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AIRCRAFT WEATHER MITIGATION FOR THE NEXT GENERATION AIR TRANSPORTATION SYSTEM

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1. INTRODUCTION

In December, 2004, an Integrated National Plan for the Next Generation Air Transportation System (NGATS) was submitted to the U.S. Congress (Joint Planning and Development Office 2004). This system is envisioned to be more flexible than that currently in place so as to accommodate new air travel options and to handle up to three times the current level of operations. A Joint Planning and Development Office (JPDO) has been created to develop and guide the collaborative planning efforts of the Department of Transportation, Department of Commerce, Department of Homeland Security, the Federal Aviation Administration, the National Aeronautics and Space Administration, the White House Office of Science and Technology Policy, and other experts from the public and private sector to achieve NGATS. The JPDO organization includes eight interagency integrated product teams (IPT), one of which, the Weather IPT, addresses the impact of weather on the safety, efficiency, and capacity of the air transportation system. This paper describes the challenges for improving aircraft weather mitigation to enable further increases in the efficiency and capacity of the air transportation system without compromising safety.

2. AIRCRAFT WEATHER MITIGATION

Atmospheric effects on aviation are described by Mahapatra (1999) as including (1) atmospheric phenomena involving air motion – wind shear and turbulence; (2) hydrometeorological phenomena – rain, snow and hail; (3) aircraft icing; (4) low visibility; and (5) atmospheric electrical phenomena. Aircraft Weather Mitigation includes aircraft systems (e.g. airframe, propulsion, avionics, controls) that can be enacted (by a pilot, automation or hybrid systems) to suppress and/or prepare for the effects of encountered or unavoidable weather or to facilitate a crew operational decision-making process relative to weather. Aircraft weather mitigation can be thought of as a continuum (Figure 1) with the need to avoid all adverse weather at one extreme and the ability to safely operate in all weather conditions at the other extreme.

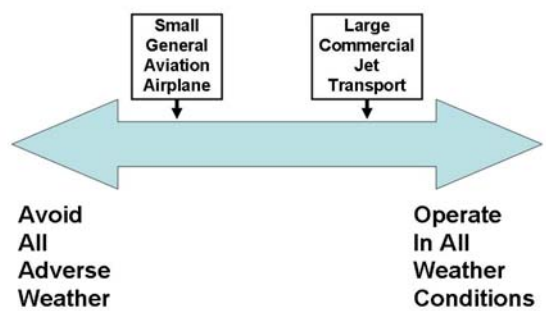

Figure 1. Aircraft weather mitigation continuum

Realistic aircraft capabilities fall somewhere between these two extremes. The capabilities of small general aviation aircraft would be expected to fall closer to the “Avoid All Adverse Weather” point, and the capabilities of large commercial jet transports would fall closer to the “Operate in All Weather Conditions” point. The ability to safely operate in adverse weather conditions is dependent upon the pilot’s capabilities (training, total experience and recent experience), the airspace in which the operation is taking place (terrain, navigational aids, traffic separation), the capabilities of the airport (approach guidance, runway and taxiway lighting, availability of air traffic control), as well as the capabilities of the airplane. The level of mitigation may vary depending upon the type of adverse weather. For example, a small general aviation airplane may be equipped to operate “in the clouds” without outside visual references, but not be equipped to prevent airframe ice that could be accreted in those clouds.

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2.1 *Weather Avoidance*

Avoidance of hazardous weather is dependent upon the availability and timeliness of observations, accuracy of forecasts, timely dissemination and presentation of this information to flight crews, and the integration of this weather information into the flight management decision process. Observations, forecasts, communication, and information integration are key elements of hazardous weather avoidance. The flight crew utilizes information derived from onboard sensors and off-airplane sources in conjunction with the out-the-window view and motion cues to establish their routing through or around adverse weather.

The availability of affordable, compact, lightweight, high-performance, data processing systems and high-capacity digital data links has facilitated the development of cockpit weather information systems to aid pilots in making weather-related decisions. A cockpit weather information system (Figure 2) consists of weather products, a means for transmitting the products, and a means to present the information to the pilot. However, pilots need more than just weather information for in-flight decision making. They need to consider aircraft capabilities, their own piloting capabilities, and flight-path-relevant terrain, obstacles, air space restrictions, and traffic. Data links enable exchange of information between airplanes and ground stations (Airline Operations Centers, Flight Service Stations, and Air Traffic Controllers). Aircraft-to-aircraft links enable timely exchange of in situ weather reports. Information from onboard sensors may be passed to ground-based weather systems for incorporation in updated forecasts and reports can be subsequently transmitted to aircraft in flight. Data-link weather information can be used to augment onboard sensors such as weather radar and lightning detectors. A prototype of such a system, the Airborne Hazard Awareness System (AHAS), has been developed and evaluated by a NASA, Rockwell Collins, and Georgia Tech Research Institute team (Stough *et al* 2005). Access to common information via data links and collaboration among flight crews and ground traffic managers should facilitate timely decision making for the safe and efficient routing of aircraft.

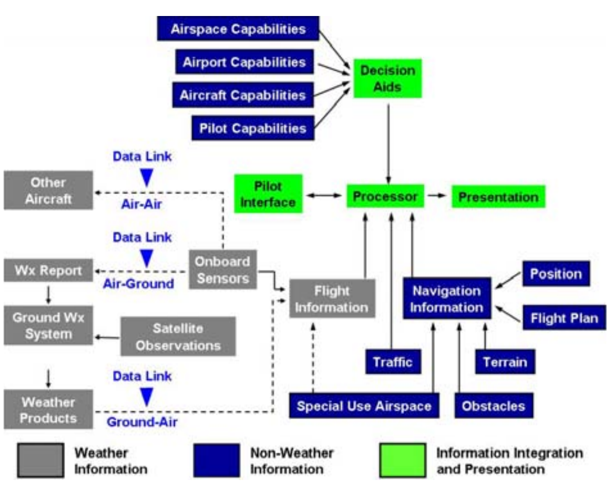

Figure 2. Block diagram of a cockpit weather information system

2.2 *Mitigation Examples*

Over the past century, continual improvements have increased the safety and operational capabilities of aircraft, especially with respect to weather. Some of these improvements include:

- Closed cabins with pressurization, heating and cooling that enable flight at altitudes above much of the adverse weather
- Lighting (airplane, airport and obstructions) that enable flight at night and in reduced visibility conditions
- Gyroscopic instruments for flight in reduced visibility conditions
- Pneumatic boots, heated leading edges, and de-icing fluid dispensers to remove or prevent ice accumulation on wings, tails, propellers, engine inlets, and other critical surfaces
- Electrical “hardening” to prevent lightning strikes from damaging critical components
- Onboard weather radar to detect and visualize precipitation intensity a hundred miles or more ahead of the airplane
- Anti-lock braking systems to prevent skidding on slick runways
- Thrust reversers to assist braking on slick runways
- De-icing fluids to clear airframes of ice accumulations prior to takeoff
- Grooved runways to improve traction on wet runways
- Autopilots and auto-throttles to precisely maintain an established flight path
- Airport lighting, signage, and surface markings to improve surface navigation at night and in reduced visibility conditions
- Instrument Landing Systems to provide precision approach guidance for landing in reduced visibility conditions

- Crosswind landing gear to increase the airplane's safe crosswind landing limits
- Lightning detection systems to indicate location of lightning discharges
- Gust alleviation systems to reduce airplane motions and structural loads caused by turbulence
- Flight Management Systems to generate precise steering commands for piloted or autopilot-assisted flight
- Auto-land systems to provide "hands-off" approach and landing in low-visibility conditions
- Wind shear detection and advisory systems to provide guidance for safely escaping wind shear encounters
- Enhanced and synthetic vision systems to increase situational awareness during landings in reduced visibility conditions
- Enhanced turbulence mode radar to identify convectively-induced turbulence twenty-five miles ahead of an airplane

As aircraft performance and ability to safely operate in adverse weather have improved, the desire has grown for aircraft to operate in more demanding environments and even worse weather conditions so as to enable further increases in the efficiency and capacity of the air transportation system.

3. NGATS and the JPDO

The Next Generation Air Transportation System Integrated Plan (Joint Planning and Development Office 2004) presents system goals and performance characteristics in six areas to be achieved by 2025: "(1) retain U.S. leadership in global aviation; (2) expand capacity; (3) ensure safety; (4) protect the environment; (5) ensure our national defense; and (6) secure the nation." The significance of weather is clearly identified in the objectives for expanding capacity: "satisfy future growth in demand (up to 3 times current levels) and operational diversity, reduce transit time and increase predictability (domestic curb-to-curb transit time cut by 30 %), and minimize the impact of weather and other disruptions (95% on time)." This expansion of capacity must include, and consider the needs of, a wide range of customers, including private, commercial, civil and military aviation. Older, less-sophisticated, and lower-performance aircraft must be accommodated while taking advantage of the capabilities of newer more-sophisticated and higher-performance aircraft. New vehicle classes, such as microjets and unmanned aerial vehicles, are seen as being a significant portion of NGATS operations by 2025.

The Integrated Plan includes eight major strategies to address NGATS goals and objectives: "(1) develop airport infrastructure to meet future demand; (2) establish an effective security system without limiting mobility or civil liberties; (3) establish an agile air traffic system; (4) establish user-specific situational awareness; (5) establish a comprehensive proactive safety management approach; (6) develop environmental protection that allows sustained aviation growth; (7) develop a system-wide capability to reduce weather impacts; and (8) harmonize equipage and operations globally." The multi-agency Joint Planning and Development Office (JPDO) has created Integrated Product Teams (IPTs) to identify what research and development is needed and the entities that need to be involved in executing these strategies. The eight IPTs are (1) Airport Infrastructure, (2) Aviation Security, (3) Agile Air Traffic Management System, (4) Shared Situational Awareness, (5) Safety Management, (6) Environmental Protection, (7) Weather, and (8) Global Harmonization. Within the Weather IPT, there are Sub-Teams to address Observations, Forecasts, Dissemination, Integration, Mitigation, Training and Policy. Systems Engineering oversight is provided at the IPT level. Communities outside the JPDO federal agencies are engaged via the NGATS Institute and participate as members of the IPT and Sub-Teams.

4. CONCEPT OF OPERATIONS

The Weather IPT has generated a NGATS Weather Concept of Operations (Weather Integrated Product Team 2006). This document is subordinate to the JPDO NGATS Concept of Operations (Joint Planning and Development Office 2006) that is currently in draft form. In the Weather Concept of Operations, aircraft systems (e.g. airframe, propulsion, and avionics) are seen as mitigating the effects of weather such as icing, turbulence, and restrictions to visibility. These aircraft systems significantly increase operational capabilities of the aircraft and reduce the associated airspace restrictions that can decrease airspace system capacity.

For weather-related decisions, observations, forecasts, and the level of mitigation that can be provided by on-board systems will be used to determine the optimal path for avoiding the hazard or for flying through the hazard region within the capabilities of the mitigation systems. To illustrate this concept, picture an airplane flying from point "A" to point "B" as depicted in Figure 3. Adverse weather exists between the two points during the time of intended transit. Through observations and forecasts, the region of adverse weather has been delineated into levels of intensity ranging from zero (no hazard) to ten (extreme hazard). If the airplane is unable to fly through conditions above level five, then it must be rerouted around much of the weather. If the airplane has the ability to fly through anything up to level seven intensity, then it's routing is unaffected. Enhanced weather mitigation capability effectively increases the usable airspace for such airplanes. Because this airplane is not constrained to the lower level of weather hazard, it has the indirect benefit of reducing the traffic congestion in the regions of lower hazard intensity.

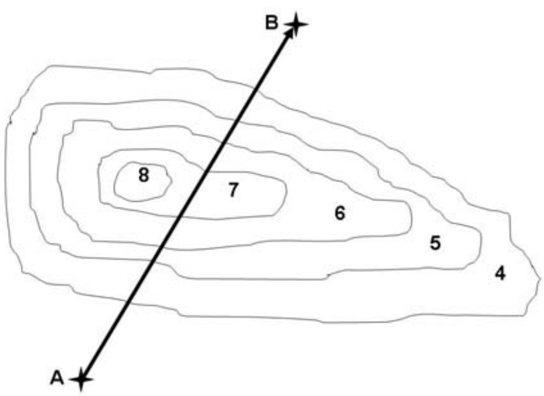

Figure 3. Depiction of route through various levels of adverse weather. Numbers indicate intensity of weather hazard with 0 being lowest and 10 being highest.

A similar concept was embodied in a route optimization decision aid developed by NASA and Honeywell for avoiding aviation weather hazards (Dorneich *et al* 2003). This aviation weather information flight planning tool had six "sliders" that could be adjusted to set acceptable hazard thresholds, ranging from not desiring to encounter any level of the hazard to willing to encounter the most severe level of the hazard. The hazards addressed by the prototype system included convection (three levels of hazard), ice (three levels of hazard), ozone (three levels of hazard), turbulence (four levels of hazard), volcanic ash (one level of hazard), and a "customer-defined hazard". Both vertical and lateral extent of the hazards were considered by the route planning tool. A shortcoming of this system was the need for a meteorologist to generate the polygons that described the boundaries of the different hazards and associated intensities. In an NGATS implementation, such a decision aid could derive the boundaries automatically from digital position, time, and probability data resident in the envisioned single authoritative source for weather information. Although the route optimization tool was evaluated as a dispatcher's decision aid, it could be incorporated into an airplane's onboard flight management systems.

5. RESEARCH AND DEVELOPMENT

The research and development that needs to be performed is being identified through the definition of Operational Improvements (OIs) that are needed to achieve the 2025 NGATS vision. The Weather IPT has defined OIs in five major areas – observation, forecast, dissemination, integration and mitigation. For mitigation, the OI describes aircraft weather mitigation improvements in six areas:

(1) Turbulence
More effective turbulence-sensing and control systems on new-design passenger and cargo transport airplanes could alleviate aircraft response to turbulence for both structural and ride-comfort purposes.

(2) Icing
Enhancements to sensors and de-ice/anti-ice systems for transport airplanes and near-all-weather GA airplanes could alleviate the effects of icing for the purpose of maintaining adequate aerodynamic, propulsion, and control capabilities.

(3) Obstructions to Visibility
Broader application of systems such as enhanced and synthetic vision could reduce the impact of obstructions to visibility for terminal area and ground operations. Enhanced vision systems are being used by some business and commercial operators today. Synthetic vision systems are being adopted by general and corporate aviation (Adams 2006). Potential benefits include runway identification on approach and taxiway identification during ground operations. One hurdle to improving the utility of synthetic vision is real-time verification of the integrity of the data used to generate the images.

(4) Wake Vortices
Advanced configurations and flight control systems for new-design passenger and cargo transport airplanes may reduce the adverse impacts of wake turbulence and enable closer spacing on approach and departure, and safe recovery from inadvertent wake encounters.
(5) Space Weather
Mitigation of the adverse effects of electromagnetic radiation and charged particles (space weather) on transport aircraft systems (especially navigation systems) and occupants could expand use of high altitudes and polar routes.
(6) Atmospheric Particulates
Passenger and cargo transport airplanes could benefit from systems to alleviate the effects of heavy rain, frozen precipitation, sand, dust, and volcanic ash on engine performance, operability and serviceability.

Information on location and severity of these hazards from observation and forecast systems could be disseminated to the airplane in flight, integrated with on-board sensor information (including terrain, obstacles, air space and traffic), and presented to the crew and automation systems as regions of airspace that can be navigated within acceptable encounter limits based on phase of flight, aircraft configuration and loading, and efficacy of the mitigation system.

Concepts for mitigation of weather-related hazards must be assessed for feasibility. The cost of development, implementation, and operation must be weighed against the potential benefits when utilized as part of an integrated weather mitigation system that also considers costs and operational benefits of enhancements to observations, forecasts, dissemination, and presentation of aviation weather information. Absent a regulatory directive, operators will determine whether such enhancements can "buy their way onto the airplane" in an NGATS environment.

6. SUMMARY

In the U.S., a Next Generation Air Transportation System is envisioned that can handle up to three times the current level of operations. A key to achieving this level of operations is minimizing the disruptions due to adverse weather. In addition to improvements in weather observing systems, forecasts, communications, and information integration, there is a desire for aircraft to operate in more demanding environments and even worse weather conditions than are currently possible, so as to enable further increases in the efficiency and capacity of the air transportation system. Needs have been identified to improve aircraft and their systems to counter the effects of turbulence, ice, wake vortices, obstructions to visibility, space weather, and atmospheric particulates. The solution is seen as an integrated system of observations, forecasts, information integration and dissemination, and aircraft enhancements that provide the greatest overall operational benefit for the least cost.

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