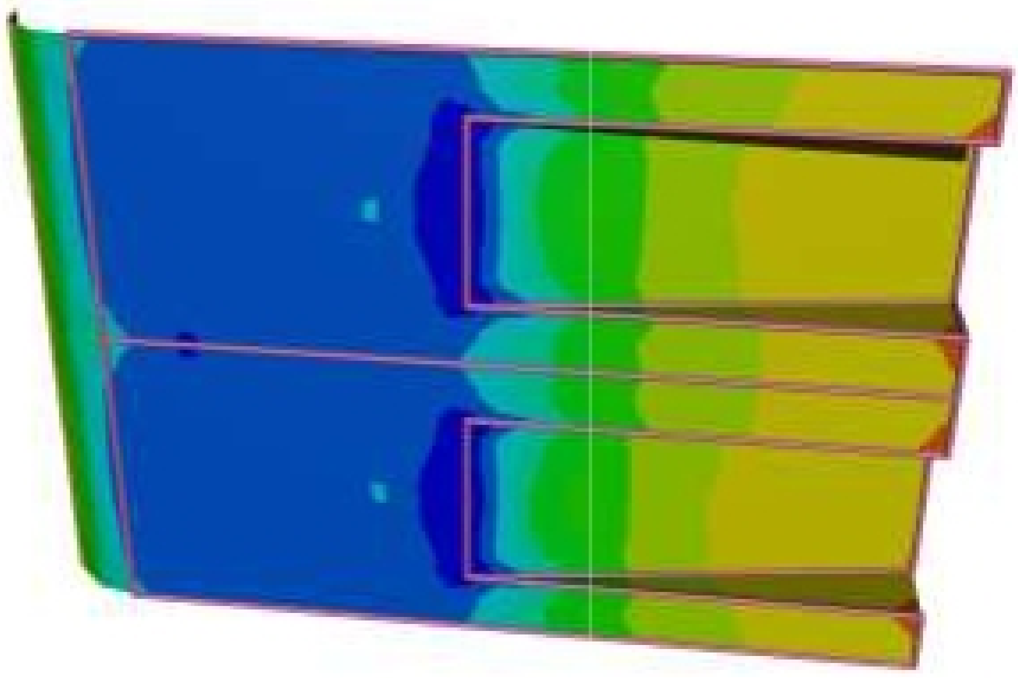
ME 200 Summer 2012

Homework 13
Assigned Monday 2 Jul 2012
Due Friday 6 Jul 2012 @730 am in Room 1130 ME

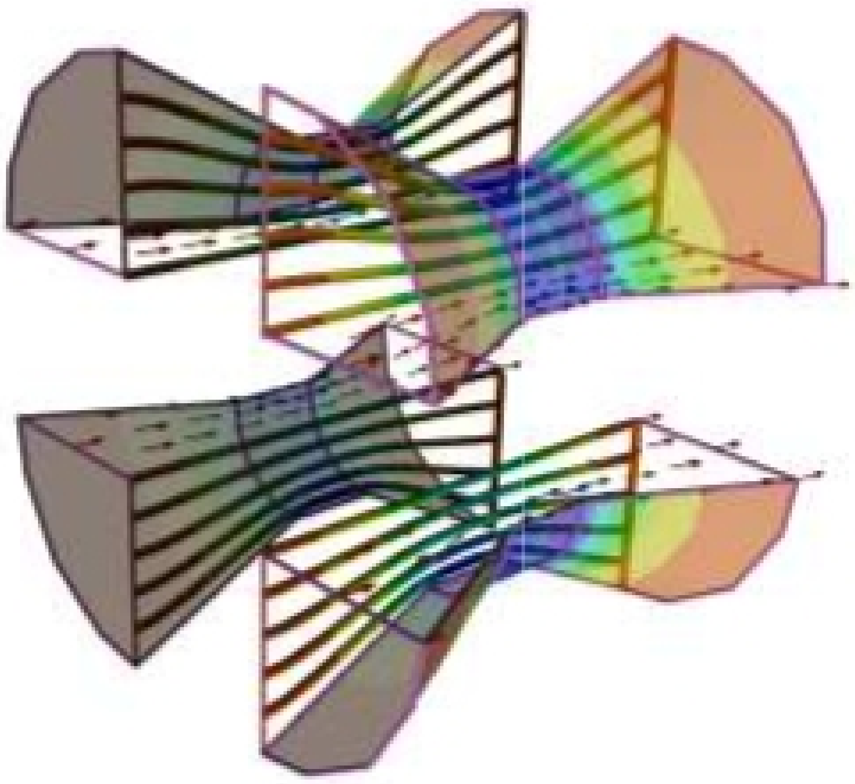
Many types of modern race cars employ various fluid dynamical phenomena to generate additional tire traction, especially at high speeds. This is termed “Ground Effects.” Such effects can be divided into a number of categories, including rear diffusers and tunnels [http://www.symscape.com/blog/secrets_of_diffusers].

The origins of the rear diffuser can be traced back to the 1977 Lotus Type 78 F1 car conceived by Colin Chapman, Peter Wright and Tony Rudd. In a brilliant example of lateral thinking the Lotus team applied the well known "airplane in ground effect" principle (reduced drag) to a racing car and found a significant increase in downforce with minimal increase in drag as a result. By incorporating inverted (compared to an aircraft) airfoil sections into the sidepods of their car, the era of ground effects in Formula 1 was ushered in. A side skirt was connected to the edge of the sidepods and extended down to the road surface. This skirt helped maintain 2D flow characteristics that provide increased downforce and reduced drag compared to a typical 3D wing. The side skirts also hid the new device from the prying eyes of competitors.



The increased cornering speeds encouraged by the first generation of racing car ground effects and the reliability of the side-skirt sealing with the ground raised safety concerns that culminated in a near universal ban of side skirts across all forms of motor sport. However, having had a taste of ground effects, the racecar designers weren't ready to give them up. This lead to tunnels.

Racecar aerodynamicists found that without side skirts it was still possible to induce downforce by sculpting the underbody of a car into 2 tunnels either side of the engine-gearbox assembly. The tunnels ideally start close to the middle of the car, where the maximum downforce will be generated, and then gradually rake upwards (between 4-14 degrees) towards the rear of the car. The overall effect is similar to a venturi in that the air is first accelerated by gradually decreasing the cross-sectional area and then decelerated back to its original speed and pressure by gradually increasing the cross-sectional area. At the highest velocity (smallest cross section) the lowest pressure is produced according to Bernoulli's principle.



Venturi Effect: Airflow through a venturi

The effect of such a tunnel on the air is similar to a nozzle followed by a diffuser. The air is first accelerated under the car by the converging nozzle and then enters the diffuser in a low-pressure, high-velocity state. By gradually increasing the cross-sectional area of the diffuser, the air gradually slows down and returns to its original free-stream speed and pressure. The diffuser's aim is to decelerate the air without it separating from the tunnel walls, which would cause a stall, reducing the downforce and inducing a large drag force.

1. Assume that the maximum tunnel width on an F1 car is 19 inches. Also assume that the nozzle has a convergence half angle of 10.25 degrees. This will cause the tunnel to decrease from 19 inches width to ~12 inches width in about 19 inches. Choose as your system the nozzle and perform an energy balance on it. You should assume steady flow, quasi-equilibrium behavior, that potential energy effects are negligible, that frictional effects between the air and tunnel are negligible and that heat transfer plays no role. **Compute the air pressure along the nozzle given a local atmospheric pressure of 14.6 psia and car speeds of 50, 100 150 and 200 mph.** Report your answer in psi *vacuum*. [You will probably want to set this problem up in a spreadsheet with the car speed differing in each column.] **Take your air pressure distribution and calculate the total force acting downward on the car for each speed.** Report your answer in lb_f. [It will be helpful if you recall similar problems from Statics where you computed the resultant force due to a distributed load, such as that applied to a beam or plate.]

2. Now consider the nozzle. Its inlet width is equal to the nozzle exit width. It is 24 inches long, but its divergence angle is limited to 9 degrees for fluid mechanical reasons. Make the same assumptions you did in problem 1, use the same initial conditions, and calculate the same quantities. Report your answers in the same units.

3. Evaluate the suitability of your assumptions. **Begin by comparing the change in air kinetic energy to its change in potential energy** (the tunnel height is no more than a few inches; you can use that for Δz). **Then compare the change in air kinetic energy to a representative change in air enthalpy. What would the air temperature rise need to be if its ΔKE and Δh were to be equal?** Finally, based on your knowledge of

F1 (or any serpentine course style of auto racing) do you think the steady flow assumption is acceptable?