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Development and Demonstration of a Field Safety Beacon for Improved Awareness of Unmanned Aircraft Flight Operations in the Vicinity of Low Flying Manned Agricultural Flights

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Abstract.

This paper provides preliminary performance results of a new safety beacon to help minimize risk of collision between Unmanned Aircraft Systems (UAS) and low flying aircraft. Unmanned aircraft are poised to realize a significant increase in use across the United States, with agricultural applications projected to be the single largest market for unmanned aircraft technologies. It is anticipated that there will be a large number of UAS flying in the National Air Space, especially at low altitudes and over fields used for agricultural production. Actually, this is already occurring as "early adopter" producers and consultants acquire the technologies and fly over production operations. While it is currently illegal to fly UAS for commercial purposes, except under limited exceptions, the Federal Aviation Administration has recently finalized rules that allow for commercial flight of "small" unmanned aircraft systems (sUAS) that will be final August 29, 2016.

At the same time, agriculture enjoys the benefits of piloted aerial aviation, offering services such as spraying, dusting, and seed sowing, resulting in increased agricultural production. The aerial aviation industry plays an important part in any yield gains that have, and will be achieved in the future. Agriculture aviation is well known to conduct virtually all flight operations at low altitudes, and traveling at high speeds (on the order of 160 mph). The potential for an unintended collision increases as more obstacles are introduced into the airspace.

It is essential that attention be focused on the very likely convergence of two technologies that will likely play key roles in sustained agricultural productivity: 1) Unmanned aircraft systems, and 2) Agricultural aerial flight operations. At this time there are no guidelines, or best management practices, for agricultural field operations that involve both unmanned aircraft and human piloted aircraft.

*This presentation describes an unmanned aircraft safety beacon, termed the **NU-AIRE Safety Beacon**, which is outfitted with directional strobe lights located on the top of the ground control vehicle associated with the unmanned aircraft. Bright strobes catch the attention of an aerial pilot, thereby alerting the approaching pilot that unmanned aircraft operations are taking place in the area. Development of the safety beacon, and flight test demonstration results are highlighted. The main point of the safety beacon is that "see and avoid" is a required and critical part of aviation safety, and since unmanned aircraft are small and don't have the typical visual cues (i.e., strobes and lights – due to power and technical constraints), there will be a need to rely on the ground support vehicle to provide the "see and avoid" visual cues for unmanned aircraft flight operations.*

Keywords. *Aircraft, Precision Agriculture, Aerial, Safety, Crop Sensor*

Introduction

The recent move by the Federal Aviation Administration (FAA) to open the National Air Space to *unmanned aerial systems* (UAS) will be a game changer for the agricultural industry. Deployment of UAS for agricultural purposes has the potential to make a significant contribution to closing the yield gap through agricultural intensification, while at the same time improving environmental and ecological sustainability. The fundamental premise is that UAS will be a key element of gathering timely plant, soil, production, livestock, and environmental information, and improve response time for agriculture production and natural resources decision-making and management. UAS technology, and in particular “small” unmanned aircraft systems (sUAS) will offer an unparalleled opportunity to place crop, soil, and livestock sensors, robotics, and advanced information systems at more timely and desirable locations as an integral part of emerging agriculture technologies, thereby increasing production and improving efficiency of agricultural operations. This will lead to increased sustainability and security of food production, efficient water resources management, and deployment of new information systems based on aerial sensor networks (Woldt, et al., 2014).

It is generally recognized that sUAS are poised to realize a significant increase in use across the United States, with agricultural applications projected to be the single largest market for unmanned aircraft technologies. It is anticipated that there will be a large number of sUAS flying in the National Air Space, especially at low altitudes and over fields used for agricultural production. Actually, this is already occurring as “early adopter” producers acquire the technologies and fly over their production operations. In addition, new Federal Aviation Administration rules that will allow legal flight of sUAS for commercial purposes, set to become final on August 29, 2016, have the potential to result in a significant increase in sUAS flight operations.

At the same time, agriculture enjoys the benefits of aerial application operations (i.e, crop sprayers) through increased production as a result of improved pest management and innovative sowing techniques. The aerial industry in the U.S. plays an important part in any crop yield gains that have, and will be, achieved. The aerial application industry, in support of agriculture, is well known to conduct virtually all of their flight operations at low altitudes, while flying at high speeds on the order of 170 mph. The potential for an unintended collision increases as more obstacles are brought into the airspace in which aerial application pilots conduct their operations in support of the agricultural economy.

It is essential that some degree of attention be focused on the very likely convergence of two technologies that will play key roles in sustained agricultural productivity as they evolve into the future: 1) Unmanned Aircraft Systems, and 2) Agricultural aerial application operations. There is a unique opportunity to contribute to the national dialogue as these technologies continue to advance, and find paths forward to co-exist. At this time there are no guidelines, or best management practices, for agricultural field operations that involve both unmanned aircraft and human piloted aircraft. Development of conceptual BMPs for unmanned aircraft operations in agricultural areas will be extremely important in this emerging area of agriculture.

Toward this vision, research has been initiated to explore deployment of sUAS across larger parcels of land at the University of Nebraska-Lincoln, Department of Biological Systems Engineering, in cooperation with the University of Colorado-Boulder, Research and Engineering Center for Unmanned Vehicles (Woldt, et al., 2014 Woldt, et al., 2015). Additional cooperators include Black Swift Technologies, developer of the autonomous navigation system, and UASUSA, developer of the Tempest airframe. At this time, the University of Nebraska-Lincoln is pursuing research on deployment of the **NU-AIRE Safety Beacon** to address and resolve, challenges in deconflicting the airspace between sUAS and other low flying aircraft. The NU-AIRE Safety Beacon provides a very real degree of “see and avoid” capability that is not available in any other manner. Research under this NU-AIRE Safety Beacon project involves defining visual acquisition distances as piloted aircraft approach an agricultural field that has an operating safety beacon.

Background

Given that it has been, and remains, essentially illegal to fly sUAS for commercial purposes (except under highly constrained exceptions from the FAA), there is virtually no data or information on the potential risk that sUAS present to piloted aircraft. At the same time, given that it will soon be legal to fly sUAS for commercial purposes, it is expected that the number and density of low flying sUAS will increase, especially across agricultural landscapes. With this likelihood in mind, it is important to take proactive steps to increase aviation safety. Furthermore, there are potential conceptual analogues that one can explore, to gain some insights into the potential risk of collisions between sUAS and piloted aircraft.

One direction to explore involves collisions between piloted aircraft and birds, often referred to as bird strikes. There is some degree of agreement that bird strikes provide at least some level of insight into what might happen if a sUAS were to collide with a piloted aircraft. In addition, there is a focused effort between the U.S. Department of Agriculture (Wildlife Services) and U.S. Department of Transportation (Federal Aviation Administration) to document bird strikes, and their associated risk to humans and economic costs (Dolbeer et.al., 2015). However, there is some controversy in this analogy, since birds consist of flesh, bones and water, and can weight up to 10 to 15 lbs., and sUAS are made of Styrofoam, plastic, carbon fiber, lithium polymer batteries, and can weight up to 55 lbs. (NAAA, 2015). Never-the-less, and in complete absence of data, this project will use the conceptual bird strike analogy to help convey the risk that sUAS can pose to low flying aircraft.

Analysis of the bird strike data indicates that during the period of focused recording in the U.S., there were 11 bird strikes that resulted in 25 fatalities, and 198 bird strikes that resulted in 353 injuries, with a total of 151,274 total bird strikes reported. Approximately 72% of bird strikes occur between ground level and an altitude of 500 ft. above ground level (agl). In terms of economic implications, there were approximately 23,000 bird strikes that resulted in reported damage (1990-2014), with a mean annual civil aviation estimate of 119,645 hours of aircraft downtime, and $193 million in monetary losses per year ($157 million in direct costs and $36 million in other costs). Thus, the average cost of damage per bird strike is $163,883. Also, it is important to note that modern aerial application aircraft have common retail values on the order of $1.0 million to $1.5 million, and damage repair can only be completed by licensed and certified individuals. Consequently, repair of aircraft is an expensive endeavor, and best avoided, if at all possible.

While not a perfect analog to risk of aircraft collision with a sUAS, bird strike data does convey that there is potential for human fatalities, human injuries, and costly damage repair in the event that a sUAS enters the flight path of an aerial applicator. Thus, “see and avoid”, which is part of the Federal Aviation Regulations (CFR Part 91, section 91.113(b)) will be a critical part of safe flight of sUAS across agricultural landscapes.

NU-AIRE Safety Beacon

The NU-AIRE Safety Beacon represents a design that seeks to place extremely bright strobe lights at the flight operations command center for sUAS field operations. In this case, the location of the sUAS ground control station and base of ground operations will be the logical location to place the safety beacon. The safety beacon is located on the top of the vehicle that is used to transport the sUAS to the field. At the same time, the safety beacon design is sensitive to economic factors, and the cost to build the NU-AIRE Safety Beacon.

In order to determine the preferred strobe light, multiple Whelen brand strobes were evaluated by long range viewing of the Whelen demonstration truck. The M-9 model strobe was selected, due to the size and intensity of the strobe light assembly. The NU-AIRE Safety Beacon was built as a square structure, using a total of 8 strobe light assemblies (M-9), with two strobes per side (see Figure 1). The strobe lights were mounted on panels that were placed at a 10 degree angle from vertical, according to the geometry of an approaching aircraft (in this case 500 ft altitude at 2500 ft distance). Three different strobe colors, red, white and green, were evaluated in flight tests to determine if there were differences in brightness.

Under this concept, when the pilot of an approaching aerial application aircraft, or other low flying aircraft, sees the safety beacon, he/she realizes that sUAS flight operations are taking place in the area of the beacon. Conversations with aerial application industry experts and practitioners indicate that a minimum visibility of about 0.8 km at an altitude of 500 ft. agl would be adequate to provide sufficient warning of sUAS flight operations in a given area. Since current regulations require that sUAS flight remain within visual-line-of-sight, the unmanned aircraft will be within about 0.8 km proximity of the safety beacon, and at an altitude of less than 400 ft. agl. Upon approaching an area with sUAS flight operations, and noticing the safety beacon, the piloted aircraft will then loiter at an altitude of above 500 ft. agl, thereby alerting the sUAS operator of his/her presence. At this point, the sUAS operator should land the unmanned aircraft immediately. Both of these factors, the minimum 500 ft loiter altitude and sUAS pilot landing immediately, are based on FAA rules that establish a maximum sUAS altitude of 400 ft. agl, and that sUAS must yield right of way to piloted aircraft.

Figure 1. The NU-AIRE safety beacon for unmanned aircraft flight operations and safety

Flight Operations

Successful testing of the NU-AIRE safety beacon required the use of a manned aircraft to conduct test flights that simulated the flight profile typically used by aerial applicator pilots when transitioning from field to field for routine spraying operations. A Cessna 172 aircraft was flown at 1000 feet agl, with a descent to 500 feet agl when approaching the target field. The vertical approach profile and an indicated airspeed of 100 to 120 knots was used to simulate an aerial spray aircraft flying enroute to a target field. These speeds and altitudes were used because they are the typical profile used by aerial applicators, and they provide for a safer and more efficient way to transit between fields, than the very low altitudes and variable speeds used by aerial applicator pilots when they are actually spraying. The goal of these test flights was to determine how far out from the safety beacon an applicator pilot flying to a spray field would be able to make visual contact with the beacon, and become aware that unmanned aircraft operations were taking place in the vicinity of their intended flight path and area of operation within a target field.

A minimum crew of three people was required for these test flights. One person was needed to deploy the safety beacon to the University of Nebraska Agricultural Research and Development Center (ARDC), and set it up adjacent to a target field at a pre-coordinated location. Two people were involved in the actual data gathering flights, a pilot and observer. The pilot knew in advance the location of the safety beacon and was familiar with the area from the air. The observers were non-pilot, university students involved in the NU-AIRE research program who were viewing the safety beacon and ARDC from the air for the first time.

All three of the data gathering flights were conducted using the same flight profile and procedures familiar to both the pilot and ground crew, and spanned a period of two weeks. Cloud conditions and time of day for the flights varied, but all flights took place with unlimited visibility conditions. A series of eight passes per flight were made over the safety beacon on cardinal headings and at the desired speeds and altitudes previously described. The first pass was made heading East toward the beacon beyond visual sight of the lights. Subsequent passes heading South, West, North, Southeast, Southwest, Northwest, and Northeast followed from left turns made to line up on the next cardinal heading inbound to the beacon (see Figure 2 for depiction of initial approach from east with turn toward north, then toward west, then a turn to the south to test acquisition with approach from the north, and process continued through all 8 approach directions.). All passes were initially set up at distances beyond visual range of the beacon lights. On each pass both the pilot and observer would independently mark the position where they first acquired sight of the safety beacon using a GPS enabled tablet computer. In this case they tapped the location cursor on the tablet, which instantaneously recorded the latitude and longitude of the aircraft location. The latitude and longitude of each of those positions was recorded into a database and used for later analysis. Distance was computed by computing north-south and east-west distance between the beacon location and aircraft position. Then the distance between the aircraft and the safety beacon was computed using the Pythagorean theorem. That analysis resulted in a calculated distance of visual acquisition of the safety beacon for both the pilot and observer for each pass made, for a total of 48 observations (8 approach directions x 2 observations per approach x 3 separate flights).

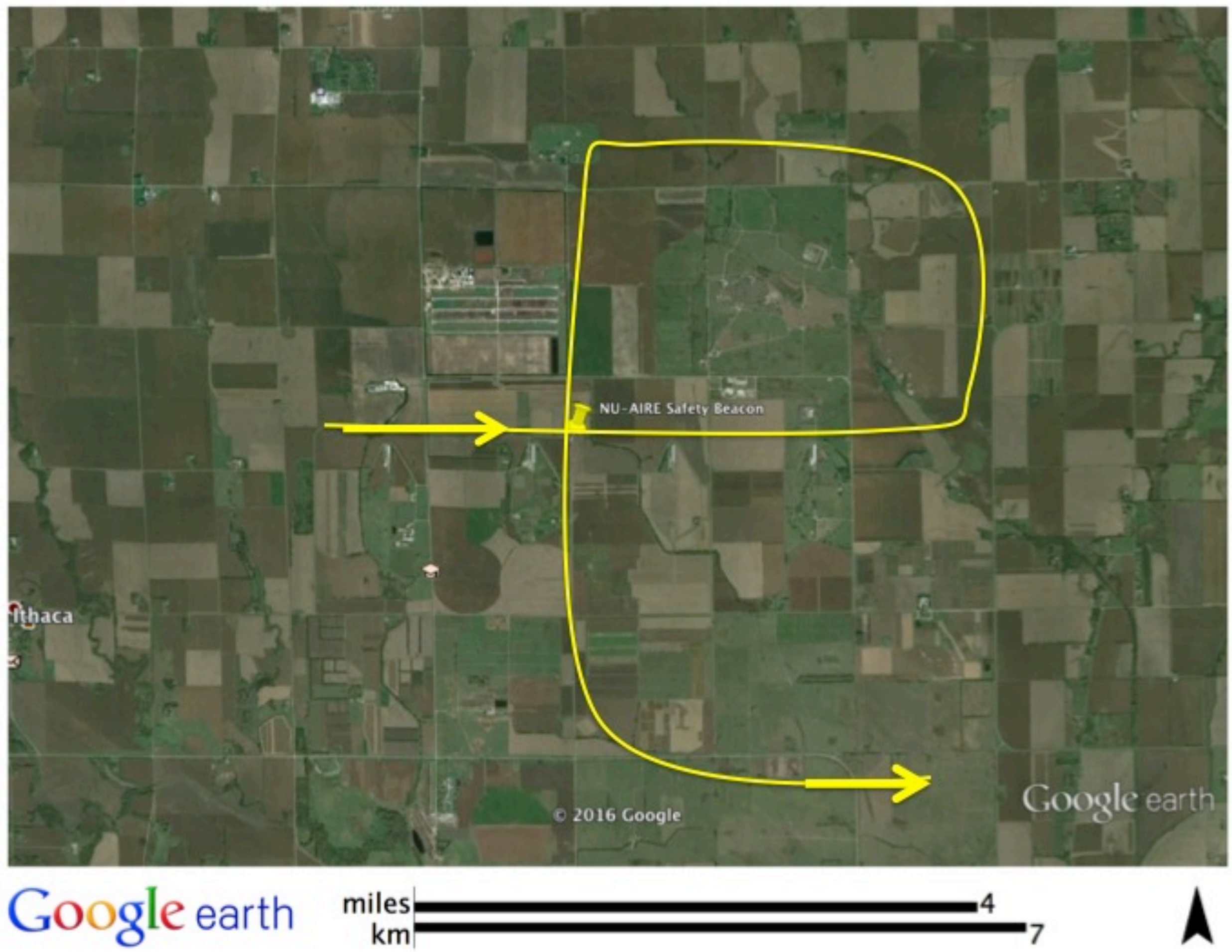

Figure 2. Schematic depicting directions of piloted aircraft approach to NU-AIRE safety beacon

Visual Acquistion - Initial Results

Results from the flight tests are presented in Figure 3. Each dot represents the location at which the beacon was visually acquired by the pilot and research assistant, as the piloted aircraft approached the safety beacon. The minimum radial distance for visual acquisition, from the three test flights, was 0.66 km., with a mean acquisition distance of 2.9 km, and a maximum visual acquisition distance of 6.1 km. These results tend to confirm that the NU-AIRE Safety Beacon provides the level of visual acquisition that the aerial application industry has requested.

Testing results with different color strobes indicate that the red strobes are the most visible, with white strobes being somewhat visible, and green strobes not very visible. These results are based on side-by-side comparisons during active flight-testing. Thus, the current NU-AIRE Safety Beacon is comprised of 8 each red

M-9 Whelen strobes, mounted on slightly angled panels (10 degrees from vertical) attached to a square structure (see Figure 1). The system is portable, and uses a 12 volt DC power source, which can be supplied by the sUAS ground support vehicle.

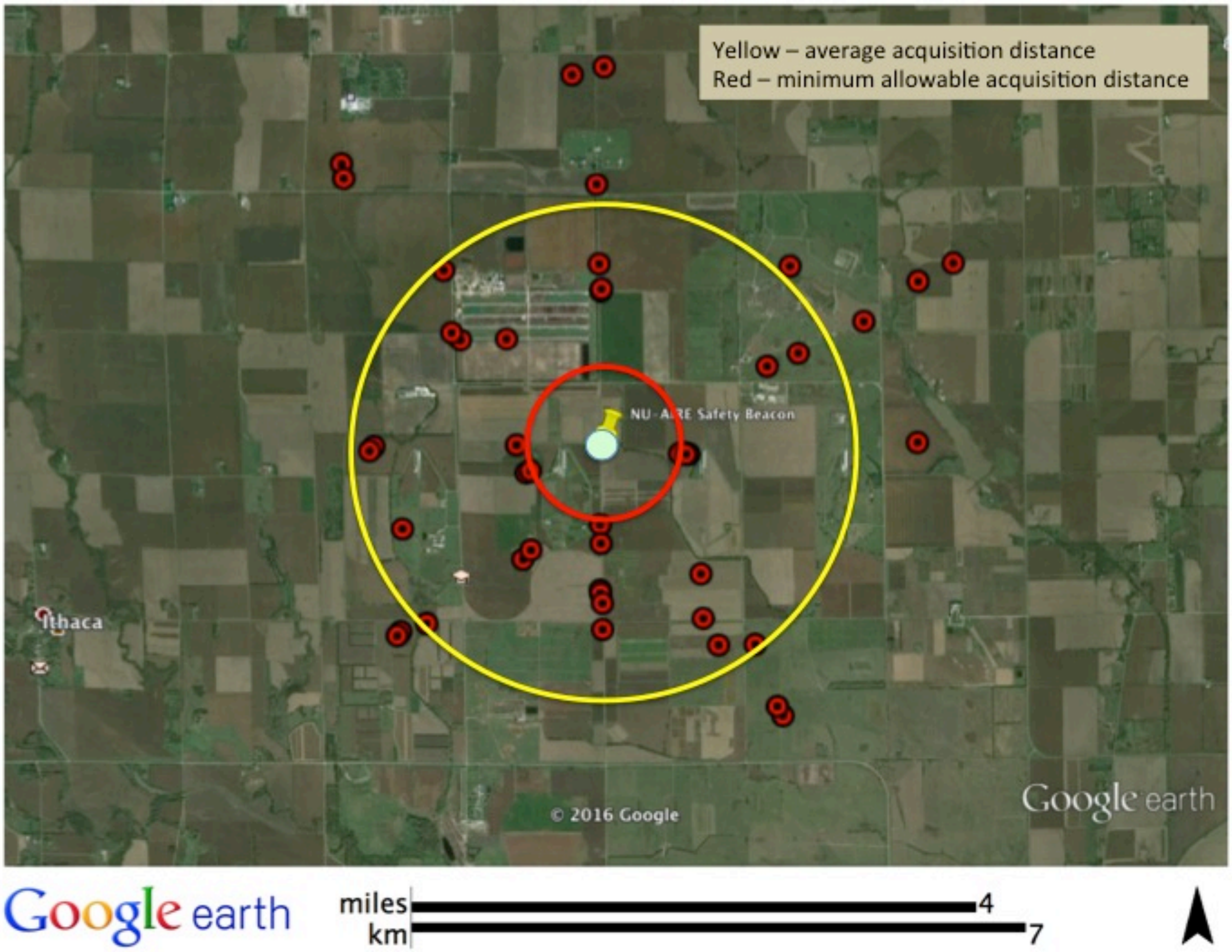

Figure 3. Point cloud depicting the location of visual acquisition of the NU-AIRE safety beacon.

Summary

Unmanned aerial systems (UAS) offer a unique opportunity for the collection of spatial, spectral, and temporal remote sensing data for use in agriculture. Research will play an important part in advancing the safe deployment of unmanned aircraft in agricultural settings. This paper describes a new safety beacon to enhance safety and airspace deconfliction during civilian flight of unmanned aircraft. The need and motivation for a NU-AIRE Safety Beacon were presented as part of the eXtension Unmanned Aircraft Systems in Agriculture Learning Network (www.learnUASag.org). Faculty at the University of Nebraska-Lincoln have been conducting sUAS flight operations under FAA approval through a Certificate of Authorization since 2013, and have been developing the safety beacon since 2014 (Woldt, 2015). The success of the sUAS in the research program at UNL reinforces the implication that unmanned aircraft have the potential to provide useful applications in agricultural and natural resources, and remote sensing, and that safety will be a key factor in their success.

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