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Breaking the Glass Coffin: BreachPen's Effectiveness in Underwater Vehicle Extrication

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Breaking the Glass Coffin: BreachPen's Effectiveness in Underwater Vehicle Extrication

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Abstract: This study evaluates the effectiveness of the DEFCO BreachPen Gen II, a thermal breaching tool, in cutting submerged laminated vehicle glass. The research addresses the increasing drowning risks in vehicle submersion incidents due to the widespread adoption of laminated glass in side windows. The experiment involved using the BreachPen to cut a submerged laminated windscreen underwater. Results demonstrated the tool's ability to successfully breach the glass, with two cuts of 76 cm and 62 cm achieved in approximately 35 seconds each. The BreachPen proved to be six times faster than manual cutting methods. The study highlights the tool's advantages, including its lightweight design, ease of use, and suitability for remote operations. However, limitations such as limited cutting distance per unit and potential safety concerns were also noted. The research provides valuable insights for emergency responders and suggests areas for further investigation, including testing in more realistic conditions and comparing performance with alternative breaching tools.

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1. Introduction

Laminated glass, widely used in vehicle windshields, consists of two or more layers of glass bonded together with an interlayer, typically polyvinyl butyral (PVB). This construction offers several advantages over tempered glass, which is commonly used in side and rear windows [1]. The PVB interlayer in laminated glass provides superior safety by holding glass fragments together upon impact, reducing the risk of injury from shattered glass. Additionally, laminated glass offers enhanced UV protection, blocking over 99% of harmful rays, and provides better sound insulation, reducing external noise by up to 30 decibels [2]. The increase in laminated glass use as a substitute for tempered glass in side windows of motor vehicles, due to changes in safety standards, is likely to have an unintended consequence of increasing drowning rates in vehicle submersion incidents. This risk is compounded by the increase in flooding due to climate change, with more vehicle-in-flood incidents anticipated in the future.

The challenge for occupants and rescuers alike is that laminated glass does not shatter, rendering many traditional window breaching tools such as spring-loaded center punches and emergency window hammers largely ineffective. This problem has led to coining the term "Glass Coffins" referring to such vehicles as inescapable for occupants in the event of submersion [3]. New technologies such as Automatic Window Opening Systems (AWOS) have been prototyped to automatically open electric windows in the event of vehicles entering deep water [4]; however, they have not been adopted by manufacturers or vehicle safety standard-setting bodies, leaving the immediate future with no easy means to escape or rescue. The hypothesis of this study was to determine whether a simple handheld thermal breaching tool, namely the DEFCO BreachPen Gen II, is effective in cutting through laminated vehicle glass underwater, as if used by a water rescue professional attempting to create access and rescue trapped vehicle occupants.

1.1. BreachPen Gen II

The DEFCO BreachPen Gen II (herein the "BreachPen") is an advanced thermal cutting tool designed for military, law enforcement, and emergency response applications. This portable device provides a versatile solution for breaching various barriers and obstacles encountered in tactical and rescue situations. It can cut through materials such as barbed wire, chains, and some metal surfaces. The BreachPen is engineered to be explosion-resistant and can function underwater, making it suitable for diverse operational environments. Its compact size allows for easy integration into existing gear loadouts, providing tactical teams with a reliable breaching capability without significant additional weight. The BreachPen is stated to reach a temperature of 5000°F (2760°C) and is ignited using specialized matches that reach a temperature of 2552°F (1,400°C).

2. Materials and Methods

A portable pool was set up for this test and filled with approximately 40 cm of cold water (14°C/57.2°F). A tray was placed on the bottom of the pool and covered with lime chips to prevent floor damage from molten slag anticipated in the experiment. A used after-market laminated windscreen (Fuyao 43R-010242-59130FLW) typically used in a Honda Civic was horizontally placed on top of bricks (for ease of experimentation) that were then placed on top of the lime chips (figure 1). The windscreen used had several cracks, but such damaged areas were not used by any of the cuts made by the BreachPen. Water covered the top of the windscreen by approximately 10 cm. Two BreachPens were used in succession, making parallel straight cuts horizontally across the glass. The ambient air temperature was 15°C (59°F) at the time of testing.

Figure 1. Test tank.

3. Results

3.1. Thermal Cutting

The first cut resulted in a generally straight cut of 76cm (figure 3) from a burn time of approximately 35 seconds. The horizontal positioning of the windscreen likely contributed to slag build-up from the melted glass, which gave an appearance that the cut was not effective. The second cut was made again, creating a generally straight cut of 62cm (figure 3) from a burn time of approximately 35 seconds. The second cut was made slower to improve on the assumption that the first cut was made too fast and not penetrating sufficiently. However, following the two cuts, slag was found to be easily removed, and remaining binding could be easily cut through using a serrated knife (NRS Pilot). In review of underwater camera footage, it was clearly visible that the thermal cutting tool's flame jet had penetrated the glass fully. Both cuts easily cut through the glass and PVB

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interlayer, both of which have lower melting points than the BreachPen's operating temperature (Table 1).

Table 1. Material Melting Points.

	Melting Point (°C)	Melting Point (°F)
Tungsten	3,399	6,150
Titanium	1,668	3,034
Steel	1,370 - 1,530	2,500 - 2,786
Glass	1,400 - 1,600	2,552 - 2,912
Polyvinyl Butyral	185	365

Cut #1

Figure 2. BreachPen Cut #1 through submerged laminated glass.

Cut #2

Figure 3. BreachPen Cut #2 through submerged laminated glass.

Post-Cut

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Figure 4. Post-cut cut and lateral separation.

3.2. Manual Cutting (Control)

For the experiment's control, an attempt to manually cut the glass with a knife (NRS Pilot) was made afterwards on the subject windscreen, switching between using the window breaking point to spider web cracks, then chipping the glass down to the PVB interlayer, then using the serrated knife blade to make a final cut in a section then repeating. This method was timed for 35 seconds (as per BreachPen cut time) and a total cut length of 11cm was achieved in this time by comparison. Initial striking of the laminated glass using the knife's window breaking point had little to no effect other than pitting marks (figure 5). However, after sustained striking at the same point, surprisingly the glass began to break off in splinters and eventually allowed the knife to cut a small length. This process was repeated to make a continued cut length using a stitch cutting method (figure 6). Safety equipment including tinted safety glasses and leather gloves were used to prevent injury which proved a salient precaution.

Figure 5. Spider cracks caused by striking.

Figure 6. Stitch cutting using serrated knife .

4. Discussion

The BreachPen demonstrated the feasibility of gaining victim access through submerged laminated glass, confirming the hypothesis. The glass used in this experiment was a windscreen, which is typically thicker than side windows (approximately 5mm vs. 4mm). Given that side windows are more likely to be used to breach to gain victim access, it is reasonable to assume that when using the BreachPen on actual side windows (laminated), the cutting distance may be increased from what was observed. It is likely that two BreachPens may be required to make a cut length sufficient to create a glass flap or remove a full section of glass to then perform victim extraction, noting that our test results may be conservative in cutting distance given the thicker windscreen glass used and that with increased familiarity with the tool, a single BreachPen may be able to cut a sufficient distance to gain access.

The advantages of the BreachPen include its lightweight design (8 oz/230g), easy storage on a swiftwater rescue technician (length 13"/33cm), no maintenance requirements (disposable, single use), ease of use, suitability for remote area operations, and the creation of a light source during cutting. However, disadvantages noted include limited cutting distance/time (multiple BreachPens may be required), potential ignition source for fuels/spills, limited flint with risk of inability to ignite, the requirement to be ignited above water, potential burn hazard to vehicle occupants on the other side of the glass, unpredictable victim reaction, and potentially limited cost-effectiveness compared to other tools for multiple usage.

The BreachPen method was six times faster than manual cutting. Using an example of a 2004 Mazda Atenza station wagon, cut distances required to create a hinged section of glass, sufficient to allow extrication were measured (175cm for the rear windscreen and 200cm for the side window). This gave an estimated cutting time of 1.5 to 1.7 minutes for thermal cutting a laminated rear and side window respectively, and 10-11.1 minutes for manually cutting a laminated rear and side window respectively. These estimates are conservative given then are based on 5mm glass as used in windscreens, as opposed to 4mm glass that would more likely be used in laminated side and rear windows. The manual cutting effectiveness may however be decreased as rising water may dampen the physical momentum of the controlling arm and hand as it passes through water. It is likely the manual cutting technique will not be effective if used underwater.

A spring-loaded punch (Fuller Auto Centre Punch 3mm) was tested and used manually and repeatedly for 35 seconds. Pitting was observed, but no penetration was noticed on the inside of the glass. The knife (NRS Pilot) blade chisel tip was then used to chip away the glass to create a straight pilot hole, and then the serrated blade used to saw through the glass. This created a large amount of

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glass splinters and was slow to continue the cut but did at least demonstrate the ability for a well-designed rescue knife that has good serration, that cutting the glass whilst wearing protective equipment (gloves and safety glasses) can be achieved. This highlights that rescuers facing vehicle in water scenarios need to carry and be able to confidently use safety equipment that is not traditionally used by swiftwater operators except for those in cold environments where the use of gloves is often required. There may well also be benefits in using evolving respiratory protection equipment such as Swiftwater Rescue Breathing Apparatus, as this is used with swimming mask for eye protection as well as providing air supply for tool and glass management just under the water surface [5].

Figure 7. Spring-loaded centre punch testing.

It was noted the current (newer) design of the NRS Pilot knife has changed the glass breaking tip to be shorter, though this should not affect its use on toughened glass, the reduction may have a negative impact on its effectiveness on breaching laminated glass.

Figure 8. Old Version NRS Pilot Knife.

Figure 9. New Version NRS Pilot (SAR) Knife [note smaller glass breaking point at base].

While side window access is common for victim extrication, rescuers should be prepared to use the rear window, especially for bariatric and disabled casualties. Training should reflect the diversity of potential victims, rather than consistently using fit, lean, and healthy rescuers as stand-ins. This approach ensures preparedness for a wider range of real-world scenarios.

Ultimately, the best solution to our *Glass Coffin* problem is mitigation through public education discouraging driving through flood water and the factory-standard fitting of automatic window opening systems. The use of BreachPen is aimed at where these proactive measures have failed.

4.1. Alternative Options

4.1.1. Glas-Master

The Glas-Master is a patented manually operated glass removal tool designed for emergency rescuers, enabling rapid vehicle extrication without the need for electricity or hydraulics. Since its development circa 1996 it has become a common tool used by fire and rescue services around the world for vehicle extrication operations. The tool measures 420 x 245 x 35 mm (16.5 x 9.6 x 1.4 inches) with a weight of 1 kg (2.2 lb.) when ready for use. Like other large hand tools, the Glas-Master is likely to be cumbersome to swim with. Information found on the internet priced the Glas-Master at approximately USD$189 which makes it financially viable. A potential challenge for this tool is when the blade and rescuer's arm action are under water, dampening the force used and reducing the efficiency of the cut. A pilot hole must also be made for the blade to commence the cut. As this study was to review the BreachPen, a comparative analysis was not undertaken across the various tools and techniques. Such an analysis warrants further consideration.

4.1.2. Umbrella Pull

Beyond thermal cutting of the glass, other options have been identified but remain untested. These include the forcibly dislodging the laminated side window by using the BreachPen to create a pilot hole in the middle and placing a collapsible/grapnel anchor/hook (like a wall anchor or umbrella) through it and using a mechanical advantage to pull the glass panel from the frame (unlike the windscreen and rear windows which are often glued into position), however this method would be limited to situations where the vehicle is highly stable such as where it has bedded down to the flow floor such as in sand or mud otherwise the mechanical advantage may de-stabilize the vehicle and cause roll-over or a pendulum effect placing the occupants at greater risk of harm.

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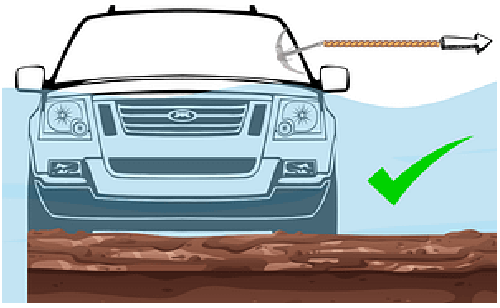

Figure 10. Side Window Umbrella Pull (stable vehicle.

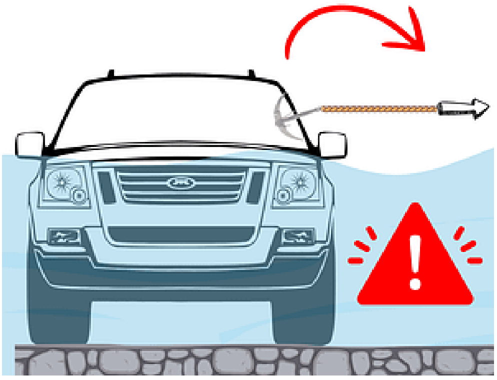

Figure 11. Side window (unstable vehicle).

Figure 12. Example of collapsible anchor.

4.1.3. BreachPen Roof Cut

Alternatively, given the vehicle roof is likely to be made of steel, cutting a section out of it to provide a means of escape may also be feasible given the metal has a lower melting point and is thinner than glass, likely to allow for a longer cut to be made. It is feasible that the BreachPen could also be used to create a hole around vehicle pillars to create anchor points for in-situ stabilization, zip line access or vehicle recovery.

4.1.4. NEMO Angle Grinder

Another option considered is the use of submersible power tools, in particular the NEMO battery-powered angle grinder and/or reciprocating saw. Both of these power tools are waterproof down to 50m as they are often used in commercial diving. They are considerably more expensive,

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heavier and bulkier than the BreachPen, but have removeable rechargeable batteries (that can be changed under water) providing a significant improvement in cutting time. As the NEMO angle grinder and reciprocating saw are reasonably heavy (2.9 kg/6.39 lbs. and 3.5kg/7.7 lbs., respectively) they will create a significant reduction in rescuer buoyancy if carried, given the minimum standard for PFD floatation under the US Coast Guard criteria is 15.5 lbs. (7 kg). These power tools, however, could be carried in positively buoyant boxes or bags (i.e. fitted with floatation foam) to counter the buoyancy reduction.

Refer NEMO proudct video: https://youtu.be/aLFJF-Y0s6c

4.1.5. Beluga Glass Cutter

In discussions with extrication specialists, the Beluga Glass Cutter was raised as a solid alternative (kit is USD$535). We have not tested the device, but it does require a drill which raises the limitation of portability like the NEMO Angle Grinder. As a specialist tool, it looks very promising but given the study's working environment, a drill would need to be waterproof like the NEMO battery operated drill (5m drill is USD$735). That begs the question if you were to get a NEMO battery drill and Beluga kit, why not get the angle grinder which can be more versatile. No information could be found if the Beluga Glass Cutter is waterproof, however this may be only limited by the lack of waterproof battery drills (as NEMO is the only one, we could find that looked appropriate).

Refer Beluga product video: https://youtu.be/d9Tkrl8QVBE?si=5GSleUkfqS8aw5xM

The range of potential options need further testing, and their suitability will be very dependent on the context it is used in. No single tool or method appears to be the *silver bullet* for the challenge of *Glass Coffins*.

Table 2. Product comparison.

Tool	BreachPen	NEMO Angle Grinder	NEMO Reciprocating Saw	Rescue Knife (C)
				
Cost (USD)	$119	$2,911	$2,251	$79
Weight (Imperial)	8 oz	6.39 lbs	7.7 lbs	3.5 oz
Weight (Metric)	230 g	2.9 kg	3.5 kg	100 g
Length (Imperial)	13 inches	15 inches	20.5 inches	7.38 inches
Length (Metric)	33 cm	38 cm	52 cm	18.75 cm
Side Window Breach	>2-3 units required	Yes	Yes, once pilot hole made	Slow
Side Window Umbrella	Yes	Not applicable	Not applicable	Not applicable

Rear Window Breach	>3-4 units required	Yes	Yes, once pilot hole made	Slow
Start Under Water	No	Yes	Yes	Limited
Operate Under Water	Yes	Yes	Yes	Limited
Cut Effectiveness	Okay	Likely to be excellent	Likely to be excellent	Poor
Cut Speed	117 cm/min	Not tested	Not tested	18 cm/min
Cut Example (Rear)	(1.5 mins, 3 units)	-	-	10 mins
Cut Example (Side) 200 cm	1.7 mins (3-4 units)	-	-	11.1 mins

Limitations & Further Research

A limitation of this study was the experiment's design to opt for a horizontal placement of the glass underwater, which may have inhibited the efficiency of the thermal cutting tool as slag pooled on the top, unable to fall away under gravity. Future testing should involve more realistic conditions such as a laminated side window in a vehicle door frame that is submerged vertically, rather than using a windscreen and being tested in a horizontal configuration. Rear window breaching testing should also be undertaken to better understand the complexities of extricating bariatric, disabled or pregnant casualties that otherwise may not be able to exit via a side window.

Alternative breaching tools such as the Glas-Master, Beluga Glass Cutter, NEMO Angle Grinder and NEMO Reciprocating Saw should be tested in water and compared in future studies to provide a comprehensive evaluation of available options for water rescue professionals.

5. Conclusions

The DEFCO BreachPen Gen II proved effective in breaching submerged laminated glass, confirming its potential as a viable tool for water rescue professionals. The experiment demonstrated that the BreachPen could create sufficient cuts to allow access for victim extraction, even through thicker windscreen glass. While the tool shows promise, considerations such as the need for multiple units, potential burn hazards, and cost-effectiveness require further evaluation. Manual cutting where time constraints are not critical is possible, conditional to the rescuer being familiar with the stitch cutting method, a suitable rescue knife that features a serrated blade and window breaking point is used, and the cutting area is not underwater. Future research should focus on testing the BreachPen in more realistic conditions and comparing its performance with alternative breaching tools. Knife designers need to take into consideration the new challenge of rescue from vehicles fitted with laminated glass such as ensuring sufficient serration and depth of glass breaking tip. This study contributes valuable insights to the ongoing challenge of improving safety in vehicle submersion incidents and highlights the need for continued innovation in rescue technologies.

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