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Safety Forum 2024

Aviation Weather Resilience

Summary and Conclusions

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SAFETY FORUM

AVIATION WEATHER RESILIENCE

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The theme of the 2024 Safety Forum was "Aviation Weather Resilience".

The conclusions of the 2024 Safety Forum reflect that all stakeholders within the aviation ecosystem have a role to play in enhancing aviation weather resilience. Some key takeaways are that weather resilience requires:

- **People:** People need to be correctly motivated, but also trained and aware of the threats of aviation weather. Resilience can be enhanced by being forewarned.
- **The Person**: The individual is part of the team, and teamwork is essential to build up aviation weather resilience, be it within the flight deck, within the air traffic control tower, or among stakeholders — working as a team increases resilience!
- **The Organisation:** The engagement by the organisation at acknowledging the threat of adverse weather, and then ensuring correct training and the investment to enhance weather resilience.
- **Technology:** Latest technology is a game-changer, and this should be implemented where available. New and emerging technologies should be investigated at industry level for the increased resilience they bring.
- **Infrastructure:** Infrastructure needs to be adapted to consider changing weather patterns and conditions — is the infrastructure available today resilient to weather? Be aware of local emerging climate threats. Is the infrastructure adapted to do what we want it to do safely?
- **Learn, Understand, and Adapt:** To build up weather resilience, we need to learn about the conditions we are facing, understand the source of any changes in these conditions, and then adapt our tactics, training, and procedures to face the existing and emerging threats.
- **Use Data to Build Knowledge and Wisdom:** Data is a key foundation and facilitator for the adaptation of tactics, training, and procedures. However, data by itself does not bring value; what brings value is the conversion of this data into safety intelligence, which builds knowledge. Over time, this widespread use of knowledge generates wisdom — wisdom about what to do to develop aviation weather resilience.
- **Predict, Detect, and Proceed:** The use of technology enables the build-up of aviation weather resilience. It is key to enabling predictions of where a threat may be, and then, at a strategic level, to detecting the conditions such as adverse weather, enabling us to proceed safely — and building aviation weather resilience.
- **Foresight, Vision, and Courage:** Developing resilience is multi-faceted, but overall, it requires foresight and vision to see what the threat is, and how it is evolving, and courage to address the issues proactively.

1. Pressures on the aviation system stemming from existing on-board weather detection and avoidance:

- *This section focuses on how aviation weather resilience is built up, looking at the existing weather detection and avoidance means, and then highlights how these can be enhanced by the use of novel and new architectures.*

PRESSURES ON THE AVIATION SYSTEM	RESILIENCE CAPABILITIES TO RESPOND TO PRESSURES
Existing tools available for flight crew have limitations in the type of information that can be displayed (e.g., poor detection of ice crystals, distance limitation in wet turbulences detection and no detection at all of clear air turbulence on weather radar). This may delay the detection of some incoming weather threats or even prevent detection.	• Current weather radar technology has some limitations imposed by the technology that is used. However, as technology evolves, opportunities are being made to improve the information provided (e.g., improved lightning and hail prediction, and the display of information). • Latest weather radars have increased automation (e.g., radars with automatic tilt, which ensures better display, and reduces crew workload). This is one of the areas which can improve resilience against adverse weather. The installation of the latest technology should be encouraged to increase aviation weather resilience. • Training on the use of this technology needs to be integrated with the installation of such technology, to ensure that better situational awareness and benefits are fully realised.
Consolidation of different types of sometimes conflicting weather data.	• Conflicting information needs to be reconciled through global harmonisation and standardisation of weather system data classifications. A common descriptive/taxonomy is needed to make it easier for all stakeholders to understand.
Limited access to immediate information or related phenomena and the operational safety consequences leads to crews being surprised by events.	• Accurate and updated information should be provided to crews to keep them aware of the forthcoming conditions. • Uniqueness of a weather phenomenon could mean that whilst the weather on one side may be benign, the return on the radar may be hiding unexpected and more severe conditions, which could trap the aviator. • No aircraft should be exposed to the risk of being damaged because of a lack of information and communication (timely and accurate strategic and tactical weather forecasting).

2. Pressures on the aviation system — to be addressed by enhancements in weather forecasting and nowcasting:

- *This section focuses on how aviation weather resilience is built up, considering the information available to flight crew for strategic decision-making when avoiding adverse weather. It considers how nowcasting and forecasting need to work hand-in-hand to build up aviation weather resilience.*

PRESSURES ON THE AVIATION SYSTEM	RESILIENCE CAPABILITIES TO RESPOND TO PRESSURES
Weather information can be determined as strategic or tactical. The strategic part is what is defined before flight, whereas tactical weather information is what should be used during flight. **Not having sufficient information to make the right decision based on the tactical information can increase pressure on the aviation system and lead to poorly adapted decisions.** **Increase in ability to better improve both tactical and strategic weather planning can enhance aviation weather resilience.**	• Increase connectivity of aircraft as an enabler for giving real-time weather information/intelligence. Better connectivity can enable the widespread use of real-time satellite data to predict/plan for adverse weather events (nowcast vs. forecast). • Push as a recommendation at industry level the use of such connectivity to give crew the real-time weather information available. Look at standardisation and training. • New nowcast products, with extended accuracy modelling of up to two hours can significantly improve interpretation of weather phenomena, and mitigate a lack of connectivity for shorter sectors • Enabling the flight-prep to post-flight implementation of real-time weather information — e.g., via the electronic flight bag to complement existing and established meteorological information products (TAFs or METARs), and aircraft sensors (weather radar). • Development of functions to use aircraft as weather sensors, sharing real-time weather data (for example, data on turbulence) among all aircraft, can enable improved tactical awareness of adverse weather phenomenon, and enable awareness of weather situations, and also situations such as degradation of runways due to adverse weather (runway conditions — refer to the Global Action Plan for the Prevention of Runway Excursions (GAPPRE)).
Weather detection systems tend to concentrate on providing precise information. **In a cockpit view, it is insufficient to provide only limited data or information. In a crowded, complex air traffic system, weather data also must encompass all aspects that help the crew to safely proceed through areas of adverse weather.**	• Weather detection and observation technologies should not only provide information but also propose suggestions. • Tools to improve phenomena prediction are necessary to take anticipated actions (e.g., avoid), to improve detection by identifying and characterising the severity of threats (e.g., new ice sensors), to continue operation in the safest environment in adverse weather (e.g., use of infrared sensors to improve visibility in foggy conditions). But do not push operations beyond the weather safety "red lines" ⇒ There are times when even the birds don't fly! • Whilst things are changing fast regarding technologies, the regulatory evolution needs to be concurrent to ensure that timely implementation will, and can, occur. • Industry also needs to look at the development of plane-to-plane–sharing weather data collaboration and at the arrival of equipment that will push the boundaries of the established traditional equipment, and use of this equipment.
Disparate level of information and accuracy of meteorological forecasts all over the world.	• Encourage the aviation community to identify the emerging threats and vulnerabilities and address the gap to ensure a consistent and accurate level of global meteorological information.

2. Pressures on the aviation system — to be addressed by enhancements in weather forecasting and nowcasting (continued)

PRESSURES ON THE AVIATION SYSTEM	RESILIENCE CAPABILITIES TO RESPOND TO PRESSURES
Capability of current MET products to provide the level of information required for today's aviation ecosystem and the increased exposure to adverse weather.	• To improve the capability and continuous enhancements of MET products, the industry needs to globally take the commitment to continue to invest (both with resources and finance) to support such continuous development. • To use advanced technologies (like AI) as a complement to the traditional tools of providing meteorological forecast enhancing/improving operational weather information. AI models can deliver the same or better forecasting products compared to the traditional ones, they can be automatic, and they can be updated rapidly. • An example is the use of numerical weather prediction models (NWP). Use of AI can make the ability to analyse NWP data for the most important data markers more accessible to the industry.

3. Pressures on the aviation system to be addressed by pilot resilience and training:

- *This section focuses on the pressures on the aviation system, and how these pressures can be managed with respect to enhancing pilot resilience, knowledge, and training. It provides areas of interest to further assess and research the global aviation industry's weather resilience.*

PRESSURES ON THE AVIATION SYSTEM	RESILIENCE CAPABILITIES TO RESPOND TO PRESSURES
Resilience by Understanding Weather and Weather Phenomena	
Knowledge retention and lessons learnt — sharing of information on weather phenomena	• The aviation community should consider the ways local knowledge is recorded, stored, and shared. Some phenomena may be localised but may impact other users; some may be common but not understood. Training can be enhanced for: - Mountain waves; - Flash flooding; and, - Temperature inversions. • This information can be shared, for example, by including it in training scenarios as part of threat and error management. • Harmonise the expected level of awareness of aviation weather phenomenon. • Promote global training and awareness tools. Holistic, real-world examples of weather information can be shared on a free-to-access platform, which can widen weather awareness among aviation stakeholders. • Ensure there is a consensus in understanding weather information so that weather information can be converted into actionable weather intelligence by all aviation stakeholders. • Promote active collaboration: Expertise + Partnership + Innovation ⇒ development of a global information/knowledge database for all.

3. Pressures on the aviation system to be addressed by pilot resilience and training (continued)

PRESSURES ON THE AVIATION SYSTEM	RESILIENCE CAPABILITIES TO RESPOND TO PRESSURES
Training on Aircraft Systems	
Insufficient knowledge of the working principles and of how to exploit all the functions of weather-related tools may impede correct assessment of incoming weather-related threats.	• Understand what and how aircraft systems interact with adverse weather. • The weather radar is a primary source of tactical weather avoidance: - Understand what the weather radar shows. - Interpret the image. - Identify areas of threat and take appropriate margins. • Ensure that relevant operational documents are available to transmit information and recommendations to flight crews on how to use weather radar. • Define training scenarios for the aircraft systems — to help see and avoid — to increase weather resilience. Use weather radar and integration of other available systems such as supplementary weather information (e.g., EFB) to improve situational awareness.
There is pressure to use new technologies to fill in the gap of accessible, understandable information and weather inputs. **New technologies and equipment are various and abundant, leading to the risk of using the incorrect technology or using it in an improper way.**	• One aspect of weather resilience is the seamless integration of new and novel technologies to enhance resilience. It is not just the development, but also the integration, of this technology into the system that needs to be managed, including in a regulatory landscape. • For weather, one area is the use of "weather prediction". There are many different softwares on the market, for example, so organisations need to decide which one to use and when to use it". • The use of new technologies needs to be integrated into the regulatory landscape and into local-level standard operating procedures, and training. • The responsibilities to harmonise the training level for such technology needs to be clearly assessed at the industry level, based on new equipment capabilities (weather radar, for example).
Flight Crew Resilience Development — Situational Training	
It is important to accurately define the concept of resilient behaviour so it can be integrated into the working culture of the company/organisation to help guide performance under adverse/unexpected events involving weather and other developments.	• "Resilient behaviour" includes anticipating forthcoming events, applying what we learned from previous experiences as we formulate our response and adapting the mission to a specific situation while achieving the overall goal through an alternative approach. At the individual and organisational level, it is about converting "knowledge" to "wisdom". • Information to build up this knowledge can be retrieved through the reports submitted from past experiences (for example, from accident and incident databases and publicly available information such as the NASA aviation safety reporting system (ASRS) database. • Weather resilience, in all situations, requires relevant individual and organisational knowledge that can be retrieved from these sources. Consider also deriving information from different regions with different actual weather conditions. • Resilience can be developed by considering "challenging adverse weather condition" scenarios during training, enabling correct decision-making by crews throughout the flight. Examples of scenarios that may be encountered during approach are : - To make a go-around decision because of fog; - To make a go-around decision because of heavy rain; and, - To introduce unexpected variables in the training scenario to leverage the simulation.

3. Pressures on the aviation system to be addressed by pilot resilience and training (continued)

PRESSURES ON THE AVIATION SYSTEM	RESILIENCE CAPABILITIES TO RESPOND TO PRESSURES
Pressures on the flight deck to handle weather-related situations. **Safety considerations and safety margins are mainly seen as a flight deck topic.**	• Weather resilience begins with technological, human, and organisational factors. Building up this resilience when only considering the aircraft in adverse weather conditions is not sufficient. The main objective is to improve awareness and develop procedures to avoid the aircraft entering these undesired flight conditions. • When accidents occur due to adverse weather, it is not only a pilot failure but an air transportation system failure, and this needs to be considered when looking at the robustness of barriers to enhance weather resilience. • Investigation authorities and regulators have a role to play to mitigate the risk of weather-related safety events by going further than just the incident/accident investigation, and to have a proactive posture by studying specific weather-related safety risks and providing strong recommendations to the aviation community. • The aviation community and stakeholders should assess these recommendations and adapt practices to manage adverse weather phenomena occurrences, (e.g., retrieval and communication of weather information, implementation and training on using weather-related tools, etc.).
Learn from past experiences and feed this newly learned information back into simulation scenarios.	• The implementation of new technologies and procedures regarding weather resilience can be enhanced using past pilot reports when training in the simulator and, thus, learning from experience when facing such situations during actual flights. Building up individual knowledge generates wisdom. • This methodology contributes to the design of technologies and procedures intended to support pilot performance.
Learn more and learn better: A lot of valuable information from cockpit experience remains hidden and is based on feedback from the experience.	• To develop understanding and resilience, use pilot reports about the simulation experience to obtain information about the way pilots communicate in such situations: informal language, adaptive communication skills, body language, tactile cues to maintain situational awareness, think-aloud activity to learn from each other. Cued retrospective think-aloud methodologies show promise for revealing insights into difficult-to-obtain operator performance. • Enhance safety data by understanding routine resilience performance for stakeholders. • Learning from such experiences is a generic enhancement that can be applied to all situations, where weather resilience is one scenario that can be applied. Use this as a debriefing technique, and share the collective knowledge.
Never just weather: Other types of contributing factors (organisational, economical, technical ...)	• Some key points when developing resilience strategies: - Adaptability: Resilient strategies may not be specific; - If you can stop, then stop! **S T O P** (**S**top-**T**hink-**O**ptions-**P**lan); - If it doesn't feel right, check/ask whomever you think might be of help (e.g., air traffic control (ATC)); and, - Don´t hesitate to exercise your authority if something needs to be done differently than planned.

3. Pressures on the aviation system to be addressed by pilot resilience and training (continued)

PRESSURES ON THE AVIATION SYSTEM	RESILIENCE CAPABILITIES TO RESPOND TO PRESSURES
Data Analysis	
The collection of data is important (the reporting), but it is just a facilitator to the analysis and interpretation of this data to make "safety intelligence".	• Ensure that the right data is collected (e.g., "resilience data" where data shows what actions have been performed to counteract the adverse weather situation. • New data processing tools can help with looking at existing data. The right tools can help (e.g., training models to help with automation). • However, technology in assessing the data is just a means to an end, a facilitator (and sometimes care needs to be taken with the output). The key resource remains the expertise provided by the individual in understanding the event from a human aspect, and asking the right questions. • The aviation ecosystem needs to adequately resource professionals specialised in using the data provided by the aviation system to get the global picture of safety in aviation.
To get a full picture of the situation and to build up weather resilience, all data sources should be considered.	• The use of weather radar is only recorded to indicate what the weather radar is doing; however, what is not recorded is what the weather radar is seeing, whether the right tilt and settings are present. • Having this information could be invaluable as part of learning from all operations — in cases when adverse weather was encountered, but also cases when it was avoided.

4. Pressures on the aviation system to be addressed by weather resilience managed by air traffic control:

- *This section focuses on the important role that air traffic control plays in building up aviation weather resilience, and how it is a key stakeholder in the aviation ecosystem against the pressure caused by adverse weather.*

PRESSURES ON THE AVIATION SYSTEM	RESILIENCE CAPABILITIES TO RESPOND TO PRESSURES
Lack of understanding of the operational impact of weather phenomena.	• Understanding the operational impact and adverse weather resilience at the ATC level is important for building up weather resilience in the aviation ecosystem. The lack of operational preparation and understanding of weather phenomena may lead to an impact on the aviation ecosystem. • This can be enhanced by having dedicated MET teams in airports to support resilience. • Standards and best practices for using this weather information should be integrated collegially within the aviation community to ensure that the data is used consistently and uniformly.

4. Pressures on the aviation system to be addressed by weather resilience managed by air traffic control: (continued)

PRESSURES ON THE AVIATION SYSTEM	RESILIENCE CAPABILITIES TO RESPOND TO PRESSURES
Economic pressure on MET contractors leads to fewer meteorologists. As a result, meteorologists cannot be dedicated to aviation only, and in some aviation facilities, specialists in aviation weather are not readily available, which may affect the accuracy of weather forecasts and reliable data.	• MET services are provided by different types of institutions (public and private providers) around the world. Economic pressure is leading to a rationalisation of MET forecasts, with a tendency to provide more services (such as advice, support at working groups, studies, and audits of MET observation facilities) in addition to forecasts to enable better mitigation of weather risks. This portfolio should be harnessed to build up weather resilience. • Absence of on-site MET offices leads to loss of local knowledge such as micro-climate specifics and local nuances. Aviation community stakeholders, therefore, should consider active efforts to ensure regular knowledge-sharing or liaisons between these stakeholders to fill some of these gaps and avoid loss of local knowledge.
Lack of real-time weather information and rapidly changing information in operation at airports.	• To build operational resilience into airports, real-time weather data can enhance situational decision-making. • Novel and new technologies being developed or available (such as runway condition monitoring (using aircraft as a sensor) or nowcasting technologies) can ensure all stakeholders have this real-time information on hand to aid in making the appropriate decision.
In changing weather patterns, there are pressures on operational activity: - Delays, rerouting, network disruption; - Aircraft damaged and grounded, impact on fleet availability; and, - Impact on aircraft performance that leads to economic pressure.	• Aviation stakeholders should build weather resilience through innovation and collaborative problem-solving to mitigate the operational impacts and the risks of adverse weather. They must constantly adapt to weather challenges. • Resilience to aviation weather also means resilience to commercial pressure. Do not push operations beyond the weather safety "red lines" ⇒ There are times when even the birds don't fly!
Rare local weather phenomena may evolve and have a large impact on operations at airports, becoming more frequent with climate change. In these cases, the sharing of local knowledge by operators, airports, and ATC becomes invaluable.	• Efforts have to be made by all aviation stakeholders (airlines and local authorities responsible for infrastructure) to share information on unique local risks. This might help operators to better anticipate risks and take them into account in their safety margins and in building up collective knowledge and wisdom across the industry. • Infrastructure should be designed to be proactively resilient, as much as reasonably practical, to sudden, adverse weather events like flash floods, taking into account local knowledge. If needed, resources should be committed accordingly. • Infrastructure planners and operators should consider that extreme weather phenomena are likely to happen more often in the future.

4. Pressures on the aviation system to be addressed by weather resilience managed by air traffic control: (continued)

PRESSURES ON THE AVIATION SYSTEM	RESILIENCE CAPABILITIES TO RESPOND TO PRESSURES
Pressures on the decision-making process arise when a weather forecast affects airport or ATC capacity.	• To improve resilience at the ATC level, a global resilience plan is needed. Implementation of such a plan can be facilitated based on the accuracy of weather data. - This can be improved by implementing a long-term proactive plan that provides a more accurate description of events throughout the appointed day. • The strategic plan relies on a collaborative decision-making process, lining-up an airport service plan, MET forecasts and advice, and flight management capacities. • Decisions need to encompass all aviation stakeholders with their own needs and specificities. • Development of such a resilience plan is an iterative process, and lessons learnt when it worked well vs when it didn't work well need to be fed back systematically into development of resilience plans to build up the plans' robustness. • The information available needs to also be converted into weather intelligence to give contextual forecasts and precise information on the risks to customers to be used in their field of activity. • This can be done by MET suppliers that are integrated at the air transport system level between different stakeholders (e.g., give crosswinds values or forecasts; and complete these with accurate runway condition information to improve awareness on the risk to heavy aircraft of going around).
Possible network disruptions as a domino effect of local disruptions (e.g., mass diversion) or when large areas are involved.	• Local disruptions or weather events that concern large areas may have side effects on neighbouring sectors, causing stress on the air transport system, and consequently safety pressures. To avoid undesirable working conditions in terms of quantity or complexity for all stakeholders (air traffic control officers, pilots), anticipation of these events should be built into contingencies at the network level. • Anticipating means having a proactive posture relying on predictive analysis, especially regarding workload in affected control areas. Keeping operators updated is the best way to prevent them from acting on a reactive basis, at the ATC level. Tools for ensuring such predictive analysis should be integrated into the air transport system. • Weather disturbance management has to be coordinated with a global cross-border network approach that encompasses high-level trustful coordination, early anticipation and predictions, a protective posture (to ensure a safe and smooth network operation), collaborative decision-making, and exploration of the use of new and emerging technologies.
Traffic management relies on data. Disparate data coming from various countries may impede correct network management.	• Accuracy, continuity, and granularity of data supply are to be assured across boundaries. For this reason, practical and tactical network procedures should be adopted by all network stakeholders.
Aircraft flying higher and new technology dependencies (e.g., GPS) expose new weather-related threats.	• Investment should be made in addressing and building resilience against emerging threats, such as space weather. • There is a proactive need to study the impact on the network and anticipate its possible threats, and impacts on all stakeholders.

5. Pressures on the aviation system involving climate change in the future:

- *This section focuses on looking ahead, and how research, investment, and collaborative work can help the aviation industry prepare for the future, considering the uncertain impact of climate change.*

PRESSURES ON THE AVIATION SYSTEM	RESILIENCE CAPABILITIES TO RESPOND TO PRESSURES
Increasing exposure to hazards, impact of extreme weather, etc. **Hail damage to windshield, risk of multiple engine shutdown because of increases in the average size of hail.** **Clear air turbulence caused by jet streams, serious injuries to passengers or cabin crew not wearing safety belts due to more frequent severe clear air turbulence encounters in the Northern Hemisphere.**	• Management of climate change adaptation is important at the regulator level to enhance the industry's global weather resilience. Without it, the strategy to manage longer term adverse weather and to build up weather resilience will be inefficient and lack of global direction on the main threats and risks. • Management of the impact of climate change should be a strategic priority, by: - - Gathering scientific knowledge and understanding the impact via industry subject matter expertise (e.g., via cross-stakeholder working groups with specified outputs); - Enhancing understanding of emerging threats to safety from climate change and focus on the priority for research; - Helping regulators to manage the effect of climate change on aviation; and, - Assessing effects of new and emerging weather hazard trends on aviation safety (e.g., airborne icing, ice crystal icing, severe convective storms and associated hazards.) • The sharing of these outputs enables prioritisation of industry focus and research areas. It orientates inputs into new designs, procedures, infrastructure investments, enhanced weather information, and priority research areas.
The rate and frequency of adverse weather exposure is increasing, and the adverse weather is becoming more extreme.	• Use of AI may help to foresee the risks of weather phenomena occurrence and predict the enhancement of weather resilience. • The aviation community should holistically consider reviewing design certification standards, training, and operational limits by identifying and implementing actions to be taken from these assessments, as key inputs to enhance global weather resilience — leadership and common vision need to be established as priorities to ensure an effective and efficient strategy. • The aviation community has to continue to look further ahead to better anticipate the incoming risks related to global climate change. Development of aviation should therefore take into account disruptive weather. • Aviation stakeholders must also look ahead and build a path for the future regarding climate change challenges.

The Flight Safety Foundation Safety Forum, hosted by EUROCONTROL, is presented in partnership with EUROCONTROL and the European Regions Airline Association, and powered by SKYbrary.

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