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Survey of sUAS Unintended Flight Termination as Depicted in Internet Video

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Key Words: drone, sUAS, crash, accident, training, pilot error

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Abstract

Studies of accidents involving large and military unmanned aerial vehicles have demonstrated that these are largely due to equipment failure. In many cases, accidents involving small unmanned aerial systems (sUAS) do not reach damage or injury thresholds which require reporting. As a result, sUAS are not represented in existing accident analysis. This study systematically surveyed unintended flight terminations of sUAS ($n = 292$) depicted in internet video. Each flight termination was categorized into four categories. Controlled flight into an object and piloting errors were the most common reasons for flight termination (49.3% and 32.5%, respectively). Hardware malfunctions were the least common reason (2.1%). Training programs for natural resource remote pilots should emphasize flight proficiency and knowledge of the flight characteristics of systems being used.

Keywords: drone, sUAS, accident, training, pilot error

Introduction

Several studies have been conducted of incidents and accidents involving both civil and military use of unmanned aerial vehicles (UAV) over the past several decades (Williams 2004; Tvaryanas et al. 2005; Joslin 2015; Wild et al. 2016). These studies were conducted by inspecting accident and incident databases maintained by military and civil aviation governing bodies, and have consistently found that equipment failures were the cause of most UAV crashes. Joslin (2015) studied 321 incidents and accidents involving both military and civil UAV systems in the National Airspace System (NAS) of the United States and found that equipment failures accounted for 73% of the reported events, with nearly half (41%) of these failures related to communication equipment. Wild et al. (2016) studied 152 civil UAV incidents and accidents globally and found that equipment failures accounted for 64% of reportable events. However, neither Joslin (2015) nor Wild et al. (2016) make a distinction between large and small UAVs, and some of the equipment failures recounted that resulted in accidents are of systems in large UAVs which have no analog in small unmanned aerial systems (sUAS) such as satellite-based beyond-visual line of sight control systems. In military systems, Tvaryanas et al. (2005) considered 221 mishaps occurring with U.S. Air Force, Army, and Navy UAV systems between fiscal years 1994-2003 finding 67.9% involved mechanical failure (although in many cases mechanical failure was exacerbated by human factors). Williams (2004) studied accidents related to five U.S. military UAVs and found that electromechanical failure was a more common cause of accidents than human factors overall, but noted that for specific UAV systems the rate at which human factors played a role varied between 21-68%. However, the majority of accidents studied have involved very expensive military or scientific systems being operated by trained and experienced professionals. To be considered in these existing analyses, accidents had to

cause relatively serious injury or substantial damage. For example, military accidents required in excess of \$2,000 or \$20,000 in damages and/or cause loss of time at work to be considered a “Class D” or “Class C” accident, depending on branch of service (Williams, 2004; Tvaryanas et al. 2005).

There has been increasing use of inexpensive sUAS in agriculture and natural resource management (Chabot and Bird 2015; Torres-Sanchez et al. 2015). In contrast to the large and expensive systems where accidents have been studied, sUAS are often operated by people with little background in aviation. In many cases, total hull loss accidents with these systems would not reach regulatory reporting thresholds (currently \$500 in the United States). However, for a small management agency or operating unit, loss of even an inexpensive sUAS may hamper that agency’s ability to use sUAS in support of their missions.

Although equipment failures may be among the significant causes of sUAS crashes, sUAS and UAVs are becoming increasingly reliable (Wolf et al. 2012). Accordingly, minimizing piloting or operator errors would be increasingly relevant to the design of natural resource agency pilot training programs. Although some data has been available on training or operations design for specific tasks (e.g. Junda et al. 2015), there is limited guidance on basic pilot training for new resource management remote pilots. Because little information is available regarding sUAS crashes and accidents, during the design phase of my natural resource agency’s remote pilot training program I systematically assessed internet video of sUAS crashes with the objective of determining what topics to emphasize during our training classes.

Materials and Methods

YouTube (YouTube.com, San Bruno, California, USA) is a repository website for videos which are distributed over the internet. During the evenings of February 20 - 21, 2017, I used YouTube's built-in search functionality to search 7 key phrases: "uav crash", "drone crash", "small uas crash", "drone pilot error", "phantom crash", "Autel drone crash", "Yuneec drone crash". The latter three terms refer to currently popular models of sUAS. I watched all non-sponsored videos from the first two pages of search results (approximately 30) for each search term. I defined unintended flight termination as a sUAS ceasing flight for reasons other than landing, including hard landings with sufficient damage so as to preclude flight prior to substantial repair. This terminology was adopted to avoid confusion with "crash" or "accident" which in some aviation contexts indicates certain damage thresholds have been reached. Unintended flight terminations during engineering tests (evidenced by being conducted in wind tunnels or having telemetry cables attached to the sUAS), terminations in which a pilot was deliberately trying to overwhelm anti-collision safeguards, and terminations where the sUAS appeared to be operated properly but was struck inadvertently by an object from the ground (e.g. soccer ball) were not included. Additionally, terminations caused by non-pilot human action were also not categorized (e.g. person striking the sUAS with a broom).

Each flight termination in each video was recorded in a spreadsheet, along with my assessment of the reason for the flight termination. When a flight termination was recognized as being a duplicate, only the first assessment was retained. As I was agnostic to the reasons for small sUAS flight termination, I developed categories while watching videos, ultimately recording 32 separate reasons for termination. Pearson's χ^2 test was used as a test of homogeneity to ensure the proportion of reasons recorded did not vary amongst search terms. An initial data

reduction step refined the 32 reasons for termination into 11 categories. A second data reduction step was performed because 83% of the cells of the resulting contingency table had an expected count < 5 , violating assumptions of the χ^2 test (Zar 1999). The second reduction step resulted in five categories: controlled flight into objects, piloting errors, interactions with animals, birds or people, hardware failures, and undetermined (Table 1). Combination of categories was based on professional judgement. The threshold of statistical significance (α) was set at 0.05.

Results

A total of 292 flight terminations were assessed ($n = 292$). A χ^2 test suggested no significant difference in proportion of flight termination reasons amongst search terms ($\chi^2 = 32.469$, $df = 24$, $p = 0.116$). Accordingly, the results from all search terms were pooled (Table 2). Overall, the most common flight termination reason was controlled flight into an object (49.3%), followed by errors in pilot operation (32.5%). Unambiguous hardware failure (e.g. propeller separation, structural failure) was the least common flight termination reason (2.1%).

Of the 144 flights terminated by controlled flight into an object, 9 involved moving vehicles including mid-air collisions with other sUAS and 9 involved sUAS being operated indoors. In the remaining 126 terminations, 50.0% involved trees ($n = 63$), 38.1% buildings or structures ($n = 48$), 6.3% utility wires ($n = 8$), 3.2% cliffs ($n = 4$), and 2.4% parked cars ($n = 3$). Of the 95 piloting errors, 38.9% were the result of loss of altitude while changing velocity ($n = 37$), 32.6% occurred during takeoff or landing ($n = 31$), 16.8% were errors of piloting judgement ($n = 16$, e.g. insufficient stopping space), and 11.6% related to operational procedures ($n = 11$). This last set included four weight and balance related terminations (all involving 'sling load' type operations), three instances of battery exhaustion, three instances of instability following the sUAS being handled while airborne, and one inflight motor shutdown commanded by a pilot. Of

the 20 terminations which involved animals or people, 65% involved a sUAS making contact with a person ($n = 13$), 20% involved inflight interaction with birds ($n = 4$), and the remainder involved terrestrial animals ($n = 3$). The six hardware failures were predominantly inflight propeller separations ($n = 5$), although there was one structural failure ($n = 1$). A reason could not be assigned for 9.2% of terminations ($n = 27$). I would note however that in 40.7% of these undetermined terminations ($n = 11$), termination was preceded by an unexplained rapid inversion of the sUAS.

Discussion

There are several limitations to this study, most notably that YouTube is primarily an entertainment venue. As a result, the sUAS flight terminations most likely to be uploaded are those which are spectacular in some way, including terminations caused by spectacularly bad judgement. Additionally, in most cases the flight termination was depicted by only a few seconds of video either from cameras onboard the sUAS or on the ground. There was no way to differentiate between flight into an object (such as a tree) because the sUAS had lost link with its ground control station, versus flight into an object because the pilot was inattentive. I suspect at least some of the flight terminations classified as “Undetermined” may have been the result of hardware failure (in particular propeller separation).

Notwithstanding these limitations, this analysis suggests that sUAS flight terminations occur for different reasons than larger UAV crashes. Hardware failure appears to be minimally important, and even those failures which do occur may be due to improper preflight preparation (e.g. propellers not being tightened or checked before flight). An alarming number of flight terminations involve striking stationary people, but this may reflect biases in what material is uploaded to YouTube. Relatively few terminations involved birds or animals. Although birds and

manned airplanes do occasionally interact, generally these interactions are assumed to be inadvertent. In comparison, in the bird and animal related flight terminations assessed during this study, the birds or animals all appeared to approach the sUAS deliberately. Shea's (2014) speculation that animals which are subject to predation by large birds may react more aggressively towards sUAS may be worth investigating further.

However, the greatest number of unintended flight terminations revolve around pilot error or pilot judgement. Not surprisingly, pilots who are inattentive to their sUAS or who fixate on filming an object run the risk of flying into nearby trees, structures, or wires. Some models of quadcopter have a tendency to lose altitude when changing speed and direction, requiring compensatory control inputs to avoid descent (personal observation). Accidents related to this behavior were surprisingly frequent. Agency pilots should be trained on the specific flight characteristics of the sUAS they are operating, as well as on landing and takeoff procedures. Pilots should be additionally be given sufficient training so as to avoid making errors in flight planning, so as to avoid weight and balance and battery exhaustion failures.

Although limited, this study suggests that pilot judgement and pilot error are important reasons for sUAS flight termination, in contrast to large UAV crashes. Systematic survey of sUAS operators (such as a survey of certified remote pilots) may provide better insight into flight termination of professionally operated sUAS. A focused questionnaire sent to natural resource scientists who have published research utilizing sUAS may additionally reveal causes of flight terminations relevant to resource management work. Until such surveys are complete, I suggest natural resource agencies who are beginning to use sUAS in day to day operations require demonstration of proficiency and judgement from their sUAS pilots. Doing so may avoid a

substantial number of flight terminations, which could prevent loss of time and equipment availability.

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Table 1. Assignment categories of flight terminations of sUAS recorded in this study. During data reduction, all categories on left side of vertical bar were included in the category on right side. CFIT = Controlled Flight into Terrain.

Initial Assignment	Intermediate Assignment	Final Assignment
Controlled flight into parked car Controlled flight into tree Controlled flight into building Controlled flight into other structure Controlled flight into cliff Controlled flight into utility wire	Controlled flight into an object	Controlled flight into an object
Midair collision with free balloon Midair collision with other sUAS Flight into moving vehicle	Collision with moving objects	
Indoor collision with walls	Indoor accidents	
Instability after aggressive maneuvering CFIT - beyond line of sight CFIT - unambiguously unsafe operation CFIT - other pilot errors	Piloting error	Piloting Error
Takeoff with horizontal vector Unsuccessful takeoff - other Hard landing with obvious damage	Takeoff and landing accidents	
Loss of altitude during forward movement Loss of altitude during lateral movement	Loss of altitude during movement	
Weight and balance failure Battery exhaustion Inflight shutdown Instability after inflight handling	Planning and procedure failures	
Flight into Person	Flight into a person	
Midair collision with bird Attacked by dog Attacked by farm animal Attacked by zoo animal	Animal and bird interactions	Animal, bird, or person interactions
Inflight structural failure Inflight propeller separation	Hardware failure	Hardware failure
Undetermined Rapid inversion with no apparent cause	Undetermined	Undetermined

Table 2. Count and percent of unintended flight terminations by reason for termination

Reason	Count	Percent (%)
Controlled flight into object	144	49.3
Piloting error	95	32.5
Animal, bird, or person interaction	20	6.8
Hardware malfunction	6	2.1
Undetermined	27	9.3
Total	292	100.0

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