

Closed Wheel Race Vehicle Aerodynamic Lift-Off

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ABSTRACT

Although, the implementation of lift-off prevention devices such as the NASCAR roof flaps have greatly reduced the frequency and severity of race vehicle aerodynamic lift-off incidents, airborne incidents still occur occasionally in motorsports. The effectiveness of existing lift-off prevention measures and future trends in lift-off prevention are addressed in this paper. The results and analysis presented in this paper will be of paramount interest to race vehicle designers and sanctioning bodies because the effects of aerodynamics on vehicle lift-off need to be comprehended, but there exists a scarcity of reliable data in this area.

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INTRODUCTION

On lap 2 of the 1987 Winston 500 at Talladega Superspeedway Bobby Allison's NASCAR racecar blew a tire at high speed, spun sideways, became airborne and impacted the catch fence (Figure 1). Significant damage to the catch fence and racecar resulted. Although there have been other airborne incidents before and since, this event comes to mind for many people in motorsports when discussing aerodynamic lift-off of race vehicles. In the decades since this incident, sanctioning bodies and racecar designers have pioneered and implemented design changes and devices such as the NASCAR roof flaps to reduce the severity and frequency of race vehicle airborne incidents. The objective of this paper is to revisit original innovations, discuss more recent design changes, and propose a course for future developments.

This paper begins with an overview of NASCAR lift-off testing. Next, the effectiveness of selected vehicle lift-off improvements are demonstrated and discussed, and finally, suggestions for future research are discussed.

TESTING

NASCAR is committed to advancing the safety of automobile racing and has been a leader in preventing race vehicle aerodynamic lift-off. NASCAR has conducted more than 200 hours of lift-off testing at four different wind tunnels in the past 15 years. During the development of the latest version of the NASCAR Cup racecar, the Generation 6 racecar introduced in February of 2013, a dedicated lift-off testing vehicle was constructed and utilized.

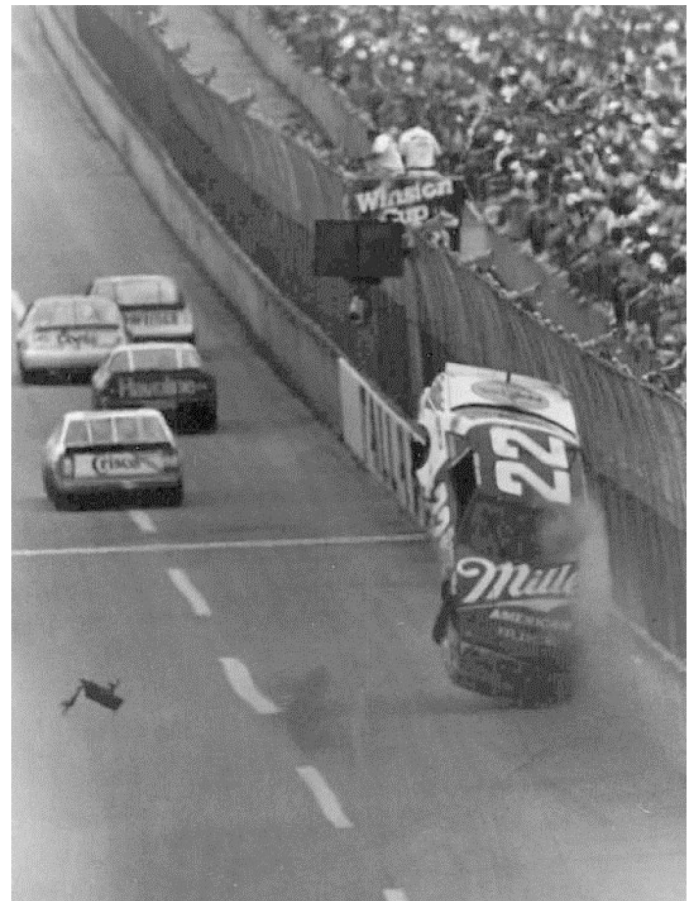


Figure 1. 1987 Talladega Incident [1].

The first lift-off testing with a NASCAR racecar was conducted at the GM Aerodynamics laboratory in 1984; see Nelson et al.[2] for details. One early lift-off test actually was conducted at an airfield using thrust from a private jet to produce the airflow to test the deployment of antilift devices [2]. However, in recent years, NASCAR has conducted much of its lift-off testing at the full scale Aero-Acoustic Wind Tunnel (AAWT) located at the Chrysler Scientific Laboratories in Auburn Hills, Michigan. All wind tunnel data presented in this paper were acquired at the Chrysler tunnel over multiple test dates. Table 1 summarizes the specifications of the Chrysler tunnel; Figure 2 shows a schematic diagram of the tunnel [3].

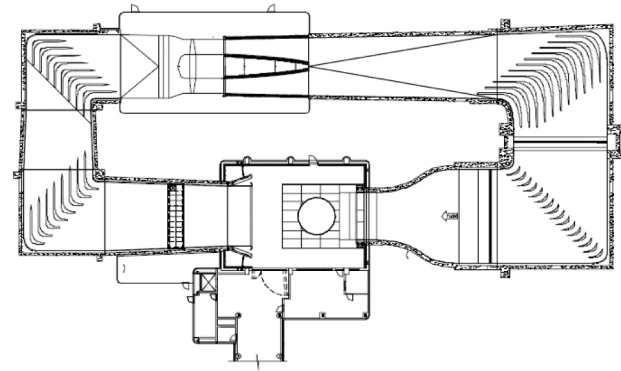


Figure 2. Chrysler AAWT Wind Tunnel [3].

The tests covered yaw angles ranging from 0 to 180 degrees in the positive and negative directions. On track experience suggests that the majority of NASCAR spin outs are counterclockwise, hence the negative yaw range is used mostly. Figure 3 is a view of a NASCAR vehicle being tested at the Chrysler tunnel at a yaw angle of approximately -140 degrees with roof flaps deployed. The red arrow superimposed onto the photo shows the nominal airflow direction.



Figure 3. NASCAR Vehicle in Chrysler Tunnel; the red arrow indicates the nominal airflow direction.

There are two main types of testing conducted at the wind tunnel related to lift-off: (1) balance data acquisition and (2) device deployment testing. Wind speed is typically 120.7 km/h for balance data acquisition runs and 136.8 km/h for device deployment runs. For balance data acquisition runs, with the roof flaps closed, the roof flaps are taped shut. For balance data acquisition runs with the flaps opened, the roof flaps are propped open with rods.

For the majority of balance data acquisition runs, 30 seconds of data per yaw angle are acquired at 10 Hz and averaged. For some balance data acquisition runs presented in this paper (Figure 4 only), balance data are acquired in a continuous manner; data are sampled at 4 Hz while the vehicle yaws at 1 degree per second.

Table 1. Chrysler AAWT Specifications [3].

Test Section Type	Open Jet, Static ground
Nozzle/Test Section Dimensions	4.0m high x 6.9m wide x 15.9m long
Nozzle Area	27.9 m ²
Nozzle Contraction Ratio	5.4:1
Boundary Layer Control	Suction scoop, tangential blowing
Boundary Layer Displacement Thickness	$\delta^* = 3$ mm at front of vehicle; 2.5m forward of the balance center
Balance System	6 component, mechanical
Fan	Single 12-blade fan, 8 m diameter
Fan Drive System	Variable speed, AC electric motor
Top Speed	>260 km/h

VEHICLE LIFT-OFF IMPROVEMENTS

NASCAR Roof Flaps

The NASCAR roof flaps, which were implemented in February of 1994, are the most notable improvement aimed at preventing vehicle lift-off. Compared to the same vehicle without roof flaps, the normalized lift coefficient is reduced by approximately 30% during a spin. The roof flaps which are passively deployable spoilers can be seen in the deployed position in Figure 3. Air pressure difference between the top and bottom side of the roof flaps initiates deployment during a spin. Figure 4 is a plot of normalized CL vs. yaw angle for a NASCAR vehicle with roof flaps closed (orange trace) and roof flaps deployed (blue trace). For this test, data were acquired at a constant yaw rate of 1 degree per second. Acquiring aerodynamic data in a continuous manner will be covered in future publications.

The roof flaps deployed run plotted in Figure 4 commenced at -90 degrees of yaw. This yaw angle was chosen for the start point since the flaps on this particular vehicle series typically do not deploy until -90 degrees or later in the spin. To acquaint the reader with the yaw

angle sequences, images of a vehicle in the spin cycle corresponding to each yaw angle are also displayed in [Figure 4](#). At zero degrees, the vehicle is traveling straight ahead; at -90 degrees, the vehicle is sideways, and at -180 degrees, the vehicle is backwards. The red arrow in [Figure 4](#) shows the wind direction.

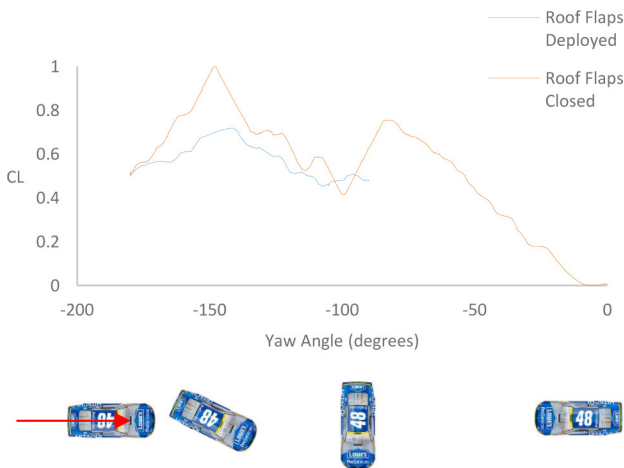


Figure 4. Normalized CL vs. Yaw

Right Roof Flap Plan View Angle Study

During the development of the NASCAR Generation 6 racecar, wind tunnel tests to determine the optimum plan view angle of the right roof flap were conducted. It was hypothesized that an optimum design angle for early flap deployment (early in the spin/yaw range) as well as lift reduction would exist. Ideally, the design angle for the largest lift reduction would be the same angle at which the flaps opened the earliest. Four different right roof flap design angles were tested:

- 0-degree
- 25-degree
- 35-degree
- 45-degree (Baseline)

The rectangular outline of these flaps overlaid on each other are displayed in [Figure 5](#). Since the inception of the roof flaps, the right side (passenger side) roof flap has been oriented such that the back edge of the flap is nominally perpendicular to the air flow at a yaw angle of -135 degrees (labeled as Baseline Right in [Figure 5](#)). Since balance data acquisition and device deployment testing (to determine the yaw angle at which the flaps open during a spin) would be conducted, fully operational flaps rather than simple sheet metal appliques were required. As such, four roof modules with fully operational flaps corresponding to each right-hand flap angle were constructed and installed on the NASCAR lift-off test vehicle. [Figure 6](#) displays the NASCAR Lift-off Test Vehicle with the 0-degree roof flap module installed in the deployed state. For the Generation 6 flap development, one of the goals was to trigger flap deployment earlier in the spin cycle to slow the vehicle velocity and spin rate. It was

postulated that the 0-degree right flap angle would open earlier in a counterclockwise spin. Many observations of the left flap (which has been at zero degrees since the inception of the roof flaps) opening very early in a clockwise spin on the racetrack led to this hypothesis. Flap deployment tests in the wind tunnel confirmed this hypothesis that a 0-degree right flap would in fact open earlier. [Table 2](#) displays the results of the flap deployment runs. Flap deployment angle is determined by simply observing the yaw angle displayed on the digital readout at which the right-hand flap opens. However, it must be noted that the velocity (136.8 km/h) and spin rate (1 degree/sec) used in wind tunnel testing are typically lower than what the vehicle encounters on the racetrack, but currently this is the best simulation available. As recorded in [Table 2](#), the 0-degree right side flap opened much earlier than the other configurations. It was expected that each successive higher right hand flap angle would open progressively later and later in the yaw angle range. Contrary to this expectation, as shown in [Table 2](#), this was not observed. The 25, 35, and 45 degree right hand flap designs all opened at about the same yaw angle (~ -135 degrees). Through this analysis it was suggested that the likely reason for the 0-degree right hand flap configuration opening early in the spin cycle is due to the high amount of lift produced on the leading edge (during a spin) of the flap that extends down over the edge of the roof where the roof curvature is high. The leading edge of the 25, 35, and 45 degree designs are located in an area of the roof that has very low curvature. See [Figure 7](#) for further explanation.

Next the acquired balance data were analyzed for each of the roof flap modules. Normalized rear lift coefficient, CL_R vs. yaw angle for each of the four right roof flap design angles are displayed in [Figure 8](#). Rear lift correlates very well to right roof flap design angle. The higher the design angle, the lower the rear lift. Due to its effectiveness at reducing rear lift, the 45-degree Right Hand Flap Design was chosen for the final design. This decision was not trivial and was made rather late in the design process. The ability of the 0-degree flap design to open early was very attractive. Opening the right-hand flap early to slow the vehicle velocity and the spin (yaw) rate are very desirable features. To obtain the goal of an early opening right hand flap, the idea to extend the edge of the 45-degree flap into the area of high roof curvature was proposed. This design change to the 45-degree flap produced the desired early opening event. In fact, the extended 45-degree flap design was observed to open at -30 degrees of yaw in the wind tunnel. In [Figure 9](#), the red lines show the extended portion of the original 45-degree flap. The extended 45-degree design opens early and results in the most lift reduction compared to the other designs.

In more recent roof flap deployment testing, instead of relying on observations of the roof flaps opening to determine the deployment yaw angle, load cells were attached to the bottom of a roof flap (with the roof flap in the closed state). [Figure 10](#) displays some of this load cell data which were acquired at -136.8 km/h and then scaled to 289.7 km/h to obtain representative track loads. Although the force peaks do not correspond exactly, it is worth noting that the force curve in