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Local and Global Environmental Effects of Aircraft Emission and Remedial Approaches

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Abstract:

As the aviation industry is growing so does its impact upon environment, although, the overall contribution in air pollution from air transport is much less than other transportation modes, emission from aircrafts are of great concern due to sensitive regions and higher levels of the atmosphere and the effects from aircraft exhaust emissions are seen as a direct contribution to the mechanisms of climate change. The environmental and health effects have wide ranging implications at the local, regional, and global levels. The present study briefly reviews the various aspects of emission caused by aviation industries and there short and long term effects on local and global environment. Few approaches requiring technological amendments and/ or advancements to curve the release of harmful gases and particulates in the atmosphere by aviation industries has also been briefly discussed.

Keywords

CO_2, No_x, Particulates, Water vapor, Fuel efficiency, Airframe modifications, Engine Technology

1. Introduction

The aircraft engines consume hydrocarbon as fuel and produce carbon dioxide, carbon monoxide, oxides of sulfur, oxides of nitrogen, water vapors, unburned hydrocarbons and other traced particulates. Consumption of fuel in aircraft is relatively smaller than the consumption of fuel in automobile industry and power generation sector but study of emissions from aircraft is of great concern as they are deposited at higher altitude where they can affect the environment entirely different than the other modes of emissions. Also, study of aircraft emission on or near to ground is very important because they are concentrated in one specific location of airport and there continuous emission can degrade the quality of air.

GLOBE-Net (2007) reported that worldwide passenger air travel is increasing by 5% annually, a faster rate of growth than any other travel mode and greenhouse gases emissions from international air travel jumped by almost 70% between 1990 and 2002. In China, air travel is growing by around 12% per year. Further, as more people in countries are able to afford airline tickets, worldwide air tourism travel is bound to increase. Most experts believe that air travel could double within fifteen years if current trends persist.

By 2050, the Intergovernmental Panel on Climate Change (IPCC) believes that aircraft could account for up to 15% of the global warming impact from all human activities. About 15,000 aircraft service nearly 10,000 airports and operate over routes approximately 15 million km in total length. Moreover 2.2 billion passengers flew on the world's airlines for vacation and business travel and well in excess of a third of the value of the worlds manufactured exports were transported by air (Penner et.al., 2001).

Air Travel is the world's fastest growing source of greenhouse gases like carbon dioxide, which cause climate change. Globally the world's commercial jet aircraft fleet generates more than 700 million tons of carbon dioxide (CO_2), the world's major greenhouse gas per year. One person flying a return trip between Europe and New York generates between 1.5 and 2 tons of CO_2. This is approximately the amount a European generates at home through heating and electricity in one year (GreenSkies).

Earth is surrounded by a blanket of greenhouse gases, which keeps the surface of the earth at the right temperature to sustain life. As we release CO_2 and other greenhouse gases, this blanket gets thicker. The result is that the Earth's atmosphere is getting warmer and our climate is beginning to change. Increment in CO_2 levels causes increase in overall temperature and Ocean acidification. Increments in temperature lead to heightened evaporation of oceans which further leads to an increase in global averaged precipitation causing more extreme storms, floods and hurricanes. Accumulation of CO_2 on ocean results destruction of food sources, in turn decreasing biodiversity levels. The IPCC stated that aviation is likely responsible for 3.5% of climate change and could grow to 5% if no action is taken by 2050.

IATA, 2008 stated that aviation industry generates 32 million jobs worldwide and contributes nearly 8% to world gross domestic product. It goes without saying that air transportation has a big economic footprint. Therefore, even though aircrafts are becoming more efficient but the fact remains that people are driving and flying more than ever. This increases the miles traveled and transport-related emissions. Also, aviation plays a vital role in society: it generates jobs and supports commercial and private travel. However one of the negative impacts of travel is its environmental impact associated with local noise and air pollution. Over the years, new technologies have been introduced to reduce the amount of emissions but with the technologies the demand of transportation is also increasing and these advances have not kept pace with the increased demand for air transportation.

The intent of this study is to review the challenges facing the aviation industry, its impact on environment and what is being done about reducing its environmental footprint.

2. Contribution of Aviation Industry in Emission

Over the years, emissions from road transport and civil aviation grew by 17% and 21% respectively; while emissions from domestic maritime transport (maritime) presented a 1% growth over the period 1990-2011 as shown in Figure 1.

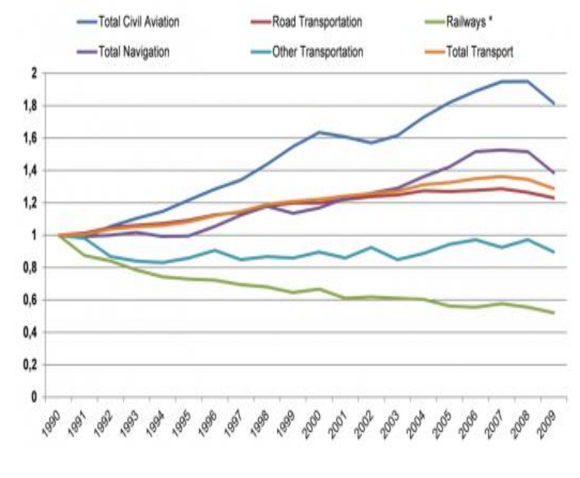

Figure 1. GHG emission trends of various transport modes

The amount of CO_2 emitted per passenger and per kilometer for different modes of transport is highly dependent on the type of vehicle as well as on the load factor. Typical CO_2 emissions of air transport are in the range of 30 to 110g per passenger/km which are comparable to passengers travelling by car or light truck whereas CO_2 emissions per passenger/km from bus or coach transport are significantly lower; usually less than 20g per passenger/km. Kirby (2008) stated consumption of more goods demands a lot of energy, getting from one place to another does too. Transportation as an industry consumes about 20% of the global energy supply, 80% of which comes from fossil fuels. He stated that 80% of transport-related greenhouse gas emissions come from road transport. 7% is related to sea transport and 0.5% is attributed to rail and air transportation is the second largest with a 13% share of transport-related greenhouse gas emissions. In contrast, emissions from railway transportation fell by 46%.

A breakdown by sector shows that road transport has dominated emissions from this sector throughout this period which is 94% as shown in Figure 2.

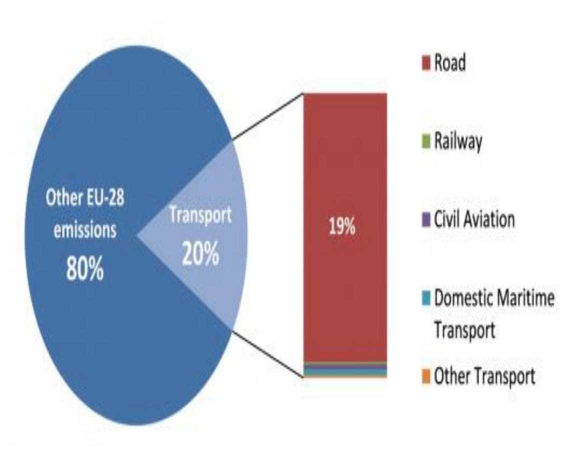

Figure 2. Breakdown by emission sectors

ICAO stated that by 2020, global international aviation emissions are projected to be around 70% higher than in 2005 even if fuel efficiency improves by 2% per year and by 2050 they could grow by a rate of 300%-700%. Aviation's total global warming impacts are more than double those estimated from its CO_2 emissions or equivalent to roughly 5% of total radiative forcing from CO_2. Nitrogen oxide emissions and aviation's impacts on clouds add significantly to the warming effect of carbon dioxide.

In 2013, ICAO members adopted a goal of "carbon neutral growth from 2020" – i.e. capping the net emissions of international flights at 2020 levels but without new policies, aviation emissions could compromise the goal of the agreement to limit the increase in global temperatures to 1.5–2 degrees Celsius above pre-industrial levels.

Environment impact is also associated with the altitude at which aircraft is flying and emitting

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carbon dioxide, higher altitude cause greater damage to ozone layer and most of the flights fly at an altitude between 9-12km. Federal Aviation Administration (2005) showed the distribution of total fuel burnt and emissions by 1km altitudes for the year 2000 (Figure 3)

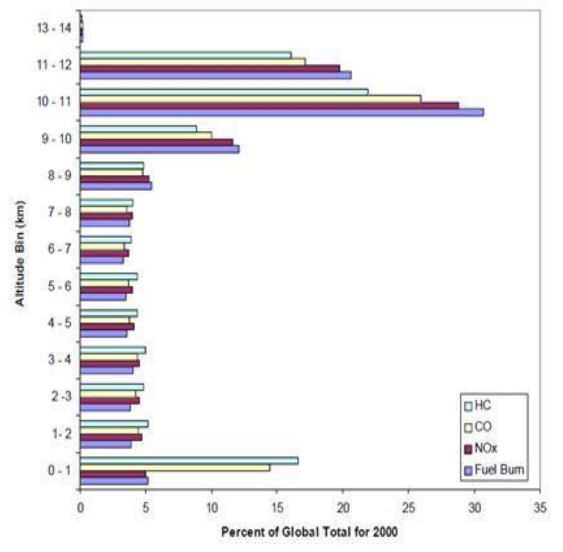

Figure 3. Altitude distribution of fuel burn and emissions

3. Impact of aviation emission on climate and health

Lehrer (2001) stated that during flight, aircraft engines emit carbon dioxide and water vapor (7%-8%), oxides of nitrogen, oxides of sulfur, hydrocarbons and particles (.03-.05%) and rest are atmospheric oxygen and nitrogen (91.5%-92.5%). These emissions alter the chemical composition of the atmosphere in a variety of ways, both directly and indirectly. While much of the CO_2 is absorbed on Earth in plants and the ocean surface, a huge amount goes into the atmosphere where it and other gases create a kind of lid around the globe which is called greenhouse effect. Heat that would normally escape into space is thus reflected back to Earth, raising global temperatures.

The major concerns with emissions are the climate change, alteration of the concentration of ozone and the effects on human health due to air pollution.

3.1 Impact on health

A journal of Environmental Science and Technology stated that cruise altitude of about 35,000 feet release pollutants that cause about 8,000 deaths globally per year. People in areas where flights are very frequent are affected by varied diseases due to presence of more emission.

Carbon monoxide: causes headaches, nervous system impairments, and nausea.

Nitrogen oxides: can damage immune system cells and capillaries, aggravates asthma, increase susceptibility to infection, critical health of the heart, acute respiratory problems. Ozone increases susceptibility to infection, reduces lung function, and aggravate allergy.

Particulate matter: causes respiratory problems, colds, decreased lung capacity and emphysema. Long term exposure can also be responsible for heart and lung disease and cancer. Particulates, however, may contribute to the formation of photochemical smog and may be a health hazard. While solid carbon is relatively inert, it tends to absorb unburned hydrocarbons, which are potentially carcinogenic and might be absorbed in the lungs. Some particulates might also be able to block some air passages in the lungs.

Sulfur dioxide: causes chronic bronchitis, breathing difficulties, lung irritation, preterm birth in humans and possible death when mixed with particulate matter.

Water vapors: aerosol droplets can contain combustion by-products in a much more concentrated form than the exhaust gases from which they are formed which may pose a health risk if they are ingested into the lungs and absorbed into the body.

Outdoor air pollution caused more than 3 million premature deaths in 2010 with elderly people and children most vulnerable. The OECD (The Organization for Economic Co-operation and Development) projections imply a doubling or even tripling, of premature deaths from dirty air or one premature death every four or five seconds by 2060.

The biggest rises in mortality rates from air pollution are forecasted in India, China, Korea and Central Asian countries like Uzbekistan where rising populations and congested cities mean more people are exposed to powerplant emissions and traffic

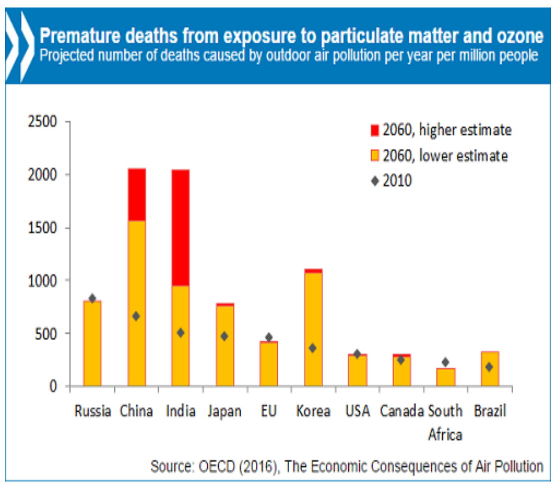

Figure 4. Projected numbers of deaths caused by outdoor pollution

exhaust as shown in Figure 4.

Premature death rates are forecasted to be up to three times higher in 2060 than in 2010 in China and up to four times higher in India. Death rates are seen stabilizing in the United States and falling in much of Western Europe, thanks in part to efforts to move to cleaner energy and transport.

Figure 5 shows projected GDP losses will be biggest in China, Russia, India, Korea and countries in Eastern Europe and the Caspian region as health costs and lower labor productivity hit output. Poor air quality will hit China's economy harder than India's because differences in household savings rates and demographics mean the knock-on effects of lower productivity and increased health spending on the rest of the Chinese economy will be much larger.

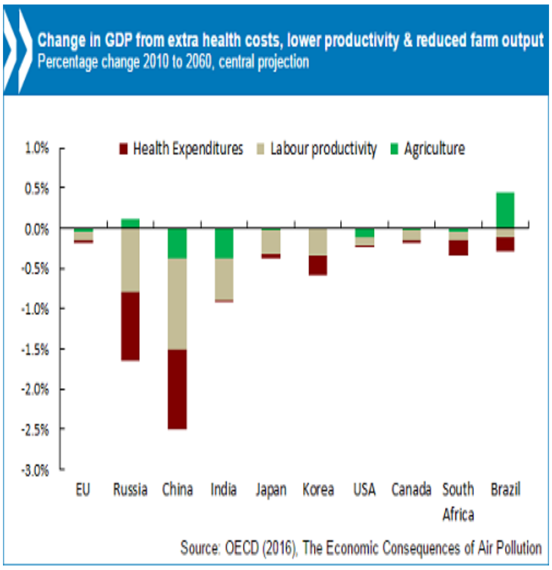

Figure 5. Change in GDP due to outdoor pollution

3.2 Impact on Environmental

Pollution caused by aviation harms not only climate but it affects aviation industry itself. High temperature rise caused storm on ground which damages the aircraft controls and equipment during take-off and landing that reduces the frequency of flight as well as operational time. Warm climate reduces the capability of load carrying capability of aircraft and its performance. To operate in severe turbulent weather new sensing, communication and navigation technology is required to maintain the safety of passengers and crew.

Emissions of nitrous oxides (NO_x) and the formation of condensation trails (contrails) from water vapor at near stratospheric levels where commercial jets fly means the actual impact on global warming is much higher - possibly as much as ten percent (GLOBE-Net, 2007).

3.2.1 Effects of Carbon Dioxide

Carbon Dioxide is a greenhouse gas which is by-product of the combustion of fossil fuels due to incomplete combustion. Increased amount of CO2 causes melting ice caps and rising ocean levels and it remains in atmosphere for 100 to 200 years which traps additional heat and causes the average temperature on Earth to rise. Results are increased frequency, duration and intensity of other extreme weather events (floods, heat waves, droughts and tornadoes). Figure 6 and Figure 7 represents increase in CO_2 and change in global temperature respectively.

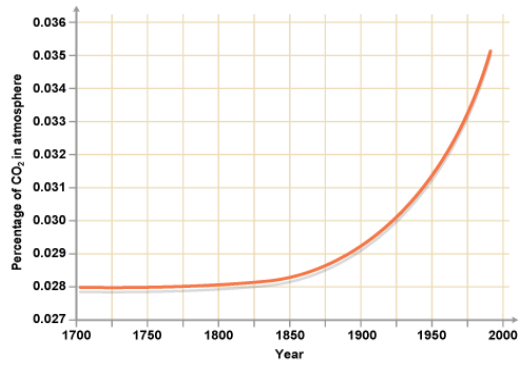

Figure 6. Increase of carbon dioxide

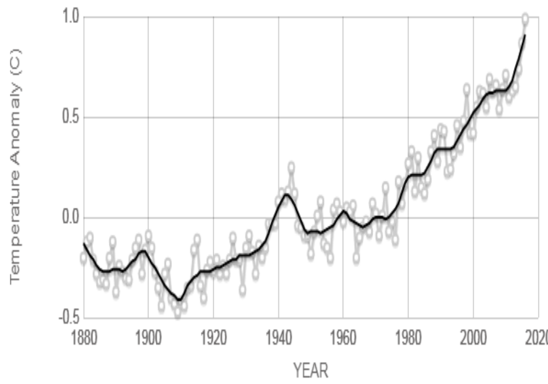

Figure 7. Increase of global average temperature.

3.2.2 Effects of Water Vapor, Contrails, and Cirrus Clouds

Water vapor is a greenhouse gas and the emission of water vapor leads to formation of contrails and cirrus clouds in the upper troposphere or lower stratosphere. The phenomenon occurs when aircraft fly above 25,000 feet where the air temperature is around minus 30°C. This causes water vapors emitted by the engines to crystallize and form the familiar white streaks across the sky known as contrails. These can be short-lived but if there is already a significant amount of moisture in the atmosphere they can linger for hours, as the excess water vapors from the engines tips the surrounding air past its saturation point. This acts as a catalyst to speed up the natural process of cloud formation and can cover up to an astonishing 20,000 square miles of sky. The level of moisture in the air at high altitudes is unrelated to weather conditions at ground level which is why it is possible to see contrails on a clear day.

Cirrus clouds cover up to 25% of the Earth (up to 70% in the tropics) and have a net heating effect. When they are thin and translucent, the clouds efficiently absorb outgoing infrared radiation while only marginally reflecting the incoming sunlight. When cirrus clouds are 100 m thick, they reflect only around 9% of the incoming sunlight prevent almost 50% of the outgoing infrared radiation from escaping, thus raising the temperature of the atmosphere beneath the clouds by an average of 10°C .

As a result of their warming effects when relatively thin, cirrus clouds have been implicated as a potential partial cause of global warming. Scientists have speculated that global warming could cause high thin cloud cover to increase, thereby increasing temperatures and humidity. This, in turn, would increase the cirrus cloud cover, effectively creating a positive feedback circuit. A prediction of this hypothesis is that the cirrus would move higher as the temperatures rises, increasing the volume of air underneath the clouds and the amount of infrared radiation reflected back down to earth. In addition, the hypothesis suggests that the increase in temperature would tend to increase the size of the ice crystals in the cirrus cloud, possibly causing the reflection of solar radiation and the reflection of the Earth's infrared radiation to balance out. These vapor trails create clouds which, experts claim, can block out sunlight. This is the reason that our skies appeared unusually blue when the Icelandic volcano was erupting.

The effect of aviation-induced cirrus clouds is highly uncertain. They may have very little or no effect or they may affect the global radiation budget more than CO_2. The effect may also vary with latitude and season. Even if the effects of contrails and aviation-induced cirrus clouds are small when averaged globally, they may have significant climatological effects in some regions.

3.2.3 Effects of Oxides of Nitrogen (NO_x)

Nitrogen in jet fuel and air forms oxides of nitrogen at high temperatures in the combustion chamber of an aircraft. The highest levels of NO_x are produced when engine is running at the highest engine power settings. NO_x emissions in the upper troposphere increase the amount of ozone. This increase may have decreased UV radiation at the Earth’s surface by 1% at 45 degrees latitude and growth in aviation could double the effect by 2050. However, NO_x emissions in the stratosphere (which can occur with some flights during winter or at high latitudes) can reduce ozone, although the net effect of subsonic aircraft is uncertain. Assessing the effect of aircraft NO_x on ozone is complex because NO_x has a short lifetime (days to weeks), high variability, and many sources other than aviation, including lightning and mixing from lower levels of the atmosphere. NO_x emissions can also produce regional variations in ozone—ozone resulting from aircraft emissions of NO_x is concentrated in the Northern Hemisphere and along major flight routes.

3.2.4 Effects of Particulates and Aerosols

Aircraft exhaust generally consist solid particulates of carbon, sulfates, and metals. The particulates of carbon particles known as soot caused by rich fuel-air mixtures within the combustion chamber at high operating pressure typically occurs during take-off and climb-out when fuel flows and pressures are at their highest. Turbine breaks up some large soot particles and small particles comes out with exhaust gases. As the atmosphere cools aircraft exhaust, particulates, water vapors, and other constituents in the exhaust of hydrocarbon-fuelled engines can form liquid aerosols, which consist of a colloidal suspension of liquid particles in a gas. It causes visible smoke like fog if the concentration is high enough.

The atmospheric effects of soot and other particulates are uncertain. Particulates provide nuclei for the formation of liquid droplets in the atmosphere and may be involved in the formation of contrails. Soot absorbs and, to a lesser extent, scatters incoming solar radiation. If soot particles are absorbed by aerosol droplets, soot absorbs more solar radiation which could contribute to climate change. Soot also has the potential to alter the abundance of atmospheric trace constituents by facilitating chemical reactions that would not otherwise be. Particulates and aerosols can contribute to changes in atmospheric visibility and ozone on a regional scale but this has not been observed as a significant problem with regard to aircraft emissions. Visible smoke emissions are highly objectionable especially

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in and around airports but low-smoke combustors were incorporated into operational engines beginning more than 30 years ago and visible smoke is no longer an issue.

4. Approaches to Reduce Aviation Emission

As demonstrated, the aviation industry plays a vital role in the global economy and provides economic and social benefits. It is also apparent that global temperatures continue to rise while the aviation industry continues to grow. The combination of aviation growth and climate change leads us to believe that CO_2 emissions from the aviation industry are one of the many other factors impacting global warming.

Estimates of the future impact of aviation are imprecise because of uncertainties about the total amount of emissions that commercial aviation will produce in the future and the accuracy of current methods for quantifying the impact of aviation emissions. GLOBE-Net (2007) stated that with development and improvements in airframe and engine technology, better traffic management systems, improved operational efficiency and with alternative energy sources can decrease CO_2 emissions with reductions in NO_x, water vapor, and other air pollutants.

4.1 Improvements in Airframe and Engine Technology

Fogarty, 2009 stated that aviation emission can be reduced by increasing fuel efficiency. Higher fuel efficiency can be achieved by increased pressure ratio within engine but increased pressure ratio also increases nitrogen oxide content. So there must be some improved control techniques for NO_x to get better fuel efficiency at higher pressure ratio.

Improvements in Aircraft Efficiency can be achieved by replacing older, less fuel-efficient aircraft with aircraft using latest fuel efficiency technology and navigation equipment. Better fuel efficiency can be achieved with better aerodynamic shape and use of light weight material (composites) to reduce aerodynamic drag. New improved design of aircraft certainly contributes to reducing the impact on environment and also can be promoted as a fuel cost-saving measure.

IPCC stated that aircraft manufacturers should also explore the benefits of other technologies such as the use of winglets, fuselage airflow control devices and weight reductions to reduce fuel consumption. In the long term, new aircraft configurations such as a flexible wing may achieve major improvements in efficiency.

To reduce NO_x, flame temperatures at the same high power conditions have to be reduced. This can be achieved using staged combustion chamber with variable geometry that provides good performance at both high and low power settings. There are some advanced combustion chamber which can reduce NO_x as much as 60 percent below the ICAO standard but have a limited market due to their high cost and weight as compared to simpler structured combustion chamber.

4.2 Improvements in air traffic management

Efficient current flight patterns at optimized aircraft speed with less consumption of fuel reduces the impact of CO_2 emissions which is an imperative approach to reduce aircraft emission.

4.3 Improvements in Operational Efficiencies

Increased load factors, elimination of non-essential weight, limiting auxiliary power (APU) used by reducing engine idle times and by shutting down engines when taxiing can reduce APU use and fuel burn and reduce taxiing time of aircraft, etc.

4.4 Alternate Energy Solutions

Alternative energy solutions will lead to reducing greenhouse gas emissions: Biofuels, Solar Cells (Converts sunlight into electricity) and Fuel Cells (Converts hydrogen into heat & electricity without combustion, reducing the need for conventional fuels and eliminating emissions)

5. Conclusion

Aircraft exhaust emissions contribute to air-quality-related health effects as do emissions from all combustion processes which cause heightened concerns locally and globally. The potential effects of aircraft emissions on the planet's climate may pose the most serious long-term environmental consequences facing aviation. Noise and emissions will be the principal environmental constraints on NAS capacity and flexibility unless they are effectively managed and mitigated.

The aviation industry (airlines, governments, non-government organizations, suppliers, manufactures) must work together and create technology advancements that catapult the industry into the future. The innovation created must not only look at how the aviation industry can improve on their CO_2 emissions but also how it can change the CO_2 emissions landscape. Improving current practices is not good enough. The aviation industry must change the way they operate in order to reduce CO_2 emissions. Governments must get involved and work with airlines to spur innovation and remove obstacles for airlines leading the environmental movement. In order to formulate an effective policy to address the challenge of climate change, important requirements are to determine the sources and level of aviation's CO_2 emissions, identify trends and make predictions about future growth.

The effects of cirrus clouds are highly uncertain, therefore, more research is needed to adequately understand the effects of contrails and aviation-induced cirrus clouds and to determine if technology goals and programs should be established to mitigate their environmental impacts. More work is being done in this area and the aviation industry is assisting with research into the effects of contrails on climate change including putting high-altitude atmospheric testing equipment on some passenger aircraft.

Additional laboratory tests, field observations of aircraft emissions and detailed studies of the chemistry involved in ozone production are needed to be developed for a better understanding.

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