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Effect of Halo Protection Device on the Aerodynamic Performance of Formula Racecar

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Abstract**—**This paper explores the aerodynamics of the formula racecar when a 'halo' driver-protection device is added to the chassis. The halo protection device was introduced at the start of the 2018 racing season as a safety measure against foreign object impacts that a driver may encounter when driving an open-wheel racecar. In the one-year since its introduction, the device has received wide acclaim for protecting the driver on two separate occasions. The benefit of such a safety device certainly cannot be disputed. However, by adding the halo device to a car, it changes the airflow around the vehicle, and most notably, to the engine air-intake and the rear wing. These negative effects in the air supply to the engine, and equally to the downforce created by the rear wing are studied in this paper using numerical technique, and the resulting CFD outputs are presented and discussed. Comparing racecar design prior to and after the introduction of the halo device, it is shown that the design of the air intake and the rear wing has not followed suit since the addition of the halo device. The reduction of engine intake mass flow due to the halo device is computed and presented for various speeds the car may be going. Because of the location of the halo device in relation to the air intake, airflow is directed away from the engine, making the engine perform less than optimal. The reduction is quantified in this paper to show the correspondence to reduce the engine output when compared to a similar car without the halo device. This paper shows that through aerodynamic arguments, the engine in a halo car will not receive unobstructed, clean airflow that a non-halo car does. Another negative effect is on the downforce created by the rear wing. Because the amount of downforce created by the rear wing is influenced by every component that comes before it, when a halo device is added upstream to the rear wing, airflow is obstructed, and less is available for making downforce. This reduction in downforce is especially dramatic as the speed is increased. This paper presents a graph of downforce over a range of speeds for a car with and without the halo device. Acknowledging that although driver safety is paramount, the negative effect of this safety device on the performance of the car should still be well understood so that any possible redesign to mitigate these negative effects can be taken into account in next year's rules regulation.

Keywords**—**Automotive aerodynamics, halo device, downforce. engine intake.

I. INTRODUCTION/BACKGROUND

THE halo protection device (Fig. 1) was introduced to Formula One racing in 2018. The device is a T-shape multi-joint CNC-and-welded titanium hoop beam assembly that protects the driver's head in the event of flying debris or collision with stationary objects [1]. The device is mandated by FIA, the governing body of formula racing series, and is manufactured by CP Autosport in Germany [2]. The halo protection device is delivered to each race team and integrated into their car. Cosmetic changes are allowed in terms of paint color, and just this past year, small aero deflector that does not alter the structural performance of this safety device. The requirement to carry this bulky safety device has been both lauded and criticized in the racing community. Supporters and pundits each have valid arguments for allowing or excluding the use of this device [3], [4]. One example is that it takes away the true spirit of open-wheel racing that is inherently risky. Another argument is that the halo device is strong enough to hold up a London bus. This paper aims to provide a scientific study of the halo effects, both positive and negative, in the specific area of aerodynamics.

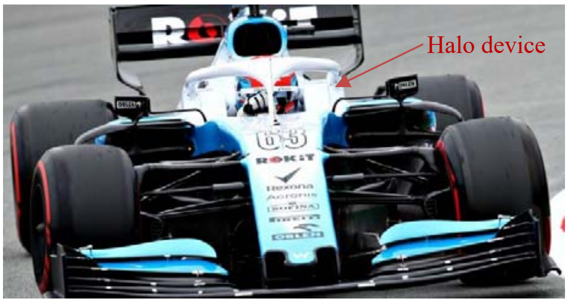

Fig. 1 2019 Formula One racecar geometry [5]

II. PROBLEM DESCRIPTION

Given the geometry of a current formula racecar, the problem is to analyze the aerodynamic behavior with and without the halo protection device using computational fluid dynamics (CFD). The question that is answered here is: is the change in airflow good or bad for the car in terms of vehicle performance parameters that are important in racing?

Some assumptions that were made in this study include: 1) In yaw simulation, while the car is rotated with respect to the vertical axis, the airflow is assumed to be linear and not curved. A 7-degree turn yaw angle is analyzed. 2) Temperature is assumed constant, while on a real track the temperature will vary as air passes over the car. 3) In yaw sim, the car is assumed to have no roll, while in reality the car will roll to the opposite side of the turn causing the floor of the car to deviate from being parallel to the ground. 4) In the model, any airduct internal to the car is not modelled, because this is a first order study. The engine air intake is modelled as an empty passthrough without engine components. A more realistic simulation model would have this boundary modelled as a passthrough with some dependence on vehicle velocity

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and engine operation.

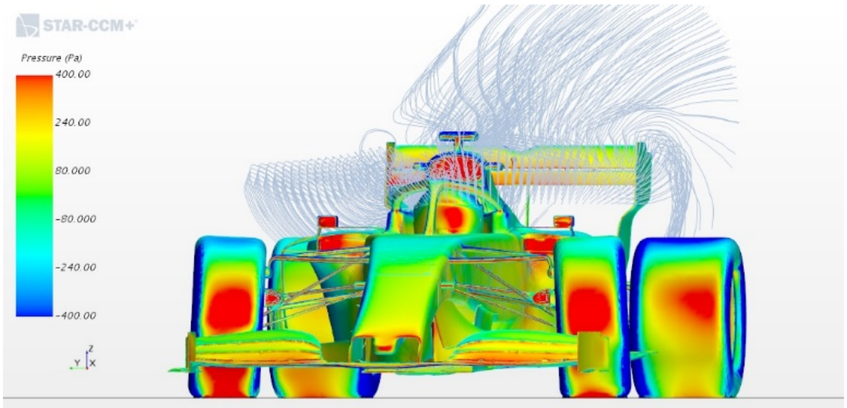

Fig. 2 CFD computation pressure profile and streamlines at 7º yaw

III. Case Setup

Two models are setup with their corresponding mesh generated and solved for a range of flow velocities. The two models are 1) a car with the halo device 2) a car without the halo device. For both cases, the base geometry starts from importing a 3D CAD model provided by N. Dhillon and used here with permission [6]. In the no-halo case, the model was modified in CAD first to remove the halo device and add a driver model before it was imported into CFD [7]. The geometry is then manipulated to isolate (or segregate) the wheels, the engine cover, and the rear wing so different parameters can be extracted during analysis. The wheels are segregated so that a rotational velocity can be applied to create a rotating wheel boundary condition, and that the front wheels can be turned 7 degrees for the yaw simulation. The engine cover is segregated (using split-by-patch), so that a separate zone can be created to measure air intake mass flowrate. The rear wing is segregated so that the downstream effect of the halo device can be measured in terms of affected downforce. For the yaw simulation that is performed later, the entire car model is rotated 7 degrees in the horizontal plane with respect to the incoming freestream.

Fig. 3 2019 Formula One racecar geometry [8]

A third model is run in this research, to study the effect of the halo protection device on the DRS (Drag Reduction System) which is comprised of the upper flap of the rear wing. The DRS system was introduced 7 years earlier in 2011 and it allows the upper flap of the rear wing to be “opened” during certain segments of the race to assist in overtaking. When the DRS flap is opened, less drag and as a result less downforce is produced by the rear wing. In the model, the DRS flap is segregated into a separate zone and rotated about its axis to give it a zero-degree of angle-of-attack (AoA α). The predicted downforce reduction can be compared for both the case with and without the halo protection device being present.

All models are meshed and ran using a commercial CFD software Star-CCM+ made available by Siemens AG. Because this is a complicated geometry with surface geometries present in the CAD model, a water-tight meshing scheme would not be possible; instead a fault-tolerant meshing scheme was used to successfully generate a cut-cell mesh [9]. As a way to improve the mesh quality, contact prevention was specified at places where there are small gaps that need to be simulated (e.g. gap between wing flaps). Prism layer is added along the car body to create inflation to capture boundary layer growth. For solving the mesh, SST κ–ω model is used to model turbulence. Since Reynold’s number here ranges from 7,000,000-35,000,000; the flow is fully turbulent even at the lowest speed that’s simulated (40 mph). Segregated flow (a.k.a. pressure-based) model is used because the Mach number is less than 1 so the fluid is assumed to have constant density. Transient effects are not considered in this study, so the problem is run as steady state.

IV. Results & Discussion

After performing five runs with different freestream velocity for each of the two models, plus an additional run for yaw simulation at maximum allowed wind tunnel velocity of 50 m/s, the results are tabulated in Tables I and II. These results are output from the CFD runs, compiled by creating reports in downforce and air intake mass flowrate. From Table I, the effect of the halo protection device on the rear wing can clearly be seen: with the inclusion with the halo device, airflow is diverted away from the rear wing, causing the rear wing to generate less downforce than it would otherwise. This is true at every velocity, with the effect being most prominent at the highest velocity (200 mph).

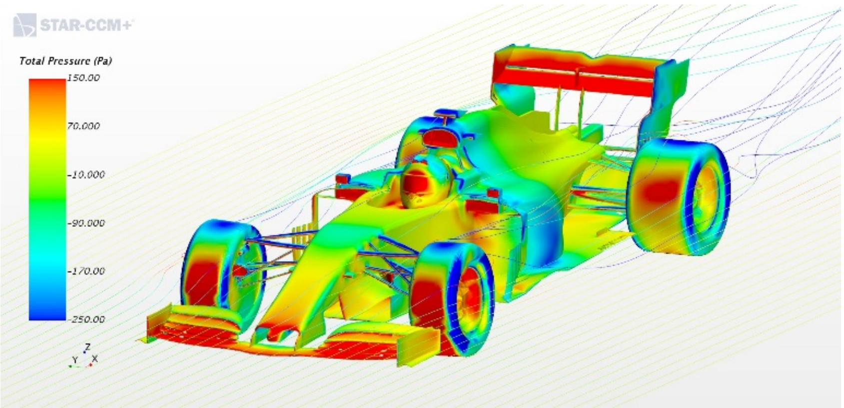

Fig. 4 Pre-2018 racecar geometry without halo device

Table II shows the halo device's effect on air intake mass flow. In this case, air is diverted by the halo device away from the engine air intake. With less airflow, this would decrease engine efficiency and ultimately result in lower power output. An analogy can be drawn with another race series: Formula SAE. In that series the air intake restrictor on the car is limited to a smaller diameter to make the design more challenging and the competition fair [10]. In the CFD model, the engine air intake was modelled as an open area instead of a blockage wall so that the flux passing through can be measured. From the results, one explanation for the lower flux seen in the case with the halo device is that airflow is diverted away from the engine intake through turbulence and vortex formation, while the design of the air intake has not changed since the halo device was introduced in 2018.

The engine air intake is simulated by first defining a region enclosed by the opening in the cowling above the driver's helmet. The same boundary condition is applied to this region as the computational domain's back surface (i.e. air outlet). This *pressure_outlet* boundary condition will create an empty hole to allow air to numerically escape. Air can pass through this surface instead of being blocked by a physical wall. Because airflow into the intake and through the engine compartment is complicated, that part of internal flow is not modeled. The numbers computed here simply represent the upper bound of the maximum airflow that can be fed into the engine air intake.

TABLE I
REAR WING DOWNFORCE

Speed	With halo device	Without halo device
40 mph	18 lbf	19 lbf
67.1 mph[a]	50 lbf	54 lbf
100 mph	115 lbf	120 lbf
150 mph	257 lbf	277 lbf
200 mph	477 lbf	493 lbf

TABLE II
AIR INTAKE MASS FLOWRATE

Speed (mph)	With halo device	Without halo device
40 mph	17.3 kg/m^2/s	17.9 kg/m^2/s
67.1 mph[a]	29.7 kg/m^2/s	30.5 kg/m^2/s
100 mph	44.1 kg/m^2/s	45.6 kg/m^2/s
150 mph	65.9 kg/m^2/s	70.3 kg/m^2/s
200 mph	88.9 kg/m^2/s	93.4 kg/m^2/s

[a] 67.1 mph is equivalent to 30 m/s which is based on 2019 F1 Sporting Regulation [11] for RWTT (Restricted Wing Tunnel Test) that states the maximum WT speed should be no more than 50 m/s and the maximum scale model size should be 60%.

In Fig. 7 the flow field is plotted. Clean air comes into the car and is disturbed and diverted as it meets the halo device in front of the driver's helmet. The flow slows down and vorticity is increased as it enters the engine air intake. After air passes the engine air intake it is diverted to left and right behind the driver, and very little of it goes into the center region of the rear wing. The little "v-notch" in the middle of the DRS flap is an attempt to draw air into this dead zone where the wing is not effective. When the interaction of the halo device and the air stream is examined closely, a complicated flow structure can be seen. Here, many unintentional vortices are introduced, causing the flow to become unattached going to the back of the car. This increased level of turbulence also makes the rear wing perform less efficiently and makes it harder to predict. Overall, the effect of the halo protection device disrupts clean airflow to both the engine air intake and the rear wing, therefore its design should be improved with a specific focus on aerodynamics because of its location in front and on top of the car, which is crucial to the flow to everything behind it [12].

In the other simulation, the DRS (Drag Reduction System) of the rear wing is opened to examine the effect of the halo protection device in combination with the DRS operation. The DRS was first introduced in Formula One in 2011, while the halo protection device was not introduced until 2018. In the seven years between the introduction of the two devices, the DRS has been improved and perfected in its design. However, when the halo protection device was introduced the DRS design did not changed because it was assumed that the DRS would work the same. In Fig. 3 and Fig. 8, a car with the halo protection device and the DRS flap open is shown. From the simulation performed, it can be seen that with the halo protection device the airflow is perturbed upstream so it is "dirty" air (i.e. highly turbulent) hitting the rear wing. As a result, it is no longer uniform flow to the rear wing but rather segmented flow with a dead spot in the center. This will reduce the amount of downforce generated by the rear wing and therefore the DRS will not work as effectively as if there were no halo device, which was the case prior to 2017. This would have ramification if the DRS was ever stuck open going into a turn and cause the rear wheels to lose grip.

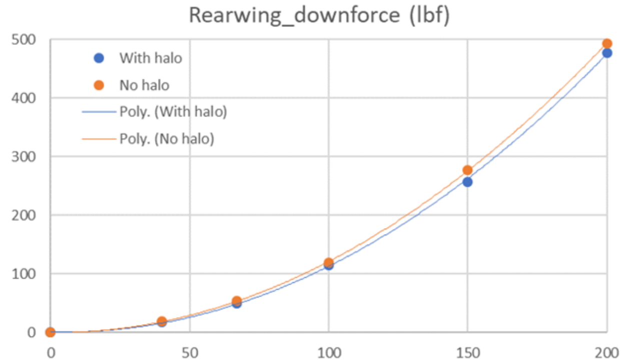

Fig. 5 CFD result of rear wing downforce comparison with the halo protection device

The halo device is situated upstream of two important devices that affects vehicle performance: the engine air intake and the rear wing. Because of its position relative to these two regions, airflow is perturbed and turbulence is formed. Fig. 9 shows the vorticity generated at 100 mph. According to Chorin [13], vorticity has direct correspondence to turbulence. One should consider the shape of the halo device so that vorticity is minimized and the flow remains laminar as much as possible when it reaches the engine air intake and the rear wing so their function is not compromised.

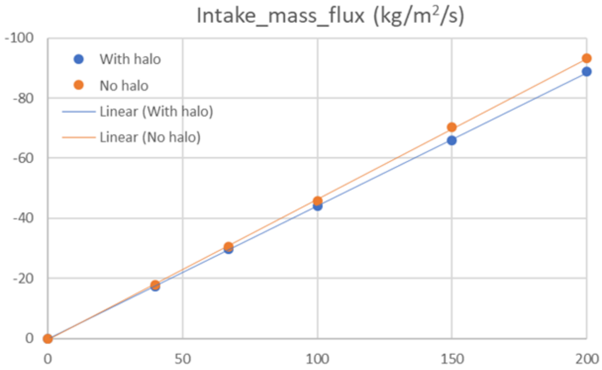

Fig. 6 CFD result of air intake mass flowrate comparison with the halo protection device

V. CONCLUSION

In this study of the halo protection device's influence on airflow over an open-wheel formula racecar, a 2019 formula 1 racecar is analyzed using CFD to get a careful look at its effect on aerodynamic parameters. From the examination of three parameters using data generated over a range of speed, it can be said:

- The halo protection device will reduce the amount of downforce generated by the rear wing, hence reduce the traction of the rear wheel.
- The halo protection device will reduce the engine intake mass flow, and as a result lower the engine's output power.
- The halo protection device plays an important role when the car is turning as shown by the yaw sim, that it reduces the downforce provided by the rear wing and hence cause rear-end instability in the event of DRS failure.

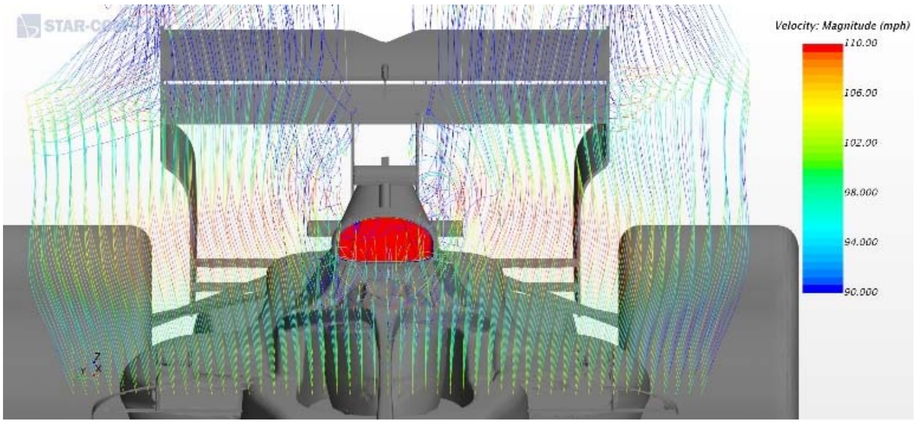

Fig. 7 Flow field disturbance due to presence of the halo device

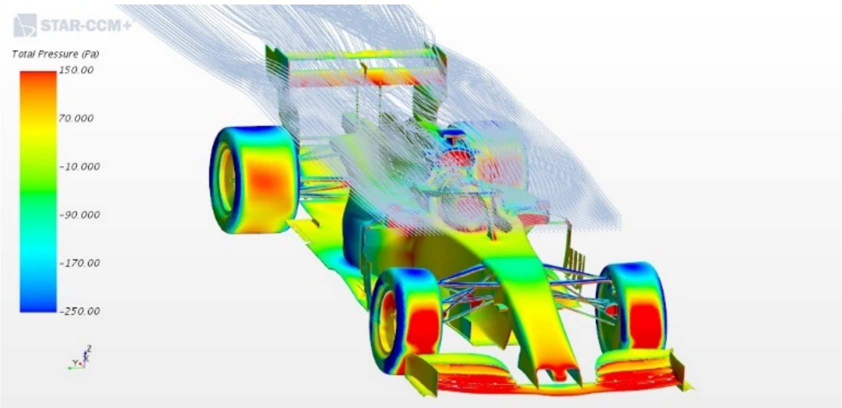

Fig. 8 Simulation of the halo protection device with DRS activated

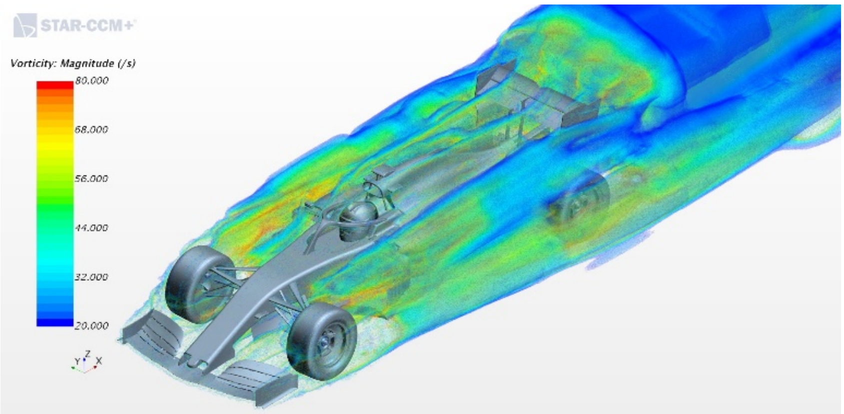

Fig. 9 Vorticity generated at 100 mph

Overall, the halo protection device is mandated by FIA regulation as a safety device to protect the driver in case of flying debris and crash against stationary barriers. Its benefit has already been demonstrated in two separate incidences as lifesaving, so the halo protection device is here to stay. However, its influence on other racing subsystems, specifically aerodynamics, should be carefully studied and vetted out so that it does not contribute to a future accident.

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