Dieter Schmitt · Volker Gollnick

Air Transport System

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Preface

This book intends to provide an overview and introduction into the physical and operational mechanism of the air transportation system. To think about new aircraft technologies or new airline business models, it is of paramount importance to understand the major interdependencies and interactions between the main stakeholders like airline, airport, air navigation services and aircraft manufacturer.

Compared to other publications on air transportation the focus is on the basic and major technical and operational characteristics of different technologies and procedures to show the functional principles. The functional and process-oriented perspective on air transportation seems to be a key for future developments and progress.

Therefore, the book starts with an introduction to the definition of the air transportation system and its main stakeholder.

A historical look back on the development of the air transportation system highlighting the big steps forward is given in Chap. 2.

Methods to predict the future of aviation, such as scenario technique and market forecasts of the various manufacturers, are presented in Chap. 3.

Chapter 4 gives an overview of governmental rules and organizations, which directly affect air transportation. The safety philosophy of aviation is presented with an introduction to the certification of aircraft and ATM-systems. Also, security as an upcoming major issue is addressed.

Chapter 5 presents an introduction to the physics of flight and the principles of aircraft design. Also, boundaries and limitations of aircraft operations are discussed. A discussion of various aircraft configurations including an outlook to unconventional future configurations closes this chapter.

Chapter 6 is dedicated to the aircraft manufacturer. A focus is put on the organization and development process in international companies. The cashflow and economical assessments of aircraft programmes are also part of this chapter. Finally, the actual supply chain and the role of the engine manufacturer is addressed.

Ways of how an aircraft is operated by an airline are discussed in Chap. 7. The development of global operation strategies is discussed including the different concepts of low-cost carrier and flag carrier. The relevance of alliances, fleet planning and network development is investigated as well. Also, pricing and ticketing are part of this chapter as well as the role of aircraft maintenance.

Chapter 8 addresses the airport as a major stakeholder. Principal airport concepts and layout are introduced and the various operations on an airport around the aircraft, especially during turn around and taxiing are presented.

The airspace structure and the principal air traffic management processes are part of Chap. 9. Also, the basics of navigation and guidance technologies including the modern satellite-based systems Gallileo and GPS are presented. The safety issues of aircraft separation and wake vortex are also part of this section.

Chapter 10 is dedicated to the environmental boundaries of air transportation. The principles of climate impact and atmospheric implications are presented. Also noise as one of the most significant environmental impacts is discussed. Within this context, emission trading concepts and fees are also presented.

Air transport and its competitors are highlighted in Chap. 11 discussing future challenges. The role of high-speed trains as automotives is investigated and also the impact of new communication technologies on the air transport market is described.

The book closes with an outlook to future challenges and perspectives of air transportation in Chap. 11.

To cover the deeper context of the entire air transportation system would not have been possible without the support and fruitful discussions of many experts in various areas and stakeholders. We cordially thank the following people for their encouraging help:

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Contents

1 The Air Transport System 1
1.1 Introduction 1
1.2 Passenger Expectations 3
1.3 Transport and Mobility 4
1.4 The Air Transport System Today 6
1.5 Current Challenges of the Air Transport System 9
1.6 A Systematic Description of Air Transport 10
1.7 Air Transport System Performances 14
References 16

2 Historical Development of Air Transport 19
2.1 The Dream of Flying 19
2.2 Physics Based Approach 20
2.3 The Technically Based Approach 22
2.4 The Beginning of Civil Air Transportation 25
2.5 The Jet Age 30
2.6 Development of Civil Transport Operation (Airlines and Airports) 34
2.6.1 Airlines 34
2.6.2 Development of Airports 35
References 37

3 Market Aspects 39
3.1 The Strategic Importance of Aerospace 39
3.1.1 From a US Monopoly Status to a Duopoly Situation 41
3.2 Specific Aspects of Aeronautics 44
3.2.1 WTO Role and Activities 45

3.3 The Instruments for Market Predictions (Market Forecast Methods) . . . 47
3.3.1 Top-Down Approach . . . 48
3.3.2 Bottom-Up Approach . . . 50
3.3.3 Scenario Techniques for Risk Assessment . . . 54
3.4 Passenger Aircraft Market . . . 57
3.5 Air Cargo Market . . . 59
3.5.1 Cargo Operators . . . 59
3.5.2 Freight Market Forecast . . . 61
3.5.3 Changes in the Aircraft Market . . . 63
3.6 Cost and Commonality Aspects . . . 64
3.6.1 Life Cycle Cost . . . 64
3.6.2 Family Concepts and Commonality Aspects . . . 67
3.6.3 Cross Crew Qualification . . . 69
References . . . 70

4 The Regulatory Framework of the Air Transportation System . . . 73
4.1 The Freedom of the Air . . . 73
4.2 Regulations for Transportation . . . 74
4.3 International and National Organizations . . . 75
4.3.1 The International Civil Aviation Organization—ICAO . . . 76
4.3.2 National and European Regulatory Organizations . . . 76
4.3.3 Air Navigation Services . . . 81
4.3.4 The International Air Transport Association . . . 82
4.4 Aviation Safety . . . 83
4.4.1 Aviation Safety Philosophy . . . 83
4.4.2 Establishing Aircraft Airworthiness . . . 88
4.4.3 Standards for Safe Aircraft Operations . . . 94
4.4.4 Operational Safety Aspects . . . 97
4.5 Security Aspects of Air Transportation . . . 104
References . . . 106

5 Aircraft Characteristics . . . 107
5.1 Classification of Flight Vehicles . . . 107
5.2 Cabin Design, Focus for the Airlines . . . 109
5.2.1 Transportation Task Requires Volume and Space . . . 109
5.2.2 Cabin Design . . . 113
5.2.3 Fuselage Cross Section, Floor Area (2-D Aspects) . . . 116
5.2.4 Cabin Layout for Several Comfort Standards (3-D Cabin) . . . 120
5.2.5 Aircraft Cabin Systems . . . 122

5.3 Basics of Flight Physics 125
5.3.1 ICAO Standard Atmosphere 126
5.3.2 Aircraft Forces: Lift, Weight, Drag, Thrust 128
5.3.3 Lift 129
5.3.4 Drag 132
5.3.5 Aerodynamic Efficiency 133
5.3.6 Aircraft Mass Breakdown 134
5.3.7 Thrust Requirements 137
5.3.8 Aircraft Stability and Control 141
5.4 Structure, Mass and Balance 143
5.4.1 Structural Components 143
5.4.2 Mass Breakdown 145
5.4.3 Payload—Range Diagram 145
5.4.4 Weight and Balance 147
5.5 Flight Performance and Mission 147
5.5.1 Flight Envelope 147
5.5.2 Definition of Speed 149
5.5.3 Flight Mission 150
5.5.4 Take-off and Landing 151
5.5.5 Cruise Performance 152
References 155

6 Aircraft Manufacturer 157
6.1 Role of Aircraft Manufacturer 158
6.1.1 Industry Mergers 159
6.1.2 Market Duopoly “Airbus Versus Boeing” 160
6.2 Industrial Organization 163
6.3 Development Process (From Idea to Product) 165
6.3.1 Product Definition 166
6.3.2 Aircraft Program Decision Point “Go Ahead” 168
6.3.3 Product Development 170
6.3.4 Production Phase 173
6.4 Production Process and Work Share 173
6.5 Cash Flow and Manufacturing Cost 176
6.5.1 Cash Flow Calculation 177
6.6 Engine Manufacturer 180
6.7 Supply Chain 182
6.8 Offset Agreements 184
References 185

7 Airlines 187
7.1 Overview 187
7.2 Airline Types 189
7.2.1 National or Flag Carrier 191

7.2.2 Charter Carrier 193
7.2.3 Low Cost Carrier 193
7.2.4 Alliances 196
7.2.5 Air Cargo Provider 199
7.3 Network Management 202
7.3.1 Traffic Flows and Networks 202
7.3.2 Flight Planning 206
7.3.3 Flight Plan Utilization and Ticket Pricing 208
7.4 Fleet Strategy and Aircraft Selection 211
7.5 Flight Operations 213
7.5.1 Stations 213
7.5.2 Passenger Services, Sales and Special Services 214
7.5.3 Aircraft Handling—Turnaround 215
7.5.4 Cargo and Baggage Handling 217
7.6 Aircraft Maintenance 217
7.6.1 Maintenance, Repair, Overhaul 217
7.6.2 Maintenance Management and Organization 218
7.7 Airline Organization 221
References 222

8 Airport and Infrastructure 225
8.1 Role of Airport 225
8.1.1 Location of the Airport 227
8.1.2 Intermodality Aspects 227
8.1.3 Classification of Airports 228
8.1.4 Important Airport Elements and Characteristics 229
8.1.5 Airport as Economy Driver 230
8.2 Regulatory Issues, Safety and Security 232
8.3 Regulatory Issues 232
8.3.1 Airport Safety and Security 232
8.4 Airport Operation and Services 233
8.4.1 Aircraft Handling Process at the Airport 234
8.4.2 Definition of Major Airport Elements and Services . . . 236
8.4.3 Turnaround Process 240
8.4.4 Airport Check-in 243
8.4.5 Baggage Handling at the Airport 244
8.4.6 Freight Handling 244
8.4.7 Fuel and Energy Needs 246
8.4.8 Business Aspects 247
8.5 Airport Planning—Infrastructure 248
8.5.1 Airport Planning Process 249
8.5.2 Terminal Layout 251

8.5.3 Runways, Taxiways and Aircraft Geometry Codes 255
8.5.4 Planning of Baggage and Cargo Handling 260
8.5.5 Specific Critical Airport Elements 263
References 268

9 Air Navigation Services 271
9.1 Principles of Operation—The Role of the Air Navigation Services 272
9.2 Airspace Structures 275
9.3 Airspace and Airport Capacity 279
9.4 Aircraft Separation 281
9.5 Flight Guidance Systems 283
9.5.1 Navigation Systems 284
9.5.2 Future Trends in Navigation 293
9.5.3 Air Transport Surveillance 294
9.6 Communication Systems 301
9.6.1 Voice Radio Communication 301
9.6.2 Data Link Communication 302
9.7 Integrated Air Traffic Management and Control Systems 302
9.7.1 Multilateration (MLAT) 305
9.7.2 Airborne Collision Avoidance Systems 305
9.7.3 Terrain Awareness and Warning System 305
9.7.4 Interfaces Between ATM and Aircraft 306
9.8 Navigation Fees 307
9.8.1 Take-off and Landing Charges 307
9.8.2 En Route Charges 308
References 309

10 Environmental Aspects of Air Transport 311
10.1 Introduction 312
10.2 Air Transport Emissions Impact on the Climate 313
10.2.1 Aircraft Emissions 316
10.2.2 Physical Principles of the Atmosphere 318
10.2.3 Emission Impact Assessment in Air Transport 326
10.2.4 Measures for Emission Reductions 330
10.3 Noise and Sound of Air Transport 332
10.3.1 Some Basics of Medical Noise Impacts 332
10.3.2 Basics of Noise and Aeroacoustics 334
10.3.3 Noise Requirements for Aircraft 337
10.3.4 Aircraft Noise Sources and Potential for Reduction 340
References 344

11 Challenges and Competition of Air Transport 347
11.1 Global Challenges for Air Transport 2050 348
11.2 Future Energy Provision and Alternative Fuels for Air Transport 351
11.3 Competitive and Multimodal Air Transport 358
11.4 Technology Trends 364
11.4.1 Technology Perspectives in Aircraft Design 365
11.4.2 Perspectives in Air Traffic Management 370
11.4.3 Perspectives in Airport Operations 371
11.5 Integrated Approaches Towards Future Air Transport 373
11.6 Compliance Achievement with Flightpath 2050 374
References. 375

Chapter 1
The Air Transport System

Abstract This chapter provides a broad entrance to transportation and the high level aspects of air transport. Starting with a description of the air transport system and its surroundings, the passenger expectations concerning highly attractive air transportation are explained. Further, the development of mobility and the principle transport chain are presented. Based on the global economic development of populations, the evolution of air transport and the general impact on climate are given. An introduction to high level global challenges as given in ACARE Vision 2020 or NextGen follows. A systems-based view of air transport and definitions of the roles of the most relevant stakeholders provide the way of thinking presented in this book. The chapter ends with a description of how performances can be described and measured to improve the air transport system.

1.1 Introduction

Transport defines all activities, which allow movement of people or goods from one location to another. There are various modes of transport like road, rail, water and air. But also pipelines, cables and space transport can be considered for special purposes.

A transport system is built on infrastructure, vehicles and operational procedures. Transport and travel are elementary drivers to develop civilization bringing people together and exchanging goods. As the air transport system is one of the major pillars of modern transport Fig. 1.1 provides a first insight into this complex system.

Since air transport is intended to move *passengers* and *cargo*, these elements are placed into the centre of the system.

Aircraft like fixed wing transport aircraft, rotorcraft, unmanned systems, etc. developed and produced by the *manufacturers* are the vehicle platforms for air transport. Aircraft are operated by *airlines*, which provide air transport as a service product. In order to enable this service product safe and efficient *Air Traffic Management* (*ATM*) performed by Air Navigation Services (ANS) has to ensure safe and scheduled aircraft flow around the world. *Airports* are understood as the interface between land and air transport, which provide the infrastructure for this interface.

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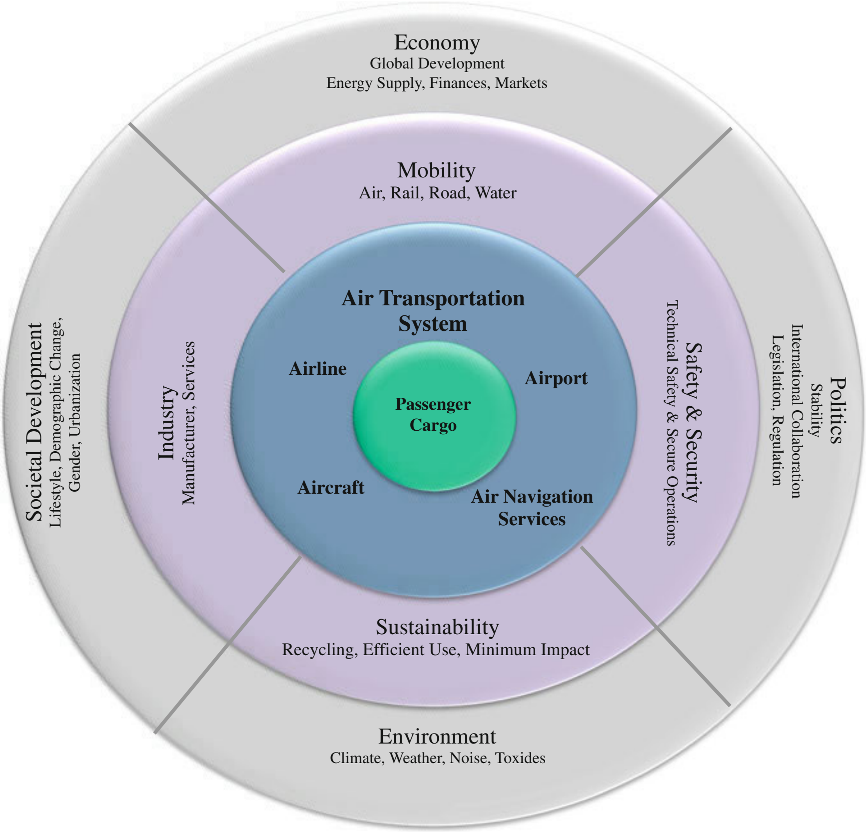


Fig. 1.1 The air transport system and its environment

Beside these main stakeholders in civil air transport, travel agencies, ground services or maintenance, as well as military and general aviation are further operators in the sky. In order to limit the focus of this book, these stakeholders are not explicitly considered.

All aircraft operations, civil as well as military and general aviation are mainly influenced by *society's* expectations and developments. *Politics* in general, represented by authorities develops and sets the legal and regulatory framework to enable air transport. *Economy*, as a key for people's prosperity and welfare influences air transport. *Other transport systems* like rail, ship or automotive are operated complementary in multi-modal operations with air transport, but they are also competing. At last, *environmental responsibility* mainly in terms of climate and noise impact has become a major influence on air transport today [1].

This brief overview gives a first impression of the main elements, which compose and affect the air transport system.

The purpose of this book is to introduce the different *stakeholders* and their ways of acting in the system. Further, it is intended to provide some awareness and understanding of the various *interactions and interdependencies* between the stakeholders. For these reasons, the major relevant *technical systems* and their principal characteristics are presented to provide the capability to assess new technologies and the impact to the overall system. Also the *main processes of air transport*, including the business models are described.

The readers, experienced professionals as well as students of mechanical and aerospace engineering, also logistics and civil engineering, shall be able to get a comprehensive technical and operational understanding and overview of the air transport system.

1.2 Passenger Expectations

Since the beginning of the twentieth century, aviation has tremendously affected mobility of people. During the last 100 years, the technical performance of the air transport system reached a very high level of maturity till date, Chap. 2.

Every day, when people make use of the air transport system, they discover some elements of discomfort and inefficiency. People complain, for example, about delays, uncomfortable seats in the cabin, toxic air in the cabin, environmental pollution, too long travelling times or too high ticket prices. It is not to be discussed here, whether these complaints are actually entitled or not; they only give an indication, that everybody has some aspects, which can be improved.

Engineers always tend to find solutions for problems or invent and develop new things. Aerospace engineers also try to improve the air transport system continuously.

Making it better will mean

- to advance *quality* and affordability
- to improve the technical *performance*
- to reduce cost and to increase *profit*
- to increase the *environmental* compatibility.

At the end, the air transport system shall be more attractive for people and be more accepted. This is the basic motivation for all stakeholders to improve, because the fulfilment of customer expectations provides market share, revenue and profit.

The **users** of the air transport system are able to use it in the most efficient way to achieve their individual goals, like travelling or sending goods between two points.

Air transport, by nature is an abstract service, performed by various contributing stakeholders, like the airline, the airport, the ANS and the aircraft and its manufacturer respectively.

The passenger or sender of freight as customer, cannot request for restitution or conversion in case of deficiencies. He pays for a service in advance, hoping for an orderly performance.

The creation and consumption of the product travel coincide. An offered seat on an aircraft, which is not used, is a loss for the airline. Therefore, an airline always targets at a high load factor (LF), which describes the relation between the offered and the occupied amount of seats.

Beside the pure travel service, supporting activities like check-in, security check, refreshments, lounges, etc. are also part of the experience of flight.

These global expectations and challenges are addressed by international targets as they are described for example in the ACARE Vision 2020 and further on Flightpath 2050, which will be introduced in Sect. 1.4, and regarding the future challenges in Chap. 11 [2, 3].

1.3 Transport and Mobility

From the beginning of human era, mobility was a fundamental prerequisite to survive and evolve. During the centuries, human mobility also became an essential pillar for prosperity and welfare (Fig. 1.2).

Mobility itself is the people's ability to move from one location to another. It can be performed by different transportation systems and measures. People can move individually or in groups either by walking or for example taking bikes, cars or aircraft.

With the development of technical features people were able to travel longer distances and reach locations much quicker. In the beginning, about 50 km could be overcome within 9 h travelling time per day, today during the same time most of the continents can be reached.

It is of paramount importance to distinguish between people´s mobility and movements of transport vehicles.

Transport Vehicle Speed (km/h)	*Distance (km)* 10 100 1000 10000	*Infrastructure*	*Destinations from Hamburg*
Walking Ca. 5 km/h	54 km (1h Rest)	Road	Lüneburg
Diligence ca. 12 km/h	70 km (1h Rest)	Driveway	Lübeck
Bicycle ca. 20 km/h	151 km (1h Rest)	Driveway	Hannover
Train ca. 70 km/h	285 km	Rail	Berlin
Ship ca. 40 km/h	770 km	Water	Dover
Automotives ca. 100 km/h	900 km	Highway	Paris
High Speed Train ca. 250 km/h	2500 km	High Speed Track	Madrid
Aircraft ca. 850 km/h	7500 km	Airport	New York

Fig. 1.2 Development of human mobility

A fixed amount of people as well as cargo can be transported, either by a large number of transport vehicles with limited capacity of payload or using fewer vehicles providing large storage capacity.

At this point, it is essential to understand, the capacity of the area where it is addressed is an essential design parameter, to set up an efficient transport system.

If capacity is associated with the transport vehicle, the required energy effort as well as fuel consumption and emissions could be shared by more people and cargo. On the other hand, when capacity is an issue of the transport flow, the frequency of vehicle movements and the capacity of the rail, road, air networks as well as air spaces, airports and railway stations become the essential design parameters.

In order to reach another location, people today often use different transport systems during a journey. This principle is called Multi Modal Transport (MMT). Each transport mission from door to door can be described by five phases [4, 5]. Further, if in a trip different transport systems might be used, this is known as Inter Modal Transport (IMT). It is possible to compare different multi-modal transport chains, using a Five-Phase-Model (FPM) with different main track transport vehicles in a transparent way as shown in Fig. 1.3.

The first phase, always beginning at home or in case of cargo transport at the production plant or logistics centre, covers the distance from this point to the border of the city. It is characterised by low speed and short distance up to 20 km approximately. Various transport choices are available like walking, taking public transport or automotive, which is a typical example of multi-modality. In case of rail or air transport on the main track, the second phase addresses the transition from those initial transport choices to trains or aircraft. Compared to all kind of automotive transport there is no transport performance for rail and air transport in the railway station or airport because no real distance is travelled! But in both cases, significant time is consumed to change from one system to another. Taking automotive transport as a reference, these systems overcome a distance of up to 100 km

	Phase 1	**Phase 2**	**Phase 3**	**Phase 4**	**Phase 5**
Mode	Departure	Transition Mode Change	Main Track	Transition Mode Change	Arrival
Range [km]	0 -20	<100	>>100	<100	0-20
Speed in [km/h]	0 - 50	0 - (100)	100 - 900	0 - (100)	0 - 50
Road	City	National Road	Motorway	National Road	City
Rail	Car, Taxi, PT	Railway Station	Highspeed Train	Railway Station	Car, Taxi, PT
Air	Car, Taxi, PT	Airport	Air Transport	Airport	Car, Taxi, PT
Water	Car, Taxi, PT	Harbor	Ship Transport	Harbor	Car, Taxi, PT

PT = Public Transport (Metro, Tram, Bus, ..)

Fig. 1.3 Five phases of multi-modal transport [4] approximately to reach the highway for the main cruise track. The cruising speed is around 70–100 km/h until the highway is reached. Further, the third phase covers the main track, which is intended to overcome the longest distance as quick as possible. Here, all transport systems use their maximum speed. Phases four and five are the reverse phase of phase two and one.

Aviation in this context provides the unique capabilities to be the fastest and offers the largest range performance compared to the other transport systems. Further, it is not limited to any continental border. Therefore, aviation can connect cities on most continents directly without being hindered by oceans or mountains. However, air transport requires normally a mode change before and after the air phase (phase 3), which might last between 30 min and 2 h typically. This “loss” of time is the reason why air transport is only efficient at distances longer than 500 km. Here the geographic situation, i.e. the density of transport networks influences the attraction of a transport system significantly. At last, the main transport systems rail, aviation, automotive and ship are facing an increasing competitive situation, which will be discussed in Chap. 11. For the design of future air transport concepts, it will become more and more relevant to identify the individual advantages and disadvantages of all elements in order to integrate them in the most efficient way.

1.4 The Air Transport System Today

Mobility as a whole and air transport in particular have grown dramatically during the last decades. This development is driven by man’s wish to move quicker and further away. Mobility around the world is state-of-the-art today.

Air transport as a whole has a significant economic relevance. Almost 15 million jobs globally are associated directly or indirectly with the aviation industry [6]. 7,80,000 people are directly working in the aerospace industry, while 2 million are associated with airlines around the world. At the airports, about 2.7 million employees are engaged, which in summary lead to 5.5 million jobs, which are directly created by the aviation industry. These figures indicate strongly the welfare impact of aviation. More the countries are developing, the more people's mobility increases and the economic power grows.

As shown in Fig. 1.4 from a certain level of Gross Domestic Product (GDP) of about 25,000 no further increase of mobility is observed. Consequently in these regions only marginal increase in passenger movements and aircraft movements are to be expected.

This growth will be heavily driven by the growing economies in Asia, especially India and China, while the highly developed countries like USA and Europe will face certain saturation in air traffic mobility, Chap. 3.

For those markets, the competitive situation for air transport is becoming stronger, especially since high speed trains with cruise speeds up to 400 km/h strengthened their advantage to link cities at their heart. Compared to this situation airports are mostly located in the surrounding of cities, which requires more travelling time.

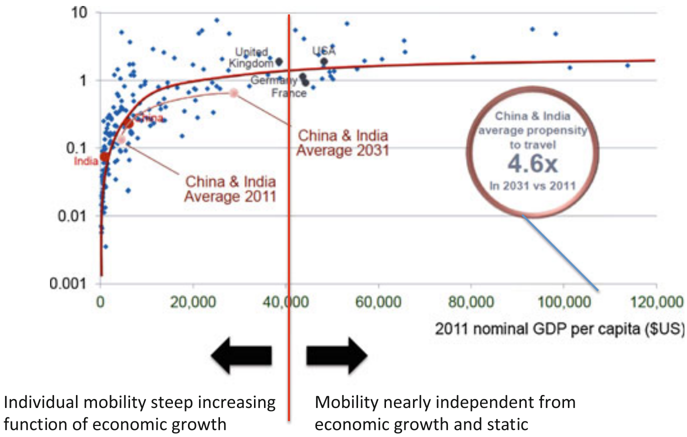


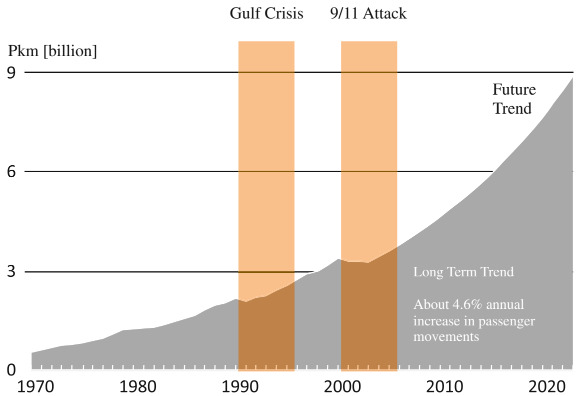
Fig. 1.4 Global mobility development depending on GDP [7]

For growing and developing countries, where passenger mobility is lower by a factor of roughly ten, there is a strong demand for more aircraft payload capacity as well as for aircraft movements. Here also airspace and airport capacity becomes essential.

From the 70s of the last century until 2000, air transport grew up to 3 billion passenger kilometre (Pkm), Fig. 1.5. In the decade 2000–2010, passenger air transport increased again from 3.5 Billion passenger kilometre to approximately 5.7 Billion passenger kilometre globally. Also for the next decade a global increase from 5.7 to 9 Billion passenger kilometre is expected.

Detailed analysis has shown that most of the world's aircraft and engine manufacturers came to the same perspectives [9]. However, this development is heavily depending on future global economic and political development. As shown in the Fig. 1.5 global events like the gulf crisis in 1990 or the 9/11 tragedy did not significantly affect the global trend. However, they shifted the progressive increase

Fig. 1.5 Expected global passenger air mobility trend 1970–2020 [8]



to later maxima. Nevertheless, this development leads to an average global passenger air transport growth of about 5.2 %.

A further aspect to be analysed refers to the development of the aircraft LF. As mentioned before, the LF of a transport vehicle describes the share how much available seat capacity is used on a trip.

In the last step, considering the aircraft movements under Instrumental Flight Rules (IFR), which are typical for civil passenger aviation, an increase from 8,500,000 to 9,500,000 movements per year, at least in Europe is observed between 2000 and 2010. Under the impression of the financial crisis in 2008, a lower increase up to 1,000,000–1,200,000 movements per year is prospected [10].

Comparing both trends, passenger movements are growing faster than aircraft movements, which is in line with the observation that the LF of the world fleet as well as the seat capacity are increasing. Therefore, with the same amount of aircraft more transport performance is provided to serve people mobility.

When this trend of growth of air transport will go on, the demand for fossil kerosene and the emission of CO_2 will increase proportionally.

The first is conflicting with the limits of crude oil causing high prices, the latter is threatening our environment and health leading to climate changes, see Chap. 10.

Normally one would assume that this development would be visible in the global air transport energy effort. Looking at Fig. 1.6 there is a significant increase of energy effort due to an effect, which is called “Rebound Effect” [11], meaning that on global level all individual effects like reduced engine fuel consumption are overcompensated by an increase in aircraft movements. On individual aircraft level, such improvements like structural weight saving are overcompensated by additional equipment for comfort, e.g. cabin entertainment systems.

This brief look at the development and status of the air transport system today has shown its social relevance to provide mobility and economic growth. On the other hand, due to its high level of maturity the ATS is facing technical limits and new breakthroughs are needed to evolve into the future. Going a step further, the established way of quantitative growth with more and more aircraft might shift to a new paradigm requesting for qualitative growth in air transport as raised by the Club of Rome in 1972 [13]. This way ahead will be discussed in Chap. 11, which is about the future challenges.

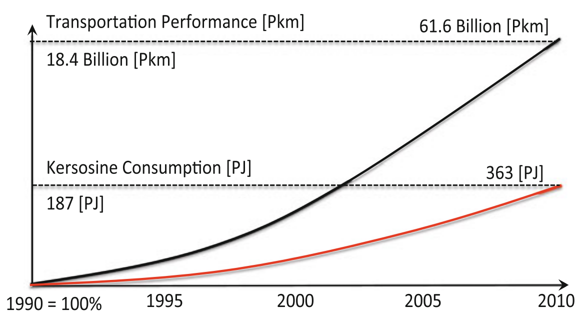


Fig. 1.6 Trend of decoupling air traffic growth and CO_2 emissions due to technologies [12]

1.5 Current Challenges of the Air Transport System

Summarising the global developments, previously described air transport grew tremendously in terms of passenger and aircraft movements. The latter is based on a significant increase in the amount of aircraft. The amount of aircraft causes limitations in airport and airspace capacities, especially in Europe and Northern America [7–9]. In the growing regions, those capacity limits are not yet reached, but need to be considered for future developments.

Responding to these challenges in 2001, the Advisory Council of Aeronautical Research in Europe (ACARE) has defined high level targets for future improvements, to make the global air transport system competitive and attractive for the twenty-first century. These high level targets are listed in Chap. 11 Table 11.1, known as the ACARE Vision 2020 [2]. Also in the United States targets for the future air transport have been formulated. Here on the operational field the *NextGen* programme especially defines objectives for more efficiency in air transport flow. The American *N+3* project driven by NASA additionally sets requirements on improved aircraft performance. Comparing both approaches the European Vision 2020 can be understood as more holistic, while the American *NextGen* ATS addresses more technologies to increase the throughput of aircraft in the airspace and at the airport. These goals are set to be achieved until 2020 and refer to the ATS performance of 2000 as the reference. It is essential to notice, that all these targets are related to a single aircraft performance of newly developed aircraft. Since there are thousands of older aircraft also in service in 2020, the entire world fleet will not be capable to come close to these targets.

A mid-term resume, however, indicated in 2011 that not all of these goals could be achieved until 2020 [14]. While the environmental goals concerning CO_2 and NO_x emissions are achievable by more than 50 %, an extension of the airport and airspace capacity as well as the improvement of punctuality are hard to reach until 2020. Further, actual research on climate impact of aviation has raised the question whether the percentage requirements on reduction of emissions are the right one, because the impact on global warming in terms of contribution to ΔT seems to be more appropriate. This metric covers interdepending effects in a better way and will be discussed in Chap. 10.

Therefore, only an integrated approach merging incremental contributions allows achieving the global goals for new air transport systems.

Following the ACARE vision, a new European revision on the future goals has been developed in *Flightpath2050* [3].

The potential reductions, which various technologies are considered to contribute, are understood as single disciplinary contributions [15–17]. It is therefore mandatory to understand the air transport system and its complexity as a whole and to

- analyse and identify *weaknesses in the entire system* as well as on substructure and subsystem level
- develop *future integrated concepts* as proposals for new solutions rather than single technology solutions

- improve *air transport processes* on global chain level and also on subsystem level.

For this purpose, the next section provides a system engineering approach for a holistic air transport system description.

1.6 A Systematic Description of Air Transport

There are different approaches to define and structure the air transport system. One proposed by *Wensveen* is driven by a management view [18]. *Wensveen* uses an economical view to address the organisational elements of air transport like regulators and associations. But he also addresses the different markets and economical influences. Further on, he describes the air transport system from airline perspective and its different business models.

Mensen provides a more organisational vision on the air transport system, focussing very much on the ATM/control and the regulatory organisations [19]. From his point of view, all institutions and procedures, which contribute to run the ATS define it. Also *Mason* and the *MIT* built the ATS description on organisational aspects.

To approach such a complex system, Systems Engineering (SE) is an appropriate method to define and structure the various elements.

A system generally consists of elements, which are related to each other, Fig. 1.7. Major characteristics of a system are its boundaries, which separate a system from its environment or other systems.

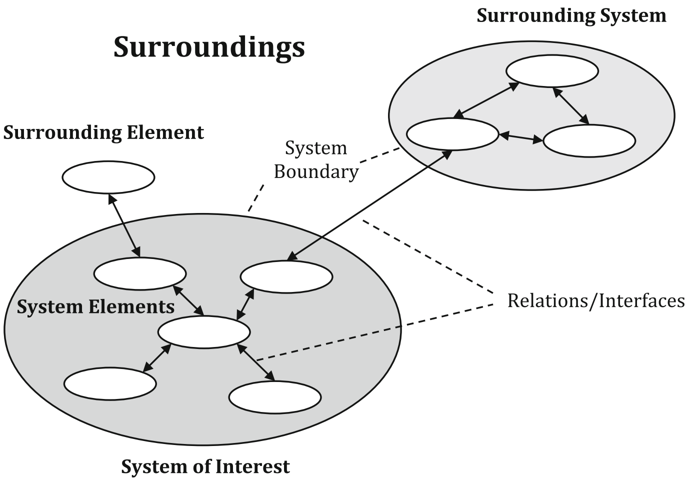


Fig. 1.7 Principle of system definition

The definition of these boundaries allows a separated analysis of a system and only the direct cross references to the outside world need to be considered. Such a system, considering also the outside impacts through interfaces or boundary conditions is understood as an open system, which is the Air Transport System. The global impacts as addressed in Fig. 1.1 need to be taken into account in further discussions. In order to provide an understanding of this approach, the societal environmental awareness should be considered in terms of CO_2 emissions. The reduction of these is a requirement for the overall aircraft and also for the engine. In this way, the aircraft and also the engine have to be considered as open systems. However, if the power supply of the electronic engine control system (EECS) is in the focus of research and development, this element is neither directly nor indirectly related to CO_2 emissions from operational perspective. Therefore the EECS can be considered as a closed system without these outer influences.

This approach simplifies the analysis and design. A system itself can also contain various substructures, which commonly affect the higher system level.

From this perspective, the air transport system is understood as a system of systems, which covers for example the aircraft, the airport and ATM as substructures.

Following the system engineering philosophy, the air transport system is hierarchically structured into the system, substructures, subsystems and components:

- the overall air transport system as the *system* is composed of
- aircraft, airlines, air traffic infrastructures, airports as *substructures*, Chaps. 5, 7–9 while
- e.g. wing, avionics, etc. of an aircraft, or e.g. surveillance radar, air space structures of the air traffic infrastructure, or the terminal, the APRON of the airport are *subsystem*s of one substructure and
- e.g. flaps and slats are components of the flight control subsystem of the aircraft, while antennas and receivers are parts of the radar subsystem of ATM, check-in areas, gates are *component*s of the airport terminal subsystem, etc.

Such an approach is suitable to develop balanced optimisations among the main substructures of the air transport system, in order to achieve multidisciplinary or global goals like those of ACARE.

Generally every stakeholder in the ATS provides some infrastructures and holds some processes to make the system run.

While this view is mainly technically driven, the stakeholder's perspective on the air transport is a different one:

- here the *aircraft manufacturer* is in charge of developing the aircraft based on various system and stakeholder requirements;
- the *airline* provides the core product air travel by operating the aircraft;
- *military and general aviation* which are also parts of the ATS occupy resources of air traffic control, airspace and airport capacities.

In addition,

- *general public* which is on the one hand the customer of the ATS and on the other hand requesting for social compliance;
- governmental and non-governmental *organisations*;
- *customer* as a passenger or one who is shipping goods

are stakeholders of the ATS representing needs, expectations and requirements, which should be fulfilled as described in Fig. 1.1.

Further on there are surrounding influences, which interfere with the air transport system. These are physical environments like natural laws, geographic conditions as well as meteorological and climatic conditions. Also, social implications like public employment and purchase power, travel demand, medial opinions or fear about terrorist attacks affect the air transport system.

At last, economical influences, e.g. world economic growth, raw material and oil market development or regional transport, economical and business situation drive the ATS.

According to other authors, there might be further stakeholders, e.g. like ground service provider, meteorological services, travelling agencies, research organisations [18–20].

Most of the stakeholders, except the general public, provide some sort of product or service like aircraft, regulations, ensuring safety, navigation performances, etc. to make ATS operational. The general public, as customer and affected community in contrast is using the ATS and raising expectations. The customer's view on air transport is quite individual. He wants to move between two points at the moment, which is very specific. He wants to move quick and comfortable, because he wants to be active at the final destination to spend his holidays, to do his business, or just to enjoy his leisure. Therefore, the passenger as a customer is always looking at air transport as a process. Typically he is not looking at a certain technology itself, but at seamless integrated performance of elements along his travel. The same is also true for air cargo transport. Also in this case the dispatcher and receiver of goods expect a seamless service and do not care about deficiencies in any technology being used, where the customer does not care about nor has any preferences.

There are two conclusions to be drawn from this observation. First, the customer does not care about who is responsible for a deficiency during the travel chain. The second issue is related to the technologies being used.
Here a technology is defined either as

- a *physical principle* being used in a sensor or machine, etc. like a laminar flow on an aircraft or a radar-based scan at a security check-in a terminal or
- a rule-based standardised *procedure*, which describes a certain sequence, like an approach and landing manoeuvre of an aircraft, or
- a *process*, which describes the chain of activities, like a production sequence during aircraft assembly, or a cargo moving process, comprising customs activities, transport activities, security checks, etc.

Especially since a lot of physical principles are known well and have reached a high level of maturity improvements in efficiency are expected to be made by investigating and developing new procedures and processes, where given physical principles are put together in a new and better way.

The development of new solutions for the ATS follows the roadmap of a V-model like it is well known from software systems development, e.g. Mil-Std 2197, IEEE 1220 (Fig. 1.8).

The system is decomposed to the relevant level of detail. On the lower level, (substructure, subsystem, component) the decomposition stops if all relevant interdependencies between the other system elements are addressed. On this level, a new solution is to be developed [21].
This leads to the aspect of integration, which is a key characteristic of a system. *Integration* of technologies in the aforementioned way can be done in different ways to create systems:

- *intellectual or descriptive integration*, merging physical principles and/or procedures to processes in a theoretical, functional way;
- *IT-based integration*, where different models for calculation and simulation are put together in order to set up a virtual system, which allows calculation, layout and simulation;
- *physical integration*, where the real hardware, operational software and procedures are put together to setup the real system;

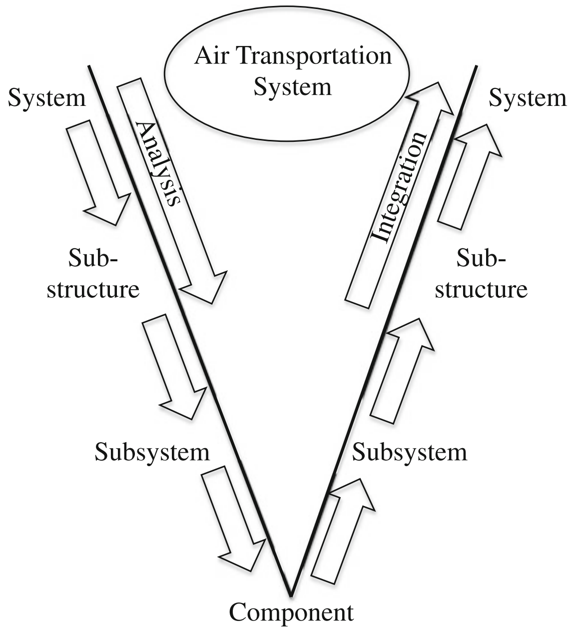


Fig. 1.8 V-Model for analysis and integration of the air transport system

All three stages of integration appear during the development and analysis of the air transport system. While the first provides a first insight to interdependencies of newly defined system architecture, the second brings out interactions between the systems elements, which have not been considered before, for example due to the huge amount of potential solutions. The physical integration at the end provides the ultimate way to merge different physical principles like hardware and software, mechanical and electrical solutions.

However it must be emphasised that currently all stakeholders follow individual interest and strategies to maximise their business instead of collaboratively contributing to an overall seamless air transport system.

1.7 Air Transport System Performances

Any kind of modification of the various air transport systems is intended to improve the entire system leading to more efficiency.

On a Meta-level, efficiency itself describes the relation between a requested benefit or target, like the movement of a certain amount of passengers and the effort and potential disadvantages which are associated with this target. Such an effort can be described as the amount of energy or fuel, which is needed to perform the transport task between A and B. Associated cost, for e.g. staff, fees or supporting services are understood as effort to be spent. Related emissions and noise, also required land use can be described as potential disadvantages, because these effects are not wanted.

In this context, it is necessary to discuss efficiency and effectiveness [22]. A popular distinction between these two performances, describes efficiency as doing things right, while effectiveness is understood as doing the right things [23]. In the context of air transport this definition means, that for example the manual assembly of an aircraft is less effective than the assembly using automation, which allows much quicker and higher quality assembly.

On the other hand, efficient air transport can be seen as the movement of passengers with as less fuel and time as possible.

As a basis for these considerations air transport work (ATW) is defined as the amount of passenger or goods being carried over a given distance, i.e.:

$$\mathrm{ATW} = \text{pax or goods} * \text{distance } [\mathrm{Pkm}] \text{ or } [\mathrm{tkm}] \tag{1.1}$$

Referring to the goals of the *Vision 2020* efficiency determines the resulting transport performance in passenger kilometre or tonnes kilometre related to the effort to be spent in terms of overall travelling time, energy effort, cost and environmental impact.

The requested air transport work is related to the time and effort necessary to be spent, i.e. energy, cost and associated environmental impact.

Transport efficiency therefore is characterised by balancing the requested transport work and the required efforts in terms of cost, energy, emissions, noise, and land use.
Although these global parameters are applicable to all stakeholders in air transport, the detailed impact and characteristics differ. Eurocontrol, in 2006 first published an approach to describe efficiency and effectiveness in air transport [24]. Here, Key Performance Areas (KPA) and Key Performance Indicator (KPI) have been defined to describe and quantify the performance of air traffic, especially. Key Performance Areas in this context have been defined, like

- Capacity and delays
- Cost effectiveness
- Environment
- Airports
- …

These KPA are extended to those agreed by the 11th ICAO conference adding:

- Access and Equity
- Global interoperability
- Predictability
- Security

To determine these KPAs, it is not sufficient to use one parameter each only. This is the reason why different KPIs have been defined to characterise the KPA. Moreover, each KPI needs to be defined in particular for its individual environment of application.

Taking the KPI for capacity as an example, those characteristics have been chosen which influence the capacity of the air space in terms of IFR flights handled by the European ANS.

Increasing amount of take-off and landings depending on the available runway capacities are characterising airport performance, as another example.

If one tries to apply this philosophy of performance areas and indicators to other air transport stakeholders like the aircraft, the following indicator can be used. Aircraft capacity is described by seat capacity on an aircraft. Distinguishing between long and short range aircraft, more seats at the same aircraft size can be used as a KPI. Cost effectiveness as a further performance area might be described as the amount of cockpit and cabin crew cost as well as maintenance and fuel cost. The latter should be related either to a single flight and to the entire life cycle. Aircraft efficiency can be defined in two ways. First, the design efficiency in terms of the maximum payload capacity related to the operating empty mass can be used to characterise the efficiency of the design. Second, the fuel burn is a further economic characteristic of the aircraft. At last, environmental performance of aircraft is characterised by the amount of emissions and the noise carpet developing during take-off, cruise and landing. At this point, one may wonder about the missing physical aircraft performance in terms of range and speed. These parameters seem to be not really useful for performance indication, since their value is depending on the individual real mission. Cruise speed and range itself provide the capabilities of an aircraft for flexible operations on various missions.

For airlines, those performance areas may address the fleet's wide amount of emissions as an emission indicator as well as the relation of the amount of aircraft to the annual flown kilometres, which indicates the efficiency of the operated fleet. Also, aircraft availability is a useful indicator for airline effectiveness and flexibility. The amount of accidents and incidents related to an airline fleet and flown kilometres will indicate the level of airline safety.

At last it has to be noted, that airport specific performance indicators are still addressed within the ATM performance areas.

Reflecting this discussion about performance areas and indicators, there are various measures to characterise the performance of the different main stakeholders in air transport. It has been shown, that the definition of these indicators is depending on the individual stakeholder's interest and perspective. In order to make such an assessment comparable, at least the performance areas should be defined in the same way, while the indicators should be set up in a similar physical description.

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Chapter 2
Historical Development of Air Transport

Abstract The historical development of air transport starts with a short review of myths and legends, the Dream of flying, which is as old as mankind. The next part covers the physically based approach of flying, starting from Da Vinci and his drawings of flying vehicles, via the Montgolfier's hot air balloon, Sir George Cayley and his principles of flying. The part about the technically based approach covers briefly the different attempts from Clement Ader, Otto Lilienthal up to the Wright brothers, who finally in 1903 managed to fly with a vehicle heavier than air. It follows the beginning of commercial air transport in Europe and US between the two World Wars. In the 1950s, the jet age in civil air transport started with a disaster of Comet, but all lessons learned from these air accidents helped other companies to start successfully these new jet engine types of civil transport aircraft, which are still flying today. The aircraft design parameters of speed, range, size and fuel efficiency and their development of the last century are shortly addressed to extract the standards and the maturity of today's air transport system. A brief review of the airline development follows with the example of KLM. It follows a short airport review, where the airport development of Atlanta—the biggest airport today—is taken as example.

2.1 The Dream of Flying

The dream of flying is as old as mankind. In all civilizations (old and new like Greek, Chinese, Roman, Inca, Celt et alii.) Gods have certain capabilities to fly and pass easily between earth and heaven. Some courageous people tried to copy this capability by intensively watching the flight of birds and adapting certain mechanisms from them. The Greek mythology tells about the genius Daedalus, who was at his time an excellent artist and innovator. As the king of Crete named Minos wanted to keep his capabilities as architect just for his personal and own profit, Daedalus decided to escape by constructing and building a flying vehicle, which

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