Unmanned Aerial Systems for Aircraft Accident Investigations: Enhancing Capabilities, Regulatory Concerns, and Implications for Safety Management Systems (SMS)

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Introduction

The use of Unmanned Aerial Systems (UAS) is growing at an exponential pace. Fueling that growth are the exceptional capabilities and low operating costs that UAS offer a number of fields. At first glance, the use of any technology for aircraft accident investigation appears to be reactive. However, data must be collected from mishaps to move an organization or culture to a more proactive, and optimistically, a future predictive state. In this regard, the use of UAS may improve the timeliness and enhance the available tools in investigators' toolkits, thus fulfilling some of the core tenant concepts of Safety Management Systems (SMS). However, this new capability must be tempered with appropriate integration and responsible use; additionally, current regulatory impediments exist to operating UAS in the national airspace system (NAS). This paper examines the enhancing capabilities, practical applications, regulatory framework and possible barriers presented by using UAS for aircraft accident investigations. The paper also considers how the use of UAS support the aims and precepts of Safety Management Systems (SMS).

Enhancing capabilities of UAS for Aircraft Accident Investigation (AAI)

In a very broad sense, for accident investigation purposes, a UAS is simply an overhead imaging platform. Accident site forensic photography has included aerial imaging for as long as there have been aircraft accident investigations, but the recent convergence of modern, capable, small UAS, with concurrent developments in miniaturization and cost reduction of payloads such as light detection and ranging (LIDAR) and infrared imaging, makes this a promising tool for investigators. Typically, many of the capabilities described below are based on manned aircraft assets, ground-based platforms, or satellite imagery; these assets have much larger associated operating costs and certain sets of limitations. The capabilities that UAS offer aircraft accident investigators, as explored in this paper, are:

A. Capability 1: Immediate Site Safety Assessment

B. Capability 2: Mishap Wreckage Survey and Documentation, to include Recovery Searches and Identification of Debris Fields, Locations of Critical Components, and/or Recovery Operations

C. Capability 3: Mishap Flight Path Reconstruction, Obstruction and Elevation Analyses, Foliage Clipping Analyses

D. Capability 4: Pilot Visual Representation of Flight Path and Induced Perceptual Issues

Advantages of UAS capabilities for aircraft accident investigation

The immediate environment around an aircraft accident can be complex, dangerous, and difficult to reach. The use of a UAS may be able to reduce risks while providing outstanding capabilities to the accident investigator. In other words, the use of an UAS might be best suited for those environments that are 3D (“dull, dangerous, or dirty”), which is similar to the concept of operation for many robotic or automated systems. In many instances UAS can provide imaging capability to the investigator in a timely manner, and with less risk exposure than manned aircraft, and potentially provide a unique perspective impossible from satellites, conventional aircraft, or ground-based platforms.

There are several UAS types (small UAS or sUAS, and larger platforms) that might be considered; generally, the deciding factor should be driven by the investigative requirements for the mishap. Even the sUAS category spans all the way from widely available and popular hobby-grade units like the ubiquitous DJI Phantom, offering low cost, and ease of use but with limited range and capabilities, to very sophisticated platforms like a Boeing/Insitu Scan Eagle, with higher cost and complexity, but long endurance and more advanced payloads. Larger, higher altitude platforms are likely beyond the reach of the typical accident board, but with coordination with appropriate other agencies, these very advanced platforms may be useful for remote or wide area searches.

A sUAS, that can be deployed rapidly, is expendable (may be sacrificed without great expense), and may have capabilities to reach into terrain too difficult for manned aircraft, such as a box canyon. A sUAS may be able to respond more quickly than traditional assets and maneuver/navigate into areas where it might be difficult for manned aircraft or ground support equipment.

A sUAS may be able to operate in contaminated or compromised environments wherein it might be dangerous to operate with humans without proper personal protective equipment (PPE); in addition, this PPE may not interface with the supporting manned aircraft or may create unique operating hazards of its own; both aircraft and occupants may need to be decontaminated. However, an UAS may be easier to decontaminate if flown in a hazardous environment than a manned asset.

A sUAS can be much less expensive to operate than a manned platform, might be able to support faster sortie turn around times, could provide for persistent surveillance to monitor changes in the wreckage site due to environmental conditions, or simply support the data collection task for the investigative activity.

The immediate on-site availability of data and video could greatly speed and focus the mishap investigation, vice waiting for the return of manned aircraft, or attempting to obtain satellite imagery (which can be sensitive to timing of orbital passes and cloud cover). Additionally, UAS may be more responsive to rapid changes at the accident site; it might be more easily re-programmed or re-tasked, or even dynamically operated as conditions change or as the sUAS discovers additional information, with much less expense.

Given these attractive capabilities, the tendency might be to use UAS for all accident investigations, however, a caveat: there will be many instances where the UAS would not be an appropriate tool; in all cases, investigators would need to select the right tool, and understand that UAS are not a panacea; sometimes a helicopter or a cherry-picker is a more appropriate overhead platform.

Through the course of this paper, the term UAS is used generically and can pertain to either sUAS or larger platforms.

Detailed capability discussions

Capability 1: Immediate Site Safety Assessment

A UAS may provide distinct advantages over manned aircraft or other search and surveillance efforts in mishaps that are significant enough to also prompt a disaster response, such as techniques used by first responders and law enforcement agencies. In general, UAS may greatly aid the assessment of hazards and the initial incident response actions leading to the protection of life, property, the environment, and mishap evidence. Small, human-portable UAS (backpack-able) can quickly provide real-time assessment of difficult to access debris fields. While not typically part of the accident investigation mission, fixed-wing longer endurance UAS can assist in locating and identifying injured personnel (especially a pilot who may not be near the primary debris or accident site due to an ejection, from parachuting from a disabled aircraft, or from attempting to walk to find aid). This capability could be better suited for military aircraft accident investigations.

UAS imagery and other data might be obtained from platforms operated by either the accident investigation team or the first responding agency. Either way, appropriate integration and dissemination via an appropriate multi-agency coordination structure can leverage the information to benefit both tasks. In the U.S., the Federal Emergency Management Agency (FEMA) National Incident Management System (NIMS) is an excellent model of a consistent nationwide template designed to protect, organize, and disseminate knowledge throughout responding organizations [see http://www.fema.gov/national-incident-management-system]. Use of such initial data gathering and dissemination supports a common operating picture for responding agencies' incident response and command system; ideally, information would be disseminated to applicable first responders and security personnel on a real-time basis. First responders and investigators may determine if areas need to be evacuated or searched, and determine where to establish appropriate controlled-access points or quarantine areas. Early information might reveal additional personnel or structures that may be in distress or threatened by the primary mishap. This early detection could result in life or property-saving help arriving with a reduced response time thus increasing the probability of a successful outcome.

Information on the location of active fires or flammable fluid leaks or other hazards that may be exacerbated or become a threat due to the accident aircraft or fire, composite hazards, and information concerning other hazardous materials can be crucial to both the investigator and responder. Similar information could be shared with environmental authorities to quickly mitigate leaching or leaking into streams or groundwater, and a site perimeter for security measures and containment can be determined and managed through coordination between the ICS commander and investigative team site command. This initial imagery might be useful for the accident investigator in developing an overall "picture" of the mishap. The data could be critical in defining immediate actions to safeguard people and property, and also can be used to help define actions to safeguard accident evidence; it may provide information used in planning how to proceed, how to access the site, identify items of primary importance for analysis and recover, identify paths or means to remove that evidence, and provide an overall picture useful in the initial situational awareness of the accident investigation team.

Imagery can aid investigators in assessing the non-visible sides of a scene, locating damaged structures, determining orientation of major aircraft structures, and determining elevation and terrain information for analyzing accessibility. Ancillary initial actions may also include identifying ground scars and foliage damage for initial flight path determination, as well as for follow-on analysis to define search areas for additional evidence and information.

This particular use of a UAS for assessing hazards complies with the suggested SMS Emergency Response of protecting responders and investigators from unnecessary risks.

Capability 2: Mishap wreckage survey and documentation to include recovery searches and identification of debris fields, critical components, and/or recovery operations

After initial response actions are completed to protect life, property, and the environment, accident investigators could use the UAS system to begin mapping the wreckage distribution, debris fields, component and evidence locations, and building airborne depictions that are extremely useful in the mishap analysis as well as determining other locations of interest or locating missing components. Ground scars, wreckage distribution, foliage damage, and other factors can be useful in determining flight path vector; this is extremely valuable in the initial stages of investigation to help determine the state, attitude, flight path, and energy of the aircraft at impact.

In mishaps associated with inflight break-ups and/or mid-air collisions, components and wreckage may be distributed many miles along the flight path; in some cases, this may be tens of miles. In the past, areas to be searched were identified by radar data and initial flight vector analysis; teams were then dispatched, either on foot or via all-terrain vehicles, to search along the flight path for additional clues and evidence. This can be a time-consuming and labor-intensive activity that may span a time period of days or weeks. However, the use of UAS, programmed to fly waypoints along the mishap aircraft's determined flight path, could considerably reduce the search time and improve the detection and recovery time for components not located near main debris fields. Either the UAS in this system would need a pre-programmed route (and one that might include a typical search and rescue pattern, such as a "zipper" pattern, grid search pattern, or other), or, an operator who could follow the UAS and fly it along the areas of interest.

One option might be a zig-zag path along the reported or planned route of flight. Data could be obtained by several means: visible light identification, infra-red (IR) identification, or, if large enough to be equipped, with radar identification.

We have recently seen the use of satellite imagery to assist in the location of debris fields following the Malaysian flight 17 event in the Ukraine. Although it was impossible to operate a UAS in the area due to the on-going conflict, the event demonstrated how a long endurance UAS could be put to good use in the search for victims and debris in an in-flight break-up scenario.

This is not a new concept as automobile accident investigators have been using UAS to shield themselves from unnecessary risk for several years. Aviation investigators could learn and build from this experience. In 2013, the Vermont State Police Department practiced using an ARA Nighthawk IV Micro Unmanned Air System for accident reconstruction. The Royal Canadian Mounted Police have recently begun flying the Draganflyer for traffic accident reconstruction and Crime Scene Forensic Services. Finally, the Arlington, Texas Police Department has been evaluating the use of an 11-pound helicopter-type UAS for accident reconstruction.

Capability 3: Mishap flight path reconstruction, obstruction and elevation analyses, foliage clipping analyses

In many mishaps, analysis of the final flight path is illuminating for several reasons: it may identify structure or terrain that was struck by the aircraft to initiate the mishap or as a result of the mishap, it may identify foliage damage that can further be used for flight path vector analysis, or it may identify other issues with the flight path of the aircraft that were casual or post-mishap factors in the accident.

Additionally, UAS may be useful in producing reconstructions of mishap events against the backdrop of the actual terrain and wreckage pattern, which would be useful for both investigator analysis and for public consumption.

New techniques in photogrammetry can greatly aid investigators in the analysis of mishap wreckage distribution. Clues that might have taken days and numerous photographs to uncover could possibly be discovered in hours. Similarly to the convergence in imaging technology mentioned above, the expanding availability of affordable stabilized camera gimbal mounts and camera systems that employ high-definition level resolution, the investigator could benefit from modern, low cost, easy to use, photogrammetry and Geographic Information System (GIS) software to develop overlays of geographical locations, elevations, and wreckage distribution photographs. This might include detailed measurements and analysis of terrain and impact factors to better understand imparted loads and detailed three-dimensional maps of the wreckage distribution, orientation, size, and condition. It may also be useful in the analysis of post-crash fire propagation, as may be imaged in structure or surround foliage, or, analysis of inflight fire damage that might not be apparent unless viewed from some angle that is inaccessible by the investigator without a UAS.

Capability 4: Pilot visual representation of flight path and induced perceptual issues

UAS could be used to perform a pilot's eye view reconstruction of the flight path vector from any starting point, to the mishap location, as long as the UAS performance can obtain the initial point and flight path angle for a real-time reproduction. However, probably more useful would be the UAS flying the final flight path vector at a slower speed, and/or stopping at various points along the flight path. This video could then be used to produce photographs and accelerated video to better approximate the actual flight path vector. This type of reconstruction might be difficult or time-consuming for a manned aircraft; the UAS could perform this task multiple times over with varying factors, to include changes in winds, changes in sun angles, various flight path angles, etc., all to further evaluate any perceptual issue or to help gather additional data. Additionally, the UAS can look horizontally, vertically, and behind to further capture flight path and associated information. To accomplish this with a manned aircraft would require multiple passes on perhaps multiple days and might be impractical or impossible due to weather, terrain or obstructions, scheduling and coordination requirements, budgetary reasons, aircraft performance limitations, or investigator safety.

Because the UAS could provide a pilot's egocentric view, it might provide information regarding any visual illusions or attempts to modify the flight path during the final portion of the mishap sequence or as a prelude to the mishap. For example, terrain or runway illusions exist that might cause a pilot to incorrectly estimate that he/she is either too high or too low on an approach; or it might provide information regarding sun glare or other blinding phenomenon that might have prevented a pilot from observing another aircraft or obstructions.

A case in point where a UAS flying a flight profile could have reduced risk for accident investigators, yet given them a great view into the pilot's perception, is an F-15E mishap that occurred in Southwest Asia in March of 2012. This accident occurred during greatly reduced visibility conditions: blowing sand and during nighttime. The United States Air Force (USAF) Accident Investigation Board (AIB) found that "...visual stimuli from light sources on the ground caused the MP to misinterpret his attitude and because this illusion was so strong, he initially did not make any attempt to call up the Electronic Attitude Director Indicator (EADI) or confirm his attitude with his standby instruments. Instead, he maneuvered the MA in accordance with his mistaken visual interpretation of his attitude and flew the MA into an inverted position. In addition, the combination of environmental and procedural aspects of the approach to the base created an environment where the MP was very susceptible to a visually induced illusion and offered a very small window of opportunity with which to correct his misperception." The Board further clarified: "…due to the lack of any significant topographical features, the expected lack of cultural lighting, the reduced visibility and the lack of a discernible horizon, the mishap pilot became disoriented by the cultural lighting in the vicinity of the mishap site and incorrectly perceived that the mishap aircraft was inverted. This perception caused the mishap pilot to roll the mishap aircraft into a truly inverted attitude" (USAF Aircraft Accident Investigation Board Report, F-15E, T/N 90-0235, 391st Fighter Squadron, 366th Fighter Wing, Mountain Home AFB, ID, 28 March 2012, retrieved from http://usaf.aib.law.af.mil/ExecSum2012/F-15E%20Southwest%20Asia%2028%20Mar%2012.pdf). Using an UAS to follow the flight path of this F-15E would help demonstrate to the board what the MP was seeing without putting other aircrew and/or expensive assets in danger of trying to simulate the conditions At night in blowing sand), let alone for the cost of use of the aircraft, pilots, fuel etc. After a review of USAF AIB reports over the past 10 years, one will see that this is not the first USAF mishap attributed to spatial disorientation in this location.

Barriers, issues, and the current regulatory environment

In the sections above, we have discussed the technical capabilities and advantages for accident investigator use of UAS. However, UAS are not a panacea for all investigative needs. Even if a UAS is appropriate, the investigator must choose the right tool for the job – from a backpack-able quadcopter, to a long-endurance fixed-wing with a ground control station (GCS). For an investigative team that is operating their own UAS, it is imperative that the operator is thoroughly trained on the platform, any autopilot functions, and have the same level of flight safety plan that would be expected of an authorized commercial or public operator. The operator must be fully aware of the limitations of the vehicle and resist the mission pressure temptation to push battery endurance, weather conditions, payload weight, or other factors.

Beyond the technical questions, the regulatory issues are far more complex. At the time of this writing, regulations for the operation of unmanned aircraft vary greatly around the world. It is imperative for the accident investigator to be thoroughly familiar with all laws and requirements applicable to the particular case. As an example, we will discuss the current application in the U.S.; however, your own situation may vary. Current barriers include the lack of regulatory guidance or operating permissions in the commercial area, privacy concerns, operator training and standardization, air vehicle design considerations, standardization and certification, and air traffic conflict resolution (especially in areas such as Class B, C, or D airspace).

At the present time, there are only limited avenues to operate a UAS in the United States. In 2007, the FAA issued a policy clarifying that an unmanned aircraft is an “aircraft” for purposes of civil regulation, with the only exceptions being for hobby and recreational use operated under specific guidelines. Most unmanned aircraft operating in the U.S. do so under the provisions of a Certificate of Authorization (COA). Presently, with a very few exceptions, only Public Aircraft (government agency) operations have been granted COAs. A very few commercial operations have been authorized, but only in limited areas.

Obtaining a COA is not the only hurdle, however. Other regulations also apply to U.S. Government agencies operating aircraft. The Federal Management Regulation requires that an agency must have a congressionally authorized aviation program before operating any sort of aircraft – whether a transport category jet, or a 10 pound multi-copter. Such a program will require robust training, risk management, and airworthiness policies before even attempting to obtain an FAA-issued COA.

This is a good-news/bad-news situation for us in the U.S. Although the NTSB does not have an authorized aviation program, the accident investigation mission does not lend itself to just the one or two platforms that such a small agency could support. It is therefore imperative that a small investigative body understand the various platforms and capabilities available, communicate with other agencies or operators, and develop a comprehensive policy to interact with those bodies that may be able to provide UAS support. For example, in the case of a large aircraft in-flight breakup, we may need to call on a federal agency or military service with a long endurance fixed wing vehicle, possibly with stand-off capability, for wreckage search, whereas for a general aviation accident in rough terrain, a local law enforcement rotorcraft, operated by personnel familiar with the area, might be the best solution.

At the current time, the option of hiring commercial providers is not available in the U.S., but some countries do have commercial UAS imaging operators, and with appropriate guidance from the investigators, could provide useful imaging or other services. Care must be taken to thoroughly understand the operating and regulatory status of the commercial operator. Imaging from hobbyist UAS is also becoming quite common, and should be treated similarly to any other bystander video or photos for twofold reasons – the photographer may not understand good forensic photography techniques, and to avoid giving tacit approval to an unapproved commercial operator.

Standard Operating Procedures (SOPs) provided to UAS operators should clearly delineate the operational control of the mission, describe in detail the type of product and procedures needed for the investigators, ensure ground safety for both on-scene team members and bystanders, provide for appropriate airspace management, and be fully integrated with the overall Incident Command System established for the accident.

Given the current high interest in privacy concerns surrounding UAS, the investigation team must also provide a plan for data protection, and appropriate public advisories of the UAS operation. It is entirely possibly that legal requirements for the protection of UAS-gathered data may be more strict than that from manned aircraft or ground-based imaging.

It is imperative that the accident investigator conform to all regulations and guidance regarding privacy issues. Explicit permission to overfly private property should be obtained by the accident investigation team. As an example, a comprehensive data management plan might allow for property owners or others whose images or property are captured in UAS video to review the material of interest in a secure area. Personnel should also be informed concerning the use, storage, and protection of the material (data handling protocols) that are in place (be they civilian or US military safety privileged material). Efforts should be made to remove any material that is objectionable if it no way alters the use of the remaining material to serve in accident analysis. Data collection should not be conducted surreptitiously; the more open and honest investigators are (without simply just releasing all material to the public domain) the easier it will be to obtain permissions for over-flight, data collection, and data release.

Safety Management Systems and UAS

SMS is how organizations systematically manage safety risks along with maintaining and improving their safety performance. The FAA defines SMS as “The formal, top-down business-like approach to managing safety risk. It includes systematic procedures, practices, and policies for the management of safety” (FAA, 2010, p. 8). SMS consists of four components: Safety Policy, Safety Assurance, Safety Risk Management, and Safety Promotion. The Safety Policy pillar consists of management commitment, safety accountabilities, appointment of key personnel, coordination of emergency response planning, and SMS documentation. The Safety Assurance component is comprised of safety performance monitoring and measurement. The Safety Risk Management component includes various tenants, including hazard identification, risk analysis and assessment, and risk control/mitigation. The Safety Promotion component is built on elements such as training, education, and communication. When one first hears the term SMS, one may focus on large aerospace firms or air carriers implementing a safety program. However, the unique perspective below demonstrates that even the smaller process of investigating accidents with a UAS supports all four components and many of the elements comprising SMS

The first capability discussed, immediate site safety assessment, which protects first responders and investigators, maps directly to the Safety Risk Management component of SMS. The UAS vehicle could identify potential hazards ranging from high-pressure vessels to hazardous materials (HAZMAT). This allows personnel to identify all the potential hazards before entering the mishap site and analyzing the risk to responders and investigators. If needed, the first on-scene personnel could use the UAS site assessment to conduct corrective actions to reduce the risk to further personnel. Corrective actions could include everything from placing barriers around flammables to spraying fixant on composites to minimize the amount of airborne respiratory irritants. These steps follow the basic SMS components of Safety Risk Management; identify the hazards, analyze the risk and then control or mitigate the risk as needed.

The second capability described, Mishap Wreckage Survey and Documentation, also supports several SMS components. The Safety Promotion element of safety communication is supported by this capability as it allows for the relay of information about the entire site while keeping investigators from potential hazardous conditions, including terrain. This capability could also minimize the amount of foot traffic needed to document the site. This would prevent fatigue of the investigator as some mishap sites can be dozens of square miles and that is after a potential long hike to reach the site. The environment can also amplify fatigue, with the potential of hot and/or humid conditions at some sites. The less on-site time, the less risk to the team members.

The last two capabilities discussed; Mishap Flight Path Reconstruction and Pilot Visual Representation of Flight Path and Induced Perceptual Issues support three of the four Components of SMS. Once again, the investigating team is being shielded from unnecessary risk while identifying and mitigating hazards which supports Safety Risk Management. This time the focus is on a pilot who may be put at risk by flying the same route as the mishap aircraft. The team is able to view the mishap pilot's perspective without risking a person and expensive assets. The team is also receiving real time communication about the potential hazards of the path that may be communicated on to other pilots. This communication is a key aspect of Safety Promotion. The Safety Assurance pillar is supported by this capability as it allows for proactive safety efforts to prevent mishaps.

In summary, all four capabilities allow the investigative team to minimize the risk to personnel responding and investigating a mishap. These capabilities decrease investigators' exposure to hazards in the field. This reduced exposure will lead to less chance of hazmat contact, injuries from sharp edges, rough terrain and fatigue from long days in extreme climate conditions. The capabilities also prevent harm to investigative personnel that may try to replicate the flight path. All four capabilities also communicate real time status to the investigative team and allow for information flow to the team and in some cases back to other pilots, FAA and aircraft manufacturers.

Additionally, having a plan is a major part of the SMS component, Safety Policy. This plan should ensure that investigators, as well as non-participating parties, the public, and private property be protected to the maximum extent possible. UAS operations for accident investigations should utilize a risk mitigation strategy, such as operational risk management (ORM), to assess real-time risks posed by UAS operations during accident investigations. In general, the risk assessment should include determining risk factors, determining assets and personnel at risk, especially investigators working near the accident site, risks to the public and private property, hazards of an airborne operation to other aviation operations, environmental risks, including operations that might ignite flammable fluids or materials, and possible undesired contamination of the mishap evidence through UAS operations. Specifically, UAS generally emit or modify the airflow around them; operators would need to ensure the UAS does not scatter or contaminate evidence. Additionally, if a UAS mishap occurs, ensure that the UAS is operated in a way that would prevent further complicating existing hazards or causing damage or contamination of the mishap site that might be caused by an unplanned landing of the UAS in the mishap debris. Clear operational guidelines must be established regarding permissible weather for operations (visibility, ceiling, total winds and crosswinds), as well as the location of hazards in the vicinity of the operation. Examples of hazards might be towers, structures, power transmission lines, approach or departure corridors, densely populated areas or roads, trees and vegetation, livestock, and any other concern that might affect the efficiency, effectiveness, or safety of the operation. There must be a contamination control plan, to include operating and return areas for UAS assigned to fly missions in compromised or contaminated environments.

This would also include the method and location of decontamination efforts and reconstitution for the next sortie.

Depending on timing of a mishap, access to UAS, and the current regulations, the UAS could be used even prior to the investigator process to protect the first responders. They, too, could assess the situation, search for survivors, and identify hazardous areas without putting themselves at risk.

Additional potential proactive and possibly predictive measures of UAS include route and obstruction verification, as well as lighting and instrument approach validation. Moving from a reactive aviation safety approach, characterized by accident investigations, to a proactive prevention of mishaps, through the capabilities offered by UAS would be consistent with the goals of SMS. A specific example could be an UAS rated for harsh environments used to check-out approaches in various remote locations and in various meteorological and environmental conditions to be more "predictive" in where spatial disorientation may be a factor. Data from these approaches could then be used for training and research, thus reducing the likelihood of mishaps.

Conclusion

The purposeful development of techniques and procedures for utilizing UAS, along with the convergence of related technological capabilities, promises a significant enhancement to traditional methods of aircraft accident investigations. Additionally, the UAS capabilities above directly relate to components of SMS; following the SMS process will continue to increase safety to all team members involved in an investigation. The results of the investigation will also allow aviation to transition from a reactive to proactive, and finally, predictive safety environment.

The authors feel that additional study into the practical use of UAS for accident investigation and mishap response is greatly warranted, as well as the potential for cross-pollination in multi-modal transportation or other major industrial or disaster investigation areas. As UAS technology and the regulatory environment continue to evolve, areas for future exploration and enhancement can be developed by accident investigation bodies and industry/academia partners. Exploration may begin with the use and evaluation of UAS during accident investigation training scenarios, with an initial goal to establish baseline guidelines and criteria for vehicle selection, reliability, safety, performance, operating altitudes and locations, test objectives (photographic, survey, immediate assessment, photogrammetry, flight path reconstruction), candidate pilot/operator selection, and reporting requirements. These programs should also evaluate the use of UAS for first responders under applicable incident response and command systems. As techniques, best practices and standard operating techniques are developed, members from national investigation boards, industry partners, and collaborative groups such as the International Society of Air Safety Investigators (ISASI) can participate, as well as serve as a clearinghouse for information regarding the efficacy, considerations, and concerns of operating UAS for accident investigation. We can foresee evaluations conducted under representative and realistic conditions to the maximum extent possible; programs should consider the operating terrain, the use of actual wreckage or test parts to evaluate effectiveness, and integration into incident reporting systems for first responder and accident investigator real-time dissemination and situational awareness. Teams should consider writing an ASI SMS plan detailing how the UAS will be operated to support the mishap investigation.

Acknowledgements

The authors would like to thank the following people for technical content and editorial review: Mr. Jim Terrell Mr. Jim "Scoop" Roberts, Mr. Bret Tesson, Mr. Jim Buse (all Boeing).