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Automating Some Measurements During Operation S.A.F.E. Workshops

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Abstract. *Operation S.A.F.E. workshops, commonly known as "fly-ins" are very helpful to agricultural pilots in "fine tuning" their aircraft. During the fly-in several ancillary measurements are taken such as: aircraft speed, aircraft height during spray release, air temperature and relative humidity, wind speed and direction. Most of those measurements are taken by people operating the flight line with the help of some instruments. It is very common in a fly-in not to have people familiar with recording those measurements, or not to have enough people to take note of all measurements. Automation of some of these measurements could improve accuracy and reliability of measurements during the fly-in. In this paper we describe an attempt to automate some of those measurements and the results of our testing.*

Keywords. *Aerial application, pesticide, automation, electronic sensors.*

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Introduction

Operation S.A.F.E. (**S**elf-regulated **A**pplication and **F**light **E**fficiency) analysis clinics sponsored by the National Agricultural Aviation Association (NAAA), aim to help agricultural pilots to fine tune their aircraft to ensure proper calibration and equipment maintenance. During an operation SAFE workshop, or "fly-in" as they are more commonly known, pilots have a chance to fly their aircrafts over a 150 feet long, one millimeter diameter cotton string that is placed perpendicularly to their direction of flight, spraying a mixture of tap water and Rhodamine WT dye. The cotton string is then analyzed with a modified fluorometer to produce an average deposition graph (Whitney and Roth, 1985). The graph is used to correct common depositional problems found in agricultural aircrafts, such as "prop wash" (spray over deposition to the left side of the aircraft, creating a hole in the middle), or overcompensation for prop wash (spray over deposition to the right side of the aircraft). Deposition graphs also help pilots understand how wide their application swath is and what is the best combination of swath width and flying method (back-and-forth versus racetrack).

During a fly-in several ancillary measurements are taken to aid in the analysis of the correspondent deposition graph. Water-sensitive cards (WSC) are used to estimate droplet size; weather variables such as air temperature and relative humidity, wind direction and speed and aircraft speed and spray release height are also measured. Weather variables are usually read from a portable weather station while aircraft speed is measured using a handheld radar. Spray release height is measured with a scope and graduated scale using similar triangles technique as shown on Figure 1.

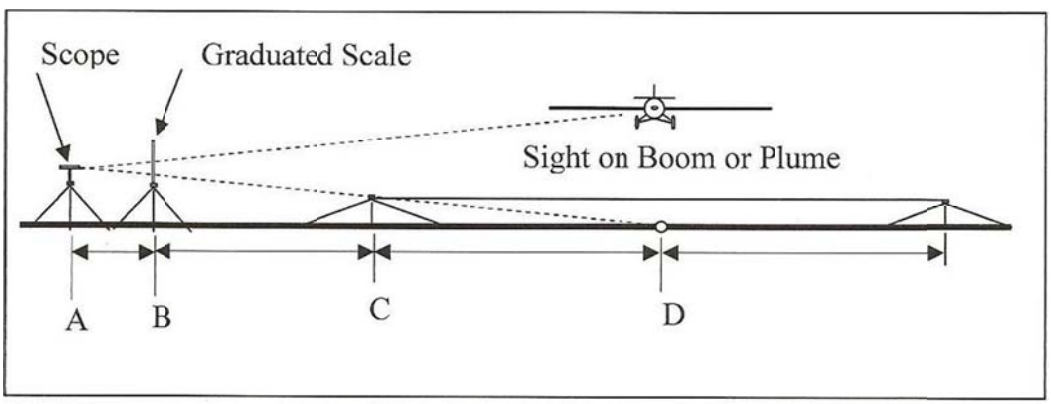

Figure 1. Similar triangles technique used to measure spray release height during fly-ins.

Perhaps the biggest challenge facing Operation S.A.F.E. fly-ins today is the lack of trained personnel to help the analyst collect all required measurements. Common mistakes such as improperly activating the radar gun in time for the speed measurement or measuring wind speed and direction while personnel is blocking the sensor occur frequently. Measuring spray release height adds an extra layer of difficulty, especially if the person does not have prior experience using the similar triangles system sometimes producing large errors and questionable results.

The objective of this research is to investigate if the automation of some of those measurements is possible. A secondary objective is to verify if automation will increase measurement accuracy and reliability while at the same time reducing the need of extra personnel during fly-ins. In this paper, tests to automate two measurements will be described: spray release height and aircraft

speed. Automation of weather variables will be reported later. Specific objectives of the project are:

1. Provide a wireless approach to automation of spray release height and aircraft speed,
2. Make measurements available in real time and recorded for post analysis if needed.

Materials and Methods

System Components and Design

A micro-processor based system was designed using two sensors for the above mentioned measurements. The LaserAce® ILM-150-R (MDL Laser Systems, York, England) was used to determine spray release height, and the Stalker® stationary radar speed sensor (Applied Concepts Inc., Plano, TX) was used to determine aircraft speed. The LaserAce® ILM OEM laser module is a compact class 1 eye safe, rugged, multipurpose laser distance meter for integration into OEM applications. The 150-R model has a reflectorless range of up to 150 m (500ft). The unit transmits a “known” pulsed signal and the return signal is then timed. The timed results are used to determine distance from the unit. This sensor is currently being used by some agricultural aviators to monitor flying altitude. The Stalker® stationary radar speed sensor uses Doppler radar effect to detect the speed of a moving target. It does this by beaming a microwave signal towards a desired target and listening for its reflection, then analyzing how the frequency of the returned signal has been altered by the object's motion. This variation gives direct and highly accurate measurements of the radial component of a target's velocity relative to the radar.

A BASIC stamp model 2-px micro-controller (Parallax Inc., Rocklin, CA) was used to connect and record data from both sensors, and a XBee OEM RF module was used for wireless data transmission. XBees are embedded solutions providing wireless end-point connectivity to devices. These modules use the IEEE 802.15.4 networking protocol for fast point-to-multipoint or peer-to-peer networking. They are designed for high-throughput applications requiring low latency and predictable communication timing. A Rogue Robotics (Toronto, Canada) uMMC Secure Digital Card Module was used to save data to a SD card.

A FiBox series ARCA 664 enclosure was used to protect all items from environmental conditions and also from spray since the laser and radar sensors need to be placed in the line of flight to capture precise information. A SLA battery with an 8.5 Ahr rating was installed to provide continuous energy for the sensors. A touch screen LCD interface (Amulet Technologies, model STK-480272C, Campbell, CA) was developed to display height and speed data remotely via the XBee radio module.

The intended functionally of the system is as follows: the analyst places the control box along with the sensors exactly halfway between both tripods used to extend the string; laser should be pointing up and radar should be facing forward, with a 30° angle from horizontal. This halfway point is exactly where aircrafts will pass. Both sensors are attached to an easily leveled platform. The analyst turns the system on and uses a handheld touch screen to start the software and capture data. Whenever aircrafts are ready to fly over the string, the analyst start collecting data. Data is simultaneously saved to the SD card and displayed in the LCD screen. After the aircraft has passed, the analyst can stop the collection. Date and time are initially set to Coordinate Universal Time (UTC) via a GPS receiver. After the initial setting, time is kept by an onboard real-time clock module. Time and an incremental number indicating the run of the day are added to every run. Figure 2 shows schematics of a fly-in and the suggested location of the control system.

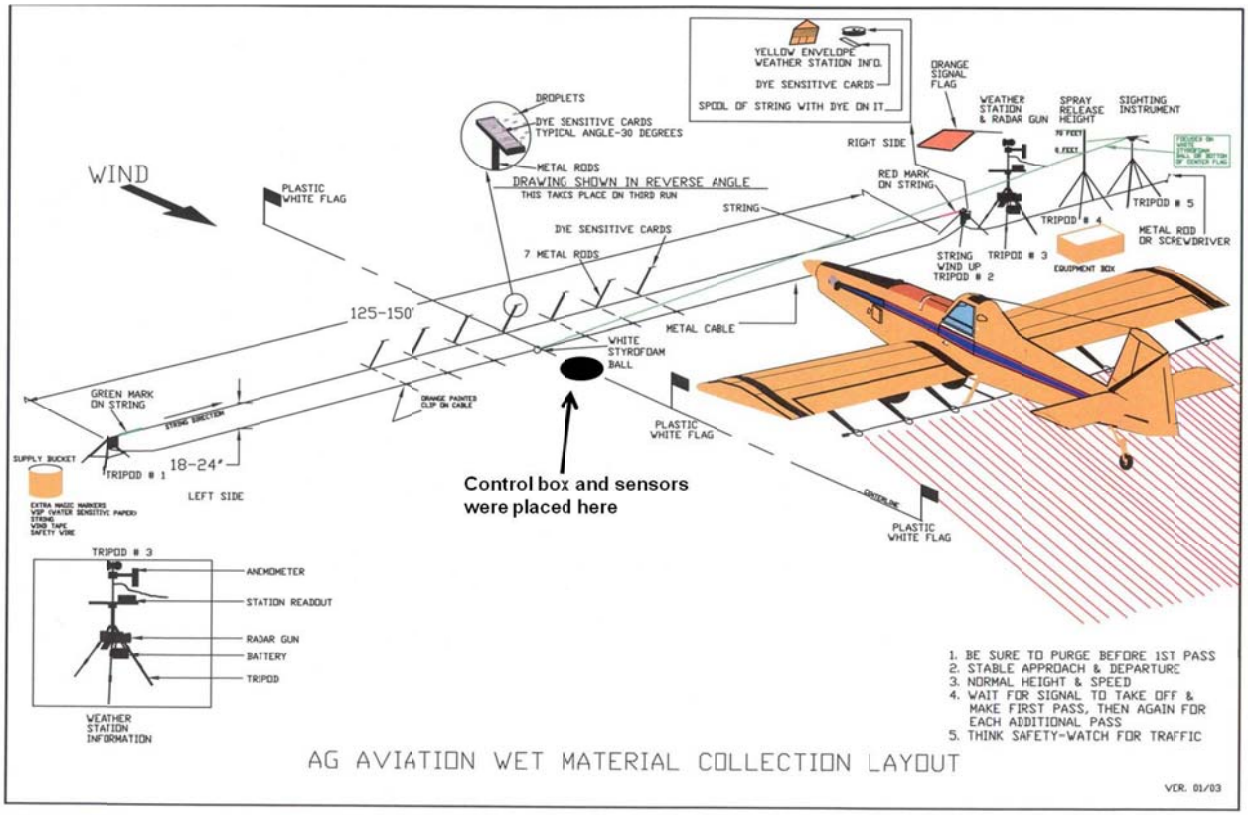

Figure 2. Operation S.A.F.E. diagram and suggested location for the control box.

Field Test

The system was field tested at the Colorado Fly-in sponsored by the Colorado Aerial Application Association (CoAAA) in La Junta, CO in September, 2010. Dr. Robert Wolf, Biological and Agricultural Engineering Department, Kansas State University and Dr. Scott Bretthauer, Extension Specialist, Agricultural and Biological Engineering Department, University of Illinois, were the analysts in charge of the fly-in. Personnel from the Colorado Department of Agriculture, from several chemical companies and local dealers help collect data and run all equipment.

During the fly-in, ancillary data was collected using the usual and customary method, one person was assigned to read/write weather data while others collected aircraft speed and spray release height. The control system was used to collect data simultaneously and results were later compared.

Figure 3. Control box and sensors placed in the flight line in Colorado during fly-in.

Results and Discussion

Eleven aircrafts participated in 2010 edition of the Operation S.A.F.E. fly-in organized by the CoAAA. Sixty nine total passes over the string were recorded. Usually at least three passes are recommended per aircraft, although some pilots take the opportunity and fly over the string multiple times. Six passes (8.7%) did not have speed data because of equipment failure or drained batteries, and one pass (1.4%) did not have spray release height data. The numbers of passes with missing information are very low because personnel used by the CoAAA have been participating in fly-ins for a long time and know what to do.

The speed/spray release height monitor recorded data for 57 of the 69 passes. Equipment performance is discussed below.

Aircraft Speed

The common radar gun used in a fly-in is a Bushnell Speedster II radar gun. Accuracy of the Bushnell radar gun is claimed to be ±1 mph. This is a radar gun with simple “point and shoot” operation. Measurements taken with the Bushnell were compared to measurements taken by the Stalker® radar speed sensor.

The Stalker® radar speed sensor locked in the aircraft speed well over 166 meters (545 feet) before the aircraft crossed the string. The signal lock averaged 2.6 seconds and the output consisted of an initial maximum speed followed by decreased speed readings. For the purpose

of comparisons between the Stalker radar and the Bushnell radar used by Dr. Wolf's team, only the maximum speed was considered.

The average absolute error was 2.4 mph (std. dev.= 2.5, n=57). Thirteen readings indicated that the Bushnell radar over predicts speed readings while 31 readings indicate that the Bushnell radar under predicts aircraft speeds. Since the operator of the Bushnell radar gun when measuring speed cannot stay in line with the incoming aircraft and need to be to the side looking at the aircraft from an angle, it is reasonable to assume that this reading is somewhat lower than the actual reading due to the cosine effect. Nine readings were exactly the same. Figure 4 shows how well both sensors correlate. The calculated coefficient of correlation (r) is 0.99.

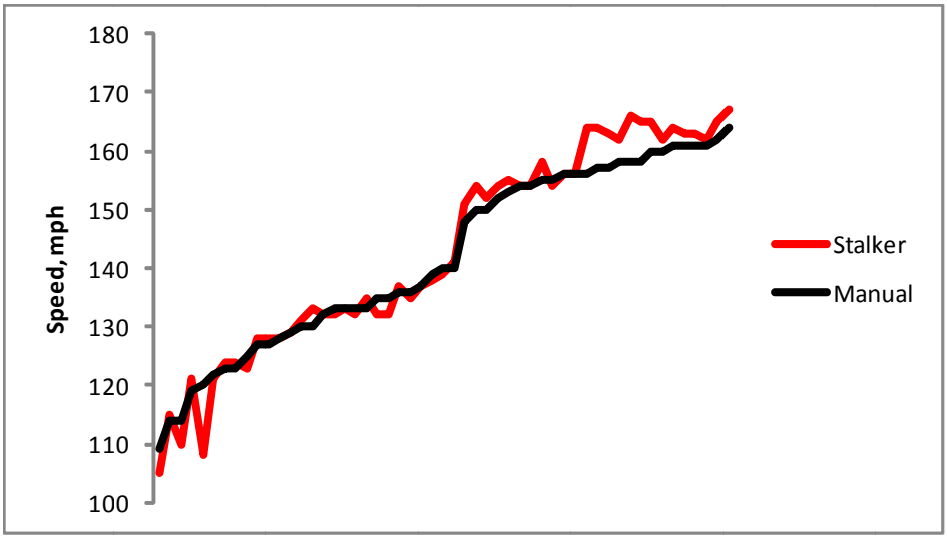

Figure 4. Graph of sensor output.

Figure 5 breaks down the absolute error rate by speed range. Note that absolute error is smaller when aircraft speeds are between 125 and 150 miles per hour.

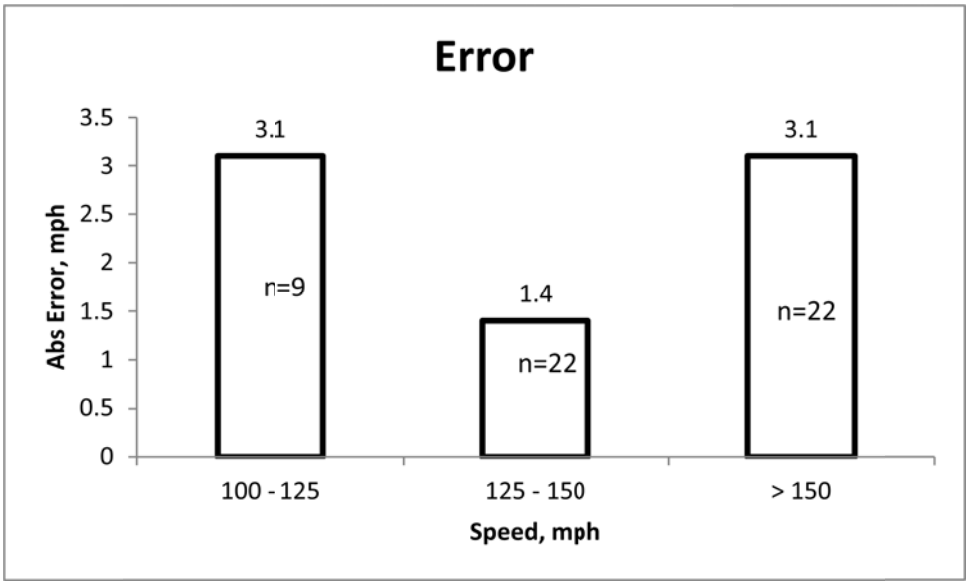

Figure 5. Absolute error as a function of speed.

Spray Release Height

The spray release height system is designed to allow a quick and accurate measurement of aircraft height as it flies over the string. It is based on the concept of similar triangles where the base leg of the triangle is predetermined by the setup spacer cable. The distances from the center of the sample line to the alignment scope, height of the scope and distance from the scope to the calibrated scale are known. Therefore the height of the aircraft may be determined by sighting through the scope at the spray boom as the aircraft passes over and the height can be read directly from the scale. During a fly-in somebody must solely be in charge of reading spray release height. It takes a few readings for the person making the measurements to adequately produce reliable results.

Measurements made using the similar triangles technique were compared to measurements made using the LaserAce® ILM-150-R. When an aircraft flies over the laser sensor multiple values are recorded since the laser intercepts the entire fuselage of the aircraft and even reflects some of the spray cloud. For comparison purposes only the first value captured by the laser sensor is considered to be the correct height.

The average absolute error was 0.49 m (1.6 ft) (std. dev.=0.32 m, n=57). The largest error was 1.19 m (3.9 ft) and the smallest error was 0.1 m (0.03 ft). In general measurements agreed with each other, the coefficient of correlation (r) was 0.85. Figure 6 graphs measurements of both systems.

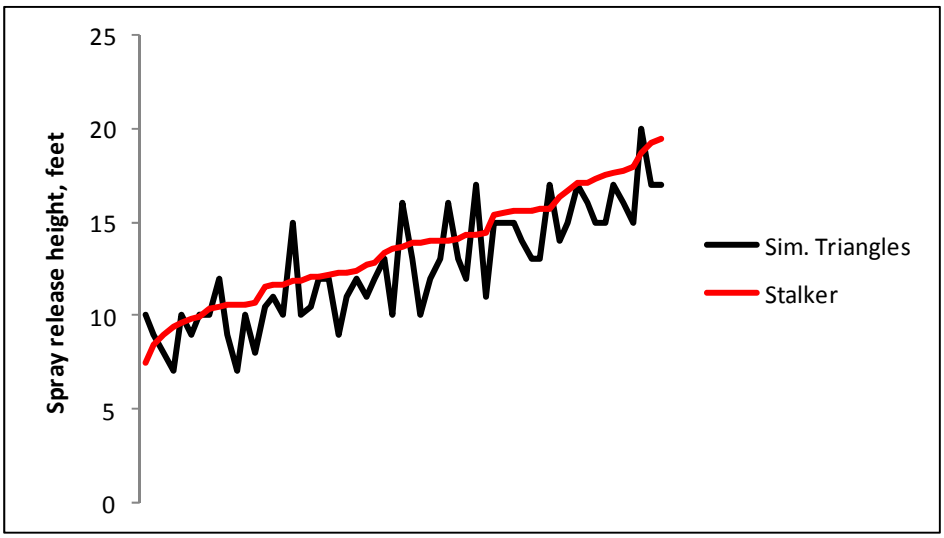

Figure 6. Spray release height comparison between the laser sensor and similar triangles.

Figure 7 breaks down the absolute error rate by height range. Note that absolute error is smaller when spray release height is less than 10 feet.

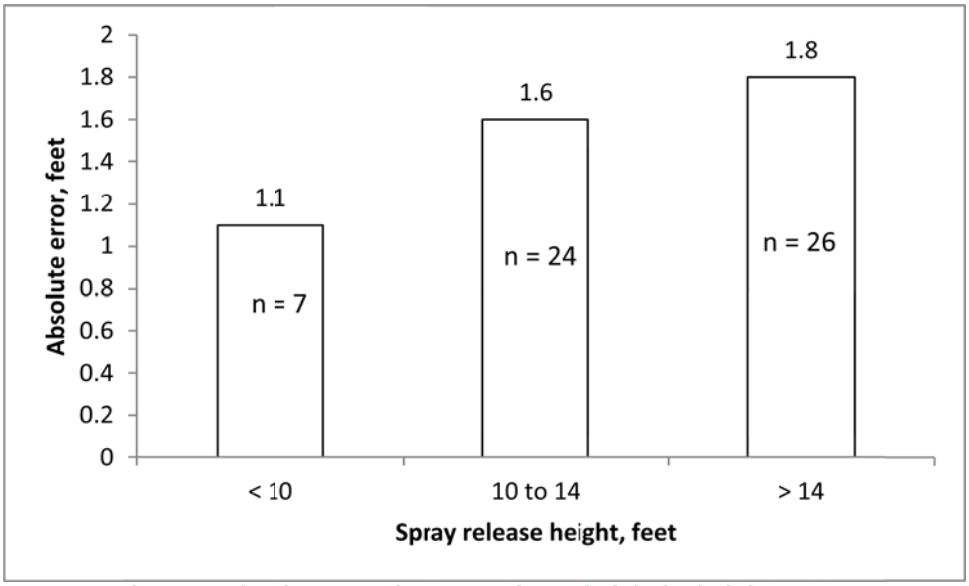

Figure 7. Absolute error in spray release height by height range.

Summary and Conclusions

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The system was tested in September, 2010 at the CoAAA Fly-in in La Junta, CO. Overall the system has successfully determined aircraft speed (absolute error = 2.4 mph, std. dev. = 2.5 mph) when compared to traditional “point and shoot” radar gun and spray release height

(absolute error =0.49 m, std.dev = 0.32m) when compared to traditional similar triangles technique. Research on this topic is ongoing with focus now on the automation of weather variables such as air temperature, air relative humidity, wind speed and direction.

Acknowledgements

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Disclaimer

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