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ESTIMATING A WINDSHEAR HAZARD INDEX FROM GROUND-BASED TERMINAL DOPPLER RADAR *

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1. INTRODUCTION

In the past decade, a great deal of effort has been invested in developing ground based wind shear detection systems for major U.S. airports. However, there has been a lack of research in developing a quantitative relationship between the wind shear hazards detected by ground-based systems and the actual hazard experienced by an aircraft flying through the affected air space. To date, the main thrust of the verification efforts for ground-based systems has been to ensure that the system accurately detect and report the presence of the meteorological phenomena that cause potentially hazardous windshear. There is a subtle, but potentially important difference between detecting the presence of a microburst and detecting the presence of an aviation hazard. With this in mind, it would seem prudent to rigorously determine what correlation exists between the wind shear warnings that are generated from ground systems and the performance impact on aircraft flying through the impacted airspace. The operational demonstration of the testbed Terminal Doppler Weather Radar (TDWR) in Orlando, Florida along with the testing of airborne Doppler radar systems created a unique opportunity to compare extensively the ground based windshear reports with in-situ aircraft measurements.

This paper presents the results from 69 microburst penetrations flown in 1990 and 1991 by the University of North Dakota (UND), the National Aeronautics and Space Administration (NASA) Langley Research Center, and Rockwell Collins under surveillance of the Lincoln-operated TDWR testbed radar. The primary goal of the research was to determine the relative accuracy of several methods designed to generate a numerical microburst hazard index, called the F factor, from ground-based Doppler radar data. It is hoped that this work will provide both a qualitative and quantitative basis for the discussion and assessment of microburst hazard reporting for ground-based microburst detection systems.

The Integrated Airborne Wind Shear Program is a joint NASA/Federal Aviation Administration (FAA) program with the objective to provide the technology base that will permit low altitude windshear risk reduction through airborne detection, warning, and avoidance. Additionally, the program aims to demonstrate the practicality and utility of real-time assimilation and synthesis of ground-derived windshear data to support executive level cockpit warning and crew-centered information display. Lincoln Laboratory joined this effort and provided the weather radar ground support and some of the post-flight data analysis for NASA's microburst penetration flights in Orlando, Florida.

2. F FACTOR EQUATION

Currently, ground based and airborne windshear sensors characterize the microburst hazard in two different ways. Airborne systems characterize the hazard in terms of F factor(Bowles, 1990), a volumetric parameter that measures the rate of change of aircraft energy. Ground based systems such as TDWR report the strength of the windshear event as a single number representing peak point-to point loss. Therefore, it was necessary to process the radar base data to compute the F factor for each penetration. This was accomplished by two methods. The first method involved using the TDWR algorithm loss estimate and the second involved a shear calculation from the radial velocity data. Both methods used a Lincoln modified version of the F factor equation proposed by Roland Bowles of NASA Langley Research Center (Bowles, 1990):

$$F_T = K' \frac{\Delta V}{\Delta R}\left(\frac{GS}{g} + \frac{2h}{GS}\right) = F_h + F_v \qquad (1)$$

where K' is a constant, ΔV is the velocity difference, ΔR is the distance over which the velocity difference occurred, GS is the groundspeed of the aircraft, and h is the height of the radar beam. The F factor equation is composed of two terms, the horizontal term(F_h, effect of headwind/tailwind loss on the aircraft), and the vertical term(F_v, effect of the downdraft on aircraft performance). The Doppler radar is only capable of measuring the wind component along a radial, therefore, the aircraft generally flew flight paths along a radial. This compensated for inconsistences between radar and aircraft measurements in the horizontal term, however, some method was needed to estimate the vertical term from the Doppler data. This was done by employing a simplified model of the mass continuity equation. The outflow region is viewed as a cylinder with the height of the radar beam acting as the top of the cylinder. Because the ground acts as a cap preventing flow out the bottom, what flows into the top (i.e. downdraft) must exit through the sides of the cylinder as horizontal outflow. With this model, the outflow is directly proportional to the downdraft depending upon the radius of the cylinder and the deceleration profile of the downdraft with height.

3. ESTIMATION OF F FACTOR USING TDWR ALGORITHM OUTPUT

The TDWR microburst algorithm defines a microburst outflow region by fitting a race track shaped icon around

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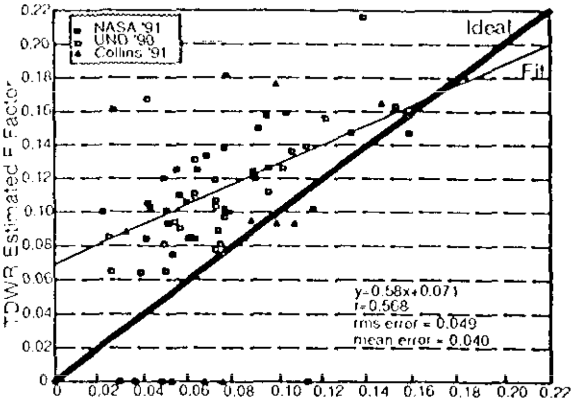

Figure 1 TDWR algorithm output vs. aircraft total F factor.

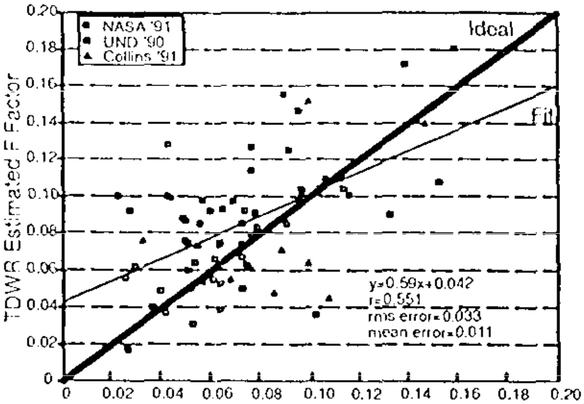

Figure 2 TDWR shear map vs. aircraft total F factor.

groups of radar radial velocity segments that show sufficient shear along their length. Site adaptable parameters control the maximum size of a shape, the minimum shape radius, and other shape characteristics. Each icon is assigned a value denoting the peak-to-peak velocity difference contained within the shape. This ranged from the largest to the second largest segment ΔV depending upon the number of segments contained within the shape. This peak-to-peak velocity difference was taken to be the ΔV term of equation (1), and the ΔR term was based upon the 85th percentile shear within the shape.

For each of the 69 microburst penetrations, an F factor was calculated from the output of the Lincoln version of the TDWR microburst algorithm using the techniques described above. Figure 1 is a plot of the TDWR estimated total F factor (TDWR F_T), compared to the *in situ* F factor. From the figure it can be seen that the computed TDWR F_T was consistently higher than the *in situ* F factor. Most notable is that the estimation was biased especially high for the NASA events.

The unexpectedly high values of TDWR F_T may be due to several factors, the most obvious of which is that the F factor computed from the microburst alarms assumes that the shear has a constant value at all points within the alarm's boundary. This assumption is incorrect, and since the aircraft sampled only a small portion of the area enclosed by the microburst alarms, it is quite possible that on many occasions they missed the localized "hotspot" of shear that caused the large value reported by the TDWR. The test pilots indicated during interviews that they occasionally avoided the most severe portion of a storm intentionally due to flight safety considerations.

4. ESTIMATION OF F FACTOR USING TDWR SHEAR MAP

F factors can be computed from the TDWR testbed's radial velocity data by creating a map of the radial shear. To do this, the radar base data were first subjected to a data quality editing process and then velocity dealiasing. The data quality editing consisted of clutter removal, point-target editing, and range obscuration editing. Next, the velocity field was median filtered using a sliding window of approximately 500 meters x 500 meters. The actual radial shear computation for each range gate was made by performing a least squares fit on seven gates centered about the point. With the TDWR radar's 150 meter gate spacing, this resulted in a fit over a radial distance of 1050 meters. This general method of shear computation is similar to work done by Britt(1992) for NASA's airborne Doppler windshear detection system.

The F factor can then be estimated along the trajectory of the aircraft by using the closest radial shear value as calculated from the TDWR base data. Figure 2 shows the peak total F factor as estimated from the TDWR shear map versus the peak total *in situ* F factor. A comparison with Figure 1 shows improved agreement between the TDWR and *in situ* F factor at the expense of an increased incidence of underestimation. Examination of the significant cases of underestimation reveals that in nearly all cases the error was due to the aircraft encountering a large downdraft that was not predicted by the shear map F factor calculation.

5. COMPARISON OF AIRCRAFT AND RADAR ESTIMATES OF HORIZONTAL F FACTOR

As mentioned in Section 3, it is useful to look at the horizontal and vertical terms of the F factor when attempting to analyze the success and failure of the various estimation techniques. From equation 1, the horizontal term can be calculated directly from the TDWR shear map data using the following formula (Note: K' is equal to one because the shear map is a one kilometer shear):

$$F_H = \frac{\Delta V}{\Delta R}\left(\frac{GS}{g}\right) \qquad (2)$$

Figure 3 compares the horizontal term of the F factor as estimated from the TDWR shear map and the aircraft. The shear map provides a fairly good estimate of the horizontal F factor, but tends to overestimate. A possible explanation for an overestimated F factor from the shear map is the difference between the altitude of the aircraft and the radar beam. For most of the events, the aircraft penetrated the microburst at a much higher altitude than the radar beam. Physical observations and modeling results suggest that the horizontal shear in a microburst varies with altitude. Thus, it would seem prudent to attempt to compensate for the discrepancy between the height at which the TDWR antenna beam and the aircraft measured the microburst intensity.

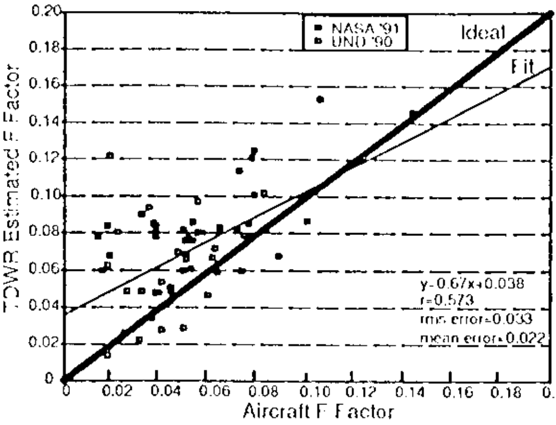

Figure 3 Shear map vs. aircraft horizontal F factor at F total peak time.

The Vicroy(1991) analytical microburst model includes a vertical shaping function for the horizontal wind velocity that is a good fit to experimental data. Correcting for altitude, Figure 4 shows that there is a marked improvement in the shear map estimates for horizontal F factor. Therefore, using the shear map and correcting for altitude seems to provide an acceptable estimation of the horizontal F factor.

6. COMPARISON OF AIRCRAFT AND RADAR ESTIMATES OF VERTICAL F FACTOR

From formula (1), the vertical term of the F factor is estimated using the following formula (Again: K' is equal to one because the shear map is a one kilometer shear):

$$F_V = \frac{\Delta V}{\Delta R}\left(\frac{2h}{GS}\right) \qquad (3)$$

Figure 5 shows the shear map estimated vertical term versus the *in situ* F factor. A probable explanation for the poor performance of the downdraft estimates is the simplistic assumption used to estimate the downdraft velocity. Observations have shown that the downdraft velocity varies with altitude as well as across the radius of a microburst. A better estimation of the vertical F factor needs to be developed that is capable of incorporating the aircraft's location within the microburst.

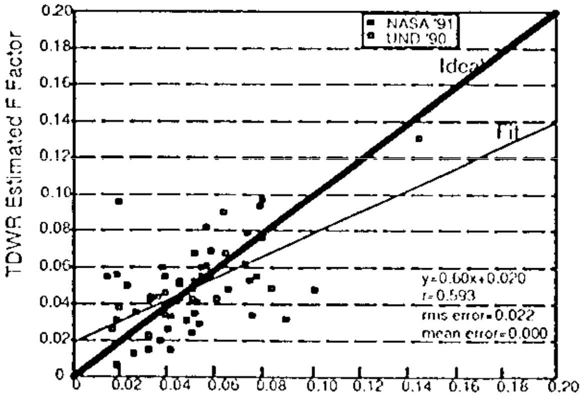

Figure 4. TDWR shear map vs. aircraft horizontal F factor at F total peak time using altitude profile correction.

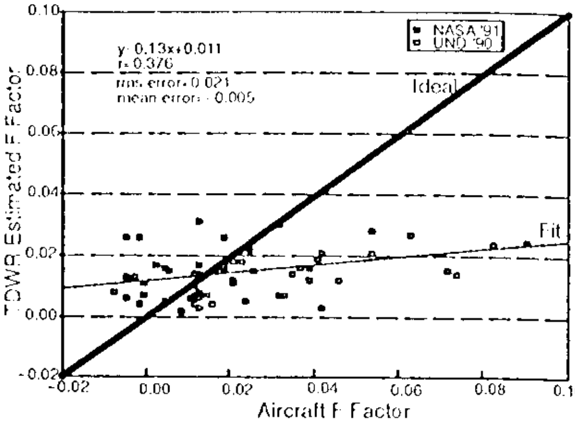

Figure 5. TDWR shear map vs. aircraft vertical F factor at F total peak time.

7. CONCLUSION

While the current TDWR microburst algorithm performs extremely well in detecting microburst hazards, some enhancements are needed to improve its ability to characterize the hazard in terms of the F factor. It has been shown that the current microburst shapes overestimate the F factor hazard if the aircraft does not encounter the core of the microburst. A shear based approach was developed which allows the horizontal F factor to be estimated accurately. However, the vertical F factor term remains poorly estimated due to an overly simplistic mass continuity assumption.

In order to improve the estimate of the vertical F factor, future research will focus on fitting an analytical microburst model to shear based microburst detections. Such a shear- based algorithm is currently under development as part of the Integrated Terminal Weather System (ITWS) program (Dasey, 1992). This new algorithm will allow the microburst hazard to be more accurately characterized by providing better localization of regions of intense horizontal shear and a better estimation of downdraft intensity.

8. REFERENCES

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