CLIMATE CHANGE AND AVIATION

AJEY LELE AND KRITIKA ROY

Aviation has been at the heart of global activity for long. Continents and people can come together, travelling over distances of thousands of kilometres only because of aircraft. Today, enhanced connectivity, cheaper tickets and more flying options have made the aviation sector an increasingly important means of transport for citizens, businesses and governments. Air travel is considered fundamental to the development of new markets, business relations, cargo and humanitarian aid. The importance of informal and spontaneous meetings can hardly be overestimated, especially for the growing markets. Some air travel, within the maritime and petroleum sectors, is also associated with inspections of physical installations or vessels, or for the transportation of crew to platforms and other technical installations. Additionally, air cargo is assuming an increasingly important role within various industries, especially among humanitarian organisations for relief work. Similarly, the aviation sector is intricately linked to so many sectors such that the smooth functioning of this sector facilitates a ceaseless functioning of all the dependent sectors. The International Air Transport Association has predicted that the number of passengers transported by airlines will reach 8.2 billion in 2037, up from 7.8 billion in 2036. The figures speak volumes for the growing popularity of air travel.[1] There is

Dr **Ajey Lele** is Senior Fellow at the Manohar Parrikar Institute for Defence Studies and Analyses, New Delhi. He has also served in the Indian Air Force.

Ms **Kritika Roy** is Research Analyst in Cyber Security Centre of Excellence at Manohar Parrikar Institute for Defence Studies and Analyses, New Delhi.

1. M. Garcia, "Air Travel Projected To Double in 20 Years, But Protectionism Poses Threat", *Forbes*, October 24, 2018; https://www.forbes.com/sites/marisagarcia/2018/10/24/iata-raises-

Climate change is a stark reality and growth in the aviation sector means an increase in emission rates. This growth rate of the aviation sector may even overshadow the Paris Agreement's quest to keep the increase in global average temperature below two degrees.

absolutely no doubt that economic growth, world trade, international investment and tourism are being facilitated by the airline industry. However, there is a sizeable downside of this growth, and that is the impact on climate change. Climate change is a stark reality and growth in the aviation sector means an increase in emission rates. This growth rate of the aviation sector may even overshadow the Paris Agreement's quest to keep the increase in global average temperature below two degrees.[2]

This paper establishes the context for the need to focus on climate change and its impact on the aviation sector. The paper also analyses various features linking aviation and climate change through case studies. Finally, the paper offers a few policy recommendations.

CLIMATE CHANGE, ENERGY AND AVIATION

Global climate change is an issue discussed not only with a lot of concern but also with a lot of passion. As an intellectual exercise, few recognise that "climate change represents the tragedy commencing on a global scale" and also gets described as the most important environmental problem of the 21st century.[3] Today, climate change is known as a 'mother of all problems' and it is believed that cataclysmic events will unfold as humanity blindly demands more and more luxuries like autos, jet travel, air-conditioned homes, etc.[4] Indeed, in the coming years, the change of the climate system

20-year-projections-to-8-2-billion-passengers-warns-against-protectionism/#4171b04e150f. Accessed on July 12, 2019.

2. Yun Gao, Xiang Gao and Xiaohua Zhang, "The 2°C Global Temperature Target and the Evolution of the Long-Term Goal of Addressing Climate Change", *Elsevier*, vol. 3, issue 3, April 2017, pp. 272-273.
3. Kathryn Harrison and Lisa McIntosh Sandstorm, eds., *Global Commons, Domestic Decisions* (Massachusetts: Massachusetts Institute of Technology Press).
4. J. Griffin, ed., *Global Climatic Change* (Camberley: Edward Elgar Publishing Limited), p. 1.

would become so intense that it would have a wide range of consequences for biological and socio-economic systems, which, in turn, would have a cascading impact on other linked man-made systems.

The earth's climate is getting warmer, and its temperature has gone up about one degree Fahrenheit in the last 100 years. Much of the warming is attributed to the increase in the levels of atmospheric carbon dioxide. The major contributor to this rise is the use of fossil fuels.

The 19th century saw remarkable development of our knowledge about climatic variations. Around the period of the 1850s, the idea of climate change on the earth was determined by the heat balance between incoming solar radiations.[5] Subsequently, this idea got developed further with more research taking place and with increased understanding about the science of climate change. The Intergovernmental Panel on Climate Change (IPCC), which was established in 1988 to develop climate policies, in its 2007 synthesis report, stated that the warming of the climate system is now "unequivocal." The earth's climate is getting warmer, and its temperature has gone up about one degree Fahrenheit in the last 100 years. Much of the warming is attributed to the increase in the levels of atmospheric carbon dioxide. The major contributor to this rise is the use of fossil fuels. The consumption of fossil energy is increasing globally. At the same time, efforts are being made to reduce the carbon dioxide emissions in order to reduce further greenhouse gas emission loads on the environment. It is a reality that the production and utilisation, mainly in the case of fossil fuels, is becoming a major cause of environmental degradation.[6] Another accepted reality is the link between the progress of a nation and the availability of energy resources, and owing to the push for development—especially in the developing countries—energy demand is growing rapidly. Fossil fuels are the most commonly used form of energy that have also been accused

5. B. Bolin, *A History of the Science and Politics of Climate Change* (Cambridge: Cambridge University Press), p. 3.

6. A.N. Sarkar, *Global Climate Change Beyond Copenhagen* (New Delhi: Pentagon Earth, 2010), p. 95.

of causing significant environmental damage like emission of various greenhouse gases. Besides burning of fossil fuel and deforestation, the transportation sector is also responsible for the global emission of greenhouse gases.

The aviation industry is one of the most important sectors for international business, tourism, transportation of goods, and military and humanitarian aid. This industry is also seen as one of the most energy and carbon intensive forms of transport, whether measured per passenger km or per hour travel. However, the aviation sector, in particular, accounts for a very small percentage of greenhouse emissions, that is, around 2 per cent of all human produced carbon dioxide emissions.[7] Nonetheless, this small percentage of emission cannot be overlooked, as it should be seen with reference to the growth rates of the aviation sector and the reduction in emission rate demanded by the IPCC.[8] Moreover, aviation is different from other energy using activities, as the majority of emissions occur at an altitude that tends to instigate different atmospheric chemical processes, thereby adding to the global warming scenarios.

AVIATION SECTOR'S IMPACT ON CLIMATE CHANGE

As air traffic increases year on year, so does the impact on the environment. The major impact of the sector on the environment occurs through the combustion of fuels leading to the emission of heat, gases, noise and particulate matter. These emitted particles and gases such as carbon dioxide (CO_2), black carbon, and hydrocarbons, oxides of nitrogen (NO_2) and sulfur (SOx), and carbon monoxide (CO) interact among themselves and the atmosphere and have an impact on atmospheric composition that contributes to global warming and ocean acidification. Additionally, the disturbance in the atmospheric composition leads to the formation of condensation trails

7. Airport Council International, "10 Questions about Aviation and Climate Change", https://aci.aero/Media/aci/file/Position%20Briefs/information%20brief_10%20QUESTIONS%20CLIMATE%20CHANGE.pdf. Accessed on July 12, 2019.

8. Stefan Gössling and Paul Upham, *Climate Change and Aviation: Issues, Challenges and Solution*, (US: Routledge, 2009).

(contrails). Many times, these disturbances also increase the formation of cirrus cloudiness that adds to the phenomena of climate change.[9] There are several reports that highlight that the rate of emission of CO and SOx from aviation has also gone up since 1990, while the rates of emissions from most other transport modes have fallen (European Environment Agency, 2017).[10] Additionally, NOx emitted from aircraft (especially the emission from subsonic and supersonic aircraft) fumbles with the ozone layer, and indirectly contributes to radiative forcing (a measure of the change in the climate). Since the emissions from these aircraft are released at a higher altitude, they have a stronger affinity to react with ozone formation. Concerns over aviation's global impact are not new; rather, these concerns gained prominence in the 1970s because of the proposed fleet of civil supersonic aircraft, namely, the Concorde and Tupolev-144. This concern was related to potential stratospheric ozone depletion because of the emissions from the supersonic aircraft. In the late 1980s and the early 1990s, research was initiated to look into the effects of nitrogen oxide on the ozone layer and also the effect of contrails from these supersonic aircraft. The sonic boom (this happens whenever an aircraft flies faster than the speed of sound, i.e. over Mach 1.0), that the Concorde produced was also a source of nuisance to people on the ground. In the 1990s, various research projects identified a number of emissions and effects from aviation. It was also noted that aviation presented unique challenges for the environment since the major fraction of its emissions is injected at aircraft cruise altitude, i.e. 8-12 km. At these altitudes, the emissions have increased affinity to cause chemical and aerosol effects relevant to climate forcing. It is also important to note that an operating aircraft's emission remains in the atmosphere for periods ranging from days to centuries, with some climatic effect felt on even longer time scales. In the year 1999, IPCC published a comprehensive report titled

9. Michael Le Page, "It Turns Out Planes are even Worse for the Climate Than we Thought," *New Scientist,* June 27, 2019, https://www.newscientist.com/article/2207886-it-turns-out-planes-are-even-worse-for-the-climate-than-we-thought/. Accessed on July 14, 2019.

10. European Environment Agency, *TERM 2017: Mixed Progress for Europe's Transport Sector in Meeting Environment, Climate Goals*, 2017; https://www.eea.europa.eu/highlights/term-2017-mixed-progress-for. Accessed on July 15, 2019.

"Aviation and the Global Atmosphere" which for the first time presented an exhaustive assessment of aviation's impact on climate using the climatic metric "Radiative Forcing (RF)."[11] Today, the aviation sector is a top-ten global emitter whose emissions are expected to rise dramatically by mid-century. Under current scenarios, the aviation sector could emit 56 $GtCO_2$ over the period 2016-50, or one-quarter of the remaining carbon budget.[12] In addition to the sector's CO_2 emissions, aviation's non-CO_2 effects are also significant in nature. Aviation emissions are 2.1 per cent of the global share, but when non-CO_2 effects are included, aviation contributes an estimated 4.9 per cent to the global warming problem.

Additionally, the rising competitiveness in the aviation industry and the competition to provide greater comfort and luxury by the airlines has added to the pressure of climate change, as the emissions also depend on where the passengers sit and whether they are taking long haul flights or shorter ones. For long haul flights, carbon emissions per passenger per kilometre travelled are about three times higher for business class and four times higher for first class. This is because there is more space per seat, so each person accounts for a larger amount of the whole aircraft pollution.[13] A World Bank study estimates that the carbon footprint of a person flying business class is three times more than one flying economy and nine times greater for a person flying first class.[14] With raised awareness and proactive measures towards environmental protection, it has been predicted that emissions from the aviation industry would continue to grow if an appropriate mitigation strategy is not formulated timely.

11. *Aviation and the Global Atmosphere* IPCC (1999) described "Radiative Forcing (RF) as a measure of the perturbation of the Earth-atmosphere energy budget since 1750 (by convention in IPCC usage) resulting from changes in trace gases and particles in the atmosphere and other effects such as changed albedo, and is measured in units of watts per square metre (W m2) at the top of the atmosphere."

12. Pidcock and Yeo, "Analysis: Aviation Could Consume a Quarter of 1.5C Carbon Budget by 2050," *Carbon Brief,* August 8, 2016; https://www.carbonbrief.org/aviation-consume-quarter-carbon-budget. Accessed on July 16, 2019.

13. "Climate Change: Should you Fly, Drive or Take the Train?" BBC News, August 24, 2019. See https://www.bbc.com/news/science-environment-49349566. Accessed on July 16, 2019.

14. Irene Kwan, "Inflight Luxury: Who Really Pays?" https://theicct.org/blogs/staff/inflight-luxury-who-really-pays. Accessed on July 16, 2019.

IMPACT OF CLIMATE CHANGE ON AVIATION

The aviation industry contributes to climate change significantly. However, unfortunately, it is also a victim of climate change. This impact, on occasions, is severe, while at times, it is extremely localised. With the aviation industry deemed to grow at an average of 4-5 per cent per year, climate change is a growing risk to the aviation sector.[15] Hot, wet, or cold, in all seasons when some extremes occur, the aviation industry gets impacted. Be it higher temperatures or storms or excessive snowfall or high-altitude icing, all these normally lead to an increase in flight disruptions.[16] Taking into consideration the prominent and prevalent climatic effect, it is important to highlight the impact on aviation. The most evident outcome of global warming has been the melting of ice caps and glaciers, thermal expansion of oceans and rise in temperature. In 2017, during the summer, extremely high temperatures prevented hundreds of flights in Arizona, USA, as the aircraft were not able to generate enough lift to take off in thinner air.[17] Very high temperatures, combined with higher values of specific humidity in some regions have a negative repercussion on take-off performance at airports at high altitudes or with short runways, limiting payload or fuel uptake. This is because, as the air temperature increases, air density decreases (if pressure remains constant); lift is reduced, so more thrust and runway length are required for take-off. As the temperature rises, aircraft would need to toss out a few passengers, some cargo or fuel to get the same lift on a hot day, thereby raising the costs and requiring more flights.

The temperature change will further have an implication on aviation infrastructure such as heat damage to runways. In addition, the method of scheduling long-haul departures for the cooler evening and night hours in some regions (the Middle East, and Central and Southern American high altitude

15 J. Griffin, ed., *Global Climatic Change: The Science, Economics, and Politics (New Horizons in Environmental Economics)*, (Camberley: Edward Elgar Publishing Limited, 2003), p. 8.

16. Fred Pearce, "Climate Change Spells Turbulent Times Ahead for Air Travel", *The Guardian*, February 19, 2018; https://www.theguardian.com/environment/2018/feb/19/climate-change-spells-turbulent-times-ahead-for-air-travel. Accessed on July 31, 2019.

17. Zach Wichter, "Too Hot to Fly? Climate Change May Take a Toll on Air Travel," *The New York Times*, June 20, 2017; https://www.nytimes.com/2017/06/20/business/flying-climate-change.html. Accessed on July 30, 2019.

The rise in temperature has led to the rise in sea level, increase in the monsoon, tropical storms, thunderstorms and cyclones that often threaten the viability of airports at coastal locations.

airports) would be affected by reduced overnight cooling where high cloud cover, partially caused by long-lived contrails, is often present. In these cases, the warming effect of contrail-related cirrus clouds, which reduce radiative cooling at night, may have to be considered as an additional problem. Such phenomena would further shorten the already restricted operational hours in some regions. The rise in temperature has led to the rise in sea level, increase in the monsoon, tropical storms, thunderstorms and cyclones that often threaten the viability of airports at coastal locations. For instance, at Ilaquit airport in North Canada, the runway and taxiway had to be resurfaced as the permafrost on which it was built started melting.[18] Also, intense precipitation due to storms and cyclones leads to flooding which affects the ground operation of airports. For instance, heavy rains in Mumbai led to the temporary suspension of activity at the airport due to fluctuating visibility. Mumbai airport is the second busiest airport in India, handling up to 1,300 movements per day.[19] The July 26, 2005, Mumbai heavy rain event had recorded 944 mm rainfall in 24 hours with significant spatial variability. This event was poorly forecast by operational models and resulted in large human and economic losses.

EVENT DESCRIPTION

Mumbai is a coastal city built on what was once an archipelago of seven islands. The weather situation of this region gets influenced by the Western Ghats mountains that run parallel to the Indian coast. The month of July is considered to be the peak period for the southwest monsoon,[20] giving

18. "Thawing Permafrost a Growing Problem for Iqaluit Airport," CBC News, 2013; https://www.cbc.ca/news/canada/north/thawing-permafrost-a-growing-problem-for-iqaluit-airport-1.1371922. Accessed on July 30, 2019.
19. "Mumbai Rain Updates: City Paralysed after Incessant Rain; Toll Rises to 35", *Livemint*, 2019; https://www.livemint.com/news/india/mumbai-rains-updates-today-flights-airport-local-trains-traffic-bus-roads-waterlogging-1562034756785.html. Accessed on July 12, 2019.
20. The word monsoon is derived from the Arabic word 'mausin' which means 'the season of winds.'

Take-off and landing are the most crucial aspects of any flight and any disruption, damage or waterlogging on the runways affects smooth operations. Upgrades of airports during their operational life-time are planned for, but climate change induced incidents may require unplanned upgrades, which, however, may be limited by local planning parameters and the state of the prevailing technology.

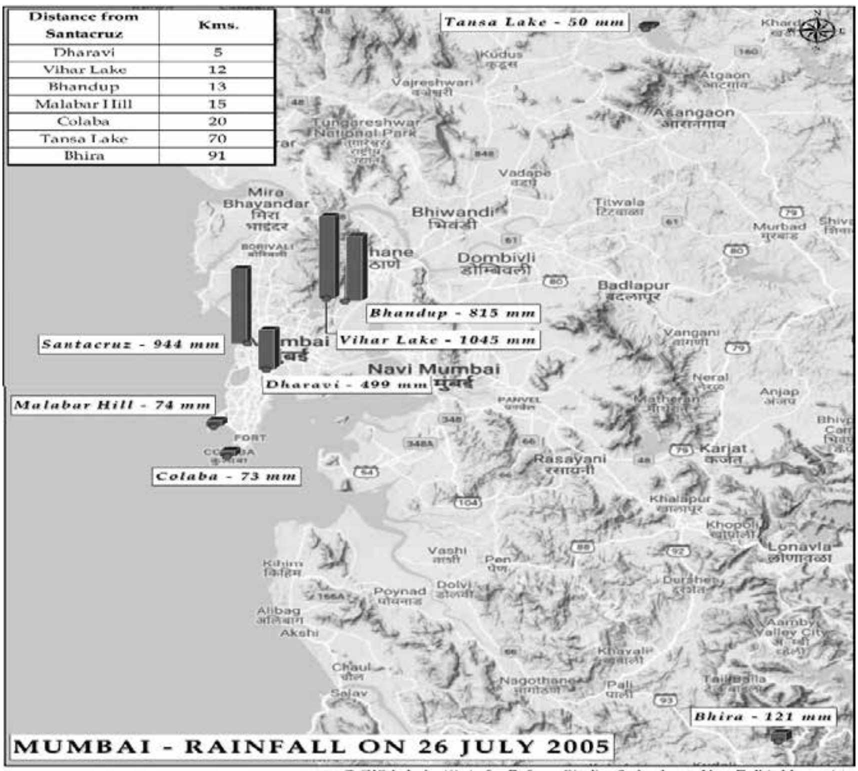
heavy and exceptionally high amounts of rainfall. However, the July 26, 2005 event was unique. First, the rainfall amount of 944 mm is, thus, far a record amount for a single day rain event for this mega city (population over 10 million). The previous highest rainfall (during the last 30 to 40 years period) never exceeded 400 mm in 24 hours. The previous highest rainfall was on June 10, 1991, amounting to 399 mm. The unprecedented rainfall in Mumbai on July 25, 2005, was a major catastrophe and resulted in more than 1,000 deaths and a near complete inundation of the city. The approximate damage was estimated to be US$ 1 billion. Along with human lives, the business economy took the hardest hit in this financial capital of India. The airport was non-operational for two days, trading on the Stock Exchange was suspended for a day, and many areas of the city remained flooded and without power for more than a week.[21] The map below (Fig 1) indicates that the 'very heavy' part of the rain was a localised phenomenon. Vihar Lake and Santacruz were the most affected areas. Santacruz is the area in Mumbai where the airport is located and the amount of rain at Santacruz was recorded by the weather observatory located at the airport itself. Santacruz received a record high rainfall of 94.4 cm. The event was highly localised, which can be gauged from significant rainfall variations found within regions 5 to 20 km away from the airport (refer Fig 1). Most of

21. Dudhia, Kumar, Niyogib, Rotunno and Mohanty. "Analysis of the July 26, 2005 Heavy Rain Event Over Mumbai, India Using the Weather Research and Forecasting (WRF) Model", *Quarterly Journal of the Royal Meteorological Society*, 2008, vol. 134, pp. 1897–1910, and Malini Dixon and Ayyalasomayajula, "Description and Impacts of the Mumbai Monsoon Flood of July 2005", *Papers of the Applied Geography Conferences*, 2008, vol. 31, pp. 162-165.

the operational numerical models had failed to predict this extreme event.[22]

It could be argued that the damage was not only due to the excess amount of rainfall but other factors like unplanned construction in low-lying areas, solid waste in urban drainage channels, and inadequacy of drainage capacity were also responsible. Such situations of urban flooding, mainly in the case of coastal cities, also include hydrological factors like the presence or absence of overbank flow channel networks and occurrence of high tides impeding the drainage in coastal cities.[23]

Fig 1: Graphical Representation of Mumbai Rains in 2005



© GIS Lab, Institute for Defence Studies & Analyses, New Delhi. Map not to

22. Sahany Sandeep, V. Venugopal Ravi and S. Nanjundiah, "The 26 July 2005 Heavy Rainfall Event Over Mumbai: Numerical Modeling Aspects," *Meteorology and Atmospheric Physics*, vol. 10, pp. 115–128.
23. K. Gupta, "Interview: Dr. Kapil Gupta* on Urban Floods", http://pib.nic.in/newsite/printrelease.aspx?relid=153050. Accessed on July 12, 2019.

The case discussed (Mumbai heavy rains) is a typical example of how heavy rains could affect locations which are close to the coast.

The air connectivity for Mumbai was totally affected for a few days and also some infrastructure got damaged. On July 26, 2005, owing to the heavy rains, the post afternoon operations were stopped. Initially, more than the rains, the problem was that of poor visibility, for both landing and take-off. However, within a few hours, the consistent rain led to waterlogging of the operations area and, subsequently, water started flowing through the international terminal building. This led to the cutting-off of the power supply and the standby generators could not be switched on because of safety concerns. The entire airport remained non-operative for a period of around 48 hours (2.15 pm on July 26 till 1 pm on July 28) and over 1,100 flights were cancelled.[24] It was found that the intersection area of the runways had as much as six feet of water at one point. Around 3,600 feet in length portion of the 8-foot-high wall around the operations area was breached, allowing water and debris to cover the runway. As a result of the submergence, the Instrument Landing System (ILS) stopped working. There was also a sad incident of the collapse of the extension wall of the airport, resulting in 25 deaths. For restarting the operations, the major task of debris removal from the runways was undertaken. Also, there was a need to restore the runway lights and ILS for smooth operations. There were issues with the approach roads to the areas housing the powerhouses and generators (all the areas were covered by water and slush).[25] Almost every agency involved in the operations had to bear some losses, with the major sufferers being both domestic and international airlines. Take-off and landing are the most crucial aspects of any flight and any disruption, damage or waterlogging on the runways affects smooth operations. Upgrades of airports during their operational life-time are planned for, but climate change induced incidents

24. Mumbai airport is the world's busiest, with single runway operations, and holds the record for handling 1,004 flights (December 9, 2018). Even during 2006, it used to manage significant amounts of air traffic.

25. "Mumbai Marooned: An Enquiry into Mumbai Floods 2005", *India Environment Portal*, 2006; http://www.indiaenvironmentportal.org.in/files/Mumbai-Marooned.pdf. Accessed on July 30, 2019.

may require unplanned upgrades, which, however, may be limited by local planning parameters and the state of the prevailing technology. This is especially true in the case of airports whose overall runway alignment and airside configuration do not allow for them to remain unoperational or with restricted operations for a long time.

Another impact of climate change is the airframe icing or high altitude icing, caused by ingestion of a high density of icicles at very low temperatures [below −50°Celcius (C)] in the vicinity of convective cloud tops. Ice content in excess of 5 g/m^3 of air, is often seen as a hindrance for aviation. This phenomenon occurs due to the presence of large supercooled droplets at a temperature range between −4 and −14°C. The presence of these droplets depends on several conditions like the availability of a substantial measure of water vapour—typically mesoscale bands of intense updrafts and a limited concentration of suitable aerosols acting as condensation nuclei, favouring the formation of large supercooled droplets. Additionally, the growing phenomenon of global warming and increase of moisture in some latitude bands, with a more active dynamic of the flow, all point to an increased chance of occurrence of conditions favourable to icing. They also lead to an upward extension of the upper limit of the icing layers due to lower temperature, and make flying trickier at higher altitudes. This phenomenon has caused more than 100 engine failures in recent years. In 2009, an Air France flight from Rio de Janeiro to Paris crashed, killing all onboard, after ice crystals disabled its speed sensors.[26] Alarmingly, modern energy-efficient lean-burn engines may be more prone to high-altitude icing. Such a phenomenon is likely to increase with more intense cumulonimbus clouds and rise of the tropopause due to the higher temperature and moisture of tropical air masses.

Atmospheric turbulence is also known to cause most weather related aircraft incidents. Clear Air Turbulence (CAT) has been the most difficult to detect by satellites or onboard radar. CAT is linked to atmospheric jet streams, which are estimated to be fortified by anthropogenic climate

26. Wichter, n. 17.

change. Flying would feel different in and around the jet stream. Flying east would become quicker in the stronger winds that result, but flying west would be slower. Thus, there would be more delays and cancellations of flights. In future, all airline schedules would need to accommodate these altered flight times and routes. There are reports that suggest that climate change would lead to bumpier transatlantic flights, in addition to an increase in travel time and fuel consumption.[27] Changes in wind patterns are also known to impact jet stream strength, position, curvature and prevailing wind direction. These impacts would, in turn, cause operational and network disruptions in many airports. Furthermore, as the storm, rain and cyclone patterns witness a change due to the change in climatic patterns, there would be an increase in delays and re-routing, thereby, leading to more fuel being used, further leading to greater loss of money. A superstorm named Sandy hammered three international airports in and around New York City, including the La Guardia airport in 2012. The storm subjugated La Guardia's protective "berm wall system" paving the way for nearly 380 million litres of water from Flushing Bay flooding the airfield and closing it for three days.[28] This incident highlights that climate change could considerably impact several airports which would not only affect civil aviation but also hamper businesses and military requirements. As the changes in climatic conditions continue to wreak havoc, many of the sectors in aviation would face difficulty, especially in areas where air travel is the only option. Some of these have been listed in Table 1.

27. Paul D. Williams and Manoj M. Joshi, "Intensification of Winter Transatlantic Aviation Turbulence in Response to Climate Change", *Nature Climate Change,* 2013, vol. 3, pp. 644-648.

28. Sandeep Sahany, V. Venugopal Ravi and S. Nanjundiah, n. 22..

Table 1: Likely Impact of Climate Change on Different Sectors of Aviation

Civil	• Frequent delays and cancellation of flights • Route changes and long waiting hours • Increase in flight prices and travel time • Increase in no-go flight days • Increased threat to life and safety • Unplanned expenditure • Disruption of tourism/leisure trips
Business/ Freight	• Frequent delays and cancellation of flights—loss of money • Delayed delivery of parcels and packages • Increase in no-go flight days • Impact on perishable goods and food products like fish • Unplanned expenditure
Military	• Flooding of airfields, access limitations and other logistic related impairments • Delay in rescue operations and humanitarian aid • Unplanned expenditure • Weather conditions impact Intelligence, Surveillance, and Reconnaissance (ISR) activities • Impact on personnel recovery/casualty evacuation • Delay/cancellation of logistics flights

CLIMATE CHANGE AND METEOROLOGY

The Mumbai rains case study highlighted two important issues: one, the need to majorly upgrade various ground systems and infrastructural facilities, and two, the need to evolve weather forecasting models which can catch the microclimate changes well in time. It appears that some changes need to be made in the practices of aviation meteorology too. As mentioned earlier, climatic disturbances have a negative impact on the safety of aircraft because of the different scales involved in weather phenomena. However, these disturbances may not have the same impact if the aircraft encounter them en-route (regional and global scales) or in the airport terminal area (local scale). Furthermore, some phenomena are only present either at the local scale or at high altitude when the aircraft is en-route.[29] Normally, weather observations which are shared with the flying aircraft are either half an hour or one hour old, depending on the session. At present, automatic weather stations are available which provide continuous weather observations. Also, various radars (including doppler radars) are available. There is other modern equipment available to address different parameters of the weather. In addition to this, improved Numerical Weather Prediction (NWP) models are available that provide timely weather forecasts at different scales. Since weather forecasting and weather data collection cannot be restricted by geographical boundaries, internationally, there is greater understanding about the exchange of timely information and forecasts. More importantly, today, the quality of forecasting is improving. Quality is gaining roughly a day a decade so that a 5-day forecast is now about as good as a 4-day forecast was a decade ago, and a 2-day forecast 30 years ago.[30]

NEW TECHNOLOGIES: NEW CHALLENGES OR NEW OPPORTUNITIES?

Advances in technology have facilitated the development of new innovative aircraft which may present new challenges but, at the same time, represent new opportunities to address the environmental challenges. The requirement is that the global aviation sector should contribute towards holding global warming to 1.5 degrees. Therefore, the aviation sector needs to evolve an effective mechanism that could rapidly reduce the emissions produced by it. Particularly for the purpose of decarbonisation, some of the possible solutions include: ensuring compatibility with the Paris Agreement, 2018, deploying near-term technology solutions, including

29. P. Christian, "Understanding Aviation Meteorology and Weather Hazards with Ground-Based Observations", in Domenico Cimini, Guido Visconti and Frank S. Marzano, eds., *Integrated Ground-Based Observing Systems* (London: Springer), pp. 161-173.

30. Peter R. Orszag, "We Need to get Weather Forecasts Right, Global Cooperation & Data Sharing is how", The Print, August 1, 2019; https://theprint.in/opinion/we-need-to-get-weather-forecasts-right-global-cooperation-data-sharing-is-how/270660/. Accessed on August 1, 2019.

Technological improvements usually involve changes in the design of the aircraft or aerodynamic modifications, fittings that weigh less, fuel efficient upgraded engines, and increased operational efficiencies. Artificial Intelligence (IA) and predictive analytics may be used for timely maintenance and upgradation.

alternative (environment friendly) fuels and creating new green business models (including ground operations) for the aviation industry. The biggest improvement in the aviation sector would typically arise from replacing or upgrading the outdated fleets. For instance, some aircraft can be retrofitted with technical devices at the tip of the wings ("winglets"), new surface treatments that reduce drag (air resistance) and even new engines. Improving the fuel efficiency of aircraft and the reduction of harmful emissions has been a major area of technological research and development since it directly improves airlines' operation cost. Technological improvements usually involve changes in the design of the aircraft or aerodynamic modifications, fittings that weigh less, fuel efficient upgraded engines, and increased operational efficiencies. Artificial Intelligence (IA) and predictive analytics may be used for timely maintenance and upgradation.

There has been considerable development in electric and hybrid aircraft, including autonomous aircraft that provide point-to-point connectivity. European companies like Pipistrel are currently developing electric power plants for aircraft. The electricity is proposed to be generated by means like solar cells, batteries, fuel cells or ultra-capacitors. Research for clean propulsion technologies like cryogenic hydrogen fuel or electric powered aircraft is still underway. The Airbus, Rolls-Royce and Siemens aircraft "Electric Fan-X" is anticipated to test fly by 2020. One of the engines of the aircraft has been replaced by two megawatt electric motors. Additional changes include the development of Counter Rotating Open Rotor (CROR) that is expected to provide fuel burn improvements up to 30 per cent. Development of the Airbus A340 laminar flow aircraft is tasked to assess the feasibility of the laminar flow wing technology that aims to reduce aircraft drag by 10 per cent and CO_2 emissions by 5 per cent.[31] Inspired by steam catapults used on aircraft carriers, research has been going on in the use of induction electric motors to accelerate planes to the desired speed in a more fuel efficient and quieter manner.[32]

Many industry experts are of the opinion that commercial deployment of advanced technologies or eco-fuels will take another two decades. Moreover, many of these adaptions do not guarantee zero per cent emission rates.

Another interesting development has been of the fuel cell powered electric nose wheel that is being proposed to be inducted in order to save fuel while reducing airport noise. Aircraft fitted with this nose wheel will be able to approach their locations travelling in both forward and reverse directions, as well as move to their take-off positions without using towing vehicles or their main engines.[33] Use of Sustainable Alternative Fuels (SAFs) has been another avenue of research by the aviation industry. There has been major focus on the bio-based fuels that are obtained from woody biomass, hydrogenated fats or recycled wastes and have lower carbon intensity. Significant interest also exists for non-bio-based feedstocks, in particular for the drop-in power-to-liquids "electro-fuels". Electro-fuels comprise synthetic alternative fuels to fossil kerosene through the use of renewable electricity to produce hydrogen from water by electrolysis and a combination with carbon dioxide captured from the air. The power-to-liquid process has been found to present a favorable greenhouse gas balance relative to conventional and bio-based aviation fuel streams, with close to zero emissions. These alternatives might be eco-friendly to some extent but present challenges of their own. For example, the use of electro-fuels may be a technically viable option to help decarbonise the aircraft, however, they

31. European Aviation Environmental Report, 2019; https://ec.europa.eu/transport/sites/transport/files/2019-aviation-environmental-report.pdf. Accessed on August 1, 2019.
32. M. G. Richard, "Civilian Airplanes Could Someday Take-Off With Electric Catapults"; https://www.treehugger.com/aviation/civilian-airplanes-could-one-day-take-off-electric-catapults.html. Accessed on July 27, 2019.
33. See Orszag, n. 30.

are 3 to 6 times more expensive than kerosene. Even the use of bio-fuels in airlines would be an expensive affair

With countries indulging in a race to develop advanced supersonic aircraft with speeds over Mach 3 for both civilian and military purposes, with a reduced sonic boom, in 2016, the National Aeronautics and Space Administration (NASA) announced a programme to develop quieter supersonic aircraft. However, these supersonic aircraft would be operating at a higher altitude in the sensitive troposphere and stratosphere which might enhance the issues of global warming. Research also indicates that non-CO_2 emissions from these flights would have a greater impact on climate change than the subsonic ones. Many of these technologies may appear promising. However, many industry experts are of the opinion that commercial deployment of advanced technologies or eco-fuels will take another two decades. Moreover, many of these adaptions do not guarantee zero per cent emission rates. Additionally, the cost factor would weigh heavy on the stakeholders and they would think twice before investing in new technologies if the profit made is nil. Nonetheless, it would be interesting to see how many of the new inventions are pushed into the realm of reality.

POLICY RECOMMENDATIONS

The effects of climate change imply that the local climate variability that people have previously experienced, and have adapted to, is changing. This change is happening at a relatively great speed and many of the climatic phenomena may soon become unpredictable and come as a relative surprise, although the impact of climate change on the aviation sector would vary according to geography, climate zone and local circumstances. However, surprise weather events like dust storms, cloudbursts and flash flooding could impact various aviation related activities and may have spillover effect in different sectors as well. Advances in technology are just one facet of curbing the impact of climate change from the aviation sector. Measures need to be taken by the policy-makers and other stakeholders, including aircraft operators, airports, air navigation service providers, aircraft manufacturers and regulators for this to happen. France has announced that it would tax air travel from 2020 as a part of its climate strategy and it has been predicted that soon the European Union (EU) might follow suit.[34] The same could be followed by countries that witness a heavy dependency on air travel. Moreover, commuters should be encouraged to travel by rail or other eco-friendly means unless air travel becomes absolutely necessary.

Air traffic management is usually discussed in terms of emissions and contrails reduction and improved operational efficiency. Airlines can also optimise their timetables, and route network and flight frequencies to minimise the number of empty seats flown. Air shows can be cut down and private aircraft allowed only in case of emergencies. Leaders or celebrities of a country often taking a chartered aircraft can set an example by travelling on commercial aircraft. Moreover, airlines should do away with business class or luxury class to reduce the carbon footprint, thereby reducing the pressure to some extent.

Although the impact of climate change on the aviation sector is fraught with uncertainties, the industry needs to build a strategy to mitigate its impact on climate change at a global level. Currently, the approach to mitigating the impact of climate change on aviation is less coordinated. However, solutions will require the involvement and collaboration of all industry participants, and the setting up of intergovernmental panels. If the aviation industry starts addressing the issue of climate change proactively, it could prove to be a win-win situation for both the aviation sector as well as the climate in the long term.

34. C. Farand, "France Announces Tax on Air Travel in Climate Push", Climate Home News, July 9, 2019; https://www.climatechangenews.com/2019/07/09/france-announces-tax-air-travel-climate-push/. Accessed on July 25, 2019.