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SAE Technical Paper Series

890753

The Cradle-Safe Infant Restraint: A Low Cost, State-of-the-Art Advance in Infant Occupant Protection

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Reprinted from SP-782–Automotive Frontal Impacts

International Congress and Exposition
Detroit, Michigan
February 27 – March 3, 1989

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ABSTRACT

An estimated one-million newborns annually ride home from the hospital without protection of car safety Sets, often because seats are too expensive. Many babies in seats are not correctly restrained because seats are not designed for newborns, and parents get little or no instruction. Premature babies have special problems and restraint needs not met by regular car seats. The Cradle-Safe concept was developed as an answer to these problems...as to achieve the goal of having every newborn correctly restrained in a car seat for the first ride home.

The patented Cradle-Safe concept has three configurations: a newborn car safety "starter seat" and general use carrier; a premature-infant "travel crib"; and a safely and comport-enhancing modification for existing safety seats.

The design is in two parts: an outer energy insulating/absorbing "shell", and an inner "bed" of energy absorbing surfaces which deform on impact to contain, orient, distribute and minimize intertial loads on-and thereby protect-the infant. Materials are plastic and/or fiberboard.

The Cradle-Safe concept represents a state-of-the-art advance in low-cost, effective protection for infants in cars.

OF THE APPROXIMATELY 3.5 MILLION BABIES born annually in the USA, an estimated one million (30%) are transported home from the hospital without the protection of a car safety seat. Many of the babies who are in car seats are scarcely better off: an estimated 50% or more of the seats with small infants are misused by parents, typically by not having the harness straps in place or snug or facing the seat the wrong way.

The life-threatening practice of non-use and misuse of car safety seats with newborns is against expert medical and safety advice and is directly in contravention of "child car seat" laws in effect in every state. (1)* Legislation such as this is designed to help ensure that an infant has some protection during an automobile accident. It is motivated by alarmingly high infant injury and fatality rates. (2)

There are several reasons why so many babies are completely or partially unprotected:

COST. Families with very low incomes who also may be on state aid have difficulty justifying spending $30 to $45 for a car safety seat when food and clothing seem of more immediate importance.

PERCEPTION OF RISK. Many parents don't learn why car seats are important and useful for new babies from their childbirth education and pre-natal programs, so they put off a purchase until weeks or months after the baby is born.

MOTIVATION. Only a minority of hospitals encourage compliance with state law by having a "policy" requiring babies to ride home buckled up, and only a minority offer a limited number of car seats for rental or sale. (More

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* Numbers in parentheses designate references at end of paper.

hospitals are starting promotional programs to give away car seats to new mothers, but these programs are limited to "for-profit" hospitals serving middle-income families who otherwise could afford seats.)

EDUCATION. Most new parents get very little or no direct and personal instruction from health professionals on how to use correctly and easily their infant-only or "convertible" (infants and toddlers) car seats. Their only source of information usually is the instruction sheet which comes with each seat.

CAR SEAT DESIGN. Infant-only seats are designed to fit the 17.3 lb infant test dummy required by NHTSA, not a 5 to 10 lb newborn. Convertible seats, especially those with harness-shield restraints, are not designed primarily to fit the 33 lb (3-year) NHTSA test dummy, not a newborn. Unless parents receive warnings --detailed instructions and strong motivtion on how to dress, position, and support a newborn in these "large" seats so that the baby is comfortable--the seats will be used incorrectly or not used at all for the first few months.

In recognition of these problems, and to accomplish the goal of making the "first ride a safe ride" for every newborn, a project was initiated in 1982 to develop a new product which would be designed for the following:

(a) to fit only newborns from 5 to 10 lbs weight:

(b) to be so inexpensive that it could be given away to every newborn by hospitals, sponsoring corporations, or local state/federal agencies:

(c) to provide protection without an expensive harness system and buckle (which is often misused on regular seats);

(d) to provide protection as good or better than that provided by a correctly used "regular" car seat;

(e) to make it so easy for parents to get started on the "car seat habit" that they would be encouraged to obtain and use a larger seat as the baby grows.

It was quickly determined that the only way to accomplish the objective of very low cost was to use a material such as fiberboard (cardboard) or a combination of fiberboard and plastic. This also seemed to be the answer for providing a high level of protection without the need for a complicated and expensive harness system. Preliminary computer simulations confirmed that fiberboard could be designed to crush and deform in a controlled manner, allowing the infant to move from a reclined to an upright position inside the shell, thereby minimizing crash loads on the boby and head, and eliminating the need for a harness.

There have been several major design variations over the five-year developmental cycle of what is now known as the Cradle-Safe concept. Figure 1, below, is the first configuration which served in May of 1984 to reduce the concept to practice for patent purposes and to illustrate the principle of operation in three sled tests conducted at the facilities of MCR Technology, Inc. in Sante Barbara, California (formerly Minicars, Inc.)

Figure 1. Original child seat with hood and cowl.

During the next two years development proceeded very slowly as efforts were made to find a corporate sponsor to fund final development costs of the Cradle-Safe in return for exclusive rights to purchase and distribute the product. It was proposed that the cost of the seat and its development would be more than offset by increased sales for products packaged in and asociated with the Cradle-Safe when distributed free in hospitals to every new mother. Unfortunately, a variety of circumstances (initial costs, fear of liability, reorganizations, etc) prevented completion of a licensing agreement.

By 1986, however, the need for this product and the market's receptiveness to it had become so clear that a decision was made to proceed with developement and certification using private funds. Laws were in full effect in every state requiring infants to be protected on the first ride home. The misuse of car seats, particularly with infants, was becoming a more visible issue in litigation and of more concern to state safety agencies and hospitals. More hospitals were starting car seat rental and give-away programs, and even more would be willing to start if less expensive seats were available.

Also at this time an additional market need was identified for which the Cradle-Safe concept seemed the ideal solution. Research at the University of Nebraska Medical Center determined that a significant percentage of pre-term babies were susceptible to episodes of apnea during and after sitting in a semi-reclined angle for 30 minutes in an infant car seat. (3) Full term babies wer not found to have this problem associated with car seat use. Computer simulations confirmed that a small, inexpensive "travel crib" in which infants from 4 to 7 lbs could lie prone could be constructed of fiberboard and provide protection as good or better than regular seats.

Numerous tests were conducted between 1986 and 1988. Computer testing used static force/deflection measurements and analytically derived dummies (weighing between 5 and 19 lbs) and crash sled testing used available physical dummies. By using the crash pulse derived from the only instrumented rear facing car seat/dummy test available, and by varying the force/deflection characteristics of the bed and shell, final configurations of the Cradle-Safe Infant Car Seat/Carrier and the Cradle-Safe Premature Infant Travel Crib were determined. After selecting the design parameters, the final test results are those shown in Figure 2 in the appendix.

The efficacy of these designs also has been evaluated through computer simulations of many "real life" crash situations in which infants in standard car seats suffered injuries. (4)

Certification of compliance to FMVSS-213 requires that a product be tested with the 17.3 lb specified test dummy, even if the product is designed to accomodate only much smaller infants. The standard does not address the vital issues of determining and reducing injury measures. Final design changes were made in 1988 which allow both the Cradle-Safe Infant Car Seat/Carrier and Travel Crib contain the 17.3 lb test dummy in the required crash test, yet still maintain those force/deflection characteristics which significantly reduce injury measures with an 8 lb newborn infant. Sled test have confirmed this performance and the Cradle-Safe concepts have been certified to be in compliance with FMVSS-213.

DESIGN DEVELOPMENT

The Cradle-Safe infant seat/carrier is illustrated in Figure 3 of the appendix. It consists of a shell and bed. The shell is approximately 15" high, 22" long and 9" wide. The bed has a back (18" long), a seat (5" long) and a foot (4" long). The width of the bed varies from 6" at the head to 8" at the foot. Other dimensions have been selected to be most appropriate for an 8 lb infant but accomodate those from 6 to 10 lbs.

The height of the shell sides above the bed at the location of an eight lb infant's head is 4". The infant's Center of Gravity (CG) must be below the seat belt attachment point to control rotation of the shell relative to the automotive seat.

The bed is separated into a back and seat each with energy absorbing, kinematic controlling wings. These wings are the static and dynamic interface between the bed and the shell Statically, the bed is held in place by the wing edges and tabs at each end inserted into the head, bottom and foot faces of the shell.

Dynamically the bottom tabs disengage, the bed and wings deform and limit the rebound of the bed, particularly when the shell sides are squeezed together by a lap belt in tension.

In addition an hour glass shaped torso girdle of velcro-compatible nylon passes under the bed back (where the wings are narrow) and over the upper torso of the infant (where the wings are wide). Two short strips of velcro hook material are provided to secure the open edges of the girdle together over the infant.

The shell is designed to support 650 lbs of force on the seat belt with some bowing of the forward surface. When the bed collapses it rotates towards the vertical, aligning the infants back to the inertial forces and placing the wings in contact with the inside of the forward facing surface of the shell. The bed then deforms at a force level rising to 400 lbs (defined and adjustable by the width and shape of the wing) when the center of the bed first contacts the shell.

The bed angle is set as low as possible to still rotate while keeping the 8 lb infant's head CG below the intersection of the bed and front face. As the length of the infant's torso increases, the angle, the length and the height of the bed must increase, though it is thought that for newborns, the lower the angle the better.

PERFORMANCE

The infant kinematics in a frontal impact are illustrated in Figure 4 in the appendix. The system protects the infant by deforming to encapsulate and distribute forces, while absorbing energy so as to limit deceleration and rebound. The maximum acceleration on a 8 lb infant should be less than twice the typical vehicle deceleration, in contrast to the 3 to 4 times more acceleraton of rigid seats. The velocity at which the infant is protected is a function of its size and the severity (but not peak amplitude) of the crash pulse.

FRONTAL--If the system is designed to minimize the deceleration forces on a 12 lb infant in a 30 mph collision (before the shell distorts), it would produce 50% higher deceleration forces on an eight lb infant and twice as high as would be necessary on the 6 lb infant.

A 17 lb test dummy is contained by collapsing the bed and shell to their limits at 30 mph. The 6 lb infant will be protected by distorting the shell in a 50 mph impact. Corresponding performance is a function of infant mass and is generally independant of the crash pulse peak amplitude.

ANGULAR AND OFFSET FRONTAL--These impacts are similiarly handled to even higher velocities due to the lower amplitude and extended length of the pulse. Depending on placement, the seat offers more head protection than a conventional seat from a non-crashworthy intruding automotive interior.

SIDE--Side impact performance is limited to that velocity at which the rotation of the shell uses up the available distance between the shell and the intruding interior side surface. For a mid rear seat position this should in most small cars be equivalent to a 15 mph delta velocity.

REAR--Rear impact performance level is a function of misuse by the person who installs the infant and seat in the car, i.e. whether the torso girdle and the automotive seat belt are in place. If both are properly used, a delta V of 20 mph should be easily tolerated. If the seat belt alone is in place there is a possibility of abdominal intrusion and internal injury. In the limit of misuse (neither torso girdle nor seat belt securement) the car seat back provides some protection. It was estimated that because of swaddling, a more sophisticated 5 point harness often could not or would not be used with a newborn. Since misuse is a big problem, the easy to use velcro girdle was deemed an acceptable choice.

ROLLOVER--Rollover protection is a matter of keeping the infant in the carrier and the carrier on the car seat, since in such an accident circumstance there is relatively low acceleration during event. A worst case rollover accident would be preceded by a high delta velocity foreward deceleration.

Significant protection is afforded even taking into account certain incorrect use of this carrier. If the automotive seat belt and shoulder harness are properly attached to the carrier, the carrier should stay with the car seat, and the torso girdle should keep the infant in the carrier.

OTHER--The unit is not designed to accomodate the 20 lb dummy required by EEC Rule 44 which governs front seat-but not rear-seat infant carrier use.

CONSTRUCTION AND DESIGN ALTERNATIVES

In the process of this development a number of construction alternatives were developed. They consist of: different ways of attaching the seat belt: preassembling, shipping, folding the bed and shell and fastening them together; alternate materials, additives, reinforcements, belt holes, handles, pockets, straps and buckles, warnings, and decoration.

The fiberboard test versions of the Cradle-Safe Infant Carrier were fabricated out of ordinary 150 lb, 225 lb, 275 lb, and mil spec 350lb corrigated materials. The shell was also molded of high density polyetheline, polypropaline and ABS.

Three sizes were considered appropriate for development.

A. The base Cradle-Safe size is designed optimally for newborn infants from weighing 6 to 12 pounds.

B. The Premie-Crib is a 21" wide transverse carrier for recumbant premature infants weighing 4 to 6 lbs and lying prone on their right or left back (rotating to take inertial forces through the back). Figure 5 in the appendix illustrates the latest configuration.

C. The deformable bed can be incorporated into or in conjunction with existing "to 20 lb" carriers. Figure 6 in the appendix illustrates a 2" shorter version of the Cradle-Safe carrier fitted into and removeable from the Century Love Seat. When the infant is larger than 10 lbs the Cradle-Safe is discarded and the original padding of the Century Love seat is replaced (but backed with a deformable panel which fits over the cut-out for the Cradle-Safe) and provides improved protection for 10 to 20 lb infants.

PATENTS

Patent protection is based on patent number 57901 for the Cradle-Safe and number 266699 for the Premie-Crib deformable structural surfaces of the carrier which function to support, contain, orient, distribute and minimize inertial loads on, and thereby protect, the infant.

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APPENDIX

Figure 2. Comparison of final Cradle-Safe sled test (computer derived measures) with that of Strolee 599 test no. 81D019. Both tests were conducted at HSRI. Both are rear-facing seats subjected to frontal impacts at 30 mph.

Data description	Strolee 599*	CRADLE-SAFE**
Infant Weight (pounds)	20	8
Head Injury Criteria	690	179
Head Resultant Acceleration (G's)	67	35
Chest Resultant Acceleration (G's)	47	37

* Strolee 599 Rear Facing Infant Seat weighing approximately 12 pound in HSRI sled test no. 81D019.

** CRADLE-SAFE Rear Facing Infant Seat weighing 1.5 pound in HSRI sled test no. RL 8801 with computer derived measures.

Figure 3. CRADLE-SAFE in both plastic and fiberboard versions.

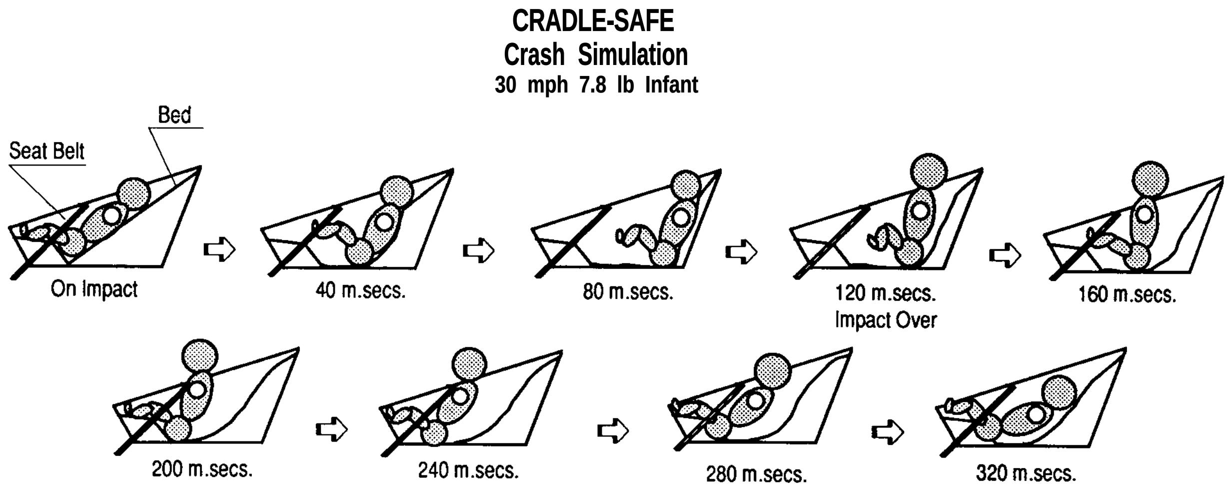

Figure 4. Infant kinematics.

Figure 5. PREMIE-CRIB (a recumbant transverse carrier) in both plastic and fiberboard.

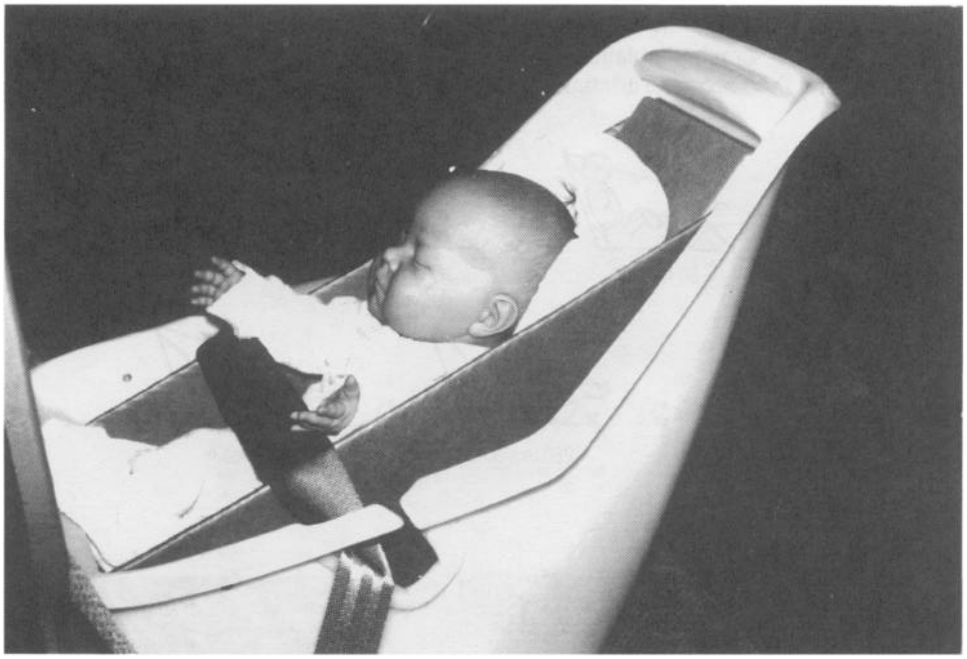

Figure 6. Cradle-Safe carrier fitted into and removable from the Century Love Seat.