Research Journal of Recent Sciences ISSN 2277 - 2502
Vol. **1(ISC-2011),** 134-144 **(2012)** *Res.J.Recent.Sci.*

CO_2 Emission Reduction potential through improvements in technology from Civil Aviation Sector in India - A Case of Delhi-Mumbai air route

Yenneti Komalirani[1*] and Sharma Rutool[2]
[1]GEES, University of Birmingham, UK, The Energy and Resources Institute (TERI), INDIA
[2]CEPT University, INDIA

Available online at: www.isca.in
(Received 26th September 2011, revised 11th January 2012, accepted 25th January 2012)

Abstract

Modern aircraft and engine technologies achieve fuel efficiencies of 3.5 litres per 100 passenger-kilometers. The A380 and B787 aircrafts are aiming for 3 litres per 100 passenger-kilometers. However, most airlines already use advanced technology and processes, making additional fuel efficiency improvement more difficult. But, India lags deeply in technological management system. A study by Down to Earth says that the flights that travel between Delhi-Mumbai are delayed for an hour and the delay cost per day is about 44 lakhs. The working paper deals with the emission reduction potential from Delhi-Mumbai Air route which is supposed to be the sixth busiest route in the world with more than 700 flights a week through improved technological options. Air craft and engine technologies have proved to be one of the best options for mitigating emissions from civil aviation sector. The traffic between the national and financial capitals contributes to over 50 per cent of the total Indian air traffic and enjoys load factors between 75-80 per cent through the year. According to a study by Petroleum Conservation Research Association (PCRA) the average fuel wastage per flight in this route is 30% to 40%. Aviation fuel, produces about 2.158 kg of CO_2 emissions per litre consumed. So in this regard this route has been taken up as priority for the study. According to base study[1], the route generated 5.62 Million Tonne(MT) of CO_2, 3.03 MT of NOx, 0.57 MT of N_2O and 0.15 MT of CH_4 for the study period (2005-09) from 93481 flights that operated for that period. It was also found that the emissions from the direct flights in the route is higher than that of via flights due to the reason that the number of direct flights (77357) are more than that of via flights (14915) for the same period. The scope of the paper is to find out the CO_2 emission reduction potential through three strategies in technological improvement which are installation of blended winglets, installation of dryers, and installation of air units while studying the various technological options available across the globe. The three strategies have been identifed after studying several strategies prevalent Internationally which can be applicable to Indian environment and state of affairs.

Keywords: Civil aviation, Delhi-Mumbai, greenhouse gas emissions, technological options, fuel efficiency.

Introduction

Air transport performs many functions in modern societies and plays an integral role in the development of an economy[1]. Aviation facilitates economic growth with 8% of world's Gross Domestic Product (GDP), helps in realizing the socio-economic objective of providing connectivity to foster travel and trade with 35% of inter-regional exported goods, exchange cultures through tourism with about 40% of international tourists and provides huge employment creating about 32million jobs[2]. The sector has been leaping skyward and seen a strong growth in demand since its advent in 1912 with (5-8) % growth per anuum[3]. Aviation, an increasing contributor to economic and social well being is increasingly being singled out as a major source of greenhouse gas(GHG) emissions, a significant contributor to global climate change and a source of air pollutants[4]. In 2004 aviation's CO_2 emissions were 705 million tonnes, including commercial, military and general aviation[5]. Statistically, this represents 2.54 per cent of global emissions of CO_2 from fossil fuel use (56.6 per cent of 49GtCO_2-eq in 2004). There is a concern among the scientific community that, despite the very low percentage of GHG emissions from commercial aircraft operations, the standard cruise altitudes of those aircraft could compound the effects of their GHG profile through a process that is commonly referred to as radiative forcing. The recent findings from 2005 indicate that aviation has grown in the intervening years and the value must be updated and increased to 3.5 per cent of all anthropogenic forcing, and this number increases to 4.9 per cent with the cirrus cloud enhancement effect[6]. By 2050, the contribution of aviation to warming would be by a factor of 3 to 4 over the value from 2000 and would contribute to 5%-6% of global GHG emissions[7]. Table-1 illustrates the contribution of international aviation to CO_2 emissions for the year 2003.

"Human-generated emissions at the Earth's surface can be carried aloft and affect the global atmosphere. The unique property of aircraft is that they fly several kilometers above the Earth's surface. The effects of most aircraft emissions depend strongly on the flight altitude and whether aircraft fly in the troposphere or stratosphere. The effects on the atmosphere can be markedly different from the effects of the same emissions at ground level. The rate of growth in aviation CO_2 emission is faster than the underlying global rate of economic growth, so aviation's contribution to total emissions resulting from human activities is likely to grow in coming years"[4]. At present, though domestic aviation is included in the system of national GHG inventories on which the Kyoto GHG reduction targets and the Climate Change Bill's targets are based, there is no agreed methodology as to how these should be assigned to individual countries[8]. Against the background of significant growth in air travel and aviation markets, and as a result of government and public focus on climate change and its consequences, airlines are coming under increasing pressure to reduce their GHG emissions.

Table-1
Carbon dioxide emissions from international aviation bunkers for 2003 (Source: TERI, 2008)

Country	Emissions (in million tonnes)	Percentage contribution in global international aviation emissions
United States	49.5	13.80
Former USSR	33.01	9.20
United Kingdom	23.47	6.54
Germany	21.34	5.95
Japan	20.56	5.73
France	15.54	4.33
China (including Hong Kong)	12.73	3.55
Mexico	7.93	2.21
India	**7.83**	**2.18**
Australia	6.87	1.92
Brazil	3.35	0.93
South Africa	2.47	0.69
Pakistan	2.39	0.67

Table-2
Gases emitted from Aviation and their impact on Atmosphere (source: IPCC 2000)

Gas	Impact
CO_2	Carbon dioxide is the product of complete combustion of hydrocarbon fuels like gasoline, jet fuel, and diesel. Carbon in fuel combines with oxygen in the air to produce CO2.Long-lived GHG. Contributes to global warming.
NOx	Nitrogen oxides are produced when air passes through high temperature/high pressure combustion and nitrogen and oxygen present in the air combine to form NOx.
CO	Carbon monoxide is formed due to the incomplete combustion of the carbon in the fuel.
O_3	It is not emitted directly into the air but is formed by the reaction of VOCs and NOx in the presence of heat and sunlight. Ozone forms readily in the atmosphere and is the primary constituent of smog. For this reason it is an important consideration the environmental impact of aviation. Lifetime weeks to months. The effect of O_3 is high at subsonic cruise levels and causes radio-active reactions at those levels.
CH_4	Lifetime of ~10 years. Aircraft NOx destroys ambient CH4
SOx	Sulfur oxides are produced when small quantities of sulfur, present in essentially all hydrocarbon fuels, combine with oxygen from the air during combustion. Scatters solar radiation to space. Impact is one of, cooling.
H_2O	Water vapor is the other product of complete combustion as hydrogen in the fuel combines with oxygen in the air to produce H_2O. The effect is small because of its small addition to natural hydrological cycle.Triggers contrails, but actual contrail content is from the atmosphere.
HC	Hydrocarbons are emitted due to incomplete fuel combustion. They are also referred to as volatile organic compounds (VOCs). Many VOCs are also hazardous air pollutants.
Soot	Absorbs solar radiation from space. Impact is one of warming.
Contrails	Reflect solar radiation, have cooling effect; but reflect some infrared radiation down to earth, that is warming effect; but net effect is one of warming.
Cirrus	Contrails can grow to larger cirrus clouds (contrail cirrus), which can be difficult to distinguish from natural cirrus. Generally warming effects.

How does Aviation sector affect climate?: Air craft typically cruise at altitudes of 8 to 13km, where they release several types of gases and particles from fuel combustion which alter the composition of the atmosphere and contribute to climate change[9]. This cruising makes the aircraft engine contribute to GHG emissions roughly of about 70% CO_2, a little less than 30% H_2O, and less than 1% each of NO_x (oxides of nitrogen), CO (carbon monoxide), SO_x (oxides of sulphur), VOC (volatile organic compound), particulates, and other trace components. CO_2 is 2 percent and NO_x is 8 percent of the global anthropogenic gases at present but will increase if the aviation sector continues to grow, which is expected to be at an average rate of 3%[10]. The emissions are to be double folded from 1992-2050 (CO_2- 476MT -2808 MT) if the sector grows on present scenario[11]. Currently, the estimates of emissions by the sector are estimated to be 1.48 billion tons by 2025, which exceeds the estimates made in 2004 by about 1.3 billion tons[12]. Aviation emissions effect not only the environment but also the industry and society as a whole. Globally the world's 16,000 commercial jet aircraft generate more than 600 million tonnes of CO_2, the world's major GHG source, per year[13]. Indeed aviation generates nearly as much CO_2 annually as that from all human activities in Africa[10]. This increase in emissions also increases the radiative forcing *(The Radiative Forcing Index is the measure of total effect of climate change. It is measured for Aviation as the ratio of total RF to that of* $CO_2 = (CO_2+O_3+CH_4+H_2O+Contrails+Particles)/CO_2)$ to (4-12) by 2050 as compared to 1992[4]. Table- 2 captures the impacts of gases emitted by the sector.

Emissions calculation: The Delhi-Mumbai case: Since its advent in India in December 1912, the sector has witnessed 5 to 8 per cent growth in demand per annum[14]. India's air travel is up by 8% with Domestic passengers increased by 27.9% in the first three-quarters of 2007-08, international passengers by 14.8% and cargo by 11%, and the air craft movements' are also increased by 23.3% in Apr-Dec (2007-08) [15]. The overall air traffic is up by 25% with freight traffic up by 11%. Growth in this sector outpaces the global average by 2025[16]. This huge growth in the sector would lead to huge emissions which are not quantified till now. The contribution of individual countries including India of the aviation sector to global emissions has not been identified[12]. But, in India too, the rise in aviation-related emissions is expected to be almost as impressive (at over 4 per cent per year). These numbers might seem small, but are significant given their rapid growth, and is of particular concern for at least two other reasons- "First, it is highly energy-intensive using more energy per person-kilometer than a single occupancy car. Second, its contribution to global warming is around three times greater than is indicated by the carbon dioxide emissions alone. During 2003-04, the total aviation emission was 7.60 Tg (2.9%) of the total transportation emissions"[17]. During 2004–2005, aviation sector has become second major source of transport emissions as there is tremendous increase in the number of passenger movement and also international and domestic flights[5]. Table 3 depicts the sectors contribution to varios GHG emissions.

Material and Methods

Calculating emissions: The Delhi-Mumbai connect: To propose the emission redcution strategies, first emissions from the route need to be calculated. The emission calculation for the route is explained through a 3 step methodology.

Step 1: calculating the air traffic: Delhi-Mumbai is said to be the sixth busiest route in the world and the busiest route in India with more than 700 flights a week and a load factors between 75-80 percent throughout the year[16]. The traffic between the national and financial capital contributes over 50 per cent of the total Indian air traffic. It is mentioned that the average fuel wastage per flight operating in this route is 30-40 percent[17]. "Under normal conditions a new generation Boeing or Airbus will take two hours and use up to 4,500 kg of Air Turbine Fuel (ATF) for a journey. According to many pilots it was common for a flight to hover in the air for an extra hour. For every hour a plane hovers in the sky, it consumes between 2,200 kg and 2,400 kg of ATF" [17]. There are several other factors which made to study the route based on several studies. According to the study by Down to earth[17], "it says that just the extra fuel being burnt everyday between Delhi and Mumbai pumps 248.2 tonnes of CO_2 which is caused by 161 small cars running for a year. In terms of monetary value this fuel burnt cost to Rs. 44 lakh for a day". "Due to the increase in the air traffic, the foggy conditions during the winters in Delhi have increased drastically over the past decade. Meteorological data for December and January in 1983 shows the average clear visibility during the day in the capital was 5:07 hours. This decreased to 10 minutes in 2005. Duration of dense fog rose from half an hour per day in early 1980's to two-three hours in 2003.The humidity during the winter months in Nation Capital has shot up by up to 90% between 1981 and 2003" [18]. He also attributes increased fog to a drop in maximum temperatures during winters and increase in aerosol in the atmosphere. So in this regard this route has been a priority to take up the study. Though the air traffic is often divided into Civil IFR (Instrumental Flight Rules) flights; Civil VFR (Visual Flight Rules) flights, also called general aviation; Civil Helicopters, and Operational Military flights, this study focuses only on commercial airlines which covers ordinary passenger aircrafts.

There are two different types of traffic in this route – the first being Direct flights (Delhi-Mumbai) and second being Via flights (Delhi – X – Mumbai). The direct flight is the flight travelling directly without any halt and indirect flight is the flight travelling via another city with a halt. From the data received by Delhi airport for the study period of 2005-09, there are 16123 direct flights and 77357 via flights at the Delhi airport. The route has a maximum density of 85 flights/day considering the direct and via flights as a whole. The traffic gradually increased from 13681 in 2005-06 to 18573 in 2006-07, 12745 in 2007-08, and 34703 in 2008-09 respectively. The growth is declined in the year 2007-08 and is increased for the year 2008-09. On the other hand, there are about 20 via routes. The via flights are also found to be increasing for the period 2008-09 compared to the decrease for the period 2007-08 from 2006-07.

Step 2 – Using the formulae (IPCC methodology): After estimating the number of flights travelling between the routes, the amount of emissions from the flights are calculated. For calculating the emissions, the present study considers the Intergovernmental IPCC Tier method for aviation under the energy sector. Of the three proposed Tiers, the present study considers the Tier-1 method which is described as very simple and is purely fuel based. The simplest methodology is based on an aggregate figure of fuel consumption for aviation to be multiplied with average emission factors. The emission factors have been averaged over all flying phases based on an assumption that 10 percent of the fuel is used in the LTO phase of the flight[19].

Emissions = Fuel Consumption * Average Emission

The following are the default emission factors: CO_2 : 19.5 tonne C/PJ; CH_4 : 0.5 kg/PJ, and N_2O : 2 kg/PJ

Table-3
Aviation fuel contribution to GHG emissions

Aviation	CO_2	CO	NO_x	CH_4	SO_2	PM	HC	N_2O	NMVOC
High speed diesel	85.860	1.1699	0.9359	0.0058	–	–	–	0.0007	0.2340
Light diesel oil	6.3600	0.0867	0.0693	0.0004	–	–	–	0.0001	0.0173
Fuel oil	222.23	2.8535	2.2828	0.0143	–	–	–	0.0007	0.5707
Aviation turbine fuel	7294.14	2565.35	8.7331	6.5498	–	–	–	–	–

(Source: Total emission from Indian Aviation sector for 2004/05 (Gg) (Source: emissions from India's transport sector: Statewise analysis, T.V Ramachandra, Shwetamala)

Table-4
Composition of flights in the study route for the study period 2005-09

Routes	Arrivals	Departures	Total
Delhi-Mumbai All flights (via)	6942	9181	16123
Delhi-Mumbai Direct flights	24821	52536	77357
Total	31763	61717	93480

(Source: calculated by authors based on data from Delhi airport, 2009)

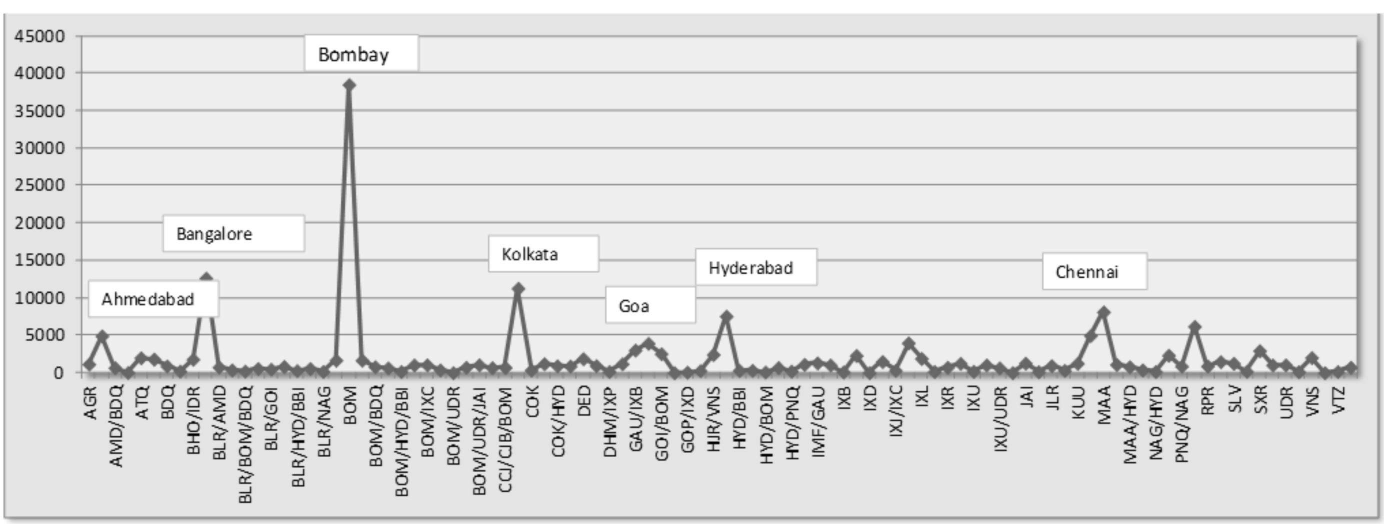

Figure-1
Flights in the via routes between Delhi-Mumbai (@Delhi airport for the period of 2007-09)
Note: For full form of abbreviations of the routes in the figure refer abbreviations at the end of the paper

Table-5 provdes the aggregate emission factors for NO_x, carbon monoxide (CO), sulphur dioxide (SO_2) and non methane volatile organic compounds (NMVOCs). For estimating the total emissions of CO_2, SO_2 and heavy metals the Tier 1 methodology is sufficient, as the emissions of these pollutants are dependent on the fuel only and not technology.

Step 3- Emissions from the route (using IPCC Tier-1 method): After considering the Tier-1 method formula for calculating the emissions, the same is applied for calculating the emissions from the Delhi-Mumbai route. The same method can be applied for any other routes or elsewhere. For the route GHG emission potential estimate is carried out considering the Landing-Take off cycles and cruising. Although the sector has different GHG emissions, the sutdy is carried out only for CO_2, NO_x, N_2O, and CH_4. Further the following assumptions are considered for calculating emissions (table-6). The assumptions as shown in the table are taken from various sources and discussions held with experts as mentioned. The emission factors are considered for Tier-1 method.

Using the above emissions and the Tier-1 formula above, the emissions are calculated for direct and via routes as mentioned below. The Delhi-Mumbai has maximum amount of emissions with maximum flights of 77357 for the study period (2005-2009). The CO_2 is maximum with about 4.71 Mt for the period followed by NO_x (2.53 Mt), N_2O (0.48 Mt) and CH_4 (0.12 Mt). It is also found that the emissions are reduced for the period 2007-08 as the number of flights of the period is decreased. Similarly the via routes had a total number of 14915 flights for the period of 2007-09 (data availability). The CO_2 is maximum with about 0.90 Mt for the period followed by NOx (0.48 Mt), N_2O (0.09 Mt) and CH_4 (0.02 Mt) (table-7). But unlike the direct flights via flight have been increasing over the period increasing the total emissions annually. However, in both the scenarios, the average emissions are found to be 61 TCO_2e/flight, 33 TCO_2e/flight (NO_x), 6 TCO_2e/flight (N_2O) and 2 TCO_2e/flight (CH_4) respectively.

Table-5
Emission factors and fuel use for the representative aircrafts

Tier 1 Emission Factors									
Domestic	**Fuel**	**SO_2**	**CO_2**	**CO**	**NO_x**	**NM-VOC**	**CH_4**	**N_2O**	**$PM_{2.5}$**
LTO (kg/LTO) – Average fleet (B737-400)	825	0.8	2600	11.8	8.3	0.5	0.1	0.1	0.07
LTO (kg/LTO) – Old fleet (B737-100)	920	0.9	2900	4.8	8.0	0.5	0.1	0.1	0.10
Cruise (kg/tonne) – Average fleet (B737-400)	-	1.0	3150	2.0	10.3	0.1	0	0.1	0.20
Cruise (kg/tonne)- Old fleet (B737-100)	-	1.0	3150	2.0	9.4	0.8	0	0.1	0.20
International	**Fuel**	**SO_2**	**CO_2**	**CO**	**NO_x**	**NM-VOC**	**CH_4**	**N_2O**	**$PM_{2.5}$**
LTO (kg/LTO) – Average fleet (B767)	1617	1.6	5094	6.1	26.0	0.2	0.0	0.2	0.15
- LTO (kg/LTO)–Average fleet (short distance, B737-400)	825	0.8	2600	11.8	8.3	0.5	0.1	0.1	0.07
- LTO (kg/LTO)–Average fleet (long distance, B747-400)	3400	3.4	10717	19.5	56.6	1.7	0.2	0.3	0.32
LTO (kg/LTO) – Old fleet (DC10)	2400	2.4	7500	61.6	41.7	20.5	2.3	0.2	0.32
- LTO (kg/LTO) – Old fleet (short distance, B737-100)	920	0.9	2900	4.8	8.0	0.5	0.1	0.1	0.10
- LTO (kg/LTO) – Old fleet (long distance, B747-100)	3400	3.4	10754	78.2	55.9	33.6	3.7	0.3	0.47
Cruise (kg/tonne)- Average fleet (B767)	-	1.0	3150	1.1	12.8	0.5	0.0	0.1	0.20
Cruise (kg/tonne)- Old fleet (DC10)	-	1.0	3150	1.0	17.6	0.8	0.0	0.1	0.20

*Sulphur content of the fuel is assumed to be 0.05% S (by mass) for both LTO and cruise activities. ** Assuming a cruise distance of 500 nm for short distance flights and 3000 nm for long distance flights. Source: Derived from ANCAT/EC2 1998, Falk 1999, and MEET 1999 and IPCC 1998.$PM_{2.5}$ data (= PM_{10} emissions) Source: inferred from smoke data from ICAO database (ICAO 2006) using the methodology described in DfT PSDH (UK-DfT 2006).

Table-6
Assumptions considered for emisssion calculation

Fuel consumption of aircrafts	**Units**	**Value**	**Emission factors (Tier-1)**	**Units**	**Value**
Total fuel consumption of Airbus	Kh/hr	1300	CO_2	CO_2e	19.5
Total fuel consumption of Boeing	Kh/hr	1200	NO_x	CO_2e	10.5
Total fuel consumption of ATR	Kh/hr	600	N_2O	CO_2e	2
Total fuel consumption of CRJ2	Kh/hr	1628	CH_4	CO_2e	0.5
Average fuel consumption	Kh/hr	1250	Radiative Force Index (RFI)		2.5

(Source: IPCC 1998 for emission factors and discussions with airlines for fuel consumption of aircrafts)

Table- 7
Emissions for the route (both direct and via flights)

Route	No. of flights	Emissions (TCO_2 e)			
		CO_2	NO_x	N_2O	CH_4
BOM-DEL (Direct flights) (2005-09)	77357	4713925	2538267	483479	120870
BOM-X-DEL (via flights) (2007-09)	16123	908909	489413	93221	23305
Average emissions		61	33	6	2

(Source: calculated by the authors)

Results and Discussion

The present section deals with the existing aviation emission strategies internationally and proposed technological strategies which proved to have a potential of emission reduction in a great deal. There would be several mitigation measures for aviation emissions, including changes in air craft and engine technology, fuel, operational practices, and regulatory and economic measures[4]. These could be implemented either singly or in combination by the public and/or private sector. Further proposals are made with respective to technological options for India taking the case of Delhi-Mumbai route.

Existing Instruments for Mitigation measures: Aircraft and Engine Technology Options: According to International Aviation Transport Association (IATA) technology advances have substantially reduced most emissions per passenger-km. However, there is potential for further improvements (Ex: Environment friendly engine, raft fan, Open rotor). Any technological change may involve a balance among a range of environmental impacts. Assuming that the goals can be achieved, the transfer of this technology to significant numbers of newly produced aircraft will take longer—typically a decade[20]. Research programmes addressing NOx emissions from supersonic aircraft are also in progress[21].

Fuel Options: There would not appear to be any practical alternatives to kerosene-based fuels for commercial jet aircraft for the next several decades[20]. Reducing sulfur content of kerosene will reduce SOx emissions and sulfate particle formation. Jet aircraft require fuel with a high energy density, especially for long-haul flights. Other fuel options, such as hydrogen, may be viable in the long term.

Operational options: Improvements in air traffic management (ATM) and other operational procedures could reduce aviation fuel burn by between 8 and 18%[22]. The large majority (6 to 12%) of these reductions comes from ATM improvements which it is anticipated will be fully implemented in the next 20 years[22]. All engine emissions will be reduced as a consequence

Regulatory, Economic, and Other Options: Although improvements in aircraft and engine technology and in the efficiency of the air traffic system will bring environmental benefits, these will not fully offset the effects of the increased emissions resulting from the projected growth in aviation[23]. Policy options to reduce emissions further include more stringent aircraft engine emissions regulations, removal of subsidies and incentives that have negative environmental consequences, market-based options such as environmental levies (charges and taxes) and emissions trading, voluntary agreements, research programmes, and substitution of aviation by rail and coach[24]. Most of these options would lead to increased airline costs and fares.

The emission reduction options thus can be mainly categorized into three categories mainly; Technology Management, Operations Management and Economic Instruments. The paper deals only with the technological options. Although there are several mitigation measures through technology improvements, the following explained are some of the measures that proved to be effective and can be implemented for Indian conditions.

Proposed technological options: This section describes what can be achieved from technology improvements to reduce fuel consumption in air transport and eventually emission reductions. These technological strategies are worked out for the case study route. However, based on a further study these strategies have a potential for the entire sector in the country. For the strategies in technology, the following base emissions is considered for GHG emission reduction calculation. As the base emission calculation is in the present scenario, the same is considered for comparison with the emission reduction scenarios. The emission reduction scenario from the technological improvements is considered only for the Delhi-Mumbai air route. Table 9 presents the emissions in the route yearly.

Installation of Blended winglets: Winglets area added parts which lower drag and improve aerodynamic efficiency, thus reducing fuel burn[25]. Depending on the missions of flying, blended winglets can improve cruise fuel mileage up to 6 percent[25]. They also make aircraft more efficient by reducing drag near wing tip making it more efficient by climbing faster. Better climb performance also allows lower thrust settings, thus extending engine life and reducing maintenance costs. Lower required thrust levels extend on-wing Life. By reducing fuel consumption, winglets help lower CO_2 and NOx emissions by 5%.

Dimensions- Each winglet is 8 feet long and 4 feet in width at the base, narrowing to approximately two feet at the tip.

Added wingspan - Winglets add approximately 5 feet to the airplane's total wingspan - from 112 feet 7 inches to 117 feet 2 inches.

Weight- Each winglet weighs about 132 pounds. Increased weight to the airplane for modifying wing and installing winglets is about 480 pounds.

According to a study by Air New Zealand and Boeing, it is found that by installation of blended winglets the aircraft would be 5% fuel efficient compared to the conventional wing tip.

Table-8
Derived Emission calculation for the years (Delhi-Mumbai only)

	2005-06	2006-07	2007-08	2008-09
Total flights	13592	19393	12821	29436
Total amount of fuel (kg)	24634723	35149295	23237545	53351973
Actual cost of fuel (US$)	16776246509	26361970982	2149728795	36332693759
Actual cost of fuel (Million US$)	16776	26362	21495	36333
Total CO_2 emissions(T)	1200943	1713528	1132830	2600909
Total NO_x emissions (T)	440376471	692001738	564236631	953733211

(source: calculated by the authors)

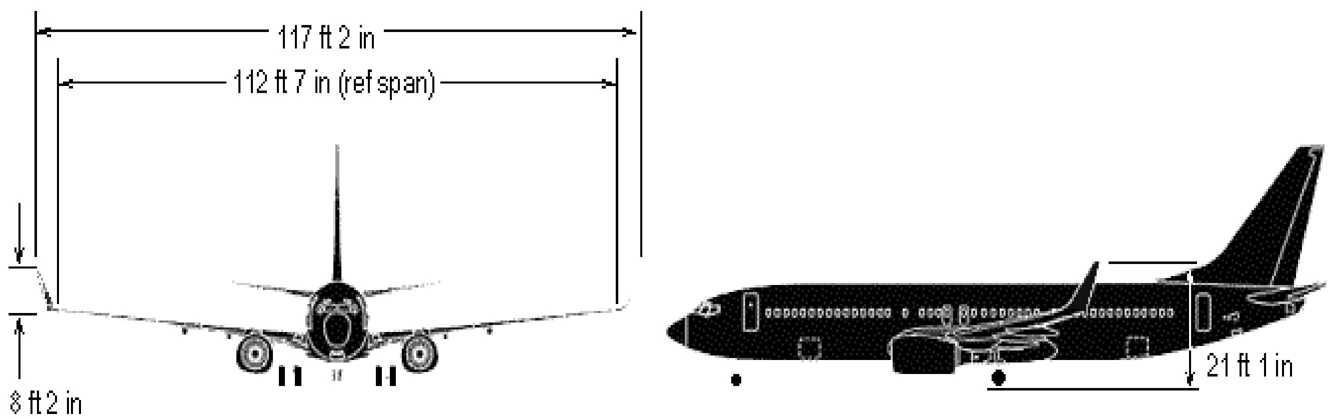

Figure-2
Dimensions of the winglets (source: Liebeck 2004)

Table- 9
Emission reduction by installation of winglets

	2005-06	2006-07	2007-08	2008-09
Fuel efficiency by installation of winglets (kg)	23402987	33391830	22075667	50684375
Cost of installation of winglets (US$)	750000			
Reduction of cost of fuel after installation of winglets (million US$)	15937	25044	20420	34516
CO_2 emission reduction potential (T)	1140896	1627852	1076189	2470863
NOx emission reduction potential (T)	614328	876536	579486	1330465
Total CO_2 emission reduction (T)	60047	85676	56642	130045
Total NOx emission reduction (T)	32333	46133	30499	70024
Total cost of fuel saving (million US$)	839	1318	1075	1817

Cost of Total Fuel saved for the study period (Million US$)	5048
Total CERs generated(T)	332410
@' price of 13$/T US$ generated	43,16,350
@' price of 13$/T Million US$ generated	4

Note: The CER price of 13$/T is taken as of the January,2009 price.
(Source: calculated by authors based on Liebeck 2004 for winglets information)

Although the installation of winglets take high price for the initial year, the payback period would be less than 3years as the fuel saving is high. Also the CERs value would also be high.

Installation of dryers: Electronically powered dryers mounted in the space above the ceiling or under the floor, reduce moisture trapped in insulation between the air craft outer skin and cabin lining[26]. They typically remove around 200 kg of water from each aircraft having a potential of saving 20, 00,000 kg fuel a year[26]. They also have potential for reducing corrosion and improve engine and aircraft life.

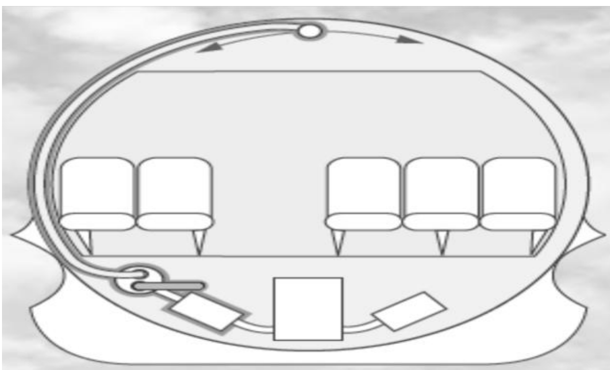

Figure- 3
Typical air dryers

Weight- Weight of the complete system is less than 32 kg. Dryers can save about 5, 00,000 US gallons of fuel a year reducing CO_2 by 4700T/year. Air New Zealand saved 9.7 million US gallons of fuel and reduced CO_2 by 90,963T. With this it is saving around $43 million each year. So accordingly, by installation of dryers around 2312kg of fuel can be saved for 42 aircraft.

Installation of Air units: Mobile ground based air units are used for cabin venting, cooling and heating on parked aircraft[27]. The diesel powered pre-conditioned air units along with ground-based electric power replace the use of aircraft's on auxiliary power unit (APU) which runs on jet fuel[27]. These ground based units burn about 10 times less fuel than APU's further by reducing the cost of fuel and eventually the GHG emissions.

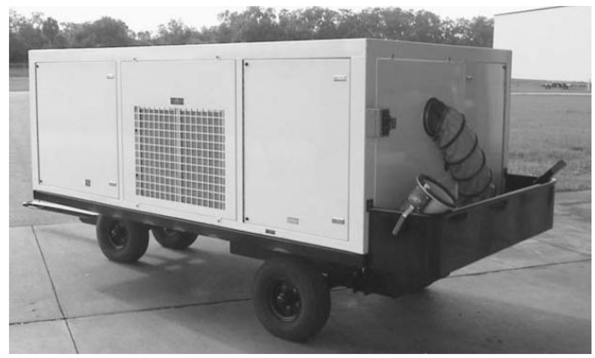

Figure-4
Typical ground based air units

Dimensions- Length: 384 cm width: 183cm Height: 194cm Weight: 2,540kg

Endurance- Approximately 8 hours of continuous operations for full fuel tank. The other features by installation are; Easy to operate, Economical and Durable. For example, at Sea-Tac airport at 19 gates, the airport could save 1.1 million gallons of fuel per year saving $ 2.6 million annually. The emissions were reduced by 24 million pounds a year.

Table-10
Emission reduction by installation of dryers

	2005-06	2006-07	2007-08	2008-09
Fuel efficiency by installation of dryers (kg)	23886540	34401111	22489361	52603790
Reduction of cost of fuel after installation of dryers (million US$)	16267	25801	20803	35823
CO_2 emission reduction potential (T)	1164469	1677054	1096356	2564435
NO_x emission reduction potential (T)	627022	903029	590346	1380849
Total CO_2 emission reduction (T)	36474	36474	36474	36474
Total NO_x emission reduction (T)	19640	19640	19640	19640
Total cost of fuel saving (million US$)	509.5	561.1	692.1	509.5

Cost of Total Fuel saved for study period (MillionUS$)	2272
Total CERs generated(T)	145896
@' price of 13$/T US$ generated	18,94,457
@' price of 13$/T MillionUS$ generated	1.9

Note: The CER price of 13$/T is taken as of the January,2009 price.
(Source: calculated by authors based on Blanchfield 2007 for dryers information)

Table-11
Emission reduction by using air units

	2005-06	2006-07	2007-08	2008-09
Fuel efficiency by installation of air units (kg)	22171251	31634365	20913790	48016776
Reduction of cost of fuel after installation of air units (million US$)	15099	23726	19345	32699
CO_2 emission reduction potential (T)	1080848	1542175	1019547	2340818
NOx emission reduction potential (T)	581995	830402	548987	1260440
Total CO_2 emission reduction (T)	120094	171353	113283	260091
Total NO_x emission reduction (T)	32333	46133	30499	70024
Total cost of fuel saving (million US$)	1677.6	2636.2	2149.5	3633.3

Cost of Total Fuel saved (Million US$)	10,097
Total CERs generated(T)	664821
@' price of 13$/T US$ generated	86,32,701
@' price of 13$/T Million US$ generated	9

Note: The CER price of 13$/T is taken as of the January, 2009 price.
(Source: calculated by authors based on Hodgkinson 2007)

Conclusion

Most innovations in aviation were probably made in the first 50 years of its development, with the difference between the Wright Flyer (first flight in 1903) and the Boeing 707 (first flight in 1954) being much larger than between the Boeing 707 and the Airbus A380 (first flight in 2005)[28]. Current technology on the market for the civil aviation sector is in effect mature. The above discussed technologies though has a signficant amount of emission reduction found to be expensive for the airline industries. Thus there is a need for technological R and D to be developed for improved technological creation. Furthermore, the strong increase of cost and risk involved with revolutionary innovative new aircraft programmes have become prohibitive factors. Without financial or new regulatory or economic pressures to innovate, only incremental developments are likely in the near and medium future. Though modern aircrafts achieved fuel efficiencies of 3.5 litres per 100 passenger-kilometers, A380 and B787 are aiming for 3 litres per 100 passenger-kilometers[27]. However, most airlines already use advanced technology and processes, making additional fuel efficiency improvement more difficult. IATA has a voluntary goal to improve their fuel efficiency by 10% between 2000 and 2010, and are planning to set more ambitious targets[5].

But not many steps are taken in India to mitigate these emissions except a few. India is a signatory member of ICAO, as a member of the ICAO it need to mitigate the emissions and follow the international aviation. IATA as its priorities in 2008 proposed to achieve reduction of atleast 6million tonnes of CO_2 from operations and infrastructure[5]. IATA has also set that there should be no growth in the Aviation climate change emissions from 2020 and that it should be carbon free within 50 years by now. A voluntary agreement (MoU) is signed between the Industry and the Government of India for mitigating the emission in 2006 but no formal study has come till now[9]. Indian Institute of Science (IISC) and Hindustan Aeronautics Limited (HAL) in a joint work are working towards calculating the emissions from the civil Aviation sector[14]. These are the few studies that are going on this sector which are comparatively less. The government should propose to work with industry to develop effective technologies along with policy framework to respond to climate change with a focus on the following elements: Finalising the design of the policy mechanism for emission reduction targets, including application of the scheme to domestic aviation; consideration of means to support the uptake of technical, operational and other measures to constrain the net carbon footprint of aviation, which complement the actions taken in the offset mechanism and ETS; propose new initiatives of Air-services to work with airlines on the implementation of fuel saving measures including flexible flight tracks, improving aircraft air traffic control sequencing and introducing continuous descent approaches; working through ICAO on a practical approach to address international aviation emissions; working towards a better understanding of aviation emissions and their impact, including through the development of tools for comprehensive carbon monitoring and foot printing; and Assisting all stakeholders in the region to respond to the need to reduce their carbon footprint through bilateral agreements through involvement with APEC and ICAO.

Acknowledgment

We acknowledge the constant support, encouragement from our parents and friends to bring out this paper successful. We also thank Dr. Dipak Sharma for his reviews and the support provided to bring out this paper successfully.

Abbreviations

Routes	Full form of the route	Routes	Full form of the route
AGR	AGRA	IXD	ALLAHABAD
AMD	AHMEDABAD	IXJ	JAMMU
ATQ	AMRITSAR	IXL	LEH
BBI	BHUBANESWAR	IXP	PATHANKOT
BDQ	VADODARA	IXR	RANCHI
BHO	BHOPAL	IXU	AURANGABAD
BHO/IDR	BHOPAL – INDORE	IXZ	PORT BLAIR
BLR	BANGALORE	JAI	JAIPUR
BOM	MUMBAI	JDH	JODHPUR-
CCJ	KOZHIKODE	JLR	JABALPUR
COK	COCHIN	KUU	KULLU
CJB	COIMBATORE	LKO	LUCKNOW
CCU	CALCUTTA	MAA	CHENNAI
DED	DEHRADUN	NAG	NAGPUR
DHM	DHARAMSALA	PAT	PATNA
GOI	GOA	PNQ	PUNE
GAU	GAUHATI	RPR	RAIPUR
GOP	GORAKHPUR	SLV	SHIMLA
GWL	GWALIOR	STV	SURAT
HJR	KHAJURAHO	SXR	SRINAGAR
HYD	HYDERABAD	TRV	THIRUVANANTHAPURAM
IDR	INDORE	TIR	TIRUPATI
IMF	IMPHAL	UDR	UDAIPUR
IXA	AGARTALA	UDR	UDAIPUR-JAIPUR
IXB	BAGDOGRA	VNS	VARANSI
IXC	CHANDIGARH	VTZ	VISHAKHAPATNAM

References

1. IATA, State of the Air Transport Industry—64th Annual General Meeting. Montreal, June **(2007)**

2. Yenneti K., Dissertation on Strategies for Reduction and Controlling GHG Emissions from Civil Aviation Sector in India-A Case of Delhi-Mumbai Air route, CEPT University, Ahmedabad, India **(2009)**

3. ICAO, Aviation Environment Outlook, available at http://www.icao.org, last accessed on August 2008 **(2007)**

4. IPCC, Aviation and the Global Atmosphere: A Special Report of IPCC Working Groups I and III. by J.E. Penner, David H. Lister, David J. Griggs, David J. Dokken, and Mack McFarland (eds), Cambridge University Press. Cambridge. United Kingdom and New York. NY, USA. June 1999, 373 **(1999)**

5. IATA. Building a Greener Future, available at http://www.iata.org , last accessed on 15 September 2008, **(2008)**

6. Aviation Environment Federation, Aviation and Global Climate Change, AEF, London **(2000)**

7. IPCC, Changes in Atmospheric Constituents and in Radiative Forcing, in S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds), Climate Change 2007: The Physical Science Basis—Contribution of Working Group I to IPCC Fourth Assessment Report, Cambridge University Press, UK and New York, 129 **(2007)**

8. Herdman A., Orient Aviation, Greener Skies Conference, Aviation and the Post-2012 Climate Change Policy Regime (Pp. 1-27). Hongkong: Association of Asia Pacific Airlines. Available at www.aapairlines.org, **(2008)**

9. Lee S. and European D., Climate Change Program. Impacts of Aviation On Climate: Why A Diffrent Appraoch May Be Necessary For Non-CO2 Impacts (Pp. 2-4). Manchester: Manchester Metropolitan University **(2006)**

10. Aviation Environment federation, Aviation and global climate change, London AEF **(2000)**

11. Jacobs Consultancy Canada Inc. Canadian Aviation and Greenhouse Gases–Literature Review, Jacobs Consultancy, Ontario, **(2007)**

12. ICAO. Proposals for Strategies and Measures to Achieve Emissions Reduction's, 1033 Civil Aviation Sector in India, Montreal. 7–9 October 2009, **(2009)**

13. Stough K.B., Air Transport Networks-Theory & Policy Implications. Northampton: Edward Elgar Publishing Ltd. **(2000)**

14. CII & NCAER. The future of civil aviation in India-Structure, policy, regulation and infrastructure. New Delhi: IDFC. **(2000)**

15. Senguttuvan P., Global Trends in Air Transport: Traffic, Market Access & Challenges, Delhi International Airport Private Limited. Indira Gandhi International Airport. New Delhi, India, **(2008)**

16. India Infrastructure research, Aviation in India – 2008, Delhi: India infratsructure Publishing Pvt. Ltd. **(2008)**

17. Dutta A.P., Suspended Animation. Down to Earth, 34-36 **(2008)**

18. Alarming Rise In Fog And Pollution Causing A Fall In Maximum Temperature Over Delhi, Journal of Current Science, R.K. Jenamani, IMD Center. Delhi Airport, **(2007)**

19. Kim B., Fleming G., Balasubramanian S., Malwitz A., Lee J., Ruggiero J., Waitz I., Klima K., Stouffer V., Long D., Kostiuk P., Locke M., Holsclaw C., Morales A., McQueen E. and Gillett W., SAGE: The System for Assessing Aviation's Global Emissions. FAA-EE-2005-01, USA, **(2005)**

20. Karagozian A., Dahm W., Glasgow E., Howe R. and Kroo I., Technology Options for Improved Air Vehicle Fuel Efficiency: Executive Summary and Annotated Brief. United States Air Force Scientific Advisory Board, Washington DC, **(2006)**

21. Director of Federal Register, Control of Air Pollution from Aircraft and Aircraft Engines; Emission Standards and Test Procedures, USA: US EPA, available at http:/www.epa.gov/edocket/ **(2005)**

22. Greener by Design, Mitigating the Environmental Impact of Aviation: Opportunities and Priorities, Report of the Greener by Design Science and Technology Sub-Group, Royal Aeronautical Society, United Kingdom, **(2005)**

23. Hamilton K., Stewart E. and Waage S., Off setting Emissions. A Business Brief on the Voluntary Carbon Market, Ecosystem Market Place and Business for Social Responsibility **(2006)**

24. Herdman A., Orient Aviation: Greener Skies Conference, Aviation and the Post-2012 Climate Change Policy Regime (Pp. 1-27). Hongkong: Association of Asia Pacific Airlines, Available at www.aapairlines.org, **(2008)**

25. Liebeck R.H., Design of the Blended Wing Body Subsonic Transport, Journal of Aircraft, **41(1)**, 10–25 **(2004)**

26. Blachfield J., Working Towards the Greener Skies: The Air Bus Family, France: Airbus, **(2007)**

27. Hodgkinson David, Workign A.C., Paper No. 2, Strategies For Airlines On Aircraft Emissions And Climate Change:Sustainable, Long - Term Solutions . Melbourne, Australia: The Hodgkinson Group-Aviation Advisors, **(2007)**

28. Paul Peeters, Victoria Williams, and Alexander de Haan, eds. Technical and Management Reduction Potentials. Edited by Stefan Gossling and Paul Upham, Climate Change and Aviation: Issues, Challenges and Solutions, London: Earth Scan, **(2009)**

29. Sanghi N., Government industry partnership to reduce environmental impact of aircraft emissions, New Delhi: Ministry of civil Aviation, **(2006)**