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SHAPING THE FUTURE OF ADVANCED AIR MOBILITY SAFETY

RAeS PRESIDENT'S 2024 BRIEFING PAPER

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Contents

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- Aerospace is on the cusp of a major revolution in Advanced Air Mobility (AAM), involving electric flight, autonomous systems and operations at volume in new spaces. But how will AAM safely integrate with legacy aviation systems and operations developed over the past 100-plus years?
- This paper explores the near-future challenges of passenger-carrying eVTOL (electric Vertical Take-Off and Landing) aircraft by illustrating three hypothetical scenarios set in the year 2035, incorporating lessons learned from traditional aviation, and offers recommendations to address some of the safety challenges that may lie ahead.

EXECUTIVE SUMMARY

Safety is the paramount priority of aviation. Today, commercial aviation provides the safest mode of transport. This is the result of an effective and highly regulated sector with an unparalleled deeply-rooted safety culture that has been shaped over the past 120-year evolution of powered flight.

Now, aviation stands on the cusp of another evolution, one powered by innovative propulsion technologies and in timely alignment with accelerated innovation in electrification, digitalisation, automation, artificial intelligence (AI) and autonomy. These technological breakthroughs not only provide significant opportunities to develop novel aircraft for a new era but, furthermore, advanced systems and enabling capabilities to support their operational environment on the ground and in the air. Moreover, these can enhance safety by addressing some of the issues impacting the current aviation system.

Advanced Air Mobility (AAM) using Electric Vertical Take-Off and Landing (eVTOL) aircraft, presents an opportunity to sustainably and efficiently connect people, transport goods and provide services across congested and disconnected places, delivering wider social and economic benefits. As these novel electric aircraft are introduced into the operating environment, mixed with conventional aircraft, the evolving aviation sector must endeavour to uphold and continuously improve the level of safety for which it is known. This responsibility lies with all actors within the expanding aviation ecosystem, comprising both well-established aerospace players and new entrants, with the challenge of varying safety cultures and safety management systems (SMS).

Today's aviation safety levels have been achieved by incremental learnings and improvements over many decades. Key to this is a non-punitive accident investigative culture aimed at determining root causes for accidents and incidents, sharing of subsequent lessons learnt and embedding preventative actions based on fresh findings.

This paper introduces a predictive safety approach for AAM by conducting innovative 'pre-mortem' investigations of forecasted accidents with a global lens to collate critical safety lessons and recommend actions now to prevent them from happening in the future.

The primary recommended actions are:

1. Industry-led collaboration
2. Real-time information sharing
3. Modern, scenario-based training for all players
4. Building safety culture throughout industry
5. Developing regulator capacity and capability

By helping to pave the way to an even safer era of aviation, the Royal Aeronautical Society (RAeS) builds on its 158-year legacy and continues its distinguished role in shaping the future of flight.

Kerissa Khan (RAeS President, 2023/24)

THE OPPORTUNITY

Aviation is a uniquely safe mode of transport and one that has few parallels when it comes to learning critical safety lessons from the past, many of which have been paid for in people's lives. The result, after 120 years of powered flight and millions of take-offs every year, is a highly regulated aviation sector that puts safety at the very core of its mission. According to the International Air Transport Association (IATA), 2023 was the safest year ever for commercial air transport, with the fatality risk lowering from 0.11 in the previous five years to 0.03 in 2023. At this latest level of safety, on average a person would have to travel by air every day for 103,239 years to experience a fatal accident(1).

In aviation, major revolutions have come about because of innovation in propulsion technology. We are now at the start of a new chapter – the age of electric propulsion. Future EVTOL aircraft form a key part of this new era. Aircraft designs must be certified against compliance with specific regulations and this new generation of eVTOL aircraft will not be different in that regard. This latest age of electric aviation has the opportunity to look back and learn from the lessons of the past 100 years while embracing today's advancements in automation and digitalisation.

GROUND-BREAKING PRE-MORTEM INVESTIGATIONS

The introduction of this new technology and new entrants, some from outside the traditional aerospace industry, such as the tech and automotive sectors, as well as the predicted high volumes of AAM air traffic, raises novel questions about how to maintain the existing rigorous standards for which aviation safety is known. For the public, government officials and media, the most overriding question is: what are we doing to ensure that these new aircraft operations are safe in our skies for both passengers and people on the ground?

The challenge is to assimilate safety enhancements from the past with current aviation technology while simultaneously embracing future safety opportunities.

To address this challenge, RAeS President (2023-2024) Kerissa Khan convened a special, multidisciplinary group (see p 21) of aviation experts from around the world, comprising both established industry and new AAM stakeholders. The group was asked to imagine themselves as accident investigators of the future, using their combined knowledge, skills and experience to forecast the unique ways and complexities in which eVTOLs are likely to operate in some of the most challenging situations. The paper discusses three hypothetical accident scenarios, informed by examples of past accidents but updated to portray how they could occur with eVTOLs in the future, specifically within a rapidly evolving aviation ecosystem introducing multiple new layers of complexity to the current system. Some of these differentiating factors include the increasing volume of operations, accelerated levels of automation and a growing community of dynamic players, including new entrants with varied safety cultures.

A 'pre-mortem' investigation was conducted for each accident scenario, identifying potential root causes. Acknowledging already ongoing work in the identified areas and considering the trajectory of current developments, the group uncovered targeted areas requiring deeper focus and urgent action. In contrast to the historical approach to aviation safety, based on

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(1) https://www.iata.org/en/publications/safety-report/

post-accident analysis to then introduce corrective actions, this forward-perspective approach provides the opportunity to proactively build critical safety lessons upstream of development and prevent the occurrence of such events in the future.

Using this novel approach, it is intended to bring these scenarios to life – especially for non-specialist, yet interested, stakeholders. Given that some of the technical terms for this emerging sector are not yet defined, the study uses terms from various existing Concept of Operations (CONOPS). Although the safety standards for AAM are still in development, the broad principles of this paper, its recommendations and conclusions are unlikely to vary significantly as these are confirmed. The recommendations in this paper are intended to steer the safest possible path for this nascent and rapidly evolving aviation sector.

THE FUTURE WORLD OF 2035

Underlying these three hypothetical scenarios in the near-future world of 2035, it is forecasted that eVTOLs will be operational in significant numbers in air taxi, commuter and specialist roles, such as air ambulances. At this time, pressure continues to build to meet the timescales of the Paris Agreement to continue to significantly curb carbon emissions, putting electric aviation in the spotlight. While some flights are being operated remotely and autonomously, for the most part, they are still piloted as AAM operations are yet to transition to a future fully networked digital autonomous system where flights might be controlled or supervised entirely by AI. This world of 2035 features a mix of legacy systems, standards and regulations in which electric and advanced aircraft are intended to be able to operate in a safe, assured and secure environment. In this age of accelerated innovation, increased regulatory capacity and skills to meet the demand, along with internationally agreed standards and norms are under development, with some concerns about keeping pace with the rapidly growing sector.

THE NEED FOR URGENCY

While the year 2035 might seem some time away to tackle these questions and challenges, these need to be acted on today – if the introduction of AAMs into service is not to be delayed significantly in the search for answers that perhaps were predictable. By highlighting some of the key safety challenges in technology, design, operations, training, airspace, ATM (air traffic management) and human factors, this paper aims to forecast and draw attention to some of the potential gaps and safety issues, allowing for swift and timely action.

SCENARIO 1 – EMS EVTOL BATTERY FIRE

Causes

- System design issue
- Environmental
- Process

Assumptions: *The aircraft has been modified (by a Supplemental Type Certificate) to adapt it from a commercial, passenger-carrying configuration to a specific medical configuration. On board are a pilot and medical staff, who have all undergone the necessary training for their roles. During this scenario, the aircraft is operated completely within all the design certification and regulatory parameters.*

In a South Asian region in 2035, eVTOL aircraft have steadily supplemented the helicopter fleet for medical evacuation services, sometimes referred to as Emergency Medical Air Rescue Services (EMS). This is due to their safety characteristics, operating costs and size, which allow the aircraft to be based closer to potential medical evacuation points. As such, operations are infrequent, with a relatively low operational tempo compared with the 'air taxi' versions. The environment is hot and humid, and the rural setting is challenging from an operational perspective, with mountainous and forested terrain.

A medical air rescue team is scrambled to assist a patient who is taken critically ill in a remote area. As the eVTOL is dispatched from a nearby vertiport, the patient is moved to one of a number of predetermined emergency clearings ready for collection. The eVTOL safely picks up the patient, who will need emergency surgery at a hospital 20km away.

During the flight, a battery cell issue necessitates the affected cells to be automatically isolated and the aircraft to run on two-thirds available power. The cause of the fault may be traced to the mishandling of a battery module during a routine inspection conducted some time previously. External damage was not noted and, during the initial run-up, no issue was detected. However, the latent internal failure would eventually be identified as the root cause of an impending thermal runaway. Post-accident analysis would find that similar maintenance events had occurred in other operator fleets, and not been shared cross-organisation.

A short time after the partial battery shut-down, a battery fire is detected and enunciated, and the pilot begins to execute an emergency landing procedure. Although the batteries are electrically isolated and propagation resistant, the thermal runaway continues to progress because of the self-oxidising nature of the thermal runaway chemical reaction. The battery cells vent heat and smoke through a designed venting port, while the aircraft descends for landing.

A short circuit caused by the damage to the battery module, combined with a latent failure of the short circuit protection system, was identified as the cause of the thermal runaway.

The increased urgency to land, combined with the limited availability of prepared landing sites, leads the pilot to choose an imperfect emergency landing point along a hillside. The aircraft touches down abruptly with damage to the undercarriage and one of the aircraft doors from the hard landing. The fire is burning on the wing in a controlled manner, but the crew's self-extrication is delayed by injuries from the emergency landing and the subsequent damaged door.

PREVENTATIVE ACTIONS

Maintenance and inspection can result in errors leading to critical safety events. For example, research has concluded that approximately 21% of fatal accidents in helicopters were linked to maintenance errors(2). Meanwhile, a NASA study found that 35% of aviation accidents and incidents related to SCFM (system/component failure/malfunction) were caused by improper maintenance(3). Examples include: Air Midwest Flight 5481 in 2003, Sundance Helicopters AS350 2011, British Airways Flight 5390 in 1990, Airbus EC120B (N421PB) in 2021 and many others. Further examples can be found in The Flight Safety Foundation Skybrary(4).

As with other parts of aviation, eVTOL operators need to be aware of the risks of improper maintenance and inspection, and the possibility of an introduction of a latent failure. Operators should look to industry best practices and to ensure a robust safety culture is inculcated throughout.

(2) Between 2005 and 2015, flawed maintenance and inspection were causal factors in an estimated 21% of helicopter accidents in the US civil fleet. Of these accidents, 31% occurred within the first ten flight-hours. Source: *Maintenance and inspection as risk factors in helicopter accidents: Analysis and recommendations* – Saleh, Ray, Zhang, Churchwell, 2019

(3) *Causal Factors and Adverse Events of Aviation Accidents and Incidents Related to Integrated Vehicle Health Management*, NASA, 2011

(4) https://skybrary.aero/articles/maintenance-error

More broadly, and in line with traditional aviation, the eVTOL community should promote the importance of collaborative initiatives focused on safety data and analysis. Good examples include: the Federal Aviation Authority's (FAA) Aviation Safety Information Analysis and Sharing (ASIAS) system and the European Union Aviation Safety Agency's (EASA) Data4Safety programme. Additionally, safety-focused forums, such as the UK's eVTOL Safety Leadership Group or the global Heli-Offshore association, are models that can help play a key role in preventing accidents and early identification of risks. This can also ensure sufficient exchanges between OEMs and component designers/suppliers to avoid misinterpretation of use cases and limitations.

This AAM scenario contemplates an external short circuit due to battery module damage leading to a battery failure and thermal runaway. Thermal runaway safety assessment and risk mitigation will be required for any certifiable battery-electric aircraft. Scenario-based simulator training should expose future eVTOL pilots to representative battery failures and in-flight thermal runaway scenarios to ensure pilots and operators have the proper skills and in-flight decision-making experience to mitigate such an event.

For in-flight mitigations to be possible, all manufacturers will need to adopt suitable in-flight monitoring of their battery systems to ensure any issues are identified at the earliest opportunity. Automated cell monitoring and data analysis can help identify cells with *out-of-family* characteristics, potentially providing additional opportunities to prevent or mitigate hazardous scenarios.

Standards Development Organisations (SDOs) can play an important role in providing a neutral setting focused on sharing experience, expertise and establishing voluntary standards. Examples include SAE ARP7131, *Verification Process for Thermal Runaway Mitigation in Large Electrical Energy Storage Powertrain Systems in Normal Category Aircraft and Rotorcraft.* Wider participation from the AAM industry, including the supply chain, can ensure further uptake and success with SDOs, some of which are already under way.

Regulators have a key role to play in all of the above. Sufficient staffing and resourcing are essential to ensure authorities can keep pace with the industry. Regulators have a role in the aforementioned collaborative bodies, not least to facilitate communication and to keep abreast of developments.

The robust management of safety throughout the emergent sector (from OEMs and maintenance providers through to operators and vertiports) is going to be essential in order to identify and mitigate issues, including for those organisations and regions where regulatory requirements are not yet in place. A robust safety culture, open reporting and learning, and effective risk management will all be key to ensuring safe operations. A good foundation is the International Civil Aviation Organization (ICAO) Annex 19 on Safety Management(5) which requires both states and service providers to promote a positive safety culture, with the aim of fostering effective safety management implementation through the State Safety Plans (SSPs) and Safety Management Systems (SMSs). *The Safety Manual Doc 9859*(6) gives the background, context and guidance on how to develop a functional SMS.

OBSERVATIONS

The following should be considered:

- Simulator training for pilots for emergency landings driven by factors, such as thermal runaways.
- In-flight monitoring of battery conditions, automated health monitoring and predictive maintenance of battery health, which should also be included in pilot and maintenance crew training.
- Sharing of safety and battery/electrical firefighting standards for vertiports and airfields.

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(5) ICAO Annex 19 – Safety Management

(6) Safety Management Manual (Doc 9859)

SCENARIO 2 – COMMUTER EVTOL HARD LANDING

Causes

- ATM
- Communications

Assumptions: *It is an IFR (Instrument Flight Rules) flight – due to variable weather conditions and high volume of traffic. The aircraft and crew are IFR capable. The ATM system is transitioning from legacy airspace management to modern, automated network management systems for low-level but high-volume eVTOL operations. Because of a sporting event, there is an increased volume of flights in the area.*

It is 2035 and eVTOLs are a common mode of air transport as people enjoy the freedom and time gained by flying easily from London city centre out to the airports and the countryside – transforming the way we live and work. The commuter journey has changed, and Jasmine and James are travelling into central London from their company offices in Oxford, enjoying the ride and views between occasional rain showers on G-ABCD, a modern multirotor eVTOL.

It is a busy day in the skies and, as they are approaching London, the pilot, John, is conscious of Heathrow and Farnborough traffic, as well as several large drone hubs that have developed over previous years, including a distribution hub for Mega Corp, an international conglomerate. The pilot is being kept aware with traffic alerts, as he follows the published low-level route structure indicated on the cockpit display.

The weather rapidly changes and the pilot finds himself in Instrument Meteorological Conditions (IMC). In the past, rotorcraft transiting into IMC was a significant hazard in this kind of scenario but augmented controls in this eVTOL means the pilot does not have issues maintaining flight.

As he approaches the vicinity of the vertiport, the pilot begins the landing procedure. Suddenly, ATC (air traffic control) advises that it has detected a non-co-operative, infringing aircraft, which has entered the control zone ahead of the eVTOL. G-ABCD is instructed to hold just inside the control zone at an IFR reporting point to maintain separation until ATC is able to establish contact with the infringing aircraft and its intentions. The *en route* holding adds a delay to the landing time and diminishes the eVTOL's energy reserves.

Meanwhile, at the destination vertiport, which has a single landing spot, a PinS (Point in Space) approach procedure only became operational two months ago. Efficient utilisation of the landing spot and the arrival procedure is managed via specialist software which is dynamically updated via flight tracking data and supplemented by manual input from the controller. Because of the ongoing disruption in the surrounding airspace, the controller is struggling to input accurate manual updates and the automated system is not working effectively. The pilot continues to wait for further clearance and monitors the state of energy available as it gets very near the point where a diversion is required.

Because of the delays in updating the vertiport status, the remote controller mistakenly issues a landing clearance, despite the single pad being occupied by another eVTOL. The pilot, already in the landing phase, spots the issue and conducts a go-around but this further depletes the battery reserves. The pilot elects to divert to the next accessible vertiport at Stratford, in accordance with the pre-planned diversions in the flight plan. The additional flight time to the diversion vertiport is automatically and continuously calculated and displayed to the pilot. However, the unexpected *en route* holding and go-around has eaten significantly into the eVTOLs planned energy margins. Stratford vertiport is made aware that the aircraft is now committed to the vertiport and that any further delay to what has already been notified will result in the eVTOL aircraft probably declaring minimum energy. The situation requires constant monitoring and adds pressure to the pilot's workload in the congested airspace. Meanwhile, updates requiring manual inputs continue to impact the controller's capacity.

Because of a major sporting event close to the diversion vertiport, the site is already working to near capacity and, as a result of the earlier airspace infringement, both landing slots at Stratford are currently occupied. Despite G-ABCD now approaching energy minimas and advising the controller at Stratford of this, the ongoing disruption and delays mean that the diversion landing spots remain occupied by other eVTOLs. Adverse weather continues to hamper the pilot in maintaining visual reference when transitioning from IMC to VMC (Visual Meteorological Conditions) in and around heavy showers.

With the alternate vertiport no longer available, procedures dictate declaring an emergency and diverting to the nearest suitable landing site, which is a non-airfield location, available on the pilot's electronic database. However, the pilot is not familiar with the location.

With all the challenges, the pilot is torn between executing a vertical landing at the charted diversion location or opting for a run-on CTOL (conventional take-off and landing) at London City. During this time the eVTOL consumes even more energy putting the batteries in an extremely low state of charge. Ultimately, while executing a vertical landing at the diversion location, the pilot approaches too quickly, runs out of available power margin at a low state of charge and suffers a hard landing. The gear collapses and the wings and rotors are damaged. The passengers suffer significant injury due to the sudden deceleration and crash.

PREVENTATIVE ACTIONS

While the simplicity of operation may provide unique safety advantages, there will be increased importance on understanding the state of charge and the availability of suitable landing locations, especially in high-density environments. Specific, relatable and tailored training and development are going to play a key part in ensuring safe operations, including both for low-level IFR crews and controllers, along with sufficient capacity to enable routine high-volume operations. This will also need to include sufficient training and competence development to support the introduction of changes to airspace and the adoption of new tools to facilitate the increased volume. Training and development for these types of operations need to be appropriate to the operation, environment, key risks and potential adverse scenarios. Training alone, however, will not be enough; it will require time and sufficient capacity for individuals and teams to build experience and resilience.

The increase in volume and complexity is going to require new systems to facilitate and enable such operations. The system requirements and the products introduced must be robust and tested rigorously in a

wide range of failure scenarios, taking into account the anticipated volumes, and the transition periods where experience may be short.

The level of interaction between aircraft and controllers, and between controllers in this environment is currently done by voice communication. With the increase in volume anticipated, the information exchanges will require automation and improvement.

Aeronautical information in many forms is collected, published and made available to support safe aviation, which includes a register of all landing sites/airfields. The level and accuracy of this information will need to be further developed to support specific criteria for eVTOL operations for planned and alternate landing sites where the information is immediately available to crews. It is especially important that this information is presented in a rapidly digestible format to the single pilot who may have limited capacity to search for and digest information in a challenging situation.

At present, there is little collective agreement on what the 'low level IFR' environment will be like, but the need is there if the AAM vision is to be realised in any sort of poor weather. The philosophy will need to be developed and then turned into supporting processes, procedures and capacity limitations/minima, including separation criteria. Global, regional and local regulatory frameworks are required here to identify and control ground-based services, including oversight of pre-flight decision-making. This will also require collective discussion on future integration and development of wider airspace categorisation, to accommodate low-level IFR, high volume VFR and manage the risk of increased flying through uncontrolled airspace.

The infrastructure required to support the AAM vision is a vital element, and it must keep pace, or even be in advance of the volume of aircraft in operation and the level of service provided. Understanding and maintaining the safe balance of aircraft and suitable infrastructure is key to ensuring viable business models with safe and resilient capacity.

OBSERVATIONS

The following should be considered:

- Training and development for low-level IFR crew and controller capability to enable routine high-volume operations, including sufficient training to support the introduction of changes to airspace and the introduction of new tools to enable high-volume, low-level operations. Real-time simulations/desk-top exercises, involving pilots, controllers and network operators stress testing procedures are recommended.
- Training and development for data communication usage.
- Expanded level of aeronautical information available to support planned and alternative landing sites.
- A robust methodology for dealing with low-level IFR or even 'IFR-lite' – processes, procedures, regulations and capacity limitations/minima, including separations. Global, regional and local regulatory frameworks are required in this context to identify and control ground-based services, including oversight of pre-flight decision-making.
- Airspace restructuring to accommodate volume and different types, including the use of 'electronic conspicuity'.(7) Work is already ongoing in this space, including Digital Network Management and amendment of airspace classification.
- Capacity to manage volume of information exchange between aircraft and controllers, and between controllers.

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(7) New study on Electronic Conspicuity published by aviation regulator, Civil Aviation Authority (caa.co.uk).

SCENARIO 3 – AIR TAXI COLLISION IN URBAN MEGACITY

Causes

- Human Factors
- Safety Management Systems

Assumptions: *All personnel are appropriately certified/licensed in accordance with regulations. Pilots are trained both* ab initio *and via conversion type-rating training, with some pilots employed via third parties. eVTOL operations are highly automated but with a pilot on board who can intervene (pilot-in-the-loop). The high levels of automation mean there are frequent software updates. The fatigue limitations are based on the current daily and cumulative hours limitations from the FAA model. The operator is well established, competent and compliant with all regulations.*

Above a large megacity in the Americas in 2035, the airspace is a congested and intricate air traffic environment. There are over 1,500 daily VTOL operations (both helicopter and eVTOLs), including both commercial passenger and cargo-carrying operations. EVTOL aircraft here are piloted by a single pilot, in both VFR and IFR.

The pilot, Maria, has been operating this eVTOL type for over two years, having trained on this aircraft without previous aviation experience. She flies short, intra-city flights, primarily ferrying executives around the city or between the city and the airport.

She is preparing for her tenth short sector of the day. This is her fifth day on the roster. It is hot, humid and she is visibly fatigued. For this flight, the four VVIP passengers are running late for their meeting and are putting pressure on Maria to shorten the ground time before take-off. This atypical interaction stays on her mind through pre-flight and departure.

Almost immediately during the *en route* phase, the pilot receives a report from the network operation centre (NOC) that the assigned landing area may not be available when they arrive, due to an unknown issue. Because of the ambiguity of the information provided, Maria makes a judgement call and assumes the incident will clear itself before they arrive.

The operator for this flight develops flight plans in a manner similar to an ETOPS (extended-range twin operations). Along the route, the aircraft has predetermined divert points to alternate landing sites. As the flight continues on to its destination, the pilot receives no direct instruction to divert.

The site is a single TLOF (touchdown and lift-off), multi-parking stand vertiport, and an aircraft has blown a tyre within the TLOF area. Ground crews have been attempting to move the aircraft, but it has taken significantly longer than expected because the required tools are not available.

At this point, three eVTOL aircraft have arrived in the vicinity of the landing site. The pilots are communicating on the Unicom frequency with the vertiport operator, who is insisting that the situation will be resolved soon. The pilots are self-deconflicting their holds and contemplating their next actions. The lack of a screen between the passengers and the cockpit in the aircraft means the passengers remain in close proximity to the pilot with constant interaction, demanding updates

from Maria and giving alternative suggestions about the decision she should take to get them to their destination as soon as possible. The demands for information from the high-profile passengers continue to distract her. Maria, feeling the pressure to please the high-profile passengers, and experiencing end-of-shift fatigue, does not decide to divert like the other two aircraft. The eVTOL passes its battery endurance limit to reach an alternate aerodrome while she continues to hold.

Maria begins to experience cognitive mental overload and urged by the passengers, firmly requests that the vertiport operator clears the site. Once it is apparent that the site will not be cleared in time, she is left with no choice but to execute an emergency landing at an empty football field nearby. However, task-saturated, with panicking passengers and fatigued, she overcontrols and clips a tall football flood light with the wing and rotors, leading to the aircraft rapidly descending and heavily impacting the ground.

The reputational impact on the operator is significant and felt immediately. For the next month, global media are highly critical of the operation and its safety culture.

PREVENTATIVE ACTIONS

A core element of this scenario was the pilot's internalised pressure to please the high-profile passengers both in pre-flight and with the selection of the final landing point. These pressures are not uncommon in aviation and not specific to AAM. There is the potential, however, for such pressures to be exacerbated by possible increased interaction between passengers and pilot communication during flights.

Pilots need to feel empowered to make aeronautical decisions, free from these pressures and other undue influences. To do so, they must feel support for the decisions they make, even when it may inconvenience, disappoint or even annoy passengers. This means operators should intentionally develop and continually reinforce a visible and just safety culture that does not penalise staff for how they manage these likely pressures and help engender trusted relationships between the company and employees, allowing open, honest reporting and a proactive learning environment.

The National Business Aviation Association (NBAA) Management Guide(8) – includes guidance on Crew and Passenger Relations (section 2.8).

A second key contributor to this incident was pilot fatigue. Fatigue can affect a pilot's judgement, decision-making and core airmanship. High-cadence, short-distance operations are not unprecedented in aviation. Regardless, the just safety culture mentioned above supports pilots who self-report excessive fatigue and make the decision to stand down from impaired operations.

The emergent eVTOL sector should consider the value of operator-specific Fatigue Risk Management Systems (FRMS). Research should be directed at developing a fatigue model that recognises the totality of the cockpit environment, including workload intensity, cockpit layout, passenger interaction and other operator-

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(8) 2016-01-nbaa-management-guide.pdf

specific factors, alongside total operational hours. The combination of true FRMS and updated models would allow operators to ensure pilots are effective throughout their duties and provide the Regulators confidence in the absence of understood and well-established Flight Time limits. In the longer term, the use of pilot on-board health and alertness monitoring may also be of value.

Ambiguous and incomplete information is a hallmark of this scenario as well. There are multiple actors involved in this scenario who share responsibility for the outcome:

1. Vertiport operator to network operations centre (NOC) – did not correctly assess the event or the duration of its impact.
2. NOC to pilot – did not provide a decisive, unambiguous direction for pilot action to divert, leaving the decision open to assumption and personal judgement.
3. Vertiport operator and pilot on Unicom – organisational shortcomings contributed to the unavailability of the correct bespoke tools at the vertiport site and the inaccurate communication of situational duration, possibly stemming from commercial pressure or fear of retribution.

Complete and clear exchange of information should not only be prioritised but trained. Scenario-based drills should be periodically exercised to ensure all actors are versed in the handling of unexpected situations. For example, NOC staff should be trained on how to assess and communicate action, based on available information.

High-fidelity flight simulators that incorporate communications with all relevant actors (via voices or datacom) should allow for highly effective scenario-based training for pilots. To maximise situational awareness, vertiport operators should consider making data feeds about pad occupancy available to network operators.

OEMs should continue to engage, where appropriate, to lead safety conversations with their operator customers. Good practice examples include: airliner, business aviation and rotary-wing major OEM safety conferences and workshops. In the context of this scenario, a workshop might focus on promoting safety for operators and how they make divert decisions to avoid endurance-limited conditions.

OBSERVATIONS

The following should be considered:

- Impacts of different methods of training delivery (eg e-learning, single control aircraft) in *ab initio* training on eVTOLS. Industry will need to cater for the increased supply of pilots while maintaining appropriate safety standards.
- Establish confidential safety incident reporting programmes – such as the UK CAA's CHIRP (Confidential Human Factors Incident Reporting Programme) to identify and capture emerging trends and to encourage a culture of open and confidential reporting where this is not available within the organisation.
- Volume of planned and alternative landing sites to accommodate aircraft airborne needs to remain aligned with the volume of aircraft and the level of services provided.
- Available landing sites should be suitably equipped with maintenance tools that may be required by all aircraft types in operation at these locations (even if they are not in common use).
- Industry should consider the value of Fatigue Risk Management Systems (FRMS). Research should be directed to developing a fatigue model that recognises workload intensity and other operator-specific factors, alongside total operational hours.
- System requirements to manage significantly increased scale of verbal and data communication, both ground and aircraft-related.
- Capacity to manage volume of traffic, and the supporting accountabilities and responsibilities in a new structure.
- A study to understand and mitigate crew distraction, due to passenger interaction, including a review of communication protocols, equipment and risk mitigation.
- Implementation of state-of-the-art knowledge in the division of work and decision-making between humans and automation. Consider pilot interaction with the software and appropriate division of functions between humans and automation.
- Potential operators should be actively involved in the design/development of the aircraft systems and automation. Acknowledging there will be many business models and types of operation, operators, training providers, third parties, OEMs and regulators must ensure that human factors considerations are incorporated in competency, procedures, SMS etc.

WORK IN PROGRESS

This paper uncovers critical areas requiring special attention and action to help ensure the safe introduction of eVTOLs globally, beyond what is already ongoing across the sector. It is important to recognise that there is substantial activity taking place in different parts of the world making considerable progress.

Outstanding collaboration and collective action are under way, with work between:

- Regulators (for example, work on regulatory alignment and equivalency),
- Manufacturers (including the work of Standards Development Organisations, such as SAE's work on Battery Charging standardisation),
- Operators (including the UK Civil Aviation Authority-facilitated eVTOL Safety Leadership Group)
- Infrastructure Providers (including the development of Vertiport regulation and CONOPs).

It is important that such efforts not only continue but further develop and mature. That said, the collaboration that exists is not all-encompassing and is, at times, not widely recognised nor publicised. This leads to the risk that regions, states and organisations can be left behind, developing in isolation and unable to learn from others who have (learnt) before. This paper can provide a (non-exhaustive) check to identify any areas which may not have been previously considered or require further focus.

In addition, electric power, configurations, fly-by-wire (FBW) controls and next-generation avionics offer a potential technological step change in safety.

Harnessing the power, sustainability and redundancy provided by multiple electric motors and advanced flight control systems represents an opportunity for how aviation safety can be enhanced. These aircraft are required to follow aviation certification procedures and to comply with operational regulations. Companies are designing eVTOLs with multiple, independent motors and battery packs to allow these aircraft to fly and land safely in the event of a loss of a propeller, motor or battery.

The fully FBW design of these aircraft means that an appropriately trained pilot can benefit from a simplified cockpit, where the emphasis is on providing inputs to a flight control computer. Unlike the majority of existing aircraft, this presents the opportunity to ensure full envelope protection in all phases of flight.

Furthermore, a number of leading eVTOL developers are addressing the complications and tragic accidents which have been linked to conventional tiltrotors, where pilots have faced significant workload in transitioning between vertical and horizontal flight. This is being mitigated against through the use of 'unified controls' in a number of eVTOL designs, leveraging automation to address human factors – allowing the pilot to focus on key actions and their surroundings.

Progressing these regulatory, operational and technological advancements will help advance a trajectory towards the safe integration of AAM in our skies. Furthermore, novel technologies being developed for this emerging sector can influence, permeate and, potentially, enhance safety across the wider aviation system, bringing further socio-economic benefits.

RECOMMENDATIONS

1. Industry-led collaboration

Establish a global, safety-focused body for the eVTOL industry, to corral and lead the safety conversation across all elements and functions. Dialogue should include operators, regulators, OEMs, infrastructure and service providers. This will enable clear discussion, identification of potential and emerging safety issues and deliver the right collective actions to ensure the whole sector can launch and operate safely. The well-recognised and respected HeliOffshore association provides a clear model for such collaboration, where it

has delivered significant safety improvements globally in the offshore helicopter industry. Such collaboration and leadership approach can then cascade down to regional, national and local levels, to enable balanced approaches to capacity and demand, forecasting and planning developments together so a change in one area does not transfer risk to another without clear understanding and acceptance. The industry simply cannot afford not to collaborate and learn together, let alone compete on safety.

2. Real-time information sharing

Establish a seamless means of operating across different classes of airspace that delivers a high level of confidence in airspace capacity, on-time performance and safety. Develop airspace policies, concepts and frameworks that support airspace integration, not segregation, that maintains airspace access for all (new and existing) users. EVTOL aircraft require higher levels of confidence in the availability of routes and vertiport capacity and this, therefore, requires management at a network, not individual flight level. This in turn requires the real-time exchange of essential flight data between all relevant stakeholders, based upon a single view of the airspace in a manner equivalent to today's SWIM (System Wide Information Management) concept. This will reduce workload both in the aircraft and on the ground, thereby enabling safety to be maintained at heightened volumes of flight.

3. Modern, scenario-based training for all players

Scenario-based training, using modern technologies, including simulators or Virtual Reality (VR)/Augmented Reality (AR) headsets, can ensure both pilots and others involved in AAM operations are equipped with the decision-making skills and experience to address realistic failure scenarios, IMC encounters and other in-flight emergencies. Authorities should embrace the most modern and efficient ways to train people effectively, including considering the best means for pilots to be trained on fully fly-by-wire eVTOLs with simplified interfaces.

4. Build safety culture throughout the industry

Establish good safety practices, including a positive learning culture across the industry. Operators should seek to develop a robust safety culture (including recommendations from the seminal work by James Reason and others on this topic) to manage pressures and require this from their suppliers. Safety must be systemic, embedded and championed. OEMs, maintenance providers, operators and vertiport operators should have comprehensive and effective SMS from the get-go, regardless of the legacy regulatory frameworks that may exist in regions. In order to deliver the safe introduction into service globally, all entities in the ecosystem need to have an SMS, and they must interface effectively so the risks are not lost in the boundaries. Introduce a liability framework that accommodates the novel nature and changeability of the end-to-end aviation supply chain (including systems and services in the air and on the ground) in a highly automated ecosystem, which does not undermine a just safety culture and enables people to feel empowered. While this is already promoted within ICAO Annex 19 and Doc 9859 and implemented, for example in the EASA regulatory framework, it is recommended that service providers and regulators should start conversations *now* about how these systems will be implemented within the AAM environment where safety in all its guises should be 'Built In, not Bolted On' afterwards.

5. Develop regulator capacity and capability

International regulators must collaborate to transform to build capacity, capability and risk considerations. Regulators must ensure they are capable (in terms of personnel and oversight ability) of overseeing the industry. Performance-based oversight will need to be measured in its introduction to match the safety culture/performance of the industry and the data must be made available. There needs to be sufficient staffing and resourcing of the AAM offices within regulators to deal with the expected demand from the industry. International norms and means of compliance should be applied to reduce resource requirements at a national level, thereby also enabling recognition of regulatory approval between states.

SUMMARY

The RAeS has been at the heart of shaping every evolution in flight since 1866. Today, the Society continues to bring together world-leading expertise to build upon more than 158 years of cumulative knowledge. With the recommendations above, the Society looks to the future to advance another exciting and dynamic new chapter in aeronautics. In this next generation of flight, the Society is once again at the forefront of impartial thought-leadership. It will continue to have a key role in convening the international aviation and aerospace communities to share insights across industry, regulatory authorities and other stakeholders.

This is not without precedent. In 1921, the Safety and Economy Committee of the Council of the Royal Aeronautical Society published a similar Paper on Cross Channel Air Transport Safety that gave safety and technical recommendations for the then emerging airline industry.

The importance of this unique kind of 'forward-perspective' exercise, in forecasting the safety challenges ahead, cannot be underestimated when potential lives are at stake. By using this innovative 'pre-mortem' approach, it flips the traditional way in which powered flight has become safer over the past 120 years – by acting ***after*** an accident has taken place. With AAM offering a clean sheet to rethink the skies, this rapidly evolving sector cannot wait for accidents to gather lessons to build in safety.

This ground-breaking paper analyses plausible accident scenarios, aims to stimulate discussion, influence the debate, help integrate AAM and, thus shape a safer future air transport system for all.

Expert Panel

Kerissa Khan MRAeS – RAeS President 2023-24

Rick Adams, FRAeS – Editor, Aviation Voices / Halldale Group
Greg Bowles FRAeS – Joby Aviation
Gary Cutts FRAeS – RAeS Council, UKRI Future Flight Challenge Director
Brian Davey MRAeS – Joby Aviation
Afrid Hassan – RAeS Next Generation Board
Capt Richard London MRAeS – RAeS Human Factors, Chair, CAA Flight Crew Human Factors Advisory Panel
Ryan Naru – Joby Aviation
Peter Neenan – RAeS Air Law Specialist Group
Kimball Newsam – Accident Investigation
Brian Phillipson FRAeS – RAeS Munich Branch Committee, ex-Lilium
Kirsten Riensema FRAeS – CAA, Chair ICAO AAM Study Group
Colin Russell FRAeS – Chair, eVTOL Safety Leadership Risk Sub-Group, European Safety Director, Flexjet
Professor Amair Saleem FRAeS – Government of Dubai Transport Authority
Andy Sage – NATS, Director of Safety Transformation
Jamie Sayer FRAeS – RAeS Learned Society Board
Dan Sloat MRAeS – AAM Institute (Vertiport Infrastructure)
Jonathan Smith FRAeS – RAeS ATM Specialist Group

Naomi Allen – RAeS Head of Research
Jonathan Clare RAeS – Head of External Affairs
Jordan Penning MRAeS – RAeS Policy and Public Affairs
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