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U.K. Studies Find That "Legs-back" Brace Position Is Optimal for Forward-facing Passengers

A landing accident provided a real-life laboratory for studying impact forces of approximately the maximum considered survivable. Several studies determined that the legs-back brace position would be best for forward-facing airliner passengers at impact. A U.K. report on the various studies also recommended an optimum 32-inch (81-centimeter) seat pitch and three-point seat belts.

Robert L. Koenig
Aviation Writer

After a Boeing 737-400 crashed short of the runway at East Midlands Airport, Kegworth, England, in January 1989, investigators found that many passengers had been seriously injured when their legs flailed against seat backs and luggage-restraint bars.

The experts also found that "differences in the initial position of the occupant appeared to have a significant effect on the magnitude and type of injuries" to the passenger. If the passengers had been in better brace positions at impact, would that have helped prevent some of the injuries?

British researchers examined that question and others in their extensive studies of the crash, the injuries sustained by passengers and crew, and the dynamics of various brace positions.

The U.K. Civil Aviation Authority (CAA) commissioned the studies, which used accident data, computer simulations and impact test dummies to find the most suitable brace position for commercial aircraft passengers.

In the CAA's May 1995 report, *A Study of Aircraft Passenger Brace Positions for Impact*, researchers for English consulting companies explained the test results. "A legs-back braced position should be adopted where possible for aircraft passengers seated in forward-facing seats," the report concluded. "Arms should be raised to envelop the head."

The CAA report suggested that using "high-friction carpeting" in airline cabins would help prevent passengers' legs from flailing in some accidents and perhaps lessen the likelihood of leg injuries. The report also said that the designs of under-seat luggage bars "should recognize the possibility of foot entrapment and subsequent foot injury" during crashes.

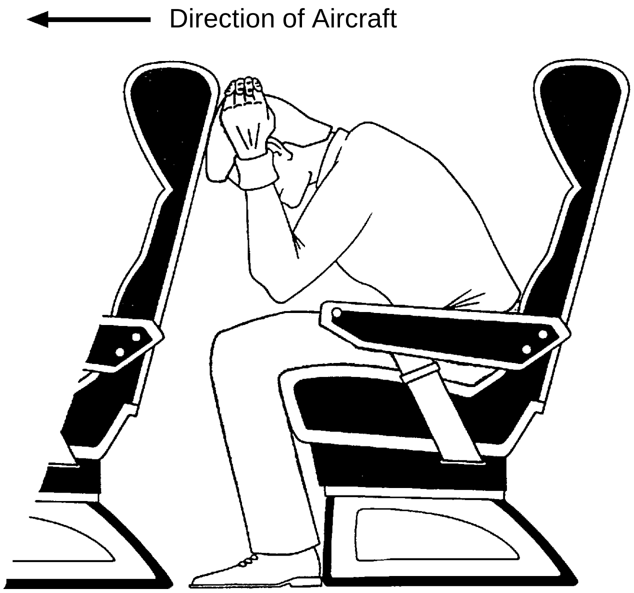
As a result of the research related to the Kegworth accident, the CAA's flight operations department issued in August 1993 a *Notice To AOC* [Air Operator's Certificate] *Holders* detailing the recommended brace position (Figure 1, page 2):

- "UPPER BODY: Should be bent forward as far as possible with the chest close to the thighs and knees, with the head touching the seat back in front.

  "The hands should be placed one on top of the other and on top of the head, with the forearms tucked in against each side of the face. Fingers should not be interlocked.

- "LEGS: The lower legs should be inclined aft of the vertical with the feet placed flat on the floor."

Forward-facing Passenger Brace Position Recommended by U.K. Civil Aviation Authority



Source: U.K. Civil Aviation Authority

Figure 1

The CAA notice also recommended that passengers wear their seat belts "as tight as possible and as low on the torso as possible."

But the CAA notice cautioned that the brace-position recommendations "may only be relevant to forward-facing passenger seats, with lap-strap restraints, in large airplanes" because the testing focused on the configurations of the B-737 in the East Midlands accident.

The CAA notice also stated that the most appropriate brace position depends on numerous factors. Those include the size and other characteristics of the passenger; the direction and strength of impact forces in the crash; the cabin configuration; the seat pitch [spacing between seats]; and the type of restraint system used in the aircraft.

Because so many seriously injured passengers survived the B-737 accident at relatively high impact, injury data from the East Midlands crash proved invaluable to researchers evaluating brace positions.

Also, the 1995 CAA report said, the East Midlands accident "provided the first example of an actual crash involving seats tested, but not certificated, to the '16G' standard."

That standard — which requires that transport-aircraft seat restraints be tested to withstand a longitudinal impact-velocity and deceleration pulse of 16G (16 times the force of gravity) — was determined by the U.S. Federal Aviation Administration (FAA), based on studies by the FAA and the U.S. National Aeronautics and Space Administration (NASA).[1]

According to the 1995 CAA report, those NASA and FAA studies "showed that, for survivable accident scenarios, the airplane structure remains substantially intact and provides a liveable volume for the occupants throughout the impact sequence" at the impact velocities studied.

Although the aircraft's structure is supposed to remain intact at such high impact velocities, the passengers inside may sustain serious or fatal injuries, depending partly on the seat-restraint system and the passengers' brace positions.

In the crash at East Midlands Airport, the B-737 was short of the runway in a "nose-high attitude" on initial impact, and the aircraft underwent the second, major impact moments later on the embankment of a highway about 230 feet [70 meters] to the west and 33 feet [10 meters] lower than the first impact. According to the report, the crash generated "high horizontal and vertical loads which approached the survivable limit." The fuselage was extensively damaged, but there was no postcrash fire, and a remarkably high number of passengers survived, but with serious injuries.

Even though the impact forces were "significantly in excess of those specified in the new standard," the report said that the seats remained substantially intact and attached to the floor in areas of the aircraft where the floor itself did not buckle or crack. Forty-seven of the 118 passengers aboard the aircraft were fatally injured; 67 passengers sustained serious injuries and four passengers had minor or no injuries. Seven of the eight crew members suffered serious injuries. Later examinations showed injuries to passengers' heads, chests, necks, abdomens, pelvises, upper limbs and lower limbs.

Analysis showed that "lower-limb injury was extremely common and that femoral fracture appeared to occur as a result of bending rather than axial-compression loading" of the femur [also called the thighbone, extending from the hip to the knee].

The pattern of injuries in the East Midlands accident led several researchers to test the impacts of varying brace positions on passengers involved in crashes of different impact velocities.

Using a decelerator testing facility with a seat configuration similar to that of the B-737 in the East Midlands crash, researcher J.M. Rowles found that positioning the lower legs of an instrumented anthropomorphic test dummy (ATD) so that they lay 12 degrees behind a vertical line through the knee "prevented flailing of the lower leg in all the conditions studied."[2] Those conditions included impacts at nine G, 16G and 20G.

Rowles' results also indicated that flailing — often involving the legs' impact against the seat ahead — tends to occur when a passenger's lower legs are positioned in front of (rather than angled behind) the knee joint.

Extending Rowles' research, P. Brownson confirmed that, at those impact levels, "the braced legs-back position avoided lower-leg flail."[3] He found that the same position was associated with the lowest risk of injury, assuming that the loads on the lumbar spine were not excessive.

In related research, the CAA and the U.K. Air Accidents Investigations Branch (AAIB) commissioned an inquiry by H. W. Structures Ltd. (in collaboration with the Nottingham, Leicester, Derby and Belfast Hospitals' Accident Study Group) into the likely causes and mechanisms of injuries to passengers on the East Midlands flight, as well as the accelerations and forces exerted on those passengers during the crash.

A 1990 report by H. W. Structures concluded that "a brace position with the lower limbs inclined slightly backwards had the potential to reduce injuries to the foot and lower leg."[4]

The CAA accepted that conclusion for the East Midlands crash, but considered that accident atypical because its impact pulse had "a high vertical acceleration caused by the secondary impact, as the aircraft moved up the motorway embankment." The agency wanted further research to determine if the legs-back brace position also could be recommended for more typical aircraft-accident impacts, which involve higher horizontal accelerations and lower vertical accelerations.

Further research was conducted during 1992 and 1993 by the Royal Air Force Institute of Aviation Medicine (IAM), which is now known as the Defence Research Agency Centre for Human Aviation Medicine, and H. W. Structures. Tests studied passenger brace positions in relation to the FAA's standard 16G pulse, considered to represent the majority of survivable impacts.

The test runs at IAM used a Hybrid III ATD. The results generally confirmed the benefits of the legs-back brace position, but indicated that there was some question about whether passengers in such a position heightened their risk of lumbar-spine injuries. Aside from the legs-back position, researchers tested dummies in the "unbraced legs-forward," "unbraced legs-back" and "braced legs-forward" positions.

To further investigate the impacts of alternative bracing positions, the CAA commissioned a series of computer simulations. At first, they used a computer model of the spine developed by Wayne State University (Ohio, U.S.), but later found that the model "was inadequate for the loading conditions experienced during a ground impact." Researchers then included the Wayne State model in an existing analytical code, called MADYMO, to create a more comprehensive model.

That computer spinal-model study "confirmed the benefits of a legs-back brace position," the report said. Specifically, the researchers drew conclusions that included the following:

- Using a brace position with the legs rearward of the vertical, as opposed to legs forward, "shows no increase in lumbar-spine loading";

- Spine axial loads, shear loads and bending moments are generally lower in the legs-back position than in the legs-forward position;

- When exposed to the 16G "dynamic test pulse," passengers wearing lap belts are "susceptible to lumbar and cervical spine injury";

- There is "little difference in results" of comparing the "arms-up" versus the "arms-down" brace positions. The only significant difference is that, in the arms-up position, there is "reduced lumbar axial loading"; and,

- The use of a forward-facing, two-point lap belt configuration "is the fundamental reason" why high loads occur on the spine during impact. "The risk of spinal injury is therefore significant in a severe aircraft impact, where this [lap belt] configuration is employed."

Other conclusions drawn from the extensive British research studies based on the East Midlands accident include the following:

- The lower legs should be inclined aft of the vertical, with the feet placed flat on the floor;

- Positioning the lower legs 11.5 degrees rearward of the vertical (as opposed to the legs-forward position) in combination with a foot-to-floor friction coefficient of 0.7 "does not show any leg flail";

- The use of high-friction carpeting "would be advantageous" because tests show such carpeting reduces leg sliding and flailing;

- Using a brace position with the tibiae [the larger of the two bones between the knees and ankles] inclined forward of the vertical "produces leg flail and knee-joint hyperextension and leads to an increase in head injury criteria and possible foot entrapment";

- In designing luggage bars, aircraft manufacturers should "recognize the possibility of foot entrapment and subsequent foot injury";

- A 32-inch (81-centimeter) seat pitch "appears to be the optimum configuration" because that pitch is "associated with a reduced injury level when adopting a brace position."

For the typical (50th percentile) occupant in the seat designs tested, "the use of seat pitches between 27 [inches (69 centimeters)] and 30 inches [76 centimeters] results in an increase" in the risk of head injuries. That is because the amount of space available for crouching down only allows "a semi-braced position." The use of higher-than-optimum seat pitches — 34 inches (86 centimeters) and 36 inches (91 centimeters) — also tended to increase the risk of head injuries;

- Future regulations for cabin and seat design should consider lower-limb injury criteria. Such design rules also should more extensively examine "femoral bending moment injury threshold limits," a criterion that researchers regard as being more important than the current 10 kN [kilonewton] axial load limit;

- Three-point seatbelt installations gave "improved restraint over the two-point lap belt installation" for forward-facing seats; and,

- Passengers in rearward-facing seat configurations are somewhat less likely to receive traumatic injury, other than facial injury from flying debris.♦

Editorial note: This article was adapted from *A Study of Aircraft Passenger Brace Positions for Impact* (CAA Paper no. 95004), May 1995, published by the U.K. Civil Aviation Authority in London. The report was prepared by Hawtal Whiting Technology Group of Leamington Spa, England, assisted by Anton, Hodges and Goodman, of Illminster, England. The 44-page report includes tables, charts and a bibliography.

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