Application of Kansei Engineering in aircraft design

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ABSTRACT – REZUMAT

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Kansei Engineering can develop a new product by translating a customer's requirements into design, which is an ergonomic technology for product development oriented towards customer emotion. Using Kansei Engineering in aircraft design is one of the most effective means to enhance flight experience. We rely on Vosviewer software to capture the research hotspots and trends of Kansei Engineering in aircraft design, which are categorized and overviewed by a visualization network. On the one hand, the importance and methods of human sensory elements, including auditory, visual, tactile, olfactory and taste, as well as human action elements in aircraft design, are studied. It is concluded that the design of aircraft layout, materials and colour schemes has an impact on human senses and behaviour. On the other hand, not only the materials and layouts for seats, cockpits and panels are discussed, but also an argument is put forward on the materials' effective application based on Kansei Engineering. Herein, we conclude with the current application of Kansei Engineering in aircraft design and advise on future design.

Keywords: *Kansei Engineering, aircraft design, ergonomics, visualization network*

Aplicarea Ingineriei Kansei în proiectarea aeronavei

Ingineria Kansei poate dezvolta un nou produs prin transpunerea cerințelor clienților în design, ce reprezintă o tehnologie ergonomică pentru dezvoltarea de produse orientată către emoția clientului. Utilizarea Ingineriei Kansei în proiectarea aeronavelor este unul dintre cele mai eficiente mijloace de îmbunătățire a experienței de zbor. Ne bazăm pe software-ul Vosviewer pentru a capta punctele importante ale cercetării și tendințele Ingineriei Kansei în proiectarea aeronavelor, care sunt clasificate și analizate de rețeaua de vizualizare. Pe de o parte, sunt studiate importanța și metodele elementelor senzoriale umane, inclusiv cele auditive, vizuale, tactile, olfactive și gustative, precum și elementele de acțiune umană în proiectarea aeronavelor. S-a ajuns la concluzia că proiectarea aspectului aeronavei, a materialelor și a schemelor de culori are un impact asupra simțurilor și comportamentului uman. Pe de altă parte, nu sunt discutate doar materialele și amenajările pentru scaune, cabine de pilotaj și panouri, dar este prezentat și un argument privind aplicarea efectivă a materialelor bazată pe Ingineria Kansei. În final, încheiem cu aplicarea actuală a Ingineriei Kansei în proiectarea aeronavelor și oferim sfaturi privind proiectarea viitoare.

Cuvinte-cheie*: Inginerie Kansei, proiectarea aeronavelor, ergonomie, rețea de vizualizare*

INTRODUCTION

Aircraft design is a complex multi-disciplinary integration process. In practice, the design of aircraft will directly influence passengers' perceived emotions and even play a role in safety. Regarding customers' perceived emotional needs, it was estimated that passengers had a relatively poor evaluation of aircraft cabin design, including spaciousness, seat comfort and aesthetics [1]. This is due to differences between the perceptions of designers and consumers [2]. Regarding the security aspect, it was discovered that defects in the design and layout of cockpit instruments led to accidents after World War II in the USA [3]. Because traditional design relied strongly on the subjective opinions and experiences of designers [4], human factors were not taken into account. Thus, the application of Kansei Engineering in aircraft design is extremely important.

Customer experience and comfort arise from perception which is an aspect of customer demand. Perception is a process that comes from human sensory awareness (e.g. touch, sight, smell, etc.), along with the generation of emotions [5]. Meanwhile, perception is highly dependent on the state of human behaviour and the environment. There are differences in emotional perceptions stimulated by the same environment, owing to cognitive, behavioural and physiological variations in humans [6]. Furthermore, Kansei is the emotional perception associated with sensory elements, i.e. perceptions that tend to be aesthetic or emotional. Kansei Engineering can transform customers' psychological needs and feelings into designs, taking human factors in design as central to meeting customer needs and increasing product satisfaction. It is a tool to develop products and can effectively reduce the perception gap between users and designers.

Kansei Engineering was successfully applied to product design by Mazda Miata in 1995 [7]. Many companies subsequently adopted Kansei Engineering to develop their products. Several disciplines such as automotive, textile, food, electronics, medical, and construction [8] are now exploiting Kansei Engineering to create new markets for themselves. Applying Kansei Engineering to emotional studies has obtained recognition in many fields, at the same time, the link between Kansei Engineering and aircraft design is being called for [9]. Ergonomics is the study of human actions and states in different environments to suit a variety of physical and psychological characteristics [10]. Kansei Engineering overcomes the shortcomings of ergonomics from an emotional perspective [11]. Therefore, ergonomics is a part of the Kansei Engineering study, while the study of ergonomics is involved in human action elements. In conclusion, both human sensory and action elements are relevant to Kansei through perception, which is an essential branch of Kansei Engineering study. Considering aircraft design based on human sensory and action elements will reduce differences in customer emotions, increase customer comfort, meet customer needs, save manufacturers testing costs and contribute to the development of aviation.

At present, Kansei Engineering is already being used to design aircraft cockpits and seats, the design core with human factors offers direction to designers. Chen et al. [12] assessed the colour scheme of aircraft cockpits by using the Kansei Engineering model and gave designers a cabin colour scheme to improve consumer comfort. Holden et al. [13] noted that the involvement of human factors in NASA's design and evaluation played a key role in the Orion Multi-Purpose Crew Vehicle development. Cao et al. [14] found that basing the principles of aircraft cockpit layout based on ergonomics could effectively reduce the pilot's perceived burden. The design elements of Kansei Engineering are of great significance for aircraft design. Nevertheless, to our best knowledge, there are no relevant systematic reviews concentrated on Kansei Engineering applications in aircraft design to date.

This review attempts to gather the methods and current status of Kansei Engineering applied to aircraft design. Due to the multi-faceted nature and complexity of Kansei Engineering research, this review selects keywords commonly used in research papers on ergonomics, perception and emotion, which are related to Kansei Engineering to retrieve and filter articles from the Web of Science (WOS) database. Publications related to these terms include journal articles, book chapters and conference papers forming a literature database. A visual network of bibliometric data is produced by VOSviewer version 1.6.16, as shown in figure 1.

Figure 1 presents the relationship between Kansei Engineering design elements and aircraft design-related topics and articles. There are a total of 38 items presented in 5 clusters: (1) perception (purple), (2) ergonomics (blue), (3) sensory perception (green), (4) Kansei Engineering (orange) and (5) emotion (red), which can be classified into 2 clusters. Among them, “Aircraft Design” (occurrences: 112 times) is a research direction derived through the crossover point (“design” (occurrences: 309 times) from Kansei Engineering and ergonomics. The first group contains categories (1) (11 items), (3) (6 items)

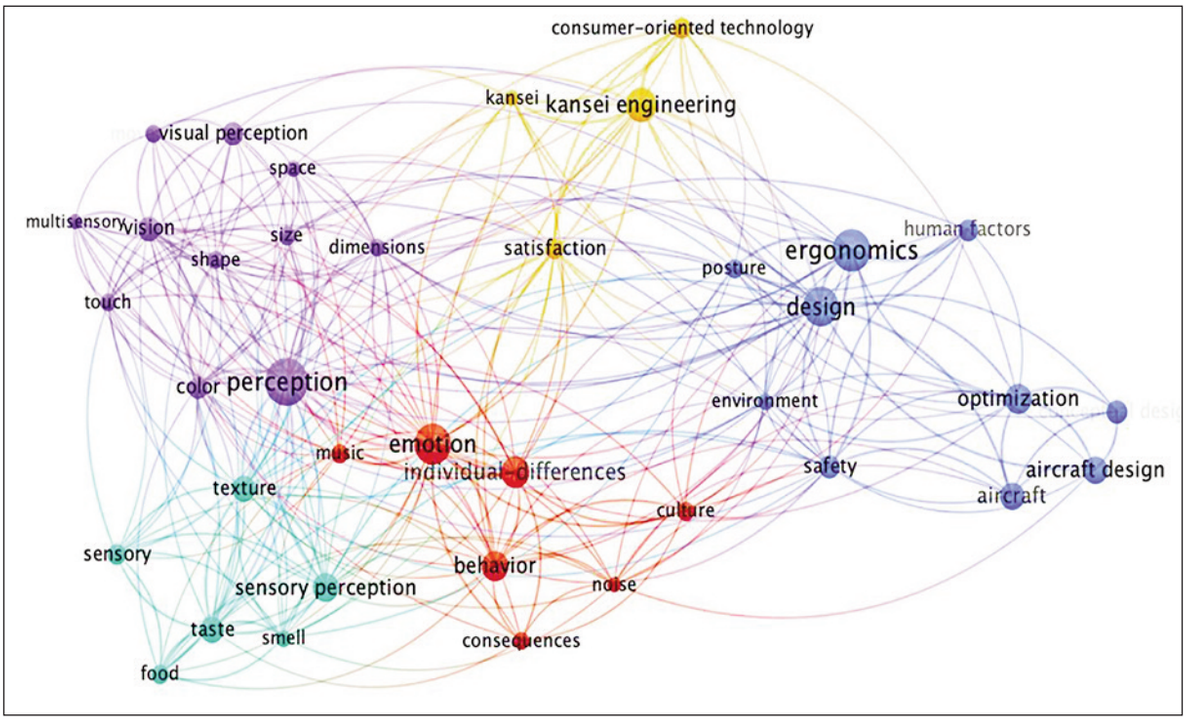

Fig. 1. Cluster analysis of keywords related to Kansei Engineering and aircraft design

and (5) (7 items), involving the classification of perception. Perception is closely related to the fields of sensory perception (occurrences: 129 times), emotion (occurrences: 328 times) and behaviour (occurrences: 150 times), and has been extended to other related disciplines. Thus, This paper analyzes the present situation and significance of aircraft design from two perspectives: human sensory perception elements of auditory, visual, tactile, olfactory and taste, alongside human action elements. The second group contains categories (2) (10 items) and (4) (4 items) involving design elements related to Kansei Engineering and ergonomics, e.g. human factors (occurrences: 60 times). Therefore, this review summarises the material selection and layout design of the cabin seats, cockpit and panels, based on Kansei's requirements and ergonomics.

This paper reviews the application of Kansei Engineering in aircraft design. The construction of the paper is as follows: 1st section analyzes the context of Kansei Engineering in aircraft design and utilizes Vosviewer software to reflect the relevant research topics. 2nd section refines the design elements of Kansei Engineering to human auditory, visual, tactile, olfactory and taste, as well as human action elements, addressing proposals and necessities for combining each design element with aircraft design. 3rd section focuses on the key points of material selection or layout of seats, cockpits, and panels in aircraft cabins, based on human Kansei needs and ergonomics. 4th section draws some conclusions. It is expected that our work will benefit the investigation of Kansei Engineering application in aircraft design and broaden its application.

RESEARCH STATUS OF KANSEI ENGINEERING IN AIRCRAFT DESIGN

Unconscious perception stimulated by the senses plays a major role in aircraft design [15]. As shown in figure 2, the first section of this chapter categorizes and outlines human sensory elements in aircraft design from a perception standpoint. Human action elements are associated with Kansei Engineering and ergonomics contained therein. The second part of this chapter deals with human action elements in aircraft design based on ergonomics and Kansei.

Aircraft design combined with human sensory elements

Human auditory, visual, tactile, olfactory, and taste sensations are complex outcomes that depend on personal history, environmental factors, object characteristics, and subjective influences [16]. It is vital to be aware of perception needs in the design process, and they are the result of multisensory integration [17]. As illustrated in figure 3, this section assesses the importance of perception in aircraft design from five sensory elements, together with a summary of ways to enhance customer sensory comfort.

Auditory sensation

As is well known, noise pollution is an increasingly serious problem arising from the expansion of the modern industry. Research has proven that aircraft noise can cause insomnia, high blood pressure, irritability and fear [18]. Pieren et al. [19] demonstrated the possibility of a perception-based evaluation on future low-noise aircraft, where a low-noise aircraft could considerably reduce one's auditory annoyance. Reducing aircraft noise using human auditory perception will not only optimize residential living conditions in the vicinity of airports but will also improve passengers' comfort in flight.

Auditory comfort evaluations are receiving increasing attention in the context of air transport [20]. Reducing noise annoyance is one of the valid ways to control noise [21], which is greatly dependent on listeners' status, life circumstances, etc. Playing a lighter sound in the headset will allow some passengers to immerse themselves in pleasant sounds so that they can ignore the cabin noise. However, this approach does not address the fundamental issue of aircraft noise. More efficient ways to promote passenger comfort are to analyze how noise is generated and how to reduce noise from the source. By adding specific noise-cancelling devices and materials, the acoustic comfort of passengers can be optimized. Examples include using tilted blades and acoustic

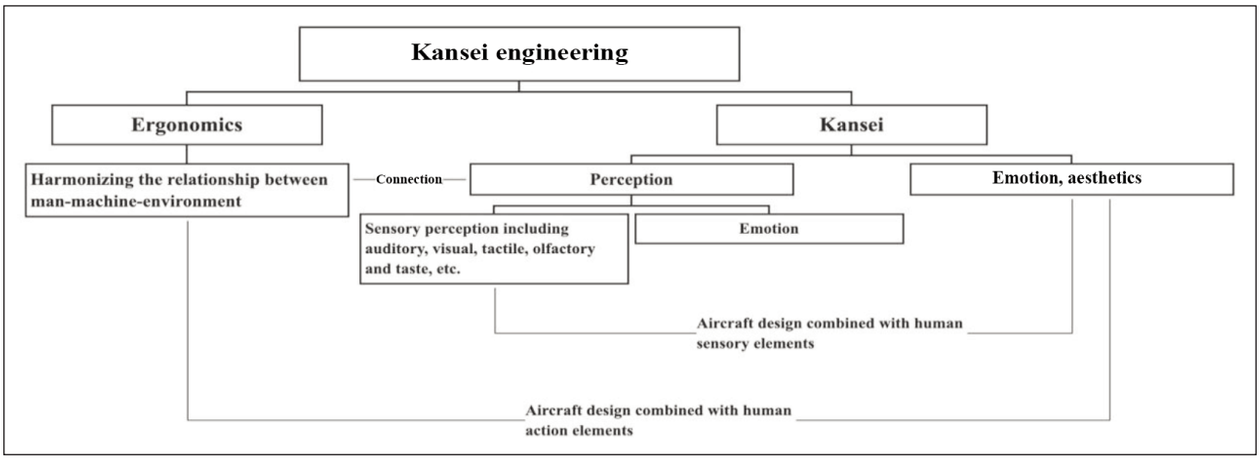

Fig. 2. A summary of the current study on Kansei Engineering in aircraft design

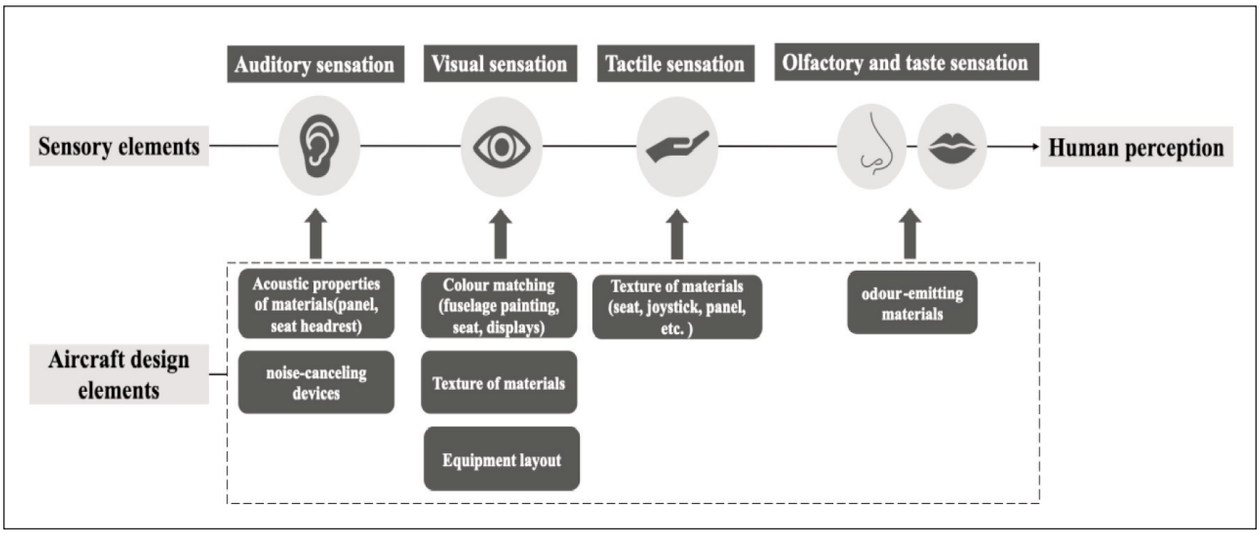

Fig. 3. Aircraft design elements associated with sensory elements

liner tubes to reduce turbofan noise [22], distributing sensor actuators on aircraft panels to reduce noise transmission [23], and using sound insulation materials such as fibreglass and honeycomb to increase sound transmission loss.

Visual sensation

One major way to create an attractive aircraft fuselage is to paint it, as shown in figure 4, *a*. Aircraft painting design can relieve visual fatigue or highlight a particular culture that will resonate with passengers. In addition, the painting design is an excellent protection for aircraft hulls by reducing corrosion in harsh environments [24], increasing ultraviolet radiation on aircraft surfaces [25], and even conferring stealth capabilities to aircraft [26].

Figure 4, *b* presents the design of cabin seats in colour scheme. Colour schemes and material choices in the cabin affect human visualization. A system to assess colour emotion using Kansei Engineering is effective in avoiding defects in colour emotion design [12]. Studies on the link between visual senses and consumers are now most commonly conducted by eye-tracking to explain consumer response to various visual stimuli [27]. One example is that data recorded by eye-tracking could be used to select Kansei words applied to user evaluations [28], thus reflecting an aircraft's visual effects.

Tactile sensation

Tactile sensation is the result of stimuli transmitted by human skin to the brain and can be applied to explore the condition of objects [29]. Currently, there is a preference for functional studies in aerospace materials. The tactile sensation of aerospace materials is often overlooked. However, the tactile properties of the material are a key characteristic that influences consumer preferences and decision-making processes [30].

Similarly, tactile adjectives allow for a systematic assessment of tactile sensations on the object's surface, to optimize the device. In addition, tactile sensations can be combined with other sensory perceptions. Tactile receptors can be applied to transform visual signals into tactile signals from the power rod in the cockpit, simplifying the complexity of the device and reducing the burden on the pilot [31]. In short, taking human tactile perception into account is a valid means to optimize aviation equipment, and will enrich the customer experience further and meet their requirements.

Olfactory and taste sensations

Studies have proven that olfactory and taste sensations are interconnected, where the sensation of taste is influenced by smell, texture, temperature, etc [32]. The unique and enclosed atmosphere of an aircraft, similar to a car, may influence passengers' sense of olfactory and taste. Aircraft internal odours are partly caused by cabin materials, components, etc., and another part by passengers, food, etc. Olfactory and taste discomfort in enclosed spaces can even result in vomiting. Fewer applications of odour-emitting materials in aircraft design can improve the odour environment in the cabin and greatly increase consumer comfort. Moreover, flight altitude can also affect human taste sensation and food flavour release [33]. Meanwhile, Yao et al. [34] pointed out that individual design requirements for odour in aircraft cabins were emphasized because of passenger odour preference diversity.

Aircraft design combined with human action elements

Kansei Engineering is an ergonomic product development technique [35]. Ergonomics is aimed at achieving the unification of human efficiency, comfort, safety and feasibility [36], closely associated with human action elements. Major parts of cabin design relevant to human action elements are things such as seats, pitch, layout, etc. Aircraft seat design covers comprehensive fields such as human seating characteristics, and movement range and limits dimensions regarding comfort, as shown in figure 4, *c*. Vink et al. [37] noted that there was a clear relationship between comfort legroom, and seat/personal space in aircraft interiors. Furthermore, improper seat

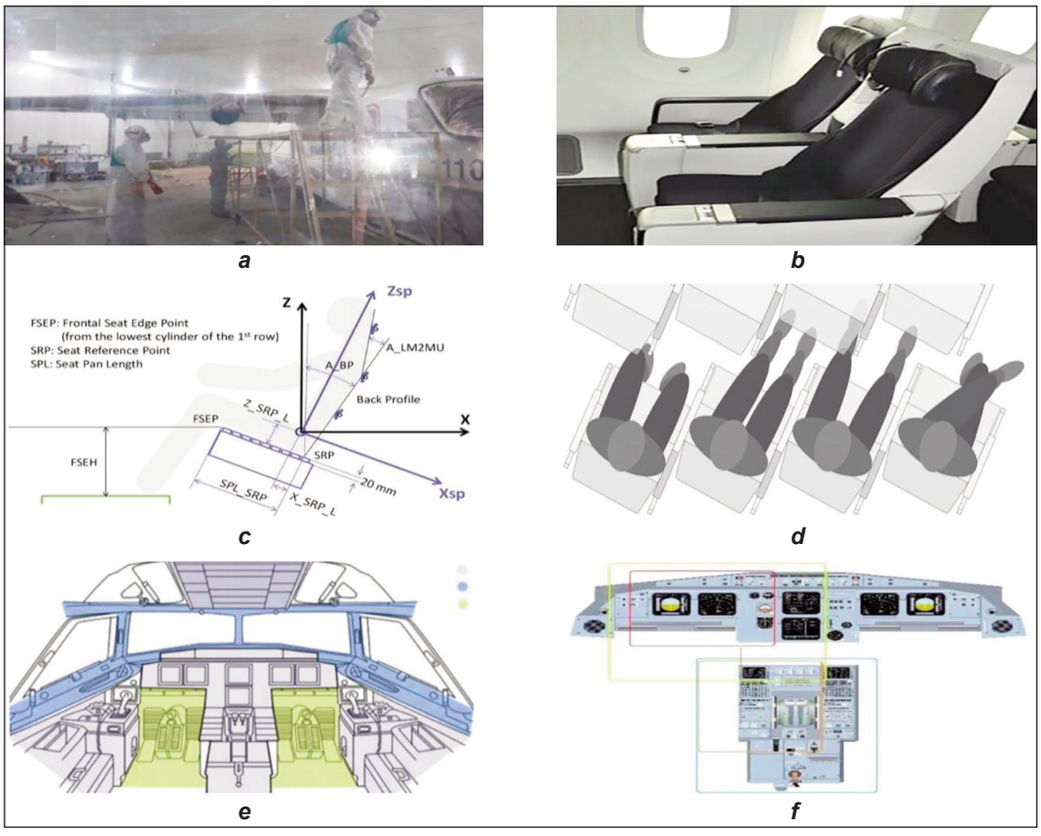

Fig. 4. Application of Kansei Engineering in aircraft design: *a* – aircraft painting work; *b* – cabin seat colour design (premium economy seats in a Boeing 787); *c* – seat profile parameters; *d* – the comfort of the seat configuration; *e* – colour distribution in an aircraft cockpit; *f* – the evaluation of the cockpit layout [12, 14, 24, 42–44]

design will increase flight personnel's discomfort in the back, neck, and lumbar areas. Sharafkhani et al. [38] invited 29 participants to sit in a simulated aircraft cabin for 180 minutes and found that from largest to smallest, were: the back of the neck, left rear shoulder, right rear shoulder, left rear hip and lower back. As is seen in figure 4, *d*, seat pitch is one of the main factors affecting aircraft seat comfort in the passenger cabin. Discomfort increases when low seat pitch disturbs passengers' necessary activities [39]. Liu et al. [40] established an evaluation model for comfort in an aircraft cabin system, which could be applied to improve comfort in the aircraft cabin. In the cockpit, to resolve inefficiencies and reduce pilots' work stress, an ergonomically constructed cockpit man-machine layout evaluation system can successfully optimize cockpit layout design [41].

CABIN EQUIPMENT DESIGN BASED ON KANSEI NEEDS AND ERGONOMICS

This chapter focuses on material selection based on Kansei's needs for aircraft cabin seating, cockpit equipment, and panels. Meanwhile, the present situation and approach to designing cabin seats and cockpit layout from an ergonomic viewpoint are discussed.

Cabin seats

Properties of seat materials

Cabin seat is usually made up of lightweight, high-specific stiffness synthetic and composite materials. Seat materials should be selected to meet not only the configuration of the aircraft but also the safety and comfort requirements of passengers. An example is using fire retardant materials to prevent fires from threatening human life [45]. Since COVID-19, passengers' demand for antimicrobial properties in materials such as seat covers and armrests has steadily increased [46]. A reasonable allocation of seats can decrease the risks of virus transmission on aircraft [47]. At the same time, lightweight materials ought to be applied to seats as much as possible to save aircraft fuel consumption and increase space utilization. Dangal et al. [48] employed spring foam technology to lighten aircraft seats while increasing consumer comfort.

Seat comfort

Studies of seat comfort involve shape and layout comfort, seat cover comfort and headrest acoustic comfort. To achieve a better coincidence in contact between human hips and the cushion, Kumar et al. [49] carried out an anthropometric data curve fitting to investigate seat comfort for pilot cushions. The insulation and breathability of seat cover materials across the seasons will affect human thermal comfort. In addition, improvements in the acoustic properties of seat headrests will enable passengers to have a more comfortable rest during the flight. Based on experimental and data results, Giannella et al. [50] proposed passive noise control improvements for seat headrests, one was based on the optimization of

the headrest shape, and the other was using a new material as a headrest cover material to improve passenger acoustic comfort.

Cockpit

The cockpit interior mainly consists of a flight display, joystick, etc. Cockpit materials are chosen on the premise of ensuring the safety of passenger life without affecting pilots' ability to drive during daytime or nighttime. Given that the cockpit is characterized by a small space, high functional integration and complex controls, the pilot's emotional perception is especially essential. Improper cockpit layout and design may lead to pilot spatial disorientation, that is, the illusion of flight [51]. Aircraft cockpit display systems are the critical interface between aircraft and pilots in human-machine interaction, which must deliver situation perception for pilots to ensure flight safety. As is shown in figure 4, *e* and *f*, the appropriate colour, language and display location of information can improve pilot efficiency. Zhang et al. [52] combined pilot performance during flight with eye movement data, and found that the red-green-yellow colour located in the centre of the aircraft display interface was more conducive to recognition. Kamine et al. [53] discovered that almost all aircraft displays, located in both vertical and horizontal visual display angles, were within the “cone of easy eye movement”. Aiming to boost the situational awareness of pilots, head-mounted virtual reality displays are one possibility for future cockpits [54].

Psychologists proved that contours contain most of the information relevant to object perception [55]. Symmetry and repetition have a major role in visual and tactile perception [56]. Hence, the shape contour design of the joystick has an impact on human sensory perception. Also, the layout of the joystick has to take into account the pilot's operational feasibility and comfort. Yang et al. [57] measured Chinese pilots' posture data while pushing the joystick that was used to assess pilots' comfort in operating posture.

Aircraft cabin panels

Aircraft cabin panels are mainly used for floors, ceilings, cabinets, etc., which are usually made up of composite materials with a certain degree of impact resistance, corrosion resistance, fire resistance and long-term cycling properties [58]. Additionally, sound insulation properties on aircraft panels were necessary to decrease aircraft interior noise [59]. Honeycomb structures have been widely applied to aerospace and automotive fields due to their excellent mechanical properties, high energy absorption capacity and low density [60]. At a certain level, honeycomb sandwich structures reduce the transmission of acoustic and optimize user acoustic comfort. Material multiple superiorities are sought after. So, improved acoustic comfort of materials can be combined with several sensory elements' design, making it possible to apply Kansei Engineering more efficaciously on the same material. For instance, a further design of honeycomb sandwich sound insulation materials to achieve aesthetic interiors and performance on a safe basis.

CONCLUSIONS

Compared with traditional design, aircraft Kansei design has the advantage of being more attuned to human demands. In this review, we gather hot topics and trends regarding the development of Kansei Engineering applied in aircraft design through VOSviewer, and then we categorize and overview them. Two perspectives of human sensory and action elements are analyzed to demonstrate the importance of Kansei Engineering in aircraft design. Moreover, the design of aircraft seats, cockpits and panel materials are discussed in conjunction with ergonomics.

It is found that Kansei Engineering has been relatively less explored in aircraft design, to improve the effective application of Kansei Engineering in aircraft design, we put forward several recommendations. Firstly, human sensory and action elements are directly related to human emotional perceptions which cannot be ignored in aircraft design processes. Secondly, human requirements are essential to developing material properties and equipment layouts. Last but not least, the application of Kansei Engineering makes it possible to achieve an efficient material application in which the same material can meet a variety of human perceptual needs. These suggestions will further promote the development of aircraft and enhance their practical application.

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