Bad weather and aircraft accidents – global vis-à-vis Indian scenario

Rajendra Kumar Jenamani and Ashok Kumar*

It is of great significance to identify and clarify the circumstances and causes of any aircraft accident which will help avoid similar accidents in the future. Besides attribution of various aircraft accidents to avionic causes, bad weather is another prime cause for accidents of many aircraft and helicopters in India. But hardly any study is available in this regard in India using their long-period data. Organizations like USA-based National Transportation Safety Board (NTSB), the Geneva-based Aircraft Crashes Record Office (ACRO) and some other researchers have analysed factor-wise causes of aircraft accidents in percentage using their long-period data, including percentage of aircraft accidents due to various weather types, e.g. low visibility/ceiling, wind shear, squalls, etc. It is high time that similar attempts are made in India for their cumulative assessment and recommending better mitigation measures and regulations. In the present article, available data from NTSB, ACRO, etc. have been reviewed from the context of bad weather as the major factor of aircraft accidents. We have made similar study using data from Annual Aircraft Accident reports of 1992–2008 published by Director General Civil Aviation of India for the Indian region. We have also discussed how efficient use of newly available technology in meteorological services may help mitigate accidents to some extent.

Keywords: Aircraft accidents, thunderstorms, visibility, weather hazards, wind.

DURING 2000–2012, two major aircraft accidents occurred in India. On 27 July 2000 the 'Alliance Air flight CD-7412' crashed at Patna airport, killing 60 passengers and on 22 May 2010, 'Air India Express Flight 812' crashed at Mangalore airport, killing 158 passengers. There also have been a number of other aircraft accidents from the non-scheduled category in India. These are either civil or defence aircraft mostly operated as non-scheduled for a specific purpose, and are smaller private aircraft and helicopters. Aircraft accidents have been reported from the North Eastern hills, Western Himalayan hills, north Indian region and the Eastern Ghats. At least 66 persons have been killed in air crashes in the North East during the past one decade[1,2]. Of the 66 killed, at least 47 were in Arunachal Pradesh alone during the past ten years.

The most recent aircraft accident[3] which occurred on 25 May 2011 near Delhi shows a case of aircraft accidents over the plains, where visual flight navigation remains a challenge. During investigation of all of these aircraft accidents, attribution was made to avionic causes and bad weather. Hence weather is an important factor for safe operation of aircraft and helicopters over India.

It is of great significance to identify and clarify the circumstances and causes of any aircraft accident which will help avoid similar accidents in the future. Various studies undertaken outside India show how weather is regarded as one of the main causes of aircraft accidents and incidents[4–6]. Among different weather hazards, thunderstorms, microburst, mountain wave turbulence, clear air turbulence (CAT), wind shear, poor visibility and fog are the major causes of aircraft accidents and incidents. Hunter *et al.*[4] carried out a survey of a large number of pilots (364) regarding weather events and the circumstances associated with those events through a web-based questionnaire. The analysis shows more pilots in the in-weather group 28% reported that they would be more careful regarding weather, compared to 17% of the near-weather group. The study provides results on both the situational and personal characteristics of pilots which are related to different degrees of weather-related encounters.

In the present study, we have briefly reviewed various weather events that affect safe flights. We have collected data on various aircraft accidents as available in annual Aircraft Accident Reports 1992–2008 published by the Director General Civil Aviation (DGCA). These data have been used to find year-wise variation of total number of aircraft accidents followed by number of weather-related

Rajendra Kumar Jenamani and Ashok Kumar are in the Meteorological Watch Office, IMD, New ATS Building (Room No. 211, 2nd Floor), Indira Gandhi International Airport, New Delhi 110 037, India.
*For correspondence. (e-mail: rjenamani@hotmail.com)

and non-weather-related aircraft accidents. Then percentages of total aircraft accidents related to bad weather have been computed. We have further studied it based on aircraft operation types, e.g. airlines operation, training and private event. We have used similar information, studies and statistics available for other parts of the globe, e.g. for USA from the National Transportation Safety Board (NTSB) (http://www.asias.faa.gov/aviation_studies/weather_study/studyindex.html)[6] and for the world covering selected accidents from the Aircraft Crashes Record Office (ACRO)[7]. We have further considered all aircraft accidents which are weather-related and categorized them based on a particular type of weather hazard, e.g. fog, winds (squalls, gusty, updraft, downdraft, etc.), low visibility, cumulolimbus (CB)/TS, turbulence, etc. to know which is the most dangerous weather for Indian aviation that caused maximum accidents and compared it with that from USA. The present study used only civil aircraft data and no discussion with respect to defence aircraft accidents has been made.

Effect of various weather events on safe flight operation

ACRO compiles data on aviation accidents of aircraft capable of carrying more than six passengers, not including helicopters, balloons or fighter airplanes. Figure 1 *a* shows such aircraft accident frequencies during 1999–2010. It shows the year 2007 as the safest year in aviation during that decade. But when ACRO considers much earlier records, again 2007 remained the year of lowest number of accidents since 1963. The year 2008 saw an increase in their numbers, whereas 2009 and 2010 saw fewer accidents of 122 and 130 respectively. Weather plays a dominant role at each stage of aircraft operation covering taxing stage at the runway (RWY), take-off stage at that airport, cruising stage in the skies, etc. including the landing stage at its destination airport. Figure 1 *b* shows an analysis of accidents of certain aircraft types with respect to various stages of flying during 1959–2009 (ref. 8). It shows that during landing phase of aircraft around 36% of the total fatal accidents occurred and hence the most crucial phase of the flight.

Among major weather events which affect aviation, convective weather such as TS with severe turbulence, intense updrafts and downdrafts, microburst, macroburst, lightning, hail, heavy precipitation, icing, wind shear, strong low-level winds, squalls, gusty winds and tornadoes have impacted flight operations the most. Low visibility and ceiling is another major cause, especially for flights which operate in the Visual Flight Rule (VFR). Other weather conditions which are hazardous to aviation are CAT, aircraft in-flight icing and ground de-icing conditions[9].

FAA[10] elaborately defines the role of various convective-related weather conditions for safe flight operations and safeguards, including dos and don’ts during such weather conditions. It states ‘A thunderstorm packs just about every weather hazard known to aviation into one vicious bundle’, e.g. squall lines, tornadoes, turbulence, icing, hail, low visibility and ceiling, effect on altimeters, lightening and engine water ingestion. Among these, the effect on altimeter setting is most dangerous for an aircraft. Pressure usually falls rapidly with the approach of a thunderstorm and then rises sharply with the onset of the first gust and arrival of the cold downdraft and heavy rain, falling back to normal as the storm moves on. This cycle of pressure change may occur in 15 min. If the pilot does not receive a corrected altimeter setting, the altimeter may be more than 100 feet in error. With regard to ingestion of water during TS, turbine engines have a limit on the amount of water they can ingest. Updrafts are present in many thunderstorms, particularly those in the developing stages. If the updraft velocity in the thunderstorm approaches or exceeds the terminal velocity of the falling raindrops, high concentrations of water may occur. It is possible that these concentrations can be in excess of the quantity of water that turbine engines are designed to ingest. Therefore, severe thunderstorms may contain areas of high water concentration which could result in flameout and/or structural failure of one or more engines.

The other important atmospheric event that severely affects aircraft operation is turbulence. It occurs at any stage during a flight, and causes a bumpy ride immediately, similar to a car on a rough road. This experience can be traumatizing and terrifying for some people and may develop into a phobia for flying. Turbulence is created by irregular and random air motion, whether as a result of different masses of air moving at different speeds and colliding with each other, or of the same air mass behaving in an irregular fashion (turbulent flow) as a result of certain other factors. Turbulence can shake any aircraft no matter how big it may be. It should be noted that aircraft turbulence occurs in cloudy atmosphere as much as it does in clear skies (atmosphere devoid of visible hydrometeors or water droplets). The latter case is often referred to as CAT.

The International Civil Aviation Organization (ICAO) classifies turbulence as slight, severe and extreme. The causes of turbulence are: (i) *Turbulence from thermals*. On sunny and hot days with calm winds, large bubbles of air similar to very large balloons but invisible to the eye rise and settle at certain points in the atmosphere where their temperature equals that of the surrounding air. (ii) *Turbulence from thunderstorms*. The cloud system responsible for thunderstorms is CB clouds. From aircraft window it appears like a mountain of clouds. Thunderstorms can cause a myriad of problems. For instance, they can suck in air from the surrounding into the system (entrainment), or vertically from below the cloud base (updrafts) and discharge large bursts of wind downward (downdrafts or downbursts), all of which can create, from

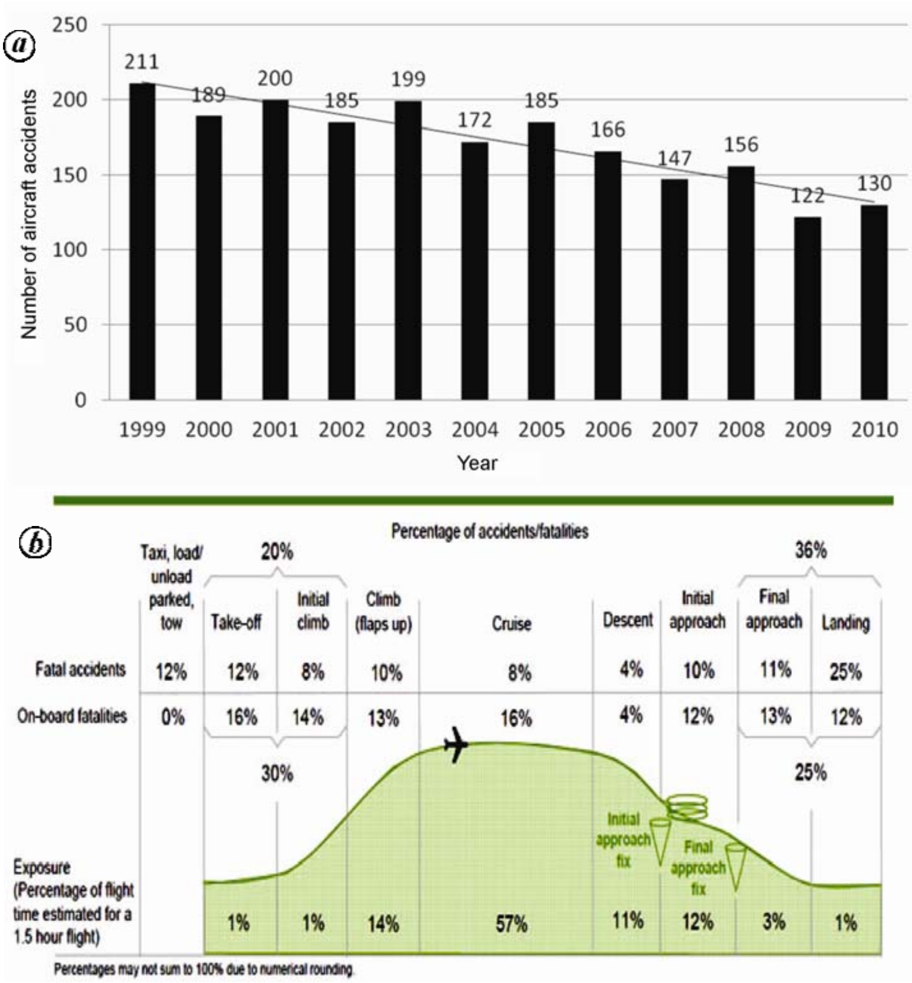


Figure 1. ***a***, Aircraft accident frequencies during 1999–2010. Data from ACRO, http://www.baaa-acro.com/ through http://en.wikipedia.org/wiki/Aviation_accidents_and_incidents. ***b***, Fatal accident and on-board fatalities by phase of the flights worldwide commercial jet fleet 1959–2010. Source: Ref. 8.

slight turbulence, when flying near them to moderate, severe or even extreme turbulence when flying through their core and depending on how well-developed they are. (iii) *Turbulence from wind shear*. This means a large change in wind speed and/or direction over a short distance. This can occur both in the horizontal and vertical directions. While considering horizontal flow, certain regions known as COL regions (between two lows and two highs) are typical wind shear zones and may create slight to moderate turbulence. (iv) *Jet streams*. At the ground level warmer air from lower latitudes moves pole-ward and at some point a boundary is formed with colder air from the polar regions moves back to tropic. This triggers some dynamical forces that create strong currents (stream) of wind, sometimes reaching or even exceeding 400 km/h, high above the ground. They usually move from west to east and are called jet in westerly. Winds progress in strength from the outer part until they reach a maximum at the middle or core. These wind changes over relatively short distances can cause slight to moderate turbulence for aircrafts. Although turbulence is an annoying part of flying, it is often an unavoidable part as well.

Weather as one of the causes of aircraft accident

Figure 2 shows year-wise aircraft accidents classified under two groups into weather-related and non-weather-related for the Indian region by DGCA and for USA by NTSB for the period 1990–2008 and 1994–2003 respectively. Figure 2 *a* shows higher number of accidents during the initial period 1990–1996 with up to 7–12 aircraft per year and in the following year till 2008 it is 3–7 per year. Though a large number of aircraft accidents have been reported (Figure 2 *b*) for USA during the initial period like that of India (Figure 2 *a*), totalling up to 2300 aircraft in 1994, such numbers have decreased to 1700 till 2003 for which data are available. On classifying them into weather-related and non-weather-related groups, Figure 2 *a* shows higher weather-related accident during

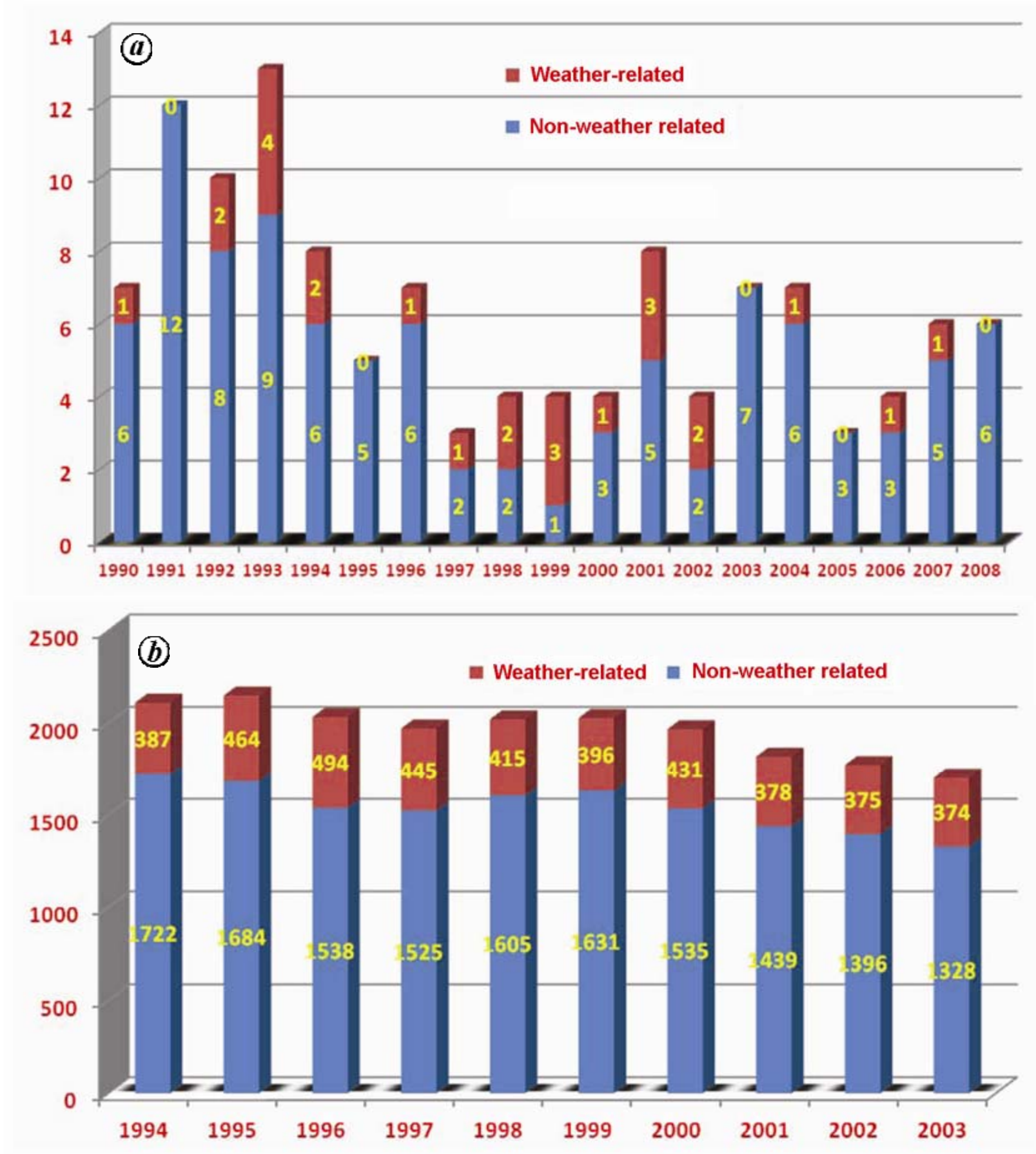


Figure 2. Year-wise aircraft accidents classified under two groups – weather-related and non-weather-related over (***a***) the Indian region from DGCA and (***b***) for USA from NTSB for the period 1990–2008 and 1994–2003 respectively.

1993, 1998 and 1999 when 4, 2 and 3 accidents over India due to bad weather and Figure 2 *b* shows that 1995 and 1996 were the years of highest weather-related accidents in USA when the total numbers touched 464 and 494 respectively. Figure 3 shows the percentage of total aircraft which faced weather-related and non-weather-related accidents. It shows that 21% of accidents in India are weather-related (17% due to both bad weather and pilot error and 4% due to only bad weather), whereas in USA, it is 22%. It shows that weather remains as one of the most significant factors for both the countries which causes flight accidents in case pilot does not set proper briefing about weather warning and forecasting before his flight departure. The problem further aggravates for him, in case sufficient in-flight weather information through in-flight weather monitoring and receiving systems is not available.

In Figure 4 we have computed proportional occurrences of various accidents by further classifying all weather-related aircrafts accidents into various categories of fog, winds (squalls, gusty, updraft, downdraft), low visibility, CB/TS, turbulence, etc. There are some cases of accidents in DGCA reports for the Indian region for 1990–2008 for which the investigating agency does not mention what type of weather event caused a particular weather-related accident. In such cases, they mainly attributed to 'bad weather as the cause' due to which we have no option but to keep a classification as 'bad weather' while comparing with data from USA. Figure 4 *a* shows the highest percentage of aircraft accidents, i.e.

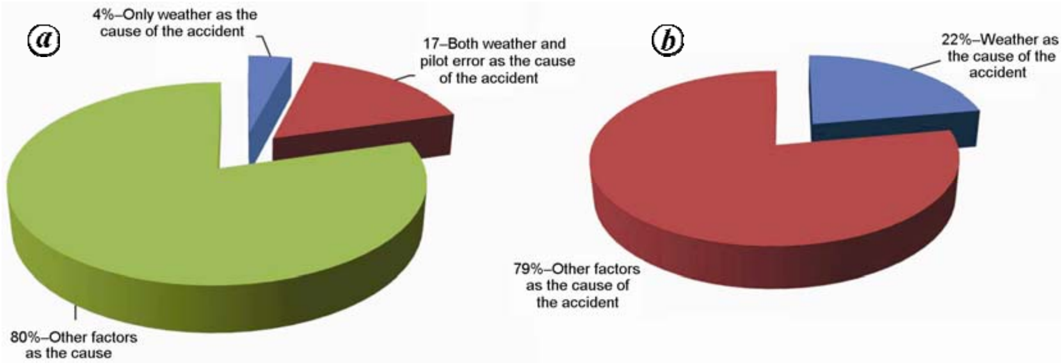


Figure 3. ***a***, A total of 121 accidents over India during 1990–2008; data from DGCA. ***b***, A total of 19,562 accidents from USA during 1994–2003, data from NTSB.

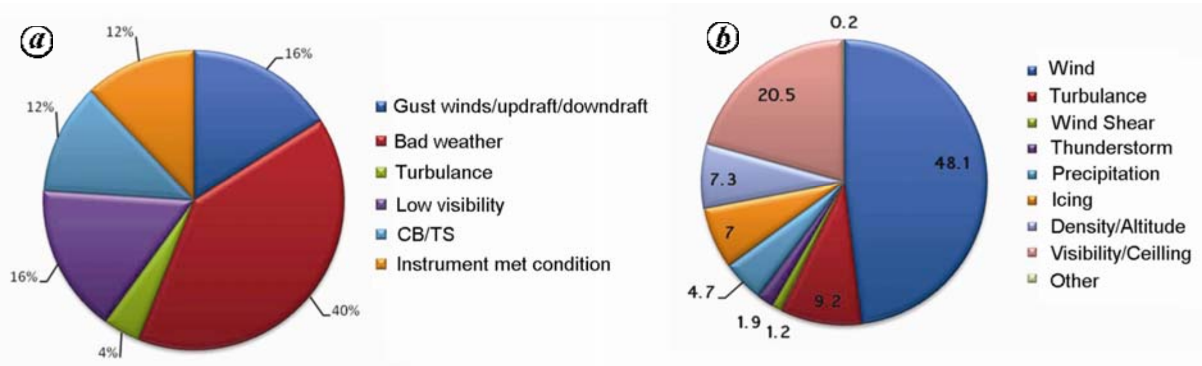


Figure 4. Proportional occurrences of various accidents by further classifying all weather-related aircraft accidents into various categories of fog, winds (squalls, gusty, updraft, downdraft), low visibility, CB/TS and turbulence for (***a***) India and (***b***) USA.

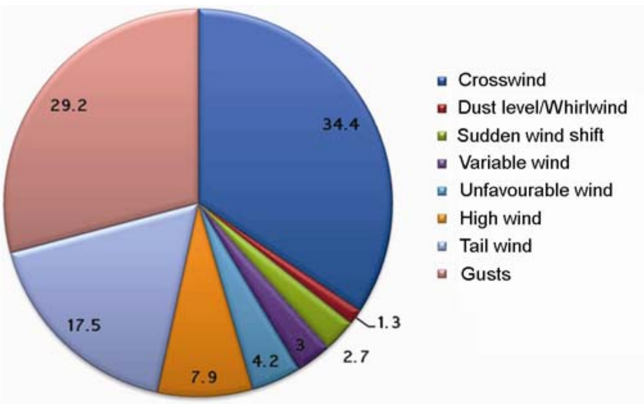


Figure 5. Distribution of wind conditions in NTSB weather-related accidents (1994–2003).

40% occurrence of weather-related accidents in India under this category. The other significant weather events which caused aircraft accidents in India, according to Figure 4 *a*, are wind-related due to gust, updraft and downdraft which are responsible for 16% of total weather-related accidents in India and low visibility and ceiling accounting for another 16%. CB and TS caused 12% of the accidents and instrument meteorological conditions accounted for 12%, with turbulence-related aircraft accidents in India being the lowest at 4%.

Figure 4 *b* shows that in USA, 48% of weather-related accidents is due to bad wind conditions, the highest among all types of weather-related accidents, as also reported in India, followed by 20.5% of total weather-related accidents related to low visibility. Capobianco *et al.*[5] using NTSB data of 1994–1998 show that the most prevalent factors in fatal weather accidents are low ceiling (20%), fog (14%), wind (10%) and night (9%). VFR to IMC flight and flight into adverse weather during the cruise phase are the most common probable causes of fatal weather accidents. In view of winds being a major factor causing high number of accidents, NTSB has provided details of various wind conditions which have caused such accidents (Figure 5). It shows highest percentage of accidents of 34.4 caused by crosswinds followed by 29.2% by gusty winds, 17.5% by tail winds and 7.9% by strong winds. For the Indian region, such data are not available in DGCA reports.

Figure 6 *a* shows the year-wise total weather-related accidents over India during 1990–2008 and Figure 6 *b* shows the decadal time series of the weather-related accidents in percentage of total in the decade over the globe for 1950–2000 (data from http://planecrashinfo.com/cause.htm). Figure 6 *b* is compiled from the PlaneCrashInfo.com accident database and represents

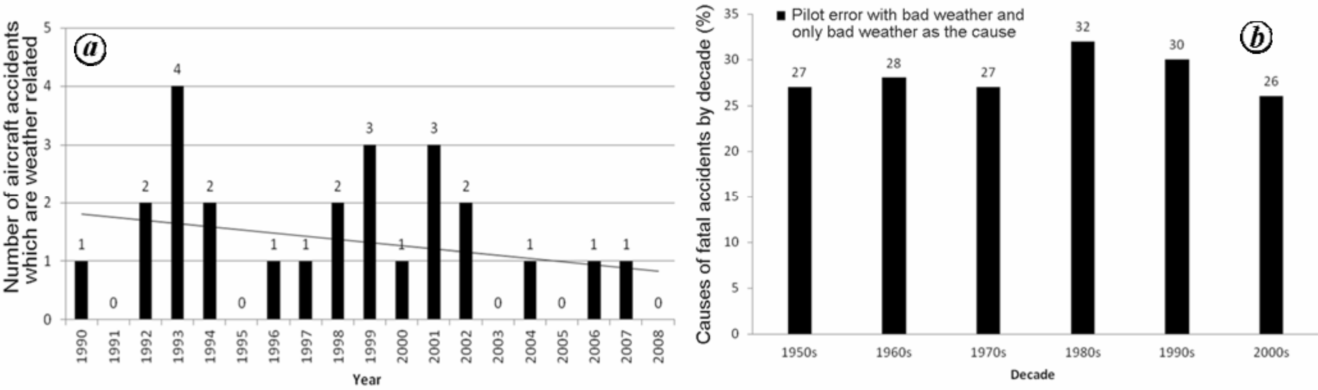


Figure 6. Year-wise and decadal time series of the total weather-related accidents in annual frequencies over India and weather-related accidents in percentage of total in the decade over the globe. ***a***, India – year-wise time series data from DGCA reports. ***b***, ACRO globe decadal data–decadal time series.

1,300 fatal accidents involving commercial aircraft, worldwide, from 1950 through 2009, for which a specific cause is known. Aircraft with 10 or less people aboard, military aircraft, private aircraft and helicopters are not included in this database. 'Pilot error (weather-related)' represents accidents in which pilot error was the cause but brought about by weather-related phenomena. 'Pilot error (mechanical-related)' represents accidents in which pilot error was the cause but brought about by some type of mechanical failure. 'Other human errors' include air traffic controller errors, improper loading of aircraft, fuel contamination and improper maintenance procedures. For India, it shows such aircraft accidents were the highest, i.e. 3–4 in 1993, 1999 and 2001. It has decreased since 2001, while for the global it has decreased since 1980, which was the decade of high weather-related aircraft accidents over the globe.

Weather-related and non-weather-related aircraft accidents based on type of aircraft

Various types of aircraft including helicopters which are used in private and business operations are mainly of non-scheduled type and smaller in size. There are also limitations in their technical design to withstand severe weather conditions. These flights have no 'weather radar' on-board and other modern navigational aids as available in the case of bigger scheduled passenger aircraft. These aircraft mostly operate in VFR in contrast to scheduled bigger passenger aircraft which operate in Instrument Flight Rules. Hence, these private and business aircrafts may be more accident-prone compared to bigger aircraft. Of the many aircraft accidents that occurred recently in India[2], most aircraft are of smaller types. Hence, it is necessary to find from aircraft accident reports whether private aircraft are more accident-prone, especially because of bad weather during the period. Like NTSB, we have classified them into various categories as follows to determine their respective percentage with respect to total aircraft accidents during the period for the Indian region.

(i) Airline operation: The operation includes all scheduled, non-scheduled and non-revenue flying by Indian Airlines, Air India, Alliance Air, Jet Airways, Sahara Air and Air Deccan.

(ii) Non-scheduled operation: The operation includes all non-scheduled ferry non-revenue, charter and test flying by other operators holding non-scheduled operators' permit and engaged primarily in such operations.

(iii) Flying training: Includes all flights used for the purpose of initial issue of a flying licence, for conversion and practice flying or qualifying for renewal/endorsement of pilots licence and test and ferry flying by organizations engaged primarily in flying training.

(iv) Aerial work: Includes aerial survey, aerial mustering on a commercial basis, aerial ambulance, aerial agricultural operations, etc. and test and ferry flying by organizations engaged principally in aerial work operations.

(v) Private and business: Includes private, pleasure and business flying and practice flying when the flying is not directly connected with the purposes of obtaining a higher licence qualification.

Figure 7*a* shows occurrence of the number of aircraft accidents according to the type of aircraft in percentage of total accidents during 1990–2008 over India. It shows that the highest percentage of flight accidents occurred in private/business aircraft touching 32%, followed by 26% for training flight operation and 22% for non-scheduled operation. Figure 7*b* shows percentage of weather-related aircraft accidents to total accidents reported, to see whether such accident rates have decreased with the time because of improvement in available weather information from the India Meteorological Department to users like

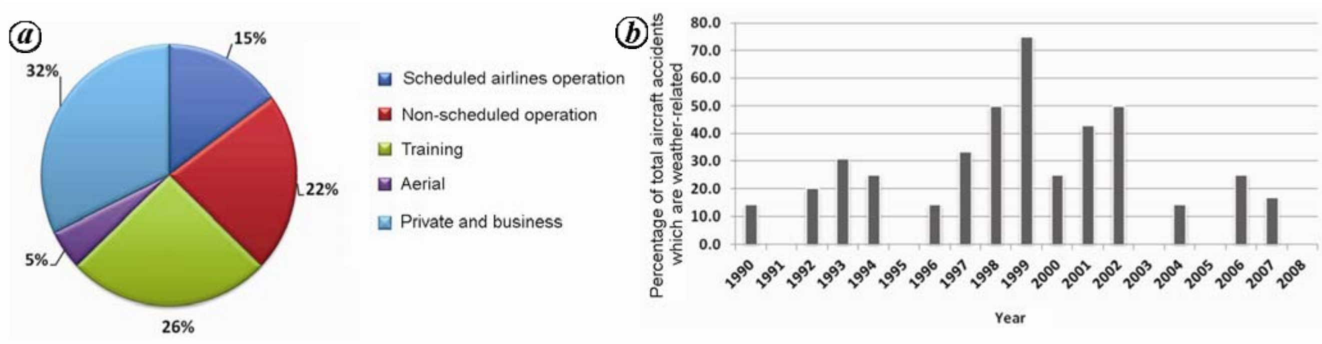


Figure 7. ***a***, Occurrence of number of aircraft accidents according to type of aircraft in percentage of total accidents occurred during 1990–2008. ***b***, Percentage of weather-related aircraft accidents to total accidents reported for India during 1990–2008.

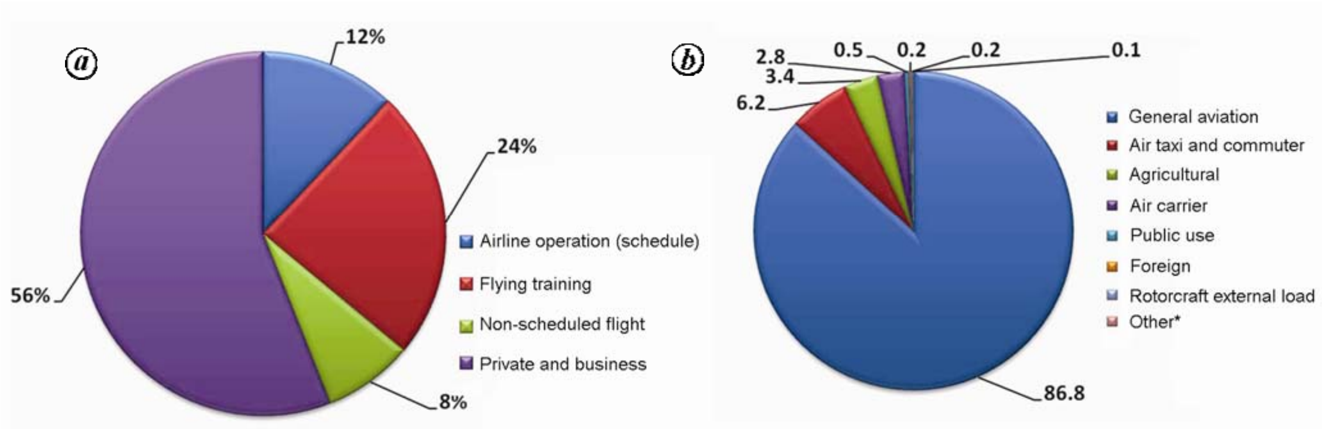


Figure 8. ***a***, Total weather-related aircraft accidents that occurred over India. ***b***, Aircraft category which was most prone to weather-related causes of accidents (in %) for USA.

Airport Authority of India and airlines. The annual number of weather-related accidents has declined (Figure 6 *a*). However, the ratio of annual number of weather-related accidents to that of total accidents (Figure 7 *b*) has not shown any systematic trend. Study of USA aircraft accident data[6] for 1994–2003 also shows similar results that the annual number of weather-related accidents has declined, whereas the annual number of weather-related accidents has remained roughly constant as a percentage of total accidents.

Of the total weather-related accident occurrences over India, aircraft category was most prone to weather-related cause of accidents (in %) for 1990–2008 (Figure 8 *a*). The highest percentage of accidents occur due to bad weather is of private/business aircraft category (56%; against their actual proportion to total number of aircraft accidents both weather and no-weather-related of 32%), followed by 24% for training flight operation (26% is their actual proportion if considered against total accident cases reported). Figure 8 *b* shows percentage of various types of aircraft accidents in USA which have been categorized with respect to aircraft operation type as defined by NTSB as air carrier operations, commuter/air taxi operations, agricultural operations and general aviation operations. It may be noted that the category of all aircraft types under general aviation operations in USA includes personal use, instructional use and business use and executive/corporate use. So it is comparable to private and business type operation of India. It shows 86.5% of total such accidents is under 'general aviation' followed by air taxi operator at 6.2% (see Figure 8 *b*).

Discussion

In view of the present study showing that weather-related aircraft accidents over the globe, including India have been presently at 21–26% of their total numbers, attempts must be made to automate and integrate all the components of aviation weather services with ATC and pilot on-board the aircraft. These include all of its observing systems, e.g. current weather parameters of RWY ends and airports, upper air wind flow, etc. and their nowcasting and forecasting products updated at each second to 3 hours in advance. There must also be provision to send these data through on-line dissemination system to users in a user-friendly format, especially to pilots both during pre-flight planning and on-board through ATC or satellite communication. Such observing systems must have capability to get a complete 3D scan of various weather events covering whole airport areas and along the flight routes. The presently available integrated aviation weather observing instruments at RWYs, cloud and wind scans by DWR and satellite, radiometer for vertical moisture contents, GPS sounding and upper air wind shear by Terminal DWR, lower level wind shear by anemometer array, wind conditions at flight path by WindTracer, etc. if integrated with a robust forecasting system over the airport, will help in reducing the weather-related aircraft accidents.

The fog monitoring, forecasting and dissemination system developed and implemented by the Meteorological Watch Office (MWO) of IMD at the Indira Gandhi International (IGI) Airport, New Delhi since 2008, where nearly 900 flights operate daily through three RWYs, is a unique attempt in this direction[11,12]. This service has been able to reduce the number flight diversion and help in safe flight operation. It may be noted that the IGI airport has been one of the worst fog-affected airports in the world and to mitigate such effect on flight, it has created world-class RWY facilities since 2009. It is the only airport in India having three-RWYs with two of them almost parallel and having all technology with CAT-IIIB ILS compliance, where flights can land up to 50 m visibility in very dense fog conditions. Now, flights are facing less disruption even during worst fog conditions. However, such integration attempts have been only restricted to special weather events like fog in winter.

In case of summer thunderstorms and dust storm for which the IGI airport is also highly vulnerable[13], further improvements are needed for strengthening its monitoring and nowcast system. Study of storm data and their impact on flight operations during May 2008 and May 2011, when a large number of storms with squally winds occurred, shows that 82 flights were diverted from IGI airport due to stormy weather, during May 2008, whereas another 40 flights were diverted in three days of TS activities during 19–22 May 2011. Hence, a similar fully integrated storm-monitoring, nowcasting, forecasting and dissemination system like the IMD Fog system, is needed for timely flight operation during summer at IGI airport.

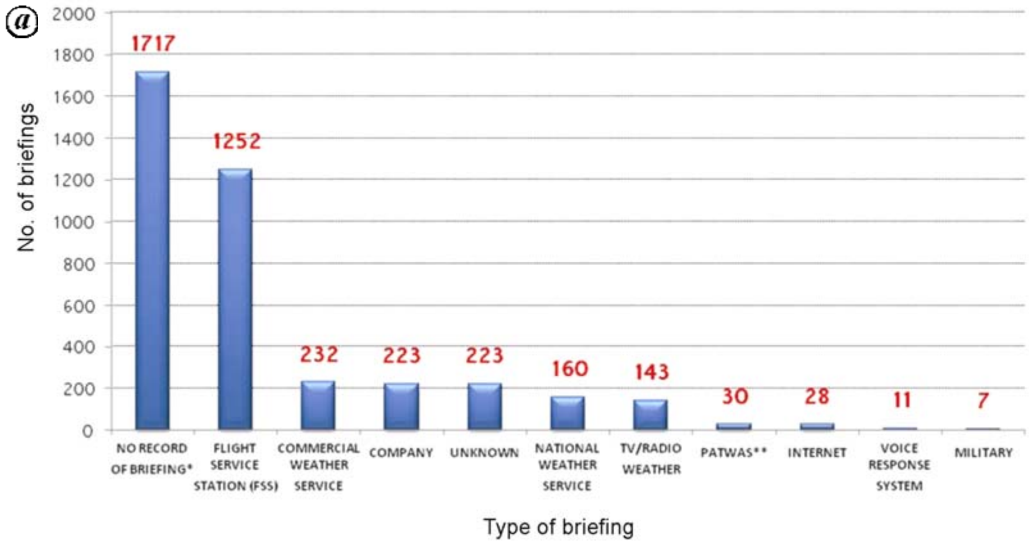
Presently, the MWO of IMD at IGI airport has a proposal to implement its most ambitious project to tackle all these aspects under the project 'Aviation Weather Decision Support System (AWDSS) at IGI Airport, New Delhi' which has to be carried out jointly by both software and aviation weather experts with provision for adding latest meteorological instruments, e.g. wind profiler, TDWR, radiometer, etc., for strengthening the existing observing, forecasting and dissemination system. The principal work components of AWDSS are as follows:

- Integration of meteorological data presently available at IGI airport and NCR Delhi from existing observing systems and likely to be available from proposed additional instruments like wind profiler, radiometer, etc. under AWDSS, for smooth and timely detection of hazardous weather affecting IGI airport and surrounding areas.
- Visualization on GIS map of these meteorological data and their products at specified map scales, with specified rates of their expected temporal update.
- Display of RWY-wise current weather data (such as wind, temperature, pressure, RVR, etc.) in seamless form which are mission critical to ATC (tower, approach and area control), and Airport Operation Control Centre (AOCC).
- Generation and transmission of auto-guidance for making various aviation weather decisions to various users: ATC, AOCC, etc. in suitable map-based and text form based on critical-range table for specified weather parameters and algorithms provided by IMD.
- Designing a dissemination support system for outputs from AWDSS and MWO of IGI airport.

Another important factor which has been affecting the safety of flight operations, especially private flights is worth discussing. It is about how serious pilots and their teams are about taking the weather briefing, warnings and looking at the latest DWR clouds of airports and about the airport from where they are landing and take-off, including weather forecasts of these areas before starting their flight operation.

But, actual longer-period data about whether pilots of various aircraft which have faced accidents during 1990–2008 due to bad weather, had taken weather briefings or not, etc. are not available in the DGCA reports to make any retrospective study. In contrast, NSBT has such data, which we have presented in Figure 9 to know how these weather-related aircraft accidents have been linked to the necessity for every pilot to take a complete weather briefing from proper sources for safe flying. The data show that 1717 flights out of 3822 weather-related aircraft accidents, which is about 55%, have no records whether the flights had taken weather briefings or not, whereas the remaining have records confirming these flights had taken weather briefings. It also shows that there only 160 flights which got weather briefings from national weather service. This shows implementation of new regulations on proper and timely weather briefings for pilots from reliable sources and greater coordination among all stakeholders as another need of the hour for mitigation of weather-related aircraft accidents.

Internationally for mitigation of these aircraft accidents, a recent innovation by NASA, the Next Generation Air Transportation System, or NextGen, will make travel through increasingly crowded skies more efficient and speedy while maintaining or increasing safety. NextGen, the state-of-the-art networking technology, will continually update its data and share that information with pilots



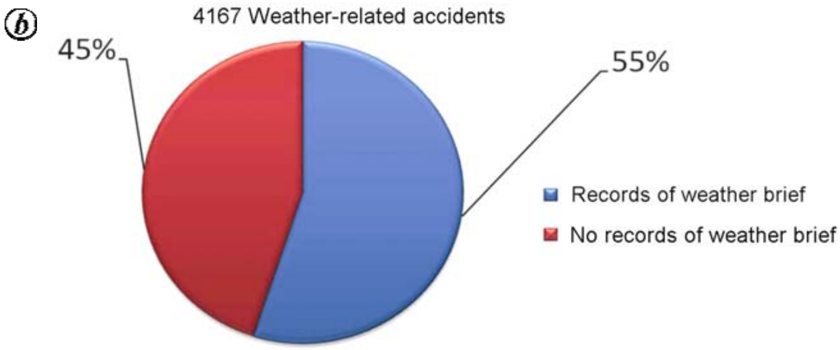


Figure 9. ***a***, Distribution of weather briefing sources in NTSB weather-related accidents (1994–2003). ***b***, Same as (***a***), but for two categories of record of weather briefing and no records of weather briefing.

and controllers. Aircraft will be able to immediately adjust to changing factors such as weather, traffic congestion, and positions of other aircraft, flight trajectories and any terrestrial or airborne security concerns. NASA's Aviation Safety Program (AvSP)[14] has many path-breaking objectives to help realize the full potential of this new future by examining the challenges that come with further reducing risk in a complex, dynamic operating domain like NextGen. Working with partners, AvSP provides fundamental research of already existing safety challenges and on new and emerging challenges. In fact, two out of ten technical challenges of AvSP have been identified as airframe icing, and atmospheric hazard sensing and mitigation.

Conclusion

The present study finds 21% of total aircraft accidents in India during 1992–2008 is weather-related, whereas in USA the proportion is a little higher, i.e. 22% during 1994–2003 and over the globe, it is 26–32%. When categorizing all weather-related aircraft accidents, a highest of 40% out of all weather related accidents has been mentioned in the DGCA Reports. But the analysis of specific weather events mentioned in the report shows that the highest number of these accidents is due to (i) wind-related from gust, updraft and downdraft and (ii) low visibility and ceiling, each responsible for 16% of total weather-related accidents. It is followed by another 12% of total weather-related accidents due to CB and thunderstorms. In USA, the highest of 48% occurrence is due to bad wind conditions, as found for India, followed by 20.5% as low visibility and ceiling. As most private aircraft, including helicopters have limited on-board meteorological and other avionic navigational aid and operate in VFR, they are more likely accident-prone compared to bigger aircraft during bad weather. Hence we carried out a study to validate this concept using data for both India and USA. The study for India confirms that about 56%, i.e. highest percentage of flight accidents occurring due to bad weather is of private/business aircraft category. This is against their actual percentage (32%) of the total number of aircraft accidents both weather and non-weather-related. It is followed by 24% of total weather-related accidents for training flight operations against 26% when considered against total accident cases reported. In the case of total weather-related accidents over USA, when categorized with respect to aircraft operation type as defined by NTSB as air carrier operations, commuter/air taxi operations, agricultural operations and general aviation operations, it shows 86.5% of total such accidents are under general aviation followed by air taxi operator at 6.2%. It may be noted that the category of all aircraft types under general aviation operations in USA include personal use, instructional use, business use, executive/corporate use; so it is comparable to private and business type operations in India. The annual number of weather-related accidents though shows an overall decline during the period both in India and USA, the ratio of annual number of weather-related accidents to that of total accidents in percentage has not shown any systematic trend. We have also discussed how coordination among all stakeholders and efficient use of newly available technology in meteorological services may help mitigate them. Remedial measures include the need for further improvement in present weather monitoring and dissemination systems and making provisions for mandatory user-oriented refresher training conducted at regular intervals covering the utility of these new systems. It may also include making regulation for each pilot to get proper and timely weather briefings from reliable sources such as national weather service before each flight operation. In case of bad weather, greater coordination and quick sharing of the severe weather information among all stakeholders at the airport, e.g. pilots, ATC, MET, airport operator, airlines operators, etc. may also help in mitigating its potential impact on aircraft in operation.

1. NE air crashes claim 66 lives in a decade. *Assam Tribune*, 22 April 2011; http://www.assamtribune.com/scripts/detailsnew.asp?-id=apr2211/oth06
2. *India Today*, 2011, Politicians who have died in air crashes at http://indiatoday.Intoday.in/story/arunachal-cm-dorjee-khandu-dies-in-helicopter-crash/1/137086.html
3. Director General Civil Aviation (DGCA), Accident to PILATUS PC-12 Aircraft VT-ACF of M/S Air Charters Services Pvt Ltd at Faridabad, Haryana on 25.05.11, 2012; http://dgca.nic.in/accident/reports/VT-ACF.pdf
4. Hunter David, R., Martinussen, M., Wiggins, M. and O'Hare, D., Situational and personal characteristics associated with adverse weather encounters by pilots. *Accid. Anal. Prev.*, 2011, **43**, 176–186.
5. Capobianco, G. and Lee, M. D., The role of weather in general aviation accidents: an analysis of causes, contributing factors and issues. In Proceedings of the 45th Annual Meeting of the Human Factors and Ergonomics Society, Santa Monica, CA, 2001.
6. NASDAC Review of National Transportation Safety Board (NTSB) weather-related accidents, 2004; http://www.asias.faa.gov/aviation_studies/weather_study/studyindex.html
7. Aircraft accident frequencies during 1999–2010 data from Aircraft Crashes Record Office (ACRO), http://www.baaa-acro.com/ through http://en.wikipedia.org/wiki/Aviation_accidents_and_incidents
8. Boeing, 2011, Statistical summary of commercial jet airplanes accidents, worldwide operations, 1959–2010; http://www.boeing.com/news/techissues/pdf/statsum.pdf. Also available at causes of fatal accidents by decade (percentage); http://planecrashinfo.com/cause.htm
9. Gloria, K., Weather and aviation: how does weather affect the safety and operations of airports and aviation, and how does FAA work to manage weather-related effects? In The Potential Impacts of Climate Change on Transportation Workshop, 2002; http://climate.dot.gov/documents/workshop1002/kulesa.pdf
10. FAA, 1983, AC00-24B – Thunderstroms.
11. Jenamani, R. K. and Tyagi, A., Monitoring fog at IGI Airport and analysis of its runway-wise spatio-temporal variations using Meso-RVR network. *Curr. Sci.*, 2011, **100**, 491–501.
12. Jenamani, R. K. and Tyagi, A., Evaluation of skill scores of real time fog forecasting system, various fog model performances of IGI airport during 2008–2011 and future prospective – a bench marking aspects, 2012.
13. Jenamani, R. K., Vashisth, R. C. and Bhan, S. C., Characteristics of thunderstorms and squalls over Indira Gandhi International (IGI) Airport, New Delhi – Impact on environment especially on summer's day temperatures and use in forecasting. *Muasam*, 2009, **60**, 461–474.
14. NASA Aviation Safety Program, 2011; http://www.aeronautics.nasa.gov/programs_avsafe.htm

ACKNOWLEDGEMENTS. We thank Mr Rajesh Kumar, Scientific Official of WMO Palam, IMD for his help in figure drawings. We also thank Dr L. S. Rathore, DG, IMD for his continuous support and encouragement and anonymous reviewers for their remarks.

Received 1 September 2011; revised accepted 15 November 2012