SHARP EDGE AND PENETRATING INJURY EVALUATION AND TESTING

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Abstract - There is ambiguity in the definition of sharp edges in the testing performance requirements for aircraft seats and passenger vehicle external mirrors. The language of these requirements is vague and does not describe the methods or criteria that should be used to quantitatively determine the 'sharpness' of an edge or point. Some tools and methodologies exist to evaluate sharp edges in products intended for use by children or for surgical use, however there is a lack of information relating these to injury severity. The objective of this work is to characterize and quantify edge sharpness with respect to loading conditions and injury severity.

Keywords: Sharp edge; Penetrating injury; Porcine Skin; Aircraft Seat

INTRODUCTION

The Code of Federal Regulations (CFR) 25.785 defines the performance criteria for aircraft seats when tested under emergency landing dynamic conditions (CFR 25.561 and 25.562). Under these impact conditions it is possible that sharp edges or points can be formed due to the damage caused by the interaction between the occupant and interior structures such as the forward seatback video monitor. The regulation aims to mitigate the possibility of occupants being injured during egress by sharp edges that were formed during the emergency landing. A Memorandum (May 9, 2005) provides Federal Aviation Administration (FAA) certification policy on demonstrating compliance with the aforementioned tests. The Memorandum notes "*Sharp or injurious edges or features could cause additional injury and thus impede occupants from exiting the airplane after a crash; they are therefore not acceptable. They are not allowed as design features of airplane interiors, nor are they allowed to be formed as a result of the impact tests […]*." The language used to describe methods of evaluating sharp edges include the following:

- Visual Assessment – "An assessment of sharp or injurious edges must therefore be completed for each seatback mounted accessory, or any other potentially injurious item located within the headstrike zone to determine compliance […]"
- Visual Assessment – "Have all sharp corners been eliminated from the monitor shroud?"
- Visual Assessment – "Do in-arm video monitors break away easily without breaking off or, if they do break, are there any sharp or hazardous protrusions?"
- Visual Assessment – "The impact shall not cause the formation of any sharp or injurious edges or features that may impede egress"
- Visual Assessment – "If a seatback accessory does not show the propensity to create sharp of injurious edges when tested […] this is sufficient to find compliance for the article as installed."

Similar wording is used in the National Highway Traffic Safety Administrations (NHTSA) Federal Motor Vehicle Safety Standard (FMVSS 111) which describes the performance requirements for external mirrors. A simple visual assessment is used to "determine that all outside mirrors are free of sharp points or edges that could contribute to pedestrian injury.” It is not uncommon for vehicle or aircraft seat test labs to evaluate sharp edges by pure visual inspection or by running a finger along the edge.

Experimental testing to evaluate the response of human skin to penetrating edges and points for injury evaluation for product design began as early as the 1970s in the United States. The quasi-static force required to puncture the skin on various locations of fresh unembalmed cadavers using Moore Penetrometer Tips ranged from 32 to 105 N [1]. The impact conditions required to cut porcine skin using sheared edges with varying degrees of roughness were investigated. It was found that thinner edges and angled edges required the lowest forces and velocities to cut through the skin. Further work determined that the sharpness of an edge cannot be determined by evaluation of its gross features (i.e. edge angle and radius) and that the depth of cut is exponentially related to applied normal force [2]. It was found that the applied force required to cut through human skin ranged from 17.8 to 89 N for select machined edges (3.2 mm thick steel ground to varying edge angle/radius) while some edges were not able to cut through more than 50% of the skin thickness with 89 N. This work led to the development of testing protocols for children’s toys (CFR 1500.49) and other equipment (Underwriter Laboratories 1439). These protocols use a hand-held tool (Figure 1) to apply a constant normal force (approx. 6.6 N depending on the standard) between mandrel covered in a specified material and the edge in question. The mandrel rotates as the tool is translated across the edge for approximately 2 inches and back to the start. The test is failed if the material covering on the mandrel is fully cut, otherwise it is passed.

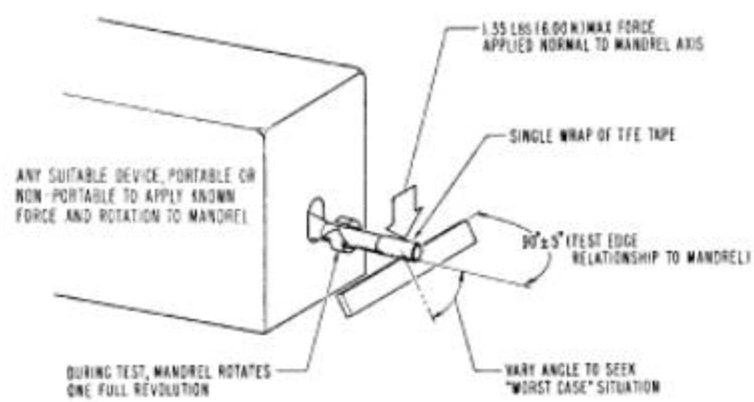

Figure 1. Principle of sharp edge test for CFR 1500.49

No known testing has been conducted to determine the response of skin to sharp edges indicative of those that could be produced under emergency landing conditions for aircraft. Though, some experiments in other areas have been performed. The onset of lacerations to the scalp due to blunt objects, e.g. hammer, wooden handle, wood floor, is between 4,149 and 5,333 N (Sharkey). Lacerations to the scalp due to impact by glass and metal edges were produced in drop tests with forces ranging from 400 to 1801 N [4].

While the testing procedures and blunt injury response requirements are clearly defined for the aircraft seat tests, there is no criteria or guidance provided to assist in determining whether an edge is considered sharp or injurious. There is an opportunity to experimentally determine the threshold for serious injury due to interaction with sharp objects formed during emergency landings. These thresholds can then be used to develop guidelines, tools, and/or injury criteria which will better inform the assessment of sharp objects in emergency landing crash tests.

METHODS

Porcine skin material was used as a surrogate for human skin due to its biomechanical and histological comparability [5]. The samples were obtained as 20 cm x 20 cm x 1.524 (± 0.254) mm sheets of non-sterile, frozen porcine skin tissue including the epidermal and dermal surfaces. This thickness roughly represents the average human facial skin thickness [6]. 25.4 x 50.8 mm specimens were cut from the larger sheets as needed and allowed to thaw at room temperature (72 deg C) for an hour prior to testing. The tests were all conducted within 10 minutes of each specimen thaw period to reduce possible degradation.

A diagram of the test setup is provided in Figure 2. Each test involved constraining the ends of a sample onto the backing surface using tape or cable ties as shown in Figure 3. The backing surface was a 127 mm diameter PVC tube meant to approximate the gross geometric shape of the face and provide a bone-like resistance behind the skin sample. For each sample a select mass was placed on the loading arm above the edge specimen and the edge was lowered on the backing surface. The backing surface was then rotated quasi-statically (approximately 5 deg/sec) under the specimen passed under the edge specimen. The specimen was then visually inspected for through-thickness cuts. If no cut was visible the procedure was repeated with additional mass until a cut was achieved. Each subsequent cut was performed on a new position on the skin specimen.

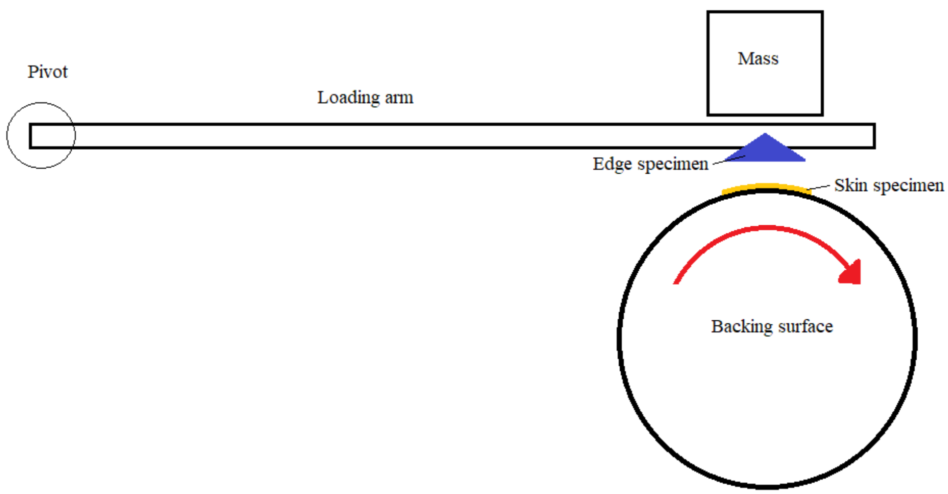

Figure 2. Diagram of test setup

Figure 3. Porcine skin specimen constrained to backing surface

For this study, a ‘serious injury’ was defined as a laceration that cut through the entire thickness of the skin sample. This simple metric was used since it relates to the laceration and penetration type injuries defined by the Abbreviated Injury Scale (AIS) to be serious, i.e. AIS 3+. These injuries include those caused by puncture, stabbing, impalement, or slicing and are classified in the AIS as “penetrating injuries.” These penetrating injuries are generally considered to be serious if they result in greater than 20% blood loss by volume or if they include penetration into the skull. Therefore, if an edge is capable of lacerating through the thickness of a skin sample it represents an opportunity to lacerate underlying arteries that could lead major blood loss [7].

Four difference edge types were assessed. These included a Razor Blade (0.025 Heavy Duty), galvanized steel hanger strap (0.5 mm thick), ABS plastic (raw broken edge), and broken glass. Razor blades were used to provide context to the results as they are known to be a sharp object. The strap was meant to represent the thin metal structures used in the design of seatback video monitor screens. The steel hanger strap was applied to the skin specimens using the manufactured edge, i.e. the long edge. It was applied in both a blunt orientation with the full thickness of the strap against the specimen as well as angled 30 deg to expose one corner to the skin specimen. The plastic edges represented pieces of seatback shrouds that can fracture during head impact. The glass edges represent the glass in the video monitors. Three specimens of each edge were tested to limit the effect of dulling after prolonged use.

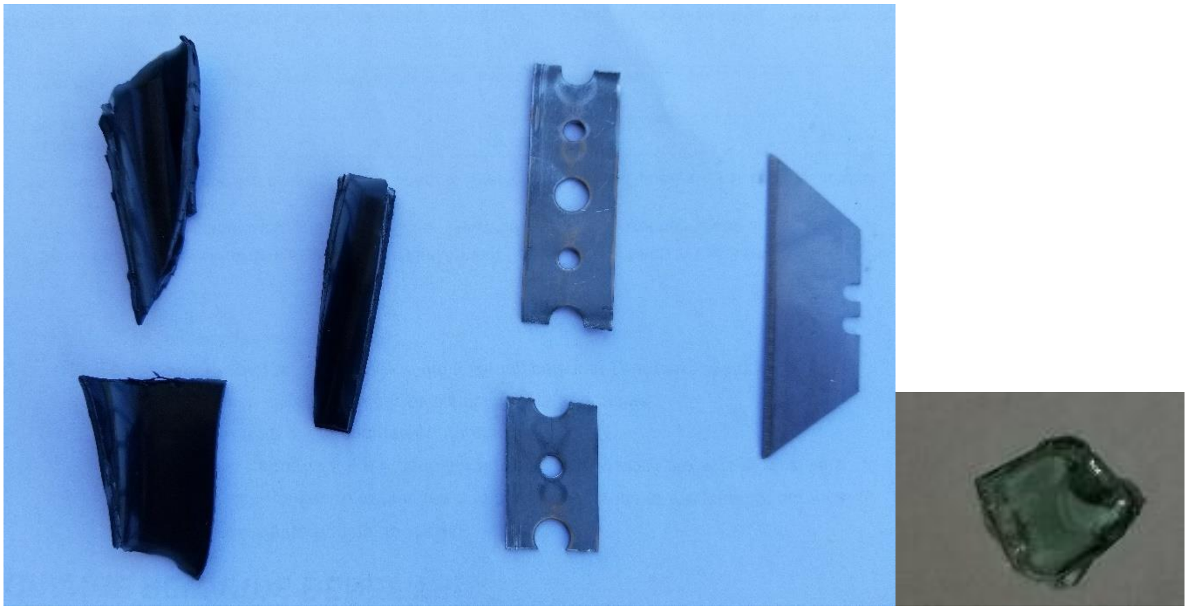

Figure 4. Edge specimens. ABS plastic with raw edge (left), steel hanger strap, razor blade, and broken glass.

Figure 5. Magnified (10 x) edge of plastic specimen.

A second series of tests using a standard synthetic material (electrical tape) instead of the skin specimens was conducted using the same procedures. This was to demonstrate the ability to assess the sharpness of edges using a common material.

RESULTS

The force required to cut through porcine skin varied with edge type as shown in Figure 6. Each edge required less force to cut through the electrical tape than the skin specimen. The Razor required the least amount of force (4.4 N) while the plastic edge was unable to cut through the specimen with less than 220 N. Testing did not go beyond 220 N as it was assumed to be an upper limit on the force a person would willingly exert against a sharp object. The steel strap required nearly double the force when oriented vertically than it did when oriented angled. The glass and angled steel strap exhibited similar responses.

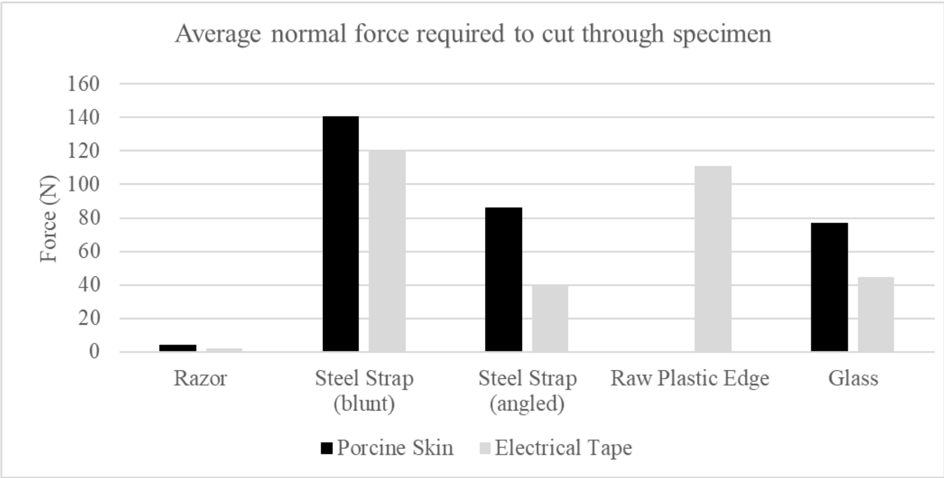

Figure 6. Force required to cut through specimen

Distinct damage patterns were created by each of the different edge specimens as shown in Figures 7 and 8. The razor blade produced the cleanest cut with no peripheral damage to the skin. The glass and steel strap produced similar damage which involved crushing of the tissue along the edges of the lacerations. The glass edge produced a slightly more ragged laceration than the steel strap. The plastic edge was unable to cut through the skin specimen and only crushed the tissue.

Figure 7. Damage patterns for cutting with glass (left), razor blade (middle), and steel strap

Figure 8. Damage patterns from plastic edge

DISCUSSION

The results of this work demonstrate the ability to identify the force required to cut through the full thickness of a skin specimen using edges representative of interior aircraft cabins. Based on the results of this study some preliminary findings can be discussed. The ability of an edge to cause a laceration is dependent on many factors including its material, geometry, reaction force, and orientation. Some materials that have the propensity to lacerate skin may not have the practical means to do so because of the way they fracture. The glass in a video monitor is a good example of this. Typically, when the glass fractures it is maintained within the screen and has limited exposure. If a piece were to become dislodged from the screen it would either have to decelerate against an occupant at over 4,000 g (based on a 2 g piece) or become lodged such that it would resist 80 N of load. Similarly, many plastic components likely lack the rigidity necessary to lacerate skin even if they had the required edge geometry. This finding suggests that in the assessment of sharp edges it may be possible to limit the assessment to certain material types.

Current methods of assessing the sharpness of edges utilize standardized and repeatable synthetic materials as the interface between the tool and the edge that provides for easy-to-use pass/fail criteria. The processes and protocols currently in place could easily be adapted to use in the aircraft seat testing arena. Using the current study as an example, electric tape would be able to distinguish between a razor blade, a steel/glass edge, or a plastic edge. One would only need to identify a threshold force and laceration relationship that would be identified as unacceptable.

While this work used a simple threshold to represent a ‘serious injury’ future work can refine these thresholds to include those types of injuries that would not only cause a serious injury as defined by the AIS, but also be relevant to those type of injuries that would significantly inhibit the egress of occupants after an emergency landing.

This work provides a preliminary look at the feasibility of defining quantitative thresholds for sharp objects within the realm of aircraft seat performance requirements. Some quantitative data that relates the sharpness of an edge to injury severity is presented. This information can be used to more accurately define test methods and criteria related to preventing injuries from sharp and edges in aircraft interior design.

LIMITATIONS

The experimental design produced conservative estimates of the force required to fully lacerate skin. The methods were used to represent loading on the thin skin of the face backed by hard bone. In other areas of the body the skin is often thicker and has a more compliant substructure that would require greater forces to produce similar levels of laceration. The testing also utilized electrical tape as an example material which may not provide a consistent performance across different test conditions due to its ability to be stretched easily and its sensitivity to temperature.

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