Airworthiness "State of the Industry" - Literature Review and Summary

Introduction

The act of maintenance keeps aircraft safe, airworthy and available. Effective maintenance requires constant compliance to regulatory requirements and the consistent achievement of safety, quality and efficiency goals in a complex and dynamic environment. The civil aviation industry demands resilient performance throughout the system of maintenance, at the level of the overall maintenance organisation and within our maintenance teams. At the level of the individual maintenance engineer the industry requires not only resilience but also integrity to achieve those goals.

However, significant issues exist at all these levels, challenging the ability of the industry to continue to meet these goals. This report summarises those issues related to continuing airworthiness, the process by which aircraft are kept in an airworthy state, and offers a window into the views of the organisations who ensure the civil aviation industry continues to meet the highest international standards.

Methods

The current issues challenging airworthiness described in this report were developed by listening to industry stakeholders; the academics who research the cutting edge and educate the next generation of aviation professionals, the leaders who face the organisational challenges day-in, day-out and those at the sharp end, the engineers who work tirelessly each day to ensure our aircraft are ready to fly. The report summarises the considered opinion from the leading organisations which regulate, build, support and report on the industry. Supporting evidence is presented from Confidential Human Factors Reporting Programme (CHIRP), European Union Aviation Safety Agency (EASA), Federal Aviation Authority (FAA), Flight Safety Foundation (FSF), International Air Transport Association (IATA), International Civil Aviation Organisation (ICAO), HeliOffshore, The Royal Aeronautical Society (RAeS) and more. This report represents a high-level summary of the issues but references are provided for more detailed consideration.

Results

It is evident that there are significant airworthiness issues at an industry level which creates challenges at an organisational level which manifest as problems at the sharp end for individual maintenance engineers.

The report identifies a number of priority issues and makes recommendations on how these may be understood better and solutions developed:

- Identify and resolve the underlying causes driving global **maintenance engineer shortages** to ensure we can meet the increasing demand for maintenance services;
- Recruit and train to ensure that maintenance engineers of the future possess the **right mix of skills and competences**;
- Address the disparities between the **value placed on maintenance engineers** compared to other aviation professionals;
- Develop an understanding of the impact of the **uncertain and uneven civil aviation recovery** and the **disrupted supply chain** and potential mitigation actions at an industry level;
- Identify, assess and treat the risks associated with an increasing percentage of **contracted maintenance staff** and an increased reliance on **non-certified maintenance engineers**;

- Support initiatives to address **part scarcity** and monitor the rate of Suspected Unapproved Parts discovered in the maintenance system;
- Monitor the effectiveness (as well as the efficiency) of training regimes and embrace the opportunities presented by **new training techniques** such as virtual reality to address the shifts in required engineering skillsets;
- Undertake research to measure the impact that **fatigue** and **mental health issues** have in a maintenance context and develop effective solutions at an organisational and individual level;
- Measure the reporting rate and overcome any barriers to address the **under-reporting of safety-related incidents** by maintenance engineers.

Above all, the industry should establish a means by which the challenges faced by organisations and individuals working in aviation maintenance worldwide can be continuously monitored, solutions developed and shared across the industry. Each and every stakeholder in the maintenance system should have the means to contribute to this process, help to develop solutions and share best practice in their implementation.

Industry Level

There are several issues at the industry level which influence airworthiness outcomes.

Global shortage of maintenance engineers

Boeing (2022) predicts that 610,000 new maintenance engineers will be required by the industry to meet the aviation industry demand over the next 20 years. However, the engineering workforce is aging. Data from the UK CAA shows that in 1988 the median age of a Part 66 license holder was between 30 and 40 and in 2020 the median age was 54 (UK CAA, 2023). The pandemic forced many organisations to offer voluntary redundancy programmes which, according to many in the industry, led to a loss of a significant number of older, more experienced engineers. This is borne out in the UK CAA data, which shows that in 2022 and 2023 the median ages were 51 and 49 respectively. To exacerbate the problem, organisations are facing difficulties in recruiting new talent. Recent data suggests that Gen Z are not interested in technical jobs, with recruitment platform Handshake seeing a 49% drop in applications for such roles since 2020 (NPR, 2023; The Boss Magazine, 2023). The industry is failing to compete with other industries such as automotive and attract those from underrepresented groups, especially women (U.S. Senate Committee on Commerce, Science and Transportation, 2023). Once engineers are recruited, many maintenance organisations are failing to provide a modern, engaging employee experience. Engineers therefore transition between industries in search of the best experience and as a result aviation engineering is no longer seen as a lifetime occupation in the way it once was (Aircraft Engineers International, 2023). Furthermore, there also appears to be trend to recruiting engineers from parts of the world where it is difficult to track training quality and the process of issuing licences. This also results in so-called “brain-drain” where experienced engineers migrate in search of a better standard of living, higher salary or better opportunities but leaving the less-developed nations without sufficient expertise to grow. Unless these fundamental issues are addressed, we will not be able to meet the growth in maintenance demand.

Changing engineer skillset

To meet the industry’s demand, employers must consider recruiting new engineers and training existing engineers to deliver a workforce with the right mix of skills. The required skills are changing in the short-term to maintain advanced aircraft systems driven by evolutionary technical development and the need to address aviation’s contribution to climate change, including advanced materials, aircraft health monitoring systems, sustainable aviation fuel, higher operating voltages, tools to counter cyber threats and artificial intelligence. Aviation regulators have recognised a need to improve the training environment with recent rule changes in Europe to Part 66 licensing (EASA, 2023) and the Part 67 licensing in the US (FAA, 2023) and to Part 147 engineering schools (EASA, 2023; FAA, 2023). These have updated training syllabi and incorporated technical training to educate the future workforce and meet the demands of the evolving aviation community. However, in the longer-term revolutionary technologies such as electric and hybrid propulsion, suborbital operations, supersonic transport, eVTOL, and unmanned aerial systems will increase the rate of training and re-training and the industry will need to react to keep up with the rapid change.

Value placed on engineers

There is a consistent disparity between the focus of the industry on maintenance engineers compared to other aviation professionals such as flight crew and air traffic controllers. This is very evident within initial airworthiness as evidenced by a recent report from the RAeS (2021). This found that there are comprehensive and focussed European certification requirements addressing human factors in flight deck design but designing to minimise or eliminate maintenance error is at best focussed on very specific material (usually in response to an accident or serious incident) and regarding maintenance error "there has not yet been a more strategic, holistic and pro-active review of the root causes" (p.49). Furthermore, flight deck requirements accept that the design has to accommodate realistic human performance and error, but no similarly comprehensive rules exist for design to avoid maintenance error.

Similar disparities exist in continuing airworthiness, for instance in duty time limitations, where there are strictly defined limits for flight crew and air traffic controllers but none for maintenance crews (EASA, 2012), and in EASA's research project, MEntal health for aviation SAFEty, there is no acknowledgement of the effect of mental disorders on maintenance engineer performance (EASA, 2023). ICAO (2012) defines maintenance engineers as "Safety-sensitive personnel" and that medical examination is a prerequisite for licensing to ensure current competency and fitness for work. However, it is acknowledged that no provision is made for maintenance engineers as their licences have "no medical fitness requirements due to the nature of duties" (p.19). Such disparities should be reviewed given the increasing complexity of aircraft. Although the Captain has the final say on go/no go on operating the aircraft, they rely the approval of the maintenance engineer standing alongside them in the flight deck that the aircraft is airworthy. To have no medical assessment in engineer licensing, no advice on how to self-assess the ability to fly, such as when using over-the-counter medications (FAA, 2023), no duty time limitations, few international requirements for fatigue risk management and poor mental health support seems incongruous with our industry's safety goals. This challenge is exacerbated by a lack of coherence between regulatory frameworks, for example, between aviation safety, workplace safety and employment law in the protection of engineers.

Uncertain and uneven civil aviation recovery

In a post-COVID world, air traffic is back on a growth trajectory but there are challenges to overcome which make the recovery uncertain and uneven (IATA, 2023). Domestic air travel is back to pre-pandemic levels and growing but international travel has been slower to recover, as has business travel. Geographically, a more rapid economic recovery in China and India will drive higher growth in these areas in future and the Ukraine/ Russia and Israel/ Palestine conflicts fuels further uncertainty. The Maintenance, Repair and Overhaul (MRO) market specifically is expected to grow accordingly but to 13% below the pre-COVID forecast by 2030 (Oliver Wyman, 2022).

Disrupted supply chain

The COVID-19 pandemic and subsequent financial instability had a significant impact on the supply chain andhas driven a shortage of raw material and component parts. "The issue now is deep down in the supply chain, tier-three suppliers and lower, where the investment and headcount required for the demand picture makes them very nervous and makes their lenders very nervous," said Andy Cronin, CEO of lessor Avolon (Reuters, 2023). This has been exacerbated by the conflict in Ukraine and the sanctions imposed on Russia, which in 2019 supplied 15% of global titanium and 50% of the titanium used for aerospace applications.

Organisational Level

These issues at an industry level result in considerable challenges at the level of the operator, maintenance organisation and also in the Continuing Airworthiness Management Organisation (CAMO).

Use of contracted staff

In order to overcome the challenge in recruiting engineers the practice of contracting maintenance engineers has "grown substantially in the UK over the last few years." (UK CAA, 2021 p.1). This Information Notice reminds operators of the requirement under Part 145 to "directly employ at least half of its staff to ensure organisational stability". Not only is there is a considerable cost implication but there is a need to monitor the potential effect on safety. The operator maintains overall responsibility for managing the safety risks and must ensure that the contract specifies safety standards and that the contractor complies with those standards (Air Safety Support International, 2023).

Ratio of certified to non-certified staff

There has been a well-established trend of operators to outsource maintenance to reduce costs and increase efficiency. However, the implication of this is that there is often a higher proportion of non-certified engineers in the outsourced organisations. Vanity Fair (2015) reported that in one El Salvador facility one engineer in eight was FAA certified and at a Chinese overhaul base the ratio was one certified engineer to 31 non-certified. Since the COVID-19 pandemic, when a considerable number of experienced engineers took early retirement, the ratio of staff is shifting towards a higher proportion of technicians with lower competency verses experienced engineers. In Europe EASA launched a contentious proposed change to EASA Part-145 in how maintenance is certified in 2011 (EASA, 2011). This has not progressed since that time but in the most recent European Plan for Aviation Safety (EASA, 2023) this has been introduced as a priority to resolve.

Strategies to Manage Part Scarcity

Maintenance organisations have been forced to rely on various strategies to cope with the shortage of material and components. Firstly, wherever possible maintenance is deferred when a part is unavailable. Beyond this, so-called aircraft cannibalisation or component robberies (where an out-of-service aircraft is used to obtain a component required in lieu of a new one) has always been seen as a last resort due to the additional time and increased potential for error. However, this is being used increasingly often to avoid Aircraft on Ground (AOG) situations. The use of alternatives to new parts made by the original manufacturer but certified by the OEM is also increasing due to part scarcity but also the considerable cost saving. Although this represents 2-3% of the component market, growth is outstripping market trends (Reuters, 2023). Furthermore, this increases the risks of Suspected Unapproved Parts (SUP) entering the aviation system and the need for the careful oversight by maintenance organisations and engineers.

Shifts in training

To meet COVID-19 restrictions, adaptations were made in how training was delivered, moving away from in-person, classroom settings to virtual sessions. As the restrictions were lifted organisations saw the cost and efficiency opportunities and in many cases retained this type of training. EASA (2023c) acknowledges that in some cases this is ineffective and lists this as a new Safety Issue which will be considered for further action. A shift towards Competency-Based Training (CBT) offers considerable opportunities but also introduces risks of misuse, especially as organisations evolve their training to embrace the approach. Changes to training listed previously are being bought in but looking farther ahead, organisations must consider flexible training content (such as advanced materials) and methods (such as virtual and augmented reality) for the emerging skills required for new technologies (Boeing, 2022).

Economic Impact

Operators and maintenance organisations have faced a considerable increase in costs in recent years as a result of the above-mentioned component, staff and training pressures. Other impacts are a requirement to expand consumable and part inventory and forward purchasing of parts (Aviation Pros, 2023). The economic impact is considerable. “Delta Air Lines reported a 13 per cent increase in parts and repair costs over 2019. United spent $2.2bn on parts and repairs in 2022, a 20 per cent rise compared with 2019 and a 64 per cent increase from 2021.” (Ft.com, 2023; Aviation Week 2023).

Personnel Level

The issues at an industry level and resulting challenges at an organisational level are leading to increased pressure on engineering personnel.

Fatigue

The impact of fatigue on human performance is well-established. Indeed, the aviation industry, which relies upon professionals to perform their jobs reliably and efficiently, has recognised this and has been regulating and supporting organisations and individuals for many years. Fatigue has long been identified as a key maintenance risk (Johnson, 2016) and the UK CAA commissioned research, known as the Folkard Review (UK CAA, 2003) provided recommendations on working hours for maintenance engineers. However, all regulatory efforts have focused on flight crew and air traffic controllers. The FAA issued an Advisory Circular (FAA, 2016) to individual engineers and

organisations for information rather than regulation. Aircraft maintenance organisations are required to establish a Safety Management System (SMS) and to plan tasks and shifts to consider the threat of maintenance engineer fatigue but this falls short of regulating a fatigue risk management system (EASA, 2016). In a recent survey conducted by HeliOffshore (the safety association for offshore helicopter operations) it was reported that the biggest drivers to fatigue are a lack of appropriately qualified staff, workload and commercial requirements. 89% of engineers agree that physical fatigue affects their performance and 91% agree that mental fatigue has an effect. Also, it is reported that 65% of engineers have observed a fatigue-related incident in the last year. The survey also revealed that organisations are failing to proactively implement an effective fatigue risk management system with 17% of operators not monitoring staff hours at all and 62% relying on personal monitoring or spreadsheets to do so (HeliOffshore, 2023). In Europe, EASA has identified fatigue as a priority issue for the aviation industry and that it will "strive to ensure that adequate prevention against effects of fatigue is provided in all aviation domains" (EASA, 2023c) but this remains a significant threat to airworthiness.

Mental health and wellbeing

Following the Germanwings Flight 9525 tragedy in 2015, aviation bodies around the world initiated studies into how they could best regulate and guide in order to prevent a similar tragic event. EASA implemented a new rule on the mental fitness of air crew which requires support programmes for pilots, mandatory alcohol testing and psychological testing before employment starts (EASA, 2018). The Flight Safety Foundation developed "An Aviation Professionals Wellbeing Guide" to support individuals in improving their personal wellbeing (Flight Safety Foundation, 2020). These efforts were extremely useful in the COVID-19 pandemic when personal and workplace stresses had a profound impact on the mental wellbeing of aviation professionals. The interest from the industry was high. The Royal Aeronautical Society webinar on the topic had over 500 registered attendees. Although the guidance material can be applied to all aviation domains this is not mandatory and there is a recognition within the industry that regulation should address all aviation professionals, not just flight crew. EASA's European Plan for Aviation Safety (EPAS) highlights the lack of industry-wide staff support programmes as one of the highest risk, cross-domain safety issues in EASA's portfolio (EASA, 2023a,b,c). In order to address this disparity, the Royal Aeronautical Society ran a conference entitled "Maintaining Wellbeing: Opening Up in the Maintenance Environment" to focus specifically on maintenance. Some operators such as Virgin Atlantic revealed that wellbeing is a mandatory programme for Part M and 145 employees but there was a general recognition that an unmodified pilot programme could not be implemented directly in engineering so there is work to do to customise the approach. More generally, the industry must move beyond simple compliance with regulation (which seeks to address only the most extreme cases) to understand root causes for all mental health challenges, develop mitigations and share best practice.

Under-reporting by maintenance engineers

Reporting of potential safety issues by aviation professionals is a cornerstone of aviation SMSs. Although engineers are mandated to report safety-related occurrences, voluntary reporting of incidents that do not make this threshold is a critical means of identifying safety hazards and undetected risks (EASA, 2022). However, it is widely recognised that maintenance engineers tend to under-report these less serious issues. CHIRP, the well-respected independent, confidential reporting mechanism consistently receives only a fraction of reports from engineers compared to flight and cabin crew. Although CHIRP confirms that there is some reporting related to many of the challenges listed in this report, including staffing levels, bullying, commercial pressure, bogus licences, mental health and fatigue, the sample size is very small. Despite 65% of engineers having observed a fatigue-related incident in the last year, half of organisational respondents to the HeliOffshore fatigue survey report no incidents due to fatigue over the last 12 months (HeliOffshore, 2023). Turkoglu (2023) suggests that this is due to a lack of fear of the consequences of not reporting, poor usability of the reporting mechanism and apathy due to a failure of the organisation to act on previous reporting. Furthermore, it is critical that engineers understand what issues should be reported as their problem-solving abilities often result in problems being identified and resolved without reports being filed. Anecdotally it has been accepted that under-reporting is a consequence of a fear of reprisals when raising concerns but given the shortage of engineers and high cost of replacing them this now seems unlikely. With whistle-blowing protection in place in Europe and the US, in aviation this is certainly growing with recent examples of reports to regulators from aviation professionals revealing significant safety issues. However, under-reporting remains a concern and should be an area of further investigation.

Discussion

Under the backdrop of a well-recognised global shortage of maintenance engineers, the pandemic forced airlines to mothball and prematurely retire aircraft and defer non-critical maintenance, leading to a reduction in the overall maintenance demand. Maintenance organisations reacted, reducing headcount with a net loss of higher cost (i.e. experienced) maintenance engineers. Alongside this, the material and component suppliers saw demand drop, lockdowns limiting production and a disruption of logistics.

The Immediate post-pandemic recovery has required maintenance organisations to scale up, bringing aircraft back to airworthiness, with fewer and less experienced staff and more contracted labour, and demanding more material and components. Suppliers have struggled to recover, leading to reduced stock and a weakened supply chain driving shortages of raw materials and components to meet demand.

As the industry moves into growth (the predicted increases in air travel will see OEMs catching up on delayed aircraft deliveries, injecting modern aircraft with new technologies existing alongside a legacy fleet.

Longer term, driven by a need to address the climate crisis and the emergence of new technologies, maintenance engineers will require a new set of skills. We must revolutionise what we train our engineers and how we train them. We must address the disparity between regulation, support and guidance for maintenance and that of the flight crew to minimise fatigue and improve mental wellbeing of our engineers. We must look at why things are going right alongside the more traditional consideration of why things go wrong, creating a positive and open working environment where all aviation professionals feel able to freely report fatigue and mental health issues.

Solutions are being researched, trialled and implemented around the world and it is our duty to promote and share great practice.

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