RENAULT F1 Team

RACE CAR AERODYNAMICS PART I

MATTHEW LAIGHT

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The UK Motorsport Industry

- The UK has a wealth of motorsport companies based in an area known as "Motorsport Valley" (an area based largely in southern and central England) and they supply the technology used in Formula One and dominate the production of cars and components to Champ Cars and other top racing formulae in the USA.
- Approximately 4,000 companies are involved in the UK motorsport manufacturing industry and its wide-ranging support activities. The engineering sector of the industry has an annual turnover of £2.9 billion, over half of which is exported. UK motorsport supports 38,500 full and part time jobs, including 25,000 engineers.
- In Formula One, all the constructors with the exception of Ferrari, Minardi, Sauber and Toyota, are based in the UK.
- UK motorsport companies also lead in supplying the vast majority of cars and components to US Indy car racing and other major racing formulae in the US through companies such as Lola. Engines built by Ford-owned Cosworth Racing, the world's largest manufacturer of racing engines, and the Ilmor company, have powered most of the Indy car winners. In the World Rally Championships. Hyundai, Subaru and Mitsubishi all have their cars prepared by UK companies.

RENAULT F1 Team

Renault F1 Team Overview

- The Renault F1 Team has two separate bases, one in France, the other in the UK. Both elements can call on the resources of Renault's Paris-based Research and Development Technocentre.
- Renault F1 Team's UK operation is partly buried into a hillside with the wind-tunnel hidden behind an acoustic mound, so as not to disturb the grazing sheep! At the heart of the building there is the Design Office, where all of the 13,000 component parts of the race car are designed using CAD.
- At Viry work is done to improve the power, reliability and fuel consumption of their ten cylinder engine; Enstone workers are responsible for every other component on the car.

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Renault F1 Team Overview

- With 85% of the car essentially made from carbon fibre fabric – twice the strength of steel, but five times lighter – the composites area is one of the biggest and busiest in the Enstone building. This is where fibre is laid up in moulds to produce the chassis and other major components, before being cured in one of 3 autoclaves.
- In the machine room, computer-controlled equipment cuts the moulds for composite components and produces model cars and parts for wind-tunnel research.
- In the fabrication area, skilled workers hand build suspension parts, pedals, exhaust systems and the aluminium radiators.

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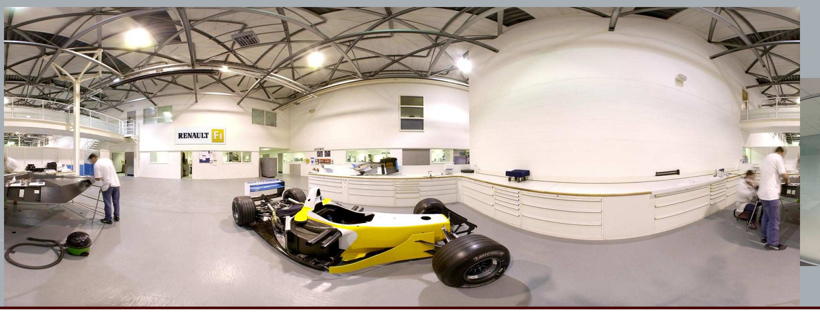
Renault F1 Team Overview

- The Renault F1 Team has its own R&D department. A seven post rig can test a full-scale car, simulating the work of the suspension on any race track on the calendar, while Computational Fluid Dynamics is used extensively to test new aerodynamic components before proving them in the wind tunnel.
- In the race shop, mechanics assemble the cars for racing and testing from scratch within two days. After every race, the car is reduced to component form and the engine goes back to Viry.
- In addition to this exchange between the two Renault F1 Team sites, staff fly between the two centres on a regular basis ensuring compatibility between engine and chassis.



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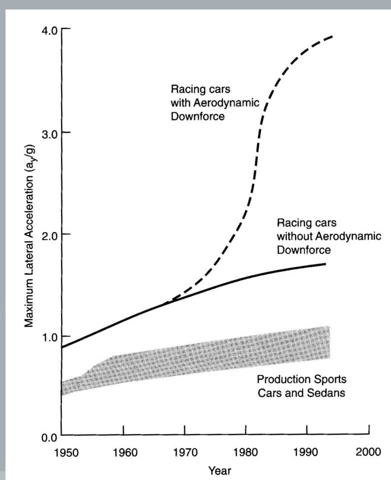
RACE CAR CATEGORIES

- Sedan-based race cars
  - IMSA GTU, IMSA GTO, NASCAR, European touring, etc.
  - Strong resemblance to passenger cars and the only allowable aerodynamic modification are minor, e.g. non-opening doors.
- Enclosed-wheel race cars
  - IMSA GTP, FISA group C, etc.
  - The body shape is mostly unrestricted, e.g. under-body tunnels (venturis) and complex wings are allowed
- Open-wheeled race cars
  - Indy, F1, F2, etc.
  - Single seater, 4 exposed wheels, narrow body, rear and front wings for downforce. Indy allows venturis.

ENCLOSED-WHEELED & OPEN-WHEELED RACE CARS

- The major design change over the last few decades (exploited since the late 60s) is the use of body shaping and wings to create aerodynamic downforce.
- Drag reduction is of secondary importance for race cars.
- Race cars do not resemble smooth inverted wing-like structures because the race regulations place, sometimes quite arbitrary, limitations on the car shape.



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AERODYNAMIC DOWNFORCE

- Downforce increases a car’s performance, particularly by improving the cornering ability of the car tyres, i.e. at race tracks with high-speed, unbanked turns.
- Downforce increases the vertical loads on the tyres without adding to the car’s weight and therefore allows higher speeds without sliding during driving, braking and cornering.
- Benefits of downforce strongly outweigh the additional drag on downforce generators.
- Downforce may be created using:
  - inverted wings;
  - body contouring;
  - ground effects.

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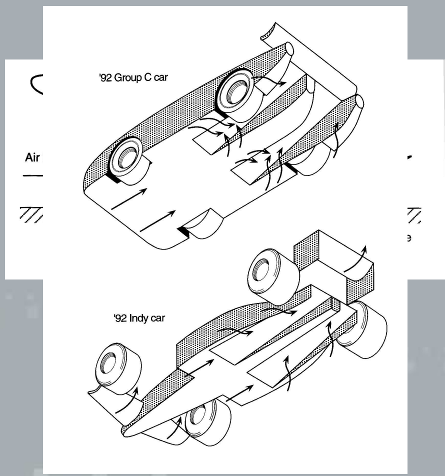
DOWNFORCE GENERATORS

- Inverted wings
  - front/rear wings.
- Body contouring
  - spoilers;
  - skirts;
  - diffusers, etc.
- Race cars based on production sports cars can have only limited aerodynamic modifications. It is important to reduce the positive lift of most production cars, especially on the rear axle. Hence
  - Front (chin) spoilers;
  - Lowered body panels (skirts);
  - Fullspan rear wings.

DOWNFORCE GENERATORS

- Ground effect
  - exploits the fact that the lift of an aerofoil (whether inverted or not) increases with proximity to the ground, i.e. since the late 70s race engineers have shaped the undertray of race cars (where the rules allow) as a smooth inverted wing, such that the ground clearance is less than the chord length.
  - undertray shaping usually takes the form of underbody tunnels, which comprise longitudinal diffusers angled upwards towards the rear of the car.



MEASURING AERODYNAMIC PERFORMANCE

- Road testing
- Flow visualization
- Wind-tunnel testing
- CFD

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ROAD TESTING

- Relatively difficult to take measurements and uncontrolled/nonrepeatable conditions.
- A pitot tube mounted high and forward gives dynamic pressure, side winds, angle of incidence and air temperature approximately in the freestream.
- LIFT: Relative displacement of suspension components can be translated into an equivalent lift/downforce but the lift of the wheels themselves is not measured, which may be a problem for the road testing of open-wheeled cars, but it can provide useful comparative data, e.g. for rear wing modifications.
- DRAG: Road test drag = aerodynamic drag + driveline friction + tyre rolling resistance.

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FLOW VISUALIZATION

- Flow visualization is a well-developed area and gives information such as the location of flow separation lines, recirculation areas on and off the surface of the car, and the general direction of flow into cooling inlets etc., which can be useful for body-shaping modifications.
- On-surface techniques: wool tufts, oil, etc.
- Off-surface techniques: smoke traces, PIV, LDA, etc.

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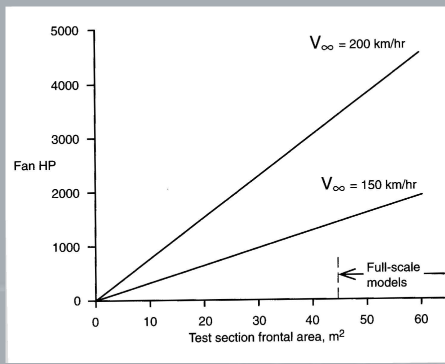
WIND-TUNNEL TESTING

- The largest possible test section is desirable to reduce blockage effects and best simulate open-road conditions but the cost of wind tunnels and their operation scales with size, as does power requirement.
- Very few full-scale automotive tunnels in existence. Most race car designers prepare test models at 0.2 – 0.5 scale, which leads to inherent compromises in the detail included in the models and to Reynolds-scaling effects, i.e. it is not possible to run the tunnels sufficiently fast with small-scale models to match to a full-scale Reynolds number.



Trends in wind tunnel power requirements versus cross-sectional area.

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Wind-tunnel corrections

- To minimize blockage effects (i.e. the overestimation of aerodynamic coefficients due to the confinement of the model within the tunnel leading to increased local flow velocity compared with free flow outside a wind tunnel):
  - 7.5% is an upper recommended limit for the ratio between the model and the test-sectional frontal area.
  - Renault F1 uses 5% maximum.
- Wind-tunnel corrections are used:
  - Mostly based on the ratio between the model frontal area and the tunnel test section cross-sectional area, e.g.

    $$C_{Lc} = C_{Lm}\,(1 + 0.25A/C)^{-2}$$

    C_{Lc} = corrected lift coefficient, C_{Lm} = measured lift coefficient, A = model frontal area, C = tunnel cross-sectional area.

    For example, for a blockage ratio of 7.5% (A/C = 0.075) and an assumed C_{Lm} = 0.300, leads to a corrected lift coefficient of 0.289.
  - In practice, more sophisticated corrections are used depending on the tunnel and model shape.

Wind-tunnels

- Typical frontal areas:
  - Open-wheeled race car (F1, Indy) – 1.5m^2
  - Sedan-based race car (IMSA GTO) – 1.7m^2
  - Enclosed-wheeled race car (IMSA GTP) - 1.8m^2
  - Production car (Porsche 928s) - 1.9m^2

- Clearly, the availability of appropriately-sized tunnels and the limit of maximum blockage ratio are the factors that determine model size.

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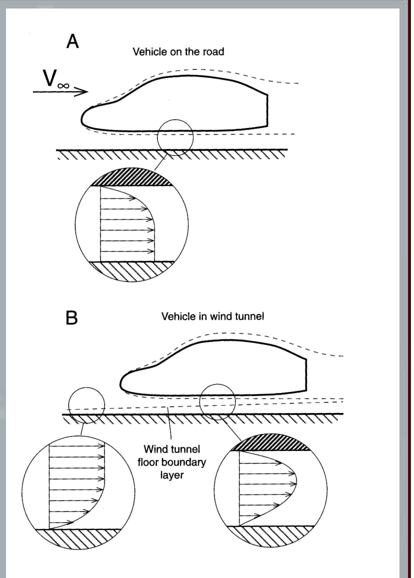
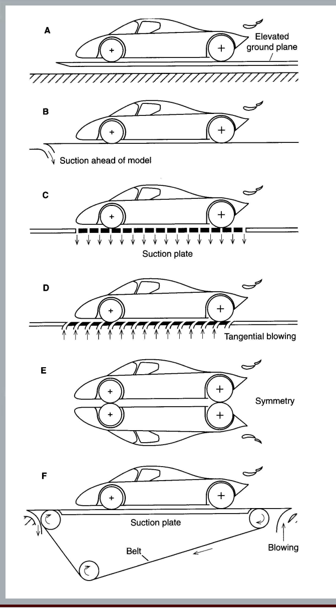
WIND-TUNNEL TESTING moving ground simulation

- Simulation of a moving ground (or road) in a tunnel adds a lot of complication to wind-tunnel testing but without a moving ground the boundary-layer formation under the model does not model reality accurately.
- The wind-tunnel boundary-layer thickness is of the same order as the ground clearance of a typical race car (even with upstream suction) and therefore it will have a significant effect on ground-effect aerodynamics in particular.



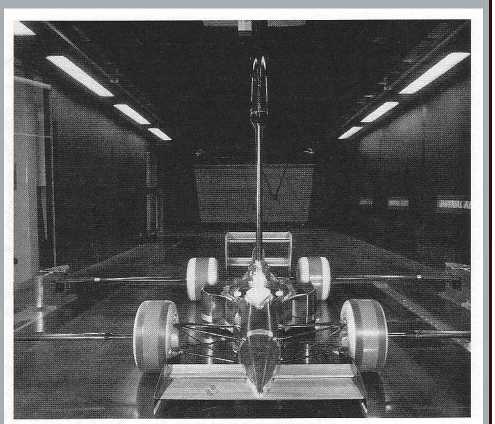
WIND-TUNNEL TESTING - moving ground

- A: Elevated ground plane to avoid thick tunnel-floor boundary layer under model.
- B: Spanwise suction upstream of model to reduce boundary-layer thickness under model (must not exceed 10% of ground clearance to be effective).
- C: Suction plate under the model, effective but complicated to achieve (constant or varying) and expensive.
- D: Injection plate under the model (tangential blowing adds momentum into the tunnel boundar-layer region), effective but complicated to achieve (constant or varying) and expensive.
- E: Symmetry approach, whereby the symmetry line is also a streamline and therefore the moving ground condition is satisfied but doubled model modification costs and larger tunnel cross-sections required.
- F: Moving-belt ground simulation – suction slot upstream and injection slot downstream.



WIND-TUNNEL TESTING moving ground simulation

- Most race car designers opt for a moving-belt ground simulation but there are inherent problems:
  - interactions between the support sting and the body;
  - difficulties in measuring loads on rotating wheels in contact with a moving belt – some tunnels have a narrow (between-wheels) belt to avoid this problem;
  - suction under the model can suck up the belt – an additional suction plate under the belt can prevent this problem but it is expensive; and
  - often the maximum belt speed is limited to a level below the maximum tunnel speed.



Open-wheeled race car mounted in a tunnel with a moving belt and showing sting and wheel struts.

Mounting Models & Wheels

- When a moving belt is used, the model is usually supported by a sting (mounted either behind or above) and wheel rotation is usually obtained by the contact between tyres and the belt.
- The forces and moments are measured on a six-component balance mounted between the model and sting to measure:
  - downforce;
  - drag;
  - side force;
  - pitching moment;
  - rolling moment; and
  - yawing moments.
- Surface pressure distributions are usually measured.

Mounting Models & Wheels

- If the wheels form part of the model itself and are rotating, then the forces on the wheels due to the belt can introduce errors into the loads measured by the balance.
- If the wheels do not form part of the body but are simply rotated by contact with the belt (which can help to stabilize and hold down the belt), and the rest of the model is attached to the balance, then the balance measures only the loads on the model body, i.e. the lift and drag of the wheels is not measured.
- As the effect of the body on the wheels is not measured directly:
  - strain gauges can be fitted to wheel struts to measure loads on the wheels – quite accurate for drag, less so for lift on rolling wheels; or
  - a soft suspension can be used so that the wheels only lightly touch the belt and then in a separate experiment without airflow the vertical and axial forces between the wheels and belt are measured with the belt running, and these measurements can be used to correct the measured lift and drag data.

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Differences Between Road and Tunnel Conditions - flow quality and Reynolds number effects

- In principle, in still air on the road, turbulence is negligible; whereas turbulence levels are measurable in closed-return tunnels.
- The boundary layers on tunnel walls gives non-uniform velocity across the section.
- Low blockage ratio is desirable to best match open road conditions.
- Usually the Reynolds number (Re) cannot be matched to full-scale actual values because the speed of the tunnel cannot be scaled up sufficiently (cost & supersonic speeds!)
  - If the flow is attached in the lower Re case then it is likely that it will also be attached in the higher Re case, and the aerodynamic effects of non-matched Re will be quite small.
  - If the flow is separated (e.g. at wheels, wings, etc.) in the lower Re case, then, due to the high dependency of reattachment positions with Re, large differences are possible with the higher Re case.

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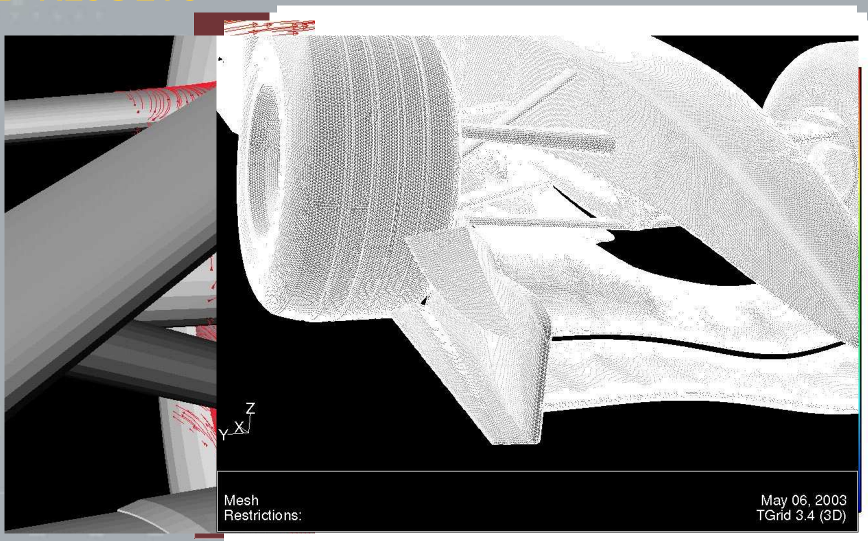
COMPUTATIONAL FLUID DYNAMICS

- With sufficient experience and after validation against experimental tests, CFD is very useful especially for:
  - race car wing designs;
  - quick generation of load distributions and modifications; and
  - completion of various parametric studies before a model for tunnel testing is made.

CFD RESULTS



Summary

- Drag reduction for fuel economy, which is a major factor in production car aerodynamics, is not significant for race car aerodynamics.
- Downforce is the major factor and can lead to increased cornering speeds.
- Road testing: difficult to take measurements and uncontrolled/non-repeatable conditions.
- Wind-tunnel testing: controlled conditions but Re-scaling issues and moving ground simulations complicate testing.
- CFD: solutions are convenient, increasingly more accurate but time consuming.

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RACE CAR AERODYNAMICS PART 2

MATTHEW LAIGHT

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AERODYNAMIC EFFECTS ON PERFORMANCE

- A vehicle's stability and handling are primarily dictated by tyre performance but this performance can be changed considerably by aerodynamic loads, i.e. optimal loading of the tyres by control of front/rear downforce can lead to increased:
  - cornering speeds;
  - braking performance.

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AERODYNAMIC EFFECTS ON PERFORMANCE – straight-line braking

- Increased downforce reduces the braking distances.
- Simplest braking method is by increasing the aerodynamic drag of the vehicle, e.g. dragsters deploy parachutes, this has the added advantage that brake pads do not overheat.
- Another method is the use of movable aerodynamic devices, e.g. flaps, but now these are mostly banned (by the race regulations in order to reduce speeds on safety grounds), although the McLaren F1 sportscar has a brake-activated rear spoiler.

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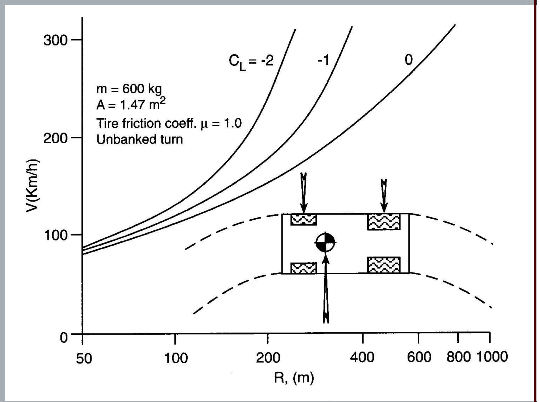
AERODYNAMIC EFFECTS ON PERFORMANCE - maximum turning speed

- Steady-state turning on an unbanked track leads to forces on the tyres, which increase with downforce, and to centrifugal forces, which increase with cornering speed (for given radius).
- Downforce increases the maximum turning speed, e.g. for R = 200m the wingless vehicle can corner at a maximum of about 150km/h, while the high-downforce vehicle can corner at a mximum of about 250km/h (of course without any additional vehicle mass).



Maximum speed versus road curvature, R, for varying lift coefficent (maximum tyre coefficient of friction = 1.0 in all cases).

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AERODYNAMIC EFFECTS ON PERFORMANCE – closed-circuit lap times

- In racing the fastest maximum speed is often not relevant and each track requires different aerodynamic settings, for example:
  - a high-speed track without serious accelerations and sharp turns requires low drag/low downforce settings; while
  - a high-speed track with unbanked turns requires high downforce settings.
- It is complete circuit times that are relevant rather then maximum speeds over sections of the course.
- Given that increased downforce implies increased drag (i.e. reduced maximum speeds), the variation in drag versus lift must be included in any analysis of race car performance on a given track.
- Mapping.

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AERODYNAMIC EFFECTS ON PERFORMANCE – lateral stability, CoP & CoG

- If a vehicle's centre of pressure is ahead of the centre of gravity then at high speeds any lateral irregularity (e.g. bump in the road) will cause a small initial side slip that tends to generate an aerodynamic side force that tends to increase the side slip, i.e. unstable without driver intervention.

- Therefore, unlike most road cars, most race cars have their centre of pressure behind the centre of gravity in order to give improved lateral stability at high speeds where aerodynamic forces are significant.

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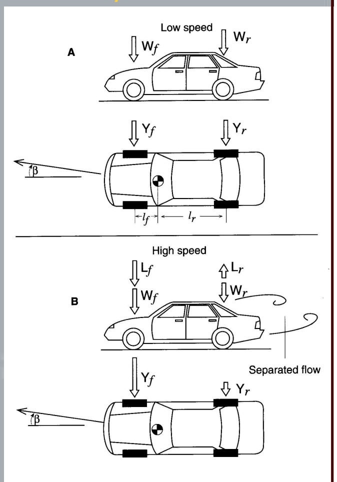
AERODYNAMIC EFFECTS ON PERFORMANCE – lateral stability, lift

- Lateral stability is also affected by the ratio of front to rear lift.
- A: Low-speed (neglible-lift) vehicle with side slip at angle β, due to momentary disturbance or a left turn.
  - The side force created by the tyres is proportional to the normal load, i.e. proportional to the weight on the front (W_f) and rear (W_r) axles.
  - If the moment about the CofG created by the rear tyres exceeds that created by the front tyres, such that the net moment tends to rotate the car in the direction of slip, then there is understeer (stable).
- B: High-speed (significant-lift) vehicle with side slip at β.
  - Here, downforce is generated at the front and there is some rear positive lift (due to some aft-flow separation) – typical is of some production sports cars without rear downforce generators.
  - If the moment about the CofG created by the front tyres exceeds the rear-tyre moment, such that the net moment tends to turn the car away from the slip direction, then there is oversteer and possible vehicle spin (unstable).



A: Low speed, i.e. without aero. effects.

B: high speed, i.e. with aero. effects.

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AERODYNAMIC EFFECTS ON PERFORMANCE – suspension & pitch sensitivity

- Pitch sensitivity is used to mean a suspension/aerodynamic interaction, and describes the influence of a vehicle's pitch on handling and how this affects the vehicle's tendency to over/understeer.
- Maintaining a constant pitch sensitivity throughout manoeuvres, when the car rolls and the suspension geometry varies, is difficult.
- Adding rear downforce, thereby increasing the car's cornering stiffness, makes the car more stable and controllable at high speeds.
- Due to the ground effect, lowering a front wing causes the front downforce to be increased and also the reduced clearance limits the airflow underneath the car and therefore causes reduced flow through the rear diffuser and to reduced rear downforce, i.e. both effects make the car more unstable and so more driver effort is required to control the car.
- With increased speeds come increased vertical tyre loads, and stiffer springs are required to avoid sudden forward pitching – added stiffness leads to more driver vibration.
- Active suspension can avoid large changes in suspension geometry (or has been used in F1 – before being banned – to create active aerodynamics via changes in ride height and pitch at different points along the track).

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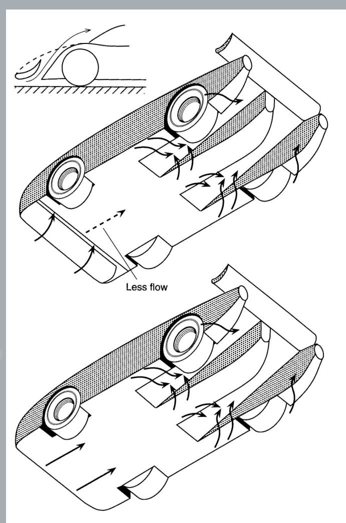
AERODYNAMIC EFFECTS ON PERFORMANCE – pitch (& yaw) sensitivity

- On enclosed-wheel race cars it is tempting to use a highly cambered front wing to generate high downforce.
- But the front wing diverts the airflow from under the nose so that the flow into the rear tunnels is very limited.
- The high downforce tunnels then become very pitch sensitive (very sensitive to loss of front ground clearance), since their front flow supply originates under the front wing and they become fed majorly by airflow from the sides.
- A more traditional design, with sufficient front flow fed to the rear tunnels, is less pitch sensitive. Downforce is still created at the nose but most is created over the whole lower surface and near the tunnel entrances.



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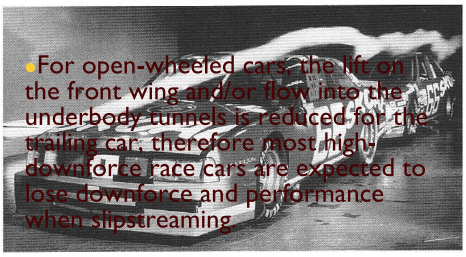
MULTIVEHICLE INTERACTIONS

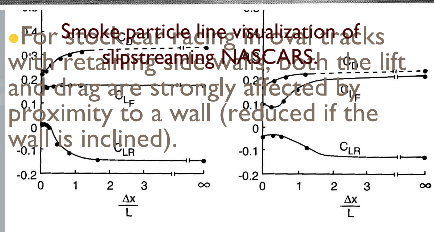
- Slipstreaming is often used in high-speed racing, e.g. stock car racing.
  - The freestream streamlines do not impinge on the front of the second car to from a high-pressure stagnation point as they would normally, i.e. the drag on the second car is reduced.
  - The rear downforce of the leading car is reduced due to the reduced turn down of the flow at its rear.
  - The front lift of the second car is reduced due to sitting inside the wake of the leading car.
  - The rear downforce of the second car is reduced due to strengthened flow separation there.
  - The stability of both cars is reduced, i.e. more oversteer, but more so for the trailing car.



- For open-wheeled cars, the lift on the front wing and/or flow into the underbody tunnels is reduced for the trailing car, therefore most high-downforce race cars are expected to lose downforce and performance when slipstreaming.

Smoke particle line visualization of slipstreaming NASCARS.

- For stockcar racing in oval tracks with retaining sidewalls, both the lift and drag are strongly affected by proximity to a wall (reduced if the wall is inclined).



Lift & drag variation for both cars during slipstreaming.

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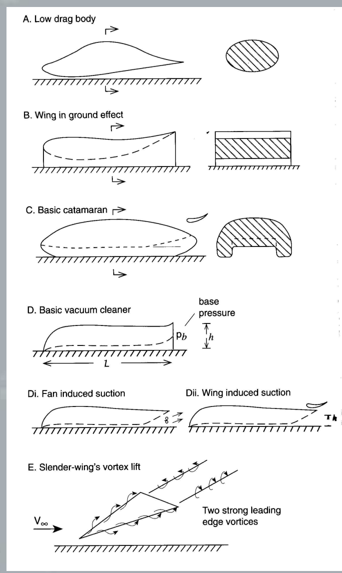
WHOLE-CAR AERODYNAMICS

- Basic body concepts.
- Flow around wheels.
- Seals and skirts.
- Underbody tunnels.
- Simple add-ons: spoilers, strakes, lips/Gurney flaps.
- Race car wings.
- Internal flows.
- Open-wheeled race cars.

BASIC BODY CONCEPTS

- A: low drag and body-generated downforce.
- B: Inverted-wing ground-effect design for high downforce.
- C: Catamaran design for enclosed-wheel cars with smooth underbody that tilts up at the rear.
- D: Vacuum-cleaner concept with sealing at front and sides to eliminate underbody airflow for strong downforce. The addition of a fan or rear wing enhances the underbody suction.
- E: Vortex-lift concept to create downforce – either as full-body shaping or as smaller deflector plates.



FLOW AROUND WHEELS

- OPEN-WHEELED: The wheels are one of the most influential components affecting the aerodynamics.
  - Rotation of the wheels moves the separation point forward.
  - The interaction between the wheels and the ground reduces vortex shedding but the flow in the wake behind the wheels may be periodic and interact with the rest of the body flow.
  - The wheel flow may dominate the vehicle's drag.
  - Near the forward stagnation point on the wheels there is a small recirculation region – mounting a plate in this area can give added downforce; see later.
- ENCLOSED-WHEELED: Wheel flows can be very complicated but usually the tyre drives a channel flow in the direction of rotation within the the wheel well. This flow can be used to channel cooling flow or to move flow from the underneath the car to generate downforce.
- OPEN & ENCLOSED: Wheel rims can acts as pump to cool the brakes – if the regulations allow.

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SLIDING SEALS AND SKIRTS

- Seals and skirts are used to prevent airflow into the low-pressure region under the car.
  - This method of enhancing downforce is now prohibited by the regulations in many classes of racing.
- Ground-effect designs also benefit from the addition of skirts such that the flow under the car with its inverted aerofoil shaping remains essentially two-dimensional (needed to generate large lift to drag ratios).
  - Hence vertically sliding skirts attached to the side pods of F1 cars in the late 70s and early 80s.
  - Skirted ground-effect F1 cars generated C_L ~ -2.6 and huge increases in lateral accelerations, but any loss of seal led to to very unsafe situations.
  - Skirted ground-effect designs banned by 1983 in most racing.
  - The concept was continued as flexible skirts that were attached to the endplates of the front wings of many open-wheeled car into the early 80s.

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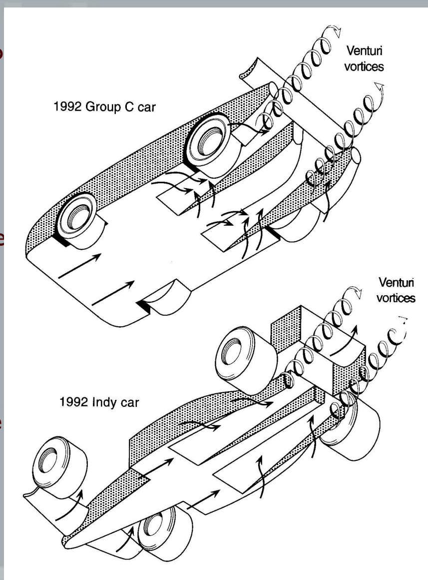
UNDERBODY TUNNELS

- Banning skirted ground-effect designs led to underbody-tunnel/channel/diffuser/venturi designs.
- The size and form of the tunnels is usually dictated by the regulations.
- The low pressure created within the tunnels leads to inflow from the sides of the vehicle between the front and rear wheels, creating strong concentrated vortices.
- The vortices keep the flow attached throughout the tunnels and stabilize the underbody flow, therefore:
  - the outer edges of the tunnels especially are sharp to promote rolled vortex strength; and
  - a closely mounted rear wing is often required to help pump the flow under the vehicles.



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SIMPLE ADD-ONS - spoilers, strakes

- Rear wings are based on well-matched aerofoil sections, whereas spoilers are made from simple sheet metal and are added on to existing cars (e.g. passenger-car based sports cars and racers) to alter the aerodynamics. Spoilers can be used at:
  - the front (i.e. front underbody dam) on:
    - passenger cars to divert underbody flow to avoid driveline and plumbing components and therefore to reduce drag; or
    - smooth underbody race cars to provide enhanced downforce at the expense of increased drag;
  - the rear (i.e. rear-deck spoiler) to:
    - reduce the separated flow area at the rear and therefore reduce drag;
    - elevate the rear stagnation line to create more downforce;
    - increase the underbody flow and therefore the downforce generated there – provided the spoiler is well placed - at the expense of increased drag.
- Strakes can be added to create vortex lift (at the expense of increased drag) at the front or rear of race vehicles.

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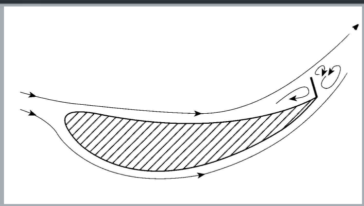
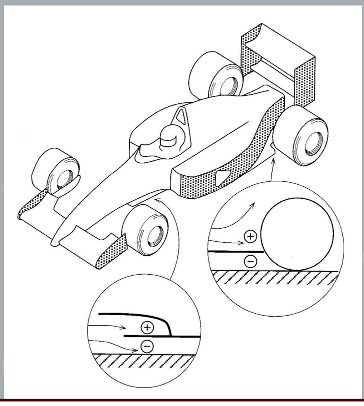
SIMPLE ADD-ONS – lips/Gurney flaps, pressure plates

- Lips/Gurney flaps/wickers can be added to the trailing edges of wings. The small trailing vortex that is created usually helps to turn the flow so that the suction-side boundary layer becomes thinner, effectively increasing the wings camber, i.e. providing more circulation.

- High-pressure stagnation plates can be placed horizontally (to add minimal drag)around the wheels of open-wheeled race cars, e.g. in the 1993 F1 car in figure.





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RACE CAR WINGS

- Differences between aeroplane-type wings and race car wings include:
  - the interaction of the race car wing with other body components, e.g. the downforce generated by the presence of the wing on the body can be as large as the downforce on the wing itself;
  - especially open-wheeled rear wings have small aspect ratio, i.e. far from two-dimensional flow and pressure distribution;
  - some race car wings operate in extreme ground effect, i.e. close enough to the ground to have significantly enhanced downforce, which can affect handling with sudden suspension motion and/or can affect the efficiency of underbody tunnels if a front wing overly restrict the airflow under the car;
  - unlike aeroplane wings, car wings are designed for a fixed point of operation.

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RACE CAR WINGS - positioning

- In general for open-wheeled cars, centrally-mounted wings (i.e. between the two wheel axles) are less efficient than far-forward or far-aft wings.
- With a smooth underbody car, the flow is usually attached over most of the front section but there may be some limited flow separation near the rear. But:
  - the addition of a rear inverted wing can cause the underbody flow to accelerate due to the lower base pressure induced by the wing;
  - this higher speed causes more downforce on the body in addition to the additional downforce on the wing itself; and
  - often the wing causes the flow separation region to be reduced.
- The addition of a rear wing to a passenger car with exposed underbody components is likely to be minimally effective.
- Two rear wings can give better front/rear downforce ratio control (but Indy racing allows only one rear wing).
- In F1, a higher rear wing may be used, which may have multiple elements, to increase downforce.
- The endplates on the wings are important for lateral stability, downforce, and in some cases to isolate the wing from the wheels.

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INTERNAL FLOWS

- Internal flows have a strong influence on the design of:
  - cooling systems;
  - air intakes;
  - interior ventilation;
  - engine intakes;
  - exhaust manifolds;
- Viscous boundary-layer flows, flow separations and heat-transfer effects are generally significant.
- Most race cars have a cooling system to transfer heat rejected by internal radiators to the external flow. Most race regulations do not allow a cooling fan and therefore the pressure difference between the two ends of the cooling system is a function of vehicle speed.

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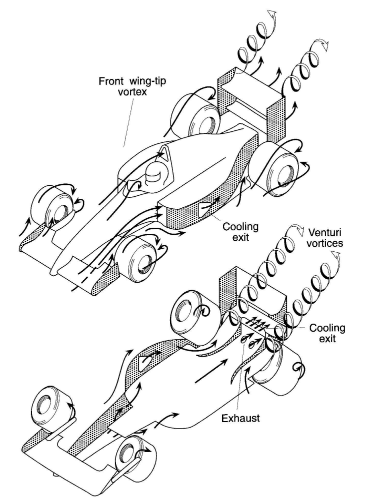
OPEN-WHEELED RACE CARS

- Open-wheeled race cars have the most complicated aerodynamics, primarily due to the four large exposed wheels.
- Thanks to regulations, an open-wheeled race car is a long way from an ideal high-speed streamlined vehicle.
- The flow behind each of the four exposed wheels is completely separated (large C_L and C_D expected).
- The frontal area of the four wheels may be as much as 65% of the total vehicle frontal area, so:
  - C_D for the wheels ~ 0.2 to 0.5; and
  - C_L for the wheels ~ 0.3 to 0.4 (positive lift).
- The bodywork of the vehicle must sit within the highly disturbed flow field and therefore the drag of such cars is inherently high.

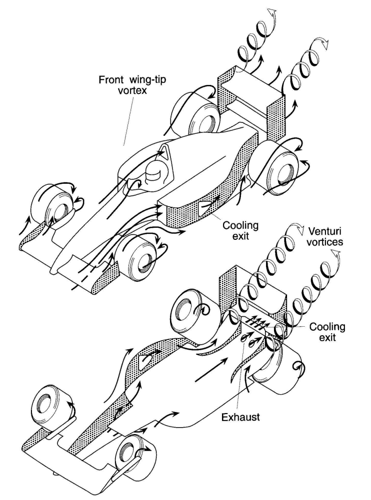
TYPICAL OPEN-WHEELED RACE CARS

- Flow separation behind wheels.
- Flow over front and rear wings is attached.
- Flow under the front wing to eventually feed the rear diffuser and to enter the cooling intakes.
- Large nose cone reduces the efficiency of the front wing – now the nose cones are raised above the wing.
- The rear wheels deflect the flow behind the narrowing tail of the body so that the flow stays attached there.



TYPICAL OPEN-WHEELED RACE CARS

- The rear venturi adds downforce by creating reduced base pressure and promoting vortex structures to keep the venturi flow attached.
- The lower rear wing helps to induce low pressure for the cooling exit flow and for the diffuser exit flow, in turn increasing flow rates there and increasing the downforce of the venturi.
- The engine intake is fed by essentially undisturbed flow above the driver's head and enters a diffuser where the flow is slowed before entering the airbox.
- The windscreen is just large enough to create a small separated region in the cockpit.
- The flow field behind the car is highly disturbed comprising majorly of the trailing wing vortices, the rear-wheel wakes, the venturi vortices and the pulsating engine exhaust.



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SUMMARY

- Vehicle dynamics and handling are primarily dictated by tyre performance but this performance can be changed considerably by aerodynamic loads, i.e. optimal loading of the tyres can lead to increased:
  - cornering speeds;
  - braking performance.
- Aerodynamic components cannot be designed in isolation – flow interactions must be accounted for.
- The race regulations dictate design changes.
- In general, for most types of race car, ride height and pitch angles can create aerodynamic variations but this can lead to serious pitch-sensitivity issues.

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REFERENCES & ACKNOWLEDGEMENTS

- Investigation of negative lifting surfaces attched to an open-wheel racing car configuration, SAE Paper 85-0283, J Katz.
- Vehicle Dynamics, JR Ellis.
- Aerodynamics of race cars in drafting and passing situations, SAE Paper 71-0213, W Kortum et al.
- The effect of deck spoilers and two-car interference on the body pressures of race cars, SAE Paper 94-2520, LT Duncan et al.
- Race Car Aerodynamics: Designing for Speed, Joseph Katz.

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