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Concept of Operations for an Integrated Turbulence Hazard Decision Support Tool for Controllers and Dispatchers

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1. Scope

Section 1 provides an overview of the Concept of Operations (CONOPS) document and the functional area to which it applies.

1.1 Identification of the Technology

The goal of the NASA Aviation Safety and Security Program (AvSSP) was to develop technologies that address the causal factors of historical fatal aviation accidents, as well as to develop proactive, system-wide risk detection technologies to prevent future accidents and mitigation technologies to reduce their severity. The AvSSP conducted research into pre-emptive identification of aviation system risk, into accident severity mitigating technologies, and into accident prevention technologies across four causal factor areas. The causal factor areas include limited visibility operations, unseen weather hazards, aircraft component failures, and human errors.

In addition, the Next Generation Air Transportation System (NextGen) development by the Joint Planning and Development Office (JPDO), aimed at trebling airspace capacity by 2025, has identified the need for improved weather information in managing air traffic in the National Airspace System (NAS). In particular, turbulence is identified as a significant hazard and real-time information of this hazard will need to be integrated with and support NextGen decision-oriented automation capabilities and human decision-making processes. This information will support trajectory-based planning and decision-making. Although this integration is not addressed in this work, it is a key design philosophy, and will be addressed as the system is developed.

This CONOPS document has been written to complement and meet many of the stated goals of the AvSSP and the JPDO. This document is intended to provide a complementary basis for NASA's continued AvSSP and airspace research as well as a baseline upon which system design can proceed to develop products whose functionality will provide those capabilities described herein. The purpose in providing this basis is to ensure that the operation of those products in their respective functional use areas is supported by a consensus of aviation industry and regulatory views. This document may also provide the basis for development of certification or approval standards for those products that would require certification or operational approval.

This CONOPS addresses the incorporation of the Turbulence Auto-PIREP System (TAPS®) and the Enhanced Turbulence (E-Turb) Mode Radar technology within an integrated turbulence hazard decision aid, referred to in this document as TurbDST, for participants of the Air Traffic Control (ATC) and Air Traffic Management (ATM) systems. The CONOPS is intended be a living document, to the extent that the concepts presented may need to be modified to ensure continued applicability in light of advances in the technology, integration with other technologies, maturation of other technologies that support or enhance the operability of the subject technology, changes to the system in which the technology is suggested for insertion, or other factors. The initial version of this document is intended to communicate an understanding of the aviation stakeholders' needs for and expectations of the proposed technologies to potential users and/or developers. It represents an understanding of how commercial products based on the proposed technologies will operate to fulfill those expectations.

1.2 Document Overview

The CONOPS is written in compliance with NASA's AvSSP Products CONOPS Guide, which was developed by the Technical Integration Project of the AvSSP as part of the Systems Engineering effort. The guide was developed through consideration of a variety of existing Concept of Operation documents, as well as a number of Concept of Operation development guides published by standards organizations and commercial entities. The guide most closely follows the IEEE Draft Standard, *IEEE Guide for Concept of Operations Document v3.1*, from January 1998, with modifications to the outline and content to ensure applicability within aviation products as opposed to software product development, and NASA's AvSSP-specific content requirements. The AvSSP CONOPS Guide also incorporates the *AIAA Guide for the Preparation of Operational Concept Documents* definition of a system as "a collection of hardware, software, people, facilities, and procedures organized to accomplish some common objectives."

At a high level the CONOPS describes the current system, justifies changes to it, and describes the resultant system, presenting scenarios to illustrate the proposed system operations.

The audience for the CONOPS includes those within the aviation industry, NASA, and the FAA or other regulatory agencies that play a role in the operation of the aviation system segment addressed by the CONOPS. The likely audiences will range from subsystem designers to aircraft manufacturers, air carriers, pilots, air traffic controllers, dispatchers, researchers, and regulators.

Section 1 of the document provides an overview of the document, its purpose, and an overview of the system and AvSSP and airspace research products addressed.

Section 2 of the document lists referenced documents and sources of further descriptions of details contained within this text.

Section 3 of the document describes the current system. An overview of the current system is provided along with a detailed description of those areas in which change is proposed.

Section 4 of the document provides justification for changing the current system.

Section 5 of the document provides an overview of the technologies proposed, along with specific operational concepts for the technologies.

Section 6 of the document details linkages between the proposed technologies and plans, policies, and programs that the NASA, FAA, and others have published.

Section 7 of the document details operational scenarios for the proposed technology that demonstrate improvement in the modes of operation within the current system.

Section 8 of the document presents operational concepts that were considered and discarded. Also presented are supporting and enhancing processes, procedures and other technologies that enhance the proposed application.

Section 9 of the document presents summary conclusions and recommendations, including follow-on plans to increase the NASA Technology Readiness Level or further refine the concept of operations.

1.3 System Overview

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. In a ten-day period in August 2003 alone, over 30 passengers and crew were hurt, some seriously, in turbulence encounters. In addition to the human costs, airlines have numerous unplanned operational and maintenance costs associated with turbulence encounters. Reports published by the National Research Council, aviation industry, and Federal Aviation Administration continually point out that weather (including all forms of turbulence) "continues to be a major factor adversely affecting National Airspace System capacity, contributing to approximately three-fourths of system delays greater than 15 minutes" and 70% of the overall delays, diversions, and cancellations. These delays, diversions, and cancellations represent significant costs to the airlines, which already have fragile bottom lines. The Air Transport Association (ATA) estimates the total direct (aircraft) operating costs of delays in 2005 to be $5.866 billion [1]. The Bureau of Transportation Statistics estimates that 77.4% of all NAS delayed minutes were due to weather delays [2]. This translates into a total cost of $4.54 billion.

A large contributor to the above injuries and costs is that flight crews, traffic management specialists, controllers, and dispatchers have poor knowledge and insufficient situational awareness of the location and severity of potential turbulence hazards to aircraft under their control. Without this direct knowledge and awareness, aircraft may be unnecessarily routed around airspace that appears threatening, but actually contains light or less-than-light turbulence, or aircraft could be inadvertently routed into areas of hazardous turbulence. Improvements to the status quo will be accomplished by the development of a TurbDST that will enhance situational awareness of the location and severity of turbulence; by providing real-time quantitative turbulence information downlinked from aircraft. This decision aid will remove the need for inference that is required to interpret current turbulence information. The TurbDST will enhance tactical and strategic decision making with regard to airspace usage and aircraft routing by enabling users to predict the effect of the reported turbulence on aircraft whose route may take them through that location.

It is envisioned that this TurbDST will enhance situational awareness for the users with improved turbulence hazard information, allowing them to operate air traffic more efficiently and safely. Significant reductions in flight delays and cancellations, fuel waste and costs associated with injuries due to turbulence are expected to be major commercial drivers for this system. The primary market for this decision support tool is all Part 121 (both domestic and international) airline operation centers and the many air traffic control facilities throughout the United States with the secondary market moving towards business and general aviation aircraft operations.

This TurbDST will be supportive of NASA's Airspace Systems program's goal to develop "high capacity, efficient, and safe airspace and airportal systems that will enable the Next Generation Air Transportation System, as defined by the Joint Planning and Development Office." The TurbDST will have direct application to the Airspace Program's Adaptive Air/Ground Automation Concepts & Technologies research area, specifically with regards to shared situational awareness, collaborative decision making, traffic flow management, air-to-ground information sharing, 4-D trajectory operations, and dynamic airspace design.

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3. Current System Description

The proposed TurbDST not only integrates information from two data sources (Pilot Reports (PIREPs) and Radar), but also integrates information from improvements to these data sources, and incorporates other new data sources as they become available. Therefore, in order to understand the final system operation and the justification to changes made to the current system, it is important to begin by considering each system separately. In current operations, a dispatcher's or air traffic controller's total "picture" of turbulence hazards is achieved by listening to reports from pilots within their region of control / influence and watching any available weather radar displays – thereby, assimilating the information mentally. This "integration" process may be different from user to user, and a description of this process may be subjective at best, and will not be attempted. Each subsection below will consider PIREPs and the radar separately. Any potential combination of the two will be addressed if applicable. The integration of improvements to the system will be dealt with in the following sections.

In addition to a background description of the current capabilities of the system, the operation policies and constraints in place, the mode of operations of the dissemination of turbulence reports and the users and stakeholders within the current system will be described. The TAPS concept and the Enhanced Turbulence Radar product integrated within a decision support tool for the current system will improve the situational awareness for the end users, thereby improving the system as a whole.

A similar CONOPS has been developed for an integrated turbulence hazard display for the cockpit and is intended to be completely complementary to the CONOPS herein (Reference [15]).

3.1 Background, Objectives, and Scope

Pilot reports of turbulence are made to allow information of flight conditions to be passed to other aircraft. These reports are often made to controllers or dispatchers. The concept is to use these reports to warn other aircraft about regions of turbulence and for pilots to prepare the occupants for a rough ride. Currently there is no automated method of making these reports, and it befalls the flight crew to perform this duty as will be discussed in the following section.

Because of the subjectivity associated with a human-based interpretation of a turbulence encounter and the steps needed to get a report available to other pilots, PIREPs, particularly in the environment of Part 121 carriers, are extremely scarce. More typically, pilots and controllers discuss reports, which may be unreliable with respect to intensity or location, made by other aircraft over designated aviation radio frequencies. Intensity is defined in Federal Aviation Administration (FAA) manuals as the spilling of liquids and/or loss of aircraft control. No formal measure of the true aircraft response resulting from g loads caused by the turbulence is made. The location given is generally an altitude with little geographical information other than a reference to a navigation aid. Because of this, several altitude levels can essentially be eliminated from the available airspace by a few non-descriptive reports of a rough ride. In addition, these reports are often not formally entered into the FAA database of PIREPs, due to high workloads and the assumption by both controllers and pilots that the other party has reported the event to be entered in the system. This has resulted in an almost exclusive reliance on frequency "chatter" and internal, company mandated pilot reports in articulating areas of turbulence within the Part 121 environment.

Another source of weather hazard information is weather radar, first introduced over 50 years ago. At the time of its introduction and for many years since, it was primarily used to avoid thunderstorms based on moisture reflectivity using basic radar hardware with no software intelligence. However, reflectivity is a represents moisture level (raindrops), not necessarily hazards such as turbulence. As aircraft weather radars have evolved over time, they have become more sophisticated using software algorithms to automate tasks such as gain and tilt control to give a better predictive depiction of hazards to the aircraft. Many of the same advances are applicable to ground based weather radars.

The following description will encompass all users for turbulence reports, both in the cockpit and on the ground. Although some of these users may not be directly relevant to each individual phase of a flight, a full understanding of how the information is produced and used is important in the development of improvements for the current system.

3.2 Operational Policies and Constraints

The current system today, as it pertains to turbulence information, is very basic in nature, with little technology support within the industry. PIREPs are scarce and unreliable because of the subjective and manual way in which they are handled. Examples of this are shown in the basic definition of turbulence and the conservative method used to avoid turbulence based on USAF policies designed in the 1950's as documented in the FAA's Advisory Circular AC120-TURB[1], "Preventing Injuries Caused By Turbulence."

There are three basic threats to the aircraft when associated with encounters of turbulence. These threats are listed below, as well as their consequences. In essence, the justification of a TurbDST incorporating TAPS and an Enhanced Turbulence Radar product is to minimize these threats as much as possible.

1. Safety - Injuries to passengers or flight crews. Flight attendants sustain most injuries.
2. Economic - the economic cost imposed by the consequences of the other two threats (injuries and structural) is fairly well documented. The economic cost of avoiding turbulence, which includes altitude and routing changes, is less straightforward but thought to be very significant. Crews and dispatchers often decide to change altitudes and routes using very conservative guidelines because of insufficient turbulence information. As the airspace becomes increasingly congested, it becomes more important to identify weather hazards versus merely areas of weather, which are currently broadly perceived as hazardous. Because of a lack of tools to distinguish between these two things, Air Traffic Control and the Traffic Management Unit (TMU) decision makers will often close large blocks of airspace based on reflectivity in a convective area. If a system can be

[1] Superseded by FAA AC120-88A, 11/19/07.

developed and implemented that will pin point the turbulence hazard, more routes and altitudes will become available in the convective areas of interest while maintaining an acceptable margin of safety. Without these tools, the economic pressure for more airspace would not be possible while meeting the national goal of NASA's Aviation Safety and Security Program of a 50% reduction in aviation accidents by 2007.

3. Structural - structural damage to the aircraft due to the turbulence encounter and/or the pilot's response to an upset from the event.

A major constraint of the current PIREP system is that of the communication and display capabilities available both on the ground and in the air. Currently communications available are VHF radio frequencies for verbal PIREPs and the ARINC Communications Addressing and Reporting System (ACARS) for textual reports. Display of turbulence information is unavailable in the cockpit in most aircraft. On the ground, those turbulence reports that are passed to the Flight Service Station (FSS) are displayed on the Aviation Digital Data Service (ADDS). This consists of a series of web pages displaying PIREPs graphically on a map of the US. In summary, there are limited methods to communicate and display the turbulence to the various users.

Another constraint is that the pilot has to be involved in the generation of the turbulence reports, either by making a verbal report by radio, or by typing a text message into an onboard computer and sending it via ACARS to the ground. In either case, the resulting report will always be made after the encounter (at typical cruise speed of 8 miles a minute, any delay can be significant), it will always be the pilot's subjective interpretation of the encounter severity, and the message will rarely be forwarded to all the users that can benefit from the information. A consequence of all these limitations is that turbulence encounters are grossly under reported especially in regions of convection that are rapidly developing. In such cases the pilot's workload can be very high, making tactical decisions to avoid the convective hazards in a busy region where all aircraft are requesting route deviations from ATC.

As mentioned above, when it comes to using the airborne weather radar for turbulence detection, there are no formal procedures in place. In fact, the current turbulence mode on weather radars is not widely relied upon by pilots. This is because the regions of predicted turbulence, depicted or "painted" in magenta on the display, are based solely on the radar measurement of second moment of velocity. There is no scaling of this measurement to take into account the aircraft's type and current in-flight configuration. Therefore, simple thresholding and a display based on that measured value leads to many false, missed, and nuisance turbulence predictions, which ultimately leads to pilots' lack of confidence in the product and its use. Pilots are left to rely on such subjective measures as the shape of the reflectivity patterns, the reflectivity gradients, cell tops identified by tilting the antenna up and down, and reflectivity strength. Much of the operation is based on the individual pilot's experience.

However, the lack of shared information of such airborne turbulence weather displays between ground controllers, dispatchers, and pilots limits the degree of interaction the users can have with one another when making decisions regarding turbulence. The current state of the art is not mature enough to downlink real-time, continuous feed of multiple airborne weather displays to the ground for display on various flight following software programs. Limitations on geographic coverage, communication bandwidth, and fleet equipage prohibit the sharing of such information. Groundside controllers and dispatchers must rely on Next-generation Radar (NEXRAD) reflectivity images and inputs from pilots to mentally paint a picture of the potential turbulence threat to an aircraft. A tool such as the TurbDST that incorporates such technologies like TAPS (short-term) and downlinked Enhanced Turbulence Radar (long-term) will allow users and managers of the NAS to communicate with pilots effectively regarding decisions of turbulence encounter mitigation.

3.3 Users and Stakeholders

The following section will describe the users, stakeholders, and their interactions that are currently involved in either making or using current turbulence PIREPs, as well as using the airborne weather radar.

3.3.1 Organizational Structure

Four categories of users / organizations have been identified that will contribute and are involved in the flow of information within the current system regarding turbulence reports.

A user is identified as anyone who interacts with the existing system and has a direct participation in the decision flow process. The users identified are the Flight Crew, Dispatchers (flight planning / following, ATC desk, and sector managers), Air Traffic Controllers (Clearance Delivery, Ground Control, Local Control, Terminal Radar Approach Control (TRACON), Air Route Traffic Control Center (ARTCC) Sector Controllers), and the Traffic Management Unit (Towers and Centers) / Air Traffic Control Systems Command Center (ATCSCC). Figure 1 illustrates the connectivity between the different users within the current system and the various resources each may pull from within their individual organizations. Specifics on the interactions among the various users and the flow of information are discussed in further within Section 3.3.3.

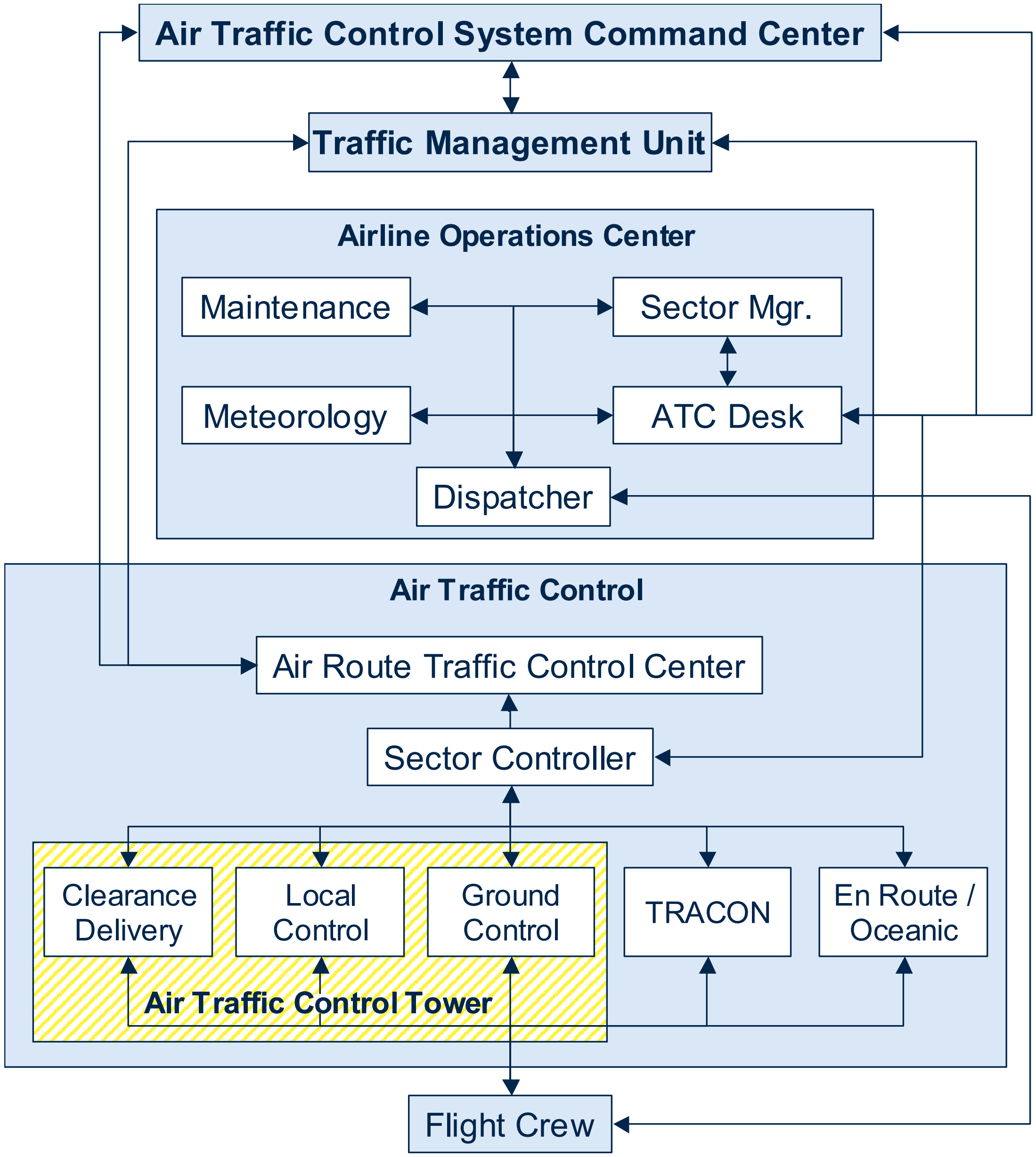

Figure 1: User Interaction Diagram

According to the Federal Aviation Administration web site, the United States has over 15,000 active air traffic controllers. Many of these controllers operate in the 24 ARTCCs controlled by the US (20 in the continental United States, Alaska, Hawaii, Guam, and San Juan). Each Control Center is broken up into various numbers of en route sectors of four different types: Low Altitude Sectors, Intermediate Altitude Sectors, High Altitude Sectors, and Ultra High Altitude Sectors. For example, the Fort Worth ARTCC has 18 Low Altitude Sectors, 7 Intermediate Sectors, 16 High Altitude Sectors, and 1 Ultra High Altitude Sector. At any particular time, there are an average of two to three controllers on duty per sector (based on the amount of air traffic in the sector). Assuming that there is approximately 1 supervisor per 5 controllers, then each ARTCC has approximately 120 controllers and supervisors on duty at any particular time, given the Fort Worth ARTCC sample. This equates to nearly 2900 controllers on duty in the US ARTCCs at any given time. The TurbDST will be a useful product for each of these controllers on duty. This number does not include the controllers at the Air Traffic Control System Command Center, any air traffic management personnel at the ARTCCs or the ATCSCC, or any personnel at the TRACONs who may benefit from the improved turbulence awareness and associated decision support. Including those personnel, the number of on duty ATC/ATM personnel who could benefit from the TurbDST would approach an estimated 3500 users.

By regulation, all US scheduled airlines operating Federal Aviation Regulation (FAR) Part 121 aircraft having more than nine seats are required to have dispatchers. Additionally, most charter and cargo operators (FAR 135) have dispatchers. According to employee statistical data available through the Bureau of Transportation Statistics (BTS) website (Reference [3]), US airlines employed over 4700 dispatchers in 2005. A typical large airline may have as many as 50 dispatchers and Operational Control Center (OCC) managers on duty on any given shift. This number equates to approximately 1/3 of their dispatchers and operations personnel. Assuming this is a typical on duty percentage, over 1500 dispatchers would be on duty in US airlines for any given shift. This does not even include terminals where pilots would access flight planning and pre-flight planning tools, where the capabilities of the TurbDST could add value. As the US airlines continue to expand operations (as of 2006 they have surpassed pre-September 11, 2001 capacity levels), the number of dispatchers and operational personnel will continue to rise.

Several stakeholders have been identified and are considered such if it is any organization (commercial or private), governmental entity, or individual that has an interest in the safe operation and maintenance of the current system. The stakeholders for the current system are the Federal Aviation Administration, Airline Operators (legacy carriers and smaller regional airlines), the Air Transport Association, and the National Business Aviation Association (NBAA).

3.3.2 Profiles of Users and/ or Stakeholders

3.3.2.1 Users

The flight crew, consisting of the pilots, is managed by the airline operator and may be considered the end users of the turbulence information regarding the operation of the aircraft in real-time. The flight crew also has direct interaction with the traveling public while flying.

Dispatchers are identified as the persons who plan for and follow each aircraft operated by the airline, as well as those charged with interfacing with ATC. The former are required to follow an aircraft to its destination using some form of graphical flight following software, and the latter are tasked to interface with ATC, specifically the traffic flow organizations to ensure efficient execution of the airline's operational plan.

ARTCC controllers, and the supervisors who interface with the Traffic Management Unit are others users of the current system. The former are tasked primarily to maintain separation between aircraft. Any impact of weather or any other external condition impacting their ability to do so will be made known to their supervisor who will communicate the needs to other organizations.

There is a Traffic Management Unit at each ARTCC and the ATC System Command Center for the entire national airspace. The former handles flow issues within each ARTCC, and the latter takes each Center's inputs and formulates national plans for airspace usage.

3.3.2.2 Stakeholders

The Airline Operator is an organization, commercial or private, providing aviation services to passengers and/or cargo. It owns or leases aircraft with which to supply these services and may form partnerships or alliances with other airlines for reasons of mutual benefit. The Airline Operator works with other industry stakeholders to develop policies and guidelines to enhance safety and security of air transportation.

The Airline Transport Association is the collective voice of numerous member commercial airline operators whose purpose to develop a business and regulatory environment for the safe and secure operation of air transportation carriers. The ATA is also charged with the responsibility to aid U.S. operated airlines to flourish and stimulate economic growth locally, nationally, and internationally. The ATA works with other industry stakeholders to develop policies and guidelines to enhance safety and security of air transportation.

The National Business Aviation Association, Inc. is an organization of more than 7,000 companies overseeing the development of aviation interests for organizations utilizing business aircraft in the United States and worldwide. The NBAA is a leader in the industry for the development of efficient, productive, and successful business partnerships in the general commercial aviation sector. The NBAA works with other industry stakeholders to develop policies and guidelines to enhance safety and security of air transportation as well as to project a positive image of the aviation industry.

The Federal Aviation Administration is the regulatory and policymaking branch of the United States federal government in all areas concerning the safety of civil aviation. The role of the FAA includes, but not limited to, the regulating civil aviation, development of new aviation technology, and the development and operations of a system of air traffic control and navigation within the National Airspace System.

3.3.3 Interactions Among Users

As mentioned above, the current system requires the collaboration and interactions among dispatchers, controllers, and pilots. The interaction between the users depends on the task at hand. In Section 3.4 the tasks are identified and the interactions described in some detail. The information presented in the following table summarizes and generalizes these interactions and the actions taken by each user class in the current information flow of the current system. In the following sections these interactions are reviewed in greater detail in the context of specific phases of flight and tasks. References to the various interactions refer to Figure 2 following the table. These descriptions reflect current practices.

Table 1: Summary of Interactions Among Users

Interaction	Turbulence Information Provided / Gathered	Decisions to be Made	Actions
Pilot to Controller	Provide turbulence PIREPs (usually verbally). Request for ride quality reports ahead (as made from other aircraft) or at other altitudes. Pilot's view of weather radar reflectivity and turbulence display provides tactical hazard information.	Request for deviation based on the information received and seen on the radar. Request for altitude change based on information received and seen on the radar.	Change route around region of convection. Change altitude (climb/ descend). Prepare cabin for possible turbulence encounter.
Controller to Pilot	Request for ride quality PIREPs. Receive ride quality reports.	Deviation clearance. Altitude change clearance.	Respond to ride reports from other aircraft.

Interaction	Turbulence Information Provided / Gathered	Decisions to be Made	Actions
Pilot to Dispatcher	Occasional verbal/text turbulence PIREPs (as workload permits). Request for ride reports ahead from other company aircraft. Request for deviation recommendations. Request for altitude recommendations.	In collaboration with dispatcher, decide whether a region of weather (convection, turbulence, etc.) should be avoided. If it is to be avoided, what is the preferred deviation (altitude, flight path, both).	Get recommended routing for reroute negotiation with ATC Execute deviation. Prepare cabin for turbulence if necessary.
Dispatcher to Pilot	Receive occasional verbal/text turbulence PIREPs from other aircraft. Ride quality requests from company aircraft. Deviation recommendations. Altitude recommendations.	Decide whether the identified regions of weather (convection, turbulence, etc.) are a threat to the safety of flights being followed, and are the affected aircraft far enough away to be able to route around/over/under the region. If so decide on the best way to route the aircraft around to optimize safety and efficiency of operations.	Notify company aircraft of threat. Recommend route deviations or altitude change based on meteorological information, and reports from other company aircraft.
Dispatcher to Traffic Management Unit/National Flow Control	Provide relevant weather information based on meteorological information and turbulence PIREPs.	Optimize airline schedules and routing (from nominal) given adverse conditions (e.g., regions of turbulence, convection, etc.). Provide airline plan – reroute schedule. Receive national flow plan.	Request for route availability. Request for changes based on "restrictive flow program." Execute national flow plan (reschedule/cancel flights accordingly).

Interaction	Turbulence Information Provided / Gathered	Decisions to be Made	Actions
Traffic Management Unit/National Flow Control to Dispatcher	Receive relevant Weather information from airlines based on their internal information sources including turbulence PIREPs.	Define a national flow plan, or, if the weather is contained within a center the flow plan can be defined within that center only. The plan will consist of defining: - miles in trail - reroutes - ground stops	Communicate with airlines and execute plan.
Controller / Supervisor to Traffic Management Unit	Turbulence disrupting normal routing based on turbulence verbal PIREPs received. When multiple PIREPs are received regarding a region, or if pilots are requesting rerouting based on the PIREPs they have overheard. The controller's ability to maintain the airspace capacity will be affected. The supervisor will be notified who will in turn raise the issue with the TMU.	Changes to the traffic flow around the region. This may entail decreasing the number of aircraft or routing them around the disturbance. This decision must be made in a strategic sense and in accordance with other traffic flow considerations (other centers, airline operations, etc.).	Raise issue to TMU and expect a flow plan. Execute flow plan.
Traffic Management Unit to Controller	Where is the region of disturbance? What is the region of disturbance (CAT, convection, etc.)? Is the region intensifying/decaying/staying the same? Is the region moving? If so where and how fast?	Develop a national flow plan for the next 2, 4, and 6 hours based on weather information. This will consist of: - miles in trail - reroutes - ground stops	Pass national flow plan to controllers for execution.

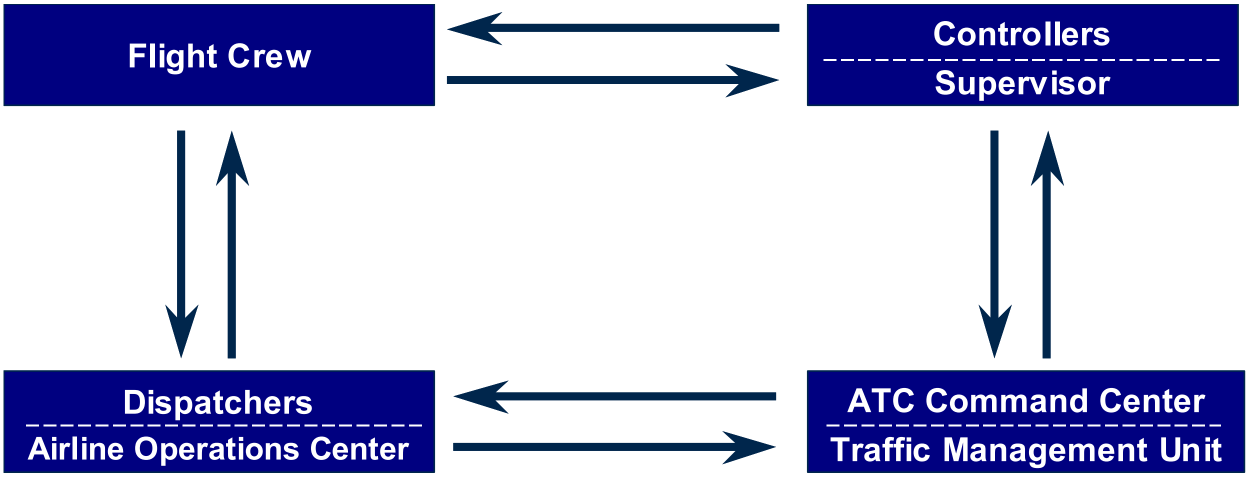

Figure 2: Current Turbulence Information Flow

3.3.4 Other Involved Personnel

In addition to the users and stakeholders discussed in the previous sections, the airline operator is also involved in the day-to-day operation of the current system. The airline makes various polices and enforces constraints on its constituents based on information feedback from various sources, including internal departments of marketing, finance, and safety. A typical policy that an airline operator is closely involved in is the operation of an aircraft near and in turbulent regions. Some airlines request a change in altitudes and routes with a very conservative approach to avoid large blocks of airspace if there is a potential presence for significant turbulence. This is primarily due to a lack of sufficient tools to identify the location and intensity of turbulence within a given region of the national airspace; thereby resulting in significantly higher fuel consumption during the operation of a flight within one of these regions.

3.4 Description of and Modes of Operation of the Current System

This section will describe the operation of the current system as it pertains to turbulence awareness and avoidance. No emphasis on any particular technology is made here, but an attempt is made in this section to separate out the various tasks, identify the primary and secondary decision-makers for these tasks, and to identify the decisions to be made. In using this approach, it will be possible to identify flaws in the system, and where the TurbDST can be used to effectively improve the decision making process.

In the following discussions, the actions and decisions of the pilots must be taken into account although the current and proposed work does not involve any direct development of displays or CONOPS for this user class. The cockpit display and associated CONOPS development currently being conducted by AeroTech Research, is funded under a separate NASA Small Business Innovative Research (SBIR) contract. Further information on this work is documented in Section 5.3.1 and Reference [4]. Because the flight crew is a key constituent of the turbulence decision-making process, it would not be possible to omit their participation and influence from the CONOPS development. In fact, the structure and form of this CONOPS is entirely consistent and complementary to the cockpit display CONOPS.

The existing system in place for the communication of turbulence reports between key role players is complex and extensive. An overview of the communications paths of and participants in the current turbulence information flow is illustrated Figure 2. This chart indicates many interactions encountered in generating useful turbulence information, disseminating it to the key decision-makers, and making sound decisions based on this information. In order to understand the limitations and deficiencies of the current system it is necessary to examine it in some detail. It should be noted that this review applies mainly to U.S. airline operators in the airspace over the continental United States. It is anticipated that the issues identified herein and the concepts developed will be applicable in some form to other airlines and other geographical regions of airspace.

In order to address a description of the current system in a meaningful way, an approach similar to the one documented by AeroTech during the development of a CONOPS for a Real-Time Turbulence Hazard Cockpit Display (Reference [4]) will be used, organizing the tasks of the users by phase of flight or modes of operation. Some additional "phases" which do not directly involve the pilot (e.g., flight planning) have been added. Under these phases, several tasks are identified and each one of these tasks can be examined from the perspective of who is the primary decision maker (i.e., who has to make a decision and act on it), and who is the secondary decision maker (i.e., who has to provide information to the primary decision maker).

The phases and tasks can be summarized as follows:

- Phase I: Flight Planning
    - Post Operational Analysis
    - Strategic Planning Operation
    - Planning A Flight
- Phase II: Preflight
    - Pilot Reviews Flight Plan Prior To Push Back.
    - Reroute Issued Prior To Pushback
- Phase III: Taxi Out
    - Pilot Reviews Turbulence/ Weather On Climb Out And Cruise Altitude
    - Reroute Issued Prior To Take-Off
- Phase IV: Climb Out
    - Pilot Reviews Turbulence/ Weather At Cruise Altitude
    - Flight Reroute Issued
- Phase V: Cruise
    - Aircraft Experiences Severe Turbulence
    - Aircraft Experiences Less Than Severe Turbulence
    - Aircraft Approaching Line Of Convection
    - Opening Up Region Of Airspace Previously Closed Due To Severe Turbulence
    - Turbulence On Arrival Path
- Phase VI: Descent & Arrival
    - Turbulence On Arrival Path

Each one of the tasks will be summarized in tabular form below. Each table describes a specific task for a particular phase of flight. The primary headings for the tables are Task, describing the tasks the groups are addressing and which group is the primary and which is secondary, and Description, describing the task itself and the potential challenges faced. Individual groupings of the rows of the table identifies the relevant user group involved within each of the dispatcher and controller organizations as well as inputs from the flight crew. For example in the first table the dispatcher group involved is the business unit and the controllers involved are the Command Center personnel.

3.4.1 Phase I: Flight Planning

A dispatcher conducts the flight-planning phase for an individual flight several hours in advance. Such planning must take into account many variables concerning the weather, suggested flight schedule (arrival and departure times), and the national airspace system status, and any current restrictions. Throughout the course of the day several planning sessions will occur between the Air Traffic Control System Command Center, Traffic Management Units, and the airlines to plan for and mitigate any potential problems for the NAS. During these sessions, assessments will be made on the previous period's performance of operation.

Table 2: Phase I – Post Operational Analysis

Task	Description
Dispatcher: (Business Unit)	
Role: Secondary May be included as a participant in post operational analysis to give the airline perspective of the disruptions experienced.	Unless there are company/FAA PIREPS stored there is no knowledge of what turbulence their company aircraft experienced during the events. Perhaps there were injuries/severe encounters. This information will be subjective and possibly inaccurate.
Controller: (ATC System Command Center / Traffic Management Unit)	
Role: Primary Must satisfy the need to assess the overall performance of the system and participants after a day of significant disruptions. This may take place within a day or so after an event. Analysis will include a review of forecasts, replay of traffic displays (using such programs like POET (Post Operations Evaluation Tool)), replay of weather, and participants' recollections of actions performed. It is very difficult to pull everything together in a coherent form (e.g., radio transmissions, dispatcher communications, what the pilots experienced, what the various controllers saw, what decisions they made and why, etc.)	No actual knowledge of what severity of turbulence the aircraft actually experienced is available unless PIREPS were reported by the flight crew and stored / shared with the airline or the FAA (e.g., displayed on the National Weather Service (NWS) ADDS webpage).
Pilot:	
N/A	N/A

Table 3: Phase I – Strategic Planning Operation

Task	Description
Dispatcher: (ATC Desk, Business Unit)	
Role: Secondary Need to plan airline routing and scheduling for the next 2+ hours	No knowledge available regarding where turbulence is, its extent, or severity. Must use and plan around forecasts, Collaborative Convective Forecast Product (CCFP), and current observations (e.g. NEXRAD, satellite, etc.) Some information may be present from existing PIREPS made by company aircraft.
Controller: (ATC System Command Center / Traffic Management Unit)	

Task	Description
Role: Primary Need to define strategic National Airspace System operations for the next 2 hours.	No knowledge available regarding where turbulence is, its extent, or severity. Must use and plan around forecasts, Collaborative Convective Forecast Product, and current observations (e.g. NEXRAD, satellite, etc.)
Pilot:	
N/A	N/A

Table 4: Phase I – Planning a Flight

Task	Description
Dispatcher:	
Role: Primary Needs to plan a flight's route, altitudes, alternate airports, and fuel requirements for multiple flights. Uses standard airline routings, information from the Strategic Planning Operation (SPO), Route Management Tool, Route Optimization Generator (ROG), and other standard weather sources to plan routes.	Does not know where turbulence is other than company/ADDS PIREPS. Turbulence is not a consideration in flight planning, other than if there has been an advisory issued by the command center closing off a route due to severe turbulence / weather.
Controller: (The Host)	
Role: Secondary Approve route and file plan within the system.	N/A
Pilot:	
N/A	N/A

3.4.2 Phase II: Preflight

This particular phase of an aircraft's flight takes place while the aircraft is still at the gate, up to the time of 'Push Back.' During this portion of the flight, the users are reviewing normal procedures and checklists for the upcoming flight. The users are also in the process of reviewing and editing the proposed flight plan given updated information.

Table 5: Phase II – Pilot Reviews Flight Plan Prior To Push Back

Task	Description
Dispatcher:	
Role: Secondary Communicates with pilot to accept flight plan as provided or to define/negotiate reroute with ATC.	May have some company/FAA PIREPS available to the user. There is a limited knowledge of turbulence location and severity.
Controller:	

Task	Description
Role: Secondary Will work with the pilot to amend the flight plan as possible.	No weather / turbulence information is available.
Pilot:	
Role: Primary Reviews the flight plan for acceptance. The company dispatcher will be contacted if a change in the filed flight plan is requested. The pilot is provided a paper copy of the flight plan information, aircraft performance information, and weather observations/forecasts. If a pilot requests a flight plan change within 45 minutes of departure (and greater than a few minutes before departure), the dispatcher will contact the TMU at the center and request the reroute. The dispatcher cannot enter a reroute into the Host at this time, but the TMU can make the appropriate changes. If the time frame is within a few minutes of pushback, the pilot can contact clearance delivery and request the reroute verbally. If a different altitude is desired the pilot will typically accept the routing and request a different altitude when en route unless the only usable altitude would significantly affect the fuel burn and would be unacceptable with the given amount of fuel supplied (e.g. only usable altitude is too low to complete a flight with given amount of fuel).	The pilot would normally not request a reroute based on weather forecast or PIREPS.

Table 6: Phase II – Reroute Issued Prior To Pushback

Task	Description
Dispatcher:	
Role: Secondary Work with flight crew on reroute. The ATC desk at the Airline operation Center will get involved if a reroute cannot be accepted. The ATC Desk will contact the Traffic Consumer Advocate (TCA) for the particular sector.	May have some company/FAA PIREPS available along old / new routing, which can be communicated with the pilot.
Controller:	

Task	Description
Role: Primary Ground Control will notify a pilot while at the gate to contact Clearance Delivery, which will subsequently give the flight crew the new routing. Rerouting may be required based on advisories from either the ATCSCC or SPO.	
Pilot:	
Role: Secondary Pilot contacts Clearance Delivery and receives new routing. May discuss with dispatch to confirm routing.	Pilot may have no concept of weather or PIREPs on new routing.

3.4.3 Phase III: Taxi Out

The taxi out phase is an extension of an earlier preflight phase from a commercial aircraft's point of view. The taxi out phase is marked by the period during 'push back' through movement at an airport's tarmac towards the final take off runway. During this portion of a flight, the users are performing any final reviews concerning the flight and have committed to a route. Last, up to date information may be reviewed for impact on the upcoming flight.

Table 7: Phase III – Pilot Reviews Turbulence/Weather On Climb Out And Cruise Altitude

Task	Description
Dispatcher:	
Role: Secondary If a pilot requests a reroute and needs help from dispatch, the dispatcher will assist in negotiating the reroute. A flight's departure maybe delayed in this particular case.	May have some company/FAA PIREPS available to the user. There is a limited knowledge of turbulence location and severity.
Controller: (Tower/TRACON)	
Role: Secondary If a pilot goes ahead with the planned take off, the tower will clear the aircraft onto the runway for takeoff and will hand the flight off to TRACON. If the flight crew decides to delay, then Ground Control will pull the flight out of the line of departing aircraft until the decision to go has been made. It is possible that the flight may go to the back of the line for take off. If a request is made for a reroute, the flight will be pulled out of the line and asked to contact company dispatch for a new clearance.	No weather / turbulence information is available.
Pilot:	

Task	Description
Role: Primary Pilot reviews weather / turbulence on climb out and may decide to request a reroute, delay the departure, or go ahead with the planned take off.	Pilot has little or no knowledge of the weather / turbulence on the departure corridor.

Table 8: Phase III – Reroute Issued Prior To Take Off

Task	Description
Dispatcher:	
Role: Secondary Involvement is only required if the aircraft cannot accept the new route (due to fuel loading), or if there will be an impact on the schedule. If the aircraft has time on the ground before take off, dispatch may be contacted.	May have some company/FAA PIREPS available along old / new routing, which can be communicated with the pilot.
Controller:	
Role: Primary Ground Control will notify a pilot taxiing to the runway to contact Clearance Delivery, which will subsequently give the flight crew the new routing. Rerouting may be required based on advisories from either the ATCSCC or SPO.	
Pilot:	
Role: Secondary Pilot contacts Clearance Delivery and receives a new routing. The new clearance is entered into the Flight Management Computer (FMC). The pilot will assess the fuel requirements and determine if it safe to proceed. Clearance may than be accepted and will proceed with take off and departure from the airport. The pilot will contact the company dispatcher after take off.	Pilot may have no knowledge of weather or PIREPs on new routing.

3.4.4 Phase IV: Climb Out

This next phase of flight considered covers the climb out portion of the aircraft from its departure airport up and towards its cruising altitude. Information within the decision support tool can provide real-time information of automatically and accurate turbulence reports of aircraft encounters along the projected flight path.

Table 9: Phase IV – Pilot Reviews Turbulence / Weather At Cruise Altitude

Task	Description
Dispatcher:	

Task	Description
Role: Secondary Dispatcher will provide guidance regarding suitable altitudes/ routing to avoid turbulence and to remain within the performance parameters of the aircraft and fuel load.	May provide advisory information to the pilot based on company PIREPs or weather forecast. Involvement may be minimal.
Controller: (Tower/TRACON)	
Role: Secondary TRACON or lower sector controller will clear a new altitude or reroute as possible.	Unless there is significant weather on departure, TRACON will not be involved in these discussions. A sector controller will handle requests from the flight crew.
Pilot:	
Role: Primary Due to rough ride / moderate or greater turbulence reported at (initial) cruise altitude, a pilot may want to request a different altitude or a reroute.	No information is available to the pilot to make this decision until the frequency of the high altitude sector is monitored. Subsequently, a request can be made regarding the ride at the planned altitude or along the route. The flight crew has the capability of the onboard weather radar, which will provide some information (reflectivity) of convective activity ahead of the aircraft. The pilot may request an altitude change or rerouting based on this information alone.

Table 10: Phase IV – Flight Reroute Issued

Task	Description
Dispatcher:	
N/A	N/A
Controller: (Sector)	
Role: Primary Will issue a flight reroute based on assigned altitudes and other aircraft routings.	Decisions are based on other PIREPs within the area or from requirements by the TMU to increase spacing, decrease traffic into a region, or close a region off altogether. A controller does not use weather / turbulence information to make this decision.
Pilot:	
Role: Secondary Will reprogram FMC and accept new attitude/ reroute as he can.	No information about weather / ride quality at the new altitude or along the new route. The onboard weather radar will provide an indication of convection (reflectivity) along the new route/ altitude.

3.4.5 Phase V: Cruise

The cruise flight phase of an aircraft occupies the most amount of operational time of an aircraft in flight. The cruise portion of a flight for this CONOPS happens between the climb out and top of descent phases of flight. Information within the decision support tool can provide real-time information of automatically and accurate turbulence reports of aircraft encounters along the projected flight path.

Table 11: Phase V – Aircraft Experiences Severe Turbulence

Task	Description
Dispatcher:	
Role: Secondary Dispatcher picks up an advisory from ATCSCC that a route has been closed due to severe turbulence. The dispatcher will start to plan reroutes accordingly. The dispatcher may also have picked up a PIREP from the event if the aircraft reporting the severe turbulence is a company airplane.	A very general understanding of the turbulence severity and location as well as the effect on other aircraft will be provided. Inexact understanding of the event relative to weather may be inferred. The dispatcher is likely to be conservative in planning a reroute for the aircraft.
Controller:	
Role: Secondary Sector controllers will warn other aircraft within the area of the severe turbulence encounter. The TMU/ATCSCC may decide to close down that portion of the NAS if several reports or several aircraft make severe turbulence reports within a particular area. If this is the case, shift supervisors will disseminate this information to other sectors (high and low), and to the Local and Ground controllers. The report may also go to the command center, which may in turn issue an advisory which will get picked up by company dispatch and passed along to pilots.	If a number of reports are made of similar severity and location (usually referenced to a navigation waypoint) then that route segment can be shut down for a period of time (until the weather clears or a pathfinder aircraft is found). ATCSCC may be conservative in rerouting aircraft, thereby incurring increased flight times.
Pilot:	
Role: Primary Pilot in cruise experiences severe turbulence and makes a report to the sector controller.	Requires manual PIREP (late, subjective, etc.). No information on the extent or severity as pertains to other aircraft is supplied. Also can be significant error in location information.

Table 12: Phase V – Aircraft Experiences Less Than Severe Turbulence

Task	Description
Dispatcher:	

Task	Description
Role: Secondary Dispatcher picks up an advisory from ATCSCC that a route has been closed due to turbulence. The dispatcher will start to plan reroutes accordingly. The dispatcher may also have picked up a PIREP from the event if the aircraft reporting the turbulence is a company airplane.	Relies on company and publicly available PIREPs and weather forecasts. May confer with pilot about where the smoother ride might be, but no direct knowledge is available.
Controller:	
Role: Secondary Sector controller will respond to requests, granting/denying changes to aircraft route.	Clears the requests as possible. Primary concern is aircraft separation. A sector controller has no turbulence information available other than existing PIREPs. Composite NEXRAD may be used as a guide, indicating locations of potential turbulence.
Pilot:	
Role: Primary Pilot in cruise experiences less than severe turbulence. The encounter may be light or moderate in intensity or even a poor ride quality issue. The flight crew wants either a route change or an altitude change. The pilot will perform this request with the sector controller.	Will inquire with the sector controller about the ride ahead of the aircraft and whether there are other smooth altitudes available. It is likely that other aircraft in the area are asking similar questions to the air traffic controllers, increasing the possibility of frequency congestion. The pilot must build a mental picture of the turbulence in the region based on verbal reports and use of the onboard weather radar.

Table 13: Phase V – Aircraft Approaching Line Of Convection

Task	Description
Dispatcher:	
Role: Secondary Provides recommendations for rerouting or altitude changes to the pilot to get through and across the line of convection.	Relies on company and publicly available PIREPs and weather forecasts. Typically, in regions of intense convection, few or no PIREPs will be available on services such as ADDS. The dispatcher will use NEXRAD and cell tops information to identify hazards and potential routes for the flight. The dispatcher will provide the pilot with recommended reroute waypoints around the region. The pilot will subsequently contact the sector controller for a reroute if necessary.
Controller:	

Task	Description
Role: Secondary Sector controller will respond to requests, granting/denying changes to aircraft route / altitudes.	Controller will provide pilots turbulence reports from aircraft ahead – although the pilot will not know where that aircraft is. The pilot may ask what was the type of aircraft was in order to "scale" the report mentally. If the controller receives multiple (3 or more) reports of severe turbulence or if a pilots refuses to fly through a region, the area may potentially be closed. A pilot may request a reroute around a line of convection approximately 100 nautical miles out. The pilot will request a routing based on a series of waypoints and the controller will approve it if possible – if there is a problem, the dispatcher ATC desk, may contact ATC to request a special routing. Close into the convective area, the pilot will be requesting deviations based on the airborne weather radar and what is heard from other aircraft in the vicinity. Much of the discussion between the users is based on finding out where the rough ride is and where the holes are that flights are passing through.
Pilot:	
Role: Primary The aircraft is approaching a line of convection that will need to be crossed. This scenario assumes that the aircraft remains en route and does not have to descend on an arrival in the vicinity of the convection. This is because on arrival there will be other constraints on the pilot's actions other than turbulence avoidance (e.g., arrival sequencing). As the aircraft approaches the convective line, there will be discussions with the sector controller about where aircraft are trying to cross the line and any reports of turbulence they may have encountered.	The pilot uses weather radar to identify regions of convective activity up to 320 nautical miles ahead of the aircraft. At a large enough distance, greater than 100 nautical miles, the pilot may discuss with dispatch about company PIREPs and possible reroute recommendations. There is limited knowledge available concerning the location of turbulence. Most decisions are currently based on reflectivity information from the onboard weather radar. If a reroute/altitude change is suggested by dispatch, then the pilot will negotiate this change with the sector controller. Close in on the line of convection, the pilot will negotiate with the sector controller for course deviations/ altitude changes. The company dispatcher is not involved during this process. The turbulence mode of the radar may be used in this case, although current radar turbulence modes are not deemed to be useful by the pilot community.

Table 14: Phase V – Opening Up Region Of Airspace Previously Closed Due To Severe Turbulence

Task	Description
Dispatcher:	
Role: Secondary If the request comes through the ATCSCC to the ATC desk, the dispatcher will communicate the request to the aircraft.	Will only have weather observation information (NEXRAD, satellite, etc.) with which to base recommendations on, thereby guessing as to where the turbulence is located.
Controller:	
Role: Primary A region or route may have been closed after multiple reports of severe turbulence or weather. After a period of time, the weather will have moved off and the route or region can be reopened. The TMU or sector controller may ask for a "pathfinder" to proceed through the region.	Based on forecast and recommendations from ATCSCC and the TMU the region/ route will be opened up again. No knowledge of turbulence location and severity other than weather observations (NEXRAD, satellite, etc.) are available.
Pilot:	
Role: Secondary The pilot can either accept or decline the opportunity to be the "pathfinder."	The pilot has no idea where turbulence is and is not. The flight crew will use the radar as much as possible, but no PIREPs from other aircraft will be available within the region. A verbal report from the pathfinder aircraft after transiting the area will be used to route other aircraft.

Table 15: Phase V – Turbulence on Arrival Path

Task	Description
Dispatcher:	
Role: Secondary Dispatcher recommends different arrival to an airport.	Relies on company and publicly available PIREPs and weather forecasts. Dispatcher will have company PIREPs of turbulence on arrival to airport, which may be adequate if it is a company hub airport, but may be lacking if not.
Controller:	
Role: Secondary Sector controller receives request from pilot to route to different arrival fix.	Sector controller has no knowledge of turbulence on arrival unless severe turbulence has been encountered and TRACON has closed the route. Otherwise, the controller will keep aircraft flying through the arrival corridor.
Pilot:	

Task	Description
Role: Primary Prior to top-of-descent pilot decides that arrival is unsuitable due to significant turbulence at or past the arrival fix. The pilot will ask the controller for a reroute to another arrival fix.	Pilot has little or no knowledge of the turbulence on arrival. May receive communications from dispatch to reconsider arrival and recommending an alternate. Pilot will request sector controller to bring him around to another arrival fix. Otherwise, the pilot may not know of the turbulence on the arrival until the arrival frequency is monitored.

3.4.6 Phase VI: Descent & Arrival

The final phase of an aircraft's flight reviewed for this CONOPS is the descent and arrival portion. Following the cruise phase, this portion of the flight begins at the top of descent for an aircraft and continues through arrival into an airfield. Information within the decision support tool can provide real-time information of automatically and accurate turbulence reports of aircraft encounters along the projected flight path.

Table 16: Phase VI – Turbulence On Arrival Path

Task	Description
Dispatcher:	
Role: Secondary May provide information on arrival corridor to pilot in advance of top of descent.	Dispatcher may have information based on reports from other company aircraft or from other weather products (Integrated Terminal Weather System (ITWS), Corridor Integrated Weather System (CWIS), etc.). The dispatcher may propose to the pilot a different arrival for negotiation with ATC.
Controller:	
Role: Secondary Sector controller reroutes aircraft to a different fix.	Sector controller has no information regarding weather / turbulence on an airports' arrival corridors. Reroute requests will be cleared as conditions make it possible.
Pilot:	
Role: Primary Due to significant turbulence weather on arrival, a pilot may decide to request routing to a different arrival fix prior to top of descent.	Pilot has no knowledge of conditions on arrival other than information supplied from the dispatcher or the Automatic Terminal Information System (ATIS) if the service is within radio range.

The content presented in the above tables has been an attempt to summarize a very dynamic and complex series of interactions among different users and the stakeholders. It may well be the case that some of the decisions may sometimes be made in ways other than described above for a variety of reasons (e.g., special airspace constraints, particular weather events). However, it is felt that the above information is a strong baseline on which to identify flaws in the system, reasons for change, and the technology required to improve the system.

3.5 Support and Maintenance

Since the current method of making turbulence PIREPs relies so much on human intervention, the support and maintenance issues do not directly apply to the concepts of the turbulence hazard decision support tool. Current aircraft situation display (ASD) position information is supplied by the FAA Enhanced Traffic Management System (ETMS). ETMS was developed and is currently used as the backbone tool for FAA air traffic management. The current version of the system does not have a turbulence information component. The current process of the sharing of turbulence information among the users is manual in nature (via voice or hand written reports) for the majority of turbulence reports. The exception is those few reports that do make it to the Aviation Digital Data Service, which is accessible as a webpage on the Internet. The addition of turbulence information being shared / exchanged more often will not incur additional maintenance requirements to the existing system. However, the radar is an integral piece of equipment, identified on the Minimum Equipment List (MEL), on an aircraft and its performance is clearly defined by the FAA (in its Minimum Operational Standards) and the airlines and vendors perform its maintenance.

4. Justification for and Nature of Changes

This section of the CONOPS describes the shortcomings of the current system or situations that motivate development of a modification of the existing system. The proposed changes to overcome these issues are also covered.

4.1 Justification for Changes

Table 17 identifies, based on the modes of operation (phases of flight) and tasks described in the previous section, the current deficiencies and limitation of today's system and lists the justifications for changing and improving these deficiencies. The identification of difficulties in each task allows an understanding of the justification for changes to be introduced. It is the goal of the proposed work to produce a system that will increase safety, reduce injuries, and increase operational efficiency in aircraft operations around turbulence.

Table 17: Current System Deficiencies and Justification for Change

Deficiencies / Limitations of Current System	Justification for Change
Phase I: Flight Planning **Post Operational Analysis**	
Within the current system, it is not possible to replay the effects the weather had on an aircraft. For example, given the decisions made by the controllers, dispatchers, and pilots, what was the effect on the level of turbulence experienced by aircraft?	Storage of quantitative reports of detected and experienced turbulence and incorporation of this information into a playback tool will allow the decision makers to understand better the effects and outcome of their decisions, and to develop improved methods to turbulence avoidance.
Phase I: Flight Planning **Strategic Planning Operation**	

Deficiencies / Limitations of Current System	Justification for Change
In the discussions and interactions between the ATCSCC, TMUs, and the airlines, there is no picture available of where the turbulence is and its severity. Some PIREPS are publicly available, but as we have noted they can be scarce and inaccurate. The airlines may have additional information from company aircraft, but there is no common view amongst all the parties involved to make the decisions about how best to avoid or prepare for turbulence.	If all parties were enabled with a common view of turbulence information, much of the discussion about the location and severity of turbulence will be curtailed, allowing the participants to focus on planning. This turbulence information must be integrated with other forecast / nowcast and observations used by participants.
Phase I: Flight Planning **Planning a Flight**	
A dispatcher has limited knowledge of where the turbulence is, or what the level of turbulence (for the aircraft in question) is at the planned cruise altitude.	Observations of turbulence conditions, in conjunction with forecasts, can be very useful in planning to avoid regions of turbulence. However, since flights are planned up to 3 – 4 hours in advance of takeoff, the turbulence information generated in this process will be speculative.
Phase II: Preflight **Pilot Reviews Flight Plan Prior To Push Back**	
Currently, pilots are provided a printout of the weather reports and forecast, but no graphical weather information. They may not have any direct information of en route or arrival turbulence conditions.	The pilot will review the flight plan and associated information approximately 30 minutes before departure. The flight route will have been planned several hours earlier. Conditions may change within that time frame. Knowledge of the conditions along the planned route and at the arrival airport will help in preparing the occupants and crew for turbulence, or deciding to request a reroute for the aircraft.
Phase II: Preflight **Reroute Issued Prior To Pushback**	
If a reroute is issued close (45 minutes or less) to scheduled pushback, the pilot will communicate with clearance delivery to acquire the new route and enter it into the flight management computers. If there is a significant difference between the routes, the pilot will have limited or no knowledge of the weather or turbulence along the new route. The pilot's main priority will be to ensure that the aircraft has enough fuel to complete the flight including reserves.	Significant weather or turbulence along the route may require the pilot to decline the new route in favor of one with better conditions.
Phase III: Taxi Out **Pilot Reviews Turbulence / Weather On Climb-Out And Cruise Altitude**	

Deficiencies / Limitations of Current System	Justification for Change
Currently, a pilot has limited knowledge of weather or turbulence on climb-out or cruise. The pilot only has what information that dispatch has provided in the printout prior to flight. The pilot will find out more information on flight conditions after take off from the many different air traffic frequencies that will be monitored; for example unless there has been a significant weather report which has been disseminated from the sector controller to the ground or dispatch, the pilot will not know turbulence conditions at altitude in that sector until the pilot begins to monitor that frequency.	Knowledge of the turbulence on climb out will allow the flight crew to decide when to allow passengers and crew to move around the cabin. Knowledge of the turbulence conditions at altitude will allow the pilots to decide on the best cruising altitude and negotiate for that altitude before getting there. This will avoid unnecessary fuel burn in climbing to an altitude and then asking for a new altitude.
Phase III: Taxi Out **Reroute Issued Prior To Take-Off**	
Currently, once a reroute is issued to a pilot taxiing out to the runway, if there is a significant change to the route, no weather or turbulence information will be available to the flight crew along the new route on which to make a decision to accept or renegotiate the route with Air Traffic Control.	If the turbulence conditions are bad along the route, the pilot will only know this once the turbulence is encountered or by monitoring the ATC frequencies. Prior knowledge will prevent unnecessary fuel burn and prevent the aircraft from penetrating significant turbulence. If ATC is aware of these conditions, they will be able to anticipate many aircraft renegotiating altitudes or routes.
Phase IV: Climb Out **Pilot Reviews Turbulence / Weather At Cruise Altitude**	
A pilot currently has no additional information regarding turbulence other than what is issued by the airline at the gate. Knowledge of new / updated turbulence conditions will not be known unless the appropriate ATC frequencies are monitored, and/or if time is available to communicate with the company dispatcher who may be able to provide additional information.	If the turbulence conditions are bad along the route, the pilot will only know this once the turbulence is encountered or by monitoring the ATC frequencies. Prior knowledge will prevent unnecessary fuel burn and prevent the aircraft from penetrating significant turbulence. If ATC is aware of these conditions, they will be able to anticipate many aircraft renegotiating altitudes or routes.
Phase IV: Climb Out **Flight Reroute Issued**	

Deficiencies / Limitations of Current System	Justification for Change
A pilot currently has no additional information regarding turbulence other than what is issued by the airline at the gate. Knowledge of new / updated turbulence conditions will not be known unless the appropriate ATC frequencies are monitored, and/or if time is available to communicate with the company dispatcher who may be able to provide additional information.	If the turbulence conditions are bad along the route, the pilot will only know this once the turbulence is encountered or by monitoring the ATC frequencies. Prior knowledge will prevent unnecessary fuel burn and prevent the aircraft from penetrating significant turbulence. If ATC is aware of these conditions, they will be able to anticipate many aircraft renegotiating altitudes or routes.
Phase V: Cruise **Aircraft Experiences Severe Turbulence**	
If the pilot perceives that the aircraft has experienced severe turbulence, a report will be made to the ATC Sector Controller. PIREPS made in this manner are known to be very subjective and inaccurate, and may not always give the correct time or location of the event. In addition, the information within the PIREP may not necessarily be distributed throughout the system to all users. The effect on other aircraft has to be inferred. For example, if the report came from a small aircraft, then the turbulence encountered may not be a threat to a larger aircraft; if a PIREP came from a large aircraft, smaller aircraft may be even more at risk. Certain actions are required of pilots, controllers and dispatchers by law, which sometimes makes flight crews reluctant to call the encounter severe.	There is a need for immediate, accurate, and automatic reporting of severe turbulence events. Moreover, there is a need for this information to be produced for a defined family of aircraft. Therefore a report must be made not only when the encountering aircraft experiences severe turbulence, but when an aircraft experiences turbulence which may be severe for a different type of aircraft in the vicinity. Clearly there is a limitation here; there is no need to scale a report from a Boeing 747 to the turbulence experienced by a Cessna 172. However, a reasonable range may be the Regional Jet fleet up to the B747 and A-380. AeroTech's development of the Turbulence Auto-PIREP system has shown that the technology and infrastructure is already in place to get this information sharing in place. What is required now is to disseminate this information to all parties in a meaningful and useful form.
Phase V: Cruise **Aircraft Experiences Less Than Severe Turbulence**	
The same deficiencies and limitations hold true as stated in the previous description, with the additional limitation that controllers are even less likely to take on the additional task of disseminating less than severe reports to users, although they are important to other aircraft.	The justification for change is similar to the above statement for a severe encounter. The threshold for making automatic reports can be lowered to the point at which the industry decides is necessary. This will potentially increase the number of reports, and the economic costs will have to be weighed against the safety and operational benefits. This is an industry decision.
Phase V: Cruise **Aircraft Approaching Line Of Convection**	

Deficiencies / Limitations of Current System	Justification for Change
Pilots, controllers, and dispatchers are currently making decisions based on radar reflectivity displays (e.g., composite NEXRAD images and onboard weather radar). These images do not show the turbulence hazards contained in convective cells, which can be very strong, very localized, and not correlated with radar indications of strong reflectivity regions. Decisions by TMUs and the ATCSCC may be based on these reflectivity images and may be overly conservative. Pilots' decisions to navigate around convection are based on their airborne radar reflectivity maps in the cockpit (and sometimes the rarely used current turbulence display). This can, and has in the past, lead to inadvertent encounters with undetected severe turbulence near convection. In fact over 80% of all turbulence accidents occur in the vicinity of convection [5]. In summary, when approaching convection, currently there is no indication of the location and severity of the turbulence hazards.	As pilots navigate in and around convection, they may provide turbulence PIREPs to the sector controller and other aircraft in the vicinity as their workload allows. As mentioned previously, these reports may be inaccurate, and in many situations, the reports and requests for deviations may lead to significant frequency congestions. In addition, if the convective region spans several sectors, pilots may not be aware of the turbulence PIREPs until they switch to the next sector frequency. If the turbulence information was reported and disseminated automatically among the pilots and controllers, the need for verbal turbulence PIREPs will be diminished, pilots will be able to get the turbulence information well in advance, sector controllers will be able to see the turbulence reports and detections as they are made and be prepared to anticipate a pilots request for deviations, and TMUs and the ATCSCC will incorporate this information with forecasts to identify regions of intensifying or decaying turbulence for their traffic flow decisions. Dispatchers will also use this information to communicate with company aircraft whose routes will take them through the affected regions, and will use the information, in conjunction with forecast products, to plan future flights around the region if necessary.
Phase V: Cruise **Opening Up Region Of Airspace Previously Closed Due To Severe Turbulence**	
If a region of airspace has been closed due to severe turbulence, there will come a time when the airspace must be opened up again to air traffic. In order to do this, a "pathfinder" aircraft is required. Currently, this aircraft will be entering a region where there are no PIREPs, and there is only NEXRAD and airborne radar information. Judgment by traffic management personnel has been made that the weather conditions that caused the turbulence has moved or dissipated. Often this judgment is very conservative, and not based on knowledge of the turbulence hazards.	Opening up the region of airspace should be based on knowledge of the turbulence hazards. The NEXRAD turbulence product (and not the reflectivity region) will provide an observation of the turbulence in a region. A pathfinder aircraft equipped with TAPS and E-Turb radar would be the perfect candidate to penetrate such a region of airspace. The E-Turb radar will provide the pilot with detection of turbulence hazards, and TAPS will provide other aircraft and the controllers with immediate reports of the turbulence encountered by that aircraft. Based on information from the pathfinder aircraft, other aircraft may be routed into the region safely and quickly.
Phase V: Cruise **Turbulence On Arrival Path**	

Deficiencies / Limitations of Current System	Justification for Change
Aircraft in cruise will have designated an arrival fix to begin their approach to their destination airport. Pilots will not have knowledge of the turbulence conditions on arrival until they begin descent and switch to the frequency of the TRACON controller handling aircraft at that fix. The sector controller will not have any information on turbulence at the fix or along the arrival corridor. If available and work load permits, the company dispatcher may pass along to the flight crew turbulence information for the arrival corridor. Otherwise, the aircraft will continue on to a particular arrival oblivious to the turbulence conditions, which, if there is convective activity in the vicinity, may be severe at the lower altitudes.	If the pilot has information of the turbulence conditions appropriately scaled for the aircraft on the arrival path, and if they pose a hazard to his aircraft, the pilot may elect to hold at the current cruise altitude and request a reroute to a different arrival fix. Subsequently, the pilot will need the turbulence information (e.g., TAPS) for the arrival path in the cockpit. Although this may add a few minutes to the flight, it would prevent the pilot from descending and flying into a region of significant hazard. If the TMUs are equipped with this information for airfield arrivals, they could anticipate the request from aircraft to select routing to other arrival fixes. If TRACONS have this information, they would be prepared to close arrivals along a particular fix until conditions improve.
Phase VI: Descent & Arrival **Turbulence On Arrival Path**	
Similar to the above statement, but when the aircraft is already committed to descent along a particular arrival corridor, opportunities to reroute may be limited and the aircraft may already have descended into the affected region.	Justifications are similar to those presented above. Better information of the turbulence ahead of an aircraft in descent will allow the crew to make sure that there are no passengers or crew standing or walking in the cabin. This is currently a major cause of injuries. Often the pilots do not know of the turbulence conditions until they switch arrival control frequencies. If the arrival approach will be turbulent and a different arrival path is not possible, and the pilot knows this well in advance, the cabin can be secured and occupants strapped in for the duration of the descent and arrival.

4.2 Description of Desired Changes

Required changes to the existing system are described below in Table 18. Changes are split up between the two parties of Controller and Dispatcher, and do not necessarily refer to a particular display. Instead the changes refer to information access. Also identified in the table are those changes that are essential to the success of a turbulence hazard decision support tool. Those are defined as features that must be provided by the new or modified system. If these features were not to be included, the effectiveness of the system would be compromised. They will be discussed in further detail within the next section.

This changes presented within the table are based on the current system described in Section 3 of the CONOPS. A detailed explanation of the proposed changes categories is given, followed by Table 18.

1. Capability Changes – Description of the functions and features to be added, deleted, and modified in order for the new or modified system to meet its goals and objectives.

2. Operational Changes - Description of changes to the users' operational policies, procedures, methods, or routines caused by the above changes.
3. Personnel Changes – Description of changes in personnel, if any, caused by new requirements, changes in user types, or both.
4. Interface Changes – Description of the changes in the system that will cause changes in the system interfaces.
5. Support Concept Changes – Description of changes in the support concept caused by changes in the system functions, processes, interfaces, or personnel.
6. Other Changes – Description of other changes that will impact the users, but which do not fit under any of the above categories.

Table 18: Proposed System Changes

Area of Influence	Controllers	Dispatchers
Capability	Sector, TRACON, Local, and Ground controllers need to get real-time turbulence information into their existing information sources either on an auxiliary weather display or into the most appropriate display. TMU and ATCSCC need to have the real-time turbulence hazard information integrated with their other decision-making tools. This may be a separate window, or may be an additional capability to an existing tool. **This is an essential change**	Dispatcher needs to know where the turbulence is, what the severity is, and whether the turbulence is a hazard for the aircraft under the dispatcher's oversight. **This is an essential change**
Operational	No change in operational procedures – information is still advisory in nature, but the users' confidence in the products and hazard awareness should be increased. This increased confidence will allow aircraft operations in regions that previously were deemed unsuitable for flight.	No change in procedures – information is still advisory in nature. There will be no changes to the operational policies in flight planning or following responsibilities or procedures.
Personnel	None	None

Area of Influence	Controllers	Dispatchers
Interface	Users' have to be able to identify regions of turbulence as well as regions where there is no turbulence, and this must be able to be achieved with very little additional workload. It may not be practical to scale the turbulence reports for different aircraft types and configurations. Some generic scaling will be developed in Phase II to account for different aircraft turbulence response. **This is an essential change**	Users' have to be able to identify regions of turbulence as well as regions where there is no turbulence. It may be practical to scale the different reports for the various aircraft that the dispatcher is following. **This is an essential change**
Support Concepts	None	None
Other	None	None

4.3 Priorities Among Changes

It is clear that in order to realize the full benefits of the TurbDST, including those benefits seen in the cockpit, the turbulence information must be integrated with other tools and products. Each of the constituents have slightly different needs and uses for the data, but one common thread is clear, the ATC users will not be able to spend a lot of time assessing the turbulence threats to individual aircraft. They must be able to obtain a more global perspective easily and quickly. Dispatchers may have more leeway depending on their workload, and therefore may require and benefit from additional capabilities for their toolsets.

Suitable interface changes will need to be made. If the interfaces cannot be configured correctly, the system may be cumbersome or difficult to use. This will also be a key area of focus in Phase II with the controllers and dispatchers.

4.4 Assumptions and Constraints

This section describes assumptions or constraints that have been identified as applicable to the changes and new features identified within this section of the CONOPS. This includes assumptions and constraints that will affect users during operation of the modified system.

Two key assumptions have been identified during the initial research of a TurbDST integrating the TAPS and E-Turb technologies. The first assumption is that there is suitable coverage of TAPS equipped aircraft within the national airspace. Whereas the feed of real-time TAPS reports is currently available, it remains to be seen how fast, and to what extent TAPS can be implemented on fleet aircraft. AeroTech currently has plans to equip more aircraft, and this remains a key goal for AeroTech's success in this business.

The second assumption is that as new sources of turbulence hazards become available, they will be incorporated into the TurbDST in such a way that there will be no new requirements on the system or on the user. AeroTech acknowledges that the development of the decision support tool can take advantage of the same time horizon as identified by the NextGen development team of the JPDO. The TurbDST will have direct application to the Airspace Program's Adaptive Air/Ground Automation Concepts &

Technologies research area, specifically with regards to shared situational awareness, collaborative decision making, traffic flow management, air-to-ground information sharing, 4-D trajectory operations, and dynamic airspace design.

An identified constraint of the proposed system includes the need to address regulatory issues. This will be an ongoing effort throughout the research and implementation process.

5. Proposed System Concepts

This section will describe the proposed system that results from the desired changes specified in Section 4 of the CONOPS. This section describes the proposed system in a high-level manner, indicating the operational features that are to be provided without specifying design details.

5.1 Background, Objectives, and Scope

Aircraft encounters with turbulence are the leading cause of injuries in the airline industry. In a ten-day period in August 2003 alone, over 30 passengers and crew were hurt, some seriously, in turbulence encounters. In addition to the human costs, airlines have numerous unplanned operational and maintenance costs associated with turbulence encounters. A large contributor to the above injuries and costs is that flight crews, traffic management specialists, controllers, and dispatchers have poor knowledge and insufficient situational awareness of the location and severity of potential turbulence hazards to aircraft under their control. Without this direct knowledge and awareness, aircraft may be unnecessarily routed around airspace that appears threatening, but actually contains light or less-than-light turbulence, or aircraft could be inadvertently routed into areas of hazardous turbulence. Improvements to the status quo will be accomplished by the development of a TurbDST that will enhance situational awareness of the location and severity of turbulence; by providing real-time quantitative turbulence information downlinked from aircraft. This decision aid will remove the need for inference that is required to interpret current turbulence information. The TurbDST will enhance tactical and strategic decision making with regard to airspace usage and aircraft routing by enabling users to predict the effect of the reported turbulence on aircraft whose route may take them through that location.

This display is an integrated approach using aircraft sensors, datalink, and displays that provides a blended solution of the following elements:

- Forecasting – Better models are being developed by several agencies and can be the first line of defense in avoiding turbulence.
- Nowcasting – The Enhanced Turbulence Radar can provide predictions of turbulence hazards for the next 25-40 nautical miles to the flight crew for making tactical decisions.
- Reporting – TAPS reports are descriptions of previous turbulence encounters by other aircraft, providing a much better picture of the actual turbulence hazard than is currently available, without cluttering ATC communications.

The fundamental purpose of the system is to improve capacity while maintaining safety within the airspace. Given forecasted increases in the demand for airspace over the next several years, encounters with turbulence are likely to rise significantly. In providing better hazard awareness tools within an increasingly constrained national airspace, the system also shows tremendous promise in its ability to help airlines and air traffic decision makers operate more efficiently, with maximum utilization of airspace at an equivalent level of safety. While safety is the driver for the process, the economic impact resulting from efficiency improvements and increased airspace capacity could be enormous.

Injuries have actually decreased in recent years, but the change has resulted from a very conservative approach to avoiding turbulence on the part of the FAA. Because of this very conservative approach to avoiding weather hazards (primarily possible areas of turbulence), the current operating environment often consists of large regions of airspace closed to traffic, frequent rerouting of flight paths, and numerous altitude changes to avoid turbulence. With a forecast of less airspace available for such measures to be taken in the future, there seems little doubt that the recent safety gains in this area are, at best, unsustainable. At worst, such a trend may undergo a significant reversal.

5.2 Operational Policies and Constraints

This section describes the operational policies and constraints that apply to the proposed decision support tool. Operational policies are predetermined management decisions regarding the operation of the new or modified system, in the form of operating specifications, operational use limitations, certification limitations, or regulations that prescribe the system's operational use and proscribe certain uses. Policies limit the decision-making freedom of users but do allow for some discretion. Operational constraints are limitations placed on the operations of the proposed system.

Several operational policies have been identified that will be considered during the development, refinement, and evaluation of the Integrated Turbulence Hazard Decision Support Tool. Most commercial air operations fall under United States government Federal Aviation Regulation Part 121. Dispatchers' decisions regarding turbulence are governed by FAA Order 8400.10 (Reference [6]), FAA Advisory Circular AC-00-30B, "Atmospheric Turbulence Avoidance," FAA Advisory Circular AC-120-88A, "Preventing injuries Caused by Turbulence," FAA Advisory Circular AC-121-25, "Additional Weather Information," and individual company policies. Additionally, FAR 121.533 designates the dispatcher as having the responsibility to exercise operational control, including route and altitude planning and rerouting when conditions demand it. Controllers' decisions are governed by FAA Order 7110.65R and Order 7210.3U, Reference [7] and [8] respectively. In addition, guidance for pilots operating around turbulence is documented in the FAA's Advisory Circular AC-120-TURB, "Preventing Injuries Caused By Turbulence." It has been observed by pilots, dispatchers and controllers that the guidance available for turbulence avoidance is sparse and based on guidelines and rules of thumb set many years ago. This is due to the paucity and subjective nature of turbulence information available up to now. With the advent of TAPS, E-Turb radar, and several new products under development, better information is available and can be readily disseminated. It is not unlikely that the development of TurbDST, along with AeroTech's turbulence hazard cockpit display efforts will prompt the FAA and industry to revisit these guidelines to the benefit of the operation, while maintaining safety.

Preventive measures for flight crews encourage the avoidance of areas of known turbulence. This includes that a flight crew should seek alternate routing prior to departure if a known area of turbulence could pose a problem in flight. The proposed system will help the flight crew make these informed decisions. In addition to conferring with Air Traffic Control about ride reports, the flight crew should slow to the manufacturer's recommended turbulence penetration speed based on information presented. As in departure, the flight crew should seek alternate routing to avoid affected areas prior to descent.

5.2.1 Planning Around Turbulence

The dynamic nature of turbulence and the implications of aircraft encounters require a very flexible reaction by the users to plan for and mitigate aircraft around regions of significant turbulence. For instance, if the turbulence within a region of airspace is reported to be so severe that aircraft begin to ask for reroutes or refuse to fly in the impacted airspace, the Traffic Management Unit for that particular sector will become involved. Airspace throughput and traffic flow must be maintained to prevent congestion, flight level compression, and ground stops. The controlling authority of the airspace that is reporting the impact will contact the ATCSCC and request reroutes around the airspace. This normally occurs in high altitude sectors and in most cases shuts down a segment of altitude along a route. Compression may then occur at the lower altitudes when too many aircraft are asking to stay low, to avoid regions of turbulence. The ATCSCC will then start rerouting aircraft to take the pressure off the impacted sector or sectors. The presence of turbulence creates a dynamic situation where very little planning can take place, therefore it is important that participants in the decision making and planning process have adequate, timely, and un-subjective information at their disposal to avoid causing ground stops, which in turn causes delays and subsequently costing airline customers money. There are very little preplanning capabilities made available within the confines of the current system except in the area where severe turbulence is reported and severe action has to be taken.

Two positions in the Airline Operations Center (AOC) are involved in developing, coordinating, and negotiating route and reroute decisions, the dispatcher and the ATC coordinator/ manager. The dispatcher is involved on an individual flight basis and the ATC coordinator/ manager is involved when there is disagreement between ATC and the dispatcher as to which route to fly. The aircraft dispatcher is responsible to select a route that most complies with safety, passenger comfort, economy, and available NAS resources to handle the flight. In many congested areas and very short stage lengths, routes are limited to only a few alternatives based on ATC preferred routes. During periods of adverse weather, available and/or mandatory routes may be selected by ATC thus limiting the selection capabilities of the dispatcher. If the dispatcher deems the ATC identified routes as unacceptable, a negotiation for a new routing through the ATC coordinator is initiated. Flight and route planning are usually accomplished 1 to 2 hours prior to departure with only limited knowledge of when and where turbulence might exist based solely on vague forecasts. The dispatcher may reassess the route/altitude due to weather, turbulence or other constants and modify these via computer automation up to 45 minutes prior to flight planned departure time. Any changes desired within the 45-minute limit must be coordinated with the ARTCC TMU.

Once a flight has departed the gate, it is difficult to be proactive and make route changes. Any changes must be negotiated with ATC, usually through the ATCSCC. Once airborne, the dispatcher is responsible for monitoring progress of the flight and providing updates on changes to forecasts and pilot reports of turbulence. Small deviations around turbulent areas are usually negotiated between the pilot and ATC Controller. However, flights deviating in constrained and high volume areas may create traffic congestion. This congestion may cause traffic management issues and mileage significant reroutes may be mandated. Flights that are involved in these ATC reroutes may be incapable of complying due to fuel or performance abilities and the new routing may be deemed unacceptable to the pilot and dispatcher. Either the pilot and/or the dispatcher must then coordinate a new routing, which both avoids the turbulence and meets the abilities of the crew and aircraft. This is a manual, time-consuming process that involves pilot, dispatcher, Sector Controller, ATCSCC and other ATC Centers.

5.2.2 Turbulence Report Dissemination

Additional operational policies encourage the use and dissemination of information to maximize the effectiveness of the flight crew response when encountering turbulence. This policy includes informing Air Traffic Control when an aircraft encounters turbulence (forecasted or otherwise) en route. The air carrier dispatch office should also be notified of the turbulence encounter so that information may be forwarded to following aircraft in the vicinity. These operational policy features can be clearly accomplished by the proposed decision support tool while minimizing the user workload and decreasing the subjectivity of the current methods of relaying turbulence encounters.

For controllers and dispatchers, the process to disseminate turbulence reports to other aircraft under the current system is a manual process filled with differing requirements and methods for each user group. In practice, turbulence is an advisory usually passed from the captain of an aircraft directly to a controller. Controllers will pass individual turbulence advisories to each other using landline phone systems. A controller will call the impacted center or tower to advise that an aircraft within the region has reported turbulence of significant intensity. If time is available, a controller will document a PIREP and pass it along to the supervisor; however, research and interviews with our Phase I experts indicates that this part of the process is rarely accomplished. Controllers will subsequently, manually advise other aircraft under their control of the turbulence report and the type aircraft reporting it if time permits. A controller can only advise an aircraft's flight crew of a turbulence report(s), proper action and steps to safely operate the aircraft within that region of airspace containing the turbulence report will be the responsibility of the captain.

The dispatcher may receive PIREPs and other turbulence reports through the National Weather Service and various weather information service vendors. These reports are usually time critical and are rarely received in significant time to react tactically or to be used in planning. A dispatcher may receive a real-time pilot report via radio, ACARS, or another company dispatcher(s), which may provide adequate time to react tactically by attempting to reroute a flight or at the least advise the crew of possible turbulence encounters. However, the receiving dispatcher may be so involved in providing the information or rerouting flights that the dispatcher is responsible for, that the information is not passed on even throughout the dispatch office in a timely manner. Only occasionally, will this real-time information be provided to dispatchers or pilots outside of the involved company.

A key discovery from the development and evaluation of TAPS and E-Turb Radar identifies the potential use of the technologies for improving capacity in the air traffic control system. New turbulence related information would allow the dispatcher and controller to be more proactive in strategic route planning. Access to real-time, subjective, and accurate turbulence information would allow the dispatcher, pilot, and controller to closer align deviations and reroutes around turbulence, creating less airspace congestion and traffic management issues. This environment requires the collaboration of dispatchers, controllers, and pilots. Because of the collaborative nature of the users, the information concerning turbulence must be compatible for the displays of the three users. The individual design of each system must take into account the needs and requirements of the other two systems.

5.3 Description of the Proposed System

The technical challenge in this work is to present the users with a meaningful and useful display depicting the location and severity of turbulence hazards to their aircraft. The information on which to base this display may come from disparate sources – each one satisfying the defined requirements of a turbulence advisory system. There is a significant technological challenge in fusing the turbulence information and bringing the display formats together. The display must present consistent, understandable information to the user no matter what the source (i.e. a moderate turbulence severity report received from one source must mean the same severity as a moderate report from another source).

There are two main sources of turbulence hazard information have been developed and operationally evaluated under NASA's Turbulence Prediction and Warning System element of the Aviation Safety and Security Program.

1. The Turbulence Auto-PIREP System, which automatically transmits and receives turbulence encounter information from aircraft, and
2. The Enhanced Turbulence Mode Radar.

These technologies are two prime candidate data sources for an integrated turbulence hazard decision support tool. As will be described below, the predictions made by both the above technologies have been designed to be entirely consistent in terms of the metrics and scaling used. What remains is to fuse the turbulence data together into a decision support tool that will be used to reduce or eliminate the types of accidents mentioned previously and increases in airspace efficiency.

The innovation of the TurbDST is fourfold:

1. It fuses and integrates disparate sources of turbulence hazard information into an intuitive and useful display to increase dispatcher, controller, and traffic manager situational awareness of turbulence hazards.
2. The tool enables the quantification of the turbulence hazard's effect on any particular aircraft, removing the need for the users to infer the expected turbulence severity from either subjective PIREPs or from weather radar reflectivity returns.

3. The tool will, both strategically and tactically, assist controllers and dispatchers in optimally routing (efficiently and safely) their aircraft, will assist traffic managers in optimizing use of the national airspace, and will improve collaboration between all users of the NAS regarding routing in and around turbulence.
4. The tool can be developed and integrated in such a manner that a phased implementation over the next 15 years will remain in accordance with the NextGen development. This system can be initially realized in the near term, and continual improvements are proposed, which will not require new infrastructure or operation, but will simply improve the product.

In a business environment that currently is financially challenging to most airlines, it is tempting to diminish the commercial potential for new products for the industry; however, it has been estimated that turbulence-related costs to the airline community amount to over $100 million per year (Reference [10]). These costs are incurred due to injuries, as well as operational inefficiencies and unplanned maintenance requirements. In addition, the ATA has estimated the total cost of weather related ATC delays in 2005 as being $5.866 billion [1]. The proposed TurbDST will enhance situational awareness of the location and severity of turbulence; by providing real-time quantitative turbulence information downlinked from aircraft. This decision aid will remove the need for inference that is required to interpret current turbulence information. The TurbDST will enhance tactical and strategic decision making with regard to airspace usage and aircraft routing by enabling users to predict the effect of the reported turbulence on aircraft whose route may take them through that location. The end result is that the aircraft are operated more efficiently around turbulence while maintaining, or even improving, the level of safety and reducing injuries due to turbulence. This improved efficiency will be translated into reduced costs for the airlines and consumers.

5.3.1 Previous Work

Work has been carried out in the past attempting to develop components of a turbulence warning system based on aircraft reports. In 1996, Search Technology, Inc., working under a NASA SBIR, tried to develop a real-time turbulence warning system based on automated turbulence reports from other aircraft. Their final system was not realized due to limitations in the measurement algorithms, lack of a suitable communications infrastructure, and a lack of integration with the onboard systems. In addition, the work did not focus on specifying the turbulence hazard to the aircraft. Instead, the system reported an "aircraft independent" turbulence value from which the pilot was required to infer a turbulence hazard.

Although work has been carried out in the past to provide pilots with real-time displays of turbulence information (References [11] and [12]), the motivation for these efforts has always been to improve safety, and the information was only intended to be used within the cockpit. In AeroTech's approach, whereas safety is a primary concern, the hazard information is intended to be disseminated amongst all the stakeholders with a view to improving airspace usage while maintaining or improving safety. AeroTech's approach achieves the goals of those previous efforts, and further extends them into areas where the customer (airline operators) may see some significant economic and safety benefits.

Under a NASA Phase II SBIR, AeroTech developed an Integrated Turbulence Hazard Decision Aid for the Cockpit that will improve pilots' situational awareness of turbulence hazards by providing them with integrated turbulence hazard information scaled to their specific aircraft. The preceding Phase I research showed that the fusing of objective turbulence hazard information from disparate sources (TAPS and the E-Turb Radar) and presenting pilots with consistent, objective, and meaningful turbulence information on one integrated display was feasible. AeroTech's prototype cockpit decision aid was tested and evaluated by commercial pilots in both Part-Task and Full-Task (flight simulator) simulations.

5.3.2 Overview of the Envisioned System

The overall objective for this project is to determine the feasibility of integrating, displaying, and using the TAPS report information, turbulence information from the E-Turb Radar, and turbulence information from other sources (such as standard turbulence mode weather radars, ground radars, etc.) on a ground station system to both increase the turbulence hazard situational awareness of controllers, traffic managers, and dispatchers, and enhance their decision making with regards to the safe and efficient routing of aircraft in and around regions of turbulence. This concept integration is illustrated in Figure 3. The innovation is that the displayed turbulence information can be scaled to a specific aircraft, so that the operator / user does not have to infer the probable effects on the airframe. With this improved situational awareness users will be able to either avoid the hazard through deviations or thoroughly prepare the aircraft for the turbulence encounter by ensuring that everyone on the aircraft is seated with their seatbelt securely fastened and that objects (laptops, food carts, etc.) are secured.

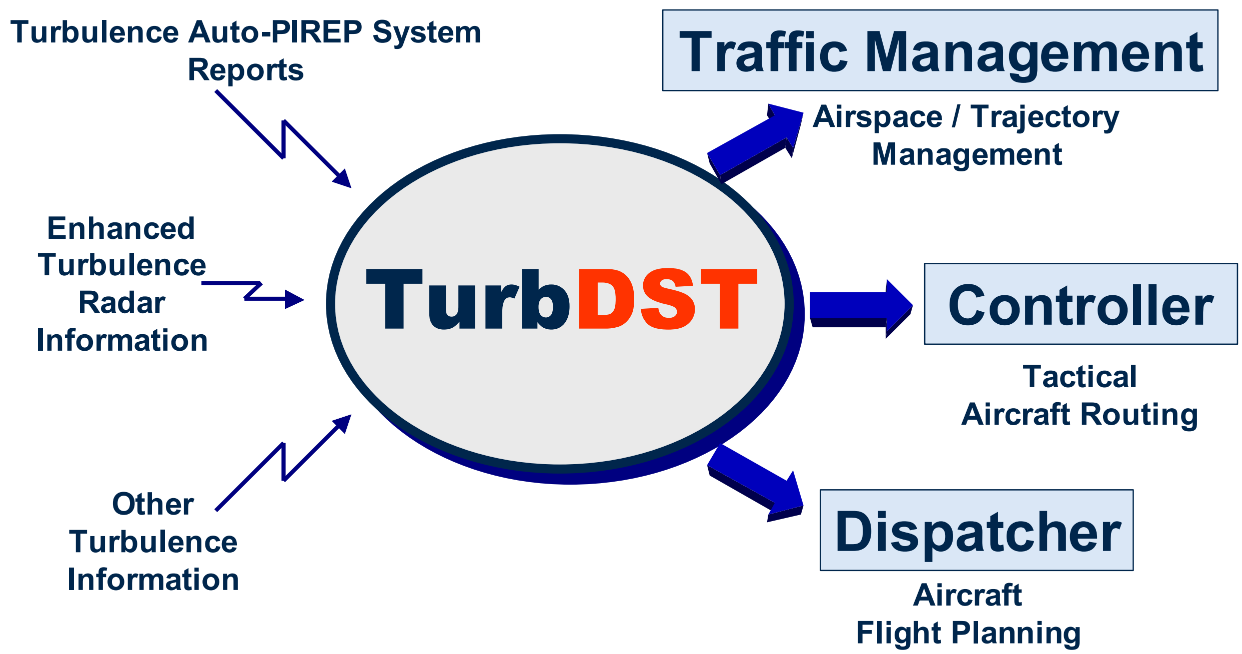

Figure 3: TurbDST Concept Diagram

One of the two underlying data sources for this display will be the TAPS. A brief outline of TAPS is offered here, but greater detail is available in Reference [13]. The architecture of the TAPS is illustrated in Figure 4. Aircraft #1 encounters turbulence (convective, clear air, mountain wave, etc.). Turbulence measurement algorithms on board the aircraft decide whether the turbulence was significant enough to transmit a report. If it is significant enough, a report comprised of a packet of data with the aircraft's position, the time of occurrence, the load experienced, and various aircraft parameters from the ship's systems are generated. This data packet is transmitted to the ground, stored in a database, and displayed on the ground station network. The data packet is also transmitted, either directly from the originating aircraft or up-linked from the ground station, to other aircraft (Aircraft #2). The receiving aircraft will, using a turbulence prediction algorithm, scale and interpret the data for its aircraft type and current configuration (altitude, speed, weight, etc.). If the turbulence hazard is severe enough for the second aircraft, the information will be displayed in its cockpit.

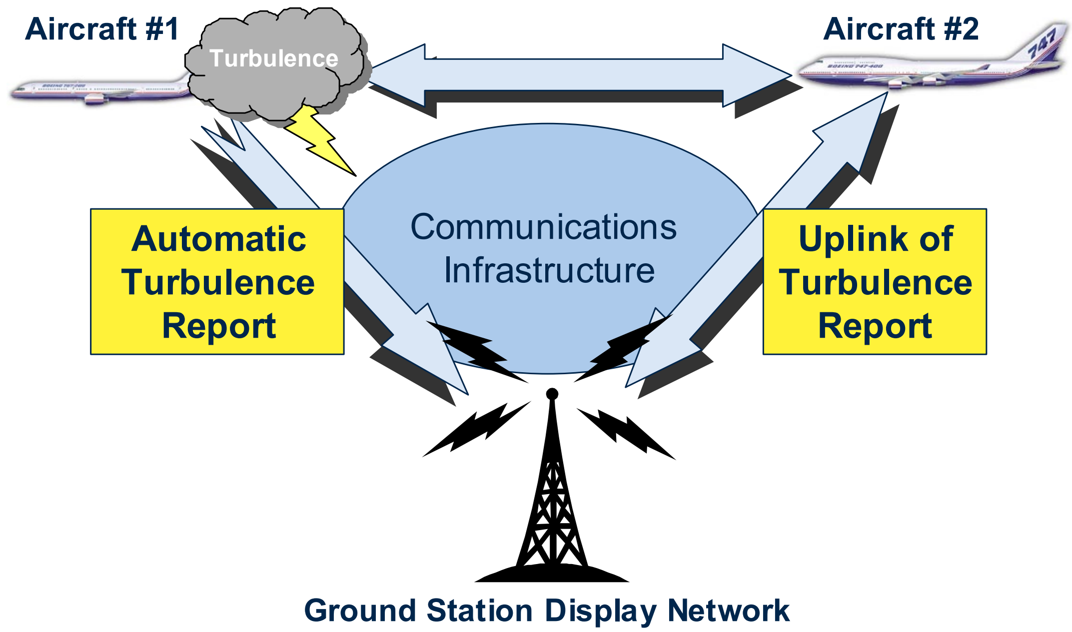

Figure 4: TAPS Architecture

The turbulence measurement algorithms were successfully validated on the NASA Boeing 757-200 research aircraft and on more than 176 commercial transport aircraft (both Boeing and Airbus design) from multiple airlines in revenue operations. During an operational evaluation on Delta Air Lines B-737-800, B767-300ER, and B767-400ER aircraft in revenue operations, TAPS reports were successfully transmitted to a ground station network via the ACARS messaging system. The reports were graphically displayed to Delta dispatchers and retransmitted up to other aircraft where they were received and interpreted, but not displayed in the cockpit.

Currently AeroTech and its partner WSI have integrated TAPS into WSI's Total Turbulence Product suite, including the Fusion™ dispatcher display tool. TAPS reporting software has been implemented on over 500 aircraft worldwide with more aircraft implementations in process.

Another data source of turbulence information for the proposed decision support tool will come from the Enhanced Turbulence Radar. Current airborne weather radars do not provide an accurate indication of turbulence hazards to specific aircraft. Ground-based weather radars are currently not capable of providing a turbulence product in real-time. Developed under the NASA Aviation Safety & Security Program, an existing airborne Doppler radar was modified using algorithms to detect and quantify convectively induced turbulence at very low reflectivity. The algorithms were initially integrated with an experimental radar on the NASA B-757-200 and flight-tested in 2002. Most recently under the TPAWS program, the turbulence hazard algorithms have been integrated into Rockwell Collins' Multiscan™ radar for an operational evaluation, on a Delta B-737-800, that continued through FY05. The Enhanced Turbulence Radar enhances a pilot's awareness of turbulence hazards to their aircraft by converting a weather radar's measurement into predicted loads on the aircraft. The E-Turb radar provides the locations and severity of turbulence hazards 3 – 5 minutes ahead of the aircraft, giving the flight crew a significant tactical advantage within turbulent regions. With the Enhanced Turbulence Radar, aircraft are better able to avoid hazardous convective turbulence by deviating or preparing the cabin for encounters and can therefore lead to a reduction in injuries and maintenance costs due to turbulence encounters. Many of the same characteristics of the airborne enhanced turbulence radar could be applied to a ground-based weather radar, thereby empowering users such as the dispatcher and controller with more detailed turbulence information that would enable them collaborate more efficiently with flight crews and therefore make better informed decision regarding the routing of aircraft within the national airspace.

The integration and implementation of the decision support tool, as described earlier, will take a phased approach along the time line proposed for NextGen. As communication bandwidth technology matures and more aircraft are equipped with E-Turb radars, convective turbulence from suitably equipped aircraft will be fused with TAPS reports to create a user friendly and intuitive display of turbulence information.. A challenge will be to ensure that the combined information is understandable and that turbulence reports of a specified severity from one source mean the same thing as turbulence reports of the same severity level from another source.

5.4 Modes of Operation

Six modes of operation for the proposed system have been identified that will pertain to the continued development and evaluation of a decision support tool incorporating the Turbulence Auto-PIREP System and Enhanced Turbulence Radar technology. These six modes or phases of flight (Flight Planning, Pre Flight, Taxi Out, Climb Out, Cruise, and Descent & Arrival) will be discussed in further detail below.

The primary modes are based on the phase of flight since the primary users (Pilots, Dispatchers, and Controllers) use them to define their tasks. Training considerations will be important as the other modes are developed. The ground and flight based modes will be defined by the requirements of the phase of flight. Operational considerations will dictate failure, operational, and default modes based on human factors' design criteria.

Each one of the tasks under each phase, previously identified in Section 3.4, will be summarized in tabular form below. Each table describes a specific task for a particular phase of flight. The primary headings for the tables are Task, describing the tasks the groups are addressing and which group is the primary and which is secondary, and Description, describing the task itself and the potential challenges faced. Individual groupings of the rows of the table identifies the relevant user group involved within each of the dispatcher and controller organizations as well as inputs from the flight crew. For example in the first table the dispatcher group involved is the business unit and the controllers involved are the Command Center personnel.

5.4.1 Phase I: Flight Planning

A dispatcher conducts the flight-planning phase for an individual flight several hours in advance. Such planning must take into account many variables concerning the weather, suggested flight schedule (arrival and departure times), and the national airspace system status, and any current restrictions. Throughout the course of the day several planning sessions will occur between the Air Traffic Control System Command Center, Traffic Management Units, and the airlines to plan for and mitigate any potential problems for the NAS. During these sessions, assessments will be made on the previous period's performance of operation.

Table 19: Phase I – Post Operational Analysis

Task	Description
Dispatcher: (Business Unit)	
Role: Secondary May be included as a participant in post operational analysis to give the airline perspective of the disruptions experienced.	Replay of TAPS reports will provide accurate and objective replay of what, when, and where turbulence was actually experienced by company aircraft for use in this analysis and future prevention. Can also be used to identify overly conservative actions on the part of dispatchers.
Controller: (ATC System Command Center / Traffic Management Unit)	

Task	Description
Role: Primary Must satisfy the need to assess the overall performance of the system and participants after a day of significant disruptions. This may take place within a day or so after an event. Analysis will include a review of forecasts, replay of traffic displays (using such programs like POET (Post Operations Evaluation Tool)), replay of weather, and participants' recollections of actions performed. It is very difficult to pull everything together in a coherent form (e.g., radio transmissions, dispatcher communications, what the pilots experienced, what the various controllers saw, what decisions they made and why, etc.)	Can show and replay turbulence experienced by aircraft being routed around or through weather to give a clear indication of the consequences of various decisions. Can also replay TAPS / turbulence info to review how these data were used in the strategic/tactical decision-making process. Can also be used to identify overly conservative actions on the part of controllers and traffic management.
Pilot:	
N/A	N/A

Table 20: Phase I – Strategic Planning Operation

Task	Description
Dispatcher: (Business Unit)	
Role: Secondary Need to plan airline routing and scheduling for the next 2+ hours	Can identify regions of current turbulence and modify routing accordingly.
Controller: (ATC System Command Center / Traffic Management Unit)	
Role: Primary Need to define strategic National Airspace System operations for the next 2 hours.	Can identify regions of current turbulence and modify routing accordingly. Can also modify forecasts based on TAPS reports and NEXRAD turbulence imagery.
Pilot:	
N/A	N/A

Table 21: Phase I – Planning a Flight

Task	Description
Dispatcher:	

Task	Description
Role: Primary Needs to plan a flight's route, altitudes, alternate airports, and fuel requirements for multiple flights. Uses standard airline routings, information from the Strategic Planning Operation, Route Management Tool, Route Optimization Generator, and other standard weather sources to plan routes.	Can use turbulence information (in conjunction with forecasts and observations) to select altitudes and preferred routings to minimize impact on flights (e.g. long periods of light or greater turbulence).
Controller: (The Host)	
Role: Secondary Approve route and file plan within the system.	N/A
Pilot:	
N/A	N/A

5.4.2 Phase II: Preflight

This particular phase of an aircraft's flight takes place while the aircraft is still at the gate, up to the time of 'Push Back.' During this portion of the flight, the users are reviewing normal procedures and checklists for the upcoming flight. The users are also in the process of reviewing and editing the proposed flight plan given updated information.

Table 22: Phase II – Pilot Reviews Flight Plan Prior To Push Back

Task	Description
Dispatcher:	
Role: Secondary Communicates with pilot to accept flight plan as provided or to define/negotiate reroute with ATC.	Can view turbulence location and severity (and even growth/ decay) and can help in the decision for a reroute.
Controller: (Clearance Delivery / Ground Control)	
Role: Secondary Will work with the pilot to amend the flight plan as possible.	
Pilot:	

Task	Description
Role: Primary Reviews the flight plan for acceptance. The company dispatcher will be contacted if a change in the filed flight plan is requested. The pilot is provided a paper copy of the flight plan information, aircraft performance information, and weather observations/forecasts. If a pilot requests a flight plan change within 45 minutes of departure (and greater than a few minutes before departure), the dispatcher will contact the TMU at the center and request the reroute. The dispatcher cannot enter a reroute into the Host at this time, but the TMU can make the appropriate changes. If the time frame is within a few minutes of pushback, the pilot can contact clearance delivery and request the reroute verbally. If a different altitude is desired the pilot will typically accept the routing and request a different altitude when en route unless the only usable altitude would significantly affect the fuel burn and would be unacceptable with the given amount of fuel supplied (e.g. only usable altitude is too low to complete a flight with given amount of fuel).	If a pilot sees unfavorable / severe turbulence along the route, indicated by TAPS reports or from Enhanced Turbulence Radar, a reroute may be requested. Depending on the timing the dispatcher may make the request on the pilot's behalf. If an optimal altitude is unacceptable due to turbulence, a pilot/dispatcher can make an educated estimate whether or not a reroute would be more efficient than a prolonged period at non-optimal altitude.

Table 23: Phase II – Reroute Issued Prior To Pushback

Task	Description
Dispatcher:	
Role: Secondary Work with flight crew on reroute. The ATC desk at the Airline operation Center will get involved if a reroute cannot be accepted. The ATC Desk will contact the Traffic Consumer Advocate for the particular sector.	The dispatcher will have the capability to view the same information regarding turbulence as presented to the pilot.
Controller: (Clearance Delivery / Ground Control)	
Role: Primary Ground Control will notify a pilot while at the gate to contact Clearance Delivery, which will subsequently give the flight crew the new routing. Rerouting may be required based on advisories from either the ATCSCC or SPO.	
Pilot:	

Task	Description
Role: Secondary Pilot contacts Clearance Delivery and receives new routing. May discuss with dispatch to confirm routing.	Can review turbulence along new routing and make a decision on whether to accept a new route, request a new route, or accept the new route and renegotiate in flight.

5.4.3 Phase III: Taxi Out

The taxi out phase is an extension of an earlier preflight phase from a commercial aircraft's point of view. The taxi out phase is marked by the period during 'push back' through movement at an airport's tarmac towards the final take off runway. During this portion of a flight, the users are performing any final reviews concerning the flight and committing to a route. Last, up to date information may be reviewed for impact on the upcoming flight.

Table 24: Phase III – Pilot Reviews Turbulence / Weather On Climb Out And Cruise Altitude

Task	Description
Dispatcher:	
Role: Secondary If a pilot requests a reroute and needs help from dispatch, the dispatcher will assist in negotiating the reroute. A flight's departure maybe delayed in this particular case.	Can view turbulence location and severity (and even growth/ decay) and can help in the decision for a reroute. The decision making process will benefit from knowledge of null (less than light) reports.
Controller: (Clearance Delivery, Ground Control, Local Control, TRACON)	
Role: Secondary If a pilot goes ahead with the planned take off, the tower will clear the aircraft onto the runway for takeoff and will hand the flight off to TRACON. If the flight crew decides to delay, then Ground Control will pull the flight out of the line of departing aircraft until the decision to go has been made. It is possible that the flight may go to the back of the line for take off.	If a request is made for a reroute, the flight will be pulled out of the line and asked to contact company dispatch for a new clearance.
Pilot:	

Task	Description
Role: Primary Pilot reviews weather / turbulence on climb out and may decide to request a reroute, delay the departure, or go ahead with the planned take off.	The pilot reviews weather / turbulence on departure corridor and decides to proceed with the departure or not. If severe turbulence were present and reported to TRACON by other aircraft, TRACON will potentially close the route. Equipped with TAPS, a pilot can also request an early runway heading deviation to avoid turbulence. Local Control / TRACON will also be equipped with similar turbulence information to aid in the decision making process. If during the review process, the pilot identifies weather / turbulence at altitude that is not desired, the flight may proceed on normal departure and can renegotiate en route or in climb out for a better position. The decision making process will benefit from knowledge of null (less than light) reports.

Table 25: Phase III – Reroute Issued Prior To Take Off

Task	Description
Dispatcher:	
Role: Secondary Involvement is only required if the aircraft cannot accept the new route (due to fuel loading), or if there will be an impact on the schedule. If the aircraft has time on the ground before take off, dispatch may be contacted.	The dispatcher will have the capability to view the same information regarding turbulence as presented to the pilot.
Controller: (Clearance Delivery, Ground Control, Local Control, TRACON)	
Role: Primary Ground Control will notify a pilot taxiing to the runway to contact Clearance Delivery, which will subsequently give the flight crew the new routing.	Rerouting may be required based on advisories from either the ATCSCC or SPO.
Pilot:	
Role: Secondary Pilot contacts Clearance Delivery and receives a new routing. The new clearance is entered into the Flight Management Computer. The pilot will assess the fuel requirements and determine if it safe to proceed. Clearance may than be accepted and will proceed with take off and departure from the airport. The pilot will contact the company dispatcher after take off.	Can review turbulence along new routing and can make an informed decision on whether to accept the new route, request a new route, or accept the new route and renegotiate in flight.

5.4.4 Phase IV: Climb Out

This next phase of flight considered covers the climb out portion of the aircraft from its departure airport up and towards its cruising altitude. Information within the decision support tool can provide real-time information of automatically and accurate turbulence reports of aircraft encounters along the projected flight path.

Table 26: Phase IV – Pilot Reviews Turbulence / Weather At Cruise Altitude

Task	Description
Dispatcher:	
Role: Secondary Dispatcher will provide guidance regarding suitable altitudes/ routing to avoid turbulence and to remain within the performance parameters of the aircraft and fuel load.	Can provide guidance to pilot regarding best routes / altitudes by having access to turbulence information.
Controller: (Tower/TRACON)	
Role: Secondary TRACON or lower sector controller will clear a new altitude or reroute as possible.	When pilot accesses a monitored frequency, the sector controller is able to see the turbulence reports / observations that can affect the flight and the initial communication from the pilot is not for ride information, but the requested new attitude or reroute information, thereby limiting the amount communications congestion. The Controller provides clearances as appropriate.
Pilot:	
Role: Primary Due to rough ride / moderate or greater turbulence reported at (initial) cruise altitude, a pilot may want to request a different altitude or a reroute.	A pilot can look at a cockpit display of E-Turb and TAPS and know turbulence conditions at altitude. When conferring with dispatch, whom will be looking the same TAPS information with a NEXRAD turbulence overlay, the process to select a suitable altitude / routing for request to the sector controller is performed more efficiently, either upon arrival into that airspace or earlier if necessary.

Table 27: Phase IV – Flight Reroute Issued

Task	Description
Dispatcher:	
N/A	N/A
Controller:	

Task	Description
Role: Primary Will issue a flight reroute based on assigned altitudes and other aircraft routings.	The controller is supplied better objective information of the location and severity of turbulence. Will have some knowledge of why some aircraft may be willing to penetrate a region if suitably equipped and if the scaled TAPS reports do not indicate significant hazard.
Pilot:	
Role: Secondary Will reprogram FMC and accept new attitude/ reroute as he can.	Sees turbulence / weather along the new route and may accept or decline the new altitude / routing base on supplied information.

5.4.5 Phase V: Cruise

The cruise flight phase of an aircraft occupies the most amount of operational time of an aircraft in flight. The cruise portion of a flight for this CONOPS happens between the climb out and top of descent phases of flight. Information within the decision support tool can provide real-time information of automatically and accurate turbulence reports of aircraft encounters along the projected flight path.

Table 28: Phase V – Aircraft Experiences Severe Turbulence

Task	Description
Dispatcher:	
Role: Secondary Dispatcher picks up an advisory from ATCSCC that a route has been closed due to severe turbulence. The dispatcher will start to plan reroutes accordingly. The dispatcher may also have picked up a PIREP from the event if the aircraft reporting the severe turbulence is a company airplane.	The dispatcher is presented with more exact knowledge of the location and severity of turbulence and its relation to the local weather. Information will be supplied very quickly and the dispatcher can also work with aircraft on the ground to get rerouted if within time constraints.
Controller:	
Role: Secondary Sector controllers will warn other aircraft within the area of the severe turbulence encounter. The TMU/ATCSCC may decide to close down that portion of the NAS if several reports or several aircraft make severe turbulence reports within a particular area. If this is the case, shift supervisors will disseminate this information to other sectors (high and low), and to the Local and Ground controllers. The report may also go to the command center, which may in turn issue an advisory which will get picked up by company dispatch and passed along to pilots.	Exact location of event can be shown very quickly and reroutes can be made with more precision. Some aircraft may be able to go through the region if the reports scale to a suitable safety level (less than severe).
Pilot:	

Task	Description
Role: Primary Pilot in cruise experiences severe turbulence and makes a report to the sector controller.	TAPS automatically makes the required report and can be displayed on ground displays within a few minutes. The location and severity of the encounter is automatically defined for other aircraft types. Dispatchers, pilots, and controllers in other jobs can quickly see TAPS report information.

Table 29: Phase V – Aircraft Experiences Less Than Severe Turbulence

Task	Description
Dispatcher:	
Role: Secondary Dispatcher picks up an advisory from ATCSCC that a route has been closed due to turbulence. The dispatcher will start to plan reroutes accordingly. The dispatcher may also have picked up a PIREP from the event if the aircraft reporting the turbulence is a company airplane.	The dispatcher is not required in this process unless there is a problem clearing the request with ATC, or if there is a significant impact on the airspace capacity in which the ATC desk's interaction will be required.
Controller:	
Role: Secondary Sector controller will respond to requests, granting/denying changes to aircraft route.	Provided knowledge of the location and severity of the turbulence quickly and efficiently. The controller is not required to provide the pilot with information about the reports from other aircraft because it is automatically supplied by the TAPS communications infrastructure. The conversation between the user groups will now be limited to just the altitude/ reroute request and clearance. Knowing where the turbulence is, the controller can also be prepared for other similar requests from other aircraft in the vicinity. May confer with the TMU and ATCSCC if there is an impact on the national flow plan.
Pilot:	
Role: Primary Pilot in cruise experiences less than severe turbulence. The encounter may be light or moderate in intensity or even a poor ride quality issue. The flight crew wants either a route change or an altitude change. The pilot will perform this request with the sector controller.	Can review TAPS/E-Turb turbulence information along flight path or preferred altitude/ routing. Uses this information to contact ATC when requesting alternate altitudes or routes.

Table 30: Phase V – Aircraft Approaching Line Of Convection

Task	Description
Dispatcher:	
Role: Secondary Provides recommendations for rerouting or altitude changes to the pilot to get through and across the line of convection.	The dispatcher will have the capability to view the same information regarding turbulence as presented to the pilot (excluding the airborne weather radar). Watching the TAPS reports and the regions of null reports within the area, the dispatcher can develop a strategy for the flight.
Controller:	
Role: Secondary Sector controller will respond to requests, granting/denying changes to aircraft route / altitudes.	The controller will have the capability to view the same information regarding turbulence as presented to the pilot (excluding the airborne weather radar). Although the TAPS reports may not be scaled to any one particular aircraft on a controller's display, the reports will indicate regions of activity and regions where pilots may make requests to avoid the turbulence. The NEXRAD turbulence information may also present information about where the hazardous areas are. The decision to penetrate a region will be made by the pilot, but presenting this information to a controller will give advance knowledge of where the trouble spots may lie.
Pilot:	
Role: Primary The aircraft is approaching a line of convection that will need to be crossed. This scenario assumes that the aircraft remains en route and does not have to descend on an arrival in the vicinity of the convection. This is because on arrival there will be other constraints on the pilot's actions other than turbulence avoidance (e.g., arrival sequencing). As the aircraft approaches the convective line, there will be discussions with the sector controller about where aircraft are trying to cross the line and any reports of turbulence they may have encountered.	The pilot will have enhanced turbulence mode radar and TAPS information within a flight deck display. This will indicate direct information about the location and severity of the hazards. Although the E-Turb radar mode will not provide turbulence information at ranges longer than 40 nautical miles, TAPS information will be available to assist in identifying regions of turbulence as well as regions of null reports (i.e., regions transited by TAPS equipped aircraft that have not made reports). The pilot can effectively discuss options with the dispatcher, who will also be able to see the TAPS reports. On closer approach to the line of convection, the pilot will be able to see TAPS reports from any aircraft ahead of the aircraft's current position and the E-Turb radar will provide turbulence information to help avoid the region. This information will also help in discussions with the Sector Controller.

Table 31: Phase V – Opening Up Region Of Airspace Previously Closed Due To Severe Turbulence

Task	Description
Dispatcher:	
Role: Secondary If the request comes through the ATCSCC to the ATC desk, the dispatcher will communicate the request to the aircraft.	Dispatcher has a NEXRAD turbulence product to identify regions of turbulence in the vicinity. TAPS reports are not useful for a region that has been closed. A dispatcher will use TAPS reports (or lack thereof) from the pathfinder aircraft to pass on to other company aircraft that may wish to use the route.
Controller:	
Role: Primary A region or route may have been closed after multiple reports of severe turbulence or weather. After a period of time, the weather will have moved off and the route or region can be reopened. The TMU or sector controller may ask for a "pathfinder" to proceed through the region.	May submit a request for a TAPS and E-Turb equipped aircraft to be the pathfinder for a previously closed region of airspace. This is a good example of "performance based operations." Reports from this aircraft will be available to other aircraft (through a TAPS flight deck display) and on the ground within minutes.
Pilot:	
Role: Secondary The pilot can either accept or decline the opportunity to be the pathfinder.	TAPS information on a flight deck display is of limited use within a region that has been closed to traffic. The E-Turb radar and a NEXRAD turbulence product (if available within the cockpit) will be used during a pathfinder flight, assuming the turbulence was convectively induced.

Table 32: Phase V – Turbulence on Arrival Path

Task	Description
Dispatcher:	
Role: Secondary Dispatcher recommends different arrival to an airport.	With TAPS information, a dispatcher is able to identify areas of turbulence and those areas lacking turbulence on the different arrival paths. This information can be passed along to the pilots if necessary.
Controller:	
Role: Secondary Sector controller receives request from pilot to route to different arrival fix.	Sees turbulence on arrival and can expect requests for different arriving aircraft, as long as the arrival corridor remains open.
Pilot:	

Task	Description
Role: Primary Prior to top-of-descent pilot decides that arrival is unsuitable due to significant turbulence at or past the arrival fix. The pilot will ask the controller for a reroute to another arrival fix.	TAPS and other turbulence information will indicate the potential for a hazard to the pilot on the arrival path. The pilot will then be properly equipped to reconsider the arrival and request a different arrival based on the TAPS reports.

5.4.6 Phase VI: Descent & Arrival

The final phase of an aircraft's flight reviewed for this CONOPS is the descent and arrival portion. Following the cruise phase, this portion of the flight begins at the top of descent for an aircraft and continues through arrival to an airfield. Information within the decision support tool can provide real-time information of automatically and accurate turbulence reports of aircraft encounters along the projected flight path.

Table 33: Phase VI – Turbulence On Arrival Path

Task	Description
Dispatcher:	
Role: Secondary May provide information on arrival corridor to pilot in advance of top of descent.	Limited involvement is required unless there is a fuel issue or the new arrival will make the aircraft significantly late.
Controller:	
Role: Secondary Sector controller reroutes aircraft to a different fix.	Controllers do not require turbulence information for all the arrivals to a particular airfield. The TMU / ATCSCC may want the reports / turbulence information if there is a significant problem affecting a major airfield, which will intern affect many aircraft within the system. The controller approves the request as possible providing current standards and policies.
Pilot:	
Role: Primary Due to significant turbulence weather on arrival, a pilot may decide to request routing to a different arrival fix prior to top of descent.	A pilot can see TAPS reports on arrival and is capable of choosing a different arrival based on these reports and those present on the different arrival corridor.

The content presented in the above tables has been an attempt to summarize a very dynamic and complex series of interactions among different users and the stakeholders. It may well be the case that some of the decisions may sometimes be made in ways other than described above for a variety of reasons (e.g., special airspace constraints, particular weather events). However, it is felt that the above information helps to identify flaws in the system, reasons for change, and the technology required to improve the system.

5.5 Users and Stakeholders

The following section will describe the users and stakeholders that may be involved with the proposed system concept described within this CONOPS. Of the users and stakeholders identified in Section 3.3, all will continue to participate in the proposed system concept.

5.5.1 Organizational Structure

Three top-level organizations have been identified that will contribute to the use of the proposed system concept as described within this CONOPS. They are the airline operators (American Airlines, United Air Lines, Southwest Airlines, etc.), the air traffic service providers (FAA ATC), and the traveling public. Users within each of the identified groups will have direct interaction with the proposed displays and information contained within them. The air traffic service providers will be a part of the approval process for changes within the routing of an aircraft and must have access to similar information contained within such a display if the decision making process is to be efficient. And finally, the traveling public has an indirect use of the display through their flights on equipped aircraft and their experiences or lack of experiences of turbulence during those flights. The significance of the traveling public is emphasized by the fact that the airlines typically take a very conservative approach in avoiding turbulence regions to provide a smooth ride for the passengers at the expense of time and money for the airline.

Within the airlines there are two primary groups identified: pilots and dispatchers who have a shared responsibility for the safety of the flight from a company perspective. The air traffic provider has a dual responsibility of efficient and safe guidance within the subject airspace through the use of controllers and the Traffic Management Unit located throughout the various levels of ATC. The passenger is the economic driver of the air transport system. The other two groups must provide not only a safe and efficient mode of transportation, but they have to consider the comfort factor since the consumer might choose another air carrier if they are not satisfied with the flight. Unfortunately, there are not many timely and accurate reports of turbulence in today's environment because of the constraints in the system. All PIREPs are subjective, based on FAA guidance, concerning control of the aircraft and movement of objects in the airplane. The current organizational structure does not support efficient and timely handling of PIREPs since both the controllers and pilots are usually busy with higher priority duties when the occasion arises to report turbulence.

If timely and accurate PIREP information is made available to the users of the system, there could be dramatic changes in the way these groups perform their jobs. Such data would allow them to make real-time decisions, which not only improve safety, but also allow a more efficient and expanded use of the national airspace.

5.5.2 Profiles of Users and/ or Stakeholders

Information of the profiles of the users and stakeholders has been identified in Section 3.3.2 and will remain unchanged within the proposed system concept. However, it will be noted that the display of turbulence information like the TAPS and the Enhanced Turbulence Radar must meet the end user's needs, and those needs may be directly related to the requirement of other primary users within the system that interact with the aircraft. The pilots and dispatchers are managed by the airlines; which set the standards for the operation of the flight. It can only be assumed that as new tools are developed that perform the job of identifying turbulence regions better, that the various constituents such as marketing, finance, operations, and safety within the airline will adjust their policies accordingly. Externally, the management for the controllers will similarly adjust their policies and procedures especially in light of the impending airspace capacity problems and limitations. The addition of turbulence information in the right user's hand will empower them with the knowledge of the potential for turbulence encounters, thereby allowing them to prepare and plan for events that otherwise may not have been known. Members of the Traffic Management Unit will be able utilize the additional turbulence information to make better and informed decision regarding traffic flow and potentially maximize previously unused airspace that may have been closed due to convective activity.

5.5.3 Interactions Among User Classes

As mentioned earlier, this environment requires the collaboration of pilots, dispatchers, controllers, and the Traffic Management Unit of ATC. Because of this, the information concerning turbulence must be compatible for the displays between each of the users. The individual design of each system must take into account the needs and requirements of the other three systems. The sharing of information between the different user classes must provide the same picture of the turbulence region of interest. Conflicting displays of turbulence information will not help in the acceptance of the system, but could in fact harm it when one user class has more information then the other and the user has no easy way to relay that information.

5.5.4 Other Involved Personnel

In addition to the users and stakeholders discussed in the previous sections, the airline operator is also involved in the operation and acceptance of the proposed system. This is exemplified by the turbulence policy of the operating airline. Airlines change altitudes and routes with a very conservative approach to avoid large blocks of airspace if there is a potential presence for significant turbulence. This is primarily due to a lack of sufficient tools to identify the location and intensity of turbulence within a given region of the national airspace; thereby resulting in significantly higher fuel consumption during the operation of a flight within one of these regions. If new tools were available, such as those proposed within this CONOPS, an airline internal team, consisting of marketing, finance, operations, and safety, could discuss and elect to accept a safe level of experienced turbulence to reduce fuel usage and increase airspace by managing the expectations of the customer.

5.6 Support and Maintenance

TAPS relies on an electronic datalink to supply information packets to and from aircraft and ground-based systems. The E-Turb radar product is based on algorithms developed by AeroTech Research and the communication of the electronic data would rely on a similar datalink as TAPS would, if supplied from the onboard radar. If the E-Turb radar product were supplied from more suitable ground based weather radar, such as a NEXRAD, the transmission of the E-Turb data would use existing communication pathways. The display of the proposed turbulence information relies on a combination of the TAPS reports, E-Turb radar products, and existing hardware within the user's environment. Because new hardware is not being installed solely for the display of turbulence information, support and maintenance of such devices would fall under normal operations and preventive inspections.

If the data is repackaged into a standard messaging format and provided to any ASD developer to display, then the storage of downlinked TAPS reports and E-Turb radar data can be handled by existing equipment within a user's environment and data contained within the database can be purged routinely designated by the time stamp associated with the data sources.

The FAA's ETMS is a prime candidate for a conduit to bring the turbulence information proposed to the users in quick and meaningful manner. Currently there is a Traffic Flow Management (TFM) Modernization Project underway to replace the existing proprietary architecture and reengineer existing TFM hardware and software to provide an expandable infrastructure that can accommodate new functions. The TFM Modernization Project could provide an opportunity to include TAPS information into the new ETMS with the potential of the FAA sharing the information with the NAS users through current ASD messaging. Additional research will be required to determine the appropriate pathway for TAPS reports generated by aircraft within the NAS to be incorporated into the data streams of the ETMS. Accuracy of the data may need to be certified to meet FAA requirements for such a critical data system.

The inclusion of the turbulence data sources would not increase the normal support and maintenance of the system.

The maintenance cycles and Minimum Equipment List required for flight with the proposed system on aircraft will need to be developed. In addition, any procedures for dispatching an aircraft with partial capability will also need to be developed.

6. System Introduction

This section will discuss the introduction of the proposed technologies within the current system, highlighting the relationships between the proposed technologies and the planned changes to the National Airspace System. A range of dependencies for the proposed technologies is presented, including the performance level expected of the proposed technologies. Also, issues associated with certification, procedures, and partial and mixed equipage environments are discussed.

6.1 Relationship to Modernization Plans

There are two main sources of modernization planning relative to the National Airspace System: the Next Generation Air Transportation System development of the JPDO, and the FAA's Operational Evolution Plan (OEP), of which the latest version of was just released. The former is a long-range vision of where the airspace operations should be for the United States by the year 2025, as well as interim steps by which to achieve this vision. The latter is the FAA's near- and longer-term plan of how to actually implement changes to facilitate the increase in capacity; one example of which is the recently released Airspace Flow Program to deal with weather induced delays. The following text will discuss how the current work fits into both of these areas.

6.1.1 Next Generation Air Transportation System (NextGen)

The role of weather information in the NextGen is to help determine where aircraft can and cannot fly within the NAS. The information contained in the TurbDST will be one component of the integrated system and will need to be combined with the various other observations and forecast products under development and consideration. The key to the relevance of the TAPS and E-Turb information is that they are observations of the hazard, and may be used to make the operational decisions, but can also be used by forecast models to improve their accuracy.

Although TAPS and E-Turb are not meteorological observations (they are observations of the effect of turbulence on an aircraft), they will still provide useful information. The current work being conducted with TAPS and the envisioned benefits of the E-Turb radar technology are very much in line with the NextGen vision.

Another area of importance in the modernization of the NAS and associated areas is that of Network Enabled Operations (NEO), or System Wide Information Management (SWIM). This is an effort to link a large number and variety of data sources covering NAS operations on one network. This will allow all the different user constituents to access data that is relevant and secure with a minimum of infrastructure required. This is a concept that has also been picked up by the FAA as part of their Operational Evolution Plan as described below.

6.1.2 FAA's Operational Evolution Plan

It is the FAA's plan to build capacity and increase efficiency in the NAS by an average of 3% per year. Their objective is to reduce delays and meet future demand. The core of the OEP focuses on four problem areas – "quadrants": Air Traffic Management Flow Efficiency, En Route Congestion, Terminal Area Congestion, and the fourth addresses activities on the airport surface and aligns to two areas of business, FAA Airports and FAA Regions / Center Operations.

The OEP comprises new technologies, procedures, and runways. In the Air Traffic Management Flow Efficiency quadrant there are segments covering improved weather information and improved traffic flow collaboration. In these areas, real-time knowledge of the turbulence hazards will be very important especially for integration into traffic flow management. This integration, which may comprise the inclusion of TAPS and other downlinked turbulence information, would enhance the Airspace Flow Program recently introduced by the FAA as part of the OEP. AeroTech has discussed this integration path with the FAA.

Also included in the OEP is the development of the System Wide Information Management (SWIM) Program, which will provide the infrastructure, standards, and procedures needed to conduct network-enabled operations in the NAS so that precise information is available in the right format and at the right time to all authorized users.

In summary, the work being proposed here, as well as other areas of AeroTech's research, are closely aligned with modernization plans by the Government and other organizations. The proposed work will be an important part of AeroTech's efforts to participate in the modernization plans and implementations, and thereby help in the ultimate commercial success of its products.

6.2 Enabling, Dependent, and Enhancing Elements

6.2.1 Enabling Elements

The enabling elements for the realization of TurbDST can be stated as:

- The steady integration of disparate information components on reliable internet-based applications will allow the turbulence information to be readily disseminated amongst all users (dispatch, air traffic controllers, traffic management specialists, and airlines). This is evident in the FAA's System Wide Information Management effort, which has the goal of integrating many disparate sources of information into one coherent information database.
- New developments in aircraft avionics architecture will allow the on board radar to be connected to the aircraft's communications system. This will allow the radar to downlink turbulence information automatically to be shared with ground personnel. The first aircraft to have this architecture will be the Boeing 787.
- The development and integration of Electronic Flight Bag (EFB) displays for the cockpit. This has already been addressed in Reference [3], but the fact that there are capable systems that can display turbulence hazard information in the cockpit will allow pilots to acquire the necessary information to realize the gains due to the implementation of the TurbDST.

6.2.2 Dependent Elements

Two key turbulence information sources for the TurbDST for Controllers and Dispatchers are the Turbulence Auto-PIREP System and the Enhanced Turbulence. Both technologies were developed under the Turbulence Prediction and Warning System element of NASA's Aviation Safety and Security Program. Neither technology has been fielded commercially, but both are currently undergoing operational evaluation onboard Delta Air Lines aircraft in revenue operations. It is expected that both products will be ready for commercialization at the beginning of 2007. This timetable will not hinder the commercialization of the proposed system.

TAPS is a *non flight critical software application* which reads flight data from a data bus, and both transmits and receives turbulence reports (as necessary) to the ground and other aircraft in real-time. TAPS uses existing aircraft infrastructure – sensors, data buses, communications – no additional hardware is required other than that already on the aircraft. TAPS automates the reporting of all significant aircraft encounters with turbulence and via datalink provides pilots, dispatchers, and controllers relevant, quantitative turbulence hazard information from which they can quickly and easily understand the impact that reported turbulence may have on specific aircraft. The quantitative turbulence hazard information is based on the loads experienced by the aircraft. When an aircraft with TAPS software onboard encounters turbulence, a report of the location and severity is automatically generated and sent out from the aircraft. This TAPS report goes to a ground station network where it can be displayed to dispatchers or controllers. The report can also be routed to other aircraft that could be affected by the reported turbulence. TAPS software onboard the receiving aircraft deciphers the report and determines the impact that the reported turbulence would have on the receiving aircraft. It is this information and the location of the reported turbulence that will be used as one of the inputs to the decision support tool. TAPS is currently installed on more than 120 Delta aircraft (including B737-800, B767-300, and B767-400 fleet types) and being evaluated during revenue service. ARINC provided the communications pathway and have assisted AeroTech Research in the development of a preliminary ground station display. The system has met every milestone of the NASA evaluation program to date. The cost of the system will be extremely reasonable based on the expected injury and operational inefficiency cost savings.

The Enhanced Turbulence Radar is a software upgrade to existing Predictive Wind Shear (PWS) radars that takes the measurements from the PWS radar and converts them into a predicted hazard to the aircraft. If the predicted information meets the requirements for display, the information can be presented in the form of a magenta advisory. The predicted downlinked turbulence information can be provided out to 25 nm ahead of the aircraft with expectations of a 40 nm range available in the future. The radar requires water or rain droplets to make its measurements; therefore, it is most applicable in areas with convective activity. The underlying physical principals used in developing the E-Turb technology are very similar to those used in developing TAPS, resulting in a very consistent loads based, hazard estimation. In the summer of 2004, the E-Turb software was integrated into a Rockwell Collins Multiscan™ Radar, which was then installed on a Delta B-737-800. The radar has been used and evaluated in revenue service since August of 2004. Technical results and pilot feedback have been exceptional. The E-Turb technology will also be ready for commercialization early in 2007.

6.2.3 Enhancing Elements

During the initial investigation of turbulence information sources, it was found that there may be considerable benefit to processing and incorporating turbulence information detected by the ground-based NEXRAD radars. These radars currently make measurements of radar spectral width in the atmosphere. This measurement can be readily converted to predicted aircraft loads in a manner very similar to the techniques AeroTech developed for the airborne radars. The problem today is that this information is not available in real-time. The data are post-processed and available within a few days to potential users. At this time AeroTech is not aware of any plans to make this data available in real-time; however, if there was sufficient need for this data, and a suitable business case presented, this product could be possibly made readily available. It is not known whether or not there is some fundamental technical impediment to processing these data in real-time, and it may well be that this information will not be available until current NEXRAD equipment is replaced by a newer system.

6.3 Transition Periods and Mixed Equipage

The transition issue will affect the coverage of the Turbulence Hazard Decision Support Tool; however, the effectiveness of the system and the concept of operations will not be affected. As more aircraft become equipped with TAPS reporting software, the density of TAPS reports will make the data more applicable to regions of airspace. So, for example, with Delta Air Lines equipage, there is good information around the Salt Lake City and Atlanta regions, but limited in other parts of the country. The users of TurbDST will know from the information on their display which aircraft are TAPS equipped. During the initial implementation period there will be gaps in coverage, but the intention will be for more and more of these gaps to be filled as more aircraft are equipped. It is envisioned that the operational and cost benefits to using TAPS will encourage airlines to participate in the program, and financial incentives will be used to encourage them to equip their aircraft to make TAPS reports. Throughout the transition period, detailed documentation of the turbulence sources available on any particular display device should be a top priority. The display will also be able to inform the user what turbulence information is available based on installed turbulence sources.

Mixed equipage will not present any major issues or concerns during the integration of the decision support tool with the users. Each turbulence input (TAPS reports, E-Turb Radar information, etc.) is independent of any others; therefore, just having one or two of the inputs will not be an issue. The standard operating procedures for the user will not change based on the presence of the display. Additionally, there will be no major effect on the system as a whole if some aircraft are downlinking TAPS and E-Turb radar data and others are just downlinking TAPS reports.

6.4 Performance Measures

The TurbDST will perform to the level of the inputs provided to it. The respective performance levels of the standard radar's reflectivity information, the E-Turb radar's turbulence prediction, and the TAPS reports will dictate the level of performance of the turbulence hazard decision support tool.

Failure modes will be built into the display software, so the users will be notified when there is a loss of input from any of the various sources of turbulence information. Because the display is designed to be advisory only and no operational procedures will be changed with the addition of the display, the loss of the turbulence inputs to the display will only return the user to the current level of turbulence awareness and method of turbulence avoidance.

6.5 Procedure Changes

It is not foreseen that there will be any changes to procedures due to the implementation of Turbulence Hazard Decision Support Tool. The potential does exist that some of the FAA guidance for operations in turbulence (References [6], [7], and [8]) may be amended once some experience is gained in using TAPS and other downlinked turbulence information. However, this is not required for the successful implementation of the proposed system.

6.6 Certification, Regulatory, and/ or Standards Issues

Additional research will be required to identify the regulatory, compliance, operational usage, and integration issues with regards to implementation and use of the TurbDST within Air Route Traffic Control Centers and airline Operational Control Centers (OCC). Currently, there are three Graphical User Interfaces (GUI) under consideration for display of turbulence information in the TurbDST (dispatcher, air traffic controller, and air traffic manager); therefore, regulatory and compliance issues need to be addressed for each of these GUIs/tools separately. AeroTech will consult with the FAA, the Airline Dispatcher Federation (ADF), and representative airlines. Amongst those issues that will be addressed and investigated for each GUI implementation are:

- Minimum Aviation System Performance Standards/ Minimum Performance Standards (Radio Technical Commission for Aeronautics (RTCA) / Society of Automotive Engineers (SAE) Standards),
- regulatory issues addressing icon selection and colors,
- regulatory issues addressing the age of the data displayed (e.g., the age of TAPS reports compared to the age of the radar data), and
- regulatory issues addressing the interaction of the user with the display and various display functions.

For each issue there are a number of Advisory Circulars, RTCA, and SAE documents addressing concerns related to these issues. The relevant issues have been reviewed by AeroTech and to date there do not appear to be any major obstacles to realizing the TurbDST; however, these issues will have to be addressed from a compliance perspective as well as from a cost perspective.

AeroTech with the assistance of the dispatcher and controller consultants will document applications, tools, and systems within the Air Route Traffic Control Centers and airline Operations Control Centers that the TurbDST should and could be integrated into. AeroTech will determine the appropriate agencies and organizations to approach with regards to integrating the TurbDST into those systems. During the research process, appropriate coordination with and briefings will be provided to the JPDO, National Air Traffic Controllers Association (NATCA), and the ADF regarding the development and requirements of the TurbDST.

7. Operational Scenarios

The purpose of the operational scenarios presented within this CONOPS is to bind together all of the individual parts of the proposed system into a comprehensible whole, allowing the readers to understand how all the pieces presented for improvements and changes to the current system interact to provide operational capabilities. The number of potential scenarios could closely follow the task and operations of the users as discussed in detail in Sections 3.4 and 5.4, addressing each phase of flight (mode of operation) and complementing the development of the CONOPS for the Real-Time Turbulence Hazard Cockpit Display (Reference [4]). However, only a single sample of the operational scenarios will be addressed here. As research and development continues on the TurbDST, additional emphasis will be placed on documenting further the details of the different areas of contribution of the decision support tool for controllers, dispatchers, and traffic management specialists. The following sections will describe in more detail for the operational scenario significant changes and additions to current operations, assumptions made, and any variations considered for the scenario. Details of the functions and features of the proposed system can be found in Reference [14].

7.1 Aircraft Approaching a Line of Convection

7.1.1 Overview

Regions of adverse weather such as convective activity can effectively close off regions of airspace to traffic. Without direct knowledge of the location and severity of the turbulence, the restricted region may be larger than necessary, placing an undue cost and disruptive burden on controllers, operators, and the traveling public. Figure 5 shows flight DAL1449 from Atlanta to Dallas. A line of thunderstorms lies between the origin and destination airports. The aircraft has been routed to the south of the line adding a considerable time and distance to the trip.

This scenario has been selected to illustrate the potential applications and gains from using TurbDST in operational use. There are many scenarios that can be considered (and will in the next phase of the work). This scenario was selected as an example since it was representative of an active convective region in the NAS – a very typical phenomenon. The example given below only considers en route traffic. There is no consideration in the discussion for traffic climbing from or descending to airports in the vicinity of the convection. Those scenarios are addressed in the CONOPS in Section 5.4 and will be covered in greater detail in Phase II.

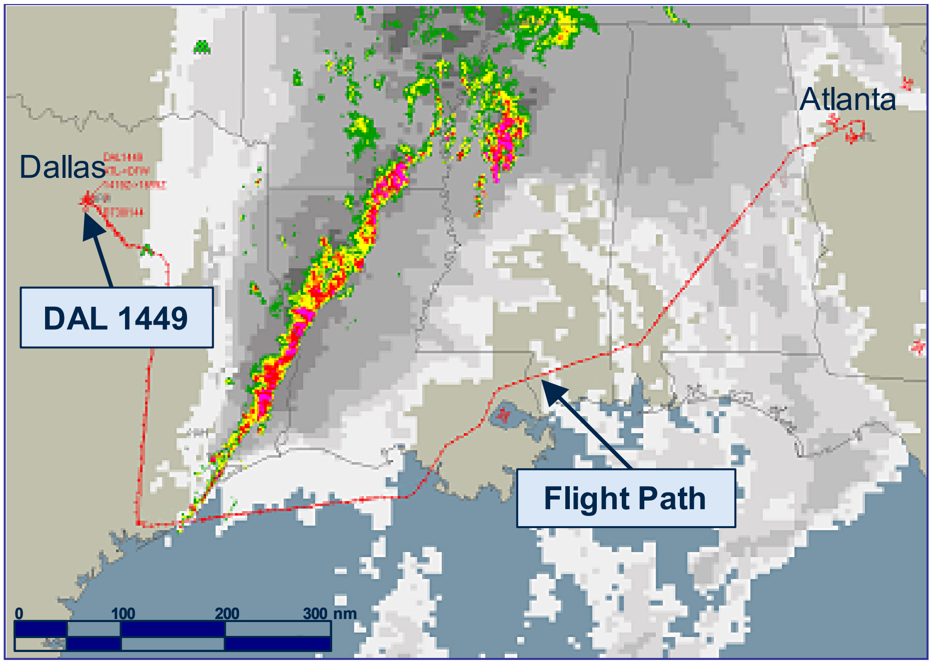

Figure 5: Aircraft Approaching a Line of Convection

7.1.2 Key Assumptions

It should be noted that for this example operational scenario, all the details of the planning and conduct of this flight especially as it pertains to air traffic control are not known. Instead, we will postulate how the flight may have been planned/conducted, and use this scenario as an example of how the TurbDST may be applied. It will also be assumed that, in the description of the future operations below, all aircraft will be equipped with TAPS reporting and display in the cockpit, as well as the E-Turb radar.

The assumption is also made that the dispatchers and controllers all have access to the real-time TAPS reports through the TurbDST, with latency of the data less than five minutes in age. In the future it may be possible to downlink the E-Turb predictions for use on the ground; however, the concepts presented below do not require this in order to be effective.

7.1.3 Description of CONOPS

7.1.3.1 Current Operations

The aircraft in Figure 5 is seen to begin its southwest heading some 350 nautical miles from the line of convection. This implies that the deviation is not due to anything seen on the airborne weather radar (which has a reflectivity range out to 320 nm). Instead it has been imposed by the Command Center as part of the Strategic Planning Operations, which include the airline, and planned by the dispatcher to take this reroute. The route was planned approximately three hours before take off (as is typical in airline operations). The strategic intention of the reroute was to avoid the region of convection as well as the region that was forecasted to intensify (as stated by the CCFP). The storm line presented in Figure 5 was moving to the east and intensifying at the northern end of the system. DAL 1449 was therefore routed to the south. The aircraft's actual flight path is as shown. In this case, the trip took approximately 160 minutes for a flight that would otherwise take just 90 minutes when a more direct routing is available.

As this storm has been intensifying and moving eastwards, aircraft have been continually routed either through gaps or around the region. In the process, these aircraft typically use their weather radars to navigate around the cells, and will make verbal pilot reports reflecting the level of turbulence experienced. The flight crew would be unaware of these PIREPs until they switched to the sector controller's frequency. The aircraft continues on its southwest course until it converges close enough with the convection that the radar will start to give some indication of the reflectivity and height of the cells. As the aircraft reaches the southern tip of the convective line, some areas may be identified visually and/or by the airborne radar reflectivity map as being suitable to penetrate. At this point however, since all other east-west / west-east traffic has also been routed around this line to the south, the aircraft's request to deviate may be denied due to traffic. There is also significant frequency congestion within this sector as pilots request information about the ride ahead and where the smooth air is. The pilot is constrained to follow the path as shown, thereby putting a delay of seventy minutes on the schedule. This delay will be compounded when the aircraft is turned around at Dallas and heads back to Atlanta.

7.1.3.2 Future Operations

Before the aircraft even took off from an airfield, the pilot has had the opportunity to see weather on the route as well as TAPS reports that had been made in the past few hours. Discussions will have taken place with dispatch and a decision to fly the aircraft southwest and monitor TAPS reports (as well as null reports) as aircraft penetrate the region will have been made. The intent is to try to cross the line of convection at various stages in the flight depending on the real-time turbulence information and ATC constraints. Turbulence is such a dynamic phenomenon that these decisions cannot be made until after take off and the aircraft is closer to the convection. Figure 6 illustrates how the system will work in the future.

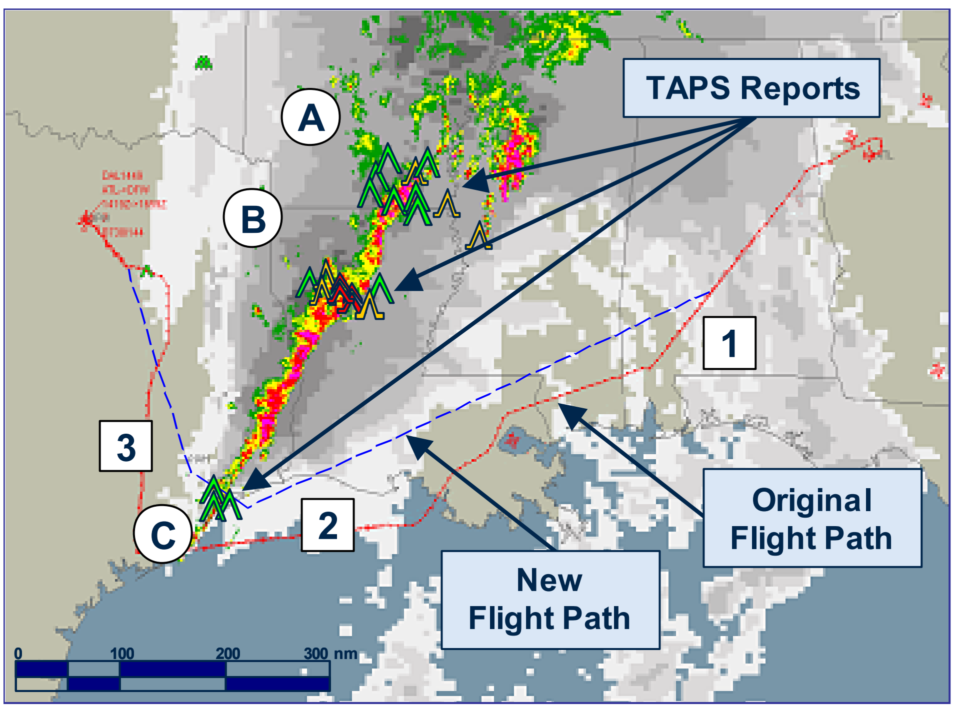

Figure 6: Future Operations with TurbDST

Within this operational scenario, DAL 1449's flight path would be planned as described in the previous section with the additional knowledge that real-time TAPS information will be available en route for tactical decision making. The Decision Point numbers refer to the numbers in the squares in Figure 6. The TAPS reports have been added to the figure artificially in order to illustrate the concepts.

- **Decision Point 1:** The flight is approaching the line of storms. At this point in the flight, a decision is to be made as to where to cross the convective line. There are some gaps in the line denoted by the letters **A**, **B**, and **C** in circles shown in Figure 6. Aircraft have been flying through the gaps while the storm has been intensifying and moving to the east (as forecast). As these aircraft have been passing through the gaps they have made TAPS reports as they encountered turbulence.

Region **A** shows some light and moderate TAPS reports and may be an appealing option. However, this part of the line has been forecast to intensify and may not be safe by the time the aircraft reaches it. In addition, TAPS reports of increasing severity have been received from this region reflecting the intensification. If the airborne radar were able to downlink its information to the ground, it would also be used to verify the forecast.

Region **B** contains some severe TAPS reports and for this reason is not an option.

Towards the southwest, in Region **C**, there is a small region of light TAPS reports. The pilot communicates intentions for the route to dispatch. No action is required on the part of the dispatcher. The pilot elects to follow a path towards region **C** and is cleared to do so by ATC. The dashed line indicates the new flight path.

- **Decision Point 2:** As the aircraft approaches the line of storms, the pilot enables the E-Turb function of the weather radar, which will show turbulence predictions out to forty nautical miles. The pilot has been watching for additional TAPS reports and can also access null TAPS reports, having seen other aircraft pass through the region on the Traffic Collision Avoidance System (TCAS). Discussions on the radio with the Sector Controller are limited to altitude and course deviation requests and clearances, freeing up much of the frequency congestion. As the aircraft transits the region, the E-Turb radar is used for close-in tactical avoidance of turbulence in and around the cells of convection. If the pilot encounters turbulence as the aircraft penetrates the region, the aircraft will make additional TAPS reports for use by other aircraft in a similar manner.
- **Decision Point 3:** Once clear of the convective region, the pilot requests and is cleared direct to the initial approach fix for DFW. The time saving on this path versus the original one is approximately 30 minutes.

Although it may appear that saving in this case is modest, it can often be the case that the gaps in convection open in the middle of the line – potentially yielding additional savings.

7.1.4 Significant Changes from Current Operations, Procedures, or Policies

This example is intended to illustrate how the dissemination of reliable turbulence information in real-time can assist in decision-making at several points in the flight allowing the aircraft to transit the region efficiently and safely. During Decision Points 1 and 2, the pilot had enough information in the cockpit to make a decision on a reroute and to make the request to ATC. By ATC having this turbulence information in hand, they can be prepared for many other aircraft to make similar requests.

- The application and use of these technologies will require close collaboration among pilots, dispatchers, and controllers. They will all need to be looking at TAPS (and other) information in order to effectively make decisions.
- As described above, the TAPS and E-Turb information must be used in conjunction with other data products (forecasts, nowcasts, etc.). It is therefore essential that these products be complementary in their application, and that the users clearly understand how they are to be used together.
- The use of these technologies cannot be successfully accomplished without coordination and integration with other ATC procedures. Any benefits and savings achieved will be lost if the aircraft is put into a holding pattern – especially if it is in bad weather.
- Exactly how these systems can be used together as a decision aid and integrated into the overall Air Traffic Management processes will have to be evaluated in simulations such as those

proposed in the Phase II of the SBIR, as well as those simulations at NASA and FAA. There are several simulation efforts currently underway, and the concepts presented in this CONOPS could be integrated into these efforts.

7.1.5 Non-Normal / Rare normal Operations

No distinct non/rare normal operations are expected for the TurbDST during this phase of operation. The primary variations expected will depend on the number of aircraft tracked, length of time of the flights within a region, and geographic location of areas of turbulence. These factors will be mixed into the decision process by the user and understood on a case-by-case basis. Restrictions by ATC or the local weather may limit the options available to a user during this scenario.

8. Analysis of the Proposed System

This section provides an analysis of the benefits, limitations, advantages, disadvantages, and alternatives and trade-offs considered for the proposed system. This CONOPS has been written to help guide the process of integration and implementation of a TAPS and E-Turb display within a decision support tool. Integration and use of such a tool should be simple and intuitive to reduce workload on the end user. An analysis of the proposed system will entail the initial testing and refinement of concepts and features using a selected user group consisting of active and retired dispatchers and controllers. Their input will help create a flexible and useful system that will give the user a product that will be accepted within the industry.

8.1 Summary of Improvements

The Turbulence Auto-PIREP System and the Enhanced Turbulence Radar technology displayed will enhance situational awareness of the location and severity of turbulence; by providing real-time quantitative turbulence information downlinked from aircraft. This decision aid will remove the need for inference that is required to interpret current turbulence information. The TurbDST will enhance tactical and strategic decision making with regard to airspace usage and aircraft routing by enabling users to predict the effect of the reported turbulence on aircraft whose route may take them through that location. Examples of how these operational capabilities can be employed are found in Section 7 of this document.

The automatic reporting of turbulence encounters as determined and transmitted by the TAPS enhances and augments the current method requiring user interaction. Subjective reports, based on location and severity, are determined by the proposed system based on accurate information of g-loading and spatial location using global positioning. The timely transmission of these reports to a ground station from a reporting aircraft puts additional information into the user's mix of available products that may have previously been late or unavailable. The transmission of reports is automatic, thereby cutting down the need of interaction between the reporting aircraft's crew, ground controllers, company dispatchers, and other receiving aircraft's crew, thereby increasing efficiency and NAS throughput and decreasing workload and communication congestion. The addition of TAPS information presented within the proposed decision support tool display will not eliminate any existing capabilities present within the user's current tool set, but enhance them.

The addition of an Enhanced Turbulence Radar product overlay within the proposed decision support tool will add to the situational awareness of the users (dispatchers and controllers) by providing a graphical representation of the probable turbulence in the atmosphere that could affect aircraft that they may be tracking. The subjective interpretation of current reflectivity levels can be replaced by a quantitative measure of the predicted turbulence level of regions of airspace. Scaling of the radar product to the current configuration of the aircraft that are being tracked makes the assessment of the potential threat very accurate and meaningful to the user. Warning times of potential encounters increases with the use of the Enhanced Turbulence Radar within the aircraft, thereby giving the user additional time to warn cabin attendants and passengers of the forthcoming turbulence. The additional time also can provide the user the opportunity to maneuver the aircraft around potential regions if other collaborative sources and airline policies permit this. The display of turbulence from an enhanced radar product will allow the ground-based users to effectively collaborate with flight crews, making appropriate and timely decision on the routing of aircraft in and around turbulence regions. However, it should be noted that the real-time downlink of Enhanced Turbulence as measured by aircraft is a long-term goal and will require a retrofit of the existing commercial transport fleet to realize greater benefits. An interim solution will be the application of the Enhanced Turbulence technology to existing ground–based radars, thereby providing users like the dispatchers and controllers a more compete view of the potential for turbulence at altitude. Additional work will be required in this area to determine the proper approach to combine the information and the range of altitudes that could be included in such displays of turbulence information. The addition of an Enhanced Turbulence Radar product will require additional refinements, testing, and acceptance before integration can be completed.

8.2 Disadvantages and Limitations

The Turbulence Auto-PIREP System relies on the information of other aircrafts' turbulence encounters to help outline an assessment of the potential threat to the primary aircraft. Even though the sophistication of the scaling algorithms will eliminate ambiguities due to the reporting aircraft with the receiving aircraft, the lack of information due to the limited initial use of TAPS on aircraft will create "dead regions" within the reporting network. TAPS relies on another aircraft to encounter the turbulence at some point in time. The user, based on experience and other information resources, then interprets the displayed information.

The airborne version of an Enhanced Turbulence Radar is currently limited in range to 25 nm from the aircraft's radar antenna. This range is expected to extend to 40 nm in the near future. Although the warning time is counted in minutes, this provides a significant advantage over no information what so ever. However, the downlink of Enhanced Turbulence as measured by aircraft is a long-term goal. To achieve this goal, a retrofit of the existing commercial transport fleet is required. Since airframes have lifetimes of 20-30 years, it may take decades for forward fit developments such as enhanced turbulence to filter throughout the air transport fleet. Retrofit capability provides the greatest opportunity for functions to be incorporated quickly. The throughput and data memory requirements of enhanced turbulence are not trivial and older radar signal processing hardware has greater limitations in these areas.

Training expected for use of a TurbDST must be kept at a minimal level and should complement existing systems. Any additional workload on the user must be minimized. Existing capabilities for the users will not be degraded, but enhanced by the addition of the TAPS and E-Turb technology. Loss of efficiency is not expected with the inclusion of these technologies.

The failure modes of the Turbulence Auto-PIREP System and Enhanced Turbulence Radar technology will need to be studied and the affordability and requirements for retrofitting aircraft with this technology will also require study. Standards that comply with existing mandates through ATC, FAA, and RTCA will need to be further researched and developed.

8.3 Alternatives and Trade-offs Considered

The primary driver for the development of the decision support tool was the turbulence parameter to be reported by the aircraft. The appropriate hazard metric for the decision support tool would have the following attributes:

- The metric would have to indicate the level of turbulence experienced by an aircraft as light/moderate/severe.
- The metric would have to be consistent over a range of sensors. For example, turbulence reported from an in situ sensor on an aircraft would have to be consistent with turbulence detected by a ground-based radar (despite their being very different measurement technologies). This is a

requirement because the data will need to be integrated together and unless this requirement is met, comparison and integration may be impossible.

- The metric would need to be scalable for different aircraft types and configurations in order to account for different aircraft's response to turbulence.
- The information must be available in real-time.

One possibility for the real-time in situ reporting of turbulence is the Eddy Dissipation Rate (EDR) estimation algorithm developed by the National Center for Atmospheric Research (NCAR). EDR is a parameter related to the fluid properties of the atmosphere, and the algorithm developed by NCAR was designed to report this value from aircraft, regardless of its value, at intervals of one minute. The EDR algorithm was not developed to be part of a safety system. A turbulence safety system requires there to be an estimate of the effect of the turbulence hazard on an aircraft – predicted loads – which can harm an aircraft's occupants or structure. For EDR to be a useful safety parameter, EDR reports received by aircraft have to be scaled to aircraft loads. This process is neither simple nor can it always be accomplished with data available. For this reason, EDR values are also reported in the TAPS reports. The two different metrics are both useful and non-exclusive (i.e., one is not a surrogate of the other).

In addition, all turbulence cockpit display work currently underway at NASA and certified by the FAA require turbulence to be reported or detected as loads on the aircraft. It would make no sense technically, and indeed be more difficult, to employ a different parameter such as EDR for a decision support tool for dispatchers and controllers when the pilots are looking at a loads-based display. For these reasons EDR was not considered a viable parameter unless these values can be referenced to turbulence severity.

AeroTech has developed techniques to estimate loads from a variety of sensors, including radars (airborne and ground-based) and LIDAR (Light Detection and Ranging) radars. As these sensors become available and the results from them become available in real-time, they can be incorporated as data sources for the TurbDST. There should be no requirement to change the CONOPS as additional data sources become available and are incorporated.

Information on the TurbDST must be able to be interpreted along with forecast products such as the Combined Collaborative Forecast Product, National Convective Weather Forecast (NCWF). It has been seen in the past that TAPS reports have been useful in actually generating forecast products. There will be a need to integrate the TurbDST products with these forecast products, especially for the planning and traffic management applications.

9. Conclusions and Recommendations

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. A large contributor to the above injuries and costs is that flight crews, traffic management specialists, controllers, and dispatchers have poor knowledge and insufficient situational awareness of the location and severity of potential turbulence hazards to aircraft under their control. Improvements to current operations will be achieved by the development of a TurbDST that will enhance situational awareness by providing real-time quantitative turbulence information automatically downlinked from aircraft. The TurbDST will enhance tactical and strategic decision making with regard to airspace usage and aircraft routing by enabling users to predict the effect of the reported turbulence on aircraft whose route may take them through that location.

The TurbDST for Controllers and Dispatchers is intended as a medium for advisory information concerning the location and intensity of turbulence, enabling users to conduct a safer and potentially more efficient operation, from preflight to touchdown. Through interaction with the airline dispatch and air traffic controller subject matter experts and the development of the CONOPS and System Requirements for the integrated decision support tool, it has been shown that there is a need of and applications for a decision support tool that will provide controllers and dispatchers improved situational awareness and information concerning turbulence location and severity that will both enhance decision-making and enable more efficient collaboration with pilots concerning flight path changes to avoid hazardous turbulence. Analysis of various turbulence information sources has shown that fusing objective turbulence hazard information from disparate sources (TAPS and the Enhanced Turbulence Radar) and presenting dispatchers and controllers with consistent and meaningful turbulence information on one integrated display is technically feasible. These CONOPS also show the need for and desire of dispatchers and controllers for a tool that will provide them with improved situational awareness of turbulence hazards to aircraft under their control and accompanying software that will enable them to manipulate the data to assist them in making informed decisions regarding operation in and around turbulence.

This CONOPS document is written and intended to be a living document throughout the development of an Integrated Turbulence Hazard Decision Support Tool. It is envisioned that this decision support tool will provide users with improved turbulence hazard information allowing them to operate more efficiently and safely. Significant reductions in flight delays and cancellations, fuel waste, and costs associated with injuries due to turbulence are expected to be major commercial drivers for this system.

Further development and research on the capabilities, impact, and benefits of an integration of a decision support tool presenting both TAPS and E-Turb information should continue. The evaluation of such products by the potential end users will give invaluable insight into the feasible use and benefit of such a system.

10. Appendices

10.1 Appendix A – Acronyms and Abbreviations

ACARS	ARINC Communications Addressing and Reporting System
ADDS	Aviation Digital Data Service
ADF	Airline Dispatcher Federation
AIAA	American Institute for Aeronautics and Astronautics
AOC	Airline Operations Center
ARINC	Aeronautical Radio, Incorporated
ARTCC	Air Route Traffic Control Center
ASD	Aircraft Situation Display
ATA	Airline Transport Association
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATIS	Automatic Terminal Information System
AvSSP	Aviation Safety and Security Program
BTS	Bureau of Transportation Statistics
CCFP	Collaborative Convective Forecast Product
CONOPS	Concept of Operations
CONUS	Continental United States
CWIS	Corridor Integrated Weather System
EDR	Eddy Dissipation Rate
EFB	Electronic Flight Bag
ETMS	Enhanced Traffic Management System
E-Turb	Enhanced Turbulence Radar
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FMC	Flight Management Computer
FSS	Flight Service Station
GUI	Graphical User Interface

ITWS	Integrated Terminal Weather System
JPDO	Joint Planning and Development Office
LIDAR	Light Detection and Ranging
MEL	Minimum Equipment List
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATCA	National Air Traffic Controllers Association
NBAA	National Business Aviation Association, Inc.
NCWF	National Convective Weather Forecast
NEO	Network Enabled Operations
NEXRAD	Next-generation Radar
NCAR	National Center for Atmospheric Research
NextGen	Next Generation Air Transportation System
NWS	National Weather Service
OCC	Operational Control Centers
OEP	Operational Evolution Plan
PIREP	Pilot Report(s)
PWS	Predictive Wind Shear
RADAR	Radio Detection and Ranging
ROG	Route Optimization Generator
RTCA	Radio Technical Commission for Aeronautics
SAE	Society of Automotive Engineers
SBIR	Small Business Innovative Research
SPO	Strategic Planning Operation
SWIM	System Wide Information Management
TAPOS	Turbulence Auto-PIREP Operational Simulation
TAPS	Turbulence Auto-PIREP System
TCA	Traffic Consumer Advocate
TCAS	Traffic Collision Avoidance System
TFM	Traffic Flow Management
TMU	Traffic Management Unit
TPAWS	Turbulence Prediction and Warning System
TRACON	Terminal Radar Approach Control