AEROTECH RESEARCH (U.S.A.), INC.

Enhanced Turbulence (E-Turb) Radar for Military Operations

An Overview

ATR-2009-17WP15

1 Introduction

Nearly every day, turbulence has an adverse effect on aircraft operations.

Typical Aircraft Operations

Encounters with turbulence are the leading cause of injuries in commercial aviation and result in significant human, operational, and maintenance costs to the community each year. Although military operations are different from commercial, the impact of turbulence can still be significant. A National Guard KC-135 had a well publicized turbulence encounter in May 2005 that resulted in over 35 injuries including the paralysis of a soldier. Turbulence or rather the threat of turbulence also can play havoc with aircraft routing. Some turbulence encounters require maintenance inspections for severe loads, result in damage to the aircraft, and can have a negative effect on the service life of the aircraft due to repeated encounters with high loads.

Airborne Refueling Operations

Turbulence can have a significant impact on the airspace used for refueling operations and the efficiency and timeliness with which the receiver aircraft can hook into the tanker (boom or drogue). It can also potentially cause safety, maintenance, and operational issues due to

1) Impact between the receiving aircraft and the boom/drogue, or

2) Uninitiated violent disconnect from the boom/drogue,

both of which can result in damage to the receiver aircraft, damage to the receiver refueling capability (probe) causing diversion of the aircraft, and or damage to the tanker's boom/drogue system resulting in cancellation of further refueling and diversion of scheduled customers. Additionally, turbulence increases the workload for both tanker and receiver crews during refueling operations.

Although turbulence will always be a factor in any operations, better knowledge and awareness of the turbulence hazards can greatly decrease the negative impact on operations by forewarning of encounters or enabling avoidance of the affected area.

This white paper describes a technology, developed by AeroTech, which processes airborne weather radar data in a way to provide flight crews with greatly improved indications of turbulence hazards. This technology has been demonstrated both with NASA and in airline operations, and is readily implemented in modern Doppler weather radars.

2 The Problem

Current airborne weather radars either cannot display turbulence (only reflectivity) or display regions of turbulence based on a radar detected parameter: spectral width. Above a given spectral width threshold, these radars paint a magenta region – below the threshold no region is displayed. No aircraft information is taken into account.

The problem arises though that the spectral width threshold for a given level of turbulence depends on the aircraft speed, altitude, weight, and response characteristics (i.e. different aircraft react differently to the same atmospheric turbulence). Without taking into account these aircraft and flight characteristics, turbulence may be displayed that is not significant ("false" detections) or significant turbulence may not be displayed at all ("missed" detections).

These false and missed detections erode a pilot's confidence in the information, contribute to a lack of awareness of the actual hazards, and may lead to a reduction in safety

3 The Solution – Enhanced Turbulence Mode

The Enhanced Turbulence Mode (E-Turb) for airborne Doppler weather radars was developed by AeroTech in NASA's Aviation Safety Program. It takes the radar measurement and processes it with real-time aircraft information (e.g., weight, speed, altitude) to calculate predicted loads on the aircraft.

The process is depicted in Figure 1 below. The radar detection algorithms (which are already in the radar) make a measurement. For current radars (depicted by the upper path), this measurement is used directly in generating a turbulence display. With AeroTech's E-Turb process (the lower branch), the radar detection is passed through a Hazard Prediction Algorithm that uses the real-time aircraft information to generate "predicted loads" specific to the aircraft, which are then sent for display in a multi-level scheme.

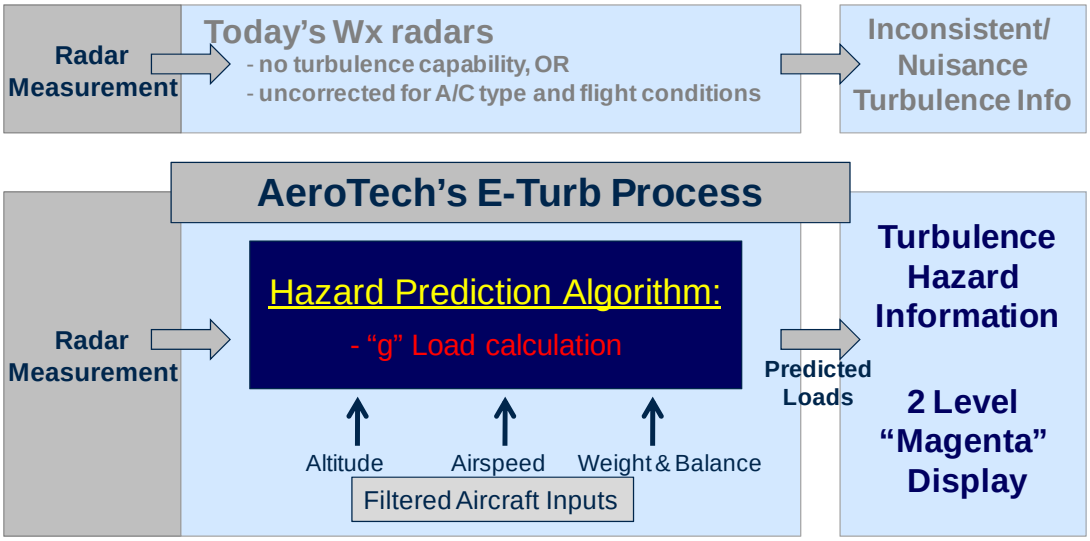

Figure 1: AeroTech's E-Turb Process

This hazard prediction algorithm was initially validated on NASA's B757 research aircraft and then subsequently was installed on a Rockwell Collins WXR-2100 radar aboard a B737-800 aircraft belonging to Delta Air Lines and validated in commercial revenue operations (over 6,000 hours) (Figure 2).

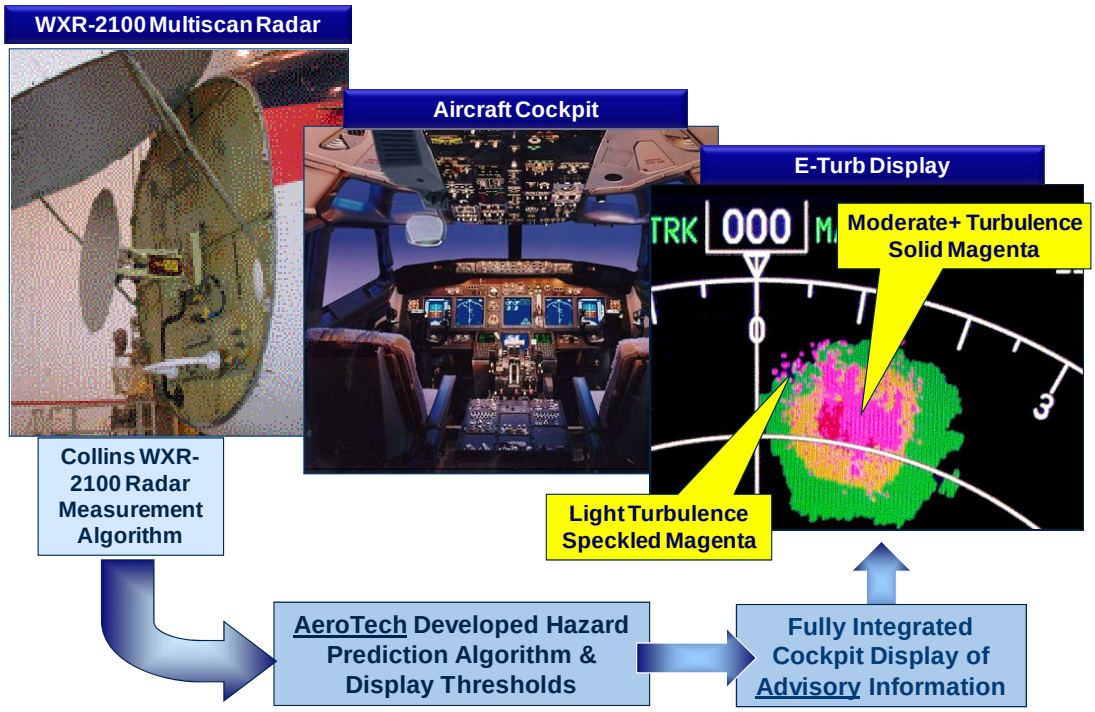

Figure 2: E-Turb Operational Evaluation

Turbulence was displayed in two levels: speckled magenta representing a region of light turbulence and solid magenta representing a region of moderate or greater turbulence. The radar and its display received very positive responses from flight crews using the radar in revenue service.[1] The FAA is currently establishing a Technical Standards Order (TSO) for the performance requirements of E-Turb.

4 Some Examples

The radar on the B737-800 was equipped with a data logging device that allowed in flight data capture for playback on the ground. In this way we are able to show images that were seen in flight. The datalogger stored the data at reduced resolution than displayed in the cockpit leading to a "clunky" appearance of the radar data in the following examples.

Example 1:

Figure 3 shows an example "snapshot" from a flight over Florida. The aircraft is located at the bottom center and its subsequent flight path has been overlaid using the white dotted line. The radar reflectivity is indicated by the green and yellow regions and E-Turb predicted the turbulence regions are shown in magenta.

[1] "In-Service Evaluation of the Turbulence Auto-PIREP System and Enhanced Turbulence Radar Technologies," J. B. Prince, B. Buck, P. A. Robinson, and T. Ryan, NASA/CR-2007-214887, July 2007.

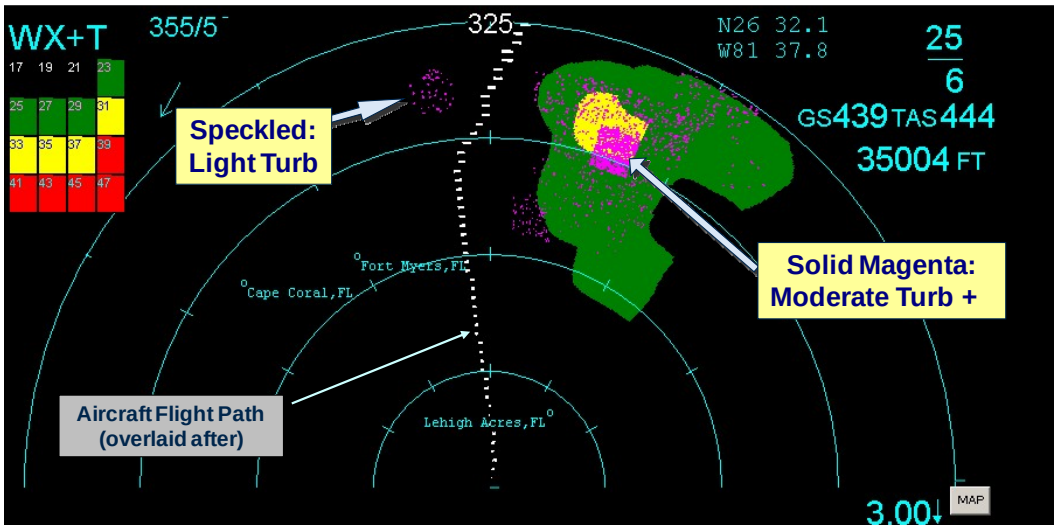

Figure 3: E-Turb Radar Display Example 1

This example is of interest because it shows a region of light turbulence outside of the green reflectivity region. This represents a very typical scenario of an unexpected turbulence encounter. The aircraft is maneuvering around the regions of reflectivity and runs (unexpectedly) into a region of turbulence. The aircraft's actual flight path is shown to deviate around this region – indicting that the pilots used the enhanced turbulence display to avoid the encounter (this was confirmed through pilot interview).

Example 2:

This next example (Figure 4) is similar to the previous one except that in this case a region of moderate or greater turbulence is detected well away (over 15 miles) from any displayed convective cells. This again is a scenario for a significant unexpected encounter if the aircraft did not have the E-Turb capability. In this case the aircraft avoided the region.

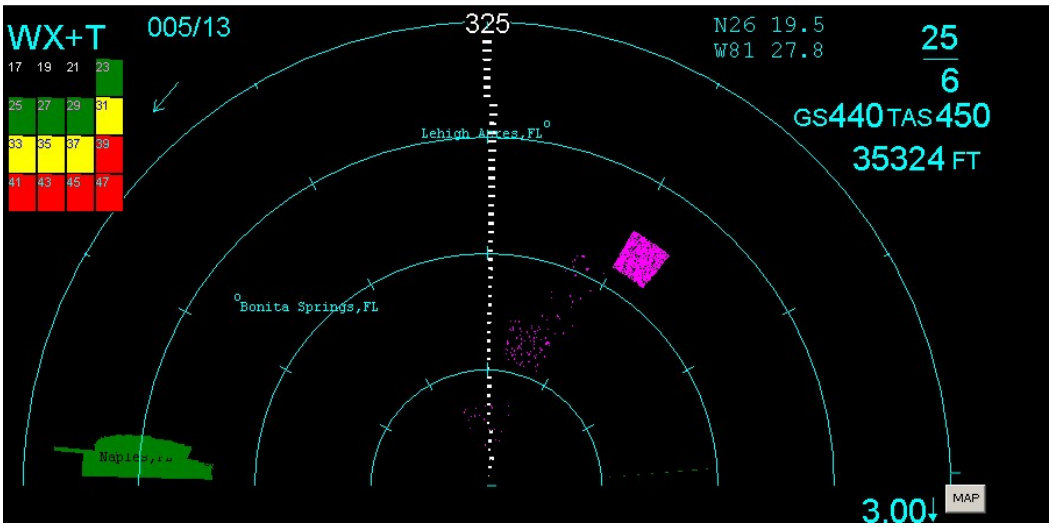

Figure 4: E-Turb Radar Display Example 2

5 Benefits of E-Turb

The Enhanced Turbulence Radar benefits tanker, cargo carrier, and passenger aircraft flight crews, passengers, and the aircraft operators in several ways:

Safety

- Reduced injuries to flight crews and passengers due to enhanced turbulence awareness by flight crews, avoidance through flight deviations, and turbulence preparation (e.g., passengers and flight crews seated with seatbelts fastened and loose items secured).

Operations

Increased situational awareness of turbulence hazards in any airspace for pilots. This situational awareness:

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

Maintenance

- Potentially less unscheduled maintenance, fewer severe loads inspections, less overall stress on the aircraft structure, and longer airframe life due to ability to avoid turbulence.

6 Some Concepts for Refueling Operations

As stated above, AeroTech's E-Turb Hazard Prediction Algorithms for weather radars can provide significant benefit to a tanker, cargo carrier, or passenger aircraft. Due to the unique nature of refueling operations, the E-Turb capability on the tanker aircraft could provide significant benefit to the overall refueling operations and the receiving aircraft. The following concepts are presented for consideration and discussion. The display shown was designed for commercial aircraft operations and could be adjusted based on needs and requirements for military operations.

- Concept 1 (Figure 5): Tanker is equipped with the E-Turb capability, which is displayed in the cockpit. The crew uses the E-Turb system to establish the tanker track within its assigned region that will keep clear of turbulence hazardous to the tanker at its current flight conditions. This would also enable the tanker to have improved turbulence awareness during normal flight operations and transits as well.

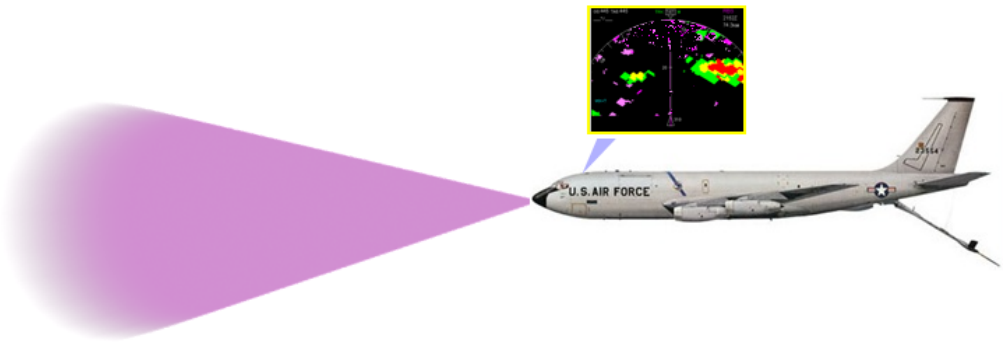

Figure 5: E-Turb Tanking Concept 1

- Concept 2 (Figure 6): Since the E-Turb hazard information is quantitative and scalable based on aircraft type and flight characteristics, the E-Turb radar information sensed by the tanker could be scaled to the receiving aircraft. A separate display (at the mission commander's or boom operator's station) could show the predicted hazardous turbulence for the receiving aircraft ahead of the tanker. The tanker crew could then verbally relay information on the predicted turbulence hazard to the receiving aircraft.

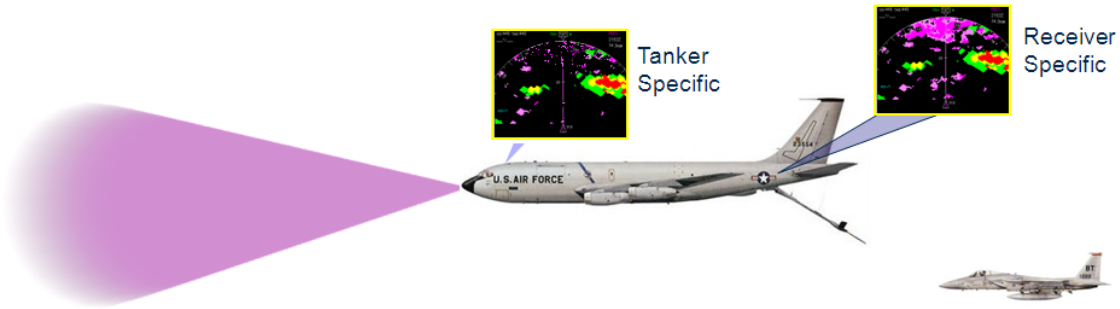

Figure 6: E-Turb Tanking Concept 2

- Concept 3 (Figure 7): Building on Concept 2, the turbulence hazard picture scaled to the receiving aircraft could be provided by data link to the receiving aircraft and displayed in their cockpit. This would provide the receiving pilot the visual picture of the turbulence hazard to his aircraft and enable better decision making between the pilot and tanker crew on refueling operations. Concept 3 would enable benefits to the refueling operation during limited- or no-communication evolutions.

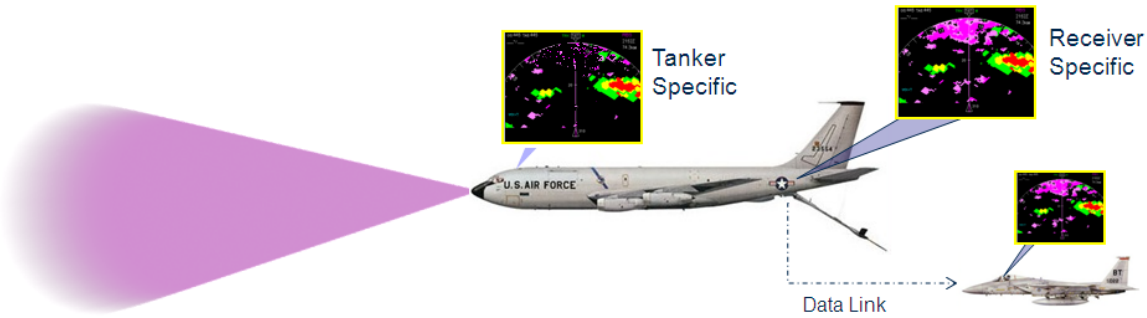

Figure 7: E-Turb Tanking Concept 3

- Concept 4 (Figure 8): Concept 4 assumes that the receiving aircraft is a UAV that will be tanking (either autonomously or controlled). Building on Concept 2, the turbulence hazard information scaled to the receiving UAV could be provided by data link to the UAV or the UAV controller. If the UAV is being controlled, the controller would have a visual picture of the turbulence hazard to his UAV and enable better decision making with the tanker crew on refueling operations. If the UAV was conducting the refueling autonomously, the turbulence hazard data could be incorporated into the UAV's control logic to enhance the safety and rendezvous decision making precontact and enhance safety while in the contact position.

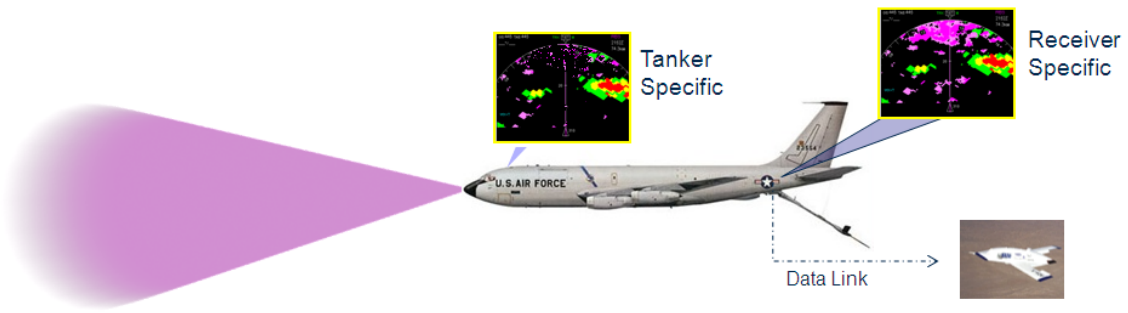

Figure 8: E-Turb Tanking Concept 4

Refueling Operation Benefits

- Better awareness of turbulence for refueling and non-refueling operations.
- Enhanced safety for the tanker and its crew.
- Enhanced turbulence hazard information for receiving aircraft.
- Enhanced decision making and safety during tanker rendezvous, contact, and refueling.

7 Summary

Hazardous turbulence continues to take a significant toll on aircraft, the aircraft operators, passengers, flight crew, and aircraft operations such as refueling. Older weather radars do not provide any turbulence information to the flight crews and the turbulence modes on modern radars do not provide a relevant picture of the turbulence hazard to the specific aircraft at its current flight conditions.

AeroTech's Enhanced Turbulence Radar algorithms and methodology enhance pilots' situational awareness of hazardous turbulence in and around convection, result in a reduction in turbulence related injuries and maintenance costs, extend aircraft service life, improve operational efficiency, and enhance the efficient use of airspace. In addition, the E-Turb information can be used to enhance tanking operations, increase refueling safety, increase situational awareness and coordination between tanker and receiver, and decrease incidents resulting in maintenance issues such as broken booms/drogues and damaged receiving aircraft.

The system can be integrated into nearly any aircraft with a PWS/Doppler radar. AeroTech's E-Turb system is a proven product that is currently flying and has flown over 6,000 hours on a Rockwell Collins WXR-2100 Multiscan™ radar in revenue operations.

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