A Grounded Theory of UAS Reported Accidents

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Context: The manufacture and operation of sUAS are not as regulated as today's commercial operation, and their widespread use introduces new risks and hazards to the general public.

Aim: Our intent is to understand the various processes that prevent or portend sUAS incidents or accidents and the influence that pilots' expectations and training have on these processes.

Method: We use classic grounded theory on sUAS reported accidents (and incidents).

Results: We identified three categories, Control Interference, Reviewing and Reporting, which describe various processes surrounding UAS accidents based on the dataset analyzed.

Conclusion: The use of grounded theory can offer a different perspective in the analysis of UAS accidents. In addition, the traceability between data sources and the method results facilitate result validation, and navigation. While the results are preliminary, the concepts can be expanded through the use of other accident datasets or used as basis for UAS accident surveys.

I. Introduction

Emerging aviation includes the use of small Unmanned Aerial Systems (sUAS) in novel operations. The manufacture and operation of these sUAS are not as regulated as today's commercial operation, and their widespread use introduces new risks and hazards to the general public. Today, there are case-by-case approvals for sUAS operations, particularly for emergency response operations in which the potential benefits of the use of sUAS are perceived to outweigh potential risks.

We argue that operational approvals, procedures, manuals, concepts of operation, and incident or accident-related information (thereafter referred simply as accidents) , when analyzed in a more systematic manner, are valuable resources that can be leveraged toward identifying risks and hazard gaps. This identification improves the safety of the national airspace. As a first step toward this gap analysis, we use grounded theory on sUAS reported accidents (and incidents). Our intent is to understand the various processes that prevent or portend sUAS accidents and the influence that pilots' expectations and training have on these processes. We argue that this understanding structured as a substantive theory can then be used in future work to compare accident structure to the resources which are used to mitigate accidents (e.g. operational manuals and checklists). A more structured manner to interpret sUAS accidents could also be used to evaluate the ways in which more commonly requested waivers for Part 107 are related to the prevalence of types of reported accidents.

To the best of our knowledge, the only work using classic grounded theory in aviation is by Nhut et al. [1], on the matter of trust. We believe, therefore, the use of grounded theory to analyze FAA Accidents offers an exciting

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Table 1 Example Indicators

Indicator	Narrative Excerpt
Malfunction	ESC's malfunctioned causing the aircraft to fall.
Power Loss	[..] lost power and struck a solar panel.
Shooting	[...] it was at this time that I realized the aircraft may have purposely been targeted and shot down.

opportunity to offer a different perspective for UAS safety, which may serve as proof of concept for future work to expand on it in other aviation domains.

II. Method

We propose the use of Classic Grounded Theory [2, 3], a type of thematic synthesis [4] and qualitative method, to systematically identify processes surrounding accidents. The goal of Grounded Theory is to generate concepts and categories that account for a pattern of behavior that is relevant and problematic for those involved [5, p. 78]. Grounded Theory is best for answering questions of the form "what is going on here?" [3]. We are in agreement with related work [3] that instantiating grounded theory is to an extent subjective, and we provide further details on our implementation of the method.

A. Indicators, Conceptual Categories and Conceptual Properties

When using a qualitative method, one has to consider how during analysis the (intermediate) results are structured and expanded upon. In grounded theory, these building blocks are "indicators", <u>conceptual categories</u> and *conceptual properties*, also defined in the method as "Elements of Theory". These building blocks also include "Hypothesis", which help explain relations between concept categories and their properties. [2, p. 35].

Indicators are actual data, such as the behavioral actions and events observed. Indicators may be a word, phrase, sentence, or paragraph in the data being analyzed [3]. Table 1 showcases some of the indicators we identified in our preliminary analysis. In discovering theory, one generates conceptual categories or their (conceptual) properties from evidence; then the evidence from which the category emerged is used to illustrate the concept [2, p. 23]. As one would expect, it is not immediately clear what should or should not constitute an indicator. Therefore, any phrase of the narratives we analyzed was considered a candidate indicator. As the process continues, however, it becomes easier to recall a similar indicator that may have occurred earlier in the text. By revisiting prior indicators as the analysis progresses, a procedure defined in grounded theory as the constant comparative method [2, p. 101], we are able to sort related indicators. The intuition gained from repeated comparison and sorting of indicators is referred to as "theoretical sensitivity". Theoretical sensitivity can be interpreted as the analyst's familiarity with the data.

By constant comparison of indicators, and as theoretical sensitivity increases, the analyst can then observe higher order concepts, which can be either conceptual categories or conceptual properties. Following on our example in table 1, we observed the indicators could be reasonably grouped as the *forced shutdown* concept. Other concepts, which we present in our preliminary results section, also emerged, eventually leading to grounded theory "hypothesis", i.e. the relations among the concepts.

B. Saturation and Theoretical Sampling

Moving from indicators to concepts is a process of saturation, rather than of quantity. A single indicator can indicate a general conceptual category or property; a few more cases can confirm the indication [2, p. 30]. We found this notion is similar to how one conducts systematic literature reviews. The expectation is that a systematic literature review is sufficient not for exhaustively including every citation, but rather for achieving saturation: The inclusion of new citations do not contribute to the conclusions. Similarly here, the inclusion of new indicators may expand our understanding of a well-defined concept, rather than constantly overwrite it. Indeed, conceptual categories and conceptual properties in grounded theory serve to structure this relationship.

Building on our example, in addition to *forced shutdown*, we identified other concepts such as *drifting*, *drone takeover*, and *malfunctioning feedback*. Further inclusion of indicators and comparison now between both indicators and also concepts, led to a new concept, <u>Control Interference</u>. In this manner, according to grounded theory, <u>Control Interference</u>

is a concept category, and *forced shutdown*, *drone takeover*, *malfunctioning feedback* and *drifting* are concept properties of Control Interference. How these conceptual properties relate to one another, and to the concept category are defined in grounded theory as "hypothesis".

As described, the intuition here is that analysis begins from narratives in the dataset. In this work, these are narratives from reported UAS accidents. Joint collection, coding and analysis of data is the underlying operation [p. 43][2]. While this qualitative method originated in social sciences, it has been successfully applied in other domains such as software engineering [6] and trust [1]. The generated theory has also been shown to be verifiable quantitatively, by using statistical models, such as structural equation modeling [7, p. 283].

C. Presentation and Evaluation of Qualitative Results

Grounded theory (results) can be presented either as a well-codified set of propositions or as a running theoretical discussion using conceptual categories and their properties. The form in which a theory is presented does not make it a theory; it is a theory because it explains or predicts something [2, p. 31]. Grounded theory prefers a discussional form, in particular because the strategy of comparative analysis for generating theory puts a high emphasis on theory as a process, i.e. that theory is an ever-developing entity, not a perfected product [2, p.32]. Our result presentation therefore is similar to [6], where the theory presentation is done in narrative form, concept categories are underlined, and *concept properties* are noted in italics. Excerpts of both concept categories and concept properties are included in the appendix, which can then be mapped to the original narratives in the dataset for evaluation.

As the method is qualitative in nature, the evaluation of the results is based on the quality of the concepts generated. The concepts should be analytic — sufficiently generalized to designate characteristics of concrete entities, not the entities themselves. They should also be sensitizing — yield a "meaningful" picture, abetted by apt illustrations that enable one to grasp the reference in terms of one's own experience [2, p. 38,39].

III. Dataset

This work utilizes the FAA Freedom of Information Act (FOIA) public dataset of UAS accidents*. This dataset's identifying information was redacted before release. A total 101 records are present in the report. Narratives range from two sentences to paragraph long. According to the dataset, the query performed in the database SPAS/A IDS include the 14 CFR Part as "Other", Event Type: "A, I", Injury Serverity: "Fatal, Non-Fatal', and the inclusion of any of the keywords "uas, uav, drone". The narratives entry date range from 4/4/2016 to 07/28/2022, subject to the query terms. Furthermore, the quality of the narratives vary considerably in level of detail. For example, report R62, in its entirety, states: "Reported passing a UAS while on final for runway 7, at KORL. No evasive action taken". In contrast, other reports may go as far as detailing analysis done by manufacturers in assessing the cause of an accident. The variance in the quality of the narratives, in addition to the uncertainty on the coverage of accidents of the dataset further motivated our choice of qualitative method such as grounded theory, which does not seek specific type of information in the data to conduct analysis, so long as there is lessons to be learned from it.

In the subsequent section, we present the three identified concept categories and their associated *concept properties* using grounded theory proposed presentation approach. The "mapping" between some of the indicators and the associated concepts is listed in the appendix. We note, as a byproduct of the extension of the analysis, these concepts are not final, and may expand or modify if further accident datasets are analyzed as defined by the grounded theory method. In particular, while we believe Control Interference could serve as a "core category", a category which explains most of the other categories, and a distinguishing factor of the grounded theory method, we chose to not define it as such, until other datasets are analyzed in future work.

IV. Results

UAS accidents generally follow a process of Control Interference, Reviewing and Reporting. Pilots are subject to Control Interference when drones undergo *Forced Shutdown*, *Drifting* or *Drone Takeover*. When experiencing Control Interference, pilots expect some form of *Malfunctioning Feedback*, in order to *Recover Control*. Conversely, pilots may cause accidents due to *Improper Control*.

To mitigate Control Interference, pilots are constantly Reviewing their operation. This may occur due to pre-flight *Preparation*, or after the accident by *Wreckage Inspection* or authority *Remediation*. Reviewing also highlight pilots

*https://www.muckrock.com/foi/united-states-of-america-10/database-of-suas-drone-accident-reports-132824/

Inconsistent Expectations, when operations occurred previously do not go as planned.

By Reporting, pilots and witnesses can assist with *Damage Control* or be provided with authority *Remediation* to prevent re-occurrence.

A. Control Interference

When performing UAS flight operations, we found accidents often resulted from some manner of Control Interference. Pilots would either immediately lose control of the aircraft due to *Forced Shutdown*, or wrestle with the aircraft when it began *Drifting*. The cause of *Forced Shutdown* included loss of power, and also external interference such as bird attack or gunshots. Drones would begin *Drifting* due to signal or GPS loss, weather conditions (wind, rain) or magnetic interference. On occasion, before experiencing *Forced Shutdown*, a *Drone Takeover* would occur to prevent it, such as the UAS entering auto-land or return to home sequences before running out of battery or experiencing signal loss. However, the automated procedure would then cause the accident instead by colliding with structure. When expecting accidents due to *Drone Takeover*, pilots also attempted to *Recover Control*, however the response time to re-establish manual control were insufficient. Alternatively, pilots also attempted to *Recover Control* by manually reaching to a flying UAS to attempt a *Forced Shutdown*, leading to lacerations from the UAS propeller blades.

In the absence of Control Interference, pilots could also cause accidents due to *Improper Control*. This ranged from incorrect mental model (e.g. drone facing the pilot reverting the directions of the controls that should be used), to misjudged distance to objects. Pilots reported or expected *Malfunctioning Feedback* leading to accidents, or utilized their absence to ensure the missions could be conducted safely. For example, the expectation of battery warnings before a *Forced Shutdown*, or by the UAS issuing "squawking" noise after losing link.

B. Reviewing

Pilots perform Reviewing to at different moments in an accident event. In *Preparing* for take-off, pilots conduct pre-flight checklists, assembling, operating checks, flight plan, battery and more. Reviewing is also performed after an accident for *Wreckage Inspection*. In addition to assist in identifying the underlying cause of Control Interference, such as by inspecting drone parts for structural failure, drones may also be shipped back to the manufacturer for further investigation. *Wreckage Inspection* also serves to mitigate the accident from escalating, for example, by proper disposal of batteries to prevent fires. Reviewing extends beyond physical inspection. It also reflects the *Inconsistent Expectation* pilots had when assessing what went wrong. For example, that the operation had been conducted in the same location, day, and that these operations were conducted successfully.

C. Reporting

Reporting occurs during UAS *Sighting* and also *Damage Control*[†] .*Sighting* reports can lead to pilot apprehension for violating local ordinances, however, it is also possible that searches do not lead to identifying the suspect. *Damage Control* reporting is made to property owners, in addition to authorities, for example, to disable the area damaged, or repair. Reporting is also followed by *Remediation*, more often presented through pilot counseling or training.

V. Literature Review

Other methods have been used to analyze hazards related to the use of UAS in previous studies. In this section, we review the identified methodologies and present how our proposed approach differs from them.

A. Safety Metrics

Metrics derived from operations and incident reports have been used in previous studies to characterize hazards and mishaps pertaining to UAS. In a recent study, researchers explored key aspects of the expanding use of UAS. The study mainly focused on the use of drones for data collection, its effects on global power dynamics, and the societal implications that carries [8]. Using a similar approach, another study reviewed hazards and safety issues related to UASs weighing 55 lbs or less. They concluded that, at the time, these vehicles do not possess the adequate safety features needed to operate safely around the general population [9].

[†]While Damage Control is an underdeveloped concept at the scope of the dataset analyzed, we found it to be an important consideration pilots should account for during an accident, and therefore, decided to keep it in the final manuscript.

Grounded Theory can be used as a preliminary analysis method on qualitative data to help inform what variables should be considered for measurement. Moreover, not all datasets can be used for quantitative analysis, as is our case, where the absence of a report does not imply an accident did not occur. As a practical example, one of our identified categories was different means by which pilots could lose control of the aircraft due to Control Interference. Further studies could define in more comprehensive datasets the rate of which these different occurrences happen, to investigate mitigations.

B. Surveys

The use of surveys for hazard analysis is a longstanding practice. Surveys give the ability to gather information first-hand from subject-matter experts or regular users of a system to gather crucial insight relative to a system of interest. The benefits from using surveys become even more relevant when the system in question is novel, and there does not exist a huge amount of historical knowledge. Surveys have been leveraged in the past studies to identify potential hazards applicable to UAS and their introduction in wildfire management efforts [10]. In that investigation, wildfire experts were surveyed to gather their input and have a better understanding on how they see the use of UAS in widlfire management, and what they foresee as being new hazards introduced and value added. In another study, researchers investigated human-UAS collaboration challenges, along with workplaces safety practices amongst pilots of UAS [11].

In Grounded Theory, surveys are one of the primary methods to collect narratives for analysis. In our work, we decided to first identify concepts to provide guidance on what questions on the topic of UAS accidents we should include in the questionnaire, through theoretical sampling (see section II.B). As an example, the Reporting category property *Damage Control* is underdeveloped: We identified only two narratives excerpts where pilots considered reporting to others who own the property which the drone collided, to mitigate damage. This could therefore be included in a questionnaire to UAS pilots when investigating what types of reporting pilots do in case of accidents.

C. Machine Learning

Advances in Artificial Intelligence and Machine Learning are continuously being leveraged to improve hazard identification and assessment efforts [12]. More specifically, natural language processing (NLP) has been used in a variety of ways to develop hazard analysis artefacts [13–15]. Previous studies have seen the named-entity recognition used to extract failure relevant information from SAFECOM reports filtered on UAS mishaps. The extracted information was then used to develop data-informed Failure Modes and Effects Analysis (FMEA) tables to aide in the safe introduction of UAS in wildfire management efforts [16]. In another study, a process using BERT-based topic modeling and information retrieval (IR) was proposed to retrieve information needed to construct a fishbone diagram chronicling potential causes of UAS inicdents in wildfire response efforts [17].

Because Grounded Theory provides full mapping to sentences that capture abstract concept categories and concept properties, we see natural language processing methods as an opportunity to leverage the manually collected information to search related concepts in large accidents databases to identify narratives that may be underdeveloped. Identified categories could also be used as ground truth against topic modelling algorithms to evaluate their reliability in controlled datasets.

D. Taxonomy

Taxonomies can be key to UAS hazard analysis due to their ability to systematically categorize both potential and identified risks and threats [18]. Such a structure enables a thorough understanding of relevant hazards, which facilitates the analysis and development of mitigation strategies needed for safe and efficient UAS operations. Previous studies have relied on the use of taxonomies to explore and assess different aspects of drone safety. A previous research leveraged a taxonomy to investigate UAS mishaps in Australia and recommend barrier measures to reduce future events [19]. In another study, authors explored wyays to identify common factors leading to remotely piloted aerial systems (RPAS) mishaps in civil aviation, in an effort to reduce occurences [20].

Taxonomies can be used to contrast the identified concepts in grounded theory versus those in use or created, to assess concept coverage. We believe Grounded Theory, in the context of UAS, to be a more flexible approach than utilizing a taxonomy for classification, as UAS technology is evolving in a rapid pace. Pre-defined categories may therefore become outdated or be too coarse for classification.

VI. Discussion and Future Work

We believe the practical utility of this early analysis of UAS accidents using grounded theory lies in the opportunity of using the identified concepts to conduct more specific analysis or validation of existing procedures. While a single dataset may not suffice to comprehensively assess the entirety of UAS accidents, we believe some of the identified properties generalize a few patterns in UAS accidents. As discussed in our theoretical sampling section II.B, underdeveloped categories can serve as basis of what other datasets or questions in a survey should be used to expand the analysis. While the extension of the categories to other datasets is beyond the scope of this work, we sampled some UAS narratives from both the Aviation Safety Reporting System (ASRS)[‡] and the National Transportation Safety Board (NTSB)[§]. To illustrate, in the NTSB, we performed a CAROL search where the "Aircraft Category" is "Unmanned", resulting in 38 investigations. We subsequently examined the dockets for NTSB Form 6120.1, which contains narrative history of flights. In NTSB# WPR24LA031, the excerpt *During the vertical climb, the drone registered a low voltage health alert, and initiated an "urgent land maneuver' [...]. During that maneuver, the drone's battery depleted [...] and impacted the ground [...]* can be observed as an instance of Control Interference, *Drone Takeover*.

We also observed some overlap between our identified categories and related literature and opportunities to search or underdeveloped or non-explored categories. For instance, in [11], the authors survey reported, among others, drone mishaps being related to "fatigue" and "workload pressure". We did not observe any indicators associated to these themes in our narratives. In contrast, "losing gps signals", "mechanical failures", "battery failures", "electromagnetic failures" are types of Control Interference in our analysis. Under the broader categories. In future work, we plan to analyze the gaps of identified concepts more systematically.

Lastly, we believe the identified UAS accidents in this work, or future extensions can also serve as a checklist to standard operating procedures and training materials. More specifically, the various types of identified Control Interference situations can be evaluated against public and private agencies UAS manuals to assess if they convey what pilots should do in those circumstances to avoid the accident or mitigate damages. Other non accident related categories, such as Reporting can be used to assess what reporting procedures are present, and Reviewing, what systems are in place to document accidents, to provide lessons learned for future operations.

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A. Concept Indicators and Concept Properties

A. Control Interference

1. Forced Shutdown

- R6: Officer had been flying approximately 393 AGL when Matrice dropped from sky
- R10: [..] lost power and struck a solar panel
- R11: approximately five minutes into the mission, the aircraft suddenly lost connection with the controller and immediately fell from a height of 210ft agl. I am unable to say with certainty that a gun was fired at the time the aircraft failed, as my hearing was impaired by a bulldozer that was being operated at the jobsite during the same time period.
- R29: As it began to move towards the left the power failed and it dropped smashing into the rear of the insured's neighbors car and then on to the ground.
- R36: A law enforcement drone conducting a lawful mission on 7/11/2021 was shot down
- R68: during a climb into a camera position, the uas lost power and fell
- R69: uas was flying north at 169 feet above ground when the uas lost signal, and instantly dropped from the sky
- R75: during the initial mission ascent, an adult raptor (bird) attacked the uas causing the drone to crash into a company owned vehicle
- R98: when he looked up he saw the unmanned aircraft falling

2. Drifting

- R2: [. . .] while the controller was on the ground, the drone somehow lost signal and moved erratically toward the main road and struck [. . .]
- R5: Pilot indicated gusty winds and a light rain were factors in the accident. The pilot maintained control throughout the flight but was not able to compensate for the wind gust, causing the SUAS to drift into a parked vehicle.
- R9: as the pic looked up from the remote control to spot the drone hovering above, the dji inspire 2 drifted towards a building making contact with the building and fell to the ground.
- R19: uas after takeoff lost communication and gps manueverability. uas started to drift toward the building
- R20: pic lost signal to uas using 2.4 ghz immediately switched to 5.8ghz but was unable to reconnect to uas. uas continued flight at orignal heading and alitude. pic maintained los while attempting to reboot controller. uas eventually made contact with verizon sign at the causing damage to both the sign and the uas.
- R21: the wind changed, possibly in a vortex motion and caused the pilot to lose control of the uas and the uas struck the bus
- R22: used rented dji inspire 2 drone lost control link with drone on way back crashed
- R33: As the uas was returning to land due to strong winds it passed between 2 metal warehouse structures and lost GPR signal.
- R35: the vehicle owner stated he believed there to be a gust of wind that came up at the same time as the uas was taking off, which he believes may have contributed to the uas moving hard left
- R43: drone was erratic by making 'sudden and quick attitude changes and operating at times close enough to them
- R78: on climb out the drone encountered a gust of wind blowing it into the edge of a tree line. the drone struck tree branches damaging one of the four props. the drone became uncontrollable and fell 25 feet landing on the company truck causing damage to the windshield and hood.
- R79: due to magnetic interruption it flew into a cell tower
- R81: the remote pilot flew too close to the structure and a gust of wind caused the drone to collide with the roof
- R83: during flight the uas was upset by a sudden gust of wind and hit a parked car causing minor damage
- R88: uas was piloted from the ground and within visual line of sight when a gust of wind pushed the uas into the home it was inspecting.
- R92: during the flight, the uas lost signal which caused it to exit the programmed geofence and lose altitude. the pilot was unable to regain control
- R93: either a rotor or airframe structural failure occurred during flight possibly due to a momentary high wind gust
- R95: the pilot was struck in the face by the rotors and the lacerations required sutures [. . .] the pilot suggested wind might have blown his uas toward him.

- R99: the left polyhedral separated from the left wing which caused an out of control situation.
- R100: he was flying the tricopter at 15 meters in the air and the remote control was controlling the uas properly. about one minute later, the uas was carried away by the wind at the same altitude and no changes applied to the controller were effective.

3. *Recover Control*
    - R8: grabbed onto the landing gear with both hands and attempted to give commands to the attendee to shut down the motors while the rpic held onto the landing gear. when that did not work, the rpic attempted to remove the drone battery and the propeller blade struck his right hand.
    - R19: operator caught the uas while flying and sustain several cuts to the arm, face and thigh.
    - R33: When a strong gust of wind blew the uas towards the RPIC and in an attempt to disable the UAS he reached to grab it and turn it upside down which would automatically disable the rotors. The wind gust made it hard to properly grab the uas and resulted in the rpic receiving cuts from the rotor blade [. . .]
    - R82: before the operator could manually intervene and prevent collision.
    - R97: the remote pilot/pic did not have time to take control of the uas from the auto-pilot.

4. *Malfunctioning Feedback*
    - R9: remote control screen was prompted "magnetic interference" and then the aircraft disconnected and screen went black.
    - R10: there were no mission application warnings on the tablet prior to the loss of power leading us to suspect either a battery failure or power failure of some sort.
    - R14: [. . .] after connecting and then losing link again the uas was observed squawking emergency
    - R15: [. . .] he had approximately 16 minutes of battery life left. he would expect a warning once it reached 7 minutes the app displayed 16 minutes and gave no warnings. there was a quick flash stating a battery problem as the drone simultaneously wobbled and crashed from its hover in flight.
    - R16: during the climb to 60ft the application on the controller said "lost connection". the rpic looked up to see where the uas was and saw it crashing to the ground.
    - R29: I inspected the lights from below and had two green lights and two red lights. _ confirmed that the light pattern was what I wanted to see.
    - R43: officers reported the drone appeared to lose battery power indicated by the changing in the light intensity and light flashes on the drone
    - R84: operator had eye contact with uav and glanced down to controller. pilot noticed that screen was black with red warning when pilot looked back up he has lost visual contact with drone.
    - R89: video feed was lost on the controller. at this time the uas pilot commanded the return to home (rth) option.
    - R98: his attention was on the video monitor when the screen went black and an error message appeared on the screen.

5. *Drone Takeover*
    - R1: Upon reaching its battery limit, entered auto-land
    - R3: when the UAS lost link to the controller and activated a return to home sequence.
    - R7: The takeoff was approximately 35 seconds after boot-up, not permitting the aircraft gps to lock on to its location. [. . .] command the drone into loiter mode, however, the drone rejected the command due to the lack of gps location lock required to transition into a gps-assisted flight mode.
    - R28: pilot was hovering uas steady indoors for several minutes at location taking a picture of a stained glass window for the church clergy when uas lost control as described by pilot, a flyaway scenario and uncontrollable. it is not known if any radio interference caused the uas to be unresponsive, an internal system fault, or momentary gps lock and unlock which might have caused the uas to default to return to home mode
    - R36: attempted to maneuver the drone into an open landing area without success as the return to home feature and auto landing 'sequences had initiated due to rapid loss of battery power
    - R39: encountered a loss of control on takeoff and made an uncommanded turn toward the operator, causing lacerations
    - R43: he was not sure what happened to the controls. he said the drone had an obstacle avoid feature and he thinks

that may have caused him to lose control.

- R49: uncommanded fly away into building destroying uas and damaged window.
- R53: about five (5) minutes into the second flight, the aircraft lost command link and initiated a pre-planned return-to-home procedure. while turning to the final waypoint, the aircraft banked steeply and collided with a tree.
- R66: the phantom drone ascended to approximately 25 feet when the controller gave a "esc error" code combined with "max height reached". the drone remained in a hover mode. the uas pilot stated the error code self-cleared. at that point, the drone continued to ascend and approximately 15 seconds later, the drone uncontrollably moved rapidly in one direction and began to lose altitude. the operator had no control over the movements.
- R72: he said that the uas acted as if it was "pre-programmed" to fly into the hangar once it got away
- R82: the suas operators flight was a pre-programmed flight plan where the drone controls everything from takeoff to landing. the operator hit takeoff and the drone ascended and struck the lower power line
- R89: the uas climbed to 60m and returned to home. however, the uas did not initiate the landing sequence. the uas pilot then executed the rth command two more times and the uas continued to hover. the uas pilot then used the secondary controller and tried to land the uas. still resulting in the uas hovering. at this point the pilot contact tech support and they were trying to troubleshoot. while they were on the phone, the aircraft rotated ccw and crashed on the roof of a building.
- R93: the failure caused the aircraft to go into is lost motor failsafe mode where it spins and descends until impact.
- R96: while he was manipulating the controls the uas attempted to fly away. the uas was approximately 100 feet horizontally and 140 feet vertically from his position. he gained control only by pressing the return to home button. when the uas returned, he attempted to manually operate the controls again. after gaining control, the uas flew away again. this time flying at maximum speed towards his neighbors driveway approximately 500 feet horizontally from his location.
- R97: the auto-pilot-computer should have reduced pitch-up command at this point but continued giving a pitch-up command which further reduced airspeed to 38 knots, followed by a 5 degree bank angle increase to 35 degrees

6. Improper Control

- R4: was operating a DJI Matrice M600 UAV which collided with a neighboring building
- R35: he made an incorrect input (the drone was facing the pilot and not away as in typical operations) to the controls and brought the uas hard left, with the propeller hitting a car
- R38: a dji inpsire drone was flown into power lines over the mid valley landfill near rialto ca. the operation was a work assignment for the san bernarino county land fill district
- R67: inadvertently ran into a crane on the pennsylvania side of the river. [. . .] pilot interview revealed that he simply misjudged his distance and should have 'panned' the camera.
- R71: uas flew into building causing over 500.00 damage to the building. uas was damaged. flight was too low over the building.
- R86: stating that their uas had struck a house while maneuvering, damaging the siding panel
- R87: uas to veered off course which struck the home siding
- R91: the uas operator was in a hover and attempted to move the uas closer to the intended landing location when the uas suddenly desended and struck a parked truck.
- R94: was being flown over a structure to do a roof inspection when the uas struck a chimney and tumbled down the roof and struck a truck

B. Reviewing

1. Preparation

- R10: [..] after completing our pre-flight and take-off cheklists
- R11: While performing assembly and pre-flight inspections
- R69: [. . .] confirmed that all systems were operating properly [. . .]
- R76: in preparation for the flight, and after loading the flight plan and payload box in accordance with upsff sop
- R84: Performed updates on october 01 from drone, controller and 3 batteries. Performed preflight and test on day of accident. performed preflight and test flight october 02, 2020 at 11:11am to mark location, altitude and systems check. flight lasted 7 min 8s. Once battery cooled it was placed on charged. 1st battery and beginning of mission flight. take off at 11:59. flight duration 18 min 11s_ first 15 s hover to check system, climbed to 350 agl. the 2nd

battery takeoff and sim card replaced. the preflight was performed between 12:18 to 12:21pm.

2. Wreckage Inspection

- R3: Some pieces of the UAS remained in the building while the rest crashed on the ground outside the building, with a resulting fire.
- R10: [. . .] the two lithium batteries that powered the uas were disposed of in a lithium battery disposal bin on site given the fire hazard damaged lithium batteries present. [...] upon inspection of the uas, skyfish (manufacturer) found that the right-side internal power connector (not the external battery connection where the pilots connect the battery), was melted with soot present indicating a short in the positive lead. The sudden loss of power in-air corresponds to the hypothesis that the internal connecter exhibiting soot lost connection to its negative lead during flight and caused a uas-wise loss of power and a surge of current into the logic pdb.
- R11: began searching for the wreckage. upon locating the crash site at 35.886214, -80.003967, I immediately took pictures of the wreckage before moving any of the components. when I did eventually retrieve the aircraft, I noticed what appeared to be a bullet hole on the bottom side of the aircraft. it was at this time that I realized the aircraft may have purposely been targeted and shot down. [. . .] I removed the bottom cover from the aircraft, in an attempt to recover the microsd card, and discovered what appeared to be a bullet inside the aircraft. I removed the object from the aircraft and placed it in a small bag. I replaced the bottom cover and packaged the aircraft for shipment back the manufacturer for replacement.
- R24: the vehicle parts were lost in the lake
- R29: drone was send to manufacturer dji for reason thedrone lost power, was told that there was a battery malfunction
- R38: a southern california edison wire was severed and a small fire started
- R53: the aircraft was recovered and sustained damage to the leading-edge of one wing. it is believed the aircraft can be repaired.
- R80: once they landed the drone, the operator inspected it for damage and found that the landing gear of the new lidar drone had been damaged where a bullet had torn through the carbon fiber and blown the retainer ring off.
- R92: a full investigation was conducted by the security department as well as the drone company, nightingale security. it was determined that there was a spelling error in the coding which caused the drone to read the gps latitude as the altitude resulting in the loss of control.
- R93: Examination of the suas post accident showed structural failure similar to failures found on other suas of the same make and model via internet search.
- R97: impacted the ground north of runway 25 at eastern oregon regional airport (pdt) near pendleton, oregon, destroying the uas and causing a 2-acre grass fire which was extinguish by the local fire department.

3. Inconsistent Expectation

- R9: The pic commenced operations from the same place as before.
- R10: a few minutes into the flight (our 5th flight that day with this uas)
- R11: [. . .] this was the second jobsite I had visited on this day. the aircraft operated flawlessly at the first location. I have operated this same aircraft at the _ location, performing the same pre-planned autonomous mission, no less than sixteen times over the past four months with no incidents.
- R21: a practice run was made prior to conducting the actual photo shoot.
- R53: this was the second flight of the mission being flown by an rpic and two visual observers. the first flight was successful.
- R72: [. . .] said that the uas experienced an error on its first calibration attempt prior to launch but calibrated correctly on the second attempt

C. Reporting

1. Sighting

- R13: After receiving a report of a possible drone above an airport tower, the little rock pd and litle rock airport security searched the area and found no sign of a drone or a pilot.
- R18: the las vegas flight standards district office received notification by the las vegas metropolitan police

department (lvmpd) of a uas that crashed into the side of the "allegiant stadium" in las vegas, nv. the uas was an unregistered dji mavic 2 zoom.

- R30: the suspect uas was found along the side of the property located at _. uas operator could not be located. uas does not have a vaild registration decal
- R31 atc contacted local law enforcement who conducted a search of the ground area near the sighting of the uas. no uas operator was identified. insufficient information is available to pursue an investigation
- R44: if lead poc identifies uas operator this report will be updated.
- R50 the pilot reported a black drone with reflectors at 2000ft
- R56: sheriffs office launched an aircraft to search for the uas, and ground search for the operator. nothing discovered.
- R59: st. jonhs county sheriff notified and st. augustine police department sent patrol unit to check area for anyone flying a drone. nothing discovered
- R60: the investigating inspector does not have additional information and is unable to identify the uas and/or its operator. the reporting pilot does not have additional information either.
- R84: pilot check around restaurant premises and surrounding areas for missing drone. a restaurant employee asked the pilot if he had crashed a drone in 'which he replied that he did. he inquired if anyone was hurt or if it hit any objects in which the employee replied that it hit a black car. the employee pointed to the location of the vehicle and met with the car owner. the pilot identified himself and exchanged insurance information.
- R85: police officers identified a uas flying over a large crowd of people during a city'sponsored event. police officers identified and apprehended subject operating the uas. subject was arrested for violating local ordinances

2. *Damage Control*
   - R10: [. . .] reported to the site manager and the panel section that incurred damage was turned off.
   - R12: realizing the uas struck the powerline the officers reported the incident. the local power company was dispatched and the power line was repaired.

3. *Remediation*
   - R2: will be offered compliance counseling
   - R8: sales director for company stated that they are developing policy for the training and use of suas as a result of the accident. before the accident, only required a practical test and a remote pilot certificate to fly for company.
   - R12: the remote pic was displayed a compliant attitude and brought back to compliange with counseling and a course from the faast website.
   - R21: regulatory violation occurred and no further action is recommended.
   - R43: this inspector counselled the individual to the extent of the following regulations, part 101 regarding hobby and recreational flying along with following a community based set of safety guidelines and if he does not follow this requirement of operation then he becomes a part 107 operator. he was further counselled on part 107 requirements regarding small unmanned aircraft and the registration requirements of part 48.
   - R53: recommendation- determine the cause of lost link and update/repair the uas communication system. learn why the return programming hit the tree. if able, fine tune the programing for better recovery of uas during lost com link.
   - R61: some inter-department training/discussion related to low battery landing procedures was determined to be the best opportunity to prevent recurrence.
   - R88: operator did not expect the turbulant air around the roof and has now set a personal limit for operating in the wind.
   - R101: fontana pd contacted individual responsible and counseled not to operate the uas so high.