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Urban Air Mobility (UAM) Vehicle Design Considerations to Facilitate Future Accident Investigation

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The introduction of Urban Air Mobility (UAM) vehicles will initiate many new and unique challenges to the current operational airspace environment. Many of these challenges are researched today, and solutions are investigated. The main goal of this ongoing research is to develop a safe and sustainable UAM system looking at the design of vehicles and airspace. However, despite research and testing, it is conceivable that when the UAM vehicles actually become operational, accidents will occur. Here in lies the problem; are accident investigators ready for UAM vehicle accidents? Historically, aviation accident investigations had been reactive and investigation outcomes provided recommendations, which paved the way for incremental safety improvements. Rules and procedures are in place to provide a feedback loop to lower the accident rate and maintain a safe aviation environment in its current form. To establish a UAM safety level, the installation and implementation of technical aids and procedures to assist investigators in future UAM accidents are required. These requirements need to be addressed before implementing a new UAM system in order to provide the required feedback loop to maintain an acceptable level of safety. This paper will address the challenges that future accident investigators will face in a UAM vehicle accident investigation. This paper provides feedback from accident investigation professionals who participated in a prognostic survey to discuss what technical means are required to investigate UAM vehicle accidents. It will provide recommendations to future UAM systems designers to address and enable accident investigation in order to maintain and enhance the future UAM safety level. The final goal of this paper is to discover potential UAM accident scenarios which may not be immediately apparent to engineers during conceptual design and identify potential design requirements in terms of investigation capability.

I. Nomenclature

$\tilde{c}$	=	median confidence rating
s	=	standard deviation answer
$\bar{x}$	=	mean rating answer
n	=	number of data set
CVR	=	Cockpit Voice Recorder
FDR	=	Flight Data Recorder
UAM	=	Urban Air Mobility

II. Background

From the beginning of flight accident investigation has been a cornerstone in enhancing aviation safety. In 1908, the first recorded accident with the Wright Flyer was investigated with to aim to determine the accident cause. Once the failure was determined a recommendation was drafted, which would be implemented to prevent recurrence and hereby enhancing the Wright Flyer safety level. Since the Wright Flyer accident, the complexity of today's aircraft has increased, as also did the accident investigations that followed.

The current legal foundation for accident investigation can be found in Annex 13[1] Aircraft Accident and Incident Investigation to the Convention on International Civil Aviation published by the International Civil Aviation Organization (ICAO). Annex 13 provides the legal foundation for investigating a major commercial aviation accident and provides a reference to the obligations and rights for states, manufacturers and other interested parties during an investigation. Annex 13 has served as a cornerstone of accident investigation and helped in providing the basis to conduct an investigation. This includes the main objective of a safety investigation: The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It is not the purpose of this activity to apportion blame or liability

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Several aides, as the flight data recorders were specifically implemented for accident investigation purposes. However, this flight data recorder became mandatory after 50 years of flight. To date, the flight data recorder and other devices are fact-finding tools that aid in reconstructing accidents for accident investigators. They have shown value in determining accident cause and helping in enhancing safey by recommendations.

With the onset of a new era of Urban Air Mobility (UAM) the aviation landscape will change. Does this also mean change for investigators investigating future UAM accidents? From history, it can be shown that common safety features were developed from accident investigation safety recommendation and implemented afterwards. The development of a UAM system is being researched in a broad community but is the vital safety feedback loop forgotten? Provided that UAM accident will be investigated, how will they be investigate in the future?

This paper will address the challenges future accident investigators will face in a UAM vehicle accident investigation. To this end, this paper will identify potential designs requirements in terms of investigation capability and to discover probable UAM accident scenarios, which may not be immediately apparent to engineers during conceptual design. This paper provides feedback from accident investigation professionals who participated in a prognostic survey to discuss what technical means are required to investigate UAM vehicle accidents. It will provide recommendations to UAM systems designers to address and enable accident investigation in order to maintain and enhance the future UAM safety level.

III. UAM conceptual Design

NASA defines UAM as a safe and efficient system for air passenger and cargo transportation within an urban area, inclusive of small package delivery and other urban Unmanned Aerial Systems (UAS) services, which supports a mix of on-board/ground-piloted and increasingly autonomous operations. MITRE describes Urban Air Mobility (UAM) as an industry term used to describe the system that enables on-demand, highly automated, passenger or cargo-carrying air transportation services within and around a metropolitan environment. The industry vision involves leveraging new vehicle designs and system technologies, developing new airspace management constructs and operational procedures, and embracing the sharing and services economy to enable a new transportation service network. The majority of vehicles being developed for UAM applications fall into the Multirotor, DEP Tilt-Lift, and Stopped Rotor categories [2]. These different examples of UAM conceptual design are just a summary of many which are currently being developed. The general consensus is however that the UAM vehicle will be able to carry four to five people at speeds of 100 to 200 knots. The cruise altitude will be around 500 and 5000 feet. The propulsion type is expected to be electric as it would be environmentally more sustainable. Currently, two different control philosophies are proposed. The centralized or decentralized control both of which it seems that the centralized would be more efficient and manageable.

IV. UAM accident factors

For this study, it is required to determine the accident causes as factors which need to be assessed by investigators who will investigate UAM accidents. As the investigators will be the research participants it is important to identify the possible UAM accident causes which can then be assessed and ranked on importance by the experts. At this time there are no set of rules and regulations for UAM vehicles but it is expected that future UAM regulation will be based on Part 23 Small airplanes [2]. Assuming that UAM vehicles are certified on the basis of Part 23 General Aviation possible accidents scenarios can be based on historical general aviation accident data. The Federal Aviation Administration (FAA) statistics [3] for general aviation lists the top 10 leading causes of fatal General Aviation accidents.

It should be noted that the leading causes for general aviation accidents do not reflect UAM future accidents as there are several key differences between GA and UAM vehicles. Firstly, the propulsion system is likely an electrical multirotor. As such, the fuel related failure should be replaced by batteries. Secondly, the UAM vehicle will be either centralized or autonomously controlled. The survey question should therefore be adapted and focused on the autonomous control system (failure) and the ground pilot.

A study by Belcastro [4] used a variety of sources including government accident reports and media reports created an Unmanned Aerial Vehicle (UAV) mishap data set. The data set was on civil UAV events and a total of 100 reports were analyzed. A list of UAV accident causes can be found in table 2.

A similar study conducted by Wild [5][6] who looked at a period of 10 years (2005-2015) analyzing 152 Remotely Piloted Aircraft Systems (RPAS) events. The data set was based on publicly available accident reports, safety reporting systems and a general website search. From this study it was concluded that the majority of RPAS events involved system component failures. The second contributing factor was human factors and the second occurrence category was

Table 1 The Top 10 Leading Causes of Fatal General Aviation Accidents 2001-2016 [3]

Rank	Causal factor
1.	Loss of Control Inflight
2.	Controlled Flight Into Terrain
3.	System Component Failure – Powerplant
4.	Fuel Related
5.	Unknown or Undetermined
6.	System Component Failure – Non-Powerplant
7.	Unintended Flight In IMC
8.	Midair Collisions
9.	Low-Altitude Operations
10.	Other

Table 2 Small RPAS Mishaps Summarized by Primary Cause [4]

Primary Cause	Incidents	Accidents	Fatal Accidents	Total
Flight Controls	15			15
Flight Crew	11	2	1	14
Propulsion	9			9
Lost Link	8			8
Software	6			6
Sensors	2			2
Remote Control	2			2
Wind Shear	2			2
Other	10			10
Undetermined	31			31
Total	96	2	2	100

loss if control in-flight. From this study it was concluded that the airworthiness should be considered as a regulation priority. It should be noted that the studies mentioned above address the necessity to have a specifically dedicated reporting of RPAS events database similar to what is currently available for large (commercial) aviation. Only with this information an improved understanding and awareness can be attained to address future RPAS accidents and incidents.

In the Annual Safety Review 2017 [7] published by the European Aviation Safety Agency (EASA) three key risk areas (Table 3) were identified for RPAS. The first key risk area which has been identified by EASA was aircraft (drone) upset and loss of control. Approximately 50% of the RPAS accidents are related to this type of event. Most of the events are related to drone pilots losing control of the drone resulting in a damage and most often a destruction of the aircraft. The resulting safety issue is flight path control and use of automation. This includes all control aspects of the drone, including loss of link and automation. Airborne Collision is the second key risk area which was identified. Even though there are very few occurrences where actual collisions between a drone and a manned aircraft occurred, the risk is considered to be substantial. As the unmanned aircraft are continuing to grow in numbers, size and shape. Therefor it is vital to monitor mid air collisions closely. Obstacle collision in flight is the third key risk area. Drones used in aerial work operations and in space constrained areas are susceptible to higher collision risk than manned aircraft.

Combining the identified occurrence types for GA and RPAS accident and incidents an aggregated list was developed. This list was used in the survey to query experts on the likelihood and investigation capability of such an event.

Table 3 EASA RPAS Priority Key Risk Areas

Rank	Area
1.	Aircraft upset
2.	Airborne Collision
3.	Obstacle Collision in Flight

V. Experimental Methodology

To determine the areas of importance for future UAM accident investigation, a systematic prognostic approach is required for this research. As the UAM system can be assumed to be a complex system, it is also vital that the experimental methodology is applicable for such complexity. Following the research, it was determined that the Delphi method would be the most appropriate methods as the method is used for establishing a set of priorities to further develop and improve a complex system [8][9]. The Delphi technique is a scientific research tool which uses a combination of quantitative and judgmental processes. The Delphi method uses expert knowledge to forecast in order to set future goals. Delphi uses interviews and questionnaires to extract estimates or prognostication on a specific issue from a valid sample of experts.

As the Delphi technique was previously applied to the 2008 survey conducted by Milosovski [10] and the technique proves to provide important and meaningful outcomes, therefore the survey in this paper was developed having the 2008 survey as a basis. In the 2008 survey, the researchers applied the Delphi method in two rounds of questioning with a working group consisting out of 10 experts. The first round was used to establish a baseline and to determine if (important) questions were missing or areas of importance were overlooked by the researchers in the research. In the second round, the results from round one were aggregated and analyzed with the group of experts to reach a consensus. When consensus was reached, the outcome was made final.

For this UAM research, it was chosen to create a survey which could be sent to various governmental safety board investigators to get their input. However, this meant that due to the nature of questioning and time constraints of this study, the two rounds could not be done in a similar fashion as was done in the 2008 survey. However, the questions from the 2008 survey, as they were previously established by the experts, could be used as a baseline for comparison. A comparison of the survey results could be made and analyzed to establish the merit and validity of the study. Furthermore, the questions in the 2008 survey were analyzed and formed the basis for creating questions for the UAM survey.

The UAM research questionnaire started with an introductory question to explain the survey setup. After an example which aimed at familiarizing the participants to the questionnaire, ten seeding questions were asked in the first group of survey questions. These seeding questions were almanac-type questions which tested the responded aviation and accident investigation knowledge. The expert was asked to answer the question and provide a confidence level from uncertain, neutral, certain and very certain [0-3]. This additional input from the respondent would allow for a more in-depth analyses of the answers provided.

The second survey question group totalling 8 questions was aimed to assess the general accident investigation questions. The respondent was asked to provide the likelihood in answering the (where, when, what, why and so on) question in an accident investigation. The range for the likelihood scale was from Never/unfeasible to Always/definitely [0-10]. The third question group composed of 12 questions related to the different portions of an accident investigation. The respondent was asked how essential is [item] within the process of aircraft accident investigation to obtain a better investigation outcome. The rating for this question was from unimportant to very important [0-10].

Both the second and third group of questions were identical to the 2008 survey. In this way, a comparison between this UAM and the previous 2008 survey can be made. However, in the UAM survey, an additional question was asked for each answer, the confidence level was also requested from the respondent. The confidence range was from uncertain, neutral, certain to very certain [0-4]. This additional input would allow for a more in-depth analyses of the answers provided.

In part four an introduction to the Urban Air Mobility vehicles is given. This part of the questionnaire aims to get insight from the experts on the odds of the major causes for a UAM accident. The survey items are derived to represent UAM mishaps based on the UAS accidents data studied in the literature. [3][4] In the follow-up part, the questions the same topics are queried but now in relation to proving that this particular item being the UAM accident cause. The reasoning behind these question sets is to identify the potential misalignment between the accident cause possibility and the possibility of identifying that as a cause. In both question groups, the likelihood rating and confidence level were asked.

In part six, questions are asked to the experts on which technical means will help in an investigation to solve a UAM accident. The purpose of this question is to solicit which technical means are required for investigating a UAM accident. For the future designers, it is useful to know which technical means method will be essential to UAM accident investigation? Also for this question groups, the likelihood rating and confidence level were asked.

Because Delft University of Technology is concerned with maintaining ethical protections for those who volunteer to help our science and engineering studies, a screening examining research which involves human subjects is mandatory. The research conducted in this study has been approved by the Delft University of Technology Human Research Ethics Committee (HREC). As such the research conducted adheres to the Delft University of Technology ethics standards. The results from the survey were processed by an independent researcher to allow for a impartial analyses and were analyzed using a predefined scheme.

VI. Results

The survey was completed by 12 air accident investigation experts from governmental safety boards around the world. This is comparable to the 2008 study in which 10 accident investigation experts participated in the survey [11]. For this survey, experts were asked to provide a rating for each item in different question groups as well as the confidence level of their answers. This paragraph will present the results and discuss the outcomes for the 6 question groups.

A. Question Group 1 - seeding questions

At the beginning of the survey, 10 seeding question were asked as questions group 1. These questions were meant to test and assess the air safety investigators knowledge participating in the survey. In Table 4 the questions and answers are given with the standard deviation. In the last column, the mean confidence level is given. As an example, question 1.6, which asked how many rotors a quadcopter has, was correctly answered by all the survey participants. This question also has a high confidence level ($\tilde{c}$=3). On the lower end, with least confidence level were questions 1.3 and 1.8. Question 1.3 asked the number of fatalities worldwide in 2018. Question 1.8 was a special question aimed to test the technical knowledge and asked the overall efficiency of a fully electric propulsion system. The reasoning was to test the state-of-knowledge of the survey participant electric propulsion. The question related to the FAR 23 strength of the aircraft safety factor (question 1.10) was not always answered correctly with a mean of 1.7(σ=0.45), whereas the correct answer is 1.5 (FAR 23 CFR Sec. §23.303 - factor of safety). The historical question in group one asked which year the first powered aircraft accident occurred and when the first data recorder was installed in a commercial aircraft. The expert answers were 1911 (σ=7.30) and 1958 (σ=7.34), respectively. The first powered aircraft accident with a passenger death was in 1908 when the Wright Flyer crashed. The first data recorder installed in a commercial aircraft was in 1958 on a Boeing 707.

Analyses of the group 1 questions show that there is a correlation between the confidence level and the provided answers correctness by the experts. This correlation shows that confidence level can further be analyzed to assess the validity of the answer. From the 12 respondents, nine answered six or more questions correctly, the mean and standard deviation of the outcomes all fall within the correct answer except for question 1.9 (What is the highest frequency in hertz (Hz) of an adult male voice?). This question was answered with a mean of 3681 (σ=3793) by the experts. Two experts provided an answer of 180 Hz which is the correct answer.

B. Question Group 2- general accident investigation question

The second group relating to general investigation questions which focus on answering questions; where, when, what, why the accident occurred? In this group, the question was asked: "Given your accident investigation experience and knowledge, what are the possibilities of determining the answers to the question [for item] within an aircraft accident investigation? And to what degree of confidence? The survey outcome is presented in Table 5. Table 5 illustrates that an investigation of aircraft accident occurrence will most likely reveal the answers to questions regarding the question 2.6 (Who was on-board the aircraft), followed by question 2.2 (where did it happen?) and question 2.1 (When did it happen?). All three answer was rated with a confidence level of 3 (very certain) meaning that the experts feel that these questions can always be answered. For answering question 2.4 (the why did the accident happen) the survey reveals a lower score and confidence level. Question 2.8 has the highest standard deviation (σ=1.70) meaning that the experts are not in agreement. However, the confidence level in this case is still certain ($\tilde{c}$=2) which seem to indicate that in (some) cases witnesses can be found.

Table 4 Survey results with respect to question group 1 [n=12].

Question	$\bar{x}$	s	$\tilde{c}$
1.1 In what year did the first powered aircraft accident investigation occur?	1911	7.30	1.5
1.2 In what year was the Fight Data Recorder (FDR) installed in a commercial certified aircraft?	1958	7.34	1.0
1.3 How many fatalities occurred with commercial (cargo and passenger) worldwide in 2018?	429	165	1.0
1.4 What portion of commercial (cargo and passenger) worldwide accidents are caused reported to be human error?	73.8%	23.28	1.5
1.5 How many FDR parameters are recorded on modern (5^{th}) generation aircraft (B787/A350)?	2225	925	2.0
1.6 How many rotors does a quadcopter have?	4.0	0.00	3.0
1.7 What is the cruise speed in knots for a SR 22?	153.8	38.3	2.0
1.8 What is the overall efficiency (0-100) of a full-electric propulsion system (electric engine and propeller)?	61.2%	22.28	1.0
1.9 What is the highest frequency in hertz (Hz) of an adult male voice?	3681	3793	1.0
1.10 What is the factor of safety for strength of an aircraft certified under FAR 23?	1.7	0.49	1.5

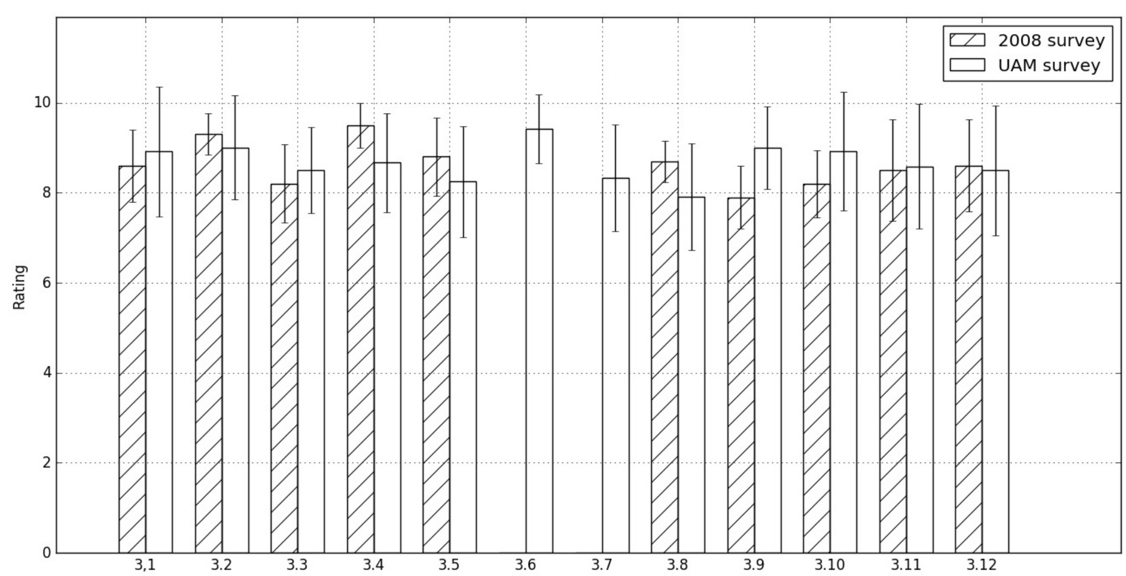

Fig. 1 Comparison question group 3 results between the UAM questionnaire and the 2008 study [11]

Table 5 Survey results with respect to question group 2: 'What are the possibilities of determining the answers to the question (for the item below) within an aircraft accident investigation?' [n=12]

Question	$\bar{x}$	s	$\tilde{c}$
2.1 When did the accident happen?	8.8	0.80	3.0
2.2 Where did the accident happen?	8.9	0.64	3.0
2.3 How did the accident happen?	7.5	1.12	2.0
2.4 Why did the accident happen?	6.8	1.34	2.0
2.5 How was the aircraft maintained?	8.4	1.04	2.0
2.6 Who were the occupants of the aircraft?	9.5	0.76	3.0
2.7 What may have prevented the accident?	7.7	1.49	2.0
2.8 Who were witnesses to the accident?	7.7	1.70	2.0

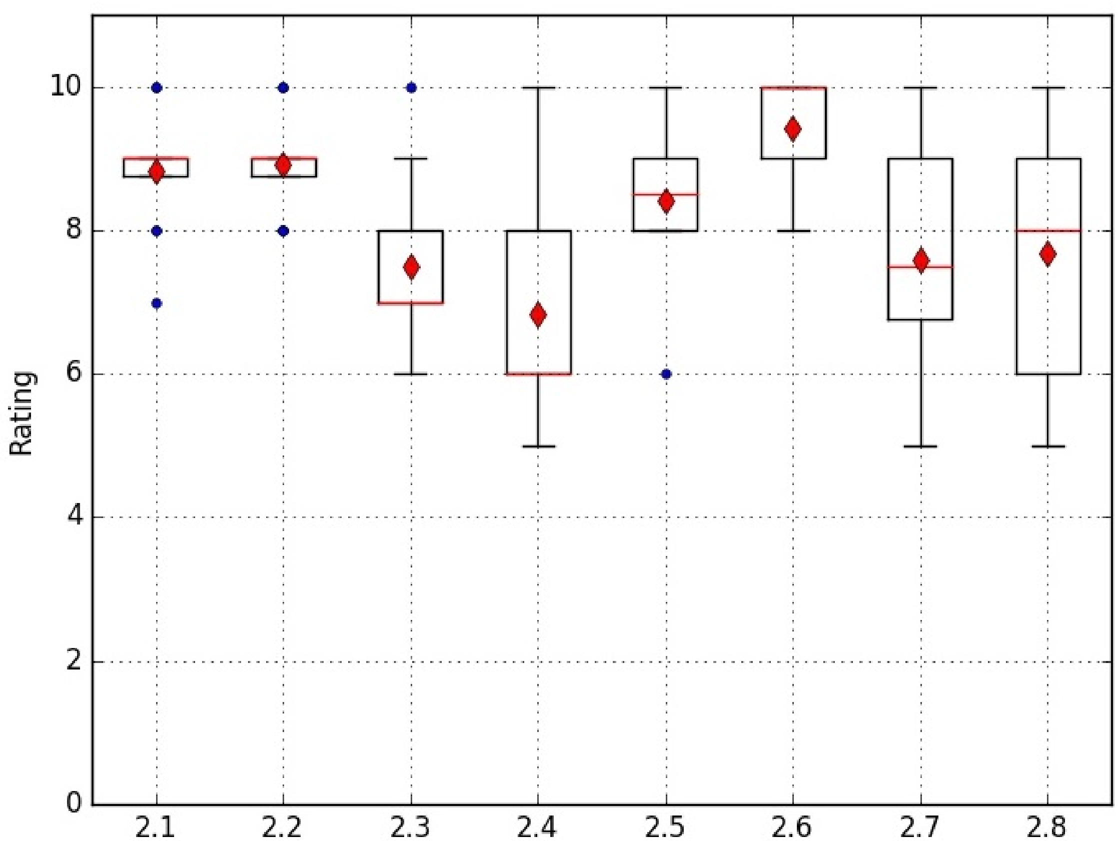

Fig. 2 Box plot survey results question group 2 [n=12].

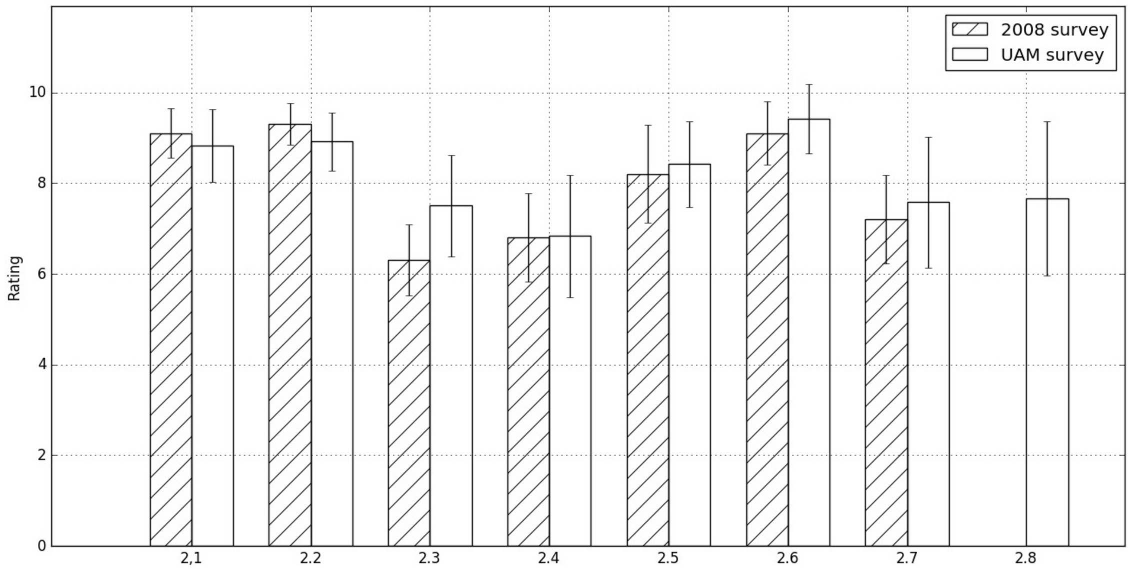

Fig. 3 Bar chart question group 2 results comparison between the UAM and the 2008 survey [11].

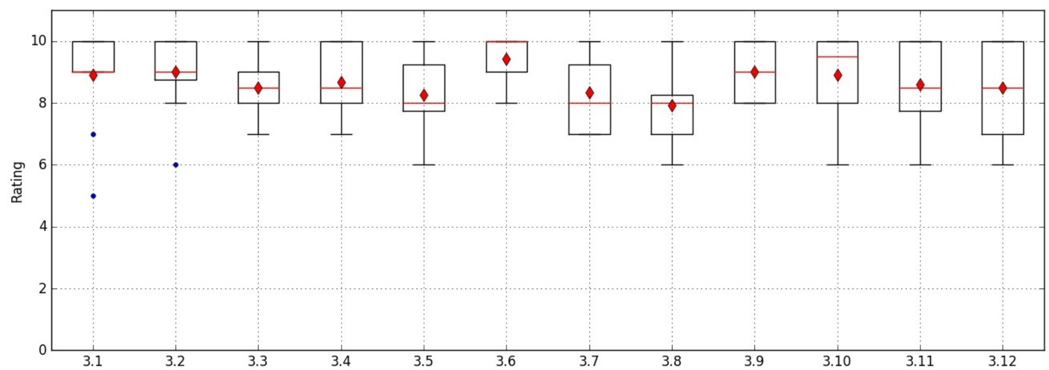

Fig. 4 Box plot survey results question group 3 [n=12].

Because this survey group question was similar to 2008 survey[10] the results can be compared. Figure 2 shows the comparison between the 2008 survey and the UAM survey results. Note that question 2.8 was introduced only in this paper and did not appear on the 2008 survey. The reason for adding question 2.8 was the potential role witnesses play in obtaining information during an investigation.

The figure shows a good correlation between the two surveys with the highest percentage difference of only 5%. This shows the background similarity between the two survey groups, despite a 10 years time gap. The results show again that there is a high similarity between the UAM and the 2008 survey.

C. Question Group 3 - achieving better investigation outcome

In part 3 of the survey, the contribution level of investigative steps on investigation outcomes is addressed. The main question asked was 'Given your accident investigation experience and knowledge, how essential is [the given item below] within the process of aircraft accident investigation to obtain a better investigation outcome?

The survey results are shown in table 6. Item '3.6 Investigation of recorder(s) and aircraft system data recordings' is the most essential in an investigation. Item '3.2 Examination of the scene of the accident' as the second most important. Item '3.8 Laboratory examination' was rated the lowest with a mean rating of 7.9 and a relatively high standard deviation. This item also scored low on the confidence level compared to the other questions. This indicates that although laboratory examination is an item that helps in an investigation, the mean rating is less compared to

Table 6 Survey results with respect to question group 3: 'How essential is (the given item below) within the process of aircraft accident investigation to obtain a better investigation outcome?' [n=12]

Question	$\bar{x}$	s	$\tilde{c}$
3.1 Immediate Notification (no delay in reporting event)	8.9	1.44	3.0
3.2 Examination of the scene of the accident	9.0	1.15	3.0
3.3 Finding and interviewing the witnesses	8.5	0.96	3.0
3.4 Wreckage analysis	8.7	1.11	3.0
3.5 Investigation of Air Traffic Control records & Radar Data	8.2	1.23	3.0
3.6 Investigation of Recorder(s) and aircraft system data recordings	9.4	0.76	3.0
3.7 Investigation of licences, manuals and other records	8.3	1.18	2.5
3.8 Laboratory examination (fracture, chemical, scanning, etc.)	7.9	1.30	2.5
3.9 Reconstruction of events (time line)	9.0	0.91	3.0
3.10 Report writing (Structure & Quality)	8.8	1.32	3.0
3.11 Accident data and information management	8.6	1.38	3.0
3.12 Managing the investigation (Plan, Report, Monitor)	8.5	1.44	3.0

other investigative methods an investigator can use. Nevertheless, the mean rating for all items lay within a numerical boundary between 7.9 to 9.4. From this, it can be concluded that all the mentioned items are very important in an investigation.

Comparing the result from the 2008 survey results and the UAM survey is shown in figure 5. Fig 5 show a good correlation between the different questions. The maximum overall percentage difference of less than 3.5%. The overall high score should be noted in both studies which show the importance of the items in the survey. As such, despite a period of 10 years between the two surveys, the experts consulted still value the methods high and no significant difference can be found. Item 3.6 and 3.7 were not asked in 2008 but introduced in the UAM survey which makes comparison with previous results not possible

D. Question Group 4 - UAM major accident cause

In the survey, question group 4 focuses on the question 'what are the odds that [the given item] is one of the major causes for a UAM accident?'. This is the part of the survey where the prognostic expert opinion is questioned. The results are that 'Pilot human error or omission' (item 4.9) and 'Ground pilot human error or omission' (item 4.5) were rated the highest with 7.4 and 6.7 mean rating, respectively. Despite the fact that in the introductory text of the survey it was stated that current UAM developments focus on a mix of on-board/ground-piloted and increasingly autonomous operations, the experts ranked human error still as a major cause. This is followed by a mid-air collision (item 4.15) with a mean rating of 5.9 (σ=2.6). Mid-air collision as the leading cause is ranked 8th in general aviation accidents 1. Lighting (item 4.11) and icing (item 4.13) are at the lowest rank in the major causes for UAM accidents with mean ratings of 3.2 and 3.4 respectively. Bird impact/foreign impact damage (item 4.10) is ranked with a mean rating of 4.6 with a σ=2.56. In-flight fire (item 4.6) and batteries (item 4.1) are ranked lower and have both the highest standard deviation. The experts seem to be torn as that it will either be a non-issue for UAM (designed out) or a likely cause. It should be noted that the mean confidence level for all the answers to question group 4 were certain ($\tilde{c}$=2). Therefore, the survey results suggest that despite technological developments the human error and mid-air collision are likely the major causes of UAM accidents.

E. Question Group 5 - Proving cause

Question group 5 focus is to look at the question "What are the odds of proving within the process of a UAM accident investigation that (item) is the major causes for a UAM accident?". The background for this question is what the experts think which accidents causes are provable. The survey results show that mid-air collision (item 5.15), batteries failure (item 5.1) and electrical engine failure (item 5.2) are rated to be the most provable by a UAM investigation. The mean

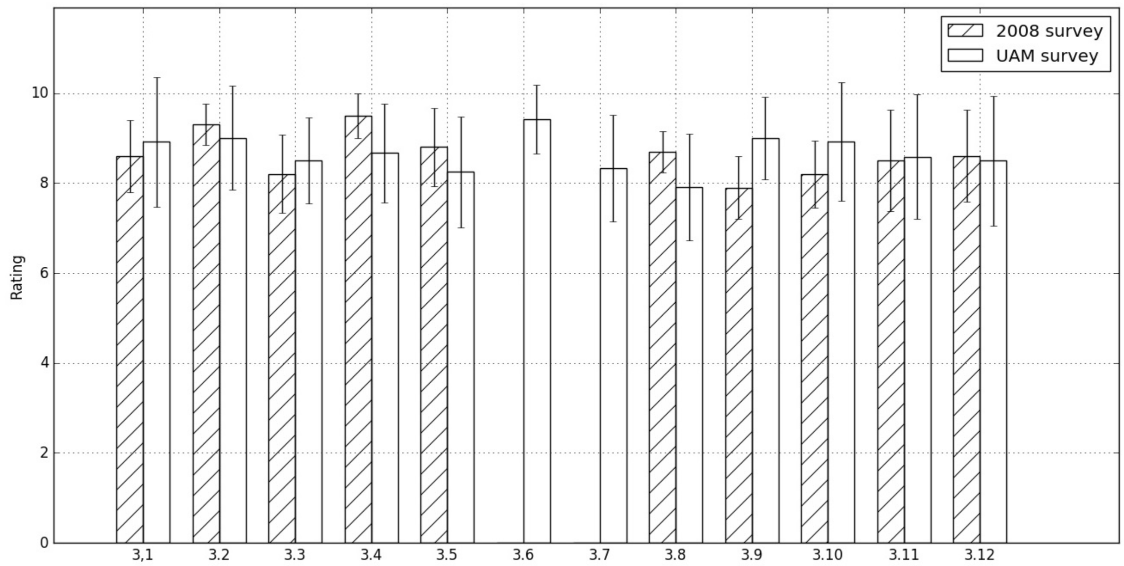

Fig. 5 Bar chart survey results question group 3 between the UAM and the 2008 survey[11].

Table 7 Survey results with respect to question group 4: 'What are the odds that (the given item below) is one of the major causes for an UAM accident?' [n=12]

Question	$\bar{x}$	s	$\tilde{c}$
4.1 Batteries (fuel)	5.1	2.69	2.0
4.2 Electrical Engine failure (power plant)	4.9	1.89	2.0
4.3 Electrical System failure (non-power plant)	4.5	1.55	2.0
4.4 Autonomous control system failure (loss of link)	5.2	2.23	2.0
4.5 Ground Pilot Human error or omission	6.8	1.62	2.0
4.6 In-flight Fire	4.6	2.69	2.0
4.7 Mechanical failure	4.2	1.86	2.0
4.8 Design inadequacy	4.7	2.75	2.0
4.9 Pilot Human error or omission	7.4	1.04	2.0
4.10 Bird impact/Foreign impact damage	4.6	2.56	2.0
4.11 Lightning	3.2	2.17	2.0
4.12 Microburst, wind gust, wind shear	5.4	2.06	2.0
4.13 Icing	3.4	2.10	2.0
4.14 Stability and control of an UAM vehicle	4.8	2.70	2.0
4.15 Mid-air collision	5.9	2.60	2.0
4.16 Maintenance	4.5	1.89	2.0
4.17 Certification (inadequacy)	4.9	2.63	2.0

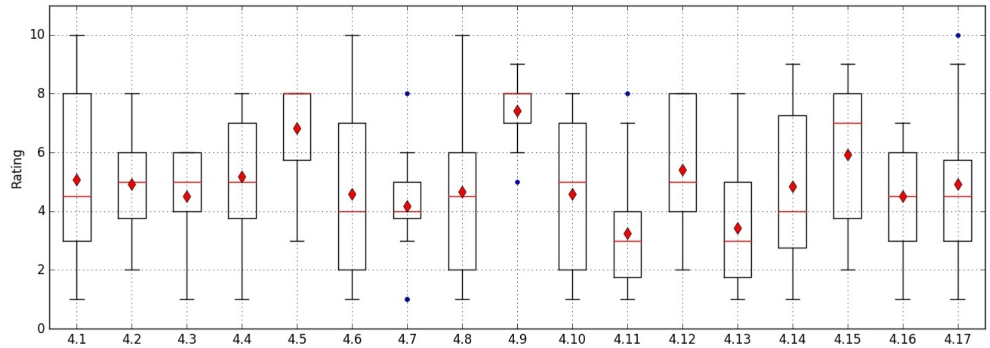

Fig. 6 Box plot survey results question group 4 [n=12].

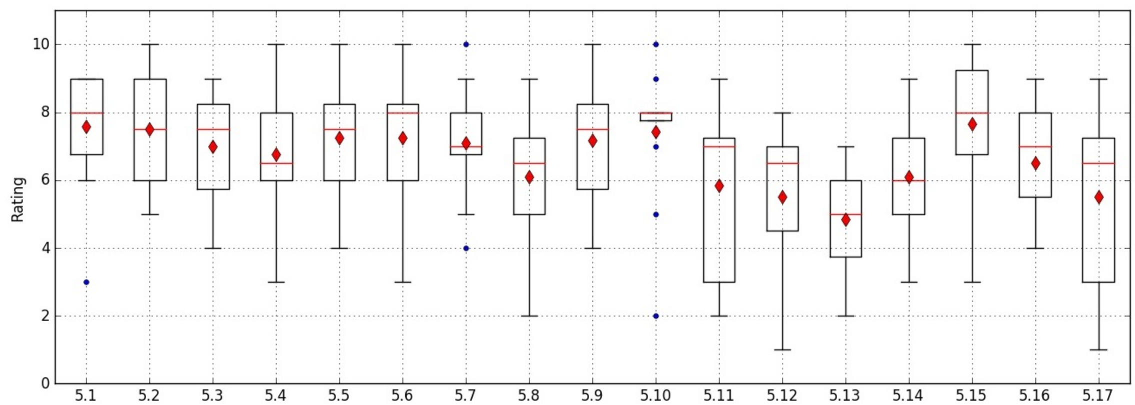

Fig. 7 Box plot survey results question group 5 [n=12].

ratings for the items are 7.7, 7.6 and 7.5, respectively. The results indicate that the survey group assumes that the future UAM vehicle is equipped with an on-board flight recorder which could record an engine or battery failure.

Given the centralized and autonomous nature of the UAM, a mid-air collision is not likely to happen as it will be designed out of the system. This, however, is not reflected in expert answers on item 4.15 which is rated 5.9 (s=2.6) and is in the top 5 of potential major causes. On the other hand, the provability of a mid-air collision (item 5.15) is high as mentioned before. The reason for the high ranking in provability is that there is usually damages on two vehicles.

Icing (item 5.13) is considered very difficult to prove according to this survey and is ranked the lowest with the mean rating of 4.8 (s=1.46). Because the nature of icing, the evidence of icing will most likely disappear on scene an investigator will have a challenge in proving this as a cause. Secondary source (weather) and disproving other causes will result in the probable conclusion of icing. As such icing is form a standpoint of provability a challenge, although according to the result in group 4 not considered to be a likely cause for a UAM accident. Microburst, wind gust or wind shear (item 5.12) received a mean rating of 5.5, but with a high standard deviation of 2.25. Recalling the results in question group 4 which shows that microburst, wind gust or wind shear (item 4.12), are ranked to be in the top 5 by the experts as the main UAM accident cause should be recognized. This result shows that microburst, wind gust or wind shear are difficult to prove, but yet considered a probable to cause UAM accidents, which makes it a future challenge for accident investigators. Recent UAS research also suggests that wind gust (shears) from the building can induce sudden negative angle of attack which results in a sudden loss of lift [12]. Currently, microburst, wind gust or wind shear on UAM vehicle can be detected with on-board anemometer [13] which can be integrated with a reactive control system to increase control in turbulence flight regime. With the UAM flying in an urban environment it will be exposed to buildings and probable various wind conditions. It is therefore very conceivable that a wind shear event can cause a UAM accident. Given this outcome, future UAM designers should acknowledge the wind shear scenario during design and flight testing. The third lowest ranked provable cause is certification inadequacy (item 5.17), this item also has a high standard deviation. Although it is mentioned in the survey introduction, the UAM will most likely be certified according to the FAR 23 standard, the expert result indicates uncertainty on this matter.

Table 8 Survey results with respect to question group 5: 'What are the odds of proving within the process of an UAM accident investigation that (the given item below) is the major causes for an UAM accident?' [n=12]

Question	$\bar{x}$	s	$\tilde{c}$
5.1 Batteries (fuel)	7.6	1.75	2.0
5.2 Electrical Engine failure (power plant)	7.5	1.75	2.0
5.3 Electrical System failure (non-power plant)	7.0	1.76	2.0
5.4 Autonomous control system failure (loss of link)	6.8	1.79	2.0
5.5 Ground Pilot Human error or omission	7.2	1.69	2.0
5.6 In-flight Fire	7.2	1.88	2.0
5.7 Mechanical failure	7.1	1.55	2.0
5.8 Design inadequacy	6.1	2.10	2.0
5.9 Pilot Human error or omission	7.2	1.77	2.0
5.10 Bird impact/Foreign impact damage	7.4	1.98	2.5
5.11 Lightning	5.8	2.44	2.0
5.12 Microburst, wind gust, wind shear	5.5	2.25	2.0
5.13 Icing	4.8	1.46	2.0
5.14 Stability and control of an UAM vehicle	6.1	1.71	2.0
5.15 Mid-air collision	7.7	2.05	2.0
5.16 Maintenance	6.5	1.66	2.0
5.17 Certification (inadequacy)	5.5	2.53	2.0

Autonomous control system failure (loss of link) is in the top 5 of causes, the provability is in the mid-range of group 5. It was expected that this automation and autonomous operation will also inherently create a new risk. This, however, is not what the expert indicates and more 'traditional' failure is considered similar to the General Aviation leading accident causes as shown in Table 1.

F. Question Group 6 - Technical means

Questions in part 6 related to the odds of solving a UAM accident with technical means available. The question was asked:"Given your accident investigation experience and knowledge, what are the odds of solving a UAM accident given the technical means below is available in an investigation". These questions were aimed to elicit a response from the investigators what technical means they would like to have available during a UAM investigation. On-board recorders (Data (item 6.2), cockpit video (item 6.3) and voice (item 6.1)) are in the top 3 and ranked the highest. On-board data recorder, image recorder and cockpit voice recorder are tools investigators expect to employ in future UAM accident investigation. At this point in time, there is no mandate to carry small (crash survivable) recorder on-board FAR 23 aircraft. On-board cockpit voice recorder means rating is lower than on-board cockpit video recorder, but with a larger standard deviation of 1.95. This suggestion varying opinions within the survey group. The data and video seem to suggest that they are more likely to help in an investigation than a voice recorder. Taking into account the mean confidence level the data recorder is ranked as very certain while video and voice are ranked between certain and very certain (2.5). It can be concluded that on-board recorders will help in the investigative effort. Not only should the recorders be installed, the legal and accessibility for investigators to the data, from either on-board recordings or centralized recordings, should be governed.

The two lowest ranked means are witnesses (6.5) and finite element analysis (6.10). While the experts indicate that the confidence level is certain (2) the standard deviation in both cases are high. In the 2008 survey[11] it was also found that investigators should not believe witnesses of aircraft accidents. Finite element analysis has the largest standard deviation and low confidence level. This suggests the uncertainty among the survey group of what this technical means can offer to accident investigation.

Table 9 Survey results with respect to question group 6: What are the odds of solving an UAM accident given the technical means below is available in an investigation?' [n=12]

Question	$\bar{x}$	s	$\tilde{c}$
6.1 On-board Cockpit Voice Recorder	7.4	1.85	2.5
6.2 On-board Data Recorder	8.8	1.09	3.0
6.3 On-board Cockpit Video Recorder	8.3	1.18	2.5
6.4 Interview pilot	7.1	1.32	2.0
6.5 Interview witnesses	5.5	1.50	2.0
6.6 Interview ground controller (remote pilot)	6.6	1.55	2.0
6.7 Central control data recorder (satellite transmission)	7.8	1.21	2.0
6.8 Video and photograph analyses (ground)	6.8	1.40	2.0
6.9 Flight Simulator	6.2	1.34	2.0
6.10 Finite element analyses	5.5	1.93	2.0

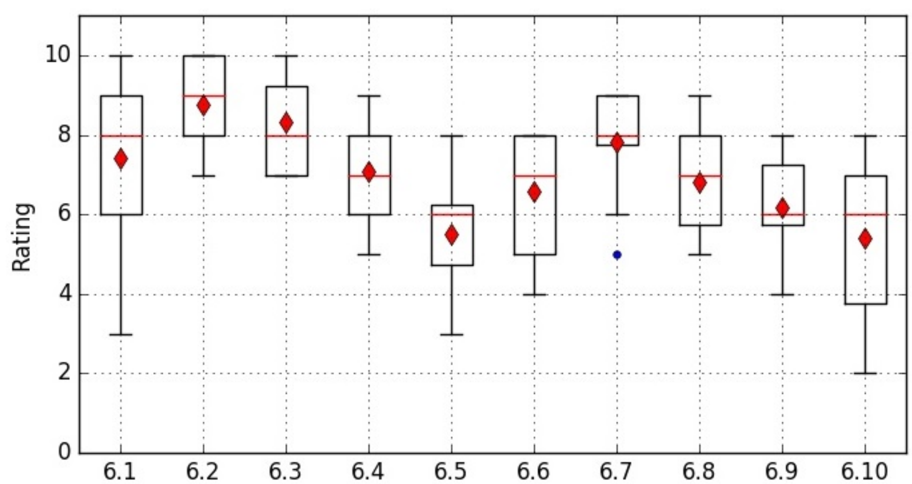

Fig. 8 Box plot survey results o question group 6 [n=12].

VII. Conclusion

This paper investigates the challenges that future aviation accident investigators will face in UAM accidents by conducting a prognostic survey study on accident investigation professionals around the world. In the 2008 survey, the researchers applied the Delphi method in two round questionings with a working group comprises of 10 aviation accident investigation experts. This UAM survey, on the other hand, used a questionnaire send out to 12 accident governmental safety board investigators around the world. Although the methodology between the two surveys was different, the outcomes in question group 2 and group 3 show correlation and similarity. Therefore, the outcomes of this survey are representative of the study in 2008. This shows knowledge and experience similarities between the two survey groups that are 10 years apart. The survey results were analyzed using standard statistical approach. The use of the seeding questions in conjunction with the confidence level attributed to each question by the expert can also further enhance the UAM study merit and be examined in future work in more detail.

From this survey, it can be concluded that accident investigators have identified two major scenarios for UAM accidents. The first is the human component both as a pilot and as a ground controller and the failure of the autonomous control system. Depending on the scenario, the probability of proving one of these scenarios is very high. The second scenario relates to the urban environment in which future UAM vehicles will operate in. According to the survey, a possible major cause for UAM accidents is wind shear (or microburst) which can possibly affect UAM vehicle stability and controllability. The outcome of the survey indicates that proving this as a major cause is much harder and making this a future challenge for accident investigators. Given the expert outcome, future UAM designers should acknowledge the wind shear scenario during design and flight testing. Also possibly looking into including warnings and systems to cope with such scenario.

Related to what investigators need in the future to solve UAM accidents the outcome is clear, data. According to the expert survey, recorders which record both data and video will provide a high likelihood of solving UAM accidents. Therefore the installation of such recorders should be considered as a mandatory design requirement for future UAM vehicles.

This paper has, based on a survey from governmental air safety investigators, discovered two potential UAM accident scenarios which may not be immediately apparent to engineers during conceptual design. It also made a recommendation to include data and video recorders to be incorporated into the UAM design to enhance and facilitate investigation capability of UAM accidents.

For future work, it is recommended to include correlation and non-parametric statistic which can be used to further describe the agreement between experts and the two surveys. Also trying to get more surveys from other investigative board would further enhance the study.

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