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OVERVIEW OF THE JUNEAU TERRAIN-INDUCED TURBULENCE AND WINDSHEAR PROJECT

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1. INTRODUCTION

The area around the Juneau International Airport is dominated by mountainous terrain and often experiences strong winds. Aircraft have encountered significant windshear and turbulence while performing the unique approach and departure procedures necessary to avoid the nearby terrain. The Juneau terrain-induced turbulence and windshear project was undertaken by the Federal Aviation Administration and the National Center for Atmospheric Research to research and develop a warning system that can alert pilots of hazardous turbulence and windshear conditions in the Juneau area. An overview of the project's background, prototype system design, and system performance is presented. Additional related papers in this volume cover specific aspects of the project in greater detail.

2. BACKGROUND

Juneau is the capital of Alaska and is only accessible by air or sea. Thus, reliable air traffic is vital. The Juneau International Airport is located at the north end of the Gastineau Channel (Fig. 1), an approximately 25-km long, 2-km wide channel oriented southeast-northwest. The mountains on either side rise to over 1000 m. The orientation of this channel plays a key role in airflow characteristics. Cohn et al. (2004) describes the weather affecting Juneau and the terrain interactions which create hazards to aviation.

When winds at the airport have an easterly component, aircraft must depart on runway 08. To remain clear of surrounding terrain, aircraft use turning departures known as the Fox and Lemon Creek departures. Several aircraft upsets reported during these turning departures in the early 1990's resulted in the FAA suspending these departures. Alaska Airlines (ASA) installed three mountaintop anemometers around Juneau to provide their pilots better wind information. ASA and the FAA agreed on an operational specification (Ops Spec), based on the mountaintop winds, to re-instate these departures. This Ops Spec was to be used to determine go/no-go conditions for certain aircraft arrivals and departures under Federal Aviation Regulations, Part 121, during adverse weather. Congress and the FAA desired a more permanent solution to the problem, so the FAA contracted with the National Center for Atmospheric Research (NCAR) to determine the feasibility of developing and implementing a wind hazard warning system. After determining that such a warning system was feasible, NCAR was contracted to develop the warning algorithms and a prototype implementation of those algorithms. The prototype system is called the Juneau Airport Wind System (JAWS).

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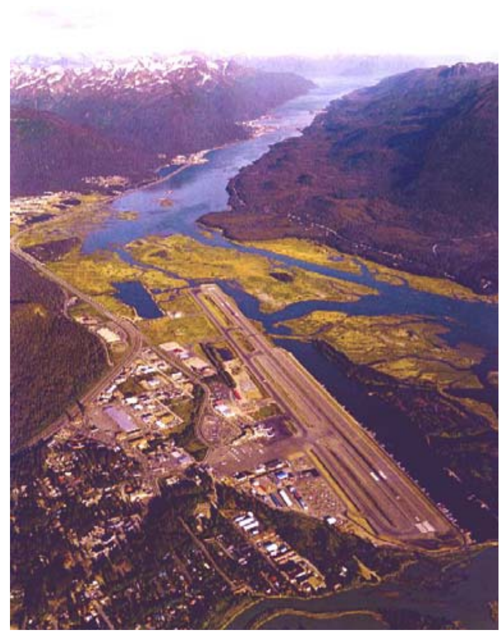

Figure 1. Aerial view of Juneau International Airport with Gastineau Channel in the background

3. PROTOTYPE JAWS DESIGN

3.1 Origins

Prototype JAWS has its origin in an earlier project conducted by NCAR in Hong Kong. An operational Windshear and Turbulence Warning System (WTWS) was developed for Hong Kong's airport at Chek Lap Kok (HKG). The WTWS provides alerts for terrain- and convection-induced windshear and turbulence and has been used by air traffic controllers and pilots since this airport's opening day, 6 July 1998. The motivation for the HKG warning system is similar to the Juneau system. Nearby terrain, in that case on

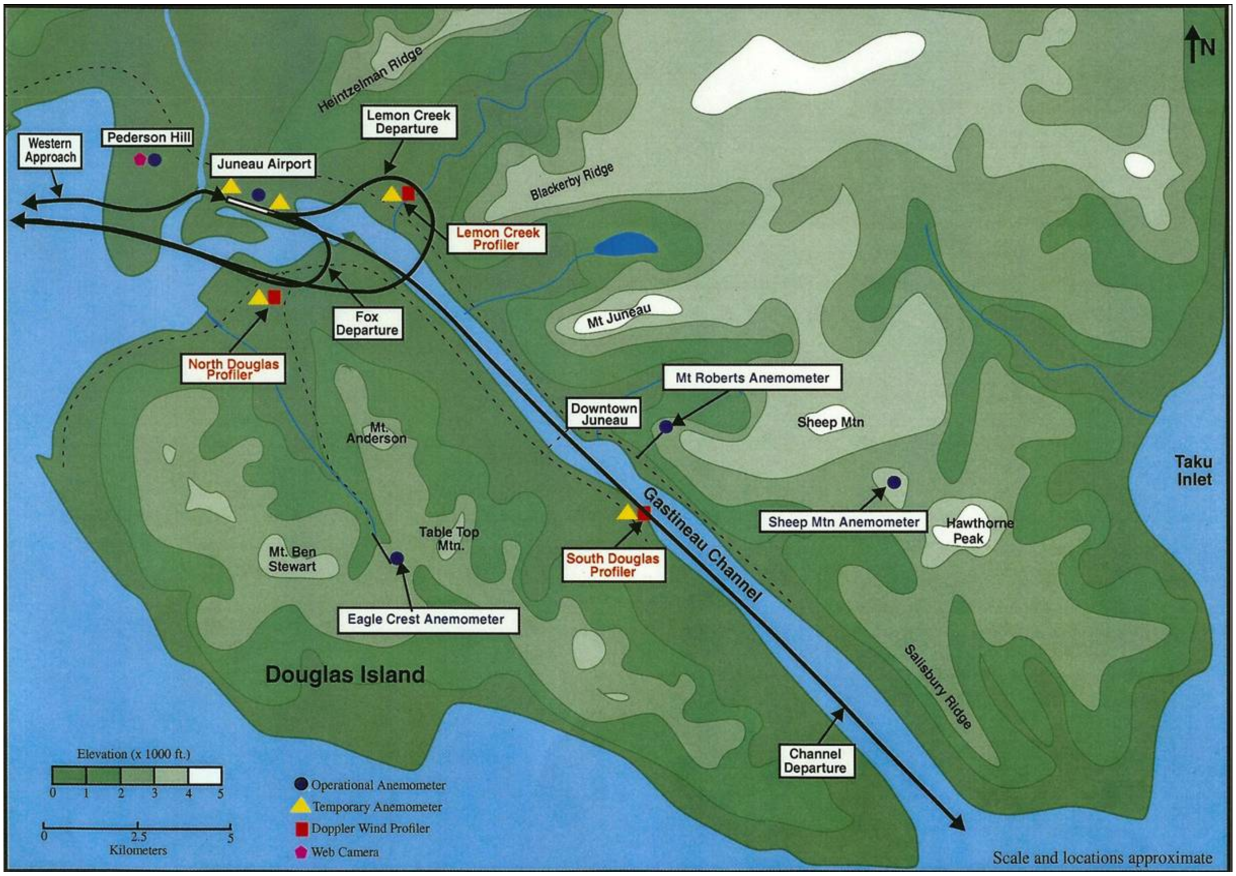

Figure 2. Juneau project map with sensor locations and air traffic routes

Lantau Island, was expected to create significant windshear and turbulence during strong winds. As will be described, the Juneau development followed a path similar to the WTWS. Meteorological sensors were deployed to characterize the winds; research aircraft flights were conducted in the terminal area to compare in situ measured turbulence with the winds; and a regression-based approach was used based on the fact that most of the turbulence and windshear in the area is created by mechanical interaction of high winds and mountainous terrain.

3.2 Key Design Features

The algorithmic design of Prototype JAWS is described in detail in Morse et al. (2004). Several design features, critical to its success, are discussed here.

Prototype JAWS, like the WTWS, relies on statistical correlations between wind-related parameters observable by the system (i.e., speed, direction, variance, etc.) and the location and severity of aviation hazards (turbulence and wind shear). Since terrain is fixed and there are distinct strong-wind scenarios, a good correlation is expected between winds and hazards. These correlations were established using the warning system's input measurements and hazards found with a research aircraft during three intensive field projects.

Redundancy is an important feature of Prototype JAWS. The calculation method to diagnose hazards does not rely on any single input. Mountaintop measurement sites have several anemometers and several independent paths to transfer data to the system. Use of both wind profilers and anemometers makes the system more robust. Together, this redundancy ensures that Prototype JAWS performance won't be degraded by the failure of any single component or path.

A key to the success of any real time system based on an input data stream is tight quality control. The wind profiler data is processed using the NCAR Improved Moment Algorithm and NCAR Winds and Confidence Algorithm (NIMA/NWCA) which removes contamination and outliers, provides rapid wind updates, and includes a confidence value to quantify the reliability of the wind measurement (Morse et al., 2003). The anemometers also undergo an extensive quality control process, which looks for outliers, checks for known failure modes, and compares collocated measurements.

Considerable effort was put into ensuring reliability of sensors in the harsh Juneau winter environment (Figure 3). The mountaintop anemometers use powerful heaters to battle rime ice, sites and systems are periodically inspected, and the built-in redundancy has already been mentioned. The Sheep Mountain anemometer, for example, is only accessible by helicopter, and only in good weather. Provision for emergency shelter and supplies are also necessary at these remote sites.

Figure 3. Sheep Mountain anemometer site after icing event

3.3 Role of Field Project Data Collection

Three field projects were conducted as part of the Prototype JAWS development, and are more fully described in Cohn et al. (2004). A first data collection in early 1998 used a research aircraft to collect turbulence and wind shear data. Combined with the anemometer and wind profiler data set, it was used to better understand the locations of hazards and their relation to the regional wind. A second field project during the winter of 1999-2000 provided a larger set of data to test regression analysis and evaluate the feasibility of the proposed regression-based system. During the final field program, in the winter of 2002-2003, additional data were collected to improve the statistical reliability of the regressions and to provide information for a verification study to test the accuracy and reliability of Prototype JAWS.

3.4 Sensors and Sites

An important aspect of Prototype JAWS is the sensor and infrastructure design. What measurements are needed to characterize the atmosphere, and how can this need be balanced against practical restrictions? The most important measurement for this system is the wind, both local and regional. Several types of wind sensors, both in situ and remote sensors, were considered to provide input to an operational alert system. Scanning Doppler weather radars are used at other airports for systems which detect low level wind shear and microbursts. These were rejected for Juneau because terrain blockage would require a network of radars, which would be very expensive. Also, radars would not provide wind information for hazards from dry northerly winds. Similarly, scanning Doppler lidars could provide broad coverage, but again several would be needed, they are quite expensive, and their performance would be poor due to both attenuation in rain and poor signal strength in the clear air. Although radar and lidar were not considered suitable for a real time warning system, they were valuable to study the wind environment during the field seasons. As discussed in Mueller et al. (2004), the Doppler on Wheels (DOW) scanning radar was used in two of the three field projects, providing visual images of the air flow and some indication of turbulence. A scanning lidar was also present during the first field season, and its performance limitations were confirmed.

The two sensor types included in Prototype JAWS are in situ anemometers and radar wind profilers. Anemometers work well in wet or dry conditions, and although they provide only a point measurement, they are reliable and inexpensive. During the system development several anemometer models and deicing heaters were evaluated including models from R. M. Young, Inc., Hydro-Tech, Inc., and Vaisala/Handar, Inc. Radar wind profilers are also relatively inexpensive (compared with scanning weather radars, for example). These provide vertical profiles of the horizontal wind, work extremely well in wet conditions and fairly well in dry conditions.

Selection of sites for both anemometers and wind profilers in Juneau required consideration of exposure to the important regional flows, blockage by local terrain, and logistics such as access to power. Three anemometer sites for Prototype JAWS are located on mountains and are based on the infrastructure of the Alaska Airlines Ops Spec anemometers. The Eagle Crest anemometer site is located at the top of Eagle Crest ski area. It has good exposure to strong on-shore flow and fair exposure to the northerly Taku flow when this flow is strong. Because of the ski area, power is available and the site is accessible through the winter. The Sheep Mountain anemometer site has good exposure to strong flows from most directions, and has fortuitous access to power from an electric line running over this saddle. The Mount Roberts site is at the top of the Mt. Roberts tram. It has good exposure to the SE flow within the Gastineau channel, and is also exposed to some northerly drainage and Taku flow. Three other Prototype JAWS system anemometers are located along the airport runway, and, like the airport, have good exposure to SE flow out of the Channel and are well blocked from northerly Taku flow. The final system anemometer is on Pederson Hill about 3 km west of the threshold of runway 08. Like the airport site, this location has good exposure to the SE flow and relatively poor exposure to northerly flow. It is accessible by helicopter or a short hike.

The wind profiler sites were selected for their exposure to local and regional flows, proximity to air traffic routes, and shielding from ground clutter. Also, possible sites were limited to those with reasonable infrastructure costs. The North Douglas wind profiler is located under the Fox and Lemon Creek departure tracks. It is in a flat area of muskeg that had commercial power available about 300 m away. A special platform was constructed to hold the profiler antenna in the soft muskeg. The Lemon Creek wind profiler is located under the Lemon Creek departure track. It is on a flat valley floor that had power available nearby. The South Douglas wind profiler is under the Gastineau Channel approach and departure tracks. It is on a pier over the Channel. All of the sites are closer to hillsides than would be ideal but the NIMA/NWCA software has been improved to control this clutter adequately.

3.5 Prototype JAWS Software

The Prototype JAWS software is made up of separate components linked together into a system that transforms raw anemometer and profiler data into user displays of hazard alerts and wind information. Figure 4 illustrates the major software components and data flow of the JAWS Prototype.

The raw one second anemometer data are processed by quality control software designed to remove bad data samples, calculate one minute statistics (i.e. averages, variances, confidences), and choose the best data from sites with redundant anemometers.

The raw spectral profiler data are also processed by quality control software. This software uses fuzzy logic image processing techniques to eliminate contaminates, such as ground clutter, point targets, and radio frequency interference, from the spectra. This software includes processing to calculate 10 minute consensus winds and 30 second high update winds.

The quality controlled anemometer and profiler data feed into the regressor generation software module that calculates regressor values. These calculations range from a simple pass through of input data, like one minute wind speed from one of the anemometers, to more complex calculations of derived quantities, such as vertical shear of the horizontal winds at mid levels as measured by one of the wind profilers.

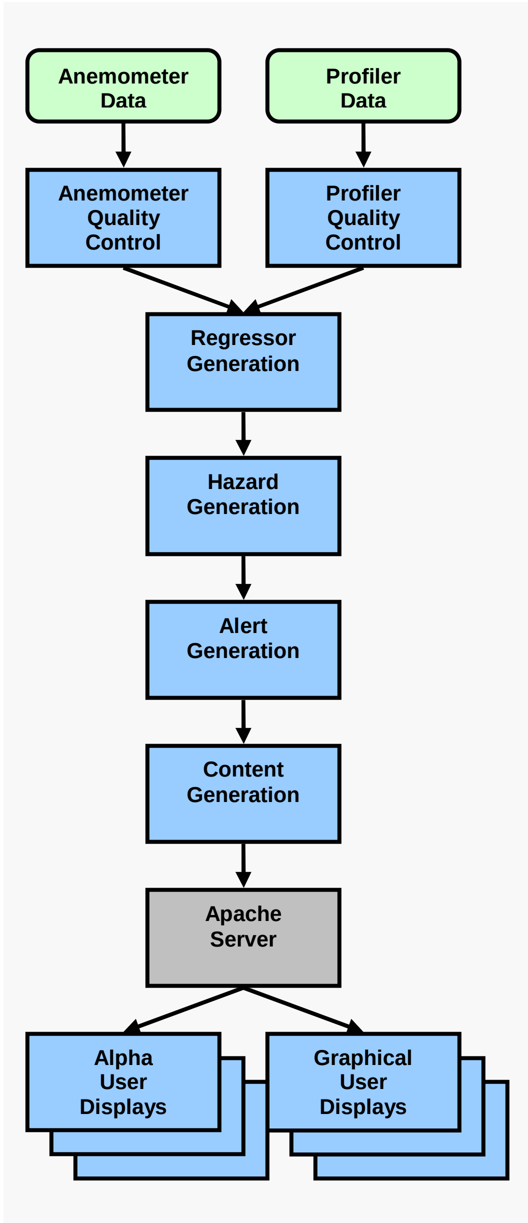

Figure 4. Prototype JAWS software and data flow

The regressor values are then passed into the hazard generation software. This module uses regression coefficients, previously determined using data from the Juneau field projects, to construct formulas that calculate the expected intensity of hazards in selected areas around Juneau. Morse et al. (2004) describes the method for generating and applying these regressions.

The alert generation software applies thresholds to the expected hazard intensities and combines the results into selected pre-configured alerts. Prototype JAWS is configured to generate alerts for turbulence with thresholds applied at levels of moderate turbulence for a BE20 (King Air), moderate turbulence for a Boeing 737, and severe or greater turbulence for a Boeing 737. The initial operational configuration does not generate alerts for windshear hazards. The alerts passed out of this module have both numeric type and intensity values, as well as pre-configured text values designed for concise communication of the alerts from air traffic controllers to pilots.

The current alerts, anemometer data, and profiler data are input to the content generation software. This software constructs graphical images and text information that are used as building blocks for the displays.

The Apache server (a commercial off the shelf software product) processes requests from the displays for graphical images or text information and sends the requested data out to the display software.

Two types of displays were developed for the JAWS prototype. The alpha display was designed to be used by active controllers in the Juneau tower and is formatted to facilitate concise communication of current alerts to pilots preparing to arrive or depart. The graphical display (Figure 5) was designed to be used by a variety of users including Automated Flight Service Station specialists, airline dispatchers, and pilots. It contains several pages of information that depict both the current alerts and conditions, as well as conditions over the last hour. Mueller et al. (2004) describes these displays in greater detail.

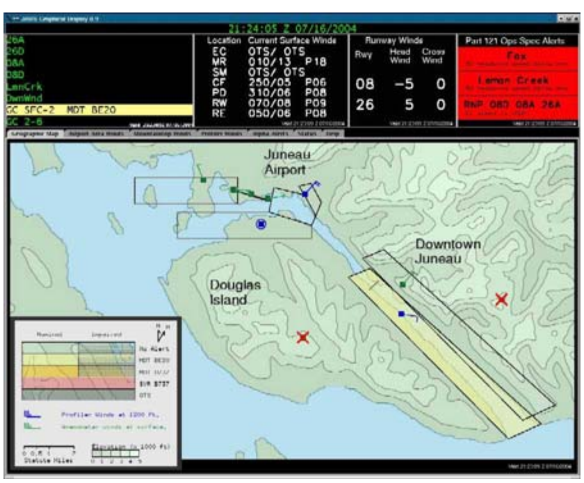

Figure 5. Graphical display with Geographic Map page selected.

4. SYSTEM PERFORMANCE

In fiscal year 2004, an evaluation of the performance of Prototype JAWS was undertaken. This study is described by Fowler et al. (2004). The system's effectiveness and reliability was quantified using statistics that describe, for example, the probability of correct detection of hazardous conditions, (probability-of-detection) and the fraction of incorrect alarms issued (false-alarm-rate). It was found that performance is generally good, outperforming the Ops Spec. However, absolute skill varied considerably over different locations and weather conditions. This is due to the limited (in some cases) number of training and testing cases available for less common hazardous conditions.

5. SUMMARY

The Juneau terrain-induced turbulence and windshear project was undertaken to develop a system that could provide alerts of these hazards in the Juneau area to aviation users. An initial prototype of the system that generates turbulence alerts has been deployed in Juneau. Prototype JAWS is scheduled to undergo an operational evaluation in fiscal year 2005. After incorporating feedback from the operational evaluation, Prototype JAWS technologies will be transferred to the FAA for long term operation and support.

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