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Turbulence Auto-PIREP System (TAPS)

An Overview

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1 Introduction

Ever had a significantly bumpy ride during air travel or experienced a sudden heave in your stomach as an aircraft drops in flight without warning?

Nearly every day, turbulence has an adverse effect on aircraft operations and capacity of the National Airspace System (NAS). In fact, aircraft encounters with turbulence are the leading cause of injuries in the airline industry and result in significant human, operational, and maintenance costs to the airline community each year. The cost of these injuries, operational inefficiencies, and unscheduled maintenance to the airline industry is over $150 million per year. A Department of Transportation study even estimates that this cost could be in the billions of dollars. Both NASA and the FAA have goals to reduce turbulence injuries, but how can these turbulence injuries, inefficiencies, and unscheduled maintenance be reduced?

2 The Problem

A large contributing factor to the injuries and unplanned costs caused by turbulence encounters is that flight crews, controllers, and dispatchers do not have sufficient situational awareness of the location and severity of potential turbulence hazards to their aircraft. Even in this age of automation, pilots' and dispatchers' tactical knowledge of turbulence hazards still relies heavily on verbal pilot reports (PIREPs) of turbulence, which are often inconsistent, often late, and totally subjective. The reports are basically flight crew "wet finger in the air" estimates of the significance of the turbulence based on their experience and on the motion of the aircraft (e.g., vertical accelerations, airspeed and altitude variations, occupant accounts, etc.). These PIREPs offer little assistance to pilots and dispatchers in predicting how their aircraft may be affected by the reported turbulence. Furthermore, the verbal PIREPs do not help the dispatcher to reroute aircraft efficiently and safely through a potentially hazardous airspace.

3 What is the Turbulence Auto-PIREP System?

Recognizing the need for automatically detecting, classifying, reporting, and displaying turbulence hazard information, AeroTech Research (ATR), under contract to the National Aeronautics and Space Administration (NASA), developed the Turbulence Auto-PIREP System (TAPS). TAPS is designed to improve pilots', dispatchers' and controllers' situational awareness of the location and severity of turbulence hazards without increasing their existing workload. TAPS accomplishes this by automating the reporting of all significant aircraft encounters with turbulence and providing the pilots, dispatchers, and controllers a display of relevant, quantitative turbulence hazard information from which they can quickly and easily understand the impact that reported turbulence may have on their aircraft.

4 How does TAPS Solve the Problems?

4.1 For the Pilots

For aircraft that encounter turbulence: TAPS automatically transmits reports of turbulence encounters without increasing a pilot's workload. In fact, it actually reduces the pilot's workload, because it removes the need for him to personally communicate (either by voice or text message) information regarding the encounter (severity, location, etc.) to a controller or dispatcher. The pilot can now fully concentrate on flying the plane and maintaining safety.

The automatic reporting enables the reporting of turbulence to be consistent, timely, and objective.

For aircraft that receive TAPS reports: Received TAPS reports will automatically be scaled based on their aircraft's configuration before being displayed on their screens.

This scaling of the objective turbulence hazard information (a unique development by AeroTech Research) will negate the need for aircrew inference that is required to interpret current turbulence information, which is often inaccurate and does not estimate the severity of the hazard to each receiving aircraft.

With objective knowledge of turbulence hazards' severity and location, pilots will be able to:

- Avoid turbulence encounters through flight path deviations.
- Prepare for turbulence encounters by having all occupants seated with seatbelts on, thereby avoiding most injuries.
- Improve their negotiations with dispatchers and controllers to select a flight level that best balances the need for safety of the passengers (least turbulent altitude) and operational efficiencies of the aircraft (most efficient cruise altitude).

4.2 For Dispatchers and Controllers

The TAPS ground station display enhances dispatchers' and controllers' situational awareness of turbulence by enabling them to graphically view all of the TAPS reports transmitted from all equipped aircraft. Using functionalities built into the ground station display, the dispatchers and controllers can then scale the TAPS reports to other aircraft (even non-TAPS equipped aircraft) to determine the impact that the reported turbulence may have on that specific aircraft.

As with TAPS implementation for pilots, this ability to scale the quantitative TAPS reports negates the need for inference that is required to interpret current turbulence information. With the enhanced situational awareness of turbulence hazards provided by TAPS, dispatchers and controllers can accurately predict the effect of reported and detected turbulence on aircraft under their control; thereby, enhancing their ability to route aircraft around regions of potentially hazardous turbulence. By having an enhanced situational awareness of the real-time turbulence in the NAS, the controllers and dispatchers will also be able to make more efficient usage of the NAS and improve decision-making on the routing of aircraft within the system.

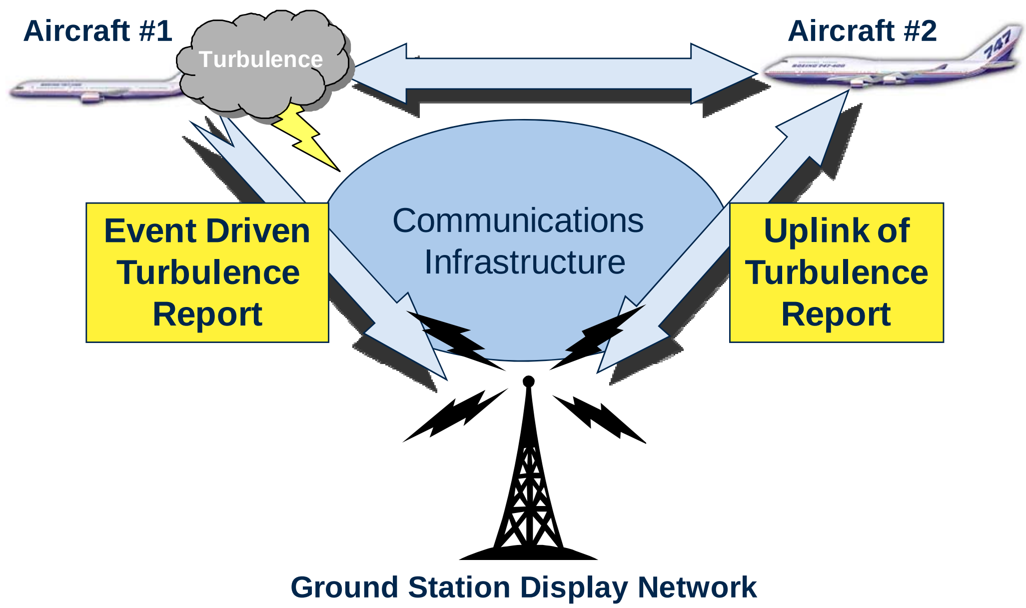
The display of real-time turbulence reports and information will also lead to a reduction in costs and number of injuries due to turbulence by assisting dispatchers in their collaboration with aircraft flight crews to avoid the hazards or to alert the crews to prepare the cabin for the potential turbulence. Also, instead of just identifying large regions of airspace where there may be (either forecast or subjectively reported) turbulence, TAPS can provide more precise, objective picture of the actual severity and location of turbulence hazards, which may allow more judicious use of airspace and lead to potential savings in fuel and reductions in flight delays.

4.3 For Airline Maintenance Personnel

TAPS reports enable Maintenance personnel, in real-time, to assess the need for a severe loads maintenance inspection based on the turbulence encounter. Currently most airlines perform severe loads inspections on their aircraft based on the pilot's interpretation of the turbulence level. This can lead both to performing severe loads inspections when they are not required, and not performing severe loads inspection when an event may have caused a maintenance issue. The TAPS reports provide an additional capability to inform Maintenance, based on quantitative information and analysis, whether a severe loads inspection is required. This enhances the efficiency of the maintenance division with regards to turbulence inspections and will save airlines significant money and labor.

5 How TAPS Works

Figure 1



Aircraft #1 encounters some form of significant turbulence (e.g., convective, clear air, or mountain wave). A TAPS report is automatically generated that contains a precise assessment of the turbulence encountered and the ship's system information below.

- Aircraft's position
- Time of occurrence
- Turbulence Severity (loads based)
- Maintenance Report
- EDR parameter[1]
- Various aircraft parameters

This report is transmitted to a ground station via a radio or SATCOM link, stored in a database, and displayed within the ground station network. The report may also be uplinked from the ground station, to other TAPS-equipped aircraft (e.g., Aircraft #2), for which the report may be of interest. An AeroTech-developed algorithm onboard Aircraft #2 will scale and interpret the data for Aircraft #2's type and current configuration (altitude, speed, and weight). If the report indicates a significant

[1] Will be available in future implementations.

turbulence hazard to Aircraft #2, the information will be graphically provided on a cockpit display. The cockpit display will contain other functions, which will enable the flight crew to filter and interpret the data.

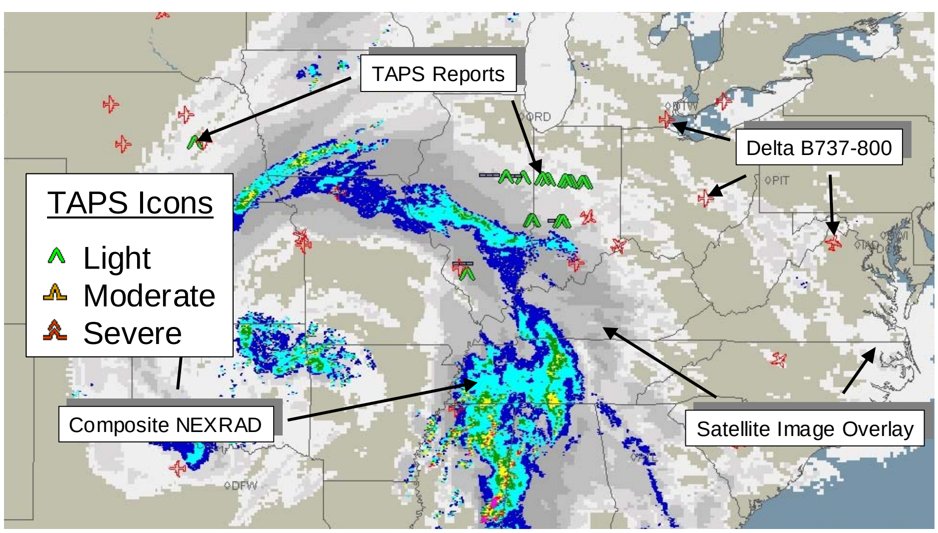
The TAPS reports may also be transmitted to other aircraft directly (Aircraft #1 to Aircraft #2) via an air-to-air communication data link. One potential air-to-air communication method is ADS-B.

The TAPS displays (both ground station and cockpit) present the TAPS reports as icons based on the severity of the turbulence. The icons are consistent with standard weather symbols representing turbulence (see below):

Iconic Symbol	Description	Color
	Light Turbulence	Green
	Moderate Turbulence	Amber
	Severe Turbulence	Red

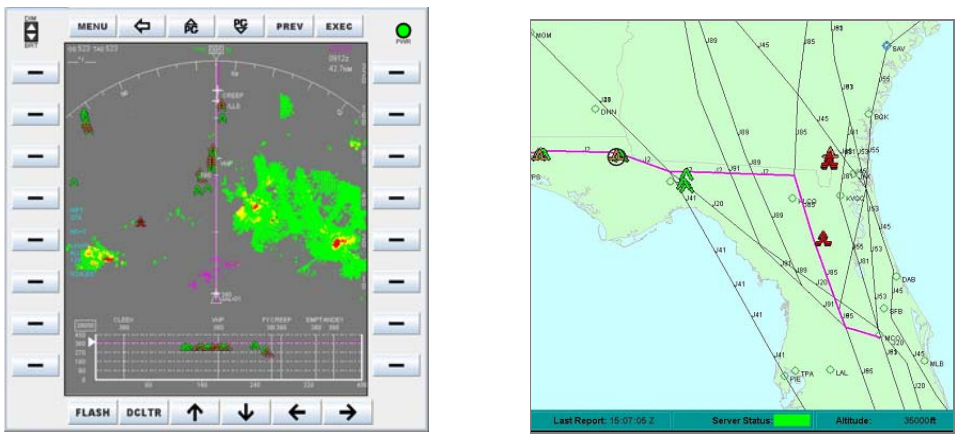
The ground station display is a web-based tool that displays the TAPS reports and information in real-time as an overlay to a graphical flight following system. Currently the TAPS icons and information are being overlayed on ARINC's Web Aircraft Situation Display (WebASD^{SM}), an interactive, web-based, graphical flight-following system. A sample screen shot of the ground station display is provided below that shows a storm system over the central United States. The colored areas represent radar reflectivity. Also shown are various aircraft in the area and the TAPS reports made by aircraft with TAPS algorithms transiting the area.

Figure 2



The cockpit display presents the received TAPS reports relevant to that specific aircraft directly to the pilots in the cockpit. Like the TAPS ground station display, pilots will have various functions that will enable them to customize their display to enhance their situational awareness of potential turbulence hazards to their aircraft. These display functions were developed with commercial airline pilot input and through evaluations in a Level D Full Flight Simulator. The simulator evaluation integrated TAPS information into what would be considered a Class III Electronic Flight Bag (EFB), but the avionics connectivity exists to incorporate the TAPS reports into a Class II/III EFB and/or a primary navigation display. Figure 3 shows the integration of TAPS reports with radar reflectivity, enhanced turbulence (E-Turb) radar information, and navigation information on a Class III EFB type display and the display of TAPS information on a Class II EFB overhead map type of display.

Figure 3



6 Components of TAPS

TAPS has been designed to take advantage of the systems and information that are already incorporated into commercial aircraft; therefore, additional hardware/software changes will be minimal.

The TAPS can be summarized as three components:

1) Algorithms/software code onboard aircraft for measuring a turbulence encounter and creating a TAPS report for transmission.
2) Ground station system with software that:
   a) Receives and displays the TAPS reports,
   b) Enables the user to customize the display of TAPS reports,
3) Algorithms/software code onboard aircraft for receiving, interpreting, and displaying TAPS reports in the cockpit.

7 TAPS Integration

The TAPS (not including the cockpit display and the direct air-to-air communication) is currently considered at Technology Readiness Level 8. The system completed Level 7 through tests onboard the NASA B757-200 research aircraft (2000-2003) and through an in-service evaluation (with NASA) on 123 Delta Air Lines aircraft beginning in 2004. The TAPS reporting algorithms are currently flying in commercial revenue service on B737-800, B767-300ER, B767-400ER, A318, and A319 aircraft. The

TAPS ground station display algorithms have been incorporated into ARINC's WebASD℠ for use by various airlines' dispatch and flight operations personnel. The TAPS interpretation algorithms and cockpit display functions have been developed for an overhead map application for a Class II/III EFB and have been evaluated in a Sector PPI (Plan Position Indicator) display on a Class III EFB display in a Full Flight Simulator.

7.1 Aircraft Algorithms:

The TAPS algorithms/code required onboard each aircraft can be integrated into any number of aircraft computer hardware as long as the algorithms have access to 429 databus ship system information or independent system measurements. One option for integration of the algorithms is within a Class II/III EFB.

7.2 Ground Station Display System:

The ground station algorithms can be easily integrated into existing Graphical Flight Following (GFF) systems or access to a web based TAPS GFF can be obtained.

7.3 Cockpit Display:

TAPS reports can be integrated into a variety of display types including Multi-Function Displays (MFD), Radar Display hardware, and Class II/III EFBs as long as a connection to the communication system and ship system information is available. Evaluations with commercial airline pilots have shown the advantages of integrating the real-time TAPS reports with weather radar reflectivity, enhanced turbulence (E-Turb), and navigation information.

8 Benefits of TAPS

TAPS benefits airlines, flight crews, flight attendants, passengers, and Air Traffic Control in several ways:

8.1 Safety

- Reduced injuries to flight attendants and passengers due to enhanced turbulence awareness by flight crews, avoidance through flight deviations, and turbulence preparation (e.g., passengers and flight attendants seated with seatbelts fastened and loose items secured).
- Improved collaboration on turbulence hazards and flight changes between pilots and dispatchers/controllers.
- Improved ability to select altitudes that best balances the need for safety with operational aircraft efficiencies such as airspeed and fuel consumption.

8.2 Operations

Increased situational awareness of turbulence hazards in the National Air Space for pilots, dispatchers, and controllers. This situational awareness:

- Enhances dispatchers and controllers ability to route aircraft around regions of potentially hazardous turbulence.
- Enables more judicious use of airspace and can lead to potential savings in fuel and reductions in flight delays.

- Enables the selection of flight level (based on real-time turbulence) that best balances the need for safety of the passengers and operational efficiencies of the aircraft. This could lead to significant fuel savings, while maintaining safe operations.
- Can be used to validate or enhance meteorologists' weather forecasts.

8.3 Maintenance

- Provides real-time notifications to airline maintenance concerning the necessity for a severe loads inspection based on quantitative measurements and analysis. Initial research studies indicate that this could safely and correctly reduce severe loads inspections by as much as 50%.
- Potentially less unscheduled maintenance and longer airframe life due to ability to avoid turbulence.

9 Summary

Hazardous turbulence continues to take a significant toll on aircraft, the airlines, passengers, flight crew, and the efficient use/capacity of the airspace. NASA has recognized that just telling passengers to buckle up and maintaining the current method of providing turbulence information to flight crews, dispatchers, and controllers will not reduce the injuries to flight crews and passengers, nor increase efficiency in the use of airspace.

NASA's Associate Administrator's recent March 16, 2005 testimony to Congress reaffirmed the need to adopt a solution to this issue.

Protecting air travelers and the public is the focus of the Aviation Safety and Security Program which develops technologies for both National Aviation System and aircraft that are aimed at preventing …unintentional events that could cause damage, harm, and loss of life; and minimizing the consequences when these types of events occur. Aviation safety focuses on technologies that can reduce aircraft accident rates and reduce aviation injuries and fatalities.

Turbulence is a leading cause of in-flight injuries and costs the airlines at least $100 M per year. To address this issue, AvSSP has designed and is performing in-service evaluations of a turbulence prediction and warning system with a major airline that gives flight crews the advanced warning needed to avoid turbulence or advise passengers to sit down and buckle up to avoid injury…….

AeroTech's TAPS is the system that will enhance pilots', dispatchers', and controllers' situational awareness of hazardous turbulence, result in a reduction in turbulence related injuries and maintenance costs, and enhance efficient use of the air space. Because the system and its algorithms are not limited to certain types of aircraft or hardware, the system can be integrated into nearly any aircraft. With the integration of TAPS, aviation safety and operations efficiency will take an important step forward in the 21st century. TAPS is a proven product that is currently flying in commercial revenue service and could be in your aircraft and operations center tomorrow.

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