.

Source: Embraer.

Business aircraft

Business aircraft are generally defined as aircraft of modest size, typically 6–20 seats, owned by companies for the purpose of providing transport for business reasons. New models recently introduced by Boeing, Airbus, Bombardier, and Embraer are significantly larger and are essentially airliners outfitted for the purpose of corporate travel. The FAA defines business transportation as 'any use of an aircraft (not for compensation or hire) by an individual for transportation required by the business in which the individual is engaged'. The FAA defines corporate/executive transportation as 'any use of an aircraft by a corporation, company or other organization (not for compensation or hire) for the purposes of transporting its employees and/or property, and employing professional pilots for the operation of the aircraft.'

In terms of value, the market is dominated by jets, but approximately 20% of business aircraft sold are turboprops, primarily at the lower end of the price range. It is a highly diverse and competitive market.

As Figures 2.13 and 2.16 show, major players on the supply side of the market are Raytheon (USA), Cessna (USA), Learjet (USA), Pilatus (Switzerland), Dassault (France), Gulfstream (USA), and Bombardier (Canada).

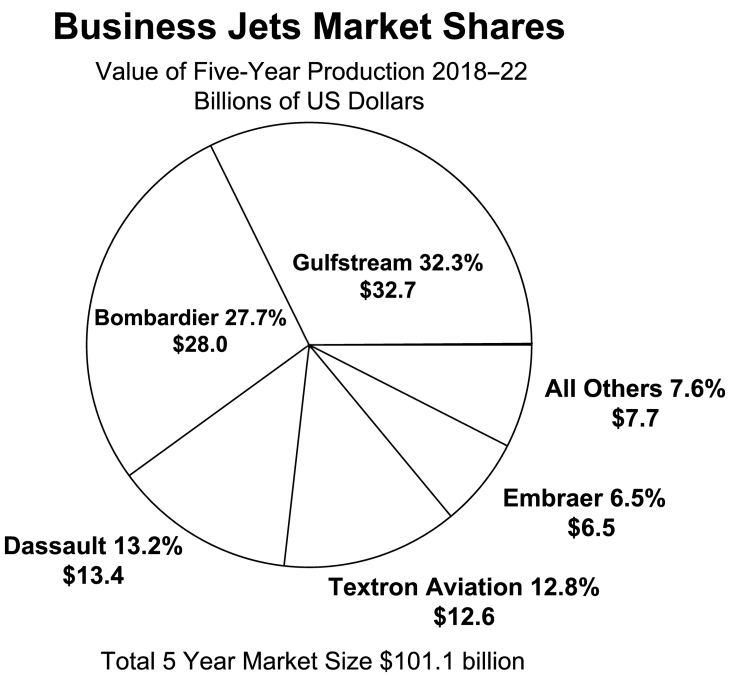

Figure 2.13 The business aircraft market is characterized by many competitors.

Source: *Aviation Week & Space Technology*.

An important development in this market in the 1990s was the advent of fractional ownership, which became a common alternative to the historical practice of company ownership of individual aircraft for their exclusive use. Under fractional ownership schemes, the aircraft is owned by intermediary companies that guarantee to provide aircraft and crews immediately upon request by participating subscriber companies or individuals. The subscribers, in turn, make large up-front payments to acquire equity shares in the aircraft, and pay hourly charges for aircraft use. Fractional ownership arrangements are viewed as advantageous by many companies because aircraft utilization rates are higher (thus diminishing the cost of ownership) and because the individual subscriber companies do not have to incur the significant expense of maintaining their own flight crews and flight operations departments.

Both Honeywell and Rolls-Royce, major suppliers of turbine engines to business aircraft, issue annual projections of future aircraft sales in the market segment. According to Honeywell's projections, 7,700 new business jets worth $251 billion will be delivered internationally from 2019 to 2028.

A conspicuous characteristic of the market for business aircraft is that the share of the USA is disproportionately large. For geographical and historical reasons, American businesses utilize business aircraft to a greater extent than enterprises in other countries. The US market is more than double the rest of the world combined. The European and South American markets are the second and third largest markets, respectively.

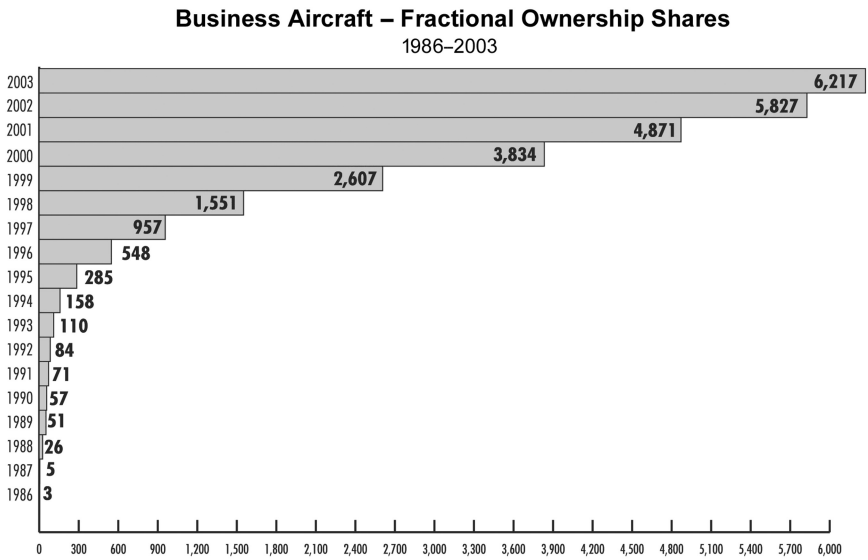

Figure 2.14 The rise in fractional ownership of business aircraft has had a major impact on the market.

Source: AvData Inc.

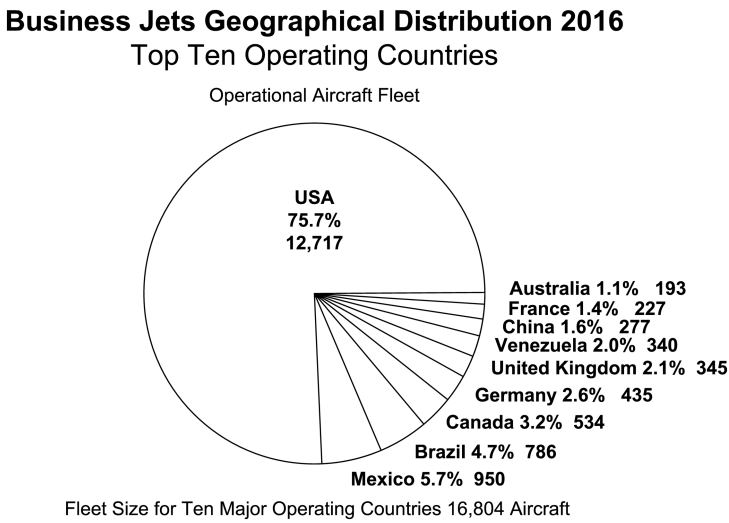

Figure 2.15 The USA is the primary market for business aircraft.

Source: Statistica.

General aviation

The general aviation (GA) segment is normally considered to consist of smaller, privately owned aircraft. However, the distinction between general aviation and business aviation is sometimes blurred, and often, data pertaining to general aviation also includes some business aircraft.

The USA has historically been the dominant supplier of general aviation aircraft, but a pattern of disastrous product liability lawsuits against the manufacturers in the 1970s and 1980s caused many of them to cease production, and international producers, notably in France, expanded to fill the void. Annual American production of general aviation aircraft plunged from over 17,000 in 1979 to only 2,600 in 1983. Cessna, the largest manufacturer of general aviation aircraft, stopped production of piston-engine aircraft in 1986. Many aircraft that had been the subject of product liability lawsuits were more than 40 years old. The tendency of general aviation owners to maintain and operate their aircraft indefinitely created an almost never-ending 'liability tail' for the manufacturers. With close to 400,000 general aviation aircraft in use by 1994, GA manufacturers faced enormous product liability exposure.

Faced with a precipitous decline of the industry segment, Congress passed the General Aviation Revitalization Act of 1994 (GARA), which immunized general aviation aircraft manufacturers against lawsuits for defects in products older than 18 years. Since the advent of GARA, the industry in the USA has experienced a resurgence, and international manufacturers have in

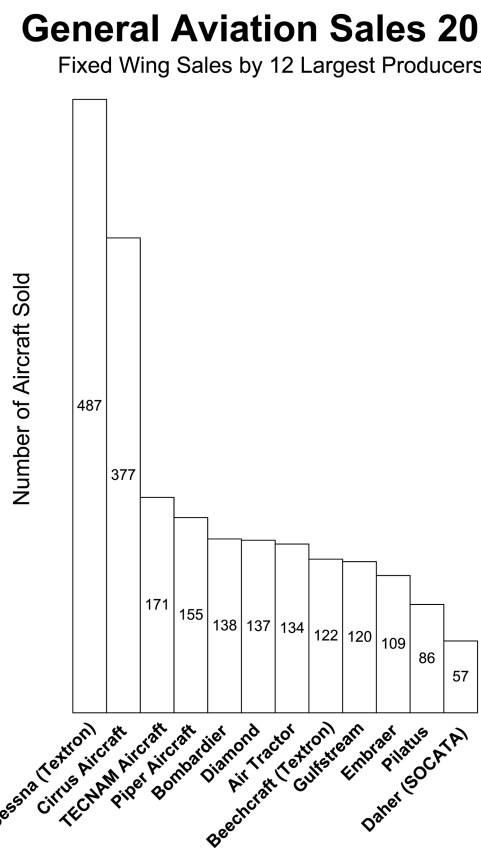

Figure 2.16 A characteristic of the general aviation sector is the large number of producers. Source: The General Aviation Manufacturers Association.

many cases managed to survive and prosper. GARA is discussed in detail in Chapter 4.

An earmark of the general aviation segment is its diversity. It is a vestige of the earliest days of aviation, when technology was relatively simple, and when a relatively modest investment was sufficient to enable new manufacturers to enter the field. Today, major general aviation manufacturers are large-scale, capital-intensive producers of highly complex aircraft, but the segment also includes smaller family-owned companies that produce cheap, simple designs.

The General Aviation Manufacturers Association (GAMA), the principal international trade group of the market segment and the authoritative source of data pertaining to the category, defines general aviation as all aviation other than military and scheduled commercial airlines. Accordingly, GAMA data

Table 2.6 North America is the biggest market for all three categories of general aviation

General aviation airplane shipments by type of airplane 2016

Worldwide delivery regions (% of total)

Piston					*Turboprop*					*Business jet*				
North America	Europe	Asia Pacific	Latin America	Middle East and Africa	North America	Europe	Asia Pacific	Latin America	Middle East and Africa	North America	Europe	Asia Pacific	Latin America	Middle East and Africa
69.6	**10.1**	**10.2**	**5.8**	**4.3**	**57.8**	**10.6**	**13.2**	**9.9**	**8.4**	**62.0**	**18.8**	**7.7**	**6.2**	**5.3**

Source: The General Aviation Manufacturers Association.