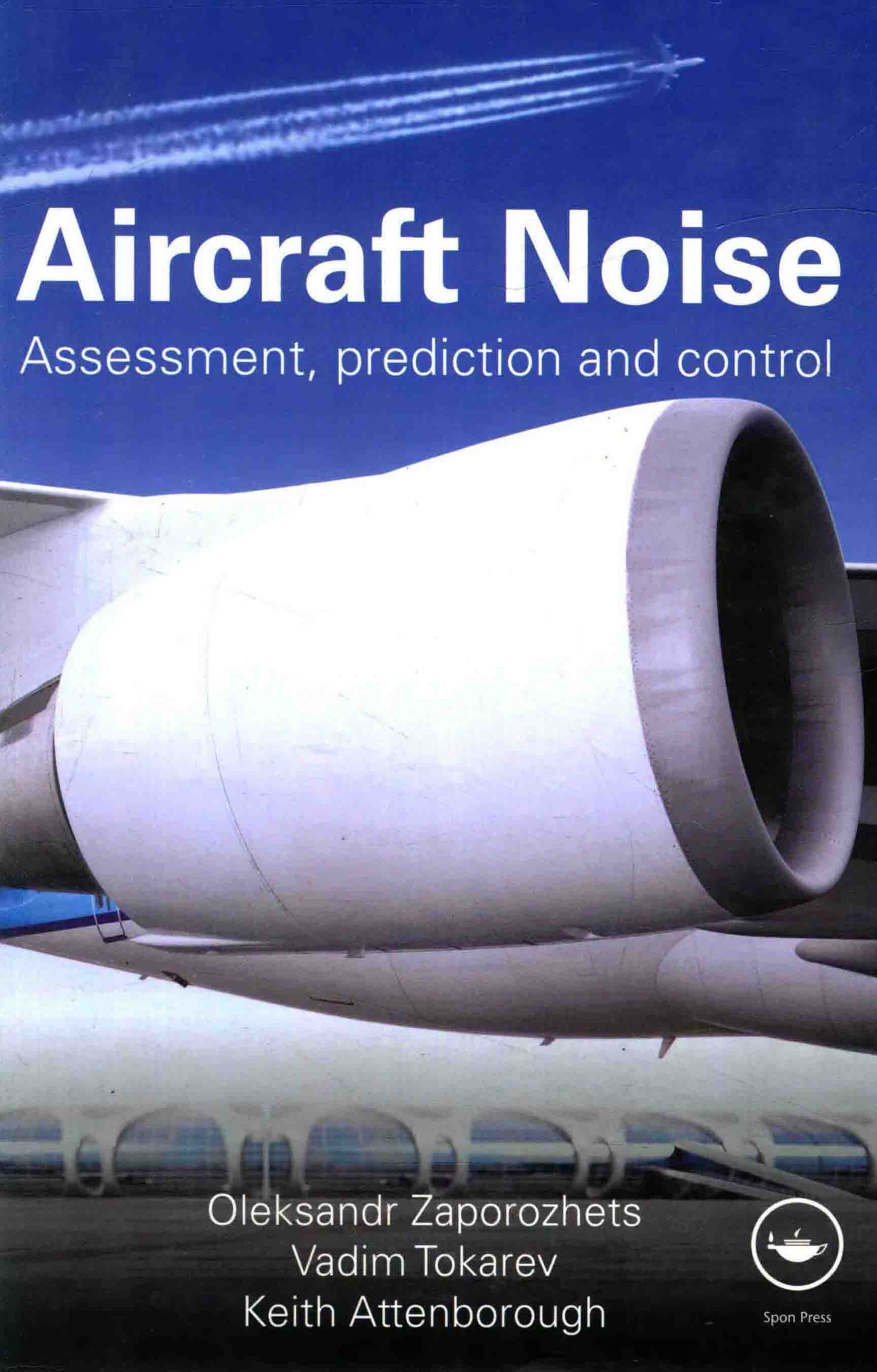

Aircraft Noise

Assessment, prediction and control

Oleksandr Zaporozhets
Vadim Tokarev
Keith Attenborough

Spon Press

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Aircraft Noise

Aircraft noise has adverse impacts on passengers, airport staff and people living near airports, it thus limits the capacity of regional and international airports throughout the world. Reducing perceived noise of aircraft involves reduction of noise at source, along the propagation path and at the receiver.

Effective noise control demands highly skilled and knowledgeable engineers. This book is for them. It shows you how accurate and reliable information about aircraft noise levels can be gained by calculations using appropriate generation and propagation models, or by measurements with effective monitoring systems. It also explains how to allow for atmospheric conditions, natural and artificial topography as well as detailing necessary measurement techniques.

Oleksandr Zaporozhets was awarded a D.Sc. for a thesis on the 'Development of models and methods of information provision for environment protection from civil aviation impact' in October 1997 at the Kyiv International University of Civil Aviation and received a Ph.D, for a thesis on 'Optimization of aircraft operational procedures for minimum environment impact' in December 1984 from the Kiev Institute of Civil Aviation Engineers. Jointly with Dr Tokarev, he was awarded a silver medal for achieving successes in the development of the national economy of the USSR in 1987. Currently he is a full Professor at the National Aviation University of the Ukraine.

Vadim Tokarev was awarded a D.Sc. in 1990 and a Ph.D. in 1969 at the Kyiv International University of Civil Aviation. Currently he is a full Professor at the National Aviation University of the Ukraine.

Keith Attenborough is Research Professor in Acoustics at the Open University, Education Manager of the Institute of Acoustics (UK) and was Editor-in-Chief of *Applied Acoustics* from 2000 to 2010. From 1998 to 2001 he was Head of Department of Engineering at the University of Hull. In 1996 he received the Rayleigh Gold medal from the Institute of Acoustics (UK) for outstanding contributions to acoustics research and teaching. He is a Chartered Engineer, an Honorary fellow of the Institute of Acoustics and a fellow of the Acoustical Society of America.

Preface

The motivation to write this book arises from over 40 years of investigations by Oleksandr Zaporozhets and Vadim Tokarev into aviation noise sources and into the technical, ecological, economical and social consequences of their impact on environment. The book also reflects these authors' experience over more than 30 years of teaching undergraduate and graduate courses within the framework of the 'Acoustic Ecology' curriculum at the National Aviation University, Ukraine, including modules on the physical factors that impact the environment, methods of biosphere protection and on environmental noise monitoring. The book contains results of research into aircraft noise modeling (including particular issues relating to aircraft noise propagation), assessment of the efficiency of operational methods of aviation noise reduction, flight planning for minimizing aircraft noise and monitoring of environmental conditions in the vicinities of airports.

The experience of these authors in applied aviation acoustics has been the result of collaborations with many scientific organizations including the State Research Center of the Central Aerohydrodynamic Institute (Moscow), the State Scientific Institute of Civil Aviation (Moscow) and the Aviation Design Offices of Tupolev, Il'ushin (Moscow) and Antonov (Kyiv). Consequently, many of the resulting publications are in Russian and in Ukrainian.

First attempts at writing a systematic overview of the subject of aircraft noise in English were made for a special issue of *Applied Acoustics* published in 1998 and for the final report of the NATO project 'Aircraft noise forecasting' (NATO grant EST.CLG.974767). The latter project also provided the impetus for the subsequent collaborations between the authors based in the Ukraine and Keith Attenborough in the UK. Although the scientific collaboration among the three authors has primarily influenced the contents of Chapters 3 and 6, Attenborough has also contributed by intensive editing of the use of English in the other chapters.

The book places equal emphasis on theory and on practical applications. The authors consider that the text differs in scope from the available texts on same topic [e.g. *Aeroacoustics of Flight Vehicles – Theory and Practice. Vol. 1, Noise Sources, Vol. 2, Noise Control* (1995), edited by H.H. Hubbard, Acoustical Society of America, Woodbury, NY, and *Transportation Noise Reference Book* (1987) edited by P.M. Nelson, Butterworths, UK] in that attention is given to operational and maintenance aspects of aircraft noise assessment and noise reduction methodology. The application of low noise operational procedures provides often neglected opportunities for noise reduction around the airports. This text provides the techniques and scientific basis that will allow for successful modeling and analysis of operational methods for aircraft noise reduction as well as the methods of control at source that are more usually considered.

It is also recognized that noise from aircraft is only part of the noise-associated problem around an airport. Mitigation of airport noise must be investigated as a problem of urban or rural soundscape. The methodology advocated in this text for decreasing the impact of aviation noise is based on a complex approach to a problem of noise reduction around the airports, which is considered as a physical process *and* as a phenomenon of social hygiene, sometimes with economic consequences. The approach to aircraft noise management in the vicinity of an airport used in the book corresponds to the balanced approach advocated by the International Civil Aviation Organization.

An important contribution of the book is to demonstrate how optimization of the control of aircraft noise through operational measures can increase the environmental capacity of the airport, particularly in cases where, otherwise, environmental constraints would reduce the operational and economic capacities of the airport. The basic theme of Chapter 1 of the book follows from the results of research on aviation noise in relation to airport noise capacity. The airport noise capacity is represented by the maximum number of aircraft that can be operated during a given period so that total aircraft noise levels do not exceed a prescribed limitation in critical zones around an airport. The capacity of an airport is a function of many different factors and aspects of airport infrastructure, including airfield layout (the number of runways, the extent of taxiways, apron development), the terminals and landsite facilities, air traffic control procedures, ground handling operations and meteorological conditions.

Aircraft are complex noise sources and a variety of noise protection methods can be employed around airports, including organizational, technical, operational and land-use methods. This is explained in Chapter 1 together with a presentation of the information about the basic noise sources on aircraft necessary for an understanding of the mechanisms of aviation noise generation.

Chapter 2 discusses models used to estimate the acoustical characteristics of the jets, fans, turbines, propellers and elements of the airframe. Parametrical investigations into the fundamental sources enable estimates of the influences of constructional and operational parameters on the overall acoustic fields due to aircraft.

Chapter 3 considers the physical phenomena involved in outdoor sound propagation under various operational conditions. These include atmospheric absorption, propagation over flat ground surfaces, over barriers, through trees, refraction by wind and temperature gradients and propagation through turbulence.

Chapter 4 explores methods for aircraft noise calculation, starting from an acoustic model for an aircraft as a whole. A model for predicting noise under the flight path is essential for operational purposes and for determining low-noise flight procedures. Models for predicting noise levels due to aircraft ground operations are important also for determining total airport noise. Some simplifications are introduced for predicting noise in the vicinity of the airport.

Using the models defined in Chapters 3 and 4, Chapter 5 investigates the influences of operational factors on aircraft noise characteristics at receivers on the ground and under the flight path. The optimal operational procedures for reducing noise impact are deduced for specific situations.

Chapter 6 reviews methods of aircraft noise reduction at source, along the sound propagation path and at the receiver, including the efficiency of acoustic screens for reducing noise from airport ground operations. The selection of optimal features of the operation scenario in the vicinity of the airport informs decision-making procedures for airport noise capacity control.

Chapter 7 introduces monitoring of aircraft noise as an essential tool for noise assessment and control around airports. The reasons for aircraft noise monitoring are operational, technical and economic. Current monitoring systems include powerful instrumentation and software, which besides recording noise levels must control the flight tracks, identify the type of noise source from each particular noise event, register noise complaints and measure meteorological parameters. To achieve effective mitigation of the impact of aviation noise on the environment, the interdependencies and trade-offs between noise and other important environmental factors associated with civil aviation, such as engine emission and third party risk, must be taken into account. It is shown that possible solutions may be reached by informational monitoring systems with the support of specifically predefined Aircraft Design Space, Flight Scenario Design Space and an Aviation Environmental Cost–Benefit Tool.

This book should be of interest to all those concerned with aircraft noise problems. After reading this book, the engineer, consultant or airport designer will be able to implement a balanced approach to airport noise management. This will include use of low noise operational procedures and the results of aircraft noise monitoring. The book should also be useful to those responsible for making or responding to decisions about the requirements for environmental control at airports. Although the book could be used as a reference text, it should be noted that the references listed at the end of the book are far from being exhaustive. Essentially, they contain only the references used in writing the book and reflect the particular questions considered by the authors. Nevertheless, by bringing together their many new scientific and practical results, the authors hope that the book's modern approach to aviation noise assessment and reduction will prove a useful addition to the literature.

Oleksandr Zaporozhets
Vadim Tokarev
Keith Attenborough

Contents

1 A review of the aircraft noise problem

1.1 Environmental impacts of airports

Aviation in the twenty-first century contributes to climate change, noise and air pollution. Together with various social and economic problems, environmental issues have the potential to constrain the operation and growth of airports. Constraints on airport capacity affect the capacity of the air navigation system as a whole. Many international airports are operating at their maximum, and some have already reached their operating limits including those resulting from environmental impact. This situation is expected to become more widespread as air traffic continues to increase. Already aircraft noise is a limiting factor for the capacity of regional and international airports throughout the world.

There are many definitions of airport capacity with regard to various issues: operational, flight safety, economic and environmental. The relative importance of each issue depends on the local, regional and national circumstances of each airport (see Fig. 1.1). Environmental capacity is the extent to which the environment is able to receive, tolerate, assimilate or process the outputs of aviation activity. Local environmental airport capacity can be expressed in terms of the maximum numbers of aircraft, passengers and freight accommodated during a given period under a particular environmental limitation and consistent with flight safety.[1,2] For example, the airport noise capacity is the maximum numbers of aircraft that can be operated during a given period so that total aircraft noise levels do not exceed a prescribed limitation in critical zones around an airport.

Aircraft noise is noise associated with the operation and growth of airports that impact upon local communities, in particular the nature and extent of noise exposure arising from aircraft operations. It is the single most significant contemporary environmental constraint, and is likely to become more severe in the future.

Local air quality is a capacity issue at some European airports, and is likely to become more widespread in the short to medium term. After aircraft noise, local air quality seems to be the next most significant environmental factor with the potential to constrain airport growth.

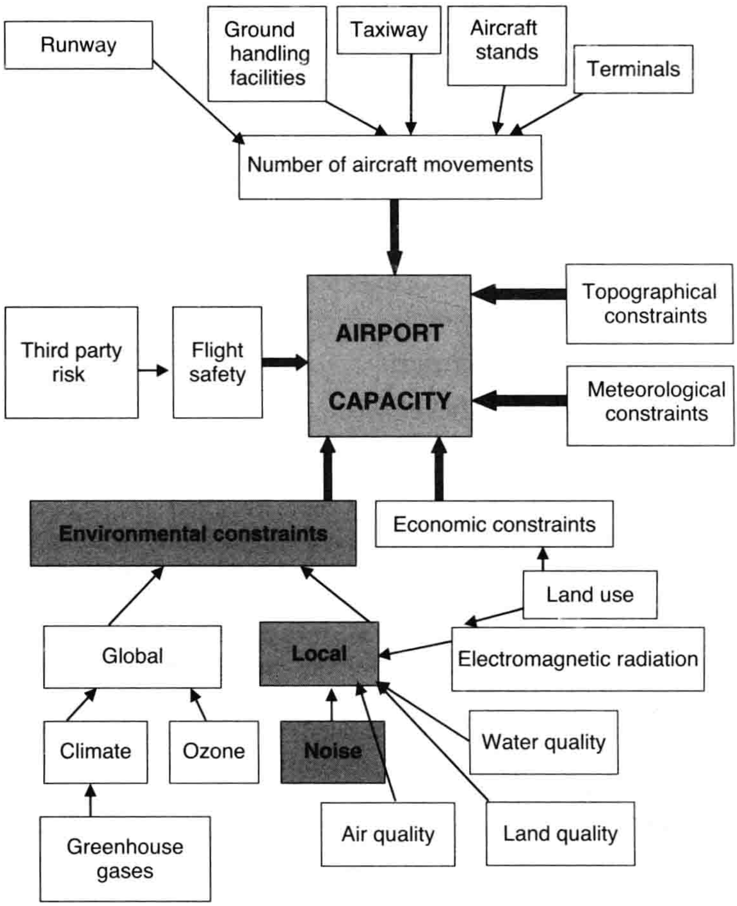

Figure 1.1 Environmental influences on airport capacity.

Third party risk is a potential future constraint for certain larger airports located close to built-up areas. The communities surrounding such airports are exposed to the small risk of an aircraft crash.

Water usage/pollution is both an existing and a potential constraint at certain European airports.

Surrounding land use and habitat value are both existing and potential constraints at a number of European airports.

Greenhouse gas emissions pose a potential constraint in the long term.

The capacity of an airport is a function of many different factors and the airport infrastructure, including the airfield layout (the number of runways, the extent of the taxiway, apron development), the terminals and landsite facilities, air traffic control procedures, ground handling operations and meteorological conditions. An individual airport capacity depends on the time between an aircraft landing and its leaving the airport, the ability of the airport to accept aircraft within a specified delay, the airport air traffic control system and its runway approach facilities.

In 2001, the International Civil Aviation Organization (ICAO) developed a balanced approach to noise management at airports. The balanced approach includes four elements: reduction at source, land-use planning and management, operational procedures for noise abatement and aircraft operational restrictions. The balanced approach has been applied to European airports by means of EU Directive 2002/30/EC concerning rules and procedures for introducing noise-related practices at airports. The noise mitigation measures should take into account specific features of the particular airport and the maximum achievable efficiency of suggested methods.

The potential to reduce noise at source is limited and land-use measures are difficult to implement in densely populated zones. Operational procedures which depend on pilot behavior may lead to a reduction in the level of flight safety. The growth of air traffic is faster than developments in new technologies and methods of noise reduction.

At present, only 2 per cent of the population is exposed to aircraft noise. This proportion should be compared with, for example, the 45 per cent of the population exposed to noise of road traffic and the 30 per cent to industrial noise. Nevertheless, ICAO analysis has suggested that there will be a 42 per cent increase in the number of people affected by aircraft noise in Europe by the year 2020.[3]

The noise produced by aircraft during operations in the areas around airports represents a serious social, ecological, technical and economic problem. Substantial levels of noise emission can bring about worsening of people's health, lowering their quality of life and lessening their productivity at work, through speech interference for example. In the areas around airports, aircraft noise has adverse influences on ground, maintenance and flight operations personnel, on passengers and on the local residential population. In abating aircraft noise, it is necessary to consider several criteria: ecological, technical, economic and social.

Methods of reducing aircraft noise have to take into account many requirements as follows:

1 Noise sources must be placed as far away as possible from built up areas.
2 Noise should be reduced to the lowest level achievable in a given case.
3 Noise abatement of aircraft involves several acoustic sources: jet exhaust stream, engine fan, turbine, combustion chamber, propellers (including the number of rotors and the tail rotor on a helicopter) and the airframe.
4 Since there are different types of aircraft in operation at an airport, the aircraft noise in the vicinity of the airport depends on the type of aircraft

in service, the number of flights by each type, the times of day and the meteorological conditions.

5 Propagation of sound from aircraft to a receiver involves direct transmission through air, reflection, diffraction and scattering from the surface of the Earth, screens and buildings, and through a turbulent and inhomogeneous atmosphere.
6 Apart from dwellings, there might be particularly noise sensitive receiver locations such as in laboratories, schools and hospitals. In developing measures for reducing noise around airports, it is necessary to take into account the short- and long-term forecasts of airport development.
7 There is a need for a balanced approach to engineering noise abatement practice from complex sources taking account not only noise levels but also the spectral characteristics at the receiver.
8 Noise abatement on aircraft can be realized at various stages including their design, manufacture, operation and repair. During operation, noise-reducing activities include reduction at the source, along the propagation path and at the receiver. The most cost-effective is to reduce noise at the source or at the design stage.[4]
9 Noise abatement requires identification of the noise sources, assessment of their contributions to the overall acoustic field and acquaintance with the accumulated knowledge of the effectiveness of available noise abatement methods.
10 The full costs associated with noise pollution (monitoring, management, lowering levels and supervision) should be met by those responsible for the noise.

Although aircraft are not the only sources of environmental noise around airports, they are the main ones. The working cycle of aircraft can be subdivided into starting engine operation, preflight engine run, taxiing to lineup, acceleration on the runway with full or reduced throttle, takeoff and roll-on, flight path, landing, run-on operation and engine run-up. The maximum noise levels are made during the acceleration on the runway, takeoff and roll-on. But these stages are of relatively short duration. Other periods of aircraft noise generation around an airport occur during engine testing, maintenance work, temporary repair and engine replacement after the end of their service life. Maintenance operations and engine run-ups have a long duration and take place at comparatively short distances in relation to surrounding residential zones, passengers and technical staff. So, although they involve lower levels than those from moving aircraft, noise from these ground operations must be considered.

The historical changes in priorities among the various operational factors during the development of civil aviation are indicated in Table 1.1.[5]

Although flight safety remains paramount in importance, currently the problems of flight operation of aircraft and environmental protection,

Table 1.1 Changes in priorities for civil aviation

1950–1970	*1970–1990*	*1990–2020*
Flight safety	Flight safety	Flight safety
Speed	Economic indexes	Environmental protection (including noise)
Range	Noise around airports	Resources
Economic indices	Regularity of operation	Regularity of operation
Comfort	Comfort	Economic indices
Regularity of operations	Speed	Comfort
Noise around airports	Range	Speed and range

including noise abatement, are combined. Noise abatement by operational measures involves additional pilot workloads for pilots and air traffic control and can result in additional operational costs for the aircraft operator. Aviation safety will always have priority over noise abatement operating measures. The pilot-in-charge will make the decision not to use low-noise flight procedures if it prejudices flight safety. For example, the pilot will ignore the demands of minimum noise impact under any kind of failure or shut-down of an engine, equipment failure or any other apparent loss of performance at any stage of takeoff. Noise abatement procedures in the form of reduced power takeoff should not be required in adverse operational conditions such as when the runway is not clear and dry, when horizontal visibility is less than 1.9 km, when a cross-wind component, including gusts, exceeds 28 km/h, when a tail-wind component, including gusts, exceeds 9 km/h, when wind shear has been reported or forecast or when thunderstorms are expected to affect approach or departure.

1.2 Description of aircraft noise

Aircraft are complex noise sources (see Fig. 1.2). So a variety of noise protection methods are employed around airports; including organizational, technical, operational and zoning methods. The main noise sources on an aircraft in flight are the power unit and the aerodynamic noise. Aerodynamic noise becomes particularly noticeable during the landing approach of heavy jet aircraft, when the engines are at comparatively low thrust.

The scientific basis for abating noise from aircraft relies on advances that have been made in aeroacoustics. Unlike classical acoustics (which is concerned mainly with the sound caused by oscillating surfaces), aeroacoustics investigates aerodynamic noise conditioned by turbulent non-stationary flow. Typically, jet aircraft noise sources include: jet noise, core noise, inlet and aft fan noise, turbine noise and airframe noise. Table 1.2 shows a classification of aircraft noise sources.

Usually third-octave band spectra are used for noise assessment of any type of aircraft in any mode of flight or during maintenance activities in the

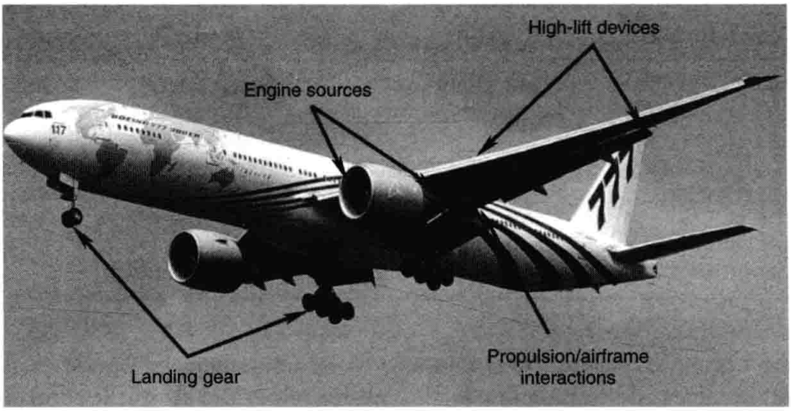

Figure 1.2 Aircraft noise sources.

Table 1.2 A classification of noise sources on aircraft

Aircraft class		*Main sources of noise*	
		Power-unit	*Airframe*
Aircraft – ordinary takeoff and landing	Turbojet	Jet, fan, core noise	Flap and wing trailing edges, flap side edges, slats, gear sources, fuselage and wing turbulent boundary layers
	Turboprop	Propeller, propfan, engine exhaust	
Aircraft – short takeoff and landing	Turbojet	Fan, engine exhaust	Interaction jet with flap
	Turboprop	Propeller	
Supersonic aircraft		Jet	Interaction of flow with frame
Helicopters		Blades of main rotor, engine exhaust	Not important
Aircraft of general aviation	Turbojet	Jet, fan	Not important
	Turboprop	Propeller, engine exhaust	

vicinity of the airport. In this case, the common computational procedure for the prediction of the aircraft noise under the flight path or around the aircraft on a ground (run-ups, taxiing, waiting for the takeoff along the runway) is based on the assumption that sound waves are spreading along the shortest distance between the aircraft and the point of noise control.