**J2.2   EXPLORING THE POSSIBILITY OF A LOW ALTITUDE GRAVITY WAVE ENCOUNTER
AS THE CAUSE OF A GENERAL AVIATION ACCIDENT
NEAR NORMAN OKLAHOMA ON DECEMBER 6, 1998 ***

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1. INTRODUCTION

On December 6th, 1998, a fatal accident involving a twin engine Beech Baron occurred near the Max-Westheimer Airport at Norman Oklahoma (OUN). Although the National Transportation Safety Board (NTSB) conducted an extensive investigation into this accident, the probable cause for the accident has yet to be determined. Since the accident occurred outside of weather echoes that might be considered hazardous, it seems difficult to deduce a meteorological explanation for this accident. However, Doppler radar data suggested the presence of wave formations near the site of the accident. This report reflects examination of the data provided by the NTSB.

2. DATA ANALYSIS

The data used for this research includes the KTLX WSR-88D base data covering the time frame of the accident from 1435Z to 1540Z, product data from the Oklahoma City International Airport (OKC) TDWR, sounding data from OUN, beacon position data, air traffic radio communications, pilot reports (PIREPS) and surface (METAR) data. The dominant synoptic-scale feature on this day was a strong cold front moving southeastward across Oklahoma. A low-pressure system over southwest Oklahoma prompted the Storm Prediction Center to issue a Severe Thunderstorm Watch for central and northeast Oklahoma, effective during the time of the accident. By 1500Z, scattered thunderstorms had developed 40 nm SW of OKC, with a general storm motion to the northeast. At 1533Z, the approximate time of the accident, the nearest

storm activity was located 22 km WNW and 18 km N of the accident site.

2.1. Radar Data

The data obtained from the KTLX WSR-88D were not optimal for evaluation of this particular accident. Due to the resolution constraints of the radar, small-scale features and fluctuations in wind speed were not clearly evident. In addition to this, the initial cold front was nearly radially aligned with the radar at the time of the accident. Thus, the azimuthal shear present at the time of the accident was not apparent in the radar base data; in fact, the velocity data along the initial front was incredibly noisy. Furthermore, the accident occurred while the radar was sampling the uppermost tilts of the volume scans and thus there were no radar data available along the flight path. However, using the available radar data, the location of fronts and waves were advected to their approximate locations that coincide with the respective times of the beacon data.

The radar data for this case did show a few prominent features. When looping the data, a secondary gust front is observed. In addition, several low-altitude gravity waves (buoyancy or density currents) are also evident. These waves appear in three major wave trains with differing forcing mechanisms. One set of waves appears to have formed due to vertical wind shear not associated with thunderstorm convection. Behind the initial gust front, the surface winds were out of the northwest while the winds at higher levels remained out of the southwest. Hence, the higher level winds became the steering mechanism for the gravity wave train and they propagated to the northeast. Another set of gravity waves appears to have formed due to thunderstorm outflow and propagated to the east. The final set of waves formed behind the initial gust front (cold front) and propagated to the southeast. Figure 1 shows the 0.5° tilt of the KTLX WSR-88D for a time that is about 15 minutes prior to the accident. The image for Figure 1 was chosen because the radar time is very close to that of two additional, separate

incidents involving severe turbulence on final approach. At 1515Z, a Boeing 737 encountered a turbulent event while on approach to 35R at OKC. The pilot reported airspeed variations of + or – 50 knots, and the aircraft diverted back to Dallas Love Field (DAL). Also at 1515Z, a twin engine Cessna C340 encountered moderate turbulence while on descent to Wiley Post airport (PWA) from 6000 feet to the surface. The pilot also reported winds of up to 50 knots. What makes these two incidents significant is the fact that the 2nd gravity wave in the train is straddling both of the incident airports.
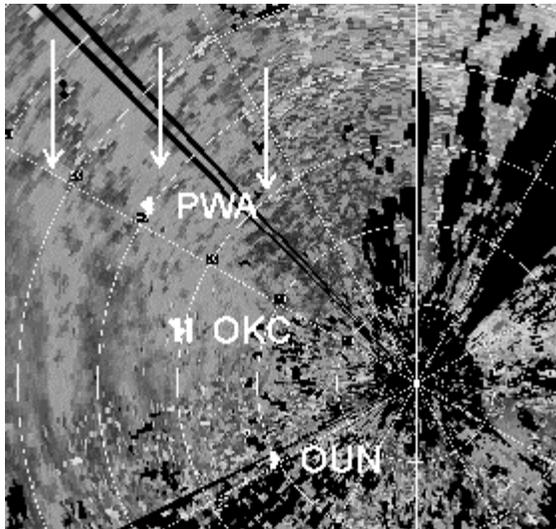
Figure 1. 0.5° tilt from the KTLX WSR-88D at 15:17:37. Three major airports are depicted: OUN – Westheimer (Norman); OKC – Oklahoma City International; PWA – Wiley Post (Oklahoma City). The white arrows show the position of individual waves within the wave train. The leading edge of the initial gust front is denoted by the abrupt loss of scatterers ahead of the front.

The radar image in Figure 1 was also chosen because of the proximity of the initial gust front to the KTLX radar site. At this time, the front is at an optimal distance from the radar in order to obtain a well saturated cross sectional analysis. The cross section in Figure 2 was taken along the 315° radial, which is the radial most perpendicular to the front.

The cross section in Figure 2 shows the initial gust front (cold front) with at least two trailing surface waves, with an upper bound of about 900 meters. In addition to this, there also appears to be a secondary wave structure in the upper levels of the cross section, with an upper boundary of 2000 meters. It is intuitive that the cross sectional view in Figure 2 represents the conditions that exist behind the leading edge of the gust front along its entire length since the PPI plot of the

base data already shows the presence of a secondary gust front.
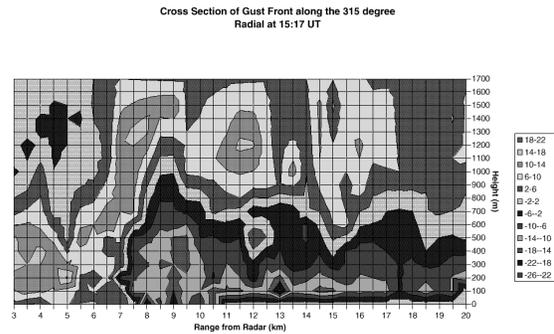
Figure 2. Cross sectional view of velocity data across the initial gust front (cold front) and trailing gravity waves using the KTLX WSR-88D along the 315° radial. The units for the velocity data are given in m/s.

2.2. Flight Path Data

The height of the gravity wave train is important since this is the approximate altitude at which the aircraft was traveling during the final minutes of flight. Figure 3 shows the vertical variations in the flight path of Baron 1826S.
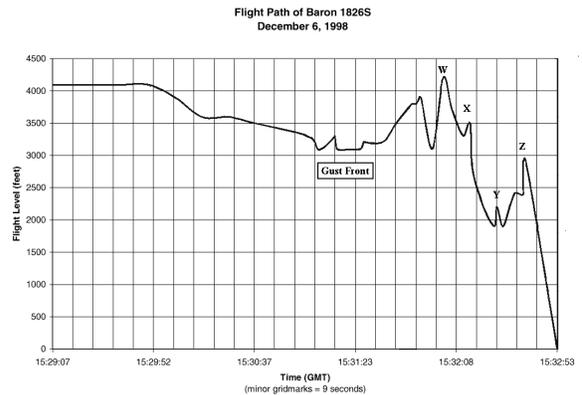
Figure 3. Vertical variation of the flight path for Baron 1826S as extracted from the beacon data. The letters W, X, Y and Z correlate to the beacon positions found in Figure 4.

Figure 3 indicates that after crossing the initial gust front, the aircraft went through several abrupt variations in altitude in relatively short periods of time. Unfortunately, as mentioned before, the height of most of the flight path lies between tilts of the radar volume scan. However, the height of the 1.4° tilt over the accident site is a close approximation (785 m). Even though the radar times are not directly correlated with the time and positions of the aircraft, one can project the weather forward in time to correlate with the time and position of the aircraft. Figure 4 (A-F) shows the projected position of the gust front(s) and

gravity waves concurrent with times in the beacon data.
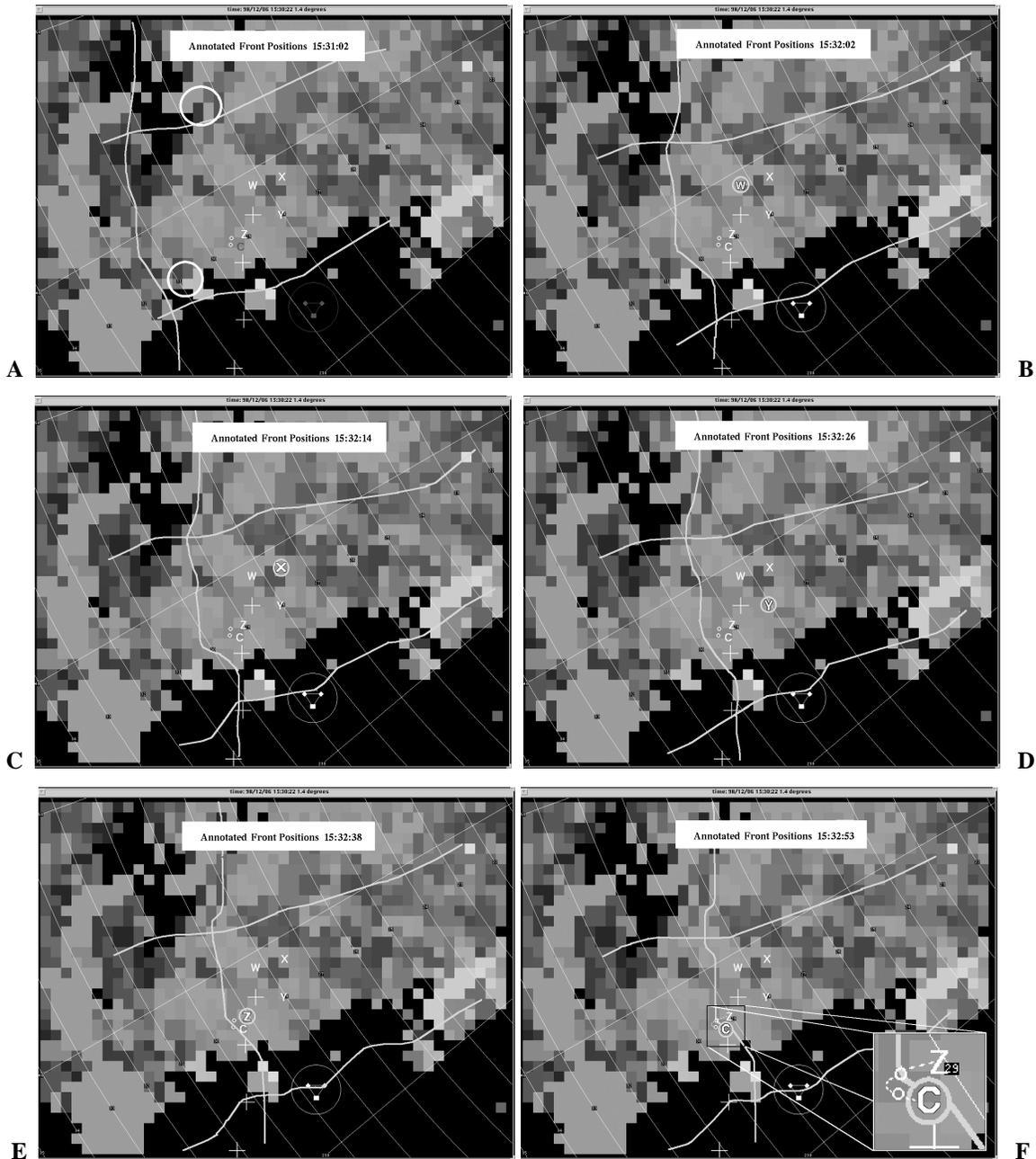
Figure 4(A-F). Radar velocity image from the 1.4° tilt of the KTLX WSR-88D at 15:30:22. Each panel shows the relative approximate locations of the initial gust front (E-W), secondary gust front (E-W), and the third wave within the gravity wave train (N-S) in pale grey lines for the given time. The time shown represents the time as indicated by the beacons data, and the position of the airplane is represented by circled letters W, X, Y, Z and C. The circles in panel (A) indicate areas of possible weak rotation.

2.3. Interpolated Data

Figure 4A shows the first in a series of plots with the gust fronts and gravity waves interpolated into the future. Positions of the fronts were calculated based on the speed and direction of movement of these features during the duration of available radar data. Using the 1.4° tilt at 15:30:22 as a base point, the positions were then interpolated to correlate to times found in the beacon data. In Figure 4A, the fronts are projected out 40 seconds into the future from the radar time (15:31:02). At this time, the aircraft had not yet

entered the plotted area. The circles denote two areas of weak rotation found near the intersections of the gravity wave and the gust fronts. The intersection of such waves has been shown to be a favorable area for development of small-scale rotation. Figure 4B shows the interpolated front positions 100 seconds after the radar time. The position of the aircraft is located at the circled (W). Figure 4C shows the interpolated front positions 112 seconds after the radar time. The position of the aircraft is located at the circled (X). At this time (15:32:14) and position, the aircraft would be very close to the trajectory of the northern rotation feature. Figure 3 also indicates a dramatic drop in altitude at around this time.

Figure 4D shows the interpolated front positions 124 seconds after the radar time. The position of the aircraft is located at the circled (Y). Figure 4E shows the interpolated front positions 136 seconds after the radar time, with the position of the aircraft denoted by the circled (Z). Figure 4F shows the interpolated front positions at the time of the accident (15:32:53), 151 seconds after the radar time. The location of the accident is denoted by the circled (C). In the bottom right corner is an expanded view of the area near the accident site.

It was surprising to see that the interpolated fronts correlated well to the possible difficulties the pilot of Baron 1826S encountered. Previous research has shown that intersecting waves tend to produce rotational features along these intersections, especially if the intersecting waves are nearly perpendicular (as they were in this case). This phenomenon has shown to be particularly hazardous to aircraft that have encountered them. In particular, two cases in the past have resulted in extreme turbulence events to commercial aircraft; namely, the event on April 12, 1996 at DFW and on April 26, 1997 at MCO. In addition, numerous other incidents have occurred in the past where aircraft encountered non-intersecting gravity waves. Some of these encounters have resulted in extreme turbulence such as experienced on November 6, 1996 at DFW, January 15, 1997 at MEM, and December 12, 1997 at MCO. In each of these cases, pilots reported gains and loses of at least 40 knots as they encountered gravity waves.

3. CONCLUSIONS

As a result of extensive research into gravity waves, we were able to identify and track several wave features in the data. Although the meteorological data do not explicitly elucidate the cause of the accident as being from an encounter with a gravity wave train, the data does show that waves existed near the site of the accident. Furthermore, there were several PIREPs indicating severe shear associated with encounters with one of the gravity waves. Currently, neither NWS nor any of the FAA's terminal or en route weather hazard detection systems provide information on possible gravity wave hazards. The circumstances of this accident suggest that ongoing research is warranted on the operational evaluation with respect to this hazard.