Chapter 2
Emission Assessment of Aviation

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ABSTRACT

Aviation-related emissions and their impacts are comprehensively discussed in this chapter. Previous studies are described in “Previous Studies,” and their relevance is discussed throughout the chapter. In “Jet Engine Emissions,” five common emissions species with contrail formation are described along with qualitative and quantitative results from important investigations. Relationships between aviation emissions and fuel usage are also illustrated. In the mitigation strategies section, emission abatement methods are investigated, focusing on three main areas: technology, flight procedures, and alternative fuels. Both theoretical and practical methods with the potential to decrease emissions are discussed. In the legislation section, the status of emissions regulations is discussed, and emissions charges applied by airports are identified. Examples are provided throughout the chapter to illustrate the points addressed. To complement the main body of the chapter, much detailed information related to aircraft emissions compiled from various sources are provided in the appendix.

INTRODUCTION

In July 2010, the first manned solar airplane, Solarlmpulse, having four 10 hp electrical engines and weighing 1600 kg, performed a nonstop 26 hour flight using only solar power to provide power both day and night. This significant development is believed to have opened a new era in aviation in terms of fuel and environmental concerns.

During the last decade in air transport (1999-2008), it can be seen that, except 2001, air travel indicators showed incremental trends. Of these indicators, the annual increase in passenger-kilometers has averaged 5.8%. Moreover, the
passenger indicator increase is an annual average of 7.5% (ICAO, 2008). According to Boeing, passenger traffic will continue to increase over the next twenty years, by about 4.1% annually, which implies the introduction of a large number of single and twin aisle new aircraft (Boeing, 2010a).

Regarding year to date (YTD) aircraft movements (as of March 2010), the maximum movement is recorded in Atlanta airport in the U.S., with a total count of 227,388 landings and takeoffs. Considering aircraft movements at the top 30 airports for the same YTD period, it can be seen that there are 20 airports from the U.S., totaling 2,394,422 movements, while there are six airports from Europe totaling 619,401 movements. The remaining four airports are from China, Canada and Mexico and accounted for 389,291 aircraft movements (ACI, 2010).

Fuel cost is one of the key direct operating costs for air transport. A variation in fuel price has a direct effect on flight cost. Fuel prices have increased annually by an average of 28.2% in the U.S. between 2003 and 2008. In 2009, however, fuel prices declined by 38.1%, ending at 0.5 $ liter\(^{-1}\) by 2010 June (BTS, 2010). Despite the fact that efficient engines have been developed in recent decades, increasing the capacity and performance of these aircraft requires higher amounts of fuel consumption compared to those built in the previous decades. The increase in fuel consumption leads to a corresponding increase in emissions and relevant atmospheric impacts.

The first jet airline, the de Havilland Comet, made its first flight in 1949. It had four engines, each capable of producing a thrust of 22 kN (Anonymous, 2010a). The specific fuel consumption (SFC) of each of the four Olympus 593 engines of the Concorde, first flown in 1969, was 33.8 g (kN s\(^{-1}\)) (1.195 lb (lb\(_f\)-h\(^{-1}\)) at cruise. The J79 is a popular military turbojet engine, which is still being used on F4, F5 and IAI Kfir and was used on the F104, B58 and some versions of Convair airline in the past, has a thrust of 53 kN (79 kN with afterburner) and a specific fuel consumption as 24.0 g (kN s\(^{-1}\)) (0.85 lb (lb\(_f\)-h\(^{-1}\)) at military thrust and 55.5 g (kN s\(^{-1}\)) (1.96 lb (lb\(_f\)-h\(^{-1}\)) with afterburner (Anonymous, 2010b).

With the advent of the turbofan, the efficiency of the jet engines increased dramatically. The first turbofan engine, the Conway, was certified in 1963. It had a by-pass ratio of 0.25-0.3 and produced 73 kN of thrust. Since that time, turbofan engines evolved continuously to provide the needs of larger aircraft carrying heavier loads over longer ranges. For instance, one of the large jet engines which is going to power the B787, the Rolls-Royce Trent 1000, has a by-pass ratio of almost 11 and a thrust of 328 kN. Current aircraft are about 70% more fuel efficient per passenger-km than those of 40 years ago (Ribeiro et al., 2007).

The radiative force (RF) is defined as the change in net radiative flux due to a change in either atmospheric composition or solar irradiance. According to the fourth assessment report of Intergovermental Panel on Climate Change (IPCC) (Forster et al., 2007), the radiative force is a parameter that is used to assess and compare anthropogenic and natural drivers of climate change. A positive value of RF leads to global warming (Marquart et al., 2001), while a negative value leads to global cooling. The contribution of common emissions on positive radiative forcing is shown in Figure 1. While the largest contributor is CO\(_2\), it can be seen that NO\(_x\) emissions and contrails also play significant roles in global warming.

Investigations indicate that the radiative forcing resulting from aircraft is 0.05 W m\(^{-2}\) or about 3.5% of the total radiative forcing from anthropogenic activities in 1992 (Schumann, 2000). Another estimation (Lee et al., 2009), which is obtained using the same approach (Schumann, 2000) but excluding aviation-induced contrails, indicates that aircraft are responsible for 4.9% of all radiative forcing including aviation-induced contrails. To provide a broader and historical perspective, the global annual mean radiative forcing from the year 1750 to around 2000 is