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Aviation and Global Climate Change

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***Abstract*— Emissions from aviation significantly contribute in climate change through radiation forcing. A new alternative index to measure the role of aviation in climate, the radiative forcing index (RFI), is defined as the ratio of total radiative forcing to that radiative forcing from carbon dioxide emissions alone. Different strategies are suggested for reducing the impacts of aviation emissions on global climate change. Among them, the most important factor is to reduce the contrails that it is possible with limiting cruise altitude flights. The principal emissions of aircraft includes: the greenhouse gases such as carbon dioxide, water vapor, other major emissions like nitric oxide, nitrogen dioxide , sulfur oxides, soot, aerosols and increase of cloudiness as shape of contrails and cirrus clouds. In addition to, Supersonic aircraft flights at high altitude have depleted the stratospheric ozone. Aircraft sulfur and water emissions in the stratosphere tend to deplete ozone. The nitrogen dioxide emissions from subsonic aircraft are estimated to have increased ozone concentrations at cruise altitudes in northern mid-latitudes. These increases will, on average, tend to warm up the surface temperature of the Earth. The travel industry can promote surface travel for trips of 500 kilometers or less and carry less baggage on short-haul flights. This paper is aimed to review the problems and difficulties that caused by aviation emissions. Few solutions are also discussed.**

Keywords- RF index; Aviation; emissions; climate change; Ozone

I. INTRODUCTION

Aviation is considered to have a small but significant effect on climate that will increase in both magnitude and share over time [1].

Aviation has experienced rapid expansion as the world economy has grown. Passenger traffic (expressed as revenue passenger-kilometers) has grown since 1960 at nearly 9% per year, 2.4 times the average GDP (Gross Domestic Product) growth rate. Aircraft emit gases and particles directly into the upper troposphere and lower stratosphere where they have an impact on atmospheric composition. These gases and particles alter the concentration of atmospheric greenhouse gases, including carbon dioxide (CO_2), ozone (O_3), and methane (CH_4); contrails; and May increase cirrus cloudiness-all of which contribute to climate change [2].

The climate impact of aviation is driven by long-term impacts from CO_2 emissions and shorter-term impacts from non- CO_2 emissions and effects, which include the emissions of water vapor, particles and nitrogen oxides (NO_x) [3].

The climate impacts of the gases and particles emitted and formed as a result of aviation are more difficult to quantify than the emissions; however, they can be compared to each other and to climate effects from other sectors by using the concept of radiative forcing. Because carbon dioxide has a long atmospheric residence time ($\approx$ 100 years) and so becomes well mixed throughout the atmosphere, the effects of its emissions from aircraft are indistinguishable from the same quantity of carbon dioxide emitted by any other source. The other gases (e.g., NO_x, SO_xO, water vapor) and particles have shorter atmospheric residence times and remain concentrated near flight routes, mainly in the northern mid-latitudes. These emissions can lead to radiative forcing that is regionally located near the flight routes for some components (e.g., ozone and contrails) in contrast to emissions that are globally mixed (e.g.,CO_2,CH_4). The global mean climate change is reasonably well represented by the global average radiative forcing, for example, when evaluating the contributions of aviation to the rise in globally averaged temperature. However, because some of aviation's key contributions to radiative forcing are located mainly in the northern mid-latitudes, the regional climate response may differ from that derived from a global mean radiative forcing [2].

These growth forecasts already allow for improvements that may be achieved through changes in air traffic management, other operational procedures and technological development. If these do not occur, emissions could be even higher. It examines the likely scale of emission reductions possible through improvements in technology and operations, including changes in air traffic management [4].

Choudrie et al prepared an Annual Report for submission under the Framework Convention on Climate Change. It contains national greenhouse gas emission estimates for the period 1990-2006, and the descriptions of the methods used to produce the estimates for emissions.[5].

Watterson et al describes an improved technique for estimating emissions and fuel use for civil aircraft in the UK and presents estimates of emissions (1990 to 2002 inclusive) from this technique [6].

Smith et al imply that Aviation is a growing industry. Government and the aviation industry recognize a link between aviation emissions and climate change, although there is uncertainty about the measurement of the exact effects. Given the predicted growth in the aviation sector, it seems likely that unless emissions are curbed, they will cancel out efforts made to reduce emissions in other sectors [7]. The last major international assessment of these impacts was made by the IPCC (Intergovernmental Panel on Climate

Change) in 1999. Aviation draw a complicated image on climate change, some of emission cause cooling and some other cause warming at atmosphere. At this paper the different impacts of aviation emission on climate change are studied.

II. Radiative Forcing

The earth absorbs solar radiation and reflects this energy in long waves form to space by atmosphere and oceans. Averagely the solar energy that radiate from sun to the earth is balanced with upward terrestrial radiation on the earth.

Forcing changes the balance between incoming sunlight and outgoing radiation at the top of the atmosphere, causing the planet to lose or gain energy. Human activities release greenhouse gases into the atmosphere. The atmospheric concentrations of carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, and tropospheric ozone have all increased over the past century. These rising levels of greenhouse gases are expected to cause climate change. By absorbing infrared radiation, these gases change the natural flow of energy through the climate system. The climate must somehow adjust to this "thickening blanket" of greenhouse gases to maintain the balance between energy arriving from the sun and energy escaping back into space. Any human-induced effect on climate, however, is superimposed on natural climate variability resulting from climate fluctuations (e.g., El Niño) and external causes such as solar variability and volcanic eruptions. The best estimate of the radiative forcing in 1992 by aircraft is about 3.5% of the total radiative forcing by all anthropogenic activities. The RFI has been used to quantify non- CO_2 warming effects of air travel. RFI is the ratio of total radiative forcing (RF) of all green house gases to RF from CO_2 emissions alone for aircraft emissions [2].

$$RFI = RF\ Total / RF\ Co_2 \qquad (1)$$

This implies that aviation is responsible for a relatively small percentage of climate change [4].

Radiative forcing is seen as a useful measure since models have shown that it is approximately proportional to the change in globally averaged surface temperatures [8].

The climate impacts of different anthropogenic emissions can be compared using the concept of radiative forcing. The best estimate of the radiative forcing in 1992 by aircraft is 0.05 Wm^{-2} or about 3.5% of the total radiative forcing by all anthropogenic activities. For the reference scenario (Fa1), the radiative forcing by aircraft in 2050 is 0.19 Wm^{-2} or 5% of the radiative forcing in the mid-range IS92a scenario [2].

Fig.1 show the globally and annually averaged radiative forcing from subsonic aircraft emissions in 1992 (Fig.1a) and in 2050 (Fig.1b) for scenario Fa1. The scale in Fig.1b is greater than the scale in Fig.1 a by about a factor of 4. The bars indicate the best estimate of forcing while the line associated with each bar is a two-thirds uncertainty range. Radiative forcing may be defined as a measure of the importance of perturbations on the planetary radiation balance and is measured in Wm^{-2}. A main reason for its use is that there is an approximately linear relationship between the change in global mean radiative forcing (ΔF) and the global mean surface temperature change (ΔT_s):

(2)

Where λ is the climate sensitivity parameter [K(WM^{-2})$^{-1}$] Positive radiative forcing values imply warming, and negative, cooling [9].

Table1 shows the global mean net radiative forcing of the three components derived from ECHAM4, CHEM, ATTILA (contrails, ozone and water vapor) for the 2000 base case and the various altitude shift scenarios.

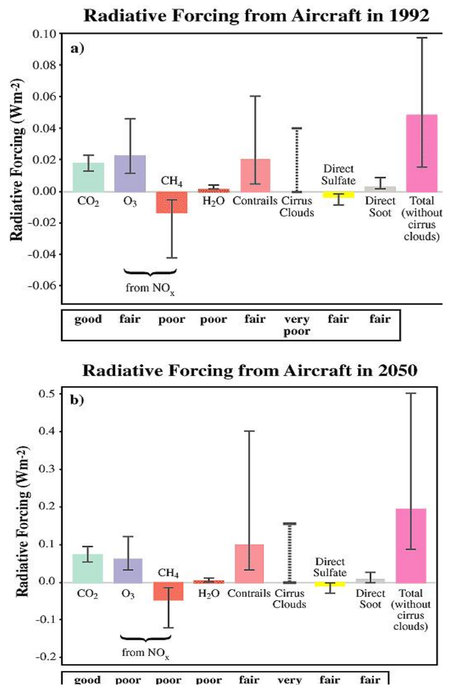

Figure 1. Estimates of the globally and annually averaged radiative forcing (Wm^{-2}): (a) from subsonic aircraft emissions in 1992 ;(b) in 2050 for scenario Fa1. (IPCC,1999)

As usual, ozone radiative forcing makes the largest contribution [10].

III. Emissions of aircraft engine

Aviation's contribution to climate change is now a topic of considerable interest [11]. This paper summarizes some key facts on aviation emissions and highlights some policy implications.

A. Carbon Dioxide

Emissions of carbon dioxide by aircraft were 0.14 Gt C/year in 1992. This is about 2% of total anthropogenic carbon dioxide emissions in 1992 or about 13% of carbon dioxide emissions from all transportation sources. The range of scenarios considered here projects that aircraft emissions of carbon dioxide will continue to grow and by 2050 will be 0.23 to 1.45 Gt C/year [2].

Bows et al have studied about emission of aviation and climate change by using different Scenario [12]. Pesmajoglou confirmed that the amount of CO_2 of aircraft emissions would grow [13].

Smirti inferred that aviation is responsible for 3.5-5.5% of global carbon emissions. Aviation may be responsible for up to 10-15% of global carbon emission by 2050[14].

Sewill believes in stop people flying; merely discourage them from flying more. On average each air passenger throughout the world is responsible for adding 300 kg of CO_2 to the earth's atmosphere. 300 kg each time they get on a plane and the same again on the return journey [15].

For the range of scenarios in Fig.2, the accumulation of atmospheric carbon dioxide due to aircraft over the next 50 years is projected to increase to 5 to 13 ppmv.

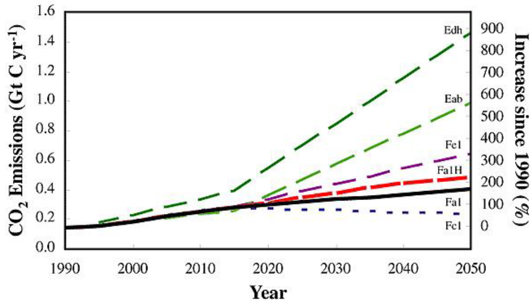

Figure 2. Total aviation carbon dioxide emissions resulting from six different scenarios for aircraft fuel use. Emissions are given in Gt C [or billion (10^9) tonnes of carbon] per year(to convert Gt C to Gt CO2 multiply by 3.67). The scale on the righthand axis represents the percentage growth from 1990 to 2050.

B. Ozone

The NOx emissions from subsonic aircraft in 1992 are estimated to have increased ozone concentrations at cruise altitudes in northern mid-latitudes by up to 6%, compared to an atmosphere without aircraft emissions. This ozone increase is projected to rise to about 13% by 2050 in the reference scenario (Fa1).

The impact on ozone concentrations in other regions of the world is substantially less. These increases will, on average, tend to warm the surface of the Earth. Aircraft emissions of NOx are more effective at producing ozone in the upper troposphere than an equivalent amount of emission at the surface.

Also increases in ozone in the upper troposphere are more effective at increasing radiative forcing than increases at lower altitudes. However, aircraft sulfur and water emissions in the stratosphere tend to deplete ozone, partially offsetting the NOx-induced ozone increases [2].

TABLE I. GLOBAL ANNUAL MEAN NET RADIATIVE FORCING (UNITS mW/m^2) BY CONTRAILS, WATER VAPOR AND OZONE FOR THE FIVE FLIGHT ALTITUDE SCENARIOS UNDER CONSIDERATION.

Altitude(ft)	contrails	Water vapor	ozone
+2000ft	+4.55	+1.27	+14.48
Base	+4.26	+0.9	+13.42
-2000ft	+3.76	+0.55	+12.60
-4000ft	+2.98	+0.34	+12.22
-8000ft	+2.18	+0.22	+11.55

C. Methane

In addition to increasing tropospheric ozone concentrations, aircraft NOx emissions are expected to decrease the concentration of methane, which is also a greenhouse gas. These reductions in methane tend to cool the surface of the Earth. The methane concentration in 1992 is estimated here to be about 2% less than that in an atmosphere without aircraft. Changes in tropospheric ozone are mainly in the Northern Hemisphere, while those of methane are global in extent so that, even though the global average radiative forcing are of similar magnitude and opposite in sign(as you can see at Fig.1) [2].

D. Water Vapor

Most subsonic aircraft water vapor emissions are released in the troposphere where they are rapidly removed by precipitation within 1 to 2 weeks. A smaller fraction of water vapor emissions is released in the lower stratosphere where it can build up to larger concentrations. Because water vapor is a greenhouse gas, these increases tend to warm the Earth's surface [2].

E. Contrails

In 1992, aircraft line-shaped contrails are estimated to cover about 0.1% of the Earth's surface on an annually averaged basis with larger regional values. Contrails tend to warm the Earth's surface, similar to thin high clouds. The contrail cover is projected to grow to 0.5% by 2050 in the reference scenario (Fa1), at a rate which is faster than the rate of growth in aviation fuel consumption. Contrails are triggered from the water vapor emitted by aircraft and their optical properties depend on the particles emitted or formed in the aircraft plume and on the ambient atmospheric conditions [2].

The climate change of aircraft emissions could be reduced by limiting the cruise altitude of aircraft. One possible impact reduction strategy is to significantly reduce the formation of contrails [16].

Stuber et al highlights that the contrail effect from aircraft is significantly worse at night. (This is because, during the day, whilst contrails reflect radiation back to earth, increasing warming, they also reflect radiation from the sun back into space, reducing warming. At night, only the former effect takes place). Hence, Stuber et al recommend rescheduling air traffic from nighttime to daytime, to help minimize the climate impacts of aviation [17].

Gardner at Fig.3 shows the relative surface temperature increase by aircrafts in different altitudes from 2000 to 2100 year. We can see the increasing of temperature trend at low altitudes aviation is very low in comparison with aviation at high altitudes [18].

Travis et al studied about contrail frequency by using Advanced Very High Resolution Radiometer (AVHRR) images [19].

Williams et al suggest that reducing aircraft cruise altitudes could be a beneficial policy for mitigating climate change impacts from the aviation sector. The flight planning to minimize contrail formation should be investigated as a possible climate mitigation policy [20].

F. *Cirrus Clouds*

Extensive cirrus clouds have been observed to develop after the formation of persistent contrails. About 30% of the Earth is covered with cirrus cloud. On average an increase in cirrus cloud cover tends to warm the surface of the Earth. An estimate for aircraft-induced cirrus covers for the late 1990s ranges from 0 to 0.2% of the surface of the Earth. For the Fa1 scenario, this may possibly increase by a factor of 4 (0 to 0.8%) by 2050; However, the mechanisms associated with increases in cirrus cover are not well understood and need further investigation [2].

G. *Sulfate and Soot Aerosols*

The aerosol mass concentrations in 1992 resulting from aircraft are small relative to those caused by surface sources. Although aerosol accumulation will grow with aviation fuel use, aerosol mass concentrations from aircraft in 2050 are projected to remain small compared to surface sources. Increases in soot tend to warm while increases in sulfate tend to cool the Earth's surface. The direct radiative

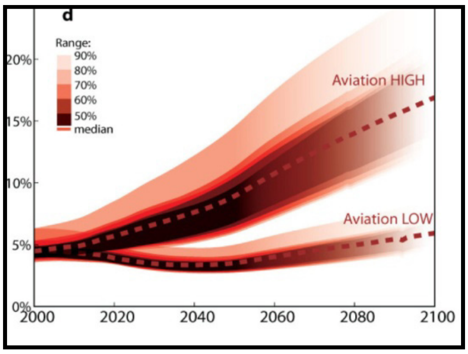

Figure 3. Relative Surface Temperature Increase by different aircraft altitudes.

forcing of sulfate and soot aerosols from aircraft is small compared to those of other aircraft emissions [2].

IV. How Do Aircraft Affect Climate

Aircraft emit gases and particles directly into the upper troposphere and lower stratosphere where they have an impact on atmospheric composition. These gases and particles alter the concentration of atmospheric greenhouse gases, including CO_2, O_3 and CH_4 [2].

Fig.4 shows that how aviation emission affect atmosphere, some of them cause warming and others cause cooling. The RF components from aviation arise from the following processes:

- emission of CO_2, (positive RF);
- emission of NOx (positive RF). This term is the sum of three component terms: tropospheric O_3 (positive RF); reduction in ambient CH_4 (negative RF), and small decrease in O_3 (negative RF);
- emissions of H_2O (positive RF);
- persistent linear contrails (positive RF);
- aviation-induced cloudiness (positive RF);
- emission of sulphate particles (negative RF); and,
- emission of soot particles (positive RF).

These emissions and cloud effects modify the chemical and particle microphysical properties of the upper atmosphere, resulting in changes in RF of the earth's climate system, which can potentially lead to climate change impacts and ultimately result in damage and welfare/ecosystem loss as illustrated in Fig. 5 [21].

Fig.5 portrays a causal chain whereby the direct emissions of aircraft accumulate in the atmosphere, change the chemistry and the microphysics, and alter radiatively active substances in the atmosphere, which change radiative forcing and hence the climate. During these mechanisms, the aircraft emissions change the radiative forcing and then make temperature, sea level, precipitation change and these changes affect on agriculture … and costs. Supersonic aircraft are projected to cruise at an altitude of about 19 km, about 8 km higher than subsonic aircraft, and emit CO_2… into the stratosphere. These emissions contribute to changes in stratospheric ozone. The radiative forcing of civil supersonic aircraft is estimated to be about a factor of 5 larger than that of the displaced subsonic aircraft in the Fa1H scenario [2].

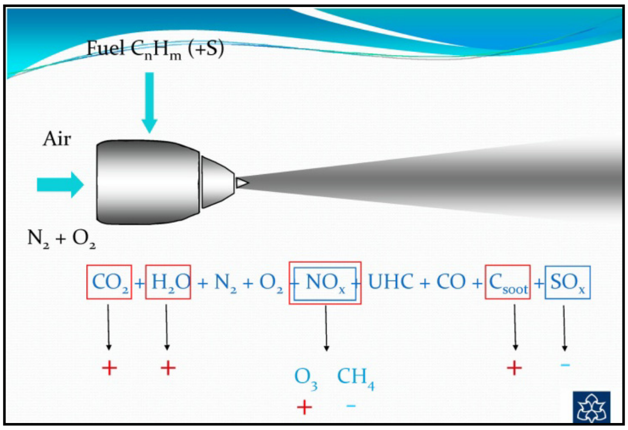

Figure 4. Aircraft Emissions of Concern to Climate

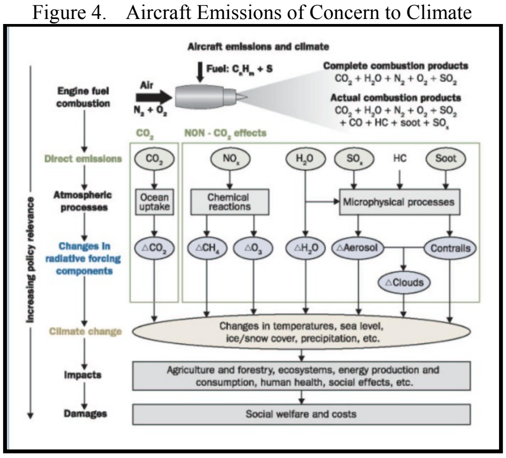

Figure 5. Schema showing the principal emissions from aviation operations and the atmospheric processes that lead to changes in radiative forcing components

Hence reducing flight altitude can protect ozone layer.

Kimber suggested some useful methods like: Airlines need to report actual fuel usage by aircraft to allow for accurate emissions labeling, Passengers can also choose direct flights, support airlines that maximize passenger load capacity and carry less baggage on short-haul flights, The travel industry can promote surface travel within Europe for trips of 500 kilometers or less, Tugs could be used in airports to reduce emissions from taxiing planes, for reducing aviation emission [22].

V. CONCLUSIONS

Aviation affects climate through a number of effects, not only by its CO2 emissions but also with some other emissions that are contrary to Kyoto protocol.

Aviation affect climate by the increasing ozone at upper troposphere and lower stratosphere, ambient methane destruction, small direct radiative effects of water vapor and particles, *RF* of contrail and enhancement of cirrus cloud. More of them cause to warm the earth and increase surface temperature. The temperature will increase rapidly in different scenario; this is a big worry for human.

The most important methods for reducing some of aviation effects are: reducing cruise altitude, shifting flight hours from night to day, improving fuel technology. These methods can reduce climate change somehow.

Some of the climate effects are still rather uncertain and require more work to make more robust estimates of *RF*. However, our ability to predict some of the effects has improved with improved models and data.

Teleconferences can reduce more of commercial and job flights. The media also can help to reducing aviation emissions by informing people of the results of scientists about aviation and climate change.

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