P4.2: Turbulence PIREPs in Juneau - An Analysis

Jamie T. Braid* and Tressa L. Fowler
National Center for Atmospheric Research, Boulder, Colorado

1 INTRODUCTION

Flights into and out of the Alaskan capitol of Juneau are an important part of the economic and political structure of Alaska. Juneau is only accessible by plane or boat making the safety of these routes very important to both the people of Juneau as well as the state of Alaska. Turbulence encounters on the approach and departure paths at Juneau International Airport (JNU) have impacted both safety and flight capacity.

The Research Applications Program (RAP) of the National Center for Atmospheric Research (NCAR) has been primarily responsible for the development of a turbulence detection system in the Juneau area. The Juneau Wind Hazard Alert System (JWHAS) estimates turbulence hazards using information from a variety of anemometers and wind profilers placed near the approach and departure paths of JNU (See Barron and Yates., 2004 for more information on the equipment and its placement). As part of the development of this system, two research aircraft, University of Wyoming's (UW) King Air and Alaska Airlines 737 (ASA737), collected turbulence and wind shear measurements during the 2003 Fiscal Year (FY2003) Juneau Field Program. This field program started on September 30, 2002 and lasted until January 20, 2003. The main focus was to gather meteorological and aircraft sensor data to be used for verifying scientific algorithms in the prototype JWHAS (Yates, 2002). During the field program the pilots also gave voice pilots' reports (PIREPs) of turbulence during their flights.

The analyses presented in this paper summarize the information obtained from these PIREPs. Case studies of two severe turbulence encounters are also presented.

2 DATA

2.1 Voice Pilot Reports (PIREPs)

During the 2003 field program, PIREPs were collected from flights of the UW King Air and ASA737. These flights were divided into three categories. These categories are ASA737 only, UW King Air only and dual flights which included both the ASA737 and UW King Air flights at the same time. A combined total of 49 flights were flown during the field program with 47 of those flights containing the PIREPs used in this verification process. Table 1 breaks down the numbers of flights in each category.

Table 1: Juneau 2002 flight information.

Aircraft/Flight Type	Number of Flights
King Air	24
737	14
Dual (KA & 737)	9

The PIREPs were collected over a four month period which lasted from October 5, 2002 until January 19, 2003. These PIREPs were logged by flight operation directors on the ground who then organized them into spreadsheets. The PIREPs include information such as the date, time in Coordinated Universal Time (UTC), flight numbers, local weather observations, anemometer wind speed and direction from the Eagle Crest, Mount Roberts and Sheep Mountain anemometers as well as turbulence observations.

2.2 Aircraft EDR Values

Eddy dissipation rate (EDR) is a measure of the energy cascade through scales of inertial sub range turbulence. In simpler terms, EDR is the measure of the turbulent kinetic energy transferred from the largest to smallest eddies (Greer 1996). The vertical EDR values (ZEDR) used in this analysis were calculated from wind values measured by the two aircraft used in the FY2003 field program (Gilbert et al., 2004).

The FY2003 Juneau Field Program utilized two types of aircraft for the gathering of EDR data. The UW King Air is an instrumented research aircraft and the ASA737 is a transport category aircraft.

The research aircraft is a King Air 200T owned and operated by the University of Wyoming. The King Air is equipped with a suite of sophisticated sensors designed to gather highly accurate, high rate data (Yates, 2002).

The transport class aircraft is a Boeing 737-400 owned and operated by Alaska Airlines and equipped with a Quick Access Recorder (QAR) that records data from onboard flight computers and other sensors. The 737 is also equipped with a dual suite of navigational equipment that

Corresponding author address: Jamie T. Braid, National Center for Atmospheric Research, Boulder, CO 80307; e-mail: braid@ucar.edu

provides sufficient positional accuracy to allow it to be flown in IFR conditions in the Gastineau Channel. This capability provides the ability to gather data in conditions acceptable for Part 121 and Part 91 operations, but where the research aircraft cannot operate (Yates, 2002).

2.3 JWHAS system

For this study, the FAA funded, NCAR/RAP developed, JWHAS algorithm was compared to the PIREPs obtained during the 2003 field program. This algorithm identifies a wind regime, and then uses a linear regression model based on Juneau wind profiler and Hydrotech anemometer data to estimate a hazard level for turbulence. For more detailed information on the JWHAS algorithm please referrer to Morse 2004.

Three wind regimes cause possible turbulence hazards in the Juneau area: southeast, Taku, and mixed. A southeasterly wind regime has winds aloft from the southwest (due to an approaching low), which are turned to the southeast as they flow up the Gastineau channel towards the airport. A Taku wind regime has winds from the north or northeast that are caused by a very strong pressure gradient between glaciers to the north (high pressure) and Juneau (low pressure) in the south. A mixed wind regime occurs when the flow is a combination of southeast and weak Taku. (Cohn et al., 2004)

2.4 Hazard Areas

Twelve hazard areas are identified on the approach/departure paths at JNU. A two dimensional view of the hazard areas is shown in Figure 1. There are a total of eight boxes with four of them around the airport and the other four down the Gastineau Channel. The four boxes that surround the airport are Coghlan Island (cog), Lemon Creek (lmn), North Douglas Island (ndi) and Outer Point (opt). The four boxes shown in the Gastineau Channel (gc) are actually eight boxes. Each of the four boxes is divided into two different altitude ranges. The lower boxes are numbered 1-4 (gc1, gc2, gc3 and gc4) and cover the surface to 2000 ft. The upper boxes, gca, gcb, gcc and gcd, are for altitudes above 2000 ft.

3 METHODS

Only cases of severe, moderate and no (none) turbulence are analyzed. The PIREPs of light turbulence are omitted for two reasons. First, the number of light turbulence PIREPs was very large and thus impractical for human analysis. Second, it is somewhat difficult to differentiate between light turbulence and no turbulence or between light turbulence and moderate turbulence. Comparison between

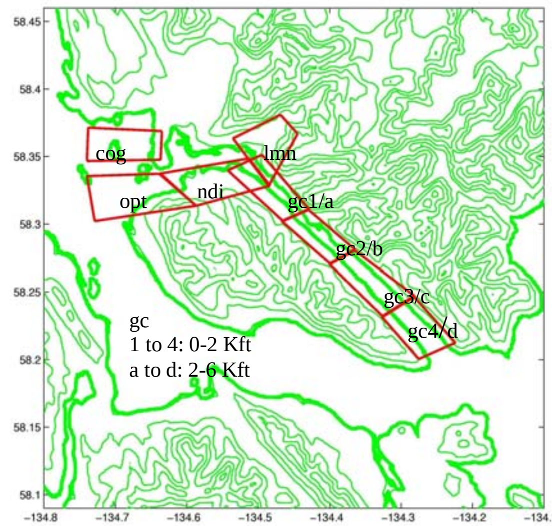

Figure 1: Juneau hazard area locations.

moderate and no turbulence is both simpler and of greater interest.

Since atmospheric conditions tend to persist over short periods of time, observations in the same airspace that are close in time are not necessarily independent. To mitigate the non-independence of the flight data, a 30-min separation between PIREPs was applied. Thus, an observation of the same type of turbulence event (e.g. moderate) found in a hazard area within thirty minutes of the initial observation is discarded. Both of these observations are considered to be a single report, and only the first is used.

A breakdown of the counts of the different turbulence PIREPs by flight types are listed in Table 2.

Table 2: Number of turbulence PIREPs by aircraft type.

	King Air	737	Total
None	210	154	364
Moderate	100	30	130
Severe	2	0	2

Each PIREP is matched to one of the twelve hazard boxes. In all PIREPs, the location of the plane was documented. These locations are either physical locations in the Juneau area (e.g. Kmart, Western Auto) or geographical points (Coghlan Island or Outer Point). For locations in the Gastineau Channel, the plane's altitude is also used to determine the hazard area.

A breakdown of the counts of each type of turbulence in each of the hazard boxes is shown in Tables 3 and 4. There are only two severe cases in the Lemon Creek and Gastineau Channel 2 boxes.

The PIREPs are also matched to the EDR values produced by the JWHAS algorithm. The algorithm values are matched to the PIREPs by hazard box location, date, and time. A window of ±5 min was allowed in the time matching process because of possible differences between the time recorded on the aircraft and on the ground.

Table 3: No turbulence PIREPs by hazard area and flight type.

	None		
	737	**KA**	**Total**
COG	21	26	47
LMN	7	15	22
NDI	12	28	40
OPT	6	11	17
GC1	29	39	68
GC2	4	7	11
GC3	2	13	15
GC4	2	6	8
GCA	20	14	34
GCB	25	17	42
GCC	12	25	37
GCD	14	9	23
Total	154	210	364

Table 4: Moderate turbulence PIREPs by hazard area and flight type.

	Moderate		
	737	**KA**	**Total**
COG	5	9	14
LMN	2	10	12
NDI	4	4	8
OPT	3	12	15
GC1	1	10	11
GC2	2	8	10
GC3	4	13	17
GC4	1	7	8
GCA	2	0	2
GCB	2	11	13
GCC	3	12	15
GCD	1	4	5
Total	30	100	130

4 SEVERE TURBULENCE CASE STUDIES

4.1 October 20, 2002

The first event of severe turbulence was observed during a dual flight with both the King Air and the ASA737. These aircraft flew from 19:10 – 23:02 UTC on October 20, 2002. The actual severe turbulence PIREP was documented at 19:48 UTC from the pilots on the King Air. The severe turbulence was reported by the King Air as it was performing a Lemon Creek departure. The PIREP shows that the severe turbulence was encountered in the Lemon Creek hazard area (lmn, See Fig. 1).

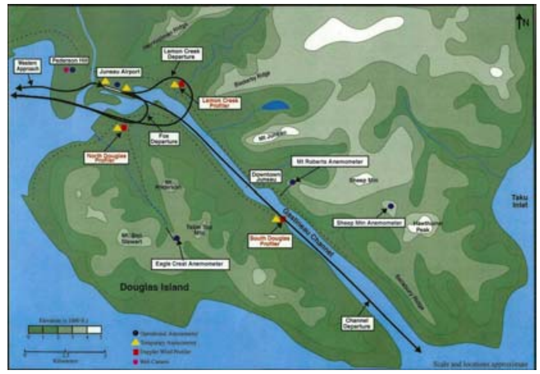

Figure 2: Map showing locations of anemometers and profilers around the Juneau area.

The weather listed on the OPS log during this flight indicates that it was an overcast day with rain in the Juneau area. The recorded winds at the Sheep Mountain and Eagle Crest anemometers (Fig 2 shows the physical locations of these anemometers) were between 16 to 21 ms^{-1} out of the southeast. These winds are very strong and would cause some concern for pilots, especially as they are crossing the channel on a Lemon Creek departure (Barron and Yates, 2004).

At JNU, the wind direction was constant from 120° (southeast) for a period from an hour before to an hour after the event. The wind speed at the airport was around 11 ms^{-1} at the time of the event. The Lemon Creek profiler data is also available at this time and it confirms that the winds are from the southeast. It also shows that the winds speeds increase with height. This event was a fairly strong and deep southeast wind (Cohn et al, 2004), which the JWHAS system correctly classified as a southeast event.

The ZEDR measurements from the King Air and the JWHAS system both indicate strong turbulence. The King Air measured a ZEDR value of 0.81 while the JWHAS system predicted a value of 0.35. The difference between these two values is large, but not unexpected given the characteristics of linear regression. Linear regression tends to model the central values well and it does not do well modeling values that are on the extremes (Neter et al., 1996). The ZEDR value from the King Air was the highest value matched to any of the PIREPs in this analysis while the nowcast EDR value for the JWHAS was the fifth highest value. The EDR values will be thresholded to produce an alarm. Though the JWHAS underestimated this hazard, the system would still produce an alarm of severe for a King Air and moderate for a 737.

4.2 November 12, 2002

The second severe turbulence event occurred during a King Air flight from 16:55 – 19:48 UTC on November 12, 2002. The actual time of the severe turbulence PIREP is 18:10 UTC. The King Air observed “occasional moderate” and severe turbulence on a Gastineau Channel departure at about 1000 ft, in the Gastineau Channel 2 (gc2) hazard area (See Fig. 1).

The closest of the Juneau area weather instruments to this event are the Mount Roberts anemometer and the South Douglas profiler. The Mount Roberts anemometer (Fig. 2) indicates the winds came mainly out of the northeast at around 15 ms^{-1} near the time of the event. The South Douglas profiler (Fig. 2) confirms the direction but indicates the speed of the winds was between 10 to 13 ms^{-1}. The Eagle Crest anemometer also verified the winds out of the northeast. Thus, this event is a Taku wind event (Cohn et al., 2004). The JWHAS system correctly classified it as a Taku event.

The ZEDR data from both the King Air and the JWHAS system indicate a turbulence event. The ZEDR value from the King Air was 0.59 and the JWHAS system EDR value was 0.30. Again, there is a fairly large gap between the two EDR values, but as stated in the previous case study this maybe due to the characteristics of linear regression. The EDR values in this case are lower than those from the first case, but this is expected since this case was listed as a moderate/occasional severe case. Nonetheless, these values still rank in the highest ten for intensity of JWHAS values that are matched to the PIREPs.

5 OVERALL RESULTS

The JWHAS system and the aircraft measurements both have an ability to discriminate between no turbulence PIREPs and MOG turbulence PIREPs, as illustrated in Figures 2 and 3. These figures are discrimination plots. Fig. 2 shows the distributions of the JWHAS nowcast EDR values matched to the no and MOG PIREPs, respectively. Similarly, Fig. 3 shows the distributions of aircraft-measured EDR values matched for no and MOG PIREPs. There is little overlap in the distribution of EDR values for no PIREPs and MOG PIREPs. This shows that the JWHAS nowcasts and aircraft measurements are able to discriminate well between no turbulence and MOG turbulence events.

In addition, the positions of the peaks of both the no PIREPs and MOG PIREPs, in both figures give some valuable information. The peak of the EDR values for the no PIREPs in both figures is around zero and decreases for higher EDR values. For the MOG PIREPs, both the JWHAS and aircraft-measured EDR values peak around 0.1 with median points of 0.17 and 0.19, respectively. The figures clearly show that the distributions of EDR values for no and MOG PIREPs are distinct and that the JWHAS and aircraft EDR measurements have good skill in discriminating between events and non-events. If the JWHAS system had no skill, then the two distributions would look similar.

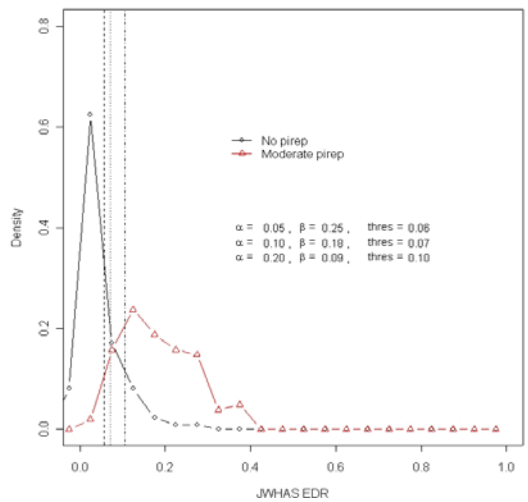

Figure 2: Discrimination plot of JWHAS nowcast EDR values for PIREPs of "No turbulence" vs. "Moderate or severe turbulence".

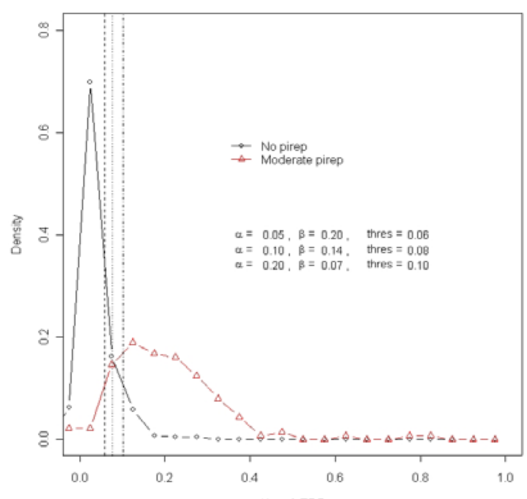

Figure 3: Discrimination plot of aircraft measured ZEDR values for PIREPs of "No turbulence" vs. "Moderate or severe turbulence".

The discrimination plots for both the JWHAS system and aircraft EDR are similar. This indicates that the JWHAS system has as much value as a warning system as sending out a research aircraft to test the atmosphere for turbulence.

By selecting a desired percentage of correctly classified events (e.g. 95%; α = 0.05), the percentage of correctly classified non-events (e.g. 75%; β = 0.25) can be determined. Figures 2 and 3 show this for 3 different values of α and β and the resulting thresholds. For example, the JWHAS system is able to correctly classify 90% (α = 0.10) of the MOG turbulence events simultaneously as it correctly classifies 82% (β = 0.18) of the non-events, using an EDR threshold of 0.07.

6 CONCLUSIONS AND FUTURE WORK

The case studies demonstrate that the JWHAS system correctly classified two severe turbulence events. In both cases, the system would correctly identify the wind regime and produced an EDR value that will translate to a turbulence alert in the operational system. However, in both cases, the JWHAS-produced EDR value underestimated the aircraft measured value.

Comparison of pilot and system-estimated turbulence shows that the system has skill in identifying null and moderate or severe turbulence events.

Future work will include more in-depth synoptic analysis of the two case study events as well as analysis of some of the stronger moderate cases.

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