UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF AN ERGONOMIC CHILD RESTRAINT SYSTEM CONCEPT FOR INFANTS IN CONVENTIONAL AIRCRAFT SEATS

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By

SYAKIRAH BINTI KAMARBHARI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Doctor of Philosophy

DEVELOPMENT OF AN ERGONOMIC CHILD RESTRAINT SYSTEM CONCEPT FOR INFANTS IN CONVENTIONAL AIRCRAFT SEATS

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March 2018

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The need to provide an ergonomic design of Child Restraint System (CRS) for infants in conventional aircrafts is the subject of much interest and research. Due to the increasing trends of infant passengers traveling by air, the need for an ergonomic design other than the safety aspects alone requires much needed improvement. Even though the safety aspect of the passengers is important, other ergonomic aspects that are lacking such as comfort, usability and convenience of the CRS also contribute to a better travelling environment should have been put into concern as it become essentials in the air transportation industry. Until now, no studies have been reported, specifically on designing the CRS for infants in aircraft, particularly focuses on other ergonomic aspects such as comfort, usability, and convenience, which may benefit both infants and their traveling companion.

Hence, this research focuses on developing a new design concept of an Ergonomic CRS for infants in conventional aircraft seats. The objectives of this research are; firstly, to determine the effective criteria of the Ergonomic CRS, secondly, to develop a framework for the design requirement of the Ergonomic CRS. Third, designing a new concept of Ergonomic CRS, and finally, the fourth objective is to evaluate the prototype of an Ergonomic CRS final concept design.

The objective was achieved by determining several effective criteria of the Ergonomic CRS, which were based on experienced users' perceptions and requirements from the focus group interviews, followed with a framework construction, which were also based on the focus groups and early findings. The conceptual design were generated from the Total Design that executed the integration of brainstorming - TRIZ methodology - methodological chart - weighted objective evaluation. The new design concept was objectively and subjectively evaluated based on the participants' responses in three different physical tests, namely; comfort, usability, and convenience test.

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The focus group findings that were deliberated from six (6) participants in six (6) individual groups have led to a framework development of the requirement criteria that consist of five (5) design requirements, which was proposed to scientifically produce theories as well as methods that can perform as a guideline for the development of CRS for infants in aircrafts. The final design which was selected out of three (3) conceptual designs revealed that the design concept-3 with a value of 4.35 was selected and were developed by using Computer Aided Three-dimensional Interactive Application Software (CATIA). The test reveals that the respondents felt much more attached to their infant when using the newly developed system with 13% higher than the Automotive CRS. The usability test revealed the overall score for the Ergonomic CRS was 14.2% higher than the Automotive CRS. Meanwhile, the convenience test revealed that the score for Ergonomic CRS was 25.4% higher than the Automotive CRS. Overall, the findings on the participants' perceptions towards the infant restraint device in conventional aircrafts outlined the most discussed elements of bonding factor, ease of use, and hassle-free, which put into attention to the criteria needed.

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PEMBANGUNAN KONSEP SISTEM KESELAMATAN KANAK-KANAK BERERGONOMIK UNTUK BAYI BAGI KEGUNAAN KERUSI PESAWAT KONVENSIONAL

Oleh

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Keperluan untuk menyediakan reka bentuk berergonomik bagi Sistem Perlindungan Kanak-kanak (CRS) khusus untuk bayi di dalam pesawat konvensional adalah subjek yang semakin dipelopori dan mendapat perhatian penyelidikan. Di sebabkan oleh trend penumpang bayi menggunakan perjalanan udara yang semakin meningkat, keperluan pelbagai aspek reka bentuk ergonomik selain keselamatan semata-mata adalah sangat diperlukan untuk penambahbaikan. Walaupun aspek keselamatan ke atas penumpang adalah penting, namun, aspek ergonomik yang lain seperti keselesaan, kebolehgunaan dan kemudahan CRS yang agak terbatas yang dapat menyumbang kepada kondisi perjalanan yang baik sepatutnya diberi penekanan kerana ia merupakan satu keperluan di dalam industri pengangkutan udara kini. Sehingga kini, tiada kajian telah dilaporkan telah merancang CRS secara khusus untuk bayi dalam pesawat, terutamanya yang memberi tumpuan kepada aspek lain ergonomik seperti keselesaan, kebolehgunaan dan kemudahan, yang boleh memberi manfaat kepada bayi dan penjaga mereka.

Berdasarkan masalah ini, kajian ini dijalankan dengan tujuan utama untuk membangunkan konsep reka bentuk baru CRS Ergonomik khusus untuk bayi, bagi kegunaan kerusi pesawat konvensional. Objektif pertama kajian ini adalah untuk menentukan kriteria paling berkesan bagi CRS Ergonomik khusus untuk bayi di dalam pesawat konvensional, manakala objektif kedua adalah bertujuan membangunkan rangka kerja bagi keprluan reka bentuk CRS berergonomik.mereka bentuk konsep baharu CRS Ergonomik untuk bayi. Objektif ketiga bertujuan mereka bentuk konsep baharu CRS Ergonomik untuk bayi dan akhir sekali, objektif keempat kajian ini adalah untuk menilai prototaip reka bentuk konsep akhir CRS Ergonomik.

Objektif kajian ini dicapai dengan menentukan beberapa kriteria berkesan untuk CRS Ergonomik berdasarkan persepsi dan keperluan pengguna yang berpengalaman. Ini

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diikuti dengan pembangunan rangka kerja berdasarkan penemuan dari wawancara kumpulan focus dan pengumpulan data awal. Reka bentuk konseptual dijana menggunakan Reka Bentuk Keseluruhan yang dilaksanakan hasil dari integrasi brainstorming - metodologi TRIZ - carta metodologi - penilaian objektif yang ditimbang. Konsep baharu reka bentuk dinilai secara objektif dan subjektif berdasarkan respons peserta dalam tiga ujian fizikal yang berbeza, iaitu; ujian keselesaan, kebolehgunaan, dan ujian kemudahan.

Penemuan hasil daripada wawancara kumpulan fokus; yang terdiri daripada enam (6) peserta dalam enam (6) kumpulan berbeza membawa kepada pembangunan rangka kerja yang dibina daripada kriteria keperluan yang terdiri daripada lima (5) keperluan rekabentuk yang telah dicadangkan untuk menghasilkan teori secara saintifik serta kaedah yang dapat dilaksanakan sebagai panduan untuk pembangunan CRS khusus untuk bayi dalam pesawat. Reka bentuk akhir yang dipilih daripada tiga (3) reka bentuk konseptual mendedahkan bahawa konsep reka bentuk-3 dengan nilai 4.35 telah dipilih dan dibangunkan menggunakan Perisian Aplikasi Interaktif Tiga Dimensi Berbantu Komputer (CATIA). Ujian mendedahkan bahawa responden merasa lebih dekat dan selesa pada bayi mereka dengan menggunakan sistem yang diperkenalkan dengan mencatatkan 13% lebih tinggi daripada CRS Automotif. Ujian kebolehgunaan mendedahkan skor keseluruhan untuk CRS Ergonomik adalah 14.2% lebih tinggi daripada CRS Automotif. Sementara itu, ujian kemudahan mendedahkan bahawa skor untuk CRS Ergonomik adalah 25.4% lebih tinggi daripada CRS Automotif. Secara keseluruhannya, penemuan mengenai persepsi para peserta terhadap peranti pengaman bayi dalam pesawat konvensional menggariskan unsur-unsur ikatan yang paling dibincangkan mengenai faktor ikatan, kemudahan kegunaan, dan kurang kerumitan memperlihatkan kriteria yang sangat diperlukan.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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4.47	Mean Score for the Convenience Evaluation	145

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LIST OF ABBREVIATIONS

AAP	American Academy of Pediatrics
AFA	Association of Flight Attendants
AHP	Fuzzy Analytical Hierarchy
ANP	Fuzzy Analytical Network Process
BCI	Brain-Computer Interface
CAA	Civil Aviation Authority
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAMI	Civil Aero Medical Institute
CAO	Civil Aviation Organization
CAR	Canadian Aviation Regulations
CASA	Civil Aviation Safety Authority
CATIA	Computer Aided Three-dimensional Interactive Application
CRS	Child Restraint System
DCA	Department of Civil Aviation
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FMVSS	Federal Motor Vehicle Safety Standard
FSR	Force sensitive resistor
NIC	Neck Injury Criterion
ICAO	International Civil Aviation Organization
ICE	Intelligent Comfort–Evaluating
ISO	International Organization for Standardization
IGES	Initial Graphic Exchange Specification
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PDE	Product Design Evaluation
PDS	Product Design Specification
TRIZ	Theory of Inventive problem solving
UAS	Universal Anchorage Systems
UPM	Universiti Putra Malaysia
SPSS	Statistical Package for the Social Sciences
QFD	Quality Function Deployment

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The ergonomics of sitting positions in certain environments concerning all walks of life including adults, teenagers or children has been a major concern and critically discussed even before the ergonomics term itself was devised. This scenario also applies to passengers aboard an aircraft that need to maintain a correct sitting posture including infants. The infants and their traveling companions require a satisfactory ergonomic environment such as comfort as their priority, as well as usability and convenience to the parents, which is a part of the entire flight experience. Specifically, for infants it is very important for them to be seated in a correct manner to ensure their comfort and their adult traveling companion's comfort as well. Therefore, the design must be suitable based on the human factor requirement so that they will have a normal head and body posture while being seated in the airplane.

With the growing number of young passengers travelling by aircraft, it is crucial to provide a comfortable flight not only to the infants, but also to their traveling companions and other passengers as well. As forecasted by Boeing Current Market Outlook, despite the uncertainties, passenger traffic for the year of 2012 rose 5.3 % as compared from 2011. The management expects this trend to continue over the next 20 years with world passenger traffic growing at the rate of 5.0 % annually (Boeing, 2013). Previous reports had also stated that infant enplanements were estimated to be approximately 1 % of all passenger enplanements (this figure is rather low as compared to other airlines which reported at a higher percentage); which means, the expectation of infants traveling by aircraft in the year of 2020 will reach to the amount of 43.8 million or equivalent to 120,000 infants every day (FAA, 2000).

In the meantime, the International Civil Aviation Organization (ICAO) also clarifies that people will increasingly travel within the globe through major population centers to develop, strengthen and sustain relationships in a way that only direct communication allows. It shows that for Airbus, the world's passenger aircraft fleet varying from small "100 seats" to very large aircraft and will grow from 15,000 at the beginning of 2011 to just over 31,000 by 2030. The airlines also continue to provide more seats and seek means to reduce the cost per seat and continue to drive for efficiency improvements (Airbus, 2011).

There were no detailed statistics or forecast made specifically on infant enplanement, except for the forecast made by the FAA on infant passenger enplanement (FAA, 2000). However, the statistic shown by Malaysian Airlines and Air Asia X (Appendix B1) on the passenger enplanement had proven that there was an increment in passenger enplanement in 2013. Due to this amplification in the industry, most airline companies

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are already gearing up and working towards improving the comfort of the aircraft passenger (Brundrett, 2001). The improvement of the comfort element for the adult and young passengers was not only on the seat aspect, but had also taken into consideration the inclusive environment in the aircraft. Comfort for infants and their traveling companions are highly related in order to achieve an optimum flying experience.

Because of this, the ultimate features of the Child Restraint System (CRS) for infants should first fulfill the safety demand of the parents, infants and the legislation; while giving adequate attention to other ergonomic aspects. In general, this should also account for the right sitting posture of the adult passengers during the long-haul flight. The setting must be possible for the infant in particular to seat and sleep in a relaxed position, taking into account the comfort and safety aspects. The infant, which will be the adults of tomorrow, has a right towards the preventive care, correspondingly with regards to comfort and safety.

1.1.1 Overview of the Child Restraint System (CRS)

Child Restraint System (CRS), which is also known as child safety seat, child safety device or child car seat is a device purposely used to restrain children for safety purposes in a moving transportation. CRS is a general term in Federal Motor Vehicle Safety Standard (FMVSS 213) for a device designed "to restrain, seat, or position children who weigh 30kg or 65 lbs. or less"; and used primarily with professional and technical audiences (Federal Register, accessed 2014).

Additionally, besides restraining and positioning children, the use of a CRS on aircrafts provide the utmost degree of protection for the children, especially infants, and is also useful as an aid in case of unexpected turbulence (Transport Canada, accessed 2014).
As presented by the Inland Transport Committee of the United Nation of Economic Commission and Social Council, CRS by definition is a device capable of accommodating a child occupant in a sitting or supine position. It is purposely designed to reduce the risk of injury to the occupant in a way that limits the mobility of the child's body in the event of a collision or an abrupt deceleration of the vehicle (Inland Transport Committee, 2013).

The European Aviation Safety Agency (EASA) under the support of the European Commission distinguishes that "Children under two years are too small to sit alone in a standard airline passenger seat and must be secured by an approved 'Child Restraint Device' on European airlines" (EASA, retrieved 2012). This agency had also issued the draft regulations including one, 'NCO.IDE.A.140', that would necessitate airplanes to be equipped with CRS for every infant on board the aircraft (EASA, 2012).

Many countries, as part of their motor vehicle safety law have implemented laws which call for children under a certain age to be physically restrained by approved systems while riding in a moving vehicle (Leuder, 2010). Safety and comfort should be offered

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equally to everyone under any design concept. CRS is an important mechanism that can provide optimum safety for infants and children in a moving transportation.

As enlightened by the National Highway Traffic Safety Administration (NHTSA), the vital elements of correct transportation of infants comprise the rear-facing system that is installed in the back seat and the infant is secured appropriately in the child restraint device. In addition to that, the CRS must also be securely installed in the vehicle (NHTSA, 2001).

1.2 Problem Statement

The capacity of the airlines to provide the most comfortable environment to an adult passenger in the aircraft such as the seat, the entertainment and other essential benefits are proven to be very effective nowadays to the passengers. However, the capacity of the airlines to provide a great basis of comfort of the system for infants below 24 months of age and their traveling companions still requires further investigations and improvements. Since, the travel activity of infants on conventional aircrafts several years back is less frequent compared to the travel activity by infants on automobile, the design improvements in many aspects especially comfort for infants and travelling companions have dawdled (Parrow et al., 2003).

Based on the current situation, the equipment used for placing and restraining infants in the aircraft are still very limited. Even though the supplementary loop belt is currently permitted to be used by the EASA in a short period of time during flight (David et al., 2012), however, in theory and research it is not optimal from a crash safety point of view (Bathie, 2009). The mechanism of the bassinet which needs to be secured to the bulkhead also contributes to difficulties and inconveniences. The use of the bassinet is only allowed on the bulkhead and not designed to be used on normal passenger aircraft seats that bring to comfort issues to the parents. In addition, most bassinet installations have not been approved for use during take-off or landing (CASA, 2002; CASA, 2014). In the case of the automotive CRS, which can only be used upon the FAA approval, it also creates difficulties in terms of usability and inconvenience since not all systems can accommodate the aircraft passenger seat. In reality, not all parents traveling with the aircraft have all the complete requirements for the system to be attached to the aircraft passenger seat. Additionally, most of the automotive CRS has only one capacity to fit all ages that is not appropriate and uncomfortable for zero aged children. The preponderance of these devices come in a large hard-shell structure and is inconvenient to transport (McClellan-Derrickson, 2004; Schramek-Flye, 2009), which can also contribute to transportation and loading problems on the passengers.

Current CRS for infant in most aircrafts such as the bassinet and the automotive CRS are proven to be safe by the FAA and other international civil aviation regulations. However, the specification that justified the ergonomic criteria of comfort, usability and convenience as a whole still needs further improvements. Most of the mechanisms used for restraining infants in aircrafts have their own shortage in some aspects (Mosler

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& Ulbrich-Gasparevic, 2011); which can cause uncomfortable and inconvenient conditions to both infants and their traveling companions. Figure 1.1 illustrates the diagram for the problem on the design aspect of current CRS for aircrafts.

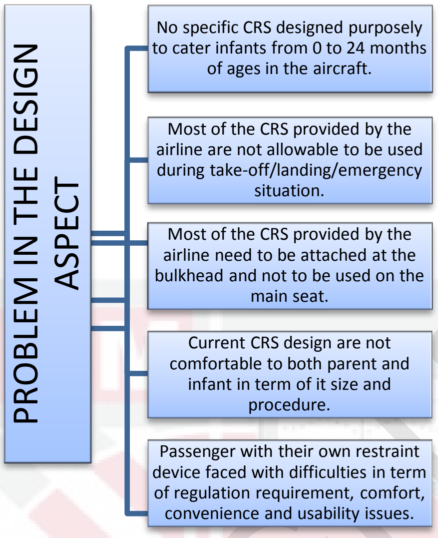

Figure 1.1: The diagram of the problem on the design aspect of current CRS in aircraft

1.3 Goal and Objectives

The aim of this study is to develop a new design concept of an Ergonomic Child Restraint System (CRS) specifically for infants in conventional aircrafts by developing a framework for the effective criteria of infant CRS and using TRIZ Methodology for the conceptual design.

Specifically, the objectives of this study are as follows:

i) To determine the effective criteria for an Ergonomic Child Restraint System (CRS) for infants in conventional aircrafts.
ii) To develop a framework for the requirement of an Ergonomic CRS in conventional aircrafts.
iii) To design a new concept of Ergonomic CRS for infants using integration of brainstorming - TRIZ Method - Morphological chart - weighted evaluation method.
iv) To evaluate the prototype of final conceptual design of an Ergonomic CRS for infants.

There are three hypotheses related to this objective:

- The comfort of a sitting person with infant using the Ergonomic CRS new concept is not affected and is better or equal to a normal aircraft sitting position which is without any add-on restraint system.

- The new concept of Ergonomic CRS for an infant is more usable compared to the existing Automotive CRS.
- The new concept of Ergonomic CRS for an infant is more convenient compared to the existing Automotive CRS.

1.4 Scope and Limitation of the Research

The focus of this work is mainly on the development of the Ergonomic CRS concept specifically designed for infants. It also focused on the response of the adult passenger while operating the new CRS concept. The new design of a restraint system for infants was discovered with a new concept and new structure-based mechanism. Even though this research focused on the ergonomic aspect, priority was given to investigate the comfort, usability, and convenience of the design concept instead of the safety aspect; as projected in the design aim and as documented from the end users' perceptions. Hence, the crash evaluation was not deeply studied due to the constraint of capital in getting the high specifications of infants and adult virtual dummies, as well as the real test dummy.

There was a limitation in the advancement of technology proposed in this study. This was in accordance to the condition that the new design concept should not incur additional charges to both airlines and passengers. High technology implementation will increase manufacturing cost and increase the cost to the industry. It will give a direct impact on the traveling fees charged on the passengers. For that reason, low technology implementation was used in this research.

1.5 Thesis Organization

The following described the outlines of the thesis:

Chapter 1 provides the overview of the thesis, the problem statement as well as the goal and objectives of the research. The chapter then briefly discusses on the scope and limitations along with the thesis organization.

Chapter 2 provides the literature study on recent developments of the CRS for infants in ground vehicle and aircrafts, which are offered in the existing work and product design. The study started with a discussion on the ergonomic sitting issues related to the comfort and discomfort factors on infants and their traveling companions. Then, the study will continue to elaborate on the usability and convenience issues, which are part of the important aspects of the CRS design. The review on the infant anatomy and the evaluation of the add-on CRS and seat comfort-discomfort are also discussed in this section. Furthermore, the review on the CRS design for infants in aircrafts will also be

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discussed, correspondingly on the current conditions and the shortcomings of the existing CRS for infants in aircrafts. Besides the raised concerns, this chapter also discusses on the aviation regulations related to the CRS use, as well as the typical conventional aircraft seat and existing CRS dimension for this research reference. Finally, the research gaps are also summarized, indicating the direction of the thesis.

Chapter 3 provides the research methodology. This includes the explanation of the selected method for developing the Focus Group interview and the proposed effective criteria framework. The chapter proceeds with the description on conceptual design task and the final design concept selection task. The development process of an Ergonomic CRS will be further described in detail. Lastly, the required evaluation to verify the developed prototype based on user evaluations is presented.

Chapter 4 discusses the findings from the research conducted. The first part of the chapter provides a deeper analysis on the use of CRS for infants in conventional aircrafts. This study generally focused on figuring out the perceptions and requirements of the parents with infants who are traveling together by aircraft using the Focus Group Interview. This research studies the state of the art of seating comfort and discomfort among parents and their infants. This research narrowly identified the most necessities by the end users with infants traveling by aircraft. This research worked on finding out the most important elements that can contribute to comfort or discomfort and outstanding design criteria towards this group of passengers in order to design a new concept of CRS for infants. This chapter presents the developed framework of the effective criteria for the Ergonomic CRS for infants. This chapter also presents the proposal for the new concept of the Ergonomic CRS for infants in aircraft based on the problems indicated earlier in the literature and from the Focus Group interview findings. The total design that comprises the brainstorming, TRIZ methodology and the weighted objective evaluation method will be elaborated in this section. Finally, this chapter presents the evaluation of the developed Ergonomic CRS for infants. Progressively, this chapter will cover the evaluation of the final design concept. The evaluation procedure was conducted to appraise the comfort, usability and convenience performance of the new Ergonomic CRS concept from the users' perspective.

Chapter 5 concludes the research outcome, discusses contributions, important issues and limitations during the research as well as provides potential improvements for future works.

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