Abstract: The development of major commercial airports promotes the air transport industry and generates positive economic benefits to the airport and to its host economy. Any increase in aircraft movement causes negative environmental impacts, especially noise pollution, and people living near airports have long suffered from aircraft noise, traffic congestion and air pollution. Air traffic continues to increase worldwide, and recent forecasts by the International Air Transport Association (IATA) predict an average annual growth in the number of air passengers of 4.3% until 2015. As a consequence, the airspace is becoming more crowded, particularly in the vicinity of airports, and pollution increases from noise and aircraft exhaust emissions as well as from the associated road traffic. The aim of this paper is to present the aircraft noise sources and to underline the high importance of the research in the fight against the noise.

INTRODUCTION

This paper is addressed to students, researchers, aeronautic and environment authorities, and above all, the many people who are living near to airports and are influenced by the aircraft noise.

The centerpiece of this paper is represented by the aircraft noise sources explanation and the construction of noise contours (footprints).

An increasing number of people are exposed to aircraft and road traffic noise. Hypertension is a major risk factor for coronary heart disease and stroke (Stamler 1992), and even a small contribution in risk from environmental factors may have a major impact on public health. Recent studies indicate that noise exposure may cause hypertension, but few investigators have studied health effects associated with exposure to aircraft noise (Babisch 2006; van Kempen et al. 2002). Studies carried out around Schiphol (Amsterdam, the Netherlands) Airport in the 1970s showed excess risks of hypertension and other cardiovascular diseases in subjects exposed to high levels of aircraft noise (Knipschild 1977). In a recent study around the same airport, only a slight increase [odds ratio (OR) = 1.2] of self-reported use of cardiovascular drugs was found (Franssen et al. 2004). A Swedish cross-sectional study indicated an exposure–response relation between residential aircraft noise exposure and self-reported (diagnosed by a physician) hypertension (Rosenlund et al. 2001). In a Japanese study near a military air base, there was an exposure–response relationship between aircraft noise and prevalence of hypertension (Matsui et al. 2004).

Noise pollution can be defined as any unwanted or offensive sounds that unreasonably intrude into and disturb our daily lives. Noise originates in all sorts of ways, but, in general, increasing noise pollution is primarily the result of the increasing population of cities. Noise pollution is the intrusion of unwanted, uncontrollable, and unpredictable sounds, not necessarily loud, into the lives of individuals
of reasonable sensitivities. Using the "reasonable person" standard removes the notion that the judgment of sounds as unwanted is subjective.

Aircraft noise has always been a problem, and even though some piston-engine planes produced noise that many found annoying, it was the arrival of jet engines that increased the level of noise on many aircraft. The operation of the Boeing 707, first delivered in 1958, immediately presented problems to the airports where it landed and took off. Their noisy turbojet engines prompted complaints about "noise pollution" from surrounding communities.

The FAA regulations on aircraft noise were tightened several times after the initial rules were set. Naturally, this has prompted aircraft manufacturers to try to develop quieter aircraft. The first attempts to reduce aircraft noise preceded government regulation and were made in the 1950s. Although there was a lot of theoretical research by engine designers on the causes of aircraft noise and a number of proposed theoretical solutions, these theoretical solutions often did not solve the problem, and aircraft designers resorted to trial and error methods. The establishment of the FAA noise regulations in the early 1970s called for a 25 to 50 percent reduction in maximum noise generated by the existing long-range Boeing 707, Douglas DC-8 and Vickers VC-10 aircraft. Larger aircraft then entering service or in development, such as the Lockheed L-1011, Douglas DC-10 and Airbus A300 were designed with the more stringent requirements in mind. The Boeing 747, a monster commercial aircraft, did not meet the new regulations and required some modification. The development of high-bypass turbofans that powered these newer aircraft was prompted by the need for greater thrust and fuel efficiency, but also resulted in a beneficial reduction in noise. In a high-bypass turbofan, the central turbine drives a large fan in front of it that passes a lot of air around the turbine (this is what is meant by high-bypass a lot of air bypasses the turbine). Not only does the fan produce less noise per pound of thrust, but the cooler air mixing with the hot jet exhaust also insulates the engine, acting as a muffler (it "muffles" the noise). This reduction can be directly observed at a major international airport, particularly one that also includes flights of older turbojet-powered aircraft operated by poorer nations. For instance, a modern Airbus A340 jet is noticeably quieter than the rare 707. These older aircraft have to gain special permission to violate the noise regulations.

BACKGROUND AND LEGISLATIVE FRAMEWORK

The Air Navigation Act 1920 provided the basis of the UK's aviation noise regulation regime, by exempting aviation from nuisance sanctions, in order to stimulate the nascent industry. This principle was reaffirmed in the Civil Aviation Act 1982, which nonetheless set out a number of provisions for controlling noise at larger airports through a process of "designation", which has only been applied to date to Heathrow, Gatwick and Stansted. By their Section 78 designation, the Transport Secretary is responsible for regulating take-off and landing noise at these airports.

In practice, noise restrictions at designated airports have been implemented through restrictions on departing aircraft noise, controls on night flying and (at Heathrow and Gatwick, under Section 79) housing noise insulation schemes.
At other airports, the successive governments have continued to favor local resolution. Councils’ main instrument in this regard is the Section 106 Obligation, a condition that can be placed on planning permission. These Obligations can limit movement numbers, operating hours and the types of permitted aircraft. Voluntary agreements can also be reached. London City Airport and Luton Airport, for example, have agreed maximum noise exposure contours, which must not be exceeded.

Aviation is necessarily an international business, making unilateral domestic regulation difficult. However, successive agreements of the International Civil Aviation Organisation (ICAO) have sought to impose controls on aircraft design in order to minimise noise pollution.

Since the 1960s, jet engines have become four times quieter. A process of driving up noise pollution standards has been pursued by the ICAO, and by the European Civil Aviation Conference. In 2002, "Chapter 2" aircraft were outlawed from the EU, and the new "Chapter 4" comes into force in January 2006, which improves upon the current "Chapter 3" standard by a cumulative 10 dBA. The majority of aircraft in service today already meet the Chapter 4 requirements. EU regulation of aviation noise has focused on improving engine technology to date.

In 2001, the ICAO Assembly agreed that a balance of at-source restrictions, planning controls, operating restrictions and noise abatement practices by pilots and air traffic controllers would form the appropriate methods to address aviation noise.

Night flights are a particularly controversial aspect of aviation noise. Studies have shown that sleep can be disturbed at a relatively low Leq level of just 30. The first restrictions on night flights were imposed at Heathrow in 1962. Reviews have taken place since then in 1988, 1993 and 1998. The US Government undertook to consult on a new night noise regime in 2004, and decided that the existing limits on night flights should remain until 2012.

A contributing factor to this decision was the widespread media publicity in 2001 following legal action by a group of residents known collectively as the Heathrow Association for the Control of Aircraft Noise (HACAN). They took their case to the European Court of Human Rights, which endorsed the Government’s right to balance the economic interests of airlines in providing night flights against the welfare of local people. The Government agreed to review arrangements in the wake of the case.

The 2003 White Paper, which led to the Civil Aviation Bill, outlined the measures required to tackle the noise problem, highlighting in particular: the need to promote low noise engine and airframe research and technology; complete integration of the International Civil Aviation Organisation guidelines on noise control; implement EU Directive 2002/49/EC regarding noise mapping; widen the use of economic instruments such as differential landing charges and amend and strengthen existing domestic legislation.

In Romania the EU Directive 2002/49/EC was implemented with success through HG 321/2005 modified by the HG 674/2007.

Military aircraft present a different sort of problem, insofar as they are exempted from all controls under Crown Immunity.
**SOURCES OF AIRCRAFT NOISE**

Aircraft noise is defined as sound produced by any aircraft on run-up, taxiing, take off, over-flying or landing. Aircraft noise is a significant concern for approximately 100 square kilometers surrounding most major airports. Aircraft noise is the second largest (after roadway noise) source of environmental noise. While commercial aviation produces the preponderance of total aircraft noise, private aviation and military operations also play a role.

Take-off of aircraft may lead to a sound level of more than 100 decibels at the ground, with approach and landing creating lower levels. Since aircraft landing in inner-city airports are often lower than 60 meters (200 feet) above roof level, a sound level above 100 dBA can be realized.

A moving aircraft including the jet engine or propeller causes compression and rarefaction of the air, producing motion of air molecules. This movement propagates through the air as pressure waves. If these pressure waves are strong enough and within the audible frequency spectrum, a sensation of hearing is produced. Different aircraft types have different noise levels and frequencies. The noise originates from three main sources:

- Aerodynamic noise;
- Engine and other mechanical noise;

Noise from aircraft systems. On approach, the airframe makes as much noise as the engine. The flow over the flaps (labeled B below), slats and undercarriage (labeled A below) is unsteady and generates sound (Image showing the strength of the sound sources, courtesy of NLR). The jet noise contribution is labeled C. (Fig 1). From the engine (Fig 2), the main sources of noise are the fan (labeled A in the diagram to the right), and the high speed propulsive jet (labeled B):

![Fig 1 Aircraft Noise Sources](image1.png)

![Fig 2 Engine Noise Sources](image2.png)

**Subsonic noise**

Turbofan and turbojet engines are major sources of intense aircraft noise. Although turboprop-powered aircraft also are used by the U.S. Air Force, their contribution to the overall noise environment is of relatively minor importance compared to jet-powered aircraft. Jet engines are generally more powerful and produce noise of higher magnitude than turboprop or piston aircraft engines. Also, jet engines produce a greater amount of noise in the high-frequency range, thus increasing their relative annoyance factor.
In jet-powered aircraft, the primary sources of engine noise are the roar of the jet exhaust stream and the high pitched noise generated by the engine’s turbo-machinery, compressor, and blades. The exhaust roar is created by the rapid expansion of high-velocity exhaust gases. In general, the amount of noise generated by a jet aircraft engine is proportional to its exhaust stream velocity raised to the eighth power. By forcing atmospheric air into the jet engine intakes, the average velocity of the exhaust stream is reduced, decreasing the resultant noise intensity. For this reason, turbofan aircraft engines produce less noise at the same power setting than turbojet engines. The fan ducts of turbofan aircraft engines create a secondary air flow around the exhaust stream, thereby decreasing noise levels by reducing the magnitude of the shearing gradients between exhaust core and the ambient atmosphere. The higher a turbofan engine's bypass ratio, the less noisy its operation. The use of after-burners in military aircraft creates the opposite effect; the velocity of the exhaust stream is increased, thereby increasing the noise level.

Other jet engine noise sources are readily apparent, and may even be dominant during stationary or low-speed ground operations. The high-frequency whine of the engine's fans and compressors tend to be particularly annoying to most human listeners, and possibly to most animals. High bypass-ratio fan jets are quieter because their engines have slower fan speed, nacelle duct lines with acoustically absorbent material, and no inlet guide vanes.

The loudest noise generated by piston- or turbine-powered propeller aircraft generally occurs during takeoff, when the engine is operated on a high power setting. This noise is composed of a wide range of frequencies, but the major portion is at the lower end of the frequency spectrum. The turboprop engine is typically quieter than the piston engine during takeoff, but the compressor has the high-frequency whine, similar to jet engines.

**Sonic Booms**

During supersonic flight, the shock waves generated from forward-facing portions of an aircraft are usually regions of positive overpressure. The waves originating from rear surfaces of the aircraft are typically regions of negative overpressure, or underpressure. The pressure signature is the variation in overpressure generated by the forward- and rearward-facing surfaces of an aircraft flying at supersonic speed, creating the sonic boom (Figure 3). As an aircraft reaches supersonic flight, the pressure signature is propagated along a path commonly referred to as the sonic boom ray (ray AC, Figure 4); the pressure signature is generated at the point on the flight line from which the sonic boom ray emanates (point P, Figure 4).

![Fig 3 Characteristics of a sonic boom; pressure (vertical axis) plotted against time (horizontal axis) (Cottereau 1978).](image-url)
The sonic boom rays emanating from an aircraft operating at supersonic speed initially form a cone (Figure 4). However, due to atmospheric variations (e.g., wind and temperature gradients) the rays conform to the laws of atmospheric refraction and become horn-shaped, forming a boom conoid (Figure 5). Because all relevant refraction properties of the atmosphere are usually not known, developing an accurate boom conoid for a given supersonic flight event is difficult.

In the absence of winds, the increase in the speed of a sonic boom along a descending ray creates a decrease in the ray angle (Peterson and Gross 1972). For this reason, a boom ray tends to be refracted upward, away from the ground. Due to this phenomenon, angles from the vertical of two boom rays from each point on a supersonic flight path are sufficiently great that the boom rays only graze, or do not reach, the ground. The sonic boom "carpet" (the area on the ground that experiences the sonic boom) is defined by the locus of points of the boom rays that just graze the ground (Figure 6). Surface areas outside these points experience no sonic boom.

A tail wind behind an aircraft enhances the effect of the increase in sound speed. A head wind creates the opposite effect and tends to refract the boom rays toward the ground. Also, the paths of
propagation of the atmospheric pressure disturbances depend on the manner the aircraft is flown, as well as on the prevailing atmospheric conditions.

Under certain aircraft operating conditions (e.g., acceleration, dives, turns, and climbs), the sonic boom conoids generated by the aircraft may intersect one another. This effect is known as sonic boom focusing. Such focusing may also result from refraction effects caused by variations in atmospheric sound and wind speed. Focused sonic booms may be of much greater intensity than unfocused booms and are typically generated by fighter aircraft in "dogfight" maneuvers.

Aircraft Noise Propagation

The propagation of aircraft noise and sonic boom from source to receiver is a function of several factors, including relative distance; atmospheric attenuation due to wind, humidity, and temperature; and intervening noise barriers (e.g., large stands of trees and buildings). The distance relationship is relatively straightforward; as acoustic energy spreads out over an increasingly larger area, the amount of sound energy per unit volume of atmosphere steadily decreases. For subsonic noise, this decrease is inversely proportional to the square of the distance between the aircraft and the receiver (i.e., a decrease in acoustic intensity of approximately 6 dB for each doubling in relative distance).

Atmospheric conditions affect noise propagation. Water vapor in the atmosphere is relatively effective at absorbing noise. Also, the higher noise frequencies are more readily absorbed. For this reason, high-frequency noise typically decreases with distance more rapidly than does either midrange or low-frequency noise. For aircraft in flight, air absorption has the greatest influence on noise propagation.

Atmospheric temperature gradients also affect aircraft noise propagation. During periods of normal temperature gradients, where air temperature steadily decreases with increasing altitude, aircraft noise is, for the most part, deflected upward, thereby producing areas of little or no noise on the ground at certain distances from the aircraft. During periods of atmospheric temperature inversion, the reverse situation is true and aircraft noise tends to be deflected downward, thus increasing ground noise level (Gladwin 1978).

During low-level aircraft operations, surface absorption and deflection may decrease the observed noise levels at low angles of observation. Intervening objects (e.g., hills, buildings) will also affect noise propagation.

NOISE CONTOURS

The noise heard on the ground near airport from which an airplane is taking off, or toward it is approaching to land can be presented by plotting lines of constant noise level.

These so-called single-event noise contours or footprints give the noise level at any particular point on the ground expressed in one of the single number noise descriptors treated in the preceding sections. Each contour encloses the area where the noise levels are in excess of the cited level. An example of a single-event noise contour produced by a takeoff maneuver of a transport airplane is shown in Figure 7.
As depicted in Figure 8, the takeoff path of the airplane with all engines operating may be divided into the following phases:

- Ground run;
- First segment climb (takeoff thrust, flaps and landing gear down);
- Second segment climb (takeoff thrust and flaps down, landing gear up);
- Third segment climb (maximum climb thrust, flaps and landing gear up);
- Continued climb (reduced thrust).

To improve rate of climb the landing gear is retracted soon after liftoff. Shortly after the thrust setting is reduced to maximum climb thrust.

Once a safe altitude has been reached thrust may be reduced again to less than maximum climb thrust since satisfactory climb performance may also be attained at a considerable lower engine thrust setting. This so-called thrust cutback procedure may yield lower noise levels than are observed during a full thrust climb, where the airplane reaches a greater distance from the ground.

Noise footprints as sketched in figure 7 may also be used to investigate the effects of noise abatement techniques and to demonstrate how much less noise is generated by new or modified airplanes compared to older or unmodified versions.

The construction of noise footprints requires calculation of the noise level at a large number of ground observations points around the airport and connecting lines through individual points with equal level.
Calculation of noise level at a given observation point caused by an individual airplane is based on knowledge of the noise characteristics of airplane, the location of its flight path relative to the observation point, and engine power and airspeed at each point along the flight path.

The noise emission characteristics, usually, are specified by the relationship between observed (peak) noise level under the flight path, shortest distance between source and receiver (slant range distance), and power setting. These noise-thrust/power-distance data are given for reference atmospheric conditions. They can be obtained by executing flyover noise measurements with the microphone located on the flight track. The resulting noise-power-distance curves for the small propeller-driven airplane considered there are presented in Figure 9.

When the airplane is close to the ground, noise propagates at low angles of incidence to the sideline. Under these conditions it may be necessary to apply adjustments to the noise levels of Figure 9 to account for excess ground attenuation (EGA). Noise levels observed at sideline locations are lower than the levels at locations directly below the airplane at the same distance. At small elevation angles an additional attenuation caused by airframe shielding may also be of importance.

The total noise level reduction from ground effects and shielding is termed lateral noise attenuation.

To simplify the calculations, airplane performance and noise data are developed for certain computational reference conditions. The influences of vertical gradients of wind and temperature, moisture content, and other real-life conditions such as local topographical features are left out of account.

CONCLUSION

One solution to reduce noise is represented by the “low noise approaches”.

A variety of techniques can be employed to reduce the noise impacts of aircraft as they approach an airport, including:
- keeping the aircraft high for as long as possible (increasing the distance from the aircraft noise sources to the ground);
- keeping the aircraft at low engine power for as long as possible (reducing engine noise);
- keeping the aircraft in a clean aerodynamic configuration for as long as possible (reducing airframe noise);
- minimising overflight of highly populated or sensitive areas;
- Continuous Descent Approaches (CDAs).

One effective technique is called Continuous Descent Approach (CDA). This technique keeps aircraft higher and at lower thrust for longer by eliminating the level segments in conventional “step down” approaches.

Significant noise, fuel burn and emissions benefits can result, but there can be potential impacts on air traffic control & flight crew procedures.

A set of advanced CDA procedures were developed for a regional UK airport which also incorporated other low noise “best practice” techniques of Precision Area Navigation (allowing the procedure to be programmed into the aircraft Flight Management System to optimise the approach path) and Low Power/Low Drag (to keep the aircraft in a clean aerodynamic configuration)

The procedures comprise a set of waypoints with:
- a lateral profile to allow low population exposure to noise;
- vertical constraints which assist the achievement of a CDA vertical profile;
- speed constraints designed to achieve low power/low drag.

Future challenges

The ‘Silent’ aircraft is currently a conceptual design. There are many challenges that would have to be overcome before it could become a reality in the 2030 time frame.

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