8.2 AN ASSESSMENT OF ICE-FREE WIND SENSORS FOR THE JUNEAU AIRPORT WIND SYSTEM

Thomas Carty* and Michael McKinney
Federal Aviation Administration William J. Hughes Technical Center
Atlantic City International Airport, NJ

Francis Law
Universal Automation Labs Solutions Group, Inc.
Silver Spring, MD

1. INTRODUCTION

Mountains and rugged terrain around Juneau International Airport (JNU) in Alaska restrict flight paths and can create complex and turbulent wind-flow patterns. To reduce the risk of aircraft encountering severe turbulence, the FAA currently requires three major departure routes at JNU be closed to Part 121 commercial aircraft whenever airport winds, and/or the wind from three wind sensors on nearby mountains exceed wind limitations outlined in Federal Aviation Administration (FAA) Operations Specifications for Part 121 air carrier operations in Juneau. A wind data collection and dissemination system, known as the prototype Juneau Wind Hazard Information System (JWHIS), is currently installed at JNU. Initial components of this system were originally developed and deployed jointly by Alaska Airlines and the National Center for Atmospheric Research (NCAR). The system gathers wind information from a series of anemometers placed strategically around the airport including mountain ridge-top locations. The information is transmitted to a processor at the airport, which generates wind products for distribution and display.

Efforts are currently underway to ultimately transition part of the current wind system into a fully operational Juneau Airport Wind System (JAWS). This end-state system will provide wind information and alerts customized to the airport's challenging terrain. It is anticipated that the information provided by JAWS will provide wind hazard alerts and assist users in maximizing the utilization of Juneau's turning and channel departure routes, as well as supporting overall airport operational decisions.

Of course, an essential element of JAWS will be accurate and reliable wind sensors capable of supporting airport operations under snow and icing conditions. To this end, the Weather Branch of the FAA William J. Hughes Technical Center (WJHTC) performed a wintertime assessment of wind sensors near JNU during the period November 2000–June 2001. The purpose of the field investigation was to first establish a sustained weather sensors test bed, then assess the severe-weather performance capabilities of wind sensors used in the current system. In addition, alternate heated anemometers including mechanical, ultrasonic, and pressure-type sensors were evaluated as possible candidates for use in the end-state JAWS system. This field study is actually a follow-up to a similar wintertime wind sensor assessment that was performed by the WJHTC over a 6-week period in 1999 on Mt. Washington, NH (FAA, 2000).

2. TEST BED DESCRIPTION

A test bed of wind sensors was established on an existing equipment tower on a well-exposed mountain ridge-top overlooking Juneau airport. This site, designated as Eagle Crest, is one of three existing JWHIS ridge-top weather stations, and has a suitable tower, equipment, and communications infrastructure to support the installation and continuous operations of the test equipment. An instrument shelter is also located beneath the tower. A photograph of the Eagle Crest tower is provided in Figure 1.

Fig. 1. Photograph of the Eagle Crest equipment tower.

Eagle Crest is situated about 11.6 km (7.2 mi) south-southeast of JNU at an elevation of approximately 803 m (2634 ft) above mean sea level. The site is subject to extreme meteorological and climatic conditions where snow and the buildup of rime ice on exposed surfaces can be substantial. Climatology of the region is characterized by two predominate air flows. Cold continental air flows from the northeast are known locally in Juneau as Taku winds. Taku winds are strong cold down-slope winds that are capable of reaching 50 m s^{-1} (112 mph). The contrasting moist maritime

---

* *Corresponding author address*: Thomas Carty, FAA William J. Hughes Technical Center, Atlantic City Int'l Airport, NJ 08405; e-mail: thomas.carty@tc.faa.gov.

southeasterly flows from the Gulf of Alaska are largely responsible for the significant snow and icing environments encountered along the mountain ridge-tops surrounding Juneau.

3. SENSOR DESCRIPTIONS

3.1 Wind Sensors

Nine electrically-heated anemometers comprising three different sensing technologies were considered in this assessment. They included the Taylor Scientific Hydro-Tech and NRG Systems IceFree II mechanical sensors, the Vaisala Handar 425AH and Metek USA-1 ultrasonic anemometers, and a BFGoodrich Rosemount Aerospace 1774W pressure-sensing anemometer. A survey with field comparisons of the Hydro-Tech, Metek, and Rosemount sensors under icing conditions was recently performed by Makkonen et al (2001).

Two pairs of Hydro-Tech anemometers are currently used in the JWHIS. Each pair consists of a WS-3 speed rotor and a WD-3 direction vane. The sensors are particularly designed for rugged applications, and their 1500-watt (W) heaters are thermostatically-controlled. An extra WS-3 unit was installed for additional testing purposes.

The IceFree II wind speed indicator and direction vane are made of cast aluminum with a black anodized finish. The sensors utilize constant temperature, self-regulating 200 W heaters. The wind speed sensor is a 3-cup design which employs a modified cup to reduce errors created by vertical wind components.

Evaluation of the Vaisala 425AH ultrasonic anemometer was of particular interest because of its growing use in other national aviation weather systems such as the FAA’s Stand Alone Weather Sensors (SAWS) system and Low Level Wind Shear Alert System Relocation and Sustainment (LLWAS–RS) program. The 425AH sensor is also used to provide JWHIS airport winds. Since the ultrasonic sensor is solid state, has no moving parts, and is resistant to environmental corrosion, it generally has a lower maintainability requirement and a higher overall reliability than the mechanical sensors.

The 425AH has an integrated microprocessor that acquires and processes wind data. An array of three equally spaced ultrasonic transducers in a horizontal plane measures the transit time for sound to travel from one transducer to another. The transit time depends on the wind velocity along the sonic path. Unreliable readings, which may occur when large raindrops or ice pellets hit a transducer, are eliminated by an internal signal processing technique.

Production models of the 425AH have thermostatically-controlled transducer heads with a total heat output of about 30 W. A modified “superheated” unit was employed in this test. The modified unit has additional heating elements covering the sensor body as well as the transducer arms, and consumes a total of approximately 240 W.

Original test plans included installation of the Metek ultrasonic anemometer. This sensor measures vertical wind components in addition to the conventional horizontal wind. The sensor is not under consideration for use in the JAWS system. The intent of installing the sensor was to measure and collect 3-dimensional wind data in order to determine the extent, magnitude, and effect of upslope winds on Eagle Crest. Because of acquisition and installation problems, and the questionable survivability of the sensor during the harsh winter months in Juneau, the sensor will be installed and utilized in the spring of 2002 during the follow-up study currently underway.

The Rosemount 1774W wind probe is solid state, and uses pressure transducers to determine wind vectors. The anemometer detects wind by measuring the differential pressure across the wind probe. Two orthogonal pressure differential measurements are taken in order to determine the North-South and East-West wind vectors.

Prior to field installation, checkout and calibration of the anemometers were performed in the WJHTC Aerolab Low Turbulence, Low Speed open-circuit type wind tunnel. The wind tunnel design provides an environment to calibrate wind speed instruments employing a highly accurate airspeed measurement capability. Airspeeds up to 71.5 m s^{-1} (160 mph) can be achieved in the 51 x 71 x 122 cm (20 x 28 x 48 in) tunnel test section. Two separate types of test were carried out on each sensor. The first test was conducted to verify sensor wind speed and direction accuracy. A second test was performed to determine the effects and dynamic response of the sensors to varying wind angles of attack from the vertical.

Finally, a full mockup of the sensors and equipment was assembled in the WJHTC Aviation Weather Research Program (AWRP) Laboratory. The purpose of the mockup was to determine required mounting fixtures and optimal video camera lenses and exposures. In addition, the mockup facilitated the fabrication of cabling and custom conformal heater blankets, and checkout of the data acquisition and collection system prior to shipping and installation in Juneau.

3.2 Ice Detection

A Rosemount 871FA Ice Detector was installed at the test site in order to provide an automated means of detecting icing conditions. The sensor measures the amount of ice mass accumulation on a cylindrical metal probe. The probe is vibrated at a natural resonance frequency of 40 kilohertz (kHz). As ice accretes, the frequency of the vibration decreases. Once a preset amount of ice mass has accumulated, the cylinder heater is activated to melt and remove the ice. For this study, extra modifications were applied to the sensor and installation. Because the sensor is designed for installation through the skin of an aircraft, a special metal housing was used to mount and protect the sensor body. The housing was wrapped in a conformal heater blanket In order to prevent the buildup of ice and/or snow around the sensor.

A Rotronic MP100H Temperature and Humidity Probe was installed. The integrated sensor consists of a platinum resistance thermometer and capacitive-type relative humidity sensor, and was housed directly in a

12-plate Gill solar radiation shield. To prevent the buildup of snow and ice directly on the sensor and shield, the unit was mounted in a specially-fabricated aluminum cylindrical canister with top and bottom openings to permit ventilation.

Four Artic Nitehawk V60 video cameras by Silent Witness were set up to provide real-time visual monitoring and recording of icing on the sensors. Special conformal and temperature-controlled heater blankets were applied to the camera housings to prevent ice buildup. The sensors were illuminated at night by two 250 W quartz halogen flood lamps each with 5,000 lumens of light. The relatively low wattage of the lamps minimized the possibility of heat transfer to the sensors. Photographs of the wind sensors and video cameras mounted on the tower are shown in Figure 2.

Fig. 2. Photographs of wind sensors and video cameras.

4. DATA ACQUISITION AND ANALYSIS

Data collection for this effort centered around a network of data acquisition and high-speed wireless Ethernet communications devices using Internet Protocol (IP) between the mountain site and an NCAR laboratory adjacent to the airport. Redundancy and backup capabilities built into the overall design facilitated continuous data acquisition and recording in an unattended mode during the 6-month period. At the same time, data were collected independently from the JWHIS sensors in a manner to ensure that operations of those sensors were not affected or degraded.

All data acquisition equipment for the weather sensors, along with recorders and receiver/servers for the video cameras, were installed in the instrument shelter located beneath the tower. An uninterruptible power supply with communications and management software allowed for remote power monitoring and auto-shutdown capabilities. Two backup devices in the shelter were used to ensure full archiving of sensor and video data in the event of network or data transmission problems. A PC in the shelter was used to directly collect data from the sensors. The second backup storage device was a digital videocassette recorder which recorded video images onto tape. Both the serial sensor and video data were recorded by the backup devices every 1 second.

Analog data from the Hydro-Tech, IceFree II, ice detector, and temperature/humidity sensors was captured and digitized by a datalogger. Digital data from the datalogger, along with the RS-232 serial outputs from the ultrasonic sensors, were converted to 10BaseT Ethernet protocol by separate serial servers. Video images from the four cameras were captured and transformed to Ethernet using a video multiplexer and server. The sampling interval of the weather sensors and the camera images was 1 second and 15 minutes, respectively.

Data transmission from the mountain-top test bed to the laboratory was accomplished via a hybrid network of 900 MHz long range spread-spectrum wireless modems and a 2.4 GHz wireless Ethernet link. The later high-speed wireless network connection provided the bandwidth necessary to carry the combined sensor and video data.

Initial data processing was performed in a separate host PC in the laboratory. This computer employed several software applications for performing the primary data collection, recording, and backup of sensor and video data. In addition, the PC furnished Internet Web and File Transfer Protocol (FTP) server capabilities for the dedicated test web site that was established and exercised for remote on-line data monitoring and control, as well as data file downloads of daily sensor and video data. Internet access was provided through a dedicated Digital Subscriber Line (DSL) modem. The continuous DSL and Internet connection provided the required speed and bandwidth to carry the volumes of combined sensor and video image data.

The web site facilitated continuous remote monitoring of sensor and video data. Software within the PC generated for each weather variable, 2-hour time series plots of running 1-minute averages updated every 1 minute. The web page displayed and updated the sensor time series and camera images every 1 and 15 minutes, respectively. FTP services were used for the bulk file download of sensor data and video images to the WJHTC. Detailed analyses and plotting of the data were performed at the WJHTC using Visual Fortran 95, Excel, and PhotoImpact imaging software.

5. RESULTS AND CONCLUSIONS

Approximately 3500 hours of test bed data were collected and analyzed over the 184-day period. Video motion clips were constructed and used to visually assess icing. In-depth data analysis was performed for the total ~37 hours of cases where winds exceeded the current limits for Juneau Part 121 air carrier operations.

With a few exceptions, the Hydro-Tech sensors exhibited minimal icing. Figure 3 shows one of the few events where icing was observed on the Hydro-Tech direction vane and supporting mast.

Fig. 3. Icing on the Hydro-Tech direction vane and mast.

Performance of the sensor was found to be consistent with data from the wind tunnel tests and results from the Mt. Washington study. A typical case showing a comparison of wind speed against the Vaisala anemometer is provided in Figure 4.

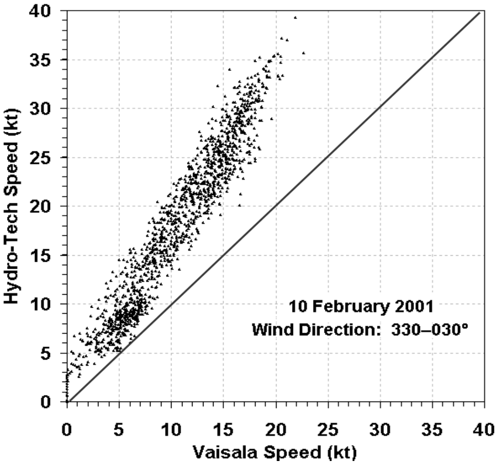

Fig. 4. Hydro-Tech vs. Vaisala wind speed comparison.

Due to the inertia of the ruggedized sensor, the observed overspeeding and a low starting threshold was expected. The overspeeding indicated in the figure is particularly pronounced for northerly winds and is possibly exacerbated by the upslope winds at Eagle Crest in this direction. The off-axis overspeed response inherent to the sensor was also noted in the wind tunnel tests.

Significant icing was experienced by the IceFree II anemometers, and were found to be operationally unsuitable for the mountain ridge-top locations due to extended ice-related outages. Photographs of icing on the sensors are shown in Figure 5.

Fig. 5. Icing of IceFree II direction vane and speed rotor.

Favorable performance was exhibited by the ultrasonic anemometer. Although this sensor also experienced icing as shown in Figure 6, animated video clips revealed that the modified superheated instrument was highly effective in shedding ice from the transducer arms and sensor body. Closer inspection was performed to determine the validity of the data when ice was apparent on the anemometer. The sensor was determined through its internal status, as well as video data, to be degraded by icing 0.8% of the 6-month period. Further analysis of the periods of degraded performance (with respect to the JAWS 1-minute wind reporting requirement), revealed that in 84% of affected cases, there were at least 75% raw data samples available to derive a valid wind report. During the entire field experiment, only 81 sporadic 1-minute wind reports were derived from 25% or less raw 1-second samples.

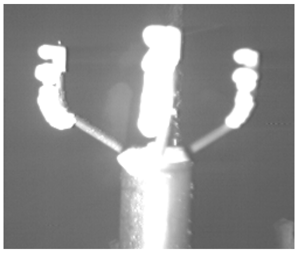

Fig. 6. Vaisala anemometer under icing conditions.

The Rosemount 1774W pressure-type probe exhibited optimistic performance as shown in Figure 7. However, the sensor was installed late in the season and the resulting data set was unfortunately limited.

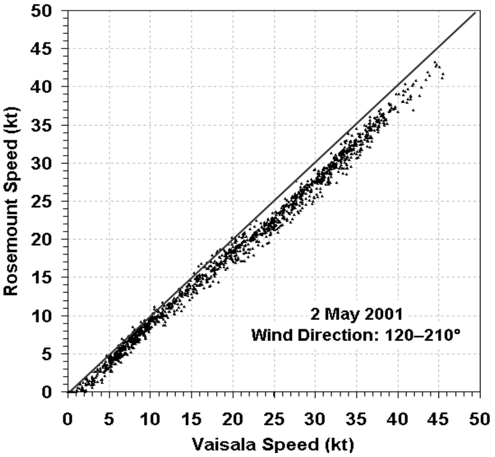

Fig. 7. Rosemount vs. Vaisala wind speed comparison.

6. FUTURE TESTING

Based on the success of the test bed setup, and encouraging results obtained from the sensor assessment, a follow-on study has been implemented for the Juneau winter of 2001–02 (FAA, 2002). The purpose of the effort is to further assess the 425AH capabilities with various heater modifications. In addition, the Metek sensor will be implemented to determine the effects of upslope winds, and the Rosemount 1774W will be further evaluated.

7. REFERENCES

FAA, 2000: A Wintertime Assessment of Wind Sensors on Mt. Washington, NH, Federal Aviation Administration Weather Branch, ACT-320, Report DOT/FAA/CT-TN00/05, March 2000.

Makkonen, L., P. Lehtonen, and L. Helle, 2001: Anemometry in Icing Conditions, *J. Atmos. Oceanic Technol.*, **18**, 1457–1469.

FAA, 2002: Juneau Airport Wind System (JAWS) 2001–02 Severe Weather Performance Test Plan, Federal Aviation Administration Weather Branch, ACT-320, January 2002.