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Citation (APA)
Pollitt, A., Vlaskamp, D. M. L., Blundell, J., & Landman, A. (2026). Whither CRM?—30 Years on: A Narrative Review and Position Paper on the Future of Aviation CRM Training. *Aerospace*, *13*(6), Article 500. https://doi.org/10.3390/aerospace13060500

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Review

Whither CRM?—30 Years on: A Narrative Review and Position Paper on the Future of Aviation CRM Training

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Abstract

For almost fifty years, Crew Resource Management (CRM) has been a cornerstone of aviation safety and training. This narrative review examines the current state of CRM training and identifies key directions for future development, including the integration of artificial intelligence, increasing attention on mental health and resilience, and workforce diversity. While there is evidence of gradual evolution in CRM practices, reflected in updated regulatory frameworks, competency-based approaches, and a growing community of human factors and aviation psychology specialists, progress remains uneven across the industry. We argue that many aviation operators and training organizations still lack robust institutional mechanisms to systematically translate emerging scientific evidence into training design and delivery. As a result, advances in research on teaching and learning methods and human performance are not consistently brought forward into everyday training practices. The review concludes with a set of practical recommendations aimed at strengthening knowledge exchange between researchers and operational stakeholders, enhancing evidence-informed training, and supporting the modernization of CRM in a rapidly changing operational environment.

Keywords: Crew Resource Management; aviation human factors; aviation training; Evidence-Based Training; training design; non-technical skills; aviation psychology; Threat and Error Management; competency-based training and assessment

Check for updates

Academic Editor: Miroslav Kelemen

Received: 24 April 2026
Revised: 22 May 2026
Accepted: 24 May 2026
Published: 26 May 2026

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1. Introduction

Defined as "using all available resources, information, equipment, and people, to achieve safe and efficient flight operations" [1], Crew Resource Management (CRM) is a core concept in aviation. CRM training is mandated by law for flight and cabin crew. It focuses on the non-technical side of effective performance such as communication, leadership, teamwork, decision making, workload management, and situation awareness, as well as related human factors topics such as fatigue and stress.

In 1979, in response to a series of accidents attributed in part to authoritarian captains, NASA convened a workshop to address the issue of cockpit gradient and ineffective team work on the flight deck [2]. This convention is widely credited as the place where the concept of CRM originated [3]. In 1993, fourteen years after its inception, Helmreich [4]

posed the question "Whither CRM?" in a paper in which he outlined future directions for CRM. Since then, CRM training has certainly grown in scope. Training objectives have expanded over the years to include significant new topics such as Threat and Error Management [5], and Resilience Development [6]. Teaching methods have shifted towards facilitated learning, with a focus on the integration of non-technical skills in Competency-Based Training (CBT), and on using scenario-based instead of event-based training [7]. Undergraduate and postgraduate courses in Human Factors have proliferated, allowing greater theoretical and academic expertise to feed back into applied research and training. And not only has the teaching of CRM expanded to encompass a wider audience within aviation, but it has also found fertile ground in other domains [8], such as the health care [9], military [10] and maritime sectors [11].

This review combines insights from research and CRM training practice to describe the current momentum in CRM training (Section 2) and to identify key directions for its future development (Section 5). We revisit Helmreich's question from the perspective of contemporary aviation operations and training and investigate what has changed, what progress has been made and where there is still work to be done (Sections 3 and 4). We argue that, although there is evidence of incremental evolution in many areas, including a growing body of specialists in human factors and aviation psychology, many air operators and training organizations still lack the mechanisms to systematically incorporate emerging scientific evidence and operational insights into their training. In Sections 6 and 7 we sum up the changes in the last thirty years and offer recommendations for how CRM can remain effective and relevant in the coming decades.

Methodology and Literature Selection Strategy

This paper was conducted as a narrative review and position paper rather than as a formal systematic review. Accordingly, no predefined search protocol, structured inclusion or exclusion criteria, or PRISMA-style review methodology was applied. Instead, the literature selection process followed an iterative and interpretive approach intended to identify influential, conceptually relevant, and operationally significant contributions to the evolution of CRM, aviation human factors, and associated training practices. The review process began with Helmreich's seminal paper Whither CRM? [4], which served as the conceptual anchor for the study. Citation tracking was subsequently used to identify later studies referencing this work, while the reference lists of relevant publications were examined recursively to locate additional influential sources. Literature searches were conducted primarily using Google Scholar, alongside searches of aviation regulatory publications, academic publisher databases, conference proceedings, and institutional reports. Selection of literature progressed thematically according to the requirements of each subsection, with sources chosen on the basis of their relevance to historical CRM development, human factors theory, instructional design, regulatory evolution, and emerging future challenges for CRM training.

The interpretive approach adopted in this review was additionally informed by the authors' combined professional experience as current aircraft captains, CRM trainers and examiners, and aviation human factors researchers. This combination of operational and academic expertise supported both the selection and critical interpretation of literature relevant to contemporary CRM practice and training development.

2. The Evolution and Current State of CRM Training

2.1. Historical Evolution of CRM

CRM first evolved from early efforts to influence pilots' individual attitudes and soften cockpit authority gradients into a syllabus centered on non-technical 'soft skills', with the

central objective of error management through improved team coordination. Described by some commentators as having gone through six discrete 'generations' of development [3,12], its latest guise since the early 2000s is the active management of operational threats taught through the model of Threat-and-Error Management (TEM). However, the widespread acceptance of CRM objectives, its embedded role in regulation, and its contribution to safety and flight training standards reflect a broader cultural and attitudinal shift over nearly four decades [13]. This suggests that its development is more accurately characterized as a slow, piecemeal evolution rather than a series of clearly separable generational step-changes in attitudes and practice. An illustration of the generations of CRM evolution is provided in Table 1.

Table 1. The evolution of CRM across six generations, according to Helmreich [2,11].

Generation	Approx Period	Label	Core Focus	Key Characteristics
1st	Late 1970s–early 1980s	Cockpit Resource Management	Individual attitudes and interpersonal style	Psychology and management-based training; leadership style, authority gradients, assertiveness; largely classroom-based
2nd	Mid-1980s	Crew Resource Management	Team coordination	Shift from individual to crew; aviation-specific concepts (briefings, situational awareness, stress, decision making)
3rd	Early 1990s	Broadening the scope	System and organizational context	Integration with technical training; automation management; expansion to cabin crew, dispatch, maintenance; attention to culture
4th	Mid 1990s	Integration into technical training	Embedded CRM	CRM integrated into technical training and checking (AQP, LOFT)
5th	Late 1990s	Error management	Managing human error	CRM framed as error countermeasures (avoid, trap, mitigate); acceptance that error is ubiquitous
6th	Early 2000s onward	Threat & Error Management (TEM)	Managing operational threats	Extension of TEM to include environmental and system threats; shift from error-manager to threat manager (anticipation)

2.2. Gen 7? From TEM to Resilience and Systems Thinking

There have been attempts to define a seventh generation of CRM, although these have not yet gained widespread acceptance. For example, Terzioğlu [14] framed 'CRM 7.0' as its acceptance as a strategic, cultural, and managerial tool involving all organizational levels, including senior management and non-operational departments. This broadening adoption of human factors principles and training beyond aircrew and in the wider aviation sphere is conceived as an essential ingredient underpinning a positive safety culture [14]. It echoes one of Helmreich's [4] original calls for CRM to move beyond the cockpit door and be embraced by a wider cross-section of aviation stakeholders, from air traffic controllers to maintenance and ground operations personnel. Indeed, human factors training has undoubtedly propagated beyond just flight crew both in scope and audience since the 1990s and is now taught in some form in all of these aviation sub-sections [15–17] as well as

reaching the sphere of management [1]. Nevertheless, the kind of integrated 'organization-wide' concept envisioned by Terzioğlu [14] is one which has still not fully materialized to date and, as the next section will show, the gap between conceptual ambition and operational implementation remains a central criticism of contemporary CRM training.

If, instead, CRM is still evolving well into the third decade of its sixth generation, what already distinguishable characteristics might go on to define the seventh? As described in Table 1, TEM has remained the focus of CRM from the sixth generation (2000s) onward. During this period there has been a growing culture shift that reframes CRM around the concept of resilience, emphasizing adaptive capability, margin management, and performance under conditions of uncertainty (e.g., [18,19]). Both resilience and startle and surprise management were topics introduced to the CRM syllabus as part of a significant update to the regulatory requirements on CRM adopted in 2015 [19].

This shift towards integrated non-technical competencies that are generalizable for any operational problem or technical failure has also been reflected in the industry's gradual move towards a 'competency-based' training framework [20]. This framework is built around universal competencies such as communication, leadership and teamwork, situation awareness, workload management and problem-solving and decision-making. Alongside CBT as a teaching and assessing methodology, there has also been a transition towards 'Evidence-Based Training' (EBT), where training content is tailored to the specific type of activity of the operator and is continuously updated based on operational and training data such as LOSA, occurrence reports, and training reports [21]. Just as Helmreich predicted, these changes together reflect an increasingly systems-thinking approach which attempts to recognize the expansion of non-technical skills, from their beginnings in cockpit discipline, to a much broader operational context. They mark a shift from the traditional understanding and teaching of CRM in terms of individuals, towards one which better accounts for the complex nature of socio-technical systems. Although it has not yet solidified sufficiently to be put forward as a distinct new 'generation', this approach might yet come to characterize the next evolution of CRM after TEM.

3. CRM Training Effectiveness and Persistent Critiques

3.1. Evidence Base for CRM Effectiveness

Two large review papers investigating CRM effectiveness (not limited to aviation) show that CRM training is generally appreciated by trainees [22,23], who reported positive effects on their attitudes and behaviors. However, these reviews draw attention to several limitations in how CRM effectiveness has been evaluated, and neither was able to determine whether there was any impact on organizational safety. They also call for more rigorous evaluation of training [22], although, judging by the lack of recent studies, these exhortations seem not to have borne fruit.

3.2. Deficiencies in Training Delivery: "Checkbox" CRM

Despite its widespread acceptance, some within the industry argue that CRM training effectiveness has decreased because it is often reduced to a watered-down, compliance-driven, 'checkbox' exercise within broader training programs, delivered through passive classroom sessions or stand-alone e-learning (e.g., [24]). Training frequently relies on didactic, lecture-heavy delivery with limited application of structured instructional design, experiential learning, or systematic practice and reflection. Poorly facilitated sessions and recycled presentations can undermine engagement and learning. E-learning formats lack interaction and team-based learning, despite the original concept of CRM being fundamentally social in nature and conceived to optimize team co-operation and performance. Forrest criticizes the use of live-stream video-conference formats which undoubtedly offer

convenience and cost benefits to operators but, compared with the quality of face-to-face group training, do nothing to facilitate "intensive introspection done publicly in a seminar style format", as it was originally conceived [24]. Flin et al. state that e-learning may "jeopardize critical development ingredients" of non-technical skills training [25] (p. 306).

As mentioned above, the industry's move towards competency-based training and assessment puts more emphasis on integrated non-technical skills. Thomas [26] argues that non-technical skills cannot be developed from classroom training alone because the end objective is not just to change attitudes, but to achieve observable changes in performance. Participants in training frequently express a preference for CRM to be more practical, interactive, and participant-centered, as demonstrated in a recent survey among cabin crew [27].

3.3. Deficiencies in Training Design: Instructional and Theoretical Weaknesses

Salas et al. [23,28] argued that pilot subject matter expert involvement is not enough to ensure effective training. Job expertise does not equal training development expertise, particularly for non-technical skills. However, in many operations it is still pilots alone who develop CRM training. This leads to accusations that CRM training design and delivery by industry practitioners is often based on subjective opinions instead of empirical data, with a limited contribution from scientifically trained experts in human factors, psychology, or training [28]. Effective CRM training and training development requires developers who also understand learning theory, instructional design, facilitation, and behavior change; otherwise training risks becoming anecdotal, inconsistent, and focused on awareness rather than skill-building. In an unpublished paper, Ant [29] supports this view, describing current CRM training as lacking an explicit theoretical and epistemological foundation, with many programs failing to specify the behavioral, psychological, or learning theories upon which their content is based. This results in a fragmented and seemingly arbitrary selection of CRM topics, which is exacerbated by the periodic and ad hoc addition of more requirements in response to generations of aviation accidents and incidents.

3.4. The Impact of the Regulatory Landscape

Limitations in training design and delivery are reinforced by the way CRM training is regulated. CRM's regulatory landscape has progressed over the years, but in fits and starts. For example, EASA ushered in a raft of new measures in 2015 [6,19]. These bursts of activity have tended to incorporate additional syllabus requirements (such as startle and surprise, and resilience) following critical incidents and accidents, rather than fundamentally restructuring or refining the training objectives [6]. This has added further weight to an already heavy syllabus that covers a broad multidisciplinary range of topics [30], thorough knowledge of which is a burden for even the most conscientious and well-read instructor.

Although the breadth of the syllabus is wide, guidance from aviation authorities on training content is shallow and limited to a long list of topics without prescribing the desired content [30]. While this gives operators the flexibility to tailor to the needs of their specific population by performing a proper training needs analysis within the organization and developing its own training material effectively, it also requires expertise, time, and resources to do so. A recent workshop of CRM developers highlighted this, with participants complaining that the design of modern, engaging and realistic training is challenging, and exacerbated by lack of time and resources in the competitive commercial aviation world [25].

In smaller organizations where both levels of resource and manning may not be sufficient to develop an in-house training program, external training providers can be contracted

to deliver training on behalf of an operator [30]. However, the regulator requires no direct oversight of freelance or contracted trainers, leaving responsibility to the individual operator to oversee quality and course content. In such cases, a full needs analysis, leading to tailored training, may not be carried out, resulting in variable quality of training design and delivery, and the inability to integrate CRM fully into other parts of the operation [25,26].

Despite the halting pace of regulatory change, civil commercial operations have nevertheless always been in the forefront of progress in the field of CRM. In comparison, both in the US and Europe, the military was slow to adopt the practice of deliberate CRM training for its crews [31]. In the U.S., having done so, the Armed Forces have stuck to their original 1990s framework of seven critical skills (decision-making, adaptability/flexibility, situational awareness, mission analysis, communication, assertiveness, and leadership) ever since [31]. A review of training in the U.S. Navy by O'Connor et al. [10] showed that although it was well received by trainees, it risked stagnating, largely because its core curriculum and academic foundations had changed so little. This is despite substantial advances in research output on teamwork, decision-making, situation awareness, and automation over the preceding twenty years. In 2019, an updated assessment of the progress of U.S. Military CRM by O'Connor and colleagues continued to highlight a heterogeneous approach across different services, lack of experience and expertise amongst trainers, and "a model largely unchanged for several decades" [31] (p. 515).

3.5. Systemic Limitations and the Disconnect Between Science and Applied Training

Taken together, the issues described in Section 3 closely mirror the same persistent limitations identified twenty years ago by Salas et al. [23], who raised an absence of standardization, wide variability in quality, and the need for improved instructional design, implementation, and evaluation. Central to their critique was the argument that aviation training systems are ill-equipped to integrate emerging human factors and teaching-and-learning science to consistently and effectively update and refresh training with new knowledge and practices.

It remains the case that science on CRM-related topics has advanced and offers new perspectives, but these do not always reach the industry. Noteworthy examples of significant advances in human factors science include Edmondson's work on teaming [32] and psychological safety [33], which offers new perspectives on how teams coordinate, learn, and speak up in complex, high-risk environments; Klein's Naturalistic Decision Making [34]; and distributed situation awareness [35], which describes situation awareness as an emergent property of the socio-technical system, rather than residing solely within individuals. The incorporation of such new perspectives into syllabi that only stipulate topic titles and not content is dependent upon the ability and propensity of individual trainers to educate themselves and update training content according to their own assessment of the value and relevance of novel research output.

Trainers' ability to remain up to date with new themes in research depends upon institutional mechanisms which can systematically translate emerging scientific evidence and operational insights into rigorous and effective crew training. The ties between those producing human factors science and the operational sharp-end are often indistinct and informal [36]. In the absence of effective two-way knowledge exchange, scientific advances in learning, training, and simulation remain difficult to operationalize and the aviation training sector lacks both the expectation and the capacity to demand evidence-based renewal. Strengthening these relationships depends upon building institutional and organizational bridges across the science-industry domain gap.

4. Addressing the Critiques: Progress and Remaining Gaps

4.1. Institutional and Regulatory Progress

Regulatory progress has been made in the twenty years since Salas et al.'s critical review in 2006 [23]. The past two decades have seen the creation of regulatory working groups such as the European Human Factors Advisory Group and the UK Civil Aviation Authority (CAA)'s Flight Crew Human Factors advisory panel. These panels provide guidance to aviation authorities and industry in the form of independent, high-level, human factors expertise on training standards and practices [37]. Although CRM is often the most visible operational application in this domain, it represents only one subset of the broader discipline of human factors, which encompasses the scientific study of human performance, cognition, ergonomics, organizational systems, and human–technology interaction in aviation. Consequently, the human factors institutions discussed here influence CRM by shaping the evidence base, theoretical frameworks, and applied methodologies upon which CRM training and assessment practices are built. For example, the UK CAA's Civil Aviation Publication (CAP) 737 Flight Crew Human Factors Handbook, which was substantially rewritten in 2023 to incorporate CBT, is probably the key industry publication for trainers and assessors on CRM and represents a collaboration between aviation and academic specialists [38]. Other examples of organizational progress include the establishment of professional institutions such as the European Association for Aviation Psychology, and the UK's Chartered Institute of Ergonomics and Human Factors, whose function is to promote the study and scientific application of psychology and human factors in aviation, connect professionals, organize conferences, and facilitate research [39]. These developments go some way towards addressing the accusation of a dearth of guidance, established standards, or credible methodologies supporting training development that has sometimes been levelled against CRM.

However, systematic, institutional support for trainers, and especially training developers, could still be improved. For example, recent feedback from CRM developers still highlighted the limited opportunities for practitioners to share expertise with other sectors and between themselves [25]. There remains a need for the industry to put weight behind increased opportunities for aviation trainers and operators to access conferences, professional training forums supported with guest speakers from academia, human factors scientists, and aviation psychologists, and the systematic dissemination of updates on the state of science and best practices.

4.2. Building Science-Industry Domain Bridges

One of the key challenges in addressing the science-industry disconnect is the building of domain bridges by strengthening relationships between those driving new science in aviation psychology and human factors, and those creating and imparting the lessons to front-line practitioners. There are few established, institutionalized paths for specialists to bridge the gap between the two fields, resulting in limited opportunities for cross-pollination and transfer of knowledge and expertise. The recent growth of master's level courses and doctoral studies in human factors has helped strengthen educational and professional opportunities for experts to move across the domain boundary between science and aviation industry, but these have mostly been self-funded. Whilst acknowledging that progress has been made in this regard, industry support or sponsorship of aviation professionals to develop academic and scientific credentials such as MSc or PhD, and the lending of industry expertise to support scientific research in relevant fields, could be a catalyst to further these aims. Movement of scientific expertise in the other direction, such as that of aviation psychologists, learning specialists, and human factors specialists, to advise and assist with training development and instructional design has also increased

in recent years. However, these specialists tend to be exclusive to larger, better-resourced operations, and further expansion of an industry role for them is likely to need explicit regulatory support.

4.3. Ecological Validity and Training Design Principles

Beyond institutional and professional structures, addressing CRM's limitations also requires rethinking how training itself is designed and delivered. In the early generations of CRM, Helmreich and colleagues noted considerable pilot resistance to classroom-based CRM exercises, which were perceived as being detached from everyday operational reality [3]. In response, Helmreich advocated for the integration of CRM principles into technical and simulator training, rather than treating CRM as a standalone classroom subject [12]. As has already been mentioned, CBT and EBT principles are a major step forward towards achieving this.

Ecological psychology, which originated in the mid-20th century through the work of James Gibson (e.g., [40]), provides a theoretical basis for this shift towards integrated non-technical skill development. Ecological psychology emphasizes the tight coupling between perception and action and argues that skilled behavior develops through direct interaction with structured information from real environments. Applied to aviation, this perspective suggests that CRM training that relies predominantly on classroom instruction and abstract behavioral models is insufficient to train crews to coordinate, communicate, monitor, and make decisions under time pressure and uncertainty. From this viewpoint, CRM training is more effective when embedded in realistic, scenario-based practice, allowing non-technical skills to emerge in context rather than teaching them in isolation. This does not imply that effective CRM training always requires high-fidelity flight simulators. As Bergström et al. [41] argue, fidelity and ecological validity are not equivalent: high physical realism supports procedural and technical skill acquisition, but low- or mid-fidelity simulations (when carefully designed) can be equally or more effective for developing adaptive coordination, problem-solving and other CRM-relevant skills.

The role of variable and unpredictable training conditions in developing resilience has been emphasized by different researchers [42]. While SOPs remain foundational to aviation safety practices, research on expertise and skill acquisition shows that training based on fixed, predictable scenarios tends to promote procedural compliance, whereas variation and controlled unpredictability encourage crews to explore alternative strategies, detect weak signals, and adapt coordination under uncertainty, leading to a better performance in unexpected events (e.g., [43–45]), and making this kind of training an important complement to procedural compliance for complex operational environments.

In the next paragraphs, current developments in the aviation industry relevant to CRM training will be discussed, intending to present an overview of where CRM is heading now and where it might end up in the future.

5. Future Drivers of CRM Development

5.1. Increasing Autonomy and Advanced Automation

Advanced automation and increasing cockpit autonomy are likely to fundamentally reshape future CRM programs by shifting the focus from human–human coordination to human–AI teaming, where issues such as trust calibration, role clarity, and monitoring of automated agents become central training objectives [46,47]. For example, single-pilot and reduced-crew operations have been a dominant and polemical theme in recent years [48]. Although recent pressure to introduce reduced crewing has subsided somewhat, it is likely to remain on the industry agenda in the longer-term. Even if a second pilot is not replaced fully, artificial Intelligence (AI) will be increasingly common operationally in the future

cockpit. Takacs et al. predict that it will manage most monitoring and routine tasks in the future, while human pilots will remain critical for non-normal, safety-critical situations, through key human skills such as critical thinking, self-monitoring, digital literacy, and decision making, supported by onboard AI (and, in the case of single-pilot operations, remote ground operators) [49].

This has the potential to permanently transform traditional interpersonal cockpit dynamics and present novel CRM challenges in situational awareness, vigilance, calibrated trust, and system understanding. Longstanding risks associated with automation, such as reduced situational awareness and automation bias, may be amplified in highly autonomous cockpits, requiring CRM to explicitly train crews to challenge, verify, and manage AI outputs rather than passively accept them [46]. The authors argue that AI should be treated not as a tool but as a full-fledged teammate in a socio-technical teaming, requiring the building of an AI-CRM framework [49]. Any such model would have to address trust and transparency in AI systems, and careful integration in areas such as human–AI communication, leadership, workload and stress management, decision-making transparency, and prevention of automation dependency and bias to ensure the preservation of pilot authority and accountability [47,50]. Research on human–AI teaming further suggests that future CRM frameworks are likely to incorporate entirely new competencies, including, for example, oversight of autonomous functions [51].

5.2. Safety II, Culture, Resilience and Adaptive Performance

The emergence of Safety II, which sees safety as the ability to succeed under varying conditions, rather than the absence of accidents [52], had a fundamental impact on aviation. From a Safety-II perspective, humans are no longer viewed primarily as sources of error, but as essential contributors to system resilience through their capacity to adapt, anticipate, and manage performance variability. In pilot training, resilience, or the ability to adapt and sustain performance under conditions of dynamic uncertainty, has increasingly become a focal concept. However, the relatively abstract nature of resilience as a concept complicates its translation into concrete training material. While CBT and EBT have signaled a shift toward a more Safety-II-informed training philosophy by emphasizing both resilience and adaptive capacity, their practical implementation remains uneven, and instructional practices continue to reflect predominantly Safety-I-oriented assumptions. Sixth-generation CRM does incorporate the broader systems perspective adopted by Safety II, as well as pay increased attention to resilience and adaptability, but its underlying training logic remains largely linear and prescriptive [45]. For example (although it remains a cornerstone of contemporary CRM training and operational practice) critics of TEM argue that it implicitly assumes threats to be identifiable and largely predictable; an assumption that does not always reflect the reality of complex operational environments [18].

5.3. Psychological Safety and Safety Culture Revisited

Psychological safety has been defined by its founding theorist as, "a shared belief held by members of a team that the team is safe for interpersonal risk-taking" [53] (p. 3). The concept was quickly recognized by the aviation community as having a role to play in effective CRM and safe aviation practice by enabling open communication, challenge, and the sharing of safety-relevant information regardless of hierarchy [54]. Evidence from a study by Perkins et al. [55] highlights that many First Officers hesitate to speak up when flight decks lack psychological safety. This suggests that traditional CRM frameworks, while addressing authority gradient and promoting communication in principle, do not sufficiently equip Captains with the practical tools to create inclusive cockpit microcultures that actively encourage junior colleagues' 'safety voice.' The authors go on

to argue that the assumption that the flight deck consistently supports safety voice and safety listening as standard practice is not always the case, asserting that current CRM "fails to adequately establish tools for designing a psychologically safe flight deck" [55] (p. 12). They therefore advocate for a redesign of CRM based on a human-centered data approach, shifting away from reliance on system-level safety metrics (e.g., incident reports, compliance data, simulator performance) toward incorporating pilots' lived experiences of interpersonal dynamics, behavior, and cockpit culture. This reframing positions safety not only as a technical outcome, but as a socially constructed phenomenon shaped by everyday crew interactions.

Linked in many ways to psychological safety, safety culture is a classic CRM concept that gained popularity in the second half of the 1980s, after several high-profile disasters with a strong organizational component such as the Chernobyl nuclear disaster and the Challenger space shuttle disaster [56]. Definitions vary, and the concept has been subject to criticism. Cooper defines safety culture as "the observable degree of effort with which all organizational members direct their attention and actions towards improving safety on a daily basis" [56] (p. 115). Safety culture is already a mandatory topic of CRM education [30], and recent problems in the industry have put safety culture back into the spotlight [57]. In 2021, IFALPA released a position paper emphasizing the importance of a positive safety culture, focusing mainly on the concept of just culture and non-punitive safety reporting [58].

5.4. Workforce Diversity

The pilot workforce is gradually becoming more diverse. The IATA Gender in Aviation report shows that women remain markedly under-represented among pilots, accounting globally for around only 5% of the workforce, albeit with a clear upward trend [59]. While overall representation remains low, growth is strongest among new hires, with women comprising around 12% of recent flight-deck recruits and the absolute number of female pilots increasing substantially from a small base. However, there are still frequent reports of bias, sexism and stereotyping when it comes to female pilots [60,61]. This shifting demographic needs to be explicitly acknowledged in current CRM training to incorporate gender-related dynamics such as bias, power dynamics, and psychological safety [61].

A dramatic increase in global interconnectedness in the past generation has transformed aviation organizations into increasingly culturally diverse workforces, creating a growing need for awareness of the impact of cultural differences [62–64]. Historically, CRM training has been developed largely from a Western perspective, shaping both its content and how "effective CRM" is defined [65]. This cultural framing influences communication styles, authority gradients, and overall CRM effectiveness in non-Western or multicultural environments. Research on multicultural cockpit crews has shown that cultural norms can moderate how CRM principles are enacted and received [66,67]. Consequently, a deeper understanding of cultural dynamics by CRM trainers working with mixed cultural groups will be essential to support effective training and address the challenges and opportunities presented by an increasingly globalized aviation workforce [62–64].

Recent work has begun to systematically examine generational diversity in airline settings, noting that different cohorts (Baby Boomers, Generation X, Millennials, and Generation Z) exhibit distinct characteristics in risk orientation, learning styles, and organizational commitment. For example, a 2025 systematic review highlights differences between Baby Boomers and Millennials in how they approach risk, learning behaviors, and loyalty to the organization, and suggests intra-generational profiles among all four cohorts in aviation contexts [68]. However, research specifically focused on generational differences in aviation is still limited. The review also cautions that results vary across countries and job roles,

and many studies find no clear generational differences once contextual factors such as experience and working conditions are taken into consideration. Moreover, wide variation within each generation challenges the idea that all people in one age group behave the same way.

5.5. Mental Health

The Germanwings tragedy [69], and subsequently the COVID crisis, put pilot mental health firmly on the map [70]. However, there is still strong stigma surrounding mental health, and pilots' fears of losing their medical certificate still hamper the reporting of problems [70,71]. Many pilots prefer not to speak up, choosing instead to suffer in silence. Systemic improvements are needed to counter this by creating an environment where pilots can safely declare mental health problems without fear of losing their medical license [72]. The addition of mental health literacy through CRM training could have a role in improving the recognition and awareness of mental health issues and reduce the associated stigmas [72].

Industry working conditions and irregular schedules cause chronic stress and sleep disturbances that negatively affect mental health, as is highlighted by a slew of recent research (e.g., [73–76]). These studies all indicate that fatigue and work-related stress should be addressed in training as dynamic internal threats that degrade mental health, resilience, and performance over time, rather than treating them solely as duty-time or compliance issues. They recommend that the recognition, verbalization, and management of degraded mental states within normal operations be integrated into scenario-based training and debriefing. To be effective, this needs to be supported by a non-punitive culture that encourages early self-regulation and peer support rather than late disclosure, as well as systemic changes designed to limit crews' exposure to these threats.

Operational pressure is common in the commercially competitive world of aviation and a frequent cause of work-related stress. It is defined by Marsman et al. as both external- and self-induced pressure which affects operations and can contribute to accidents and incidents [77]. Commercial pressure, staff shortages, time pressure, and last-minute planning changes have all been shown to be commonplace. Awareness and mitigation of these should form an important part of CRM training.

5.6. Emotional Intelligence and Personal Resilience

The significance of emotional intelligence and personal coping skills in effective aviation performance, especially under conditions of uncertainty or high stress, is beginning to be discussed (e.g., [78]). This argument highlights that EBT and current CRM practice focus mainly on technical and team competencies, but do not address the psychological state of the individual pilot, including self-awareness, emotion regulation, and stress resilience—all key components of emotional intelligence. High emotional intelligence has been shown to consistently correlate with safer decision-making and fewer risks, and acts as a buffer against cognitive biases [79].

Recent research suggests that pilots often struggle with performance anxiety, especially in training environments [80,81], which sometimes leads to long-term mental health issues. Lessons from sports psychology could offer some of the necessary tools for coping with this, such as mental imagery, breathing, temporization (slowing down), relaxation, acceptance, perspective shifting, and self-talk, to help pilots regulate arousal and maintain cognitive flexibility [78]. These individual-oriented psychological techniques are not currently part of CRM training but could be integrated. An example of internally orientated stress management training is the establishment in some airlines of a breathing-based startle

management method for pilots [82]. A recent study demonstrates that pilots are, on average, open to using these types of techniques and generally believe that they are beneficial [83].

The United States Air Force Comprehensive Readiness for Aircrew Flying Training (CRAFT) program is a contemporary example of a holistic human performance initiative centered on personal resilience [84]. Designed to prepare pilots for the physical and cognitive demands of modern flying, it integrates physical conditioning, cognitive performance training, stress management, and resilience coaching within aircrew training. The program uses multidisciplinary support teams and a range of psychological and physiological performance-enhancement techniques, including breathing protocols, mental regulation strategies, and cognitive simulation exercises, to improve stress management, focus, decision-making, and overall operational performance.

Traditionally, military and civil pilot training focused almost exclusively on teaching flying techniques. Developing emotional intelligence and personal coping skills by addressing pilots' individual psychological states, stress regulation, and cognitive resilience alongside technical and team competencies has the potential to make a significant contribution to decision-making, performance under pressure, and long-term safety in aviation operations, and may represent the most significant emerging evolution in CRM training [54].

5.7. Data-Driven and Personalized CRM

A major new (2026) systematic review by Yiu et al. highlights how artificial intelligence (AI) is rapidly changing the way aviation understands and manages human performance, with major implications for both Human Factors research and CRM training [50]. AI's ability to analyze large volumes of operational data quickly and consistently makes it possible to study workload, stress, and crew interaction in operational settings and opens the door to more evidence-based models of human performance in complex environments. For example, advanced machine learning models are now capable of identifying subtle patterns such as physiological signals of rising cognitive workload or declining situational awareness long before performance visibly degrades [85]. Together, these tools are enabling a shift toward real-time human performance monitoring.

The implications for CRM training are equally significant. Training programs can implement safety and training data analysis more easily and effectively using Large Language Models which read and summarize reports, extract causes and safety lessons, and support investigators and instructor pilots through intelligent assistants [50]. Real operational and flight training data could be used to design CRM exercises grounded in actual human performance challenges, helping crews better recognize pressure, manage cognitive overload, and coordinate effectively under stress. CAE's CORe project [86], which uses simulator data to inform training scenarios, is one example of this. The potential of AI and increased data storage could create opportunities for novel training modalities, such as personalized training needs, something that could eventually result in completely different training formats and means of regulatory compliance. A multitude of intelligence assistance apps are already becoming available to pilots. For example, the CRMSON app delivers CRM-based micro-interventions based on academically validated sources and techniques [87].

5.8. Lessons from Other Sectors

CRM originated in aviation but, just as Helmreich anticipated, it has now been expanded to other sectors as well, including (most notably) healthcare [9], nuclear, maritime, ATC, and military aviation [8,10]. Across these industries, aviation is still viewed as the primary reference point for the development and application of CRM, with healthcare, maritime, and military domains largely adopting methods developed in aviation. However,

other sectors have advanced CRM in ways that offer lessons for aviation, particularly through integrated, multi-disciplinary training, modular and flexible delivery, and more systematic assessment of training effectiveness [88]. For example, healthcare has become a major focus for human factors and CRM research. The output of human factors-related studies in healthcare has proliferated in recent years. This is in part because clinicians are expected to conduct and publish research as part of professional development, making them a major source of peer-reviewed CRM research [9]. This provides evidence-based insights and metrics that can inform human factors in aviation and help validate CRM approaches across other high-risk domains.

6. Discussion

The future direction of CRM outlined by Helmreich in 1993 has since been realized to a considerable extent. He expressed a vision of CRM extending 'beyond the cockpit door' which might one day include groups from cabin crew and ATC to maintenance and dispatch. Indeed, resource management and human factors training have become a reality in many of these spheres within aviation. So too, have we seen the pollination of human factors and CRM into other domains where teams work in high-risk environments.

In terms of training itself, Helmreich foresaw the integration of CRM with technical training and the increasing use of simulation to facilitate the learning and application of classroom non-technical skills in practice. He also predicted a greater focus on specific behaviors and a move towards a more systems-oriented philosophy, both of which have come to fruition with competency-based approaches using behavioral markers, and a new paradigm with an increased focus on the dynamics of socio-technical systems.

Perhaps less presciently, he anticipated the refining of curricula and programs that have taken place incrementally over the past three decades, including the incorporation of important new concepts such as TEM and resilience development. He underscored the growing importance of organizational and national cultures and the need to develop training strategies that are more sensitive to cultural differences. Rather than representing this progress in terms of a series of generational 'leaps forward' [3] much of this change is better characterized as a gradual evolution, sometimes in response to specific events. One of these was the 2009 accident of Air France flight 447, which became the catalyst for significant research effort driving subsequent change in both the CRM syllabus [19] as well as human factors thinking related to socio-technical systems [35].

However, persistent critiques remain. Passive classroom sessions or e-learning formats undermine CRM's interactive, team-based foundations. Weak theoretical grounding, limited use of instructional design principles, and an overreliance on subject matter experts rather than training specialists can contribute to fragmented, awareness-focused programs rather than structured skill development. These shortcomings are reinforced by regulatory guidance that emphasizes topic lists over learning outcomes. This leaves the quality vulnerable to variability across operators, particularly where resources and training expertise are limited. Collectively, these issues reflect long-standing concerns about curricular stagnation, inconsistent implementation, and the aviation industry's limited capacity to integrate advances in human factors and learning science into CRM, suggesting that many of the structural weaknesses identified over two decades ago remain largely unresolved today.

In this paper we have attempted to address some of these criticisms and suggest where their solutions could lie at the same time as looking ahead to the dynamics shaping the future of human factors and non-technical skills training in aviation. Undoubtedly, several contemporary developments, such as the rise in AI, an increasingly diverse workforce, and

the potential shift towards increasing autonomy, advanced automation, and reduced-crew operations in the future will create new challenges for CRM.

7. Recommendations

Against this background, the question is how CRM can remain effective and relevant in the future. Based on this review, we propose the following action points for aviation authorities, aviation training specialists and human factors research institutions in industry and academia.

1. Increase multidisciplinary expertise into CRM training development. Include learning and instructional design specialists, aviation psychologists, and human factors experts as integral members of CRM development teams, rather than relying solely on operational subject matter experts.
2. Establish sustained and structured collaboration between academia and aviation operators to bridge research, training, and frontline operations.
3. Professionalize CRM trainers and training developers by strengthening their research literacy, access to current academic knowledge, and opportunities for professional exchange such as joint conferences and forums.
4. Improve the quality and scope of evaluations of CRM training effectiveness. Move beyond participant satisfaction measures to include behavioral, operational and longer-term, outcome-based evaluations of CRM training.
5. Enhance inter-airline cooperation and sharing of CRM materials across airlines and operators, allowing the support of smaller operators with limited training budgets.

The limited amount of recent peer-reviewed literature in the field of CRM training suggests a clear need for renewed research attention. More empirical work is needed on the drivers of CRM effectiveness, including its impact on safety outcomes. A thorough survey assessing practitioner perspectives on the current state of CRM training would be a good starting point, because, as Forrest raises [24], there often is a disconnect between the assumptions underlying CRM training design and practitioner experiences in practice. Further research on how sports and performance psychology can be adapted for use in aviation could provide a rich source of knowledge into managing individual psychological states and performance within the context of CRM.

Author Contributions: A.P. and D.V. contributed equally to this work; Conceptualization, A.P. and D.V.; Writing—Original Draft Preparation, A.P. and D.V.; Writing—Review & Editing, A.L. and J.B.; Supervision, A.L. and J.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

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