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Child Restraint System in the Aircraft: Comfort for the Infant

[1]Syakirah Kamarbhari, [2]A.A. Faieza, [3]M.Y. Rosnah, [4]I.R. Fairuz

[1,2,3]Mechanical and Manufacturing System Department, Faculty of Engineering, Universiti Putra Malaysia, 43400, UPM Serdang, Selangor, Malaysia

[4]Aerospace Engineering Department, Faculty of Engineering, Universiti Putra Malaysia, 43400, UPM Serdang, Selangor, Malaysia

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ABSTRACT

This paper critically reviews Child Restraint System for infants in commercial aircraft and generally discussed the importance of an ergonomic Child Restraint System in the aircraft in the aspect of comfort for the infants. The main objective of this paper is to figure out the existed position and mechanism of the Child Restraint System that can ensure comfort for infants in the aircraft. Another objective of this paper is to determine the anatomy aspect of the infants that could contribute to the factor of comfort or discomfort in designing the Child Restraint System in aircraft. The outcome from this study will be implemented in a direction to design the new ergonomic Child Restraint System for infants in the commercial aircraft.

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INTRODUCTION

In automobile industry, restraining infants and children is vitally important for their safety purpose. Few studies on the safety and comfort issues regarding sitting position have been conducted, but it is only limited to the automotive purpose. In the area of air transport, huge numbers of research have been done to improve the safety aspect of the Child Restraint System. Therefore, it can be said that there is no in-depth discussion on the comfort of infants aged between 0 and 24 months travelling by air. However, for adults, the research and improvement to provide a better comfort for them in air transportation is very exhilarating.

The National Transportation Safety Board (NTSB) emphasized that all occupants should be restrained during takeoff, landing, and turbulent conditions. This includes all infants and small children that should be restrained in an approved child restraint system appropriate to their height and weight (NTSB, 1996).

According to Federal Aviation Authority (FAA), as in the current situation which has been drafted since 50 years ago, parents with infants travelling with aircraft are left with few choices according to the regulation. The first choice is by holding their infant on their lap either with or without supplementary loop belt. The second choice is to take a personal child restraint seat and hope for an empty seat or by else purchases the seat. The next choice is using the bassinet or other Child Restraint System provided by the airline upon request and availability (FAA, 2014).

People nowadays are more likely to choose air transportation for the purpose of travelling, especially when travelling with infants or toddlers. Most of the commercial airlines nowadays allow the infants between 0 and 24 months old to fly without fares or at reduced fares, provided that they remain seated on their adult travelling companion's lap during flight. For this situation, the infants are probably given the supplementary loop belt provided by the airline or the bassinet upon request.

As has been updated, there is no specific Child Restraint System for the infant provided by the airlines for the purpose of maximum comfort and usability towards infants and their travelling companion. The existing Child Restraint Systems for aircraft are highly dependable on strict regulations. Because of this, manufacturers need to rely on the regulations for every single detail on the systems.

Total ergonomic Child Restraint System for infants confirmed that the comfort and usability has not been fully achieved yet and the design, as well as requirement, still need to be improvised. Comfort in the aspect of infant travelling with aircraft is very subjective and difficult to determine. However, as it is concerned, the most effective way to deal with comfort and discomfort of an infant is by determining the very basic need of this group of travelers without compromising their safety.

Corresponding Author: Syakirah Kamarbhari, Department of Mechanical and Manufacturing System, Faculty of Engineering, Universiti Putra Malaysia, 43400, UPM Serdang. Selangor. Malaysia.
Ph: 60126144010. E-mail: syaki_k@yahoo.com

Child Restraint System for Infants:

According to the Federal Motor Vehicle Safety Standard and Regulations (FMVSS 213), Child Restraint System is a device designed to restrain, seat or position children who weigh 50 pounds or less, and used primarily with professional and technical audiences (Huntley, 2002). The use of a Child Restraint System on aircraft provides the utmost degree of protection for the children, especially infants, and it is also useful as the aid in case of unexpected turbulence (Transport Canada, 2014). As stated by Weber, the major purpose of child safety seats with restraint system is to protect the central nervous system of children during traveling in vehicles (Weber, 2000).

Restraint systems in automobiles, which comprise a safety seat and seat belt, are designed to limit and control the body's rate of deceleration during a crash. Consequently, it could also lower the forces acting on the body surface to diminish the differential motion between the skeleton and internal organs (Weber, 2000). Similar to adult seat belts, Child Restraint Systems are projected to keep a child firmly secured in their seat, so that in the event of sudden impact, the child is not thrown against the vehicle interior or ejected from the vehicle. It is essential for the Child Restraint System to absorb kinetic energy which created by the motion of the child during the crash without contributing injury to the child, and it must also be easy to use (Kate *et al*., 2009)

There are many types of Child Restraint Systems designed for infants and toddlers, and a few are intended for the infants use. It was also shown in previous studies that the performance of automotive safety seats and beds for infants in crash situations has improved dramatically (Marilyn *et al*., 1999). However, many research revealed that the automotive safety seat remains one of the most effective strategies available to protect children from injury and death in the early years of life (Weber, 2000). This is due to the systematic and complex design that appears in the features of the automotive safety seat itself besides the element of comfort presented by this system. In the case of automotive safety seat, it was found that the rear-facing automotive safety seats offer a maximum protection in a frontal crash because the forces are transferred from the back of the restraint to the infant's back, the strongest part of an infant's body. Besides that, the restraint supports the infant's head correspondingly. Severe tensile forces on the neck in flexion can also prevent from the use of rear-facing car safety seats (Weber, 2000). This characteristic made the rear facing automotive safety seat as one of the ideal mechanisms of a restraint system for the infants.

Ergonomic Design of Child Restraint System:

The central attention of ergonomic design refers to the compatibility of objects and environments with human factors. Its intention is to balance the functionality of the tasks with the human's capability to perform the tasks. The understanding of an ergonomic design is wide and extensive as it could differ in many ways (Kaljun and Dolsak, 2012). The ergonomic design itself cannot be justified without proper study and validation.

The design of the Child Restraint System needs to cover all aspects of ergonomics and human factor. The most important criteria need to be considered is safety, while for infant and children, it is vitally important to follow with the criteria of comfort. The element of comfort and discomfort of the infant may not only affect the infant itself, but also to their travelling companion and to the extent of other passengers.

According to the China National Standard (CNS 11497) regarding the standard classification of the safety seat, Table 1 shows the individual component of the typical child safety seat used for transportation (Central Standard Bureau, 1998):

Table 1: The individual components of the typical child safety seat used for transportation.

Child safety belt	Composed of weaving belt, buckle and length adjuster to restrain a child, and is a part of protection device.
Assistant safety belt	To protect a child car seat from sliding and to make the protection device more stable by adding a fixed safety belt from the back support of the seat.
Buttock support	Part of protection device to support a child's buttock.
Back support	Part of protection device to support a child's back and head.
Lateral support	It is a part of back support to protect the head against moving horizontally.
Contact surface	While fitting up a child's model to the protection device, the entire surfaces surround the head and human body of a child's model.
Top slots	These are slots to make the safety belt to go through the rear side of the car seat.
Bottom slots	Functions are the same as top slots. Children can use different height of slots in accordance with their stature.
Shoulder straps	These are safety straps, which mount the shoulder through the frontal body to fix a child's shoulder.
Buckle	To tighten the safety belt.
Crotch strap	Safe strap to jump over a child's hips.
Harness adjuster	Used to tighten the shoulder belt, which is adjustable and generally possesses a lock device.
Frontal railing	Cushion device to protect a child from turnover and causing injuries.

Infant's Anatomy and Comfort:

The anatomy factor of children, especially infants is one of the elements that increased the risk of fatalities and serious health losses in the transportation system (Evans, 1991). This factor might influence the comfort and could affect the long term health of the infants. Infants and children have totally different body size proportions, muscle bones and ligament strength compared to adults (Huelke and Arbor, 1998). The skeleton of the adults changes throughout life. However, the changes in infants are most dramatic.

The Head Section:

A major dissimilarity in anatomy between infants and adults is the proportions of total mass in the head. At birth, an infant's head encompasses 20% of body weight, whereas an adult's head makes up only 6% of body weight. That is the reason why most infants cannot hold up their heads until the age of about three months (Marieb, 2004). Figure 1 shows a comparison of face-braincase proportions in the child and adult that are represent by the horizontal line passes through the same anatomical landmarks on both skulls.

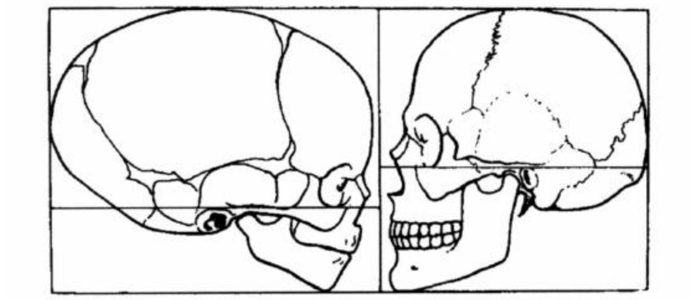

Fig. 1: A comparison of face-braincase proportions in a child and an adult (Marieb, 2004).

In addition to that, an infant's head is about ¼ of the total height, whereas an adult's head is about 1/7 of the total height (Klinich *et al*., 1996). The cranium of an infant is huge relative to its face, and some bones are still not bonded. By the age of nine months after birth, the cranium will reach half of its adult volume because of the rapid development of the brain (Marieb, 2004).

The Neck Section:

The size of the head, which is relatively large for the infant, may particularly affect neck loads, as a larger proportion of mass is being supported by a smaller structure. This condition may permit discomfort and more neck injuries if not supported appropriately. The risk for whiplash injuries is therefore much bigger for an infant compared to an adult. Compared to adults, infants are more common to suffer neck and head injuries in many conditions and situations (Nilsson, 2005), since infants have specifically heavy heads and fragile necks. If case of a crash, an infant's soft spinal column can stretch, leading to spinal cord damage if the infant is riding facing forward. The infant could die or become permanently paralyzed. This is important to be considered, even for bigger infant who have strong neck muscles and good head control. The neck bones are flexible and the ligaments are loose to allow for growth (Nilsson, 2005). If the infants are not properly seated, it could also give a negative impact on their comfort level towards the development of their growth. On the other hand, injuries to other parts of the body are more common among adults.

The neck vertebrae of children are considered as immature in comparison to adults. These cervical vertebrae are mainly cartilaginous or to be exact, referred as a tough elastic tissue in an infant. This cartilage will slowly make a complete replacement by bone at one final stage (Huelke and Arbor, 1998). While the progression makes its way to the final stage, special consideration and extra care need to be given to the infants so that they would not encounter any unwanted situation. Moreover, at birth, the vertebral centers are oval in shape and it has the same height as the height of the intervertebral disc. With progressing age, vertebral physiques will develop into a more rectangular shape and their height also increases (Yogandan *et al*., 1999).

The Vertebral Column:

In case of adults, the vertebral column or the spine is formed from 24 bones. They are disseminated as cervical vertebrae with 7 vertebrae in the neck, thoracic vertebrae with 12 vertebrae that lie posterior to the thoracic cavity, and finally, lumbar vertebrae with 5 vertebrae that support the lower back.

Figure 4 describes the curvature of the vertebral column emphasizing the development of primary curvatures (P) and secondary curvatures (S). The figure shows that there are only two primary curves in infants, which are thoracic and sacral, while for adults, there are secondary curves in the cervical and lumbar region. There are only primary curves persisting in the aged [modified from Johnson and Kennedy "radiographic anatomy of the human skeleton"] (Burdy *et al*., 1969).

On the other side, there are 33 separate bones that can be found in the vertebral column of infants. Nine of these bones form two composite bones, the sacrum and the coccyx. The remaining 24 bones build up the vertebrae, separated by intervertebral discs (Marieb, 2004).

A newborn does not have the typical S-formed vertebrae, as illustrates in Figure 4. Only the thoracic and sacral curvatures are present during birth. On top of that, the cervical and lumbar curvatures are accompanied with a child's development. When the young infants start to lift their head at about 3 months, it pronounces the existence of the cervical curvature. The lumbar curvature develops when the baby begins to walk (Marieb, 2004). All curves are fully developed by the age of 10 (Tortora and Grabowski, 2000).

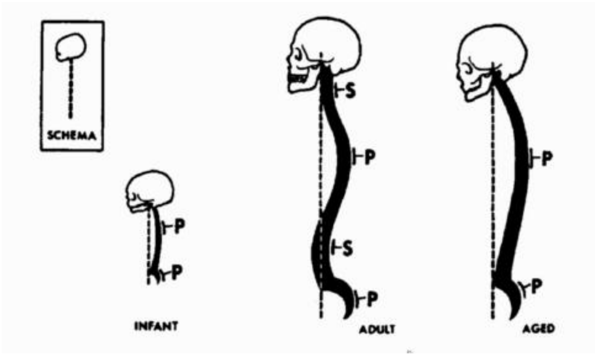

Fig. 2: Curvature of vertebral column emphasizing the development of primary curvatures (P) and secondary curvatures (S) (Burdy *et al*., 1969)

Abdomen:

The bulge of the newborn abdomen is brought out by the abdominal viscera that are pushed forward during respiration against the weak and atonic muscle wall of the abdomen (Huelke and Arbor, 1998). The right side of the infant and newborn abdomen is specifically enlarged due to the low position of the liver, which conquers two-fifths of the abdominal cavity. Therefore, any blunt abdominal injury can be potentially serious. However, since the infant anatomy are still developing and in the immature stage, such injuries will be more critical and harmful to them (Huelke and Arbor, 1998).

Other Differences:

The abdomen of infants is different to an adult in a way that a smaller part is covered by the pelvis and rib cage (Tingvall, 1987). An infant ribs are more elastic and it could be easily bent and break due to the force apply to it. In addition, the force will be transferred to the inner organs (Anund *et al*., 2003). There is also a difference between a child and an adult pelvis. The hip crest, also known as anterior superior iliac spine, is important for the use of a lap belt, which is not developed yet until the age of ten years old (Tingvall, 1987) (Anund *et al*., 2003).

The center of gravity of a child differs according to various aspects such as age, child size, weight, body form and sitting posture. In the case of a newborn, the midpoint of the body is somewhat above their umbilicus, while for 2 years old infants, the midpoint of the body is slightly below the umbilicus. Later, a related study by Young on the 'Unpublished Infants Center of Gravity Data' stated that infants aged 8 weeks to 3 years found that their center of gravity is located even higher on their body (Huelke and Arbor, 1998). In addition, the differences in body segment proportions also give a higher center of gravity in a child, which may affect the body kinematics in the event of an accident (Tingvall (1987), Anund *et al*. (2003)). Figure 5 describes the changes in sitting height from birth to adulthood.

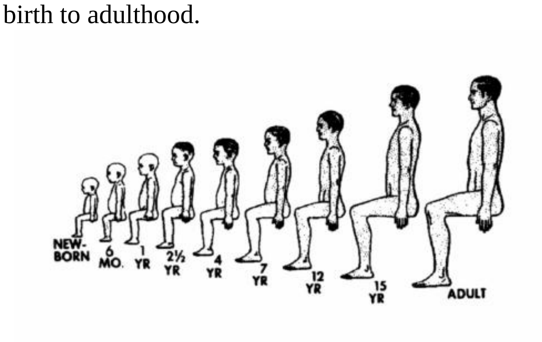

Fig. 3: Changes in sitting height from birth to adulthood (Burdy *et al*., 1969).

Factor of Comfort on Infant:

Maldonado from his idea of comfort interpreted it as a property of the environment (Thomas and John, 1991). Slater sees comfort as a pleasant state of physiological, psychological, and physical synchronization between a human being and the environment (Slater, 1986). Therefore, it could be said that Slater's definition is more wide range since it covers all major elements that bring to the factor of comfort or discomfort. In the analysis of comfort conducted by Coelho, the sub-branches of comfort measured can be seen as an aspect of the surrounding environment. The sub-concepts included are not an attempt to cover all the instances of comfort, but only a few that are linked to seat comfort (Coelho, 2002). There is also a condition where human interaction with the environment could generate discomfort, such as auditory comfort, visual comfort, or movement comfort.

According to Helander (2003) in his previous study, he stressed that a good ergonomic design of a seat is a prerequisite for seat comfort. This idea can be applied as well to the Child Restraint System for infant and children travelling by air with their travelling companion. Helander and Zhang (1997) described how comfort is related to emotional aspects, such as the feeling of safe and luxurious. Discomfort in general is more related to the physical aspects, such as feeling pressure and pain in the muscle. In the aspect of an infant, the condition of comfort is most likely easier to be achieved but hard to determine.

The measurement of comfort for adult is difficult to quantify and it depends on the influence of factors such as user subjectivity, occupant anthropometry, seat geometry, and amount of time spent sitting (Thakurta *et al*., 1995). This situation is even harder when it applies to the infants because they cannot express their feeling with words. Few types of the objective methods such as pressure study, vibration study, and muscle stress study can be applied for seat comfort measurement. In earlier research, the objective measurement results were brought forward for the comparison with subjective measurement data for better seat comfort projection (Nawayseh and Griffin, 2005). Boggs (2004) in his investigation have shown that some of the essential factors that affect the comfort of seating are seat-interface pressure distribution, whole-body vibration, and pressure change rate.

In the case of infants, the factor of attachment to their caregiver is considered as one of the additional factors to achieve the comfort level requirement. The characteristics of the infant under 24 months of age are difficult and hard to predict. Since the feeling of emotionally secure is crucial for the development of infants, it could be said that responding sensitively to the infants helps them feel secure and learn to manage their own emotional state. These 'self-regulation' skills are important because it helps children to calm themselves or settle themselves to sleep (The Open University, 2013).

Zhang and Helander (1996) presented a model that exemplifies the interaction between comfort and discomfort (Chee Fai *et al*., 2010). When an individual executes a task for a longer period while in sitting position, then the discomfort factor will increase. In contrast, when an individual undergoes the feeling of well-being during sitting, the comfort factor will increase.

Another researcher also found that the most important issues in designing and using child car seats are safety and comfort (Hsin Hsi, 2006). However, there are only small amounts of studies that focus on child car seat than the general chair seat in the aspect of comfort.

It is clearly stated in many research that the safety and ergonomic compatibility are the most significant parts in designing the Child Restraint System. Looking back to the nature of the children, especially infants, they are not able to objectively express their aptitude of safety, comfort, and opinion very well. Because of this reason, infants and young children cannot be the proper subjects for the ergonomic design experiments. According to Hsin Hsi (2006), the application of computer technology to simulate human motion for solving ergonomic design problems has been explored for so many years, especially in substituting real human engaging in high-risk tasks. However, in other mode of field of product design, the models of Intelligent Man-Machine suitable for designers are barely studied. It is well recognized nowadays that in the industry, several computerized human models have been applied for product designers for the purpose of design enhancement (David and Grossman (1998), Frank and Marach (1998), Glass and Graham (1999)). These models contribute a lot in the industry of seat and Child Restraint System.

Vibrational comfort is a crucial aspect in child safety seat design. Vibration is mutually a source of discomfort and a possible risk to infant health (Giacomin, 2000). Ever since infants and children are now becoming regular passengers in the aircraft and other transportation, this area of comfort should become the main priority.

Based on the principle, mechanical vibration delivers negative effects on the human body. However, it should not be taken on that side only, as there are also positive effects of the vibration. Vibration stress can cause the relaxation of certain tense or uncomfortable conditions. The commencement of the acceleration must remain within a frequency range that does not exceed the capability of the human body sensitivity. It must be not too high in terms of amplitude and the effective time must not exceed the limitation. It is important to take note that when the exposure time is longer, a condition of boredom and flatness will be reached, which will lead to adaptation and result in reduced activity and fatigue (Dupuis and Zerlett, 1986). Fatigue is the dominating symptom for the exposure of vibrations with low intensity (Lidstrom and Hansson, 1976).

In two previous vibration studies of child safety seats fastened to the seat belt by Giacomin (2000); Giacomin and Gallo (2003), the belt-fastened child seats were found to be less effective than the automobile seats in reducing vibrations. The outcome of these two research mentioned that attachment systems such as ISOFIX would be expected to result in diverse vibration characteristics, since the connection between the child safety seat and the car body is very rigid.

Contact comfort is universally perceived as reassuring by both human infants (Wolf *et al*., 1996). From many studies, there is much evidence to hold the position that young infants, whether alert or asleep, feel comfortable in a situation that includes fairly constant auditory stimulation, movement and firm tactile contact, especially when the holdings of the stimuli resemble characteristics of the prenatal environment (Regine and Maarit, 2007).

Child Restraint System Used to Offer Comfort in the Aircraft:

There are several mechanisms of Child Restraint System for infant used in aircraft. These mechanisms are initially for the purpose of safety in the aircraft. Children, including the infants, are offered with these mechanisms to ensure their safety position in the aircraft. Besides safety, the issue of comfort also needs to be emphasized so that the infants, even though cannot express their words to show the feeling, can experience a comfortable journey. Below are the main mechanisms used in aircraft and the explanation based on the comfort factor.

Bassinet:

The bassinet is a type of restraint system for infant, which is used in an aircraft by simply mounting it to the front panel or bulkhead of the aircraft. Most of the airlines provide a bassinet for infants less than 6 months. As suggested by the Civil Aviation Safety Authority Australia, the bassinet offers a comfortable position for infant or small baby under approximately 6 months with a weight less than 12 kg or 13 kg to lie down in a safe and comfortable place (CASA, 2002). The purpose of the bassinet in an aircraft is to offer safety and at the same time offer comfort for both the infant and their travelling companion. In terms of safety and comfort, the bassinet is highly productive for young infants who are not yet able to roll or crawl. The infant can have their nap inside the bassinet without the need to be held for a long time by their travelling companion. The travelling companion is free to move whenever the infant is sleeping in the bassinet. Definitely, this system could contribute comfort to both infant and parent. However, the bassinet is not allowed to be used during take-off, landing and turbulence since the mechanism could harm the passengers facing the bassinet. It is not considered as a fully Child Restraint System for the infants since the infant still needs to be lap held during a certain condition. In addition, the effectiveness of this mechanism is only valid for infant prior to 6 months old a proper restraint system needs to apply the older infant during travel.

Fig. 4: Bassinet.

Supplementary Loop Belt:

The supplementary loop belt is a type of Child Restraint System provided by the airline management for the passenger with an infant less than 24 months old. This belt provides additional seat belt with stitch loops through the passing adult seat belt, which is a derivation from the normal lap belt in term of its width, material, and buckle (EASA, 2014). This device is used by the parent by simply inserting the end part of the supplementary loop belt into the main passenger belt and fastened the secondary belt around the infant's body. This device is the only restraint that proved to be acceptable by the regulation for a lap-held infant during the time specified in CAO 20.16.3 subsection (CAA, 2013). In the aspect of young infants, the position of being lap held is considered to be comfortable as they are attached to their parents and increase the feeling of secure. But for older infants, this position might not last long since they are more active when they are awake. The supplementary loop belt is said to be less effective for a newborn infant as their skeletal structure would be unable to cope with any significant load from the 5 cm wide webbing. For the maximum level of protection, all infants should be seated in an individual infant restraint device in a separate passenger seat (CASA, 2002). In addition, the design of normal lap belt for adult passenger is purposely to support the webbing on the iliac crest

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of the adult. Adult from the aspect of biomechanical term is restrained by the seat belt over their iliac crest in an accident, while for the infant, their iliac crest is not fully developed. For the situation of infants, the supplementary loop belt rest by almost 100 percent within the infant's abdominal region. Therefore, the induction of forces into the infant's abdominal region will cause extremely serious internal injuries (EASA, 2014).

Fig. 5: Supplementary Loop Belt.

Automotive Safety Seat Type Restraint System:

Automotive Child Restraint System or car seat type of restraint system has become the choice of parents for their small baby to travel by air. Currently, the use of the automotive Child Restraint System in the aircraft has been found significant and widely used to increase the safety of an infant passenger during abroad or during unexpected condition (Gowdy and DeWeese, 1994).

Some international carriers, including Virgin Atlantic and British Airways, provide infant seats on-board for babies and toddlers. The Virgin's Infant Child Care is similar to a car seat and can be placed in the airplane seat facing forward or backward. There is also a system offered by British Airways, which is made by one of the car seat manufacturers. The infant seat is hooked onto the bulkhead or a plane partition often found in front of the economy class, but it is not designed for take-off and landing situation (Michelle, 2010). The availability of this Child Restraint System is also based on the first come first serve basis.

For younger infants with a weight less or equal to 10 kg, incompetent to sit upright, and spend most of their time sleeping, the most suitable car seat type restraint system is the rear facing type (Kristy *et al*., 2001). It was stated in details in Subsection 13 of Civil Aviation Organization (CAO) 20.16.3 that it is permissible for an infant to be carried in an acceptable separate Child Restraint System fastened to a passenger seat (CASA, 2014).

Fig. 6: Automotive Safety Seat Type Restraint System.

Conclusion:

It is clear to state that infants in the aspect of comfort level are difficult to predict compared to the adults. The infants naturally need the environment to be secured to fulfill their comfort, which is one of their needs. At the early age, they need to be close to their parents in order to be in their comfort position. Despite the environment element, pressure distribution, vibration, and pressure change rate, the Child Restraint System design should also consider natural elements, such as the attachment and the state of being secured by the infant itself. The design of the Child Restraint System that fulfill the inner criteria for infants, are the most brilliant ways to improve the comfort of this group of air travelers. The literature study revealed that most of the research of Child Restraint System had focused on the aspect of safety. From the anatomy aspect of the infant, obviously, their early structure and development needs to be given extra attention and support so that their growth will not be disrupted or exposed to any harmful distress. Since their feeling is difficult to predict, more research on the design that can offer better comfort for the infants have been explored in many different aspects and approaches.

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