Development of a strategy to enhance human centred design for aircraft maintenance.

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SUMMARY

This paper describes the results of a study commissioned by the Royal Aeronautical Society (RAeS) to develop an aviation industry-wide strategy to enhance human-centred design for aircraft maintenance. The authors will set out the problem, describe the conception of the project and the novel approach taken. The resulting published report (RAeS 2022) will serve as guidance for the aviation industry on how it might proactively and strategically change to embed human-centred design for maintenance into the fabric of the aviation system.

KEYWORDS

Human-centred, Aircraft, Design, Maintenance

Introduction

Maintenance error continues to feature prevalently as a cause or contributor to aircraft accidents and incidents despite various initiatives to address this by-product of work in a complex environment. Existing initiatives have predominantly been tactical and reactive, aimed only at the maintenance engineers and the aircraft maintenance environment. The RAeS specialist Human Factors Engineering sub-group (HFG:E), which aims to promote and influence the reduction of risks to airworthiness arising from human performance in engineering, recognised that more effective action is required and in 2021 it commissioned a major study to develop a strategy to enhance human-centred design for maintenance (HCDM). Relying on volunteer researchers and contributors, the study adopted a novel and holistic approach, exploring all of the key industry areas most relevant to HCDM. The results of the study and its far-reaching recommendations describe a way forward by which each of the industry areas can be advanced equally and thus assure significant, tangible and sustainable development.

Problem statement

Human performance variability can be both an asset and a threat to aircraft safety. The way an aircraft is designed has a profound impact on the ease and efficiency with which it can be maintained and the consequential risk of maintenance error. Aircraft design, and the design of procedures, tooling and documentation are often found to lack a human-centred approach. The industry has expended considerable effort on addressing the human factors (HF) affecting flight crew performance, and flight deck design requirements now dictate that the design must accommodate realistic human performance. Whilst some effort has been applied to maintenance, remarkably little has been done to improve HCDM.

Commissioning the study

Following an appeal for volunteers from within the RAeS membership community with a background in HF and aircraft design, five experienced contributors, knowledgeable and passionate about the subject, were selected by the HFG:E to lead the study. Together with three project commissioners the project was launched in March 2021.

The contributors were tasked to:

- summarise the current industry position, outline existing regulatory requirements, design best practice and other industry expectations.
- produce recommendations to guide the HFG:E in what it should be asking of aircraft designers, maintenance organisations, regulators and other industry stakeholders, accompanied by an engagement strategy for doing so.
- document the findings, supporting evidence and recommendations in a final report.

Originally intended only for use by the HFG:E, such was the quality of the final report and the underlying research, that the commissioners decided the study should be published (RAeS 2022) so that it could serve as an industry reference, and a baseline against which organisations may wish to conduct their own gap analyses.

Methodology

The contributors sought to define the problem by conducting a literature review, considering research between 1993 and 2021. Once the context was understood, an analysis of the trends in maintenance-related incidents was undertaken to build on the body of knowledge based on a taxonomy of maintenance error developed for the purpose. The source of data was the Air Accidents Investigation Branch (AAIB) database, considering events investigated since 2010.

A mind-map of issues was developed based on the literature review and the experience of the research team and the commissioners (Figure 1).

Each contributor was assigned as a primary lead for one section, responsible for research and documentation, and as a reviewer of a secondary section. Each section was to contain an introduction, detail of the issue and recommendations.

One of the contributors acted as the overall report editor, collated the sections and standardised the tone-of-voice to counter the risk of inconsistencies when multiple authors are involved. The commissioners provided a final review before the document was published. Alongside the final document the contributors also delivered a spreadsheet of the recommendations scored according to the impact that they would have if successful and the anticipated effort to implement, suggesting a prioritisation of the recommendations. The aim of this was to support the ongoing efforts of the HFG:E to achieve real, sustainable change in HCDM.

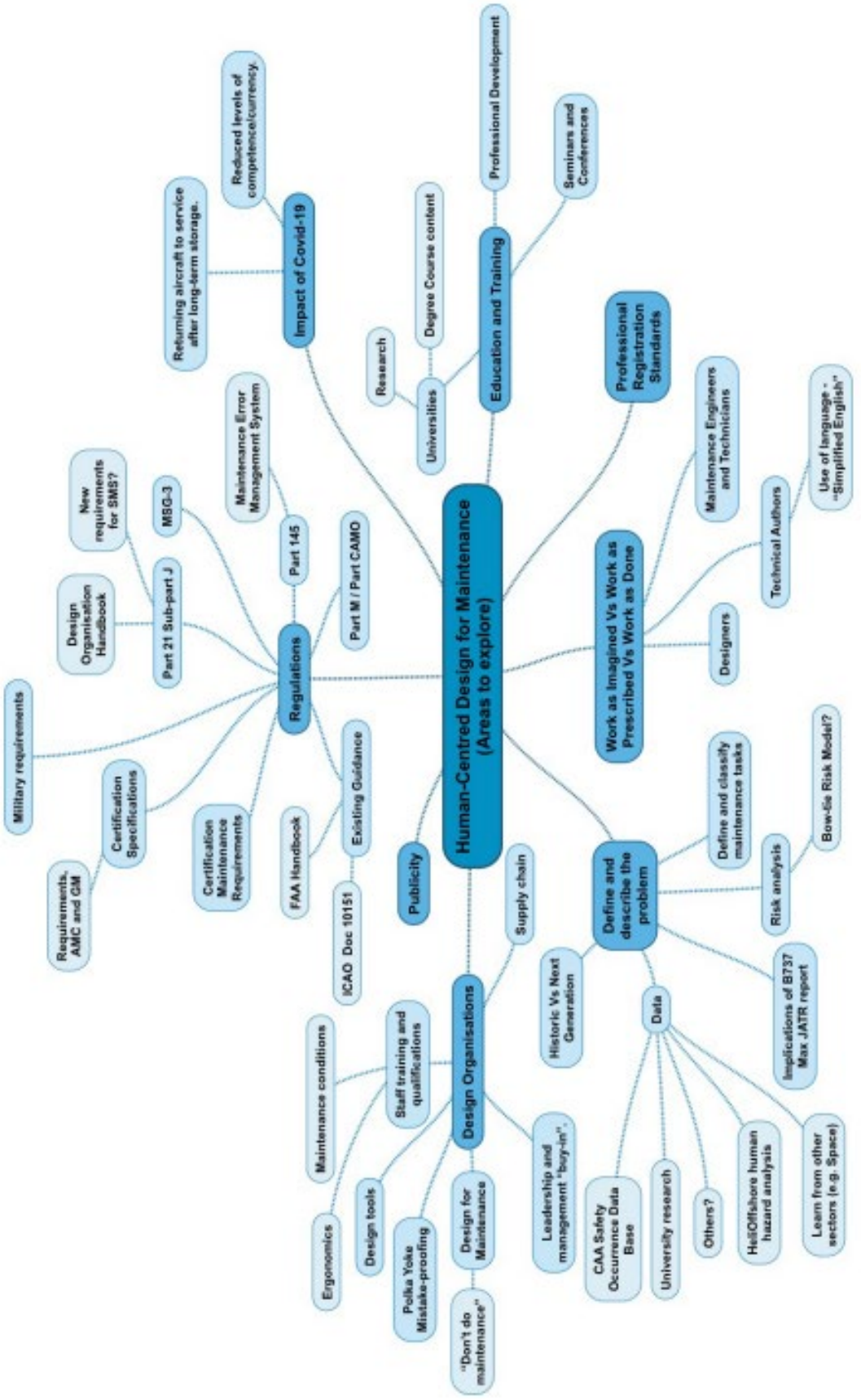

Figure 1: Mind map of areas the project explored

Body of evidence

The report presents an extensive examination of the body of evidence concerning maintenance errors spanning the last three decades, along with a fresh analysis of maintenance-related AAIB investigations. Findings indicate minimal change in the types of errors, their prevalence, and their consequences over time, despite the concerted efforts of regulators, operators, and maintenance organisations. The evidence consistently highlights deficiencies within the maintenance system, particularly in installation, demonstrating that industry actions targeting maintenance engineers have fallen short in addressing maintenance errors. Discrepancies persist between the maintenance-as-imagined, maintenance-as-prescribed and maintenance-as-done. Current remedial efforts remain largely reactive and tactical, lacking proactive strategic initiatives from design organisations. While retrospective analyses offer valuable insights, there's a crucial need to shift focus from merely examining past failures (i.e., event data) to extracting lessons from successes (i.e., adapting maintenance practices). Embracing a "Safety-II" approach can facilitate the identification of system weaknesses, conducting thorough assessments of the issues, and devising effective interventions to enhance industry safety.

Findings

This work concludes that there are significant challenges to overcome if the industry wants HCDM to become a standard part of aircraft design processes, which is likely to be the only way to achieve a significant and sustainable reduction in maintenance error.

Education

Aviation professionals joining the industry typically follow structured educational paths but while some institutions have taken steps to incorporate HF awareness in the next cohort, such efforts are not widespread. The host companies of those pursuing vocational paths into the industry have the opportunity to instil an understanding of HF issues pertinent to their specific niche and to influence the academic component of apprenticeships. However, it appears that little action has been taken in this regard. For those on the academic trajectory, only a limited number of universities include HF modules within engineering degree programs. While there are indications that universities are beginning to integrate specialised areas into their curricula, there is a need for greater involvement to promote the incorporation of HF into these programs. If both industry and academia aspire to advance HCDM, there must be a more coordinated effort to integrate HF principles at these educational levels.

In order to achieve these aims, the report recommended that professional engineering bodies:

- actively encourage universities offering engineering degrees to expand their curricula to include HF.
- encourage and accredit engineering degrees with HF content.
- take steps to promote the need for college engineering courses to include HF modules for students that may enter the engineering profession without undertaking an apprenticeship or graduate programme.
- take steps actively to promote the need for engineering apprenticeship standards to include appropriate HF within both the vocational and academic content/learning objectives.

Training

Despite mandatory HF training requirements for maintenance engineers, similar provisions are absent for design engineers. Consequently, there is a significant scarcity of training materials addressing HCDM for design engineers and they generally lack awareness of HF. Although certain sectors within the industry acknowledge the significance of HF, and various organisations are

making strides in advancing HF topics (such as in military and offshore aviation), these efforts are often isolated and lack broader industry collaboration. While specific HF training courses exist, there are limited options tailored specifically for design engineers. This weakness must be addressed at an industry level to fully leverage the practical insights and actions HF can offer.

To ensure that the industry has the best opportunity to achieve the aims, the report recommended that:

- action be taken to introduce relevant regulations to make initial and refresher HCDM training mandatory for all staff in design organisations.
- design organisations produce some digestible 'bite size' human factors material, such as short videos or illustrations, aimed at design engineers, highlighting the impact and importance of effective HCDM.

Professional Standards

The issuance of an aircraft maintenance engineer licence requires a detailed understanding of HF, how these can affect the work being undertaken, and the safety of the aircraft, However, professional and occupational competence and commitment standards set by the Engineer Council make no mention of any knowledge or skills in HF for aerospace design engineers. Therefore, engineers being recognised by the industry as Engineering Technician (Eng.Tech), Incorporated Engineer (I.Eng) or Chartered Engineer (C.Eng) are currently not required to have any HF competence. This position must change as we seek to improve HCDM in aviation, or in any other engineering discipline.

Among the recommendations arising from this work, the report recommended that the RAeS:

- engage with the Institute of Apprenticeships and Technical Education to ensure that the new apprentice standard, ST0785 "Human Factors Practitioner" contains appropriate requirements for HCDM.
- work with the Engineering Council to amend the UK Standard for Professional Engineering Competence and Commitment (UK-SPEC), so that it includes appropriate, relevant HF standards.
- engage with other, non-aerospace, engineering disciplines to address HF as a specific issue early on in the careers of apprentice engineers.

And that more widely, professional engineering bodies:

- work together to highlight the importance of engineers having an awareness of HF.
- ensure that apprenticeship programmes within aerospace design organisations include HF within both the vocational and academic content.

Design Organisations

The current aircraft design process and ongoing maintenance program monitoring operate under the assumption that no errors occur during maintenance procedures. However, there is a notable absence of widely recognised or accepted guidance for designers regarding maintenance considerations, and no mandatory training exists to educate them on even fundamental HF principles.

In civil aviation, regulations mandate design organisations to establish an in-service reporting system for collecting incidents from operational aircraft. While this system includes a section dedicated to maintenance and HF, there is a lack of detailed guidance regarding equipment design and operation. In other sectors of the industry, comprehensive guidance on Design For Manufacture

exists, which could potentially be adapted for design considerations. Additionally, the military sector is aware of the challenges posed by maintenance HF and is actively addressing them through mandatory training and design handbooks. Although these approaches may not directly translate to the civil design sector, they present valuable opportunities for knowledge transfer and learning.

The report recommended that the following action be taken:

- that regulations be established for design, production, maintenance and training organisations to ensure all relevant staff undertake HCDM training, to incorporate HCMD in their safety reporting systems and to mandate the reporting HCDM related events to the responsible organisation.
- to develop guidance for design organisations on HCDM.
- that design organisations produce 'bite size' HF material aimed at design engineers, highlighting the impact and importance of effective HCDM.

Certification Requirements

Within current aircraft certification requirements, designing to minimise or eradicate maintenance errors is either covered by very specific material or completely overlooked. Requirements related to engine design have the most extensive set of guidelines, primarily focused on ensuring that maintenance errors cannot lead to hazardous engine failures. However, regulations pertaining to smaller airplanes and rotorcraft lack any such requirements, despite a prolonged history of maintenance errors causing accidents and incidents in these domains.

Conversely, there are comprehensive and targeted requirements, along with supporting acceptable means of compliance and guidance material, addressing the necessity to incorporate HF considerations in flight deck design, particularly in regulations applicable to large aircraft. This is where the majority of design requirements for HF are concentrated.

It is evident that previous regulatory changes related to maintenance errors have been reactive responses to accidents or serious incidents, some resulting in significant loss of life. Moreover, these activities have solely focused on the specific issues related to the accidents themselves, and there is a lack of a strategic, holistic, and proactive review of the root causes. Furthermore, given that cockpit design requirements have acknowledged the necessity to accommodate realistic human performance and error, it seems incongruous that similarly comprehensive rules do not exist for design to prevent maintenance errors.

To this end, the report recommended that regulators:

- review the implicit assumption that aircraft maintenance is carried out with no allowance for error.
- further develop the human-centred guidance and provide more detailed guidance for the in-service safety reporting system.
- consider introducing mandatory requirements for HF and design for maintenance training for approved design organisations.
- audit type certificate holders' in-service reporting systems.
- initiate rule-making activity to develop requirements for design and certification specifications, to put HCDM at the heart of the design process, and to ensure appropriate consideration of the maintenance environment, and potential for maintenance errors, when designing aircraft and engines.
- revise certification panel arrangements to ensure they have capacity and capability to thoroughly assess HCDM as part of aircraft and engine certification activities.

Conclusions and next steps

While some of the recommendations have been summarised in this paper, the report makes a total of 42 recommendations on how the aviation industry may effectively address HCDM. Overall, it is concluded that more effort is required to close the gap between the way in which maintenance is actually performed (so-called "work as done") and the assumptions made by designers on how maintenance should be conducted ("work as imagined") and as described in the maintenance procedures ("work as prescribed"). If we design maintenance in a human-centred way we accept the conflict between policy and practice, accept that human performance is variable and, as a result, ensure that the easiest way to perform maintenance is the right way, making maintenance, quicker, cheaper, more reliable, and safer.

Following on from publication of the report, the HFG:E organised a conference on the same theme in February 2023, bringing together representatives from across the aviation industry with an interest in HCDM. The HFG:E continues to work towards actioning the recommendations from the report. The group is currently focusing on establishing networks of interested and influential individuals and organisations within each industry sector. A key challenge ahead will be identifying opportunities to influence the certification, design, education, training and professional standards landscapes to adopt a focus on HCDM as business-as-usual.

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