AIR TRANSPORTATION SYSTEMS (R15A2121)

COURSE FILE

III B. Tech II Semester

(2018-2019)

Prepared By

Mr. J Sandeep, Asst. Prof

Department of Aeronautical Engineering

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

(Autonomous Institution – UGC, Govt. of India)

Affiliated to JNTU, Hyderabad, Approved by AICTE - Accredited by NBA & NAAC – 'A' Grade - ISO 9001:2015 Certified)
Maisammaguda, Dhulapally (Post Via. Kompally), Secunderabad – 500100, Telangana State, India.

MRCET VISION

- To become a model institution in the fields of Engineering, Technology and Management.
- To have a perfect synchronization of the ideologies of MRCET with challenging demands of International Pioneering Organizations.

MRCET MISSION

To establish a pedestal for the integral innovation, team spirit, originality and competence in the students, expose them to face the global challenges and become pioneers of Indian vision of modern society.

MRCET QUALITY POLICY.

- To pursue continual improvement of teaching learning process of Undergraduate and Post Graduate programs in Engineering & Management vigorously.
- To provide state of art infrastructure and expertise to impart the quality education.

PROGRAM OUTCOMES

(PO's)

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design / development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multi disciplinary environments.

12. **Life- long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

DEPARTMENT OF AERONAUTICAL ENGINEERING

VISION

Department of Aeronautical Engineering aims to be indispensable source in Aeronautical Engineering which has a zeal to provide the value driven platform for the students to acquire knowledge and empower themselves to shoulder higher responsibility in building a strong nation.

MISSION

The primary mission of the department is to promote engineering education and research. To strive consistently to provide quality education, keeping in pace with time and technology. Department passions to integrate the intellectual, spiritual, ethical and social development of the students for shaping them into dynamic engineers.

QUALITY POLICY STATEMENT

Impart up-to-date knowledge to the students in Aeronautical area to make them quality engineers. Make the students experience the applications on quality equipment and tools. Provide systems, resources and training opportunities to achieve continuous improvement. Maintain global standards in education, training and services.

PROGRAM EDUCATIONAL OBJECTIVES – Aeronautical Engineering

1. **PEO1 (PROFESSIONALISM & CITIZENSHIP):** To create and sustain a community of learning in which students acquire knowledge and learn to apply it professionally with due consideration for ethical, ecological and economic issues.

2. **PEO2 (TECHNICAL ACCOMPLISHMENTS):** To provide knowledge based services to satisfy the needs of society and the industry by providing hands on experience in various technologies in core field.

3. **PEO3 (INVENTION, INNOVATION AND CREATIVITY):** To make the students to design, experiment, analyze, and interpret in the core field with the help of other multi disciplinary concepts wherever applicable.

4. **PEO4 (PROFESSIONAL DEVELOPMENT):** To educate the students to disseminate research findings with good soft skills and become a successful entrepreneur.

5. **PEO5 (HUMAN RESOURCE DEVELOPMENT):** To graduate the students in building national capabilities in technology, education and research

PROGRAM SPECIFIC OUTCOMES – Aeronautical Engineering

1. To mould students to become a professional with all necessary skills, personality and sound knowledge in basic and advance technological areas.

2. To promote understanding of concepts and develop ability in design manufacture and maintenance of aircraft, aerospace vehicles and associated equipment and develop application capability of the concepts sciences to engineering design and processes.

3. Understanding the current scenario in the field of aeronautics and acquire ability to apply knowledge of engineering, science and mathematics to design and conduct experiments in the field of Aeronautical Engineering.

4. To develop leadership skills in our students necessary to shape the social, intellectual, business and technical worlds.

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

III Year B. Tech, ANE-II Sem	L	T/P/D	C
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(R15A2121) AIR TRANSPORTATION SYSTEMS
(CORE ELECTIVE – IV)

Objectives:

- The subject will introduce the air transportation systems in detail.
- To study the basic governing bodies of ATS, its laws and regulations
- To understand the Airspace sectors, setting up Airport, Airlines and economic considerations involved in it

UNIT-I

Aviation industry & its regulatory authorities: Introduction, history of aviation-evolution, development, growth, challenges. Aerospace industry, air transportation industry-economic impact- types and causes. Airline Industry-structure and economic characteristics. The breadth of regulation- ICAO, IATA, national authorities (DGCA, FAA).Safety regulations-risk assessment-human factors and safety, security regulations, environmental regulations.

UNIT-II

Airspace: Categories of airspace-separation minima, airspace sectors-capacity, demand and delay. Evolution of air traffic control system-procedural ATC system, procedural ATC with radar assistance, first generation 'automated' ATC system, current generation radar and computer-based ATC systems. Aerodrome air traffic control equipment and operation-ICAO future air-navigation system service provides as businesses. Communication, navigation and surveillance systems (CNSS). Radio communications-VHF, HF, ACARS, SSR, ADS. Navigation- NDB, VOR, DME, area-navigation systems (R-Nav), ILS, MLS, GPS, INS.

UNIT-III

Aircraft: Costs-project cash-flow, aircraft price. Compatibility with the operational infrastructure. Direct and indirect operating costs. Balancing efficiency and effectiveness-payload-range, fuel efficiency, technical contribution to performance, operating speed and altitude, aircraft field length performance, typical operating costs. Effectiveness-wake-vortices, cabin dimensions, flight deck.

UNIT-IV

Airports: Setting up an airport-airport demand, airport-siting, runway characteristics-length, declared distances, aerodrome areas, obstacle safeguarding. Runway capacity- evaluating runway capacity –sustainable runway capacity. Runway pavement length, Maneuvering area- airfield lighting, aprons, Passenger terminals-terminal sizing and configuration. Airport demand, capacity and delay.

UNIT-V

Airlines: Setting up an airline-modern airline objectives. Route selection and development, airline objectives. Route selection and development, airline fleet planning, annual utilization and aircraft size, seating arrangements. Indirect operating costs. Aircraft- buy or lease. Revenue generation, Computerized reservation systems, yield management. Integrating service quality into the revenue-generation process. Marketing the seats. Airline scheduling, Evaluating success-financial viability, regularity compliance, efficient use of resources, effective service.

Outcomes:

- The operational structure of the Airport, its establishing, working strategies in detail
- The economic and the business outcomes of the operations of ATS
- The student with acquire operational knowledge of air transport system

TEXT BOOKS

1. Hirst, M., The Air Transport System,Wood head Publishing Ltd,Cambridge, England, 2008.

REFERENCES

1. Wensven, J.G.,AirTransportion:A Management Perspective, Ashgate, 2007.
2. Belobaba,P.,Odoni,A.andBarnhart,C.,Global Airline Industry, Wiley,2009.
3. M.Bazargan,M., Airline operations and Scheduling Ashgate, 2004.
4. Nolan,M.s., Fundamentals of Air Traffic Control,fourthedn., Thomson Learning, 2004.
5. Wells, A. and young, S.,Airport Planning and Management, fifth edn., McGraw-Hill, 1986.

III B.TECH II SEMESTER – AERONAUTICAL ENGINEERING
AIR TRANSPORTATION SYSTEMS
MODEL PAPER I

PART A

ANSWER ALL THE QUESTIONS **25 M**

1. Write about the history of Aviation evolution in the era of 1960. 2M
2. Focus on Development growth in the Aircraft Transportation 2M
3. Define Oligopolistic. 2M
4. Define the following : Industry , Transportation systems 2M
5. Write about the Economic growth in a country. 2M
6. What do you mean by Passenger Load Factor 3M
7. Describe the Aviation Industry Characteristics 3M
8. Write about Economic impact types in Air Transportation Systems 3M
9. What are the characteristics of Oligopolistic Industries 3M
10. What are effects that got improved after world war- II 3M

PART B

ANSWER FIVE QUESTIONS **5X10=50M**

1. Explain about the evolution for the Aircraft Systems.

   or

   Explain the Economic Characteristics.
2. Explain the Significance of Airline Passenger Load Factors.

   or

   Explain the Significance ofEconomic Impact.
3. Explain the Development, growth and challenges of ATS

   or

   Explain the Airlines as Oligopolistic.
4. Explain the Airline Industry structure in the 1960-1980's.

   or

   Explain the Economic growth in the Air Transportation
5. Explain the Economic impact- types and causes in the airlines

   or

   Explain the Aerospace Industry as a common term.

III B.TECH II SEMESTER – AERONAUTICAL ENGINEERING
AIR TRANSPORTATION SYSTEMS
MODEL PAPER II

PART A

ANSWER ALL THE QUESTIONS **25 M**

1. What do you mean by Physical issues 2M
2. Define the following the term Demand forecasting 2M
3. Define the following FAA,ICAO ,DGCA 2M
4. Write about the types of risk assessments 2M
5. Write about the functions of FAA 2M
6. Write about the functions of DGCA 3M
7. List out the functions of ICAO 3M
8. Write about the functions of IATA 3M
9. Write about the security regulation types 3M
10. Write about Reliability of forecasts 3M

PART B

ANSWER FIVE QUESTIONS **5X10=50M**

1. Explain the formation of International Air Law

   or

   Explain the formation and responsibilities of regulatory bodies like ICAO,IATA,DGCA and FAA
2. FEDERAL AVIATION ADMINISTRATION (FAA) is the one of the national authority what are the main functions of the FAA ,and how can you support your answer as it's very important to fly with these certificates in every national policies,Explain with FAA administration chart

   or

   The International Civil Aviation Organization (ICAO)) is the one of the national authority what are the main functions of the ICAO ,explain with flow chart support your answer it's compulsory required license to fly different nations.
3. Give a brief about ICAO Future Air Navigation Systems (FANS) and its advantages and disadvantages when compared to existing systems

   Or

   The International Air Transport Association (IATA) is an international industry trade group of airlines write about its functions and regulations
4. Write about the risk assessment in the airport; support your answer whether it is compulsory for every airport.

   or

Write the security regulation types in the airport and aviation field for traveling of passenger in different countries

5. Write the functions of ICAO and its certifications

or

Give a brief notes about ICAO Future Air Navigation Systems (FANS) and its advantages and disadvantages when compared to existing systems.

III B.TECH II SEMESTER – AERONAUTICAL ENGINEERING
AIR TRANSPORTATION SYSTEMS
MODEL PAPER III
PART A

ANSWER ALL THE QUESTIONS **25 M**

1. Explain about the about the DME with the help of neat sketch. 2M
2. Discuss about the SSR with the help of neat sketch 2M
3. Explain about the NAVIGATION with the help of neat sketch 2M
4. What do you mean by the ACARS and explain with the help of neat sketch. 2M
5. What do you mean by the GPWE and explain with the help of neat sketch 2M
6. What do you mean by TCAS and explain with the help of neat sketch 3M
7. What do you mean by EFIS and explain with the help of neat sketch 3M
8. What do you mean by AFCS and explain with the help of neat sketch 3M
9. What do you mean by VHF and explain with the help of neat sketch 3M
10. What do you mean by the PMS and explain with the help of neat sketch 3M

PART B

ANSWER FIVE QUESTIONS **5X10=50M**

1. Explain deferent types of the frequencies used in the navigation field with ranges in hedges

   or

   Explain the process of Secondary surveillance radar (SSR) in the aviation signalling process explain with
2. Explain Distance measuring equipment (DME)process for the aviation system with neat figure and support your answer it's compulsory in the pilot cabin Aircraft Communications Addressing and Reporting System (ACARS) is the navigation system used from satellites for navigation explain the process of ACARS in detail with figure

   or

   Explain Distance measuring equipment (DME)process for the aviation system with neat figure and support your answer it's compulsory in the pilot cabin Aircraft Communications Addressing and Reporting System (ACARS) is the navigation system used from satellites for navigation explain the process of ACARS in detail with figure
3. Aircraft Communications Addressing and Reporting System (ACARS) is the navigation system used from satellites for navigation explain the process of ACARS in detail with figure

   or

   Traffic collision avoidance system(TCAS) is important in safe journey explain process with figures
4. Write a short notes on:

a) Passenger Load factor b) Unique economic characteristics of air transportation systems.

or

Instrument landing system (ILS) is for the safety landing system explain the process with neat sketch

5. VHF omni-directional radio range (VOR) is the signals explain with diagrams and write applications of any four

Or

Navigation has the process of locating points and positions in the earth this is done by satiates explain the process of navigation

III B.TECH II SEMESTER – AERONAUTICAL ENGINEERING
AIR TRANSPORTATION SYSTEMS
MODEL PAPER IV
PART A

ANSWER ALL THE QUESTIONS **25 M**

1. What do you mean by air fleet utilization 2M
2. What do you mean by Indirect operating costs 3M
3. What do you mean by direct operating costs 2M
4. What do you mean by Computerized reservation system 2M
5. What is the meaning of run way capacity 2M
6. Explain about run way characteristics of an airport 2M
7. What is the meaning of apron 3M
8. What do you mean by passenger terminals 3M
9. What do you mean by monitoring 3M
10. What do you mean by manoeuvring area, airfield lightening 3M

PART B

ANSWER FIVE QUESTIONS

[5X10=50M]

1. Define the runway length according to the length it has been categorized four types what are they explain in detail.

   or

   What is the importance of the safe guard in the airport explain in detail with figures
2. Passengers terminals plays an important role in the airport environment write the terminal entrance role in the airport and security process

   or

   How did the computer reservation systems revolutionize the profits out of the industry?.
3. Explain the need for the Manoeuvring area airfield lighting, in the airport

   or

   Explain the indirect cost in the aviation budgets for the airline growth and it’s development.
4. Explain the direct cost in the aviation budgets for the airline growth and it’s development.

   or

   What is mean by apron are in the airport explain in detail.
5. What are the different approaches to meet the airport construction successfully by taking issues explain in detail?

   or

   Explain the ticketing process growth in the last few years with neat figures

III B.TECH II SEMESTER – AERONAUTICAL ENGINEERING
AIR TRANSPORTATION SYSTEMS
MODEL PAPER V

PART A

ANSWER ALL THE QUESTIONS **25 M**

1. Explain the Categories of airspace 2M
2. What is meaning of demand and delay 2M
3. What do you mean by radar assistance 2M
4. What do you mean by service providers 2M
5. What do you mean by CAPACITY 2M
6. What is the purpose of airspace sectors 2M
7. Write about CRS 2M
8. What is the purpose of Air-navigation service 3M
9. Explain the purpose of ATC SYSTEMS 3M
10. What do you mean by FANS 3M

PART B

ANSWER FIVE QUESTIONS **5X10=50M**

1. The Future Air Navigation System is the modern approach for the navigation explains in detail for this type of approaches in future and what are they?

   (or)

   a) Describe the characteristics of a modern airport. b) Are they economically viable?
2. Distinguish efficiency and effectiveness of an aircraft balanced by an airline? Explain.

   or

   Explain

   a) State-of-art ATC b) Separation in air c) Role of radar at the airport.
3. Broadly explain various communication systems used in air transport system

   or

   Define passenger load factor. Explain its role in airline industry
4. Is there a scope for starting a new airline company in India now? Extend your arguments

   or

   How are range, payload and fuel efficiency balanced? What are the roles played by the speed and cruisealtitude of aircraft in the economics of an airliner? Explain

5. What is the role of human factors in the safety of aviation? Discuss.

or

Explain in brief a)Runway characteristics b) Runway capacity.

UNIT-I

AVIATION INDUSTRY & ITS REGULATORY AUTHORITIES

INTRODUCTION:

Aviation is the practical aspect or art of aeronautics, being the design, development, production, operation and use of aircraft, especially heavier than air i.e aircraft. The word *aviation* was coined by French writer and former naval officer Gabriel La Landelle in 1863, from the verb *avier* (synonymous flying), itself derived from the Latin word *avis* ("bird") and the suffix *–ation.*

History of Aviation: The **history of aviation** has extended over more than two thousand years, from the earliest forms of aviation, kites and attempts at tower jumping, to supersonic, and hypersonic flight by powered, heavier-than-air jets.

Kite flying in China dates back to several hundred years BC and slowly spread around the world. It is thought to be the earliest example of man-made flight.

Leonardo da Vinci's 15th-century dream of flight found expression in several rational but unscientific designs, though he did not attempt to construct any of them.

The discovery of hydrogen gas in the 18th century led to the invention of the hydrogen balloon, at almost exactly the same time that the Montgolfier brothers rediscovered the hot-air balloon and began manned flights. Various theories in mechanics by physicists during the same period of time, notably fluid dynamics and Newton's laws of motion, led to the foundation of modern aerodynamics, most notably by Sir George Cayley.

Balloons, both free-flying and tethered, began to be used for military purposes from the end of the 18th century, with the French government establishing Balloon Companies during the Revolution.

Experiments with gliders provided the groundwork for heavier-than-air craft, and by the early-20th century, advances in engine technology and aerodynamics made controlled, powered flight possible for the first time. The modern aeroplane with its characteristic tail was established by 1909 and from then on the history of the aeroplane became tied to the development of more and more powerful engines.

The first great ships of the air were the rigid dirigible balloons pioneered by Ferdinand von Zeppelin, which soon became synonymous with airships and dominated long-distance flight until the 1930s, when large flying boats became popular. After World War II, the flying boats were in their turn replaced by land planes, and the new and immensely powerful jet engine revolutionised both air travel and military aviation.

In the latter part of the 20th century the advent of digital electronics produced great advances in flight instrumentation and "fly-by-wire" systems. The 21st century saw the large-scale use of pilotless drones for military, civilian and leisure use. With digital controls, inherently unstable aircraft such as flying wings became possible.

DEVELOPMENT AND GROWTH OF AVIATION INDUSTRY

Primitive beginnings

The origin of mankind's desire to fly is lost in the distant past. From the earliest legends there have been stories of men strapping birdlike wings, stiffened cloaks or other devices to themselves and attempting to fly, typically by jumping off a tower. The Greek legend of Daedalus and Icarus is one of the earliest known; others originated from India, China and the European Middle Age. The kite may have been the first form of man-made aircraft. It was invented in China possibly as far back as the 5th century BC by Mozi (Mo Di) and Lu Ban (Gongshu Ban) The use of a rotor for vertical flight has existed since 400 BC in the form of the bamboo-copter, an ancient Chinese toy From ancient times the Chinese have understood that hot air rises and have applied the principle to a type of small hot air balloon called a sky lantern. From ancient times the Chinese have understood that hot air rises and have applied the principle to a type of small hot air balloon called a sky lantern.

- On 4 June, the Montgolfier brothers demonstrated their unmanned hot air balloon at Annonay, France.
- On 27 August, Jacques Charles and the Robert brothers (*Les Freres Robert*) launched the world's first unmanned hydrogen-filled balloon, from the Champ de Mars, Paris.
- On 19 October, the Montgolfiers launched the first manned flight, a tethered balloon with humans on board, at the *Folie Titon* in Paris. The aviators were the scientist Jean-François Pilâtre de Rozier, the manufacture manager Jean-Baptiste Réveillon, and Giroud de Villette.
- On 21 November, the Montgolfiers launched the first free flight with human passengers. King Louis XVI had originally decreed that condemned criminals would be the first pilots, but Jean-François Pilâtre de Rozier, along with the Marquis François d'Arlandes, successfully petitioned for the honor. They drifted 8 km (5.0 mi) in a balloon powered by a wood fire.
- On 1 December, Jacques Charles and the Nicolas-Louis Robert launched their manned hydrogen balloon from the Jardin des Tuileries in Paris, as a crowd of 400,000 witnessed. They ascended to a height of about 1,800 feet (550 m)[15] and landed at sunset in Nesles-la-Vallée after a flight of 2 hours and 5 minutes, covering 36 km. After Robert alighted Charles decided to ascend alone. This time he ascended rapidly to an altitude of about 9,800 feet (3,000 m), where he saw the sun again, suffered extreme pain in his ears, and never flew again.
- Work on developing a steerable (or dirigible) balloon continued sporadically throughout the 19th century. The first powered, controlled, sustained lighter-than-air flight is

believed to have taken place in 1852 when Henri Giffard flew 15 miles (24 km) in France, with a steam engine driven craft.

- Another advance was made in 1884, when the first fully controllable free-flight was made in a French Army electric-powered airship, La France, by Charles Renard and Arthur Krebs. The 170-foot (52 m) long, 66,000-cubic-foot (1,900 m^3) airship covered 8 km (5.0 mi) in 23 minutes with the aid of an 8½ horsepower electric motor.

The first published paper on aviation was "Sketch of a Machine for Flying in the Air" by Emanuel Swedenborg published in 1716. This flying machine consisted of a light frame covered with strong canvas and provided with two large oars or wings moving on a horizontal axis, arranged so that the upstroke met with no resistance while the downstroke provided lifting power.

Sir George Cayley was first called the "father of the aeroplane" in 1846. During the last years of the previous century he had begun the first rigorous study of the physics of flight and would later design the first modern heavier-than-air craft.

Drawing directly from Cayley's work, Henson's 1842 design for an aerial steam carriage broke new ground. Although only a design, it was the first in history for a propeller-driven fixed-wing aircraft.

December 17, 1903.

The first flight by Orville Wright, of 120 feet (37 m) in 12 seconds, was recorded in a famous photograph. In the fourth flight of the same day, Wilbur Wright flew 852 feet (260 m) in 59 seconds. The flights were witnessed by three coastal lifesaving crewmen, a local businessman, and a boy from the village, making these the first public flights and the first well-documented ones.

The Pioneer Era (1903–1914)

This period saw the development of practical aeroplanes and airships and their early application, alongside balloons and kites, for private, sport and military use. In March 1907 Gabriel Voisin flew the first example of his Voisin biplane. On 13 January 1908 a second example of the type was flown by Henri Farman to win the Deutsch-Archdeacon *Grand Prix d'Aviation* prize for a flight in which the aircraft flew a distance of more than a kilometer and landed at the point where it had taken off. The flight lasted 1 minute and 28 seconds.

In 1914, just before the start of World War I, Romania completed the world's first metal-built aircraft, Vlaicu III. It was captured by the Germans in 1916 and last seen at a 1942 aviation exhibition in Berlin

The first time a manned helicopter is known to have risen off the ground was on a tethered flight in 1907 by the Breguet-Richet Gyroplane. Later the same year the Cornu helicopter, also

French, made the first rotary-winged free flight at Lisenux, France. However, these were not practical designs. Almost as soon as they were invented, airplanes were used for military purposes. The first country to use them for military purposes was Italy, whose aircraft made reconnaissance, bombing and artillery correction flights in Libya during the Italian-Turkish war (September 1911 – October 1912). The first mission (a reconnaissance) occurred on 23 October 1911. The first bombing mission was flown on 1 November 1911.

World War I (1914–1918)

France, Britain, Germany and Italy were the leading manufacturers of fighter planes that saw action during the war, with German aviation technologist Hugo Junkers showing the way to the future through his pioneering use of all-metal aircraft from late 1915.

Between the World Wars (1918–1939)

The years between World War I and World War II saw great advancements in aircraft technology. Airplanes evolved from low-powered biplanes made from wood and fabric to sleek, high-powered monoplanes made of aluminum, based primarily on the founding work of Hugo Junkers during the World War I period and its adoption by American designer William Bushnell Stout and Soviet designer Andrei Tupolev. The age of the great rigid airships came and went. The first successful rotorcraft appeared in the form of the autogyro, invented by Spanish engineer Juan de la Cierva and first flown in 1919. In this design, the rotor is not powered but is spun like a windmill by its passage through the air. A separate powerplant is used to propel the aircraft forwards.

Less than a decade after the development of the first practical rotorcraft of any type with the autogyro, in the Soviet Union, Boris N. Yuriev and Alexei M. Cheremukhin, two aeronautical engineers working at the *Tsentralniy Aerogidrodinamicheskiy Institut*, constructed and flew the TsAGI 1-EA single rotor helicopter, which used an open tubing framework, a four blade main rotor, and twin sets of 1.8-meter (5.9 ft) diameter anti-torque rotors; one set of two at the nose and one set of two at the tail. Powered by two M-2 powerplants, up-rated copies of the Gnome Monosoupape rotary radial engine of World War I, the TsAGI 1-EA made several successful low altitude flights. By 14 August 1932, Cheremukhin managed to get the 1-EA up to an unofficial altitude of 605 meters (1,985 feet) with what is likely to be the first successful single-lift rotor helicopter design ever tested and flown.

Only five years after the German Dornier Do-X had flown, Tupolev designed the largest aircraft of the 1930s era, the *Maksim Gorky* in the Soviet Union by 1934, as the largest aircraft ever built using the Junkers methods of metal aircraft construction.

In the 1930s development of the jet engine began in Germany and in Britain – both countries would go on to develop jet aircraft by the end of World War II

World War II (1939–1945)

World War II saw a great increase in the pace of development and production, not only of aircraft but also the associated flight-based weapon delivery systems. Air combat tactics and doctrines took advantage. Large-scale strategic bombing campaigns were launched, fighter escorts introduced and the more flexible aircraft and weapons allowed precise attacks on small targets with dive bombers, fighter-bombers, and ground-attack aircraft. New technologies like radar also allowed more coordinated and controlled deployment of air defense.

Me 262, world first operational jet fighter

The first jet aircraft to fly was the Heinkel He 178 (Germany), flown by Erich Warsitz in 1939, followed by the world's first operational jet aircraft, the Me 262, in July 1942 and world's first jet-powered bomber, the Arado Ar 234, in June 1943. British developments, like the Gloster Meteor, followed afterwards, but saw only brief use in World War II. The first cruise missile (V-1), the first ballistic missile (V-2), the first (and to date only) operational rocket-powered combat aircraft Me 163 — with attained velocities of up to 1,130 km/h (700 mph) in test flights — and the first vertical take-off manned point-defense interceptor, the Bachem Ba 349 *Natter*, were also developed by Germany. However, jet and rocket aircraft had only limited impact due to their late introduction, fuel shortages, the lack of experienced pilots and the declining war industry of Germany.

World War II saw a great increase in the pace of development and production, not only of aircraft but also the associated flight-based weapon delivery systems. Air combat tactics and doctrines took advantage. Large-scale strategic bombing campaigns were launched, fighter escorts introduced and the more flexible aircraft and weapons allowed precise attacks on small targets with dive bombers, fighter-bombers, and ground-attack aircraft. New technologies like radar also allowed more coordinated and controlled deployment of air defense.

The postwar era (1945–1979)

After World War II, commercial aviation grew rapidly, using mostly ex-military aircraft to transport people and cargo. This growth was accelerated by the glut of heavy and super-heavy bomber airframes like the B-29 and Lancaster that could be converted into commercial aircraft. The DC-3 also made for easier and longer commercial flights. The first commercial jet airliner to fly was the British de Havilland Comet. By 1952, the British state airline BOAC had introduced the Comet into scheduled service. While a technical achievement, the plane suffered a series of highly public failures, as the shape of the windows led to cracks due to metal fatigue. The fatigue was caused by cycles of pressurization and depressurization of the cabin, and eventually led to catastrophic failure of the plane's fuselage. By the time the problems were overcome, other jet airliner designs had already taken to the skies.

USSR's Aeroflot became the first airline in the world to operate sustained regular jet services on September 15, 1956 with the Tupolev Tu-104. The Boeing 707 and DC-8 which established new levels of comfort, safety and passenger expectations, ushered in the age of mass commercial air travel, dubbed the Jet Age.

The Harrier Jump Jet, often referred to as just "Harrier" or "the Jump Jet", is a British designed military jet aircraft capable of Vertical/Short Takeoff and Landing (V/STOL) via thrust vectoring. It first flew in 1969, the same year that Neil Armstrong and Buzz Aldrin set foot on the moon, and Boeing unveiled the Boeing 747 and the Aérospatiale-BAC Concorde supersonic passenger airliner had its maiden flight. The Boeing 747 was the largest commercial passenger aircraft ever to fly, and still carries millions of passengers each year, though it has been superseded by the Airbus A380, which is capable of carrying up to 853 passengers. In 1975 Aeroflot started regular service on the Tu-144—the first supersonic passenger plane. In 1976 British Airways and Air France began supersonic service across the Atlantic, with Concorde. A few years earlier the SR-71 Blackbird had set the record for crossing the Atlantic in under 2 hours, and Concorde followed in its footsteps.

In 1979 the Gossamer Albatross became the first human powered aircraft to cross the English channel. This achievement finally saw the realization of centuries of dreams of human flight.

The digital age (1980–present)

The last quarter of the 20th century saw a change of emphasis. No longer was revolutionary progress made in flight speeds, distances and materials technology. This part of the century instead saw the spreading of the digital revolution both in flight avionics and in aircraft design and manufacturing techniques.

In 1986 Dick Rutan and Jeana Yeager flew an aircraft, the Rutan Voyager, around the world unrefuelled, and without landing. In 1999 Bertrand Piccard became the first person to circle the earth in a balloon.

Digital fly-by-wire systems allow an aircraft to be designed with relaxed static stability. Initially used to increase the manoeuvrability of military aircraft such as the General Dynamics F-16 Fighting Falcon, this is now being used to reduce drag on commercial airliners

21st century aviation has seen increasing interest in fuel savings and fuel diversification, as well as low cost airlines and facilities. Additionally, much of the developing world that did not have good access to air transport has been steadily adding aircraft and facilities, though severe congestion remains a problem in many up and coming nations. Some 20,000 city pairs are served by commercial aviation, up from less than 10,000 as recently as 1996.

There appears to be newfound interest in returning to the supersonic era whereby waning demand and bureaucratic hurdles in the turn of the 20th century made flights unprofitable, as well as the final commercial stoppage of the Concorde due to a fatal accident.

In the beginning of the 21st century, digital technology allowed subsonic military aviation to begin eliminating the pilot in favor of remotely operated or completely autonomous unmanned aerial vehicles (UAVs). In April 2001 the unmanned aircraft Global Hawk flew from Edwards AFB in the US to Australia non-stop and unrefuelled. This is the longest point-to-point flight ever undertaken by an unmanned aircraft, and took 23 hours and 23 minutes. In October 2003 the first totally autonomous flight across the Atlantic by a computer-controlled model aircraft occurred. UAVs are now an established feature of modern warfare, carrying out pinpoint attacks under the control of a remote operator.

Major disruptions to air travel in the 21st century included the closing of U.S. airspace due to the September 11 attacks, and the closing of most of European airspace after the 2010 eruption.

In 2015, André Borschberg flew a record distance of 4481 miles (7212 km) from Nagoya, Japan to Honolulu, Hawaii in a solar-powered plane, Solar Impulse 2. The flight took nearly five days, during the nights the aircraft used its batteries and the potential energy gained during the day.

Like all activities involving combustion, operating powered aircraft (from airliners to hot air balloons) releases soot and other pollutants into the atmosphere. Greenhouse gases such as carbon dioxide (CO_2) are also produced. In addition, there are environmental impacts specific to aviation: for instance,

Water vapor contrails left by high-altitude jet airliners. These may contribute to cirrus cloud formation.

- Aircraft operating at high altitudes near the tropopause (mainly large jet airliners) emit aerosols and leave contrails, both of which can increase cirrus cloud formation – cloud cover may have increased by up to 0.2% since the birth of aviation.
- Aircraft operating at high altitudes near the tropopause can also release chemicals that interact with greenhouse gases at those altitudes, particularly nitrogen compounds, which interact with ozone, increasing ozone concentrations.
- Most light piston aircraft burn avgas, which contains tetraethyllead (TEL). Some lower-compression piston engines can operate on unleaded mogas, and turbine engines and diesel engines – neither of which require lead – are appearing on some newer light aircraft.

Another environmental impact of aviation is noise pollution, mainly caused by aircraft taking off and landing.

Three major challenges — safety, convenience, and environmental and financial sustainability — that concern the industry as it heads into the future.

Flying today is extremely safe. It wasn't always that way. In the early days it was a risky business. But right from the beginning there was an understanding among governments and industry that safety was not a competitive issue. And there has always been great cooperation among all the industry's stakeholders in efforts to make flying ever safer.

In 2013 there were some 36.4 million flights and 16 fatal accidents. If you were flying on a jet aircraft, your chances of being involved in a major accident were one in 2.4 million. And among the three billion passengers that flew (the equivalent of about 40% of the world's population) there were 210 fatalities. There is no safer way to get from A to B than by plane.

Any business is expected to be sustainable. But it is particularly challenging for airlines that burn fuel to propel their aircraft. Nonetheless, the industry (not just airlines but the whole value chain) has committed to some very ambitious goals. From 2020 we will cap our emissions and our growth will be carbon-neutral. And by 2050 the aspiration is to cut our net emissions back to half the levels that we emitted in 2005.

The other vector of sustainability is profitability. Over the last century airlines have just broken even. Despite all of the value that they bring to the world—as we have discussed—they have basically destroyed a vast amount of capital. It is a very competitive and very tough business.

The good news is that this is an improvement on the recent past. And continuing strong demand for passenger travel—despite economic uncertainties—shows that the world's thirst for connectivity that only aviation can provide is still growing.

Aerospace Industry: The aerospace industry includes those firms engaged in research, development, and manufacture of all of the following: aerospace systems, including manned and unmanned aircraft; missiles, space-launch vehicles, and spacecraft; propulsion, guidance, and control units for all of the foregoing; and a variety of airborne and ground-based equipment essential to the testing, operation, and maintenance of flight vehicles. Virtually all of the major firms in the aerospace industry are members of the Aerospace Industries Association (AIA) or the General Aviation Manufacturers Association (GAMA). Founded in 1919 and based in Washington, D.C., the AIA is a trade association representing the nation's manufacturers of commercial, military, and business aircraft, helicopters, aircraft engines, missiles, spacecraft, and related components and equipment. GAMA, also based in Washington, D.C., is the trade association that represents the interests of manufacturers of light aircraft and component parts.

As the 21st century began, approximately two-thirds of the aerospace industry's output was bought by the federal government. During the past two decades, this figure has ranged as high as 74 percent. At the same time, the aerospace industry is the world's largest producer of civil aircraft and equipment. Roughly 6 out of every 10 transports operating with the world's civil airlines are of U.S. manufacture, and in addition, the industry turns out several thousand civil helicopters and general aviation planes yearly.

Naturally, such an industry is vital to the economy, especially in the following areas:

1. Trade balance. The excellence of aerospace products has created strong demand abroad, with the result that the industry consistently records a large international trade surplus.

2. Employment. Despite several years of decline in number of workers, the aerospace industry remains one of the nation's largest manufacturing employers.

3. Research and development. The industry conducts more research and development (R & D) than any other industry, and R & D is a major long-term determinant of national economic growth.

4. Impact on other industries. A great many new aerospace-related products and processes have spun off from the initial aerospace requirement and have provided value to other industries, both in sales and in productive efficiency. In addition, the aerospace industry is a large-scale user of other industries' goods and services: it has been estimated that for every 100 aerospace jobs created, another 73 are created in other industries.

Each of these factors represents a significant contribution to the economy; collectively, they elevate aerospace to a key position among the nation's major industries.

Economic Profile of the Industry

The aerospace industry is composed of about 60 major firms operating some 1,000 facilities, backed by thousands of subcontractors, vendors, and suppliers. The principal product line—aircraft, missiles, space systems and related engines, and parts and equipment—is characterized by high performance and high reliability, and hence high technology and high unit value. Activity, as measured by sales volume, focuses on aircraft, both civil and military, which account for almost 55 percent of the industry's workload. Missile systems represent about 6 percent of the total, and space fabrication for about 21 percent. In addition, 17 percent comes from related products and services, which embrace the industry's growing efforts to transfer to the nonaerospace sector some of the technology developed in aerospace endeavors. Sales in 2005 amounted to $170 billion, broken down as follows: aircraft, $89.1 billion; missiles, $15.3 billion; space-related materials, $37.3 billion; and related products and services, $28.3 billion.

Related products and services include all nonaircraft, non-space vehicle, and nonmissile products and services produced or performed by those companies or establishments whose principal business is the development or production of aircraft, aircraft engines, missile and spacecraft engines, missiles, or spacecraft. The early 1990s were difficult for U.S. aerospace companies. Declining defense spending and a protracted airline recession caused U.S. aerospace sales to plummet, resulting in the industry's worst downturn in 40 years. By 1996, the industry began to turn around. The 8 percent rise between 1995 and 1996 was largely attributable to increased sales of civil aircraft, engines, and parts. Sales of missiles have steadily increased for the years 2000–2005. This category should increase in the years ahead as the war on terrorism continues around the globe.

Over the past 60 years, the air transportation industry has become an increasingly important part of the U.S. economy. Aviation is the nation's dominant intercity mode of transportation for those passengers and goods that must be transported quickly and efficiently. It has become so universal that no one questions aviation's importance as an essential form of transport. Aviation employs many thousands of people, and thousands more work in aviation's support industries, such as hotels, restaurants, rental cars, real estate, construction, and manufacturing. Individuals in these industries benefit economically from aviation regardless of whether they actually fly.

Air transportation is now as much a part of our way of life as the telephone or the computer. Speed, efficiency, comfort, safety, economy—these are the symbols of both modern society and modern air transportation. If you need to get somewhere in a hurry, and most businesses do, because time means money, then fly—comfortably, safely, and economically. Air transportation has enabled employees of business and government organizations to reach any point in the world within hours, whether flying by air carrier or a general aviation aircraft. Certain values are associated with this timeliness:

1. Quicker on-the-spot decisions and action

2. Less fatigue associated with travel

3. Greater mobility and usefulness of trained, experienced executives, engineers, technicians, troubleshooters, and sales personnel

4. Decentralized production and distribution

5. The ability to expand market areas through more efficient use of management and sales personnel

To visualize a world without modern air transportation, consider the world of 1940, when surface transportation was still in its prime and air transportation was in its infancy. The 800-mile New York–Chicago trip took 17 hours each way on the fastest rail routing. The same trip today can be made in a couple of hours. Also consider the thousands of smaller communities now served by business representative's flying in and out the same day—it took days and weeks to cover the same territory back in the 1940s.

Airline Industry-structure and economic characteristics

An **airline** is a company that provides air transport services for traveling passengers and freight. Airlines utilize aircraft to supply these services and may form partnerships or alliances with other airlines for code share agreements. Generally, airline companies are recognized with an air operating certificate or license issued by a governmental aviation body.

Airlines vary in size, from small domestic airlines to full-service international airlines. Airline services can be categorized as being intercontinental, domestic, regional, or international, and may be operated as scheduled services or charters. The largest airline currently is American Airlines Group.

Most commercial airlines feature a chief executive officer (CEO) who oversees the operations of the company. A board of directors, with a chairman, usually meets regularly with the CEO and his subordinates. The CEO often has a chief financial officer (CFO) and a chief operating officer (COO) to assist him. Working beneath this trio are executive vice presidents (EVPs). These EVPs oversee broad-based organizations such as airline operations and flight operations.

Major Airlines are Structured

Line Personnel

These include everyone directly involved in producing or selling an airline's services - the mechanics, who maintain the planes; the pilots, who fly them; the flight attendants, who serve passengers and perform various inflight safety functions; the reservation clerks, airport check-in and gate personnel, who book and process the passengers; ramp-service agents, security guards, etc. Line personnel generally fall into three broad categories: engineering and maintenance, flight operations, and sales and marketing. These three divisions form the heart of an airline and generally account for 85 percent of an airline's employees.

Operations

This department is responsible for operating an airline's fleet of aircraft safely and efficiently. It schedules the aircraft and flight crews and it develops and administers all policies and procedures necessary to maintain safety and meet all FAA operating requirements. It is in charge of all flight-crew training, both initial and recurrent training for pilots and flight attendants, and it establishes the procedures crews are to follow before, during and after each flight to ensure safety.

Dispatchers also are part of flight operations. Their job is to release flights for takeoff, following a review of all factors affecting a flight. These include the weather, routes the flight may follow, fuel requirements and both the amount and distribution of weight onboard the aircraft. Weight must be distributed evenly aboard an aircraft for it to fly safely.

Maintenance

Maintenance accounts for approximately 11 percent of an airline's employees and 10-15 percent of its operating expenses. Maintenance programs keep aircraft in safe, working order; ensure passenger comfort; preserve the airline's valuable physical assets (its aircraft); and ensure maximum utilization of those assets, by keeping planes in excellent condition. An airplane costs its owner money every minute of every day, but makes money only when it is flying with freight and/or passengers aboard. Therefore, it is vital to an airline's financial success that aircraft are properly maintained

Airlines typically have one facility for major maintenance work and aircraft modifications, called the maintenance base; larger airlines sometimes have more than one maintenance base. Smaller maintenance facilities are maintained at an airline's hubs or primary airports, where aircraft are likely to be parked overnight. Called major maintenance stations, these facilities perform routine maintenance and stock a large supply of spare parts.

A third level of inspection and repair capability is maintained at airports, where a carrier has extensive operations, although less than at its hubs. These maintenance facilities generally are called maintenance stations.

Sales and Marketing

This division encompasses such activities as pricing, scheduling, advertising, ticket and cargo sales, reservations and customer service, including food service. While all of them are important, pricing and scheduling in particular can make or break an airline, and both have become more complicated since deregulation. As explained in the next chapter, airline prices change frequently in response to supply and demand and to changes in the prices of competitor's fares. Schedules change less often, but far more often than when the government regulated the industry. Airlines use sophisticated computer reservation systems to advertise their own fares and schedules to travel agents and to keep track of the fares and schedules of competitors. Travel agents, who sell approximately 80 percent of all airline tickets, use the same systems to book reservations and print tickets for travelers. More information about airline pricing and scheduling can be found in Chapter 4.

Reservations and Ticketing

There are major changes in air transportation, which simplify the process for airline passengers to make a reservation and to purchase a ticket. Electronic commerce is playing a significant part in the airline industry. In addition to the paper tickets issued in the past, all of the major airlines are now offering electronic ticketing for domestic and international air travel. Electronic ticketing allows an airline to document the sale and track the usage of transportation. Passengers no longer worry about carrying flight coupons or losing their tickets. Passengers have the ability to shop for the lowest priced transportation, make or change a reservation, request refunds etc., not only from their travel agent but from their own personal home computer or from a telephone, on the way to the airport. A boarding pass is issued at the airport in exchange for proof of a reservation (an airline confirmation number) and payment (cash or a major credit card). The number of air travelers shopping, making reservations and purchasing electronic tickets using the Internet is increasing daily. Self-service automated ticketing machines are also widely available at major airports around the country.

The next step for airlines will be to automate the check-in procedure. Electronic self-service check-in computer kiosks at major airports will soon be available for most passengers using electronic tickets. Self-service machines will enable passengers to verify their itinerary, obtain class of service upgrades, select specific seat assignments, check baggage with bar-coded baggage tags and obtain their own boarding passes.

Staff Personnel

These include specialists in such fields as law, accounting, finance, employee relations and public relations. Their function is to support the work of the line personnel, so that the airline runs efficiently and earns a profit. For the most part, staff personnel work out of corporate headquarters and fall into seven broad job categories typical of major corporations: finance & property, information services, personnel, medical, legal, public relations and planning.

Finance & property handles company revenues and finances. In addition, it oversees all company property and the purchase of food, fuel, aircraft parts and other supplies needed to run an airline. Information services designs and maintains the company's internal computer systems, used to store and analyze data needed for operations and planning. At an airline, this includes the important function of fleet planning, explained in greater detail in the next chapter.

Subcontractors

While major airlines typically do most of their own work, it is common for them to farm out certain tasks to other companies. These tasks could include aircraft cleaning, fueling, airport security, food service and in some instances, maintenance work. Airlines might contract out for all of this work or just a portion of it, keeping the jobs in house at their hubs and other key stations. However, whether an airline does the work itself or relies on outside vendors, the carrier remains responsible for meeting all applicable federal safety standards.

Economic development worldwide is getting a significant boost from air transport. This wider economic benefit is being generated by increasing connections between cities - enabling the flow of goods, people, capital, technology and ideas - and falling air transport costs. The number of unique city-pair connections is expected to reach more than 19,000 this year, almost double the connectivity by air twenty years ago. The price of air transport for users continues to fall, after adjusting for inflation. Compared to twenty years ago real transport costs have more than halved.

Another impact on the wider economy comes through the influence increased airline activity has on jobs in the sector, in its supply chain, and the jobs generated as spending ripples through the economy. These 'supply chain' jobs around the world are estimated to rise to 69.6 million in 2017. But in many countries the value that aviation generates is not well understood. The commercial activities of the industry remain highly constrained by bilateral and other regulations. Moreover, regulation is far from 'smart', leading to unnecessarily high costs. Visa requirements discourage inbound tourism and business travel. Encouragingly visa openness levels are improving. Unfortunately, the number of individual ticket taxes has risen to 236, while the level of many existing taxes continues to ratchet upwards.

The breadth of regulation

There are two major aspects to regulation – economic and technical. They are administered separately in most countries and there is a major international coordination body in each sphere, these being the International Civil Aviation Organisation (ICAO) looking after safety- orientated regulation and the International Air Transport Association (IATA) looking after commercially sensitive regulation.

The structure and function of each will be examined separately, but as their separate responsibilities are shared over a broad common boundary, the degree to which individual nations are free to negotiate their own terms of reference for legislation, especially nation-to-nation, need to be considered. Most combinations of nations have negotiated and ratified 'bilateral traffic agreements'. These are reviewed periodically, and overall the rules that emerge from such negotiations will set limits on points of access, capacity on services and the actual designation of air service suppliers. The negotiations have to respect the influence of 'freedoms of the air', which are vested in ICAO and detailed later, and the competitiveness of nations in seeking to manage market share, through the use of computerized reservation systems (CRS) and such mechanisms as code-sharing, which are topics vested within IATA. Both organizations will monitor such developments and in many cases, through their regular involvement and oversight, they can assist in the drafting of such agreements, thus saving time and money.

Where 'deregulation' is being approved, national authorities are given freedom to dismantle components of their own regulatory organisation and procedures, where they so wish. However, an overriding provision is that the less bureaucratic legislative processes that emerge must still be compatible with the requirements of the international community. The clearest example of this has been the dismantling of route-licensing procedures, whereby an airline had to seek approval to compete on a route with an incumbent operator. While allowed in principle, this is not allowed to proceed without some restraint, for example in terms of respecting capacity constraints at airports, which might be administered by the IATA through its Scheduling Services division.

International Civil Aviation Organisation (ICAO)

The International Civil Aviation Organisation (ICAO) is the supreme legislative body overseeing technical-based aspects of international air transport operations. ICAO takes responsibility for the framework against which much of the international air law pertaining to operations and safety worldwide is drafted.

Its responsibilities date from 1944, when it was founded, but many of the principles it adheres to can be found in legislation that pre-dates this period. It was in Europe, where nations were cheek by jowl and air travel was beginning to take hold, that the first international air agreements were drafted and enacted, from as early as 1919. Once in place, regulations have to live and breathe. They are under perpetual review, with experts tracking every issue, almost day-by-day, and urging the re-drafting of time-expired or hole-riddled statutes. As international laws are debated at length before being enacted, they can seem to be part of a process that, to those driven by entrepreneurial flair, is apparently staid, slow and counter-productive. Thus far, ICAO has walked the tightrope between being overzealous and too relaxed very successfully. Given the tribulations on which it has often to be arbitrator, this is a statement made with considerable respect.

International Air Transport Association (IATA)

The International Air Transport Association (IATA) was created almost at the same time as ICAO, and also with worldwide reach and also headquartered in Montreal. However, this is not an organisation that sets rules for governments. It is a less kindred association of representatives from privately and publicly owned aircraft operators. Those organisations that are members have chosen to join it, and the 278 airline members as of 2017 representing 117 countries (of some thousand airlines worldwide) were responsible for 95% of the total passenger-kilometres performed each year.

IATA produce considerable quantities of statistical data concentrated on routes and financial and other business information. These data tend to be derived from member company records, as the membership is almost wholly scheduled carriers. They are a useful source for forecasters, but IATA does withhold commercially sensitive information from the public.

IATA can pick up current technical affairs, but these tend to be ICAO's responsibility, and they only take issue where there are commercial implications. An example in the 1980s was the way that IATA addressed issues with the bias of computerised reservation systems (CRS) and acted as an authority able to draft and impose a workable set of fair-trading rules. At the present time IATA is active with regard to several issues in the areas of safety, security, the environment and e-ticketing.

National authorities

Within each country, the national authority is the main point of contact with a regulatory body. Almost every country in the world has a Department of Civil Aviation (sometimes called DCA). It can be referred to as the DCA, with the head called the Director-General of Civil Aviation (DGCA). It is a part of the national 'civil service' and the staff will be partly specialists and partly governmental administrators who move between departments. In many large countries, the task is large enough to have a specialist body, within which staffs are able to follow a refined career structure and where incoming and departing administrative staffs are comparatively low in number. In the USA the specialist team is the Federal Aviation Administration (FAA) and in Britain the Civil Aviation Authority (CAA). It is a member of the national authority that will be a nation's representative in ICAO, and the organisation will have less clear but equally strong links with IATA.

Essential in all organisations, invariably, are two different groups. In the UK these are termed the Economic Regulation Group (ERG) and Safety Regulation Group (SRG). There are additional groups in all regulatory authorities for administration and personnel, for example.

Safety regulations

Broadly, there are two models that can be applied by a national authority in terms of exercising their authority as a safety regulator

- One is to apply onerous and detailed technical regulation rigorously, giving little leeway and showing no favour. This was the almost universal practice for many decades, but the model was challenged from the late 1980s.
- The newer, alternative, policy is to give participants freedom to interpret regulations that are principles rather than expressions of adherence, and to let the users apply the regulations within a safety management system (SMS) that they have created. In approving the SMS the regulator and the user will define criteria that the regulator can monitor and set attainment targets against each one.

Whereas organisations often used to look to regulators to influence their choice as technology delivered new capability, the new paradigm is that users have an obligation to seek, or encourage, new developments and to introduce them to meet their own aims.

Risk assessment

In respect of having a justification system for action or inaction, or to act as a stimulus for change, the most far-reaching principles in safety regulation are in risk assessment. It is a framework that is simple in terms of its philosophy and is a prime example of taking a 'systems approach', in that a key property of the system is recognised and managed through regulation. Examples of the latter are FARs (Federal Airworthiness Requirements) administered by the Federal Aviation Administration (FAA) in the USA and JARs (Joint Airworthiness Requirements) administered by the Joint Airworthiness Authority (JAA) in Europe, which declare objectives that govern the latitude for judgement in the design and operation of aircraft and their components. In assessing the applicability of procedures an organisa- tion has to submit a functional hazard analysis (FHA) to the regulator. This can take many forms, but it will invoke several defined steps, and thus it might range from involving a panel of specialists with different but relevant disciplines to being a competent mathematical model based on acceptable data and analytical criteria.

Human factors and safety

Trends in accident statistics in the 1960s showed that aircrews, even when competently trained, occasionally set up flight conditions that lead to disasters. Two trends emerged.

First, a crew can set up systems controls that can be read ambiguously such that the aircraft does not do what they expected it to do. However, because they have not monitored it adequately, they are too late in responding to the unexpected situation when it does arise. This is not so much a failure as a 'blunder'. There is a strong body of opinion that such situations can be controlled, to a reasonable extent, by improvements in design or by installing monitoring systems that will react to such a mistake. Design requirements have been improved and have been reviewed and changed considerably over time. The advent of smaller crew sizes and more automated and electronic-based control and display systems has invited the chance of less monitoring and greater ambiguity. Safety regulators make the designer as responsible as the user in respect of performing human-factor related safety risk assessments in such areas.

Security regulations

These are not particular safety regulation issues for, while it is convenient to associate them in this portion of the presentation, in most nations the security legislation pertaining to aviation is lodged within government departments that are concerned with national affairs. Security, for example, is handled by the UK Department of Transport, while immigration is handled by Customs and Immigration Control. Since late 2007 the services have been re-organised and now perform the same duties in a more integrated manner, and are referred to as a border control organisation. In the USA the Department of Homeland Security takes the lead on security issues and immigration is the responsibility of the Customs and Border Protection Agency.

Environmental regulations

Environmental regulations are growing fast and becoming a major concern to aviation. Most environmental issues are aligned to planning consent and conditions. They can therefore be administered locally and very parochially. It is quite possible that, wherever one is in the world, the conditions applied at one airport will be different to those applied at any other airport.

There are ICAO Annexes that define noise certification requirements for aircraft and that set environmental guidelines. Aircraft manufacturers cannot certify an aircraft that does not meet requirements for peak approach, take-off and sideline noise levels. The requirement is refined periodically and has called for a substantial decrease in the allowable noise over several decades. This has been a fine balancing act, representing the best interests of the general public and ensuring targets are technically attainable without imposing onerous conditions that will impact the ability of aircraft operators to offer services. Each successive generation of aircraft has been significantly quieter than its predecessor generation, but the margin of improvement diminishes as the engine noise level reaches a level similar to that of the noise created by the aircraft's structure. There are some doubts about how far the regulation of noise at the design stage can be pushed further.

UNIT - II
Airspace

Introduction

Most aviation professionals fail to consider 'airspace management' in the same breath as the rest of aviation. The excuse is not one of disrespect but because it is a ground-based, and thus almost invisible, component of the air transport system. Originally it was called air traffic control (ATC), and ATC is still the preferred term with regard to the work that is conducted from airport control towers. This occupies a cab, atop the highest of an airport's buildings, and also requires an 'approach' unit. This is usually a room where radar screens glow and where much of the strategic and tactical work that complements the activities in the control tower is conducted.

ATC is more than that, and in the 1980s the phrase 'airspace manage- ment' was coined to cover the breadth of activities conducted at airports and in often unseen air traffic control centers (ATCCs) throughout the world. ATC service providers have always had a high proportion of their staff located at ATCCs, and although these usually started life in buildings on the periphery of airports, nowadays they have often moved into parkland or on to an anonymous plot within a city industrial estate.

ATC was set up as, and remains, a service industry. Its mandate is to utilize and police the skies, ensuring (according to the original and long-held mantra of the business) 'safe, orderly and expeditious flow of traffic'. In its early days, in the 1930s, it was never considered necessary to add the word 'capacity' to that description. The skies were regarded as a vast three- dimensional ocean in which aeroplanes could fly. An individual aircraft seemed insignificant in this enormous cavern, and the job was not to impede but to 'control' access to the sky and to assure flyers that they would be provided a separation service that would eliminate the risk of mid-air collision. The control element relied upon rules that would uphold the profession's objectives, and these were formalised during the 1940s in ICAO Annex 11 (Air Traffic Services).

Solving the conundrums of the increasingly capacity-strapped en route airspace depends on more information, and thus more sophisticated sensors. As information flows in ever-greater volumes, the digital computer is used to help to digest and present that information with reduced ambiguity. The computer is a decision-support tool. Over time, circumstances have driven this role deeper, and now it threatens to reach into the decision-making regime. The implications, in terms of capacity and safety, and indeed the whole balance of power in the decision-making chain throughout the air transport system, are enormous. Purists might deplore it, but the route that has been followed, and seems sure to be followed, leaves little doubt about the significance of the changes that are about to take place. The questions that are difficult to answer are those that determine at what speed this change will occur.

Meanwhile, the humble airport-based ATC unit has seen plenty of change in the same era, but nothing is ever likely to change here to the extent that it will in ATCCs. In this chapter the way that ATC has evolved into the so- called air-navigation service provider (ANSP) network will be charted with an eye on each of the four objectives that previous chapters have drawn out from analysis of how aircraft are manufactured, and how airlines and airports are planned and operated. This is because ANSPs also have to be financially viable, to be compliant with international statutes (and more than any other part of the business, the air traffic profession is watching the statutory scene change almost more rapidly than they can react), to be efficient and to offer that effective (expeditious) level of service that has been central to its belief system from the earliest days. By the chapter end, the four main components of the air transport system will have been described in equivalent terms. The remaining chapters of the book will be able to look at the symbiosis between these components of the system.

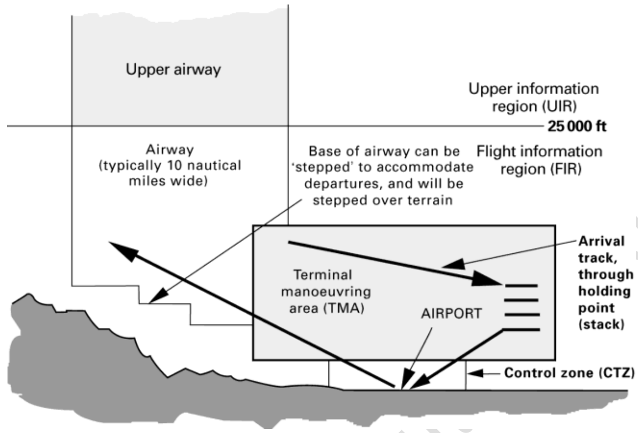
Initially air traffic control was seen as a public service. In the 1930s and 1940s nations did not look upon ATC as a, potentially, commercially viable business. The service was set up on a national basis to exercise control over the airspace in which the operator nation has been ceded 'sovereignty'. How the limits of this airspace were defined was, and remains, a semi-political task. The need for redrafting of boundaries is not day-to-day work, but it is necessary when a nation subdivides, as has happened many times in the 20 years or so since the Soviet Union and neighboring nations took independence.

Within the airspace, which is 'controlled' with regard to all air-breathing vehicles (officially up to an indefinite altitude, but clearly not extending into the vacuum of space), there are categories of airspace that are defined in terms of the service quality that is provided within them. There are seven categories defined in ICAO Annex 11, characterized as A through to G, with the highest level of service offered in Category A and the most basic service in Category G.

Categories of airspace

The subtle division of different segments within which aircraft are provided with different levels of service, while easy to draw on a map, is difficult to distinguish in reality. Navigating routes was initially a task performed using radio navigation aids, and these were sited and used in such a way that they aided aircraft to maintain a position within the sections of airspace allocated to them. Hence the shape of 'airspace' was linked directly to radio navigation aid location and performance, and the navigation aids (nowa- days usually VORs with co-located DME – see Chapter 4 on the operational environment for a description of this and other navigation aids) have become the 'reporting points' through which flow has been monitored and controlled by ATC staff.

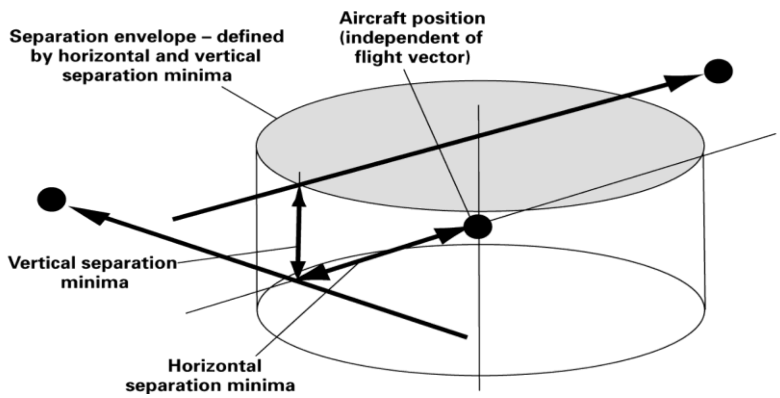
Airways are the routes, akin to aerial highways, along which airlines fly when cruising and during the higher level stages of climb and descent. In most cases they are 10 nautical mile wide and aim straight between radio beacons. The 'base' of an airway is always 1000 ft or more above terrain and rarely below 5000 ft above mean sea level, and extends up to 25 000 ft, and may even extend higher. These general rules allow space beneath airways in which aircraft can roam freely (and accept that a collision risk is present), thus allowing non-commercial aircraft to fly for pleasure. They usually accept responsibility for collision avoidance by flying under 'visual flight rules' (VFR), meaning that they fly during the day and stay clear of clouds.



Categories of airspace

Separation minima

The concept of separation minima is at the heart of ATC operations. The principle is intrinsically simple; there should be a minimum distance between two adjacent aircraft that will never be infringed. The minima are expressed as horizontal and vertical separation distances. If the minima are infringed then the situation, even if there is no operational consequence, is regarded as serious enough to warrant investigation. This is done to determine if any lessons have been learned from the experience. For example, knowledge of the frequency of infringements can be used as evidence to refine the apportioning of risk to operating procedures. This is occasionally necessary, such as when refining separation standards as CNS system improvements are introduced. In recent years the results of incident frequency analyses have shown to regulators that further improvements in system positioning accuracy will not necessarily count for less separation without inviting an unacceptable increase in the collision risk, which is one source of capacity concerns



Horizontal and vertical separation requirements

Airspace sectors

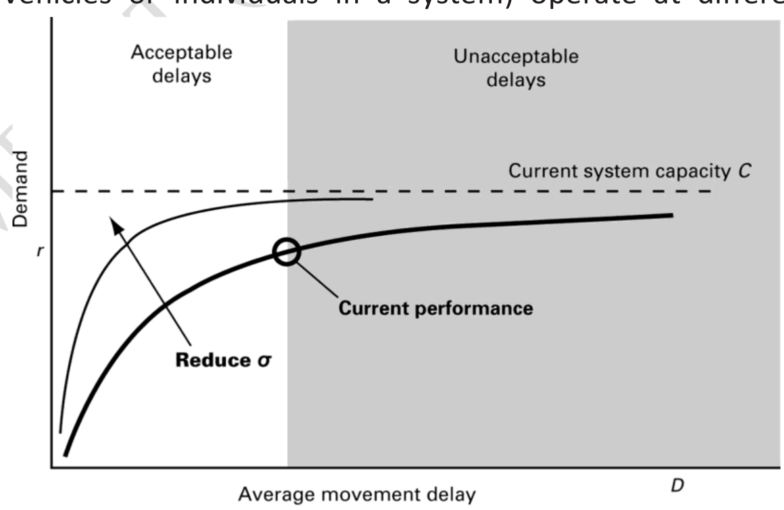
ATC is about vectoring aircraft, and because there is so much decision- making involved it is a human based business, so the capacity of the human being to handle more and more aircraft simultaneously is a necessary limit on the capacity of ATC functions. Workload models are used to assess the capability of controllers put into certain control situations, and these are usually based on empirical evidence of capability that has been derived from assessment projects. If within a sector the simultaneous arrival capacity is assessed to be 15 aircraft and the typical path through the sector is 45 nautical miles long, the time that it will take for an aircraft to pass through the sector might be 10 minutes. This would indicate that 1.5 aircraft per minute can enter the sector – or 90 per hour. The longer the typical sector path, and the longer therefore the transit time, the fewer aircraft can enter in a given period of time.

Such an assessment depends on knowledge of the traffic configuration, with merging and crossing points causing the biggest reduction in capacity, which might mean not more than, say, eight aircraft on the sector simultaneously. In the situation considered already (10 minute average transit time) this would approximate to an aircraft joining the airspace every 1.25 minutes – or 48 per hour. If this is too low the sector size has to be reduced, meaning that an additional sector is introduced; thus more controllers are needed to handle the flow along a given route as it becomes more complex and longer. If there is no infusion of technology that will assist in handling higher levels of workload, the ATC staff levels needed to support a given region (an en route area or an airport) will inevitably rise as traffic levels rise. The rate of increase can be assessed empirically, but the inclusion of more and more 'handovers' between controllers means that a controller has to devote more time to communications within the ATC system, and the cost-effectiveness of services can often fall as traffic level targets rise. The sectorisation of airspace is a complex planning task. Once a configuration has been determined, its planners will test its effectiveness by using computer-based simulations that require large facilities (and draw on controller resources). This is almost reason enough to resist the re- sectorisation of an ATCC, or TMA, region, but additionally there is a vast amount of re-training involved, and the new airspace procedures affect aircraft worldwide. Consequently, the process is applied sparingly, and when it does happen it will have been meticulously pre-planned and the new flight instructions promulgated widely with substantial warning.

Capacity, demand and delay

The well-documented tool in the arsenal of ANSPs, when they come to justify choices that balance the desire for orderly and expeditious service within their area of responsibility, is illustrated in a traffic flow diagram, where delay, capacity and demand are all related. It is a graph that has numerous applications, such as describing the relationship between service, demand and queues affecting passenger flows through an airport terminal, or the way that surface-based transport systems – railways and highways – operate. Its applicability to airspace issues is no different, albeit this is a three-dimensional capacity issue with vehicles that cannot stop and can suffer perilously if they run out of fuel.

Essentially, the graph shows that the more orderly the flow (in which case the smaller will be the value of *s*), the closer a system can run to its capacity limit while causing a given level of delay (averaged over all movements). If the demand was perfectly regular (implying that all aircraft were spaced evenly from one another), $s = 0$, and the delay curve would rise from the origin, proceed straight up the *Y* axis (i.e. no delay at any demand level) and, as demand reached the capacity level, the line would go horizontally to the right. This is a theoretical solution, not least because aircraft (indeed any set of vehicles or individuals in a system) operate at different speeds.



$$D = \left(\frac{1}{1-r}\right) + \left(\frac{r\lambda + \lambda\sigma^2}{2}\right), \qquad r = \frac{\text{rate of arrivals } (\lambda)}{\text{system capacity } (C)}$$

where σ = variation in service rate
D = average movement delay

Capacity, demand and delay relationship

A brief chronology of air traffic control system evolution

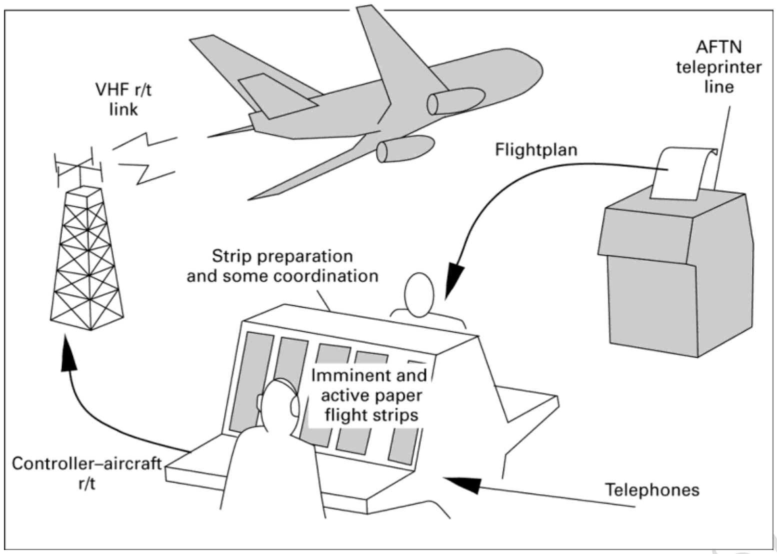
The description so far has shown how the ATC system applies the procedures that have evolved over the last 50 years or so. The fact that the mechanisms of the ATC system have changed is also relevant to the rest of the story, because change has to be accommodated in such a way that a system can evolve. In the ATC profession there is less latitude for radical evolution than in any other components. While airliners are being manufactured from newer materials, airlines are adopting new economic paradigms and airports are extending runways or razing old terminals to the ground, the ATC system has to change in a more incremental manner. This section expresses the way that many of the changes already enumerated have been implemented, and a point to savor from the four stages that are identified and described is that while the ATC systems in the busiest parts of the world have undergone all of these transitions, there are places where the first, and most elementary, stage is still the normal operating mode. Whatever the transition proposed to carry ATC development forward from Stage 4, it has to be compatible with the transitions from Stages 1, 2 and 3. This is a very significant system design task, which will require the cooperation and understanding of all air transport system stakeholders.

Stage 1: procedural ATC system

Stage 1 ATC systems use procedural methods. They require:

- that aircraft file a ‘flight plan’, a declaration of all relevant flight intentions
- a telecommunication system to distribute the flight plan to all relevant ATC units
- paper strips, at the ATC units, on to which flight details are written
- ‘reporting points’ over which aircraft report their positions as they fly their routes
- A radio system (invariable radio r/t) to communicate between aircrew and ATC units.

The region over which an ATC authority assumed control became known as the flight information region (FIR) and the routes along which separation was assured became known as ‘airways’. The system depended on the adoption of an internationally recognized flight plan and the provision of a ground-based communication system, called the aeronautical fixed telecommunication network (AFTN). This has changed considerably over time, but has remained capable of supporting the same general requirements overall. The basic infrastructure of a Stage 1 ATC system is shown.



Schematic diagram of a Stage 1 (procedural) ATC system

Stage 2: procedural ATC with radar assistance

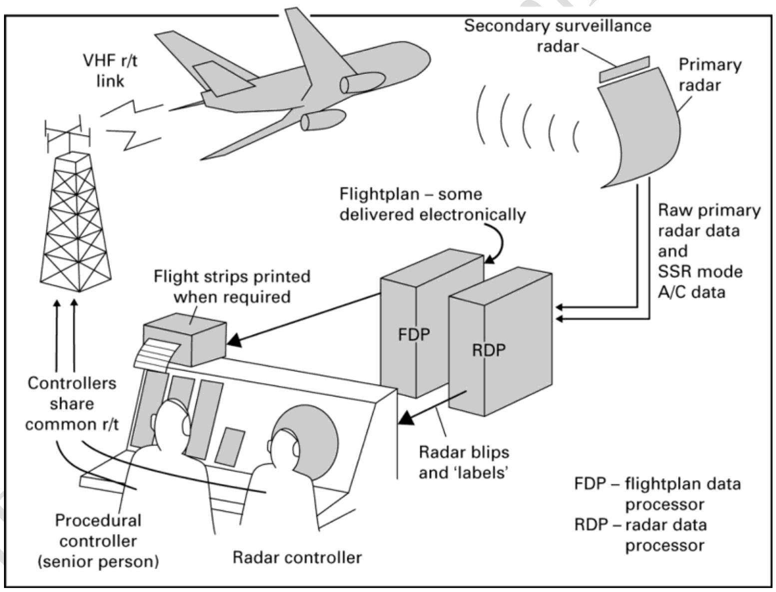
In the 1960s ATC began to use radar in earnest. Some radar applications had arrived after World War II, with surveillance approach radar (SAR) serving the aerodrome ATC units, which developed the ‘approach’, function using this system. The SAR radar was a short-range, relatively narrow field- of-view and fast-rotating, radar. The approach path could be seen on the screen, and the aircraft was a small target that could be guided. Some radar installations also had a vertical scanning unit, so that the plan and side view of the aircraft’s progress down the approach was visible to the approach controller. This allowed ‘talk-down’ approaches to be conducted in low cloud base on runways that had good approach lights, even if they had no navigation aids.

At airports that had ILS the radar could be used to monitor aircraft but was used more routinely to guide aircraft into the narrow beam of the ILS, so that the crew could establish a stable approach as soon as possible. Note that if SAR was used and there was only one radar screen, the operator took about 10 minutes to ‘talk down’ and then pick up the next aircraft to sequence, so the runway capacity was approximately 6 arrivals per hour. This was a big improvement on being shut because of low cloud, but the system did not provide as much capacity as busy airports wanted. Where an ILS was available to provide direct guidance to the aircrew, the approach radar operator now simply ‘sequenced’ aircraft to a point where they could acquire the ILS guidance signal. Movements could be monitored during their approach, and as aircraft could be brought in as close as was safely sustainable, the ILS solved the runway approach capacity problem many decades ago. This kind of operation has remained almost unchanged, apart from improvements attributable to ‘daylight-viewing’ radar displays and more sophisticated electronic data-exchange systems, especially between the airport and the local ATCC.

Stage 3: the first–generation 'automated' ATC system

In the ATCC, radar and computers were combined, creating an installation that was a major leap forward in the way that radar provided real-time surveillance within the ATCC. Now ATC was no longer dependent on the periodic reports that were given over reporting points. Indeed, aircrew often no longer had to pass on such information. In addition to getting primary radar, which detects aeroplanes (and a lot more) and presents a 'blip', there was a surge of interest in the secondary radar. This could detect aircraft with an ATC transponder on board and determine a code that identified the aircraft and the aircraft level. These radars were placed strategically around the region and the information was encrypted on to a landline and sent to the ATCC. At the same time, the signal that had made teleprinters tap out flight plan data for many years was ideally suited to being read and interpreted by a computer. Two large computers were usually installed, and their functions were:

- The flight-data processor (FDP) collected the flight-plan data and kept



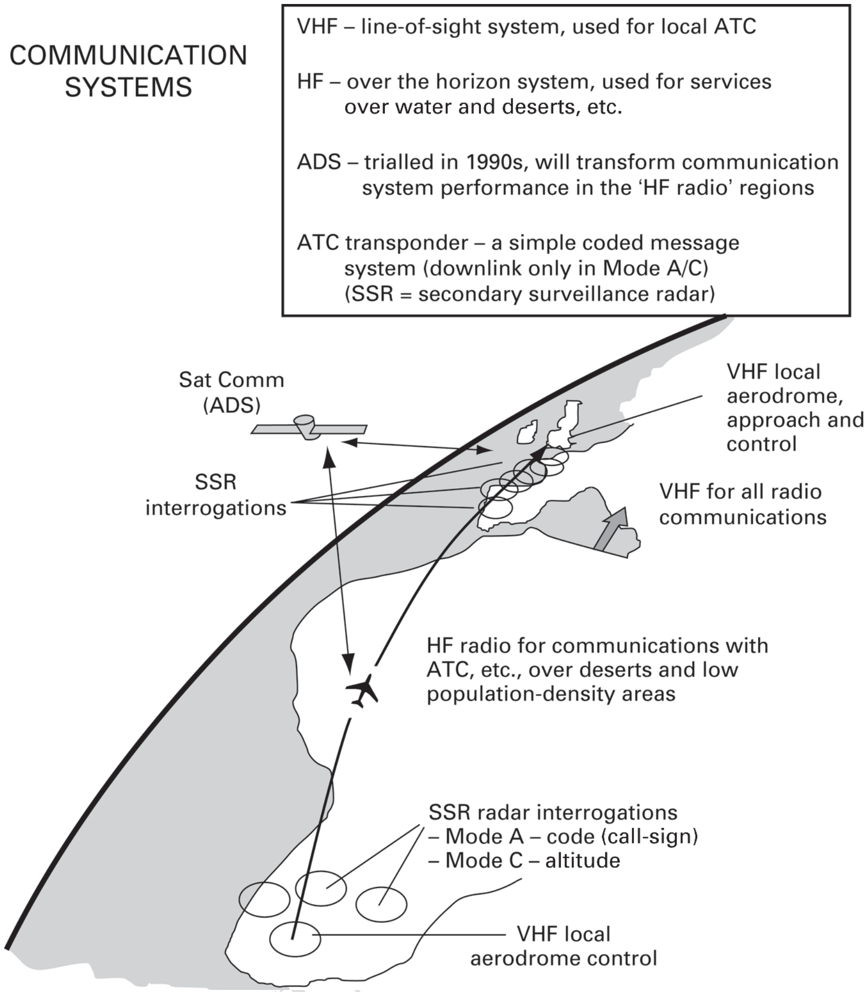
Schematic diagram of a first-generation 'automated' ATC system

Communications

Wireless-telegraphy (w/t) and *radio-telephony* (r/t) are two ways of conveying information by wireless. The first system, w/t, is a wireless- based version of the telegraphy system that was used throughout the 19th century, where messages were transmitted using discrete signals, such as the dashes and dots of the Morse code. The system was able to convey information through conditions of poor reception, and while it was bulky it needed less power than a voice-carrying system. These devices were used in the 1930s and phased out by about 1940. It can be argued that the discrete signal system is re-emerging with the advent of digital radio, and technology has a habit of recycling ideas, but modern discrete signal radios are used in a very different way.

The r/t system used a radio system that transmitted a voice message as a continuous signal. The signal characteristics were modulated at the transmitter in such a way that the receiver could reproduce the transmitted voice. This was used as radio broadcast in the 1920s, but needed huge transmitters, and it was only when compact radio systems that could be installed in aircraft were developed that the system arrived in aviation.

The *very high frequency (VHF) radio* is the continuous-signal radio- telephony (r/t) system that emerged in the 1940s. It met the need for air/ ground and air/air communications to be achieved using voice messages. VHF wavelengths propagate roughly according to line of sight (LOS), so the usable range is a function of aircraft altitude, although terrain can also play a part in terms of coverage. The system uses press-to-transmit (PTT) buttons, as only one user can transmit a message at any one time. When a radio system is used by a large number of aircraft, the ability to convey all messages and safety-related acknowledgements in a timely manner can limit the strategies open to users. VHF is widely used, but its limitations do impose constraints on operational capability in busy airspace regions. All VHF radio communications systems are installed under local aviation authority approval. (They can be eavesdropped by the public, but to transmit in the allocated frequency bands is a criminal offence.)



Summary of aircraft communication system options

Navigation

The *radio range* was the first en route radio navaid in civil aviation and was withdrawn from use by the 1960s. The device set some operating concepts that are a legacy and make a useful stepping-off point in this review of systems. It required a ground-based transmitter and an airborne receiver with a directionally sensitive antenna. The transmitter worked in a radio band that has been largely abandoned by the aviation community (the next system, NDB, being the only device that still operates in the same waveband). It created a number of sectors (or lobes) within which there were different Morse code messages (an A (dot–dash) or an N (dash–dot)), and the antenna configuration allowed them to overlap at their edges. The aerial could be adjusted to make the overlap occur in four directions from a ground station, or beacon. These were detectable by an aircrew with Navigation.

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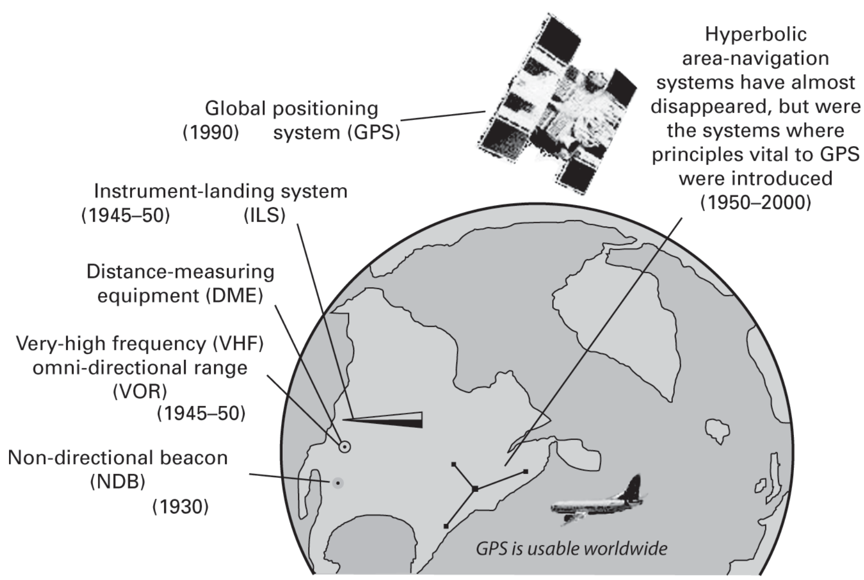


Surveillance

A *radar* or *'primary' radar* (to distinguish it from a *secondary surveillance radar* (SSR), which follows) is a radio-detection device, the principles of which were proven in the late 1930s. There are many kinds of 'radar', all used in aviation – weather radar, interception radar, height-finding radar, etc. – but in respect of the air transport system, only ground-based surveillance radar will be considered. Radar is a 'line of sight' system (roughly) that detects objects in the area swept by its narrow, rotating, beam by detecting reflected electromagnetic energy. The bearing of an object is determined from the beam position and the range is determined by the time taken for energy to return to the radar station. An ATC surveillance radar will typically detect airliners from 20 to 150 naut. mile maximum range, the absolute range being determined by the power transmitted and the application for which the radar is employed.

Throughout development from the 1960s radar has been integrated with the digital computer, in what is often called a radar data-processing (RDP) system. This is a way of extracting position from a radar, or a set of radars, and of developing each return into a 'plot' that can be shown at a position on a display system. (The circular 'rotating strobe' form of display is not nearly as common in ATC workplaces as it is in movie renditions.)

UNIT - III

Aircraft

Introduction

Aircraft are the most recognisable element of the air transport system. They are iconic within society and are, above all, the root of the solutions to any of the industry's 'pollution' problems. The understanding needed of airliners is of their value in commercial and service terms. There is no easy way of changing the course along which aviation technology is orientated. It can be deflected, but not changed abruptly, without grave economic consequences – on society, not just the air transport business. However, the manufacturers in turn are increasingly aware of how their products connect the natural and operational environments to the needs of the air transport system and the desires of society, both in the short term and the long term.

Costs

Aircraft are considerably more expensive in terms of cost per unit of mass than simpler items. For example, an airliner will cost between 800 and 400 US$/kg (note that all prices will be quoted in US dollars). Generally, the smaller the aircraft, the higher the cost per kg. (This is an evaluation based on the maximum permissible mass for operations.) As an example of how expensive an airliner is, if a family car that took to the road at 1.5 tonne maximum and was sold at an equivalent scale it would cost in the order of $750 000.

Banks and finance companies or, occasionally, airlines themselves finance the purchase of aircraft, and they must expect an aircraft's capital cost to be recovered during its operational life. As well as seeking to recover this initial cost, it has to be borne in mind that running and servicing an airliner incurs additional costs. Even a relatively small (150–200 seat) airliner can cost $50 million, and the largest of all reach the dizzy heights of a quarter of a billion (250 million) dollars. Look at an Airbus A380 and one is looking at a business, in its own right, that will need to generate about $2.5 to 3 million per week. The Boeing 747, which has already graced the skies for almost 40 years, is not far behind. These simplified examples illustrate that, within airlines, each airliner is often a respectable-sized business in its own right.

Project cash-flow

Those manufacturers who have tried to break the mould with regard to the variables involved inevitably have been ruled out of the business. Boeing continues a long-standing name, but on the way has subsumed Douglas, and at times has owned and operated other companies that it has sold on again. Airbus in Europe evolved from a consortium of European manufacturers. Between them these two firms account for almost all airliner production in the 150-seat and above category, throughout the world. The Soviet Union seeded a small and in industrial terms an inefficient industry, and there are signs that one day soon its legacy might re-emerge, but it has been in Brazil and Canada where small airliner production, the so-called regional jets, has been handled successfully. There are signs that there will be an Asian challenger, perhaps in the Boeing and Airbus sector, that will emerge from China or India.

Consider what is involved, financially, in a modern airliner development and production programme. The A380 has been quoted to be a $10 billion investment by Airbus Industry, and the company's commitment is reported to be much higher by some independent sources. In other words, Airbus has had to invest a vast sum to cover the cost of designing the aircraft, create facilities for its production, nurture numerous support roles (both technical and commercial/administrative), certificate it and to maintain a steady rate of production. If each aircraft costs, in round figures, $250 million per example, a simple comparison of the cost to create with the cost to customer might suggest that only 40 aircraft would generate sufficient revenue to recover costs.

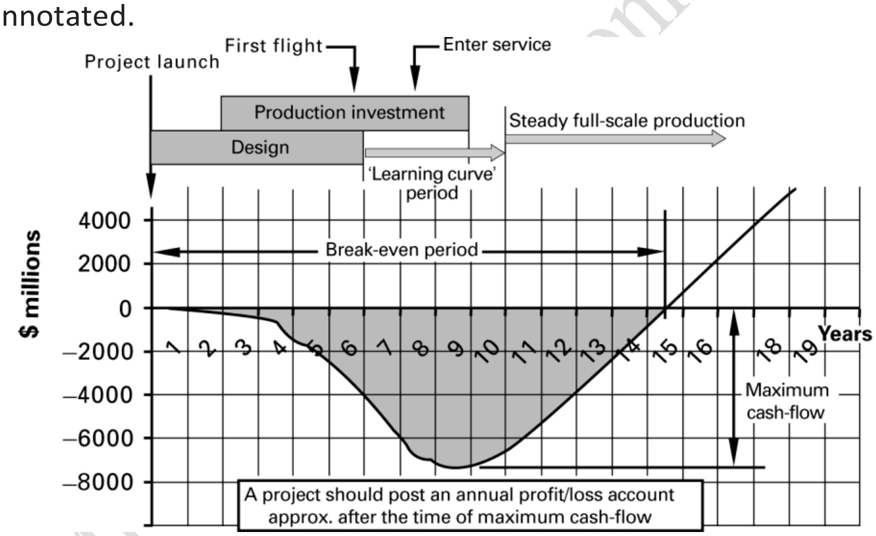
The true figure almost certainly will be in the order of 250 aircraft, or $62.5 billion worth of production, before all attributable financial liabilities are paid off. Airbus suggest that the production rate will be around 4 aircraft per month, or 48 per year, so the production line will have to run, at its best capacity, for at least 5 years. However, before production deliveries can commence there is the full design and certification programme. Designing an airliner from project launch (and thus ignoring the cost of a lot of pre-launch research and development work) to when the first components can be fabricated is usually a number of years. Then there is a period when design and build activities overlap, leading up to the aircraft roll-out. In this period many of the facilities that will support production are built from scratch and novel processing techniques are tested, so development is often an on-going part of the job.

After the first aircraft is 'rolled out' (more significant to the press than to the engineers) the aircraft will be tested on the ground. Eventually it will make its first flight, and then it and further examples will embark on a flight- test programme. The flight-test phase is usually 15–18 months and can require 5 or 6 aircraft – or fewer if it is a 'derivative' rather than a 'new' design. Usually one complete aircraft structure is built and instrumented in a test rig on the ground, and although it will never fly itself, this test specimen will be the testing ground where aircraft longevity and structural safety issues are tested and have to be proved. Only after the landmark of certification, which follows successful ground testing and demonstration of performance, can deliveries commence to customers, and this will thus be some 6 to 7 years after the project launch date. Production effort can already be intense, but the rate at which units appear is initially sedate, as the supplier chain gears up and the production workforce in the manufacturer and supplier workplaces progress along what is often called the 'learning curve'. That critical 48 aircraft per year production rate is illusive, with perhaps 100 aircraft delivered in the first 3 years and the full complement of 250 achieved over a 6- or 7-year period. This will be 14 or 15 years after the project was started, and the time involved is called the break- even period, for by the end date cumulative revenue (nominally now $62.5 billion for a programme such as the A380) will equal the costs to date. Clearly, that $10 billion investment requires a lot of further confidence, financially and technically, to get to the point where the programme is a business success for the manufacturer.

Table Estimated current aircraft programme costs (Source: evaluations based on published data)

Project	Production rate (aircraft/year)	Maximum cash-flow ($ millions)	Break-even period (years)
EMB-170	48–72	1600-2000	16.5-17.5
Boeing 787-9	48–72	7500-10000	16.5-17.5
Airbus A380	48	15000	16.5-17.5

A cash-flow plot for a typical project will have a shape and a timescale similar to that shown in Fig. On the diagram the maximum cash-flow value and the break-even period are annotated.



An aircraft programme cash-flow curve.

The data shown in Table are illustrative. The range in cash-flow values is based on assuming different levels of subcontractor liability, or cost- sharing. There are many hidden factors, perhaps subsidies that are unacknowledged, and pay rates from country to country can influence the costs greatly. In Brazil, where the EMB-170 has been developed, the labour costs are considerably less than in the USA or Europe, but the company relies on subcontractors that do face US and European costs, so while the illustrative estimates are good for comparison they may be wide of the real data.

Table Aircraft prices (April 2006) (Source: Airclaims)

Airbus	$ millions	Boeing	$ millions
A318-100	21.9–28.4	737-300	6.00–15.6
A319-100	18.9–34.9	737-800	28.75–42.75
A320-200	11.95–42.15	747-400	37.3–107.55
A330-200	57.4–88.7	757-200	7–28.55
A340-300	46.8–100.16	767-300ER	19.4–67.75
A340-500	89.9–115.4	777-200ER	85–112
A340-600	92.9–126.4	777-300ER	67.5–136.3

Aircraft price

The quoted prices for some leading aircraft types, at early 2006, are shown in Table. The range of data represents the price range for oldest and newest examples of each aircraft type, so where a type has been in production for many years the oldest aircraft, like used cars, are relatively much cheaper than new production examples.

There are tales of aircraft being bought well below the published price, which buoys optimism, but the circumstances have to be understood. In order to get a good discount, as with any purchase transaction, cash is more valuable than a presentation of credential, but just as important is timing. A good time to approach an aircraft builder is at a time of economic uncertainty. Just as the monthly production rate is beginning to wilt the builder could be in a position to offer a cut-price deal in order to hold a steady production rate, with a steady workforce, and thus to be in a position to respond more quickly to an upturn in demand when the sales situation improves. This is only possible if the market place looks certain to assure sales of this type in the long term. In terms of an example of business in action, the manufacturer is actually forfeiting short-term profitability with a view to achieving financial viability in the long term.

Manufacturers do not give aircraft away, but in such circumstances they are likely to be receptive to assisting an established customer to make a good purchase and thus be more likely to return and do business with them again. Of course, the customer has to get their timings as good again to obtain as favorable a deal a second time.

Compatibility with the operational infrastructure

The cost of operating an airliner, as experienced by the operator, is also dependent on issues that concern operational compatibility and the regulations that arise from safety legislation. An essential requirement for an airliner is that when it enters service it interacts with everything around it in a compatible manner. The first way of providing such confidence is building the aircraft to established airworthiness rules, and it is therefore typical for all airliners to be designed to attain US and European ‘certification’. The standards they use are the Federal Airworthiness Requirements (FAR) in the USA and the Joint Airworthiness Requirements (JAR) in Europe. They are similar in terms of structure, but subtly different at the content level. The implications of this paper ‘qualification’ in fact go very deep. The aircraft will have been designed according to well-defined design rules, and the design assumptions involved in its definition will have been monitored thoroughly so that the assured ‘life’ of the aircraft – hours or cycles – is a genuinely attainable target. A complete test specimen airframe will have been used to validate a lot of assumptions in this regard. Its systems and components, from engines to light-bulbs, will have been shown to be able to meet the needs demanded by risk assessments of failure cases. Stemming from these rather esoteric studies many operating principles will have evolved, which will be the basis of the safety management system (SMS) process content implied in the aircraft’s type of ‘certificate of airworthiness’ (COA).

Hence, as it leaves the factory every aircraft has a set of documentation associated with it that will support both design-case evaluations and in- service operations. An aircraft flight manual (AFM), for example, will present performance data that have been validated in the design and flight test, and checklists will express crew responsibilities as procedures that arise from the risk assessments that have accompanied design and operating assumptions. Likewise, technical documentation will define maintenance programme needs that are justifiable against operating criteria. Each example of the aircraft type has an individual COA. It presents data confirming that the aircraft complies with the assumptions of the type of COA, quoting precise mass data, and so on. It is the responsibility of the aircraft owner (and that might be a leasing company, not an actual airline) to ensure that throughout its operational life the attributes of the aircraft remain within the specification and that all who work on it adhere to the procedures appropriate to maintaining a valid ‘certificate of continuing airworthiness’ or ‘certificate of compliance’. Such requirements mean that only appropriately qualified personal can take decisions in regard to the adherence of appropriate policies. There are no short-cuts, and aircraft can be ‘grounded’ for lack of due care and attention to any operational procedures. The many onerous requirements for an aircraft engineer’s license ensure that they can perform such duties effectively.

Direct and indirect operating costs

When the operation of an aircraft is portrayed in simple terms, it is usually expressed in terms of minimization of costs. This is to do with efficiency, in that the more efficiently an aircraft is used, the cheaper it will be to operate. Operating costs are divided into two regimes, direct and indirect costs, namely:

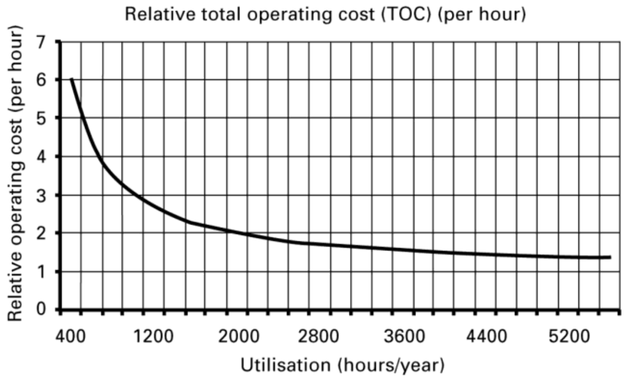
Table Relative direct and indirect operating costs per hour related to utilization

Utilization (h/year)	X_i	X_d	Total
400	10.0	1.0	11
500	8.0	1.0	9
667	6.0	1.0	7
1000	4.0	1.0	5
2000	2.0	1.0	3
4000	1.0	1.0	2
8000	0.5	1.0	1.5

- Direct costs are those incurred at the time of flight. They will include crew salaries (factored to including training, etc.), fuel, on-condition maintenance, airport and air navigation service charges, and so on.
- Indirect costs are those incurred as a matter of ownership.

The aircraft value, or the repayment lease if it is not fully owned, will be recovered as an annual repayment cost. Likewise there will be hull insurance, charges attributable to airline functions (administration, ticketing and reservation, building leases), and so on.

In terms of using an aircraft efficiently, this works between two extremes. Buy an aircraft and never fly it and it costs nothing in direct terms (but there will still be indirect costs) and its operating cost is theoretically an infinite cost per unit of production. Buy an aircraft and fly it every hour of every day of the year and one gets (24 365) = 8760 hours per year from it. There will be a direct cost of X_d per hour and an indirect cost of X_i per hour, where direct costs are incurred at the time of use and it is usually acceptable to treat them as a constant 'per hour' cost. As indirect costs are associated with expenditure that must be recovered annually, as utilization increases this will be a diminishing 'per hour' cost. If the direct cost is treated as a constant and the indirect cost is expressed as a proportional quantity based on hours flown, the total operating cost is the sum of these. The relative values are as shown in above Table.
The utilization value shown is based on the assumption (reasonable but not assured) that at 2000 h/year the indirect costs are twice those of the direct costs. If the aircraft was worked much harder – twice the utilization – the simplest assessment is that the total operating cost will fall from 3 to 2 units per hour. If an operator uses the aircraft less frequently, and for as little as 400 h/year, the operating costs rise to 11 units per hour. Thus the costs are well on their way to being 'infinite' at zero hours of utilization.



Relative total hourly operating costs.

Note that once 8760 hours have been reached, the other extreme limit is reached, and at this point the relative operating cost value is 1.228.

Figure shows how the total hourly operating cost can be expressed, in such a theoretical assessment, against utilisation. In reality, there are additional costs associated with very high utilisation values, and the total hourly operating cost does not necessarily follow such a gentle curve. It tends to rise at high levels of utilisation.

Balancing efficiency and effectiveness

Mention has been made of balancing efficiency with service quality attributes. Some of the service quality attributes arise from design and some from the way the aircraft is operated. These two roles will be discussed in conjunction, because it is the way that an airline uses the ‘flexibility’ that the designer offers that determines much about service qualities.

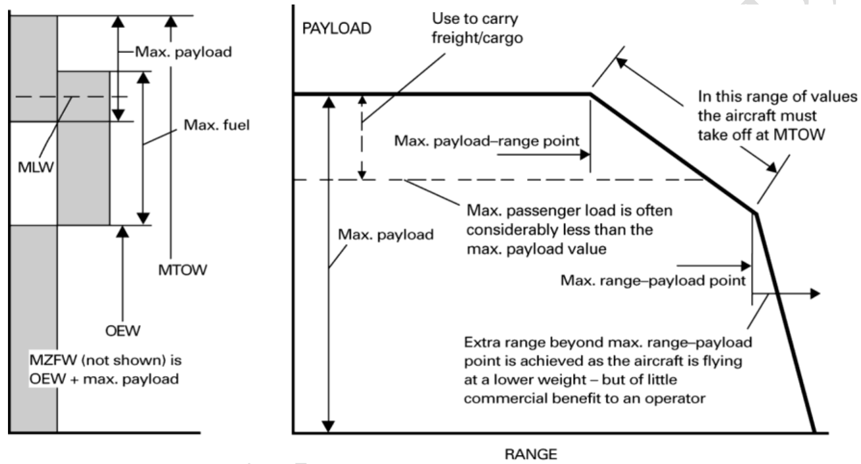
The designers are responsible for the actual efficiency. This is addressed, in a traditional design process, by consulting with users on their operational requirements. The actual requirement for an airliner can be a very detailed document. Some stated needs will be very detailed, but the principal requirements that will affect efficiency and effectiveness are far from numerous and for general analysis they can be expressed in terms of four main issues. These are:

- payload range
- operating speed (and altitude)
- maximum allowable field length performance
- target operating cost.

The design team has to hold a common ‘mental model’ of how the issues they address will affect the aircraft design. This process is engineering based and built upon an understanding of the four principal forces that affect an aircraft – lift, drag, thrust and mass – as well as being able to attribute the relationships that link them through these four properties of the design.

Payload–range

Payload is the fee-paying load that can be carried between the origin and destinations, excluding any fuel remaining on landing. Most aircraft are designed to trade payload and range, such that the maximum payload can be carried only a proportion of the maximum distance over which the aircraft will fly with a reduced payload, which might approximate to the maximum passenger load. Essentially, the design is limited by the design maximum take-off weight (MTOW), the maximum payload and the maximum fuel load. Because it is a statutory requirement, the MTOW can never be exceeded in operations. The other two mass values are interchangeable. A 'constant' in all of this is the operational empty weight (OEW), being the weight of the aircraft prepared for service, but without passengers or fuel on board. The principle whereby fuel and payload can be interchanged, and how this translates into a payload–range diagram, is shown in Fig.below.



Aircraft masses and the associated payload–range diagram.

Provisional data for the Boeing 777-200LR (where LR means long range) provide an example. The aircraft weights (taken from a generic Boeing specification – there are differences in service) are:

OEW	145 149 kg (320 000 lb)
MTOW	347 814 kg (766 800 lb)
Maximum payload	63 956 kg (141 000 lb)
Maximum fuel	145 541 kg (320 863 lb)

The aircraft is, nominally, a 300-seat design, and at 100 kg per passenger (including baggage) the typical full passenger payload will be 30 000 kg. The design has been configured to carry as much payload again, meaning that, potentially, it will accommodate considerable freight as well as passengers up to a certain range.

Fuel efficiency

The conversion of this performance to a measure of fuel efficiency requires prior knowledge of what operating conditions have been assumed. In the majority of payload–range assessments the aircraft is assumed to cruise in still air and to carry a nominal reserve of fuel. Assuming the reserve is 8000 kg for the 777-200LR, there are two points where fuel usage can be evaluated. These are

Maximum payload–range (63 956 kg–7500 nautical miles (13 900 km)):
fuel used 131 616 kg
Maximum range–payload (41 164 kg–9700 nautical miles (17 980 km)):
fuel used 156 408 kg

These translate into per kg fuel burn figures of

Maximum payload–range 6754 kg-km per kg of fuel Maximum
range–payload 4732 kg-km per kg of fuel

Most airliners operate typically with 75% of attainable payload, so these figures diminish to around 5060–3550 kg-km per kg of fuel in normal service.

Compare this to a car that achieves 50 miles per gallon (in the UK this is 80 km from 2.55 kg of fuel) and can convey four 80 kg people (320 kg payload), which has an equivalent per kg fuel burn figure of 10093 kg-km per kg of fuel

This car, with reduced occupancy, attains

3 occupants 7570 kg-km per kg of fuel

2 occupants 5040 kg-km per kg of fuel

1 occupant 2520 kg-km per kg of fuel

These data show how relatively fuel-efficient a modern airliner can be. The actual fuel efficiency has improved steadily over gas-turbine airliner evolution. In terms of a benchmark, the equivalent full-payload use fuel data for the 707-320C of the mid-1960s was approximately one-half of the values quoted for the 777-200LR.

This fuel efficiency figure has been chosen as a benchmark because it is the kind of criterion on which civil aviation will have to hang its reputation in the increasingly environmentally enlightened age. It is difficult to evaluate precisely; the spread between the extremes shown is about 0.7:1 for the 777- 200LR and it was in excess of 1:3 for the older 707-320C when equivalent data were evaluated. Even then, aircraft are not used to their full capability, which is also true of most surface transportation systems, so the full- capacity data are perhaps the fairest comparison to cite, and in such light the airliner fares well.

Technical contribution to performance

Air-vehicle performance is technology-based, and as technology evolves so performance is improved. This links to a gradual change in airliner design criteria, and while aircraft configuration has been relatively static, the shape of airliners has changed subtly in recent decades. It could change remarkably over coming years as new performance demands are made by customers.

A new structural material having the most influence is carbon-fibre reinforced plastic (CFRP). The Airbus A380 uses some all-CFRP components and has a large proportion of the fuselage manufactured using a unique aluminium/reinforced-plastic sandwich (trade name 'Glare'), while the newer Boeing 787 Dreamliner and its even newer Airbus equivalent aircraft, the A350, will use carbon-fibre extensively. The Boeing design is in a more advanced state of development and is anticipated to have an almost all-CFRP fuselage shell and CFRP wings. Airbus A350 plans are based on a similar technological basis.

CFRP offers durability and is relatively light. The designers have to exploit the potential weight saving with care. For the 787 Dreamliner Boeing has allied airline requests for fuel efficiency improvements with a desire stemming from other areas of concern in the airports and airspace environments to offer more flexibility in operations. This is an early indication of the needs of the air transport system as a whole taking a part in the debates that range outside their direct area of interest. Boeing believe that the 787 will offer better fuel efficiency over a wide combination of payload and range values, and they also believe that being a smaller aircraft than most current long- haul types it will offer the opportunity for more point-to-point operations. The analysis of route networks has shown that airline hubbing is often the reason that some airports become congested, while others see their direct-route possibilities diminished. The 787 is being marketed as an aircraft capable of making hubs a thing of the past and opening more direct routes. The converse solution is to offer more capacity per movement at hubs, which is where the 600–800-seat A380 will be exploited. The reality will be, surely, that both types will make their mark.

Operating speed and altitude

The cruising speed of all jet airliners is about Mach 0.7 to 0.9 (410 to 527 knots TAS), with most concentrated in the lower half of this band. Some designers have attempted to offer speeds between 0.82 and 0.88, but the aerodynamic performance is affected by increasing 'wave drag', which is attributable to the development of the supersonic shock wave that occurs at the speed of sound. To penetrate this region the wing has either to have increased sweepback or reduced thickness, and the trade-off with other performance attributes has never been acceptable. Technology developments could change that, but for the time being the short-haul airliners tend to cruise between 410 and 450 knots and have modestly swept and relatively thick wings that offer best field performance and good climb efficiency, while longer-range airliners have more swept-back wings and pay a price in terms of runway length requirement on take-off and landing, and cruise between 450 and 500 knots, with 480 knots being a very typical long-range economical cruise speed.

These speed targets are achieved at between 30 000 and 45 000 ft. The shorter-haul aircraft use the lower altitudes, rarely climbing above 36 000 ft, whereas long-haul aircraft will use the higher altitudes. The latter is subject to aircraft mass, for on a very long-range flight the aircraft will be so much heavier at the commencement of cruise that it might not be able to climb above about 32 000 ft. For best performance aircraft should conduct a cruise–climb, with the aircraft steadily increasing its cruise altitude while maintaining a constant speed as fuel is burned and mass reduces. This does not tend to happen, as airspace service providers require that aircraft stay at a designated cruise altitude. They do allow a long-haul flight to climb in steps throughout the cruise phase.

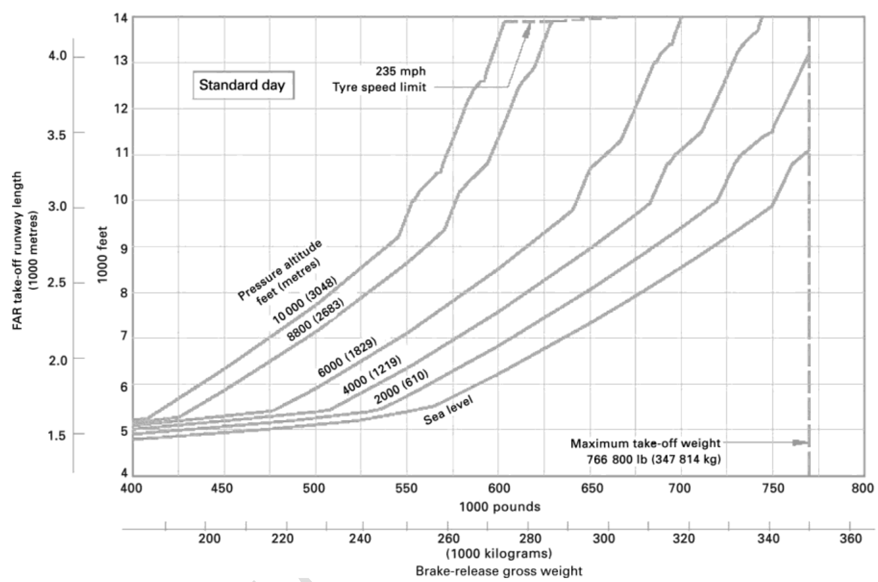
Aircraft field length performance

Consideration of cruise performance has intimated a trade-off with field performance, but there is much more to this. In essence, the larger the wing, the slower the take-off and landing speeds, and thus the less length of runway is needed to accelerate on take-off and to decelerate on landing. The actual area that will be needed, compared to the area needed for best fuel efficiency in cruise, is huge, and the palliative that overcomes this dilemma is the aerodynamic flap on the wing trailing-edge and slats on the leading-edge. As flaps and slats are extended, they increase the degree of curvature in the cross-section, the so-called wing camber, and allow a given lift force to be generated at a lower speed. The flaps create drag, so they are used sparingly on take-off (when a small flap extension will bring considerable lift benefit without as much drag increase as with larger flap extensions), but on landing the extra drag is tolerable because the aircraft is lighter. The extra drag both reduces speed sensitivity and helps to improve the descent angle, making it easier to reach a designated aiming point on the runway. Flaps are a nuisance as they are complex devices that add mass and increase the maintenance burden. Many types of flap configuration have been used as designers have sought to trade-off mass and cost implications in an equitable fashion.

The considerations introduced so far have shown that take-off is critical in terms of being able to take-off within an acceptable runway length. Safety regulation plays a large part in determining what will be acceptable overall, and the most significant failure case to consider – and the one that all pilots train to face, but hope that they will never do so – is the loss of an engine at take-off.

Aircrew do not work in distances. They use what is readable on their instruments and what is critical to aspects of performance, chief among which is speed. A safety requirement is that in operation the aircraft should be able to accelerate to a certain speed, with all engines running, and that should an engine fail at this speed the crew should have enough runway ahead of them to execute either a take-off (with an engine failed) or to stop (assuming they will have brakes only). This is the take-off safety speed (called 'vee-one', presented as V_1). The handling pilot will be 'heads-up' and watching the runway and the supporting pilot will be 'heads-down' monitoring speed. The supporting pilot calls V_1 when the computed speed has been reached, and it is at that point that they know the take-off can no longer be abandoned without running out of runway length. The three major conditions that determine the safety speed are aircraft mass (or weight), airfield elevation (or altitude) and air temperature, and these are used to form the acronym WAT. Figure below shows the take-off field length performance of the Boeing 777-200LR for ISA standard day temperature. In order to assess other temperatures, further charts would need to be consulted and a take-off field length determined by interpolation.

A take-off field performance chart shows that the longer the runway, the greater the take-off weight that can be achieved, and hence the greater the payload–range capability of the type can be exploited. The higher the airfield elevation and the higher the air temperature, the more runway length is needed to achieve a given take-off mass.



Take-off performance chart (Boeing 777-200LR) (Source: Boeing)

Typical operating costs

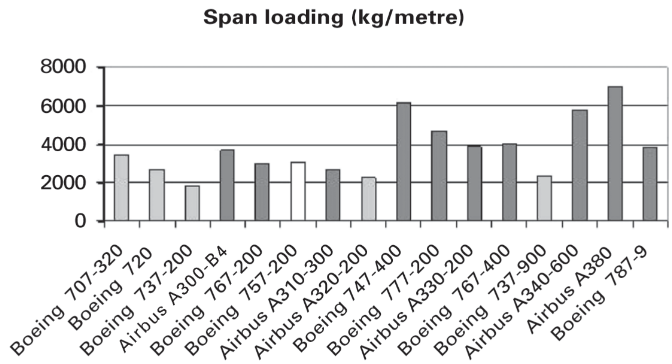
The structure of operating costs and their dependence upon many operational variables has already been explored (Section 5.4). The actual cost on a particular flight will also be affected by such issues as the payload– range and runway length available. If the payload–range is limited, by either airport elevation, runway length or air temperature, the operating cost will be affected in some way. It is always important to gather as much information as possible about the proposed operation, right down to knowing whether freight will be a significant part of payload and what en route weather conditions (especially wind direction and speed) will be frequently encountered. The dependence on the variables outlined will remain the same, but there will be limitations imposed by operations that will sometimes militate significantly against achieving optimum performance. These are considered within the context of airline operations.

Effectiveness

In addition to being efficient, aircraft have a considerable impact on many issues that can be referred to under the 'service quality' banner. If little regard is taken for the norm, the differences can have an effect on operations that range from irritating to catastrophic. Some indication of the way these are tailored alongside the efficiency and cost issues already explored is relevant here, with the objective of setting out, in addition, the way that an operator's wish-list for non-technical operational parameters can be related to the design. For example, the way that airport stand dimension requirements have been allowed to play such a great influence with regard to the A380 design (it has a 79.7 m span, against a requirement that it should not exceed 80 m) is an indication that not all technical matters are assessed and decisions made solely on technical efficiency criteria.

Wake-vortices

A significant operational consideration is that wings create a swirl around each wing tip, called a tip-vortex. This swirls inwards, causing a 'downwash' behind the aircraft. Sometimes the swirling flow is turbulent and so energy- laden that any aircraft entering into this region of flow will face the possibility of being upset. This is called wake turbulence, and thus if the vortex strength is large enough to cause the 'upset' of a following aircraft, the separation between it and any following aircraft as they approach a runway has to be increased. This can reduce the attainable runway capacity, thus affecting the total amount of traffic that can be handled in busy periods at an airport. A rough indication of the vortex strength is provided by the span-loading (mass per unit span). Based on MTOW, the span loading has been plotted as a bar chart in Fig. below and the most vortex-critical types are the darker bars. Interestingly, the Boeing 757-200 has been classified as an aircraft that needs extra approach separation behind it, although it is not, on this assessment, significantly worse than smaller aircraft. A perplexing problem for the A380 design team has been ensuring that the vortex behind this very large aircraft does not upset following aircraft. The impact of this issue on airport runway capacity is considerable, and it has been important that Airbus show that their new aircraft will not require any substantial change in spacing between successive arrivals.



Span-loading: comparing categories of 'heavy' jets.

Cabin dimensions

An airliner's fuselage is usually a tubular, streamlined, component that accommodates the crew and payload. It might also enclose fuel tanks and even have space devoted to stowage of the landing gear. There will be the flight deck, where the aircrew sit, the passenger cabin, with seats, galleys and toilets, baggage and freight holds, and small regions that are packed with electronic systems used to communicate or navigate the aircraft and perhaps to assist in its detection in surveillance systems.

The most important design consideration is the selection of a cross- section. As aircraft cruise high in the stratosphere, the air pressure within the passenger cabin has to be much higher than it is in the atmosphere. To accommodate the pressure differential at typical cruise altitudes (it is about half the sea-level atmospheric pressure) makes designers prefer a circular, or near-circular, cross-section. An oval cross-section is desirable for multi-deck aircraft, so that the 'walls' are reasonably close to being vertical, but the Boeing 747 experience has been that the structural loads can cause the oval- shaped frames to crack sooner than circular frames, thus diminishing airframe life. Nevertheless, Airbus has adopted a very noticeably oval section for the A380, which has three decks – two for passengers and one for the baggage and many of the aircraft's systems. Newer materials (in the case of the A380, an aluminium/carbon-fibre sandwich) offer the prospect of balancing the requirements of obtaining a lightweight design and a structure that has good fatigue-resistance. Boeing is using carbon-fibre fuselage sections for the first time on an airliner, on the 787 Dreamliner, and this promises the prospect of a less maintenance-intensive design solution, thus offering long-term operating cost savings.

In all airliners the passenger accommodation is invariably in rows of seats set a fixed distance apart (the seat pitch) and with seats in double or triple sets next to the windows. A small aircraft might have only three or four seats per row, and up to six seats if the cabin has just one aisle. These are narrow- body airliners. Larger-diameter cabins have two aisles and a central set of seats. This is usually only justifiable (in that the wider a cabin, the more frontal area it has and the more drag it will generate) when it is able to accommodate eight or more seats in a row, with ten seats the maximum number used, in an approximately 6 m (about 20 ft) diameter cabin.

The flight deck

The evolution of this part of airliners makes an interesting case study, not least because as systems have been made simpler to use, the crew size has diminished, and now almost all aircraft have a two-place flight deck for the captain and first officer. In the 1950s the long-range airliner had two pilots, a flight engineer, a radio operator and a navigator. These three additional crew members still have a place on a few older aircraft, but everything on the drawing board since the mid-1970s has had a two-place crew compartment. The systems that have wrought so much change need to be examined, to see where technology has been applied, almost invisibly, but on a massive scale, as the changes that have taken on historical connotations are liable to be overshadowed by as much change again in the future. diminished, and now almost all aircraft have a two-place flight deck for the captain and first officer. In the 1950s the long-range airliner had two pilots, a flight engineer, a radio operator and a navigator. These three additional crew members still have a place on a few older aircraft, but everything on the drawing board since the mid-1970s has had a two-place crew compartment. The systems that have wrought so much change need to be examined, to see where technology has been applied, almost invisibly, but on a massive scale, as the changes that have taken on historical connotations are liable to be overshadowed by as much change again in the future.