

Ballistic Testing of Motorsport Windshields

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ABSTRACT

Since its inception in 1948, NASCAR® (National Association for Stock Car Auto Racing, Inc) has continually strived to promote and improve driver, crew and spectator safety. As the vehicles used in NASCAR have changed over the years, their windshields have evolved also. The 1948 NASCAR Rulebook specified that all cars must have safety glass. In 2013, the NASCAR Sprint cup Series will use a laminated polycarbonate windshield. This paper describes the ballistic testing of the latest polycarbonate laminated design as well as previous monolithic polycarbonate designs.

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INTRODUCTION

Modern windshields in passenger car vehicles are generally made of laminated safety glass. Windshields protect passenger car vehicle occupants from flying debris such as dirt, trash, insects and rocks. Windshields in passenger car vehicles have changed from ordinary window glass, to tempered glass to laminated glass. Current passenger car vehicles have windshields which also serve as a structural component of the vehicle.

While there are safety requirements for passenger car vehicle windshields, they primarily relate to limiting the displacement into the windshield area of vehicle components and windshield retention during frontal impacts [1, 2].

For the National Touring Series NASCAR has always incorporated a complete windshield mounted in a steel frame to protect the driver. As the personal safety equipment in NASCAR has progressed and changed with improvements and innovations over time, so too has the windshield. A brief timeline of the major NASCAR windshield rule changes are shown in [Table one](#).

Similar to passenger car vehicles, the windshield in a stock car serves comparable purposes. While normal on-track debris can include trash such as paper, dirt, rubber and insects, it can also include larger, denser pieces of debris. These pieces of debris are occasionally the result of on-track incident involving contact between vehicles and/or the track retaining walls. Examples of possible types of debris from these incidents include wheel assemblies, body panels such as hoods or deck lids, rear coil springs, or pieces of broken brake rotors. Much effort has been focused on retaining these types of components. NASCAR requires that each National

Touring Series vehicle be equipped with tether systems to reduce the risk of debris detaching from the vehicles. Specifically, each front wheel assembly is tethered to the vehicle chassis with redundant front spindle tethers. Redundant tether assemblies are also required on the hoods and deck-lids. When used, items such as onboard television broadcast cameras located in the rear vehicle fascia are tethered to the vehicle chassis. Rear coil springs are also tethered between the chassis and rear axle.

Table 1.

Year	Rulebook wording
1948	All cars must have a full windshield in place and used as a windshield. No glass or material other than safety glass may be used.
1988	A full 1/8 inch Lexan Plastic (polycarbonate) #FMR-104 windshield may be installed beneath the full laminated glass windshield.
2000	Only approved standard production 1/4 inch thick hard-coated polycarbonate windshields will be permitted.
2013	Only approved standard production 1/4 inch thick laminated hard-coated polycarbonate windshields will be permitted.

However, some types of debris cannot be secured to the chassis in this manner, such as broken pieces of brake rotor. Further, debris such as full aluminum beverage cans, originating from spectator areas and birds may pose potential strike hazards to the windshields.

[Figure one](#) shows the damage to a monolithic NASCAR vehicle windshield after it struck a broken piece of brake

rotor while at speed on the race track. The debris originated from a vehicle contacting the retaining wall ahead of the vehicle shown in [Figure one](#).



Figure 1.

While no driver injuries have been sustained from debris striking the windshield, an opportunity for improvement was identified, pursued and implemented for the 2013 NASCAR racing season.

DISCUSSION

Ballistic Test Setup

As shown in [Table one](#), from 2000 through 2012 NASCAR vehicles were required to use a ¼ inch thick hard coated polycarbonate windshield. The typical properties for this polycarbonate material are shown in [Table two](#).

This windshield had an actual thickness of 0.236 inches and was a solid monolithic polycarbonate extrusion. Flat planks of polycarbonate were then formed, coated, trimmed and drilled for use in NASCAR. For the purposes of this paper, this 2000-2012 monolithic windshield will be referred to as the baseline windshield.

While standardized impact testing protocols are available, an adapted version, specifically designed to analyze the challenges presented in motorsports was developed [3, 4]. Ballistic testing of the baseline and new laminate prototype windshields was conducted.

The test windshields were stationary and test projectiles were propelled at the windshields using compressed air. Windshields were tested when installed in both actual vehicle windshield beds as well as a rigid windshield bed test fixture.

[Figure two](#) shows the pneumatic cannon and rigid windshield test fixture.

Table 2.

Property	Value
Tensile Strength, Ultimate	9,500 psi
Tensile Strength, Yield	9,000 psi
Tensile Modulus	340,000 psi
Elongation	110%
Compressive Strength	12,500 psi
Compressive Modulus	345,000 psi
Instrumented Impact @ 0.125" (ASTM D3763)	>46 ft-lbs
Shear Strength, Ultimate	10,000 psi
Shear Strength, Yield	6,000 psi
Coefficient of Thermal Expansion	3.75×10^{-5} in/in/°F
Brittleness Temperature	-200 °F



Figure 2.

To conduct a test the appropriate size barrel was installed and a projectile loaded. The barrel was connected to the pressure vessel with a two inch flexible hose and in-line two inch butterfly valve. The butterfly valve was modified to be sprung open. The valve was held in the closed position by a pin. The pressure vessel was charged with compressed air to the appropriate pressure. A lanyard was used to remove the pin, which released the spring, opened the valve and allowed pressure transfer to the barrel. Barrel length and initial pressure were tuned to acquire the desired projectile test speed of 200 mph. High speed video recorded at 2,000 frames per second was used to determine projectile velocity at the barrel exit.

Aluminum Beverage Can Ballistic Testing

Using the test method described above, full aluminum beverage cans were propelled at the baseline monolithic windshields at 200 mph (293.3 fps). These windshields were installed in a 2011 NASCAR Sprint Cup car and a 2011 NASCAR Camping World Truck. The baseline windshield car has a nominal windshield angle of 30° from horizontal.

The baseline windshield truck had a nominal angle of 37° from horizontal. Several tests on both the car and truck were conducted. [Figure three](#) and [four](#) show a single high speed video frame of the impacts for the car and truck, respectively.



Figure 3.



Figure 4.



Figure 5.

During the aluminum beverage can testing it was observed that the can tumbled significantly prior to impact with the windshields. It was also noted that the cans ruptured within the first millisecond of contact with the windshields,

prompting immediate venting of their fluid mass. None of the aluminum beverage can tests resulted in passage of projectile shrapnel or liquid into the interior of the vehicles. However, the baseline monolithic polycarbonate windshields sustained fractures in all tests. [Figures five](#) and [six](#) show the resulting fractures from the impacts shown in [Figures two](#) and [three](#), respectively. Note the red "X" inside the red circle in [Figure five](#), marking the impact location.



Figure 6.

[Appendix A](#) shows high speed video frames of the car testing and [Appendix B](#) shows high speed video frames of the truck testing.

Steel Projectile Ballistic Testing

A rigid steel windshield frame was constructed to serve as a test bed for the windshields. This fixture allowed for quick angle adjustments and was robust enough for repeated tests. This fixture is shown in [Figure seven](#).



Figure 7.

For this testing, the end of the barrel was placed 22 inches from the surface of the windshield. This distance allowed for projectile speed measurement just prior to contact with the windshield. Projectile attitude at windshield contact was very repeatable. The projectile used for this testing was a solid steel slug made from nominal $1 \frac{1}{4}$ outer diameter mild carbon steel bar stock. Slugs were saw cut to 2.5 inches long. The striking end of each slug was then faced in a lathe, prior to weighing. Slugs used for the testing weighed 0.86 lbs. At 300