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16. Abstract

The subject of the best position for passengers to take in anticipation of an aircraft emergency landing has been studied for many years. The purpose of this "Brace for Impact" position is well understood. Simply stated, the goal of the brace for impact position is to pre-position your body against whatever it is most likely to hit during the crash, and thus avoid the secondary impact which could otherwise take place. While this goal is simple, the many conditions which can exist in aircraft operations have resulted in misunderstandings and doubts, so that questions pertaining to the best brace for impact position are possibly the most frequent questions asked of researchers in cabin safety at the Civil Aeromedical Institute (CAMI). This paper will attempt to explain the problem of secondary impact, summarize pertinent research done at the CAMI, and will attempt to explain the basis for answers to the most frequent questions asked about the brace for impact position.

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Brace For Impact Positions

Richard F. Chandler
Protection and Survival Laboratory
Civil Aeromedical Institute
Federal Aviation Administration

INTRODUCTION

The subject of the best position for passengers to take in anticipation of an aircraft emergency landing has been studied for many years. The purpose of this "Brace for Impact" position is well understood. Simply stated, the goal of the brace for impact position is to pre-position your body against whatever it is most likely to hit during the crash, and thus avoid the secondary impact which could otherwise take place. While this goal is simple, the many conditions which can exist in aircraft operations have resulted in misunderstandings and doubts, so that questions pertaining to the best brace for impact position are possibly the most frequent questions asked of researchers in cabin safety at the Civil Aeromedical Institute (CAMI). This paper will attempt to explain the problem of secondary impact, summarize pertinent research done at the CAMI, and will attempt to explain the basis for answers to the most frequent questions asked about the brace for impact position.

Statements expressed in this paper are those of the author, and do not necessarily represent recommendations or policy of the Government of the United States.

SECONDARY IMPACT

The term "secondary impact", as used in this paper, refers to an impact between a body segment, such as your head, and whatever it might hit in a crash. It might hit some interior part of the aircraft or its furnishings, but it could hit some other part of your own body. This secondary impact takes place because there is space between the body segment and whatever it might hit during the crash. Secondary impact is a potential problem because the deceleration (the "g's") can be much higher than the deceleration of the crashing aircraft. For a greatly simplified example, consider an airplane which crashes at a relatively mild level of only 3 g. (For many years a 9 g crash has been referred to as a minor crash landing in the regulations.) Let's assume that your head could hit some hard part of the aircraft interior which is 3 feet away, and that there is nothing to retard your head from hitting it. When the airplane crashes, it will begin to stop at the rate of 3 g, but your head would keep on going until it hits the hard "stop" provided by the aircraft interior. In this example, your head would hit the aircraft interior with a speed of about 24 feet per second (about 16 miles per hour). Almost instantly, your head would be stopped by the aircraft interior. If your head was stopped by crushing one half inch of material (either your head or the interior) your head would be exposed to an average of 215 g during that time. Since this is an average g, the maximum peak g would be even greater, perhaps as much as 500 g. This could result in fatal injuries. Note that in this example, even though the airplane crashed at only 3 g, your head could be exposed to as much as 500 g.

There are several things which we could do to improve this situation. First, we would use a restraint system, either a seat belt or a combination seat belt and shoulder belt system. This would retard your forward motion, and may even keep you from hitting the interior of the aircraft at all. A suitable restraint system provides the most important protection from secondary impact injuries. We could also design the interior of the aircraft so that it would crush when your head hit it, and have the interior absorb the energy of the secondary impact instead of your head. If we did a good job, and the interior crushed evenly for six inches, your head would be exposed to only 18 g. This technique is called "delethalization," and is an important approach in reducing injury in crashes. But, even though the interior of the aircraft crushed six inches when your head hit it, your deceleration would still be six times as high as the aircraft crash deceleration in our example. But, if you were able to rest your head against the aircraft interior you could avoid the secondary impact altogether. Instead, you would "ride down" the aircraft as it crashed at 3 g, and your head would be decelerated at the same 3 g rate. This last technique forms the basis for recommending a "brace for impact" position.

EARLY TESTS AT CAMI

In 1966, John Swearingen, then Chief of the Protection and Survival Laboratory at CAMI, evaluated eight different (then current) passenger seat designs by impacting a dummy head against various locations on the seat backs. He estimated that, of 34 test impacts at a head impact velocity of 30 feet per second, 30% would have been fatal, 97% would have rendered the passengers unconscious, 80% would have resulted in facial fractures, and only 3% would have produced no injuries or unconsciousness (1). While the conclusions of Swearingen's study focused on the design characteristics of seats, they also indicated the importance of a proper "brace for impact" position so that passengers could avoid these potentially fatal secondary impacts.

The first study of the best bracing position was done at CAMI in December, 1967, by J. D. Garner, then Chief of Emergency Escape Research in the Protection and Survival Laboratory (2, 3). This work was undertaken in response to questions raised by the Society of Automotive Engineers (SAE) S-9 Cabin Safety Committee, and because of concerns about various recommendations for "protective positions" which might be unsafe or dangerous. Twelve impact tests were completed during this investigation. The tests were done on the CAMI sled facility, and used two rows of passenger seats spaced at 35 inch pitch. Passengers were represented by 95th percentile anthropomorphic dummies, and were instrumented with accelerometers in their heads. The dummies were restrained with conventional seat belts. These tests indicated that the greatest head impact, as high as 80 g, was recorded when dummies were initially seated in the upright position. The lowest head impacts, 8 to 32 g, were recorded when the dummies were seated so that their heads were resting against crossed arms which were placed against the seat back in front of the dummy. Test results indicated that to "bend all the way forward and grab ankles" would put the head directly against the lower seat back in front of the dummy, and compress the neck and the head between the torso and the seat, generating concern about cervical spinal column injury.

These tests provided the basis for an early Air Carrier Operations Bulletin pertaining to the brace for impact position (4). This Bulletin, issued in 1969 (and extensively revised since then), indicated that the "grab ankles" position was one of the least desirable positions with the 34 to 42 inch seat spacing then in use. It also showed a position where the head was resting on crossed arms on the seat back in front, and indicated that this position produced the least "g forces" in the CAMI tests. Unfortunately, the figure used in the Bulletin showed the passenger with his feet pushing against the seat back. This condition was not tested at CAMI, and is almost impossible for a typical passenger to assume while seated in a typical passenger seat. This Bulletin also recommended a position for a rear facing seat arrangement where the hands were clasped behind the head, apparently not recognizing that the mass of the hands and arms would increase the stress on the neck if the crash produced a lateral (sideways) or forward component of deceleration.

RECENT CAMI TESTS

One of the limitations recognized by Garner in his tests was that the anthropomorphic dummies then available were poor representations of the human passenger seated in the brace for impact position. While significant improvements of anthropomorphic dummies come slowly, the current standard 50th percentile dummy is considerably improved in both biofidelity and repeatability over the dummies available in the 1960's. These new dummies were used in a broad study of transport aircraft passenger seats conducted at CAMI in 1981. Tests to evaluate the brace for impact position and secondary impact of the dummies with passenger seats were included in this series of tests.

The tests conducted in this program evaluated passenger injury through the use of the Head Injury Criterion or "HIC" (5). This is a mathematical procedure that uses the acceleration time history measured in the dummy head to calculate a numerical criterion, the HIC, for evaluating the threshold injury from head impact. A value of the HIC of 1000 is considered "dangerous to life," a criterion originally based on linear skull fracture. HIC values that deviate significantly from 1000 are not considered to give proportional chances for injury. Seven tests, using three different seat designs were conducted in this series. Sled impact velocity varied between 48.3 and 51.2 feet per second, and sled deceleration was varied between 6 and 9 g. Seat pitch was varied between 30 and 34 inches. Fifth percentile female, fiftieth percentile male, and ninety-fifth percentile male dummies were used as passengers seated behind the seats.

The highest HIC measured in these tests was 863, well below the 1000 level considered as life threatening. This was measured on a 95th percentile dummy which was initially seated in the upright position. This tends to support the success of the "delethalization" designs used in these seats. All the seat backs were of easily crushable construction, and were covered with foam padding to distribute the impact load, and seat back food service trays were of light frangible construction. Even so, the dummies which were placed in the brace for impact position, the same as used by Garner in the earlier studies, experienced HIC values which were only about half of those measured when the dummies were seated upright.

In 1984, tests were done to investigate the effect of clasping the hands behind the neck as part of a brace for impact procedure for occupants wearing restraint systems with shoulder belts. These tests were made possible because of the development of a technique for measuring the loads and bending moments in the neck of a 95th percentile dummy. Tests were done in a forward facing seat with combined seat belt and shoulder belt restraint system because these conditions are the most sensitive to the measurement of increased neck stress. In the 10 g tests, neck tension increased 84%, neck shear increased 59% and neck bending moments increased 26% when the arms were positioned so that the hands could be clasped behind the neck. Although tolerance levels for these measurements are not defined, the increase in neck stress is still significant. Tests were also made using side facing seats with impacts at only 3 g, but the results were inconsistent, with some measurements increasing and others decreasing.

The results of these tests are reflected in a new Air Carrier Operations Bulletin (6). This Bulletin represents the most recent guidance for the brace for impact positions. The following discussion should provide an insight to the reasoning which led to that guidance.

DISCUSSION OF BRACE POSITIONS

The best "brace for impact" position for each occupant of an aircraft will depend on many factors, such as the environment of the crash (magnitude, direction and sequence of crash forces), the layout of the interior configuration of the aircraft within the strike envelope of the occupant, the design and use of the seat/restraint system provided to the occupant, and the size and physical characteristics of the occupant. Obviously, with so many factors involved, it is impossible to describe a single, simple "brace for impact" position which would be best in every case. Fortunately, it is possible to identify a few general principles which will allow an appropriate "brace for impact" position to be selected on the basis of those factors which can be predetermined.

The primary goal for the brace for impact position is to reduce the effect of secondary impact of the body with the interior of the aircraft. Secondary impact can be reduced by pre-positioning the body, or individual body segments like the head, against whatever interior surface it would be likely to impact during the crash. The brace for impact position can also reduce flailing, and the adverse effects which would result. The effects of flailing can be reduced by having the occupant pre-position their body in the direction their body is likely to be driven by its own inertia during the crash. Understanding these two principles, and then making a careful assessment of the environment around the occupant will aid in selecting an appropriate brace for impact position for any configuration.

Certain basic guidelines will apply to all configurations. The seat belt should always be located low on torso, just above the legs. The seat belt should be adjusted after the occupant has pushed back in the seat so that the lower torso is firmly against the seat back. The more tightly the seat belt is adjusted, the better restraint it will provide. The occupants feet, unless the occupant is a crew member who must use the feet for aircraft control, should be placed firmly on the floor, slightly in front of the edge of the seat. Passengers should not attempt to put their feet on the seat in front of them and brace with their legs, because this could double the loads acting on that seat. The seat is not designed to accept these additional loads and it would be likely to break. Likewise, do not wedge the legs under the seat in front because the legs may act as levers trying to pry the seat off the floor, and this could break the legs or the seat.

Passengers should not use pillows or blankets between them and any object they would brace against unless they are designed for that purpose. Pillows and blankets are usually not designed to absorb energy or distribute impact loads over the body, and they could increase the likelihood of injury by giving a false impression that the body is being properly supported. Also, pillows and blankets may become loose during the crash, no matter how hard the passenger tries to hold on to them, and would create additional clutter in the aisles of the aircraft cabin which could impede an emergency evacuation.

Following these principles and guidelines, appropriate brace for impact positions can be defined for some common configurations.

Forward Facing Seats with Safety Seat Belt Restraint. The occupant should bend forward, over the snug seat belt. If this moves the occupant's head so that it would contact the seat back or other part of the aircraft interior, place the hands and arms so that they are between the head and the contact surface, to provide a "pad" to support the head. Don't just stretch out the arms and push on the seat back and then tuck your head down, because then the arms won't support the head effectively and this would position your upper torso away from structure which could provide it support. As long as the hands and/or arms act as a pad to support the head, their exact placement is not important. If resting against a seat back with a "break-over feature," it may be possible to get slightly better support if the seat can be folded over until it stops or until it rests gently on the occupant in front. But if this is not done, good support will still be provided by the seat back as it folds forward of its own inertia during the crash, and is followed by the arms and head. The head and arms will slide down the seat back as it folds, but shouldn't be seriously injured. Do not try to hold on to the edge of the seat back with the fingers.

If the seat is located so that the head will not contact any portion of the aircraft interior as the occupant bends forward over the seat belt, the occupant should continue to bend forward and rest the upper torso against the upper legs. The head should be tucked down, and not twisted to one side. Twisting the head will twist the neck, and this reduces the ability of the neck to withstand the loads it will encounter during the impact. Flailing of the arms may be reduced in low level crashes if the occupant grasps their ankles or legs.

There may be installations where the interior of the aircraft or the forward seat is too far away to provide a secure support for the head and upper body, but will still be close enough to contact the head during the crash. Data at CAMI show that the head strike envelope for a 95th percentile male will extend 40 to 42 inches in front of the intersection between the seat cushion and the seat back (the "seat reference point"). If the seat or interior is, for example, 38 inches away, it will be too far away to provide support for bracing for the impact, but will still be a potential source of secondary impact for the occupant. No completely satisfactory brace for impact position can be given for such installations. Perhaps the only suggestion is to take the brace position described in the previous paragraph, and keep the head well tucked in.

Rear Facing Seats with Seat Belt Restraint. Passengers in rear facing seats should push themselves back into the seat and tighten the seat belt. They should sit upright with their head firmly against the headrest. Their lower arms should be placed on the arm rests. This may help to support the upper body and reduce loads in the spinal column. If arm rests are not available, the arms can be positioned with the hands on the thighs or clasped in front of the waist. The feet should rest flat on the floor. Clasping the hands behind the head is not recommended because this may increase the stress on the neck due to the mass of the arms and the hands as they react to the impact if the aircraft yaws during the crash.

Side Facing Seats with Seat Belt Restraint. Side facing seats without lateral support for the whole body, including the legs, do not provide good protection from impact loads.

A major problem is that the legs will twist sideways in the crash, and this will twist the spinal column as it is being bent sideways as the torso flexes laterally and as it is being compressed by vertical impact forces. This combination of loading can generate high stresses in the spinal column, perhaps causing fractures and spinal cord injury. Because the sideways twisting of the legs cannot be easily prevented, it is difficult to reduce the injury potential of this seat configuration. However, if it were possible to follow the principles of the brace for impact position, an occupant would sit facing forward in the seat, perhaps placing his legs on the surface of the seat if it is a couch arrangement, and then bend over the seat belt until his upper torso and head are resting on his legs, and wrap his arms around his legs. If this were not possible, all an occupant could do is lean towards the front of the aircraft, and rest his upper torso and head against whatever he might contact. Neither of these alternatives is very efficient, but no better approach is known.

Forward Facing Seat with Seat Belt and Shoulder Harness. The occupant of a forward facing seat with a seat belt/shoulder harness restraint system should adjust the seat belt tightly after pushing back in the seat so that the lower torso is firmly against the seat back. If the shoulder harness has manual adjustment, it should then be adjusted so that it is tight. If non-locking retractors are used on the webbing, the webbing should be pulled all the way out, and adjusted with the manual adjustment fittings provided. If non-automatic locking retractors are used, the webbing should be pulled out until the locking system is actuated, and then fed into the retractors until the restraint is tight. If the shoulder harness is equipped with automatic locking retractors (inertia reels), any extra slack in the webbing of the shoulder belts should be taken out and fed into the reel. The webbing should always be flat against the body, and not twisted as it goes into the retractor. The occupant's head should be tucked down as far as possible, to try to eliminate secondary impact of the chin with the sternum. The occupant's hands can be clasped and placed in the lap, the occupant can hold on to the front edge of the seat (but don't lock the elbows or wrists), or the occupant can sit on the palms of the hands. All of these hand positions are effective in most circumstances. But, the occupant should not hold on to the restraint system with the hands. This can introduce slack into the system, especially if it is equipped with an automatic locking retractor, and any slack will tend to increase injury. The feet should be firmly placed flat on the floor, slightly in front of the forward edge of the seat, so that if the clearance between the seat and floor is reduced during the crash, the front edge of the seat won't catch the back of the lower legs.

Rear Facing Seat with Seat Belt and Shoulder Harness. The brace for impact position for the occupant of a rear facing seat with seat belt/shoulder harness restraint system is the same as for a forward facing seat with seat belt/shoulder harness restraint system, except that the head should be placed firmly against the head rest.

Side Facing Seat with Seat Belt and Shoulder Harness. The comments previously given for side facing seats with seat belt restraint also apply here, except for the limitation in upper torso movement provided by the shoulder harness. Unless full support is given the legs by a sufficient lateral support surface which is part of the seat or aircraft interior, the legs are likely to twist sideways and compound the stress on the spinal column. No brace for impact position has been devised to prevent this movement. Possibly all that can be beneficially done by a brace position is to move the head in the direction of the anticipated impact, so as to help reduce head flailing.

Helicopter Seat/Restraint Installations. Occupants in seats in rotary wing aircraft should take the same brace for impact positions as they would in conventional aircraft. The impact direction of a rotary wing aircraft is difficult to predict, so the optimum brace for impact position is also difficult to establish. If the crash should generate extremely high vertical forces, serious injury may not be reduced by the brace position. Inertial reactions of the head or of internal body organs cannot effectively be controlled by bracing, and can cause serious or fatal injuries. Sophisticated energy absorbing seat/restraint systems can be used to reduce the probability of injuries due to vertical impact loads to some extent, but these have not yet seen widespread use in civil aircraft.

Children. Children seated in passenger seats should follow the same procedures to brace for impact as previously described for adults. Because of their smaller stature, the flail envelope of children is smaller than that of the adult, and so they are less likely to suffer secondary impact with the interior of the aircraft. Seat belts in most passenger seats are installed so that they can provide effective restraint for the child with little chance of moving into the child's abdomen. The seat belt buckle is usually located so that it will be at the side of a small child when it is tightened, so that the likelihood of injury from contact with the buckle is reduced. The belt should be placed low on the child's torso, just above the legs. If the seat belt cannot be adjusted so that it is tight on the child, pillows or blankets can be placed behind the child to aid in moving the child into the tightened belt. It is important for small children to bend forward over the seat belt, and rest their head on the seat cushion between their legs, or to bend their head forward, over the edge of the cushion, as appropriate for their height. This is done to reduce head flailing which might result in secondary head impact with the front or bottom of the seat.

Children seated in approved child restraint systems should not be removed from those systems in preparation for a planned emergency landing. Children seated in approved child restraints should be braced in accordance with the instructions of the manufacturer of the child restraint if any such instructions are provided. Because of the wide variety of child restraints available, and because these restraints are usually provided by the parents of the child, it should be sufficient to alert the parents to the need for bracing so that they can instruct the child. If no instructions are available, the principles of bracing which were previously described can be followed. Approved infant seats usually provide even support to the infants torso and head, so that no additional brace for impact efforts are necessary.

Children which are being held by adults should be held in a manner that will support the child's head and torso as evenly as possible. The adult should then bend forward, over the seat belt, so that the child is held in the space formed between the adult's torso, legs, and the forward seat back. Both arms should hold the child to provide as much support for the child as possible. However, the ability of an adult to safely hold a child in a significant crash environment is very limited.

An adult and child should not share the same seat belt because the adult may crush the child against the belt.

Special child belts or harnesses which attach to the adult's seat belt and are intended to position the child in the adult's lap generally do not protect the child from crushing between the adult's torso and legs as the adult flails over the seat belt. These child belts/harnesses can also concentrate the restraint forces on the child's abdomen, an area particularly sensitive to internal injuries. This situation is sometimes worsened by placing a conventional buckle on the child belt at a location where it could cause internal abdominal injuries to the child as the child bends around the belt. These devices provide no support for the child's head, and so provide no protection from neck injuries which could result from head flailing. For these reasons, the use of these devices, as are presently available, is not recommended, and they are not currently considered to be approved child restraint systems.

Suggestions are sometimes made for alternative brace for impact positions for the child that would be held by an adult. These suggestions are usually offered in the belief that almost anything is better than holding the child. While it is unlikely that a child could be safely held by an adult in a severe crash, there is presently little evidence to show that a child held by an adult is at unusual risk in a crash of a civil aircraft where the area surrounding the adult/child pair maintains a survivable environment. The only alternative which is likely to provide improved survival for the child is an approved child or infant restraint system which is used in the proper manner. Typically, the alternative suggestions are good ideas which would work if everything happened as planned, but unplanned events could increase the possibility of injury to the child. For example, a frequent suggestion is that the child be rolled up in a blanket, and held supine at the intersection of a bulkhead and the floor. This technique would provide even load distribution over a large area of the child's body, and should help to reduce injury. This technique has been successfully used in the past. However, if the adult holding the child in place were to transfer his own body inertia to the child during the crash, or if the crash had a lateral component of force which would cause the child to slide along the floor into the aisle, the child could be severely injured. Another suggestion involves the use of a blanket, folded so that it forms a pocket open to the rear of the aircraft, and closed on it's sides by adults who are seated on the edges of the blanket. The child is then placed in the pocket, and is supported by the blanket/pocket during the crash. This would work if the crash environment is not so severe as to move the adults off of the blanket edges. However, if the child is placed in the pocket with the child's head exposed, or moves or is moved into that position before the crash, the edge of the blanket pocket may catch the child under the chin during the crash. This could cause severe injuries to the child's neck. Since the adverse results of using these alternate suggestions cannot be predicted or adequately controlled, their use cannot be generally recommended.

Handicapped or Pregnant Passengers. The brace positions for handicapped or pregnant occupants of a airplane do not differ from those recommended for other occupants. Assistance should be offered if necessary. Pregnant women should be instructed to place the seat belt low, below the abdomen, so that it applies its forces to the pelvis. If rearward facing passenger seats are available in the aircraft, handicapped or pregnant passengers should be relocated to those seats to take advantage of a brace position more effective for their condition.

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RICHARD F. CHANDLER

Richard F. Chandler has conducted research concerned with protection against crash injury for over 33 years. He began his professional career with the United States Air Force at Holloman AFB, New Mexico, where he first provided engineering support for the Aeromedical Research Laboratory under the direction of Col. John P. Stapp, a pioneer in research of human tolerance to impact. He later served as Chief of Biodynamics Research at the Laboratory, and was responsible for directing impact tests to define human tolerance and to demonstrate the performance of crash injury protection systems for use in aircraft, automobiles, and space vehicles.

He joined the Office of Vehicle Research at the National Bureau of Standards in 1978 to do research in human impact and restraint systems for use in automobiles. He joined the Federal Aviation Administration in 1980 to become Chief of the Protection and Survival Laboratory at the Civil Aeromedical Institute in Oklahoma City, where he has specialized in seat restraint system research, and has provided guidance for programs in evacuation, cabin safety, protective breathing equipment, survival, and human measurement.