10.12 USING IMPROVED AWARENESS OF TURBULENCE TO INCREASE AIRSPACE UTILIZATION

Dr. Paul A. Robinson*
AeroTech Research (U.S.A.), Inc., Newport News, VA

1. STATEMENT OF THE PROBLEM

Regions of adverse weather such as convective activity, clear air turbulence, or mountain wave 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.

With forecasts of significant increases in the demand for air travel over the next 20 years, these capacity constraints appear likely only to worsen with time. In such an environment, blocking airspace in accordance with current practices on bad weather days will not be a viable strategy. To keep the system going, it seems only natural that air traffic decision makers will need to route more aircraft in closer proximity to areas of weather currently deemed as hazardous. Better tools to identify and pinpoint areas of actual hazard will therefore be needed to safely negotiate these weather systems.

New turbulence detection and avoidance technologies developed under the auspices of NASA's Aviation Safety and Security Program will alleviate this problem. If pilots, dispatchers, and controllers use this hazard information in a collaborative manner, operational decisions may be made that can allow for increased airspace usage with no decrease in safety.

This pper frames the issues and presents operational concepts, which, if implemented and integrated with other Air Traffic Management Procedures, will have potentially large payoffs to those operating in the National Airspace System.

* Dr. Paul A. Robinson, AeroTech Research (U.S.A.), Inc., 11836 Fishing Point Drive, Suite 200, Newport News, VA 23606-4507; e-mail: paulrobinson@atr-usa.com.

2. BACKGROUND

Aircraft encounters with turbulence are the leading cause of injuries in the commercial aviation industry. In 1998, NASA set a goal to reduce the number of accidents due to turbulence by 50% by 2007. Under the auspices of NASA's Aviation Safety and Security Program, two technologies have been developed to detect and avoid turbulence in order to reduce the number of turbulence injuries. These technologies were developed to give users on the ground and in the cockpit better information about the location and severity of turbulence. The two technologies are the Turbulence Auto-PIREP System and the Enhanced Turbulence Mode Radar. Widespread implementation of these technologies will go a long way to achieving NASA's stated safety goal.

2.1 Turbulence Auto-PIREP System (TAPS)

The TAPS makes automatic reports from aircraft that encounter turbulence and displays the information on the ground and in aircraft cockpits. Ground displays are accessed via the Internet, and can be incorporated with other information such as the Aircraft Situational Display, NEXRAD, and satellite images. An example display is shown in Figure 1.

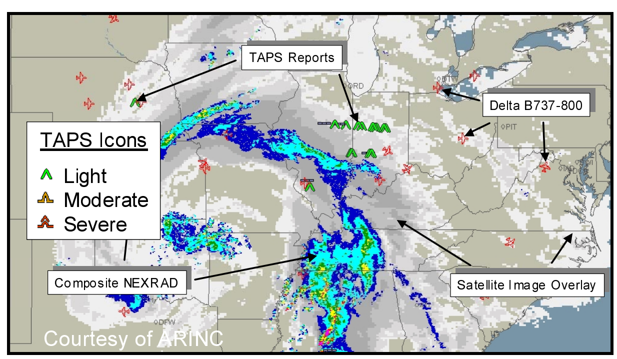

Figure 1. *Example of a Turbulence Auto-PIREP System (TAPS) ground display.*

Cockpit displays may be made to look like Figure 1 or may be integrated with other systems (e.g., radar). Cockpit displays of TAPS are not currently available due to existing hardware and communications limitations, however the ground station display is available and is being used today.

Currently TAPS reports are being made from over 120 Delta Air Lines' aircraft (B-737-800's, B-767-300, -400's), and Delta's dispatchers are currently evaluating the ground station display. There has been significant positive feedback about the system by the various user communities (dispatchers, pilots, and maintenance personnel).

2.2 Enhanced Turbulence Mode Radar (E-Turb)

This system uses advanced algorithms to improve the airborne radar detection of turbulence in and around clouds. Although current weather radars have a turbulence mode, the system creates so many false, missed, and nuisance predictions that it is not widely used by pilots. Under the Aviation Safety and Security Program a new technique of processing the radar measurement was developed and tested that scaled the measurement to display the predicted ***g-loads*** that will be experienced. In keeping with how turbulence has been displayed on legacy systems, areas of potential hazard are represented on the radar display by the color magenta. The E-Turb radar has been flying on one Delta Air Lines B-737-800 (also equipped with TAPS) since August 2004, and the turbulence information has received very positive feedback.

Both TAPS and E-Turb technologies were initially developed with a view to making air travel safer for the occupants inside an aircraft. This White Paper examines how they could be applied to improving the management and use of airspace while maintaining or even improving safety. This will be done in two steps. First the current problem will be illustrated using actual scenarios observed on ARINC's WebASD^{SM} flight-following display. Operational concepts will then be postulated assuming that aircraft are equipped with TAPS and E-TURB radar, and that pilots, dispatchers, and controllers will have displays of TAPS information. For this exercise, only the pilots have displays of the turbulence on their weather radar, although a concept is provided by which radar data downlinked from aircraft may be applied.

3. A TYPICAL AIR TRAFFIC SITUATION TODAY

Figure 2 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 considerable time and distance to the trip. This routing was chosen based on weather considerations and Air Traffic Control (ATC) restrictions.

Currently, in planning for such a flight, weather (and associated) products consist of:

Observations: Examples include satellite images showing water vapor, cloud temperature, cloud formations. NEXRAD images showing areas of reflectivity, inferring regions of heavy rain.

Forecasts: These products predict weather pattern development over 2-, 4-, 6-hour (and greater) periods. Some of these are referred to as "Nowcasts." In the case of convective activity there are currently several products available that forecast a storm's movement, speed, direction, and its intensification or decay.

Other: Sigmets, Convective Sigmets, and Airmets are advisories issued by the National Weather Service to indicate regions of significant weather (turbulence, icing, etc.).

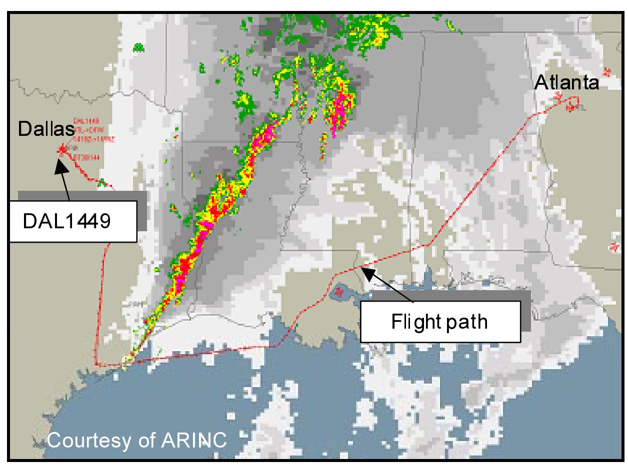

Figure 2. *DAL 1449 flight diversion around a storm.*

The storm line 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 (PIREPS) reflecting the level of turbulence experienced. If this turbulence hazard information were to be improved and automated, such as with TAPS and E-Turb, could the localized hazardous regions be identified and avoided, thereby freeing up other areas for traffic?

The future concept will consider what could be done in this scenario with improved radar turbulence predictions, and automated turbulence reports disseminated among the pilots, dispatchers, and controllers.

4. THE FUTURE CONCEPT

There are several ways to improve the situation described in the previous section. Improving the reliability and accuracy of the weather products and forecasts is very important and there are several ongoing research efforts working in that area. However, one major improvement, and the focus of this White Paper, is the use of automated real-time reports from aircraft in flight. Used in conjunction with the observations and forecasts, tactical decisions can be made during flight that can significantly reduce flight time and hence operating costs, with no reduction in safety.

Figure 3 illustrates how these concepts might work. The assumption is made that the pilots, dispatchers, and controllers all have access to the real-time TAPS reports. The pilots will have the E-Turb display in the cockpit. 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.

In the future concept, 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 3. 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 3. 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 elects to follow a path towards Region **C** and is cleared to do so by ATC. The blue line indicates the new flight path.

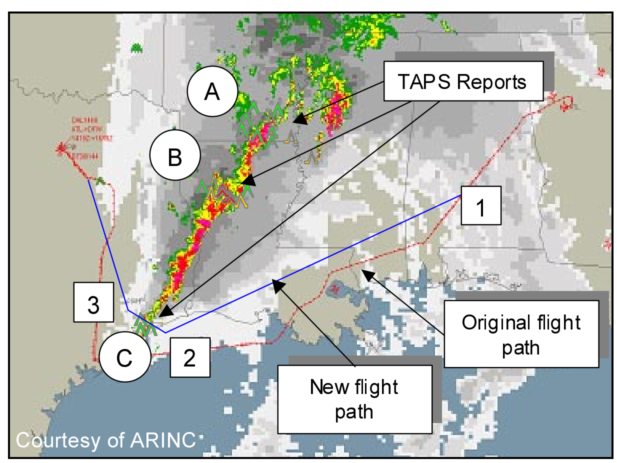

Figure 3. *Other options to navigate the line of storms.*

Decision Point 2: As the aircraft approaches the line of storms, he enables the E-Turb function of the weather radar, which will show turbulence predictions out to 40 nm. He has been watching for additional TAPS reports, having seen other aircraft pass through the region on TCAS and listening to discussions on the radio. As he transits the region, the E-Turb radar is used for close-in tactical avoidance of turbulence in and around the cells of convection. If he encounters turbulence as he penetrates the region, his 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. An example of this is shown in Figure 4.

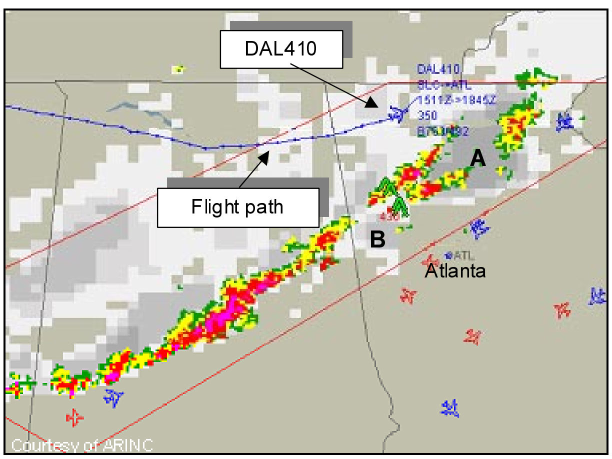

Figure 4. *DAL410 deviation around convection.*

As can be seen, flight DAL 410 is approaching Atlanta from Salt Lake City. There is a line of convective storms between it and the airport. Because of this, the flight has been routed around the northeast tip of the line. There are two gaps in the line indicated by **A** and **B** in Figure 4. There are some TAPS reports from an aircraft passing through gap **B** indicating light turbulence (these reports actually were made and were not added artificially). In fact, DAL 410 ended up flying northeast until over Ashville, North Carolina before turning southwest to Atlanta – a significant deviation. Passing through the gaps **A** or **B** (where the TAPS reports are), while using the E-Turb radar for tactical avoidance would have shortened the flight with no reduction in safety.

The key issue here is how the Atlanta arrival controllers would then sequence the aircraft into the airport. This illustrates how the concepts of using the turbulence technologies for increased airspace utilization must be integrated with other ATM practices.

5. SUMMARY & CONCLUSIONS

Operational concepts have been presented whereby new turbulence detection and avoidance technologies may be used to improve operations in and around regions of adverse weather. These concepts have been described only in a very high-level manner, but the ideas are based on experience in using these systems in day-to-day operations at Delta Air Lines.

Some conclusions can be drawn from the above:

- 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 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. For example, there would be no point in DAL 410 in Figure 4 using the technologies to navigate through the gaps in the convection if the aircraft cannot be sequenced into the arrival sequence for Atlanta. 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 using sophisticated tools developed and being used by NASA and the FAA. There are efforts currently underway, and the concepts presented in this paper could be integrated into these efforts.

- There may be use in the future of downlinked airborne weather radar turbulence information. This has not been attempted before, but recent advances in the E-Turb radar development may make this achievable if the communications infrastructure were to be available.

Suitable implementation of these technologies and their use in a collaborative manner could significantly reduce the impact of adverse weather on airspace usage. By preventing unnecessary rerouting of aircraft around weather it will also reduce the airlines' operating costs.

6. ACKNOWLEDGEMENTS

The Author would like to acknowledge the contributions of Captain Bill Watts, and Christian Amaral of Delta Air Lines, and Bill Buck of AeroTech Research. Images of the TAPS display and WebASD^{SM} are shown courtesy of ARINC.