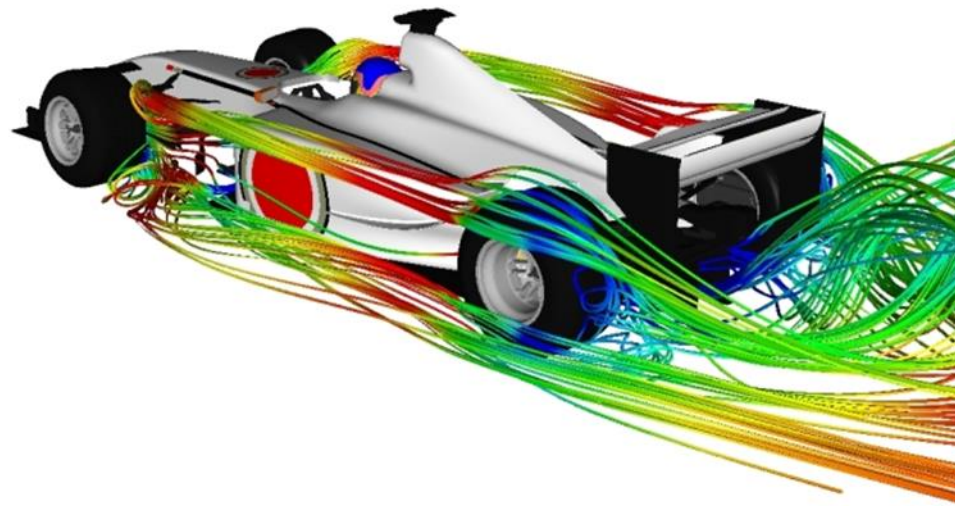


Basic Aero

VEHICLE SYSTEMS

Introduction

The study of the flow of air around and through a vehicle, primarily if it is in motion



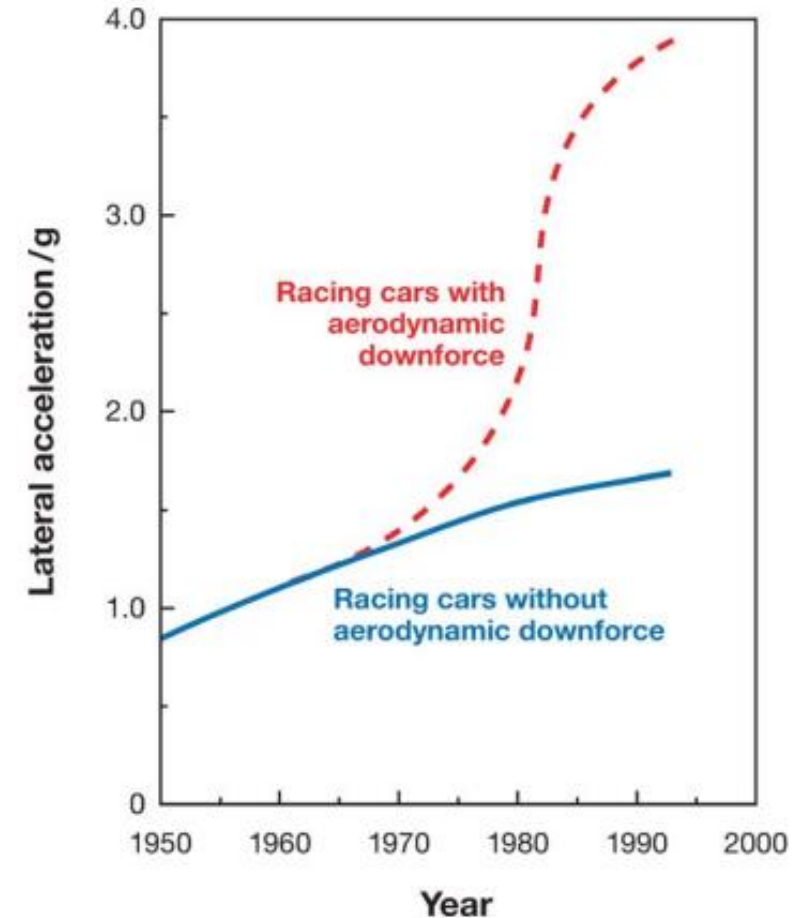
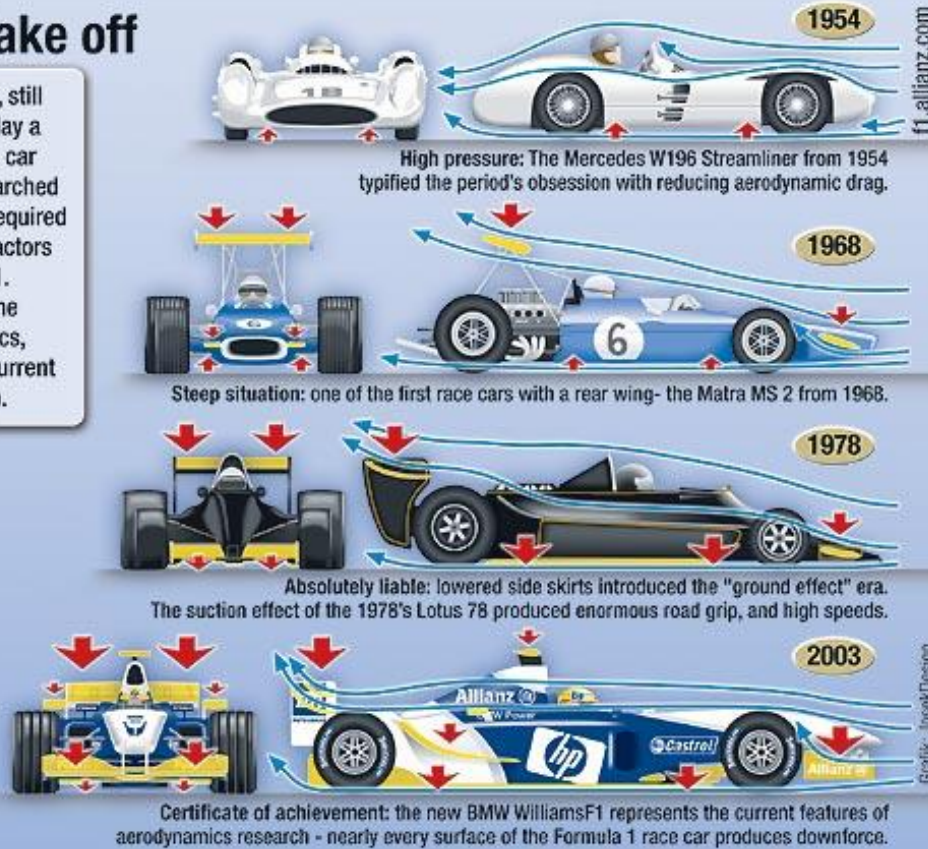
Designers now design surfaces of vehicles to manipulate the air flow for their gain.

Introduction

Ready for take off

What was, in the 1950's, still unknown territory, is today a guiding principle in race car development: well-researched aerodynamics and the required downforce are the top factors for success in Formula 1. The graphic illustrates the evolution of aerodynamics, from the 1950's to the current BMW WilliamsF1 (FW25).

Downforce ↓
Lift ↑
Airflow →
Downforce-producing surfaces



Introduction

Aerodynamics on the road....



Fuel consumption....



Why????



Introduction

How does air flow interact with the car?

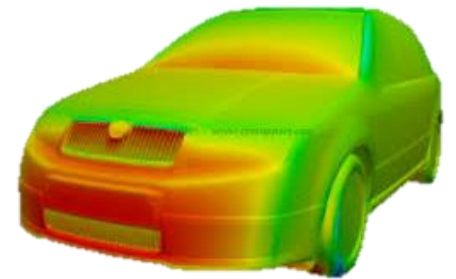
Air interacts with a vehicle only by applying pressure to surfaces

This pressure always produces a force that is perpendicular to the surface on which it acts.

The pressure the air applies is linked with the air's velocity

So aerodynamics is all about controlling the air's velocity and pressure around the vehicle.

KEY TOOL : BERNOULLI'S THEOREM

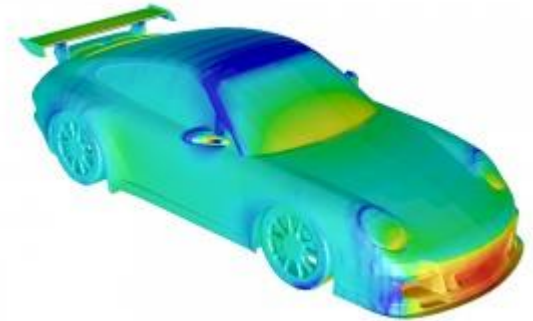


Bernoulli's

Before we look at Bernoulli's theorem, let's define Pressure

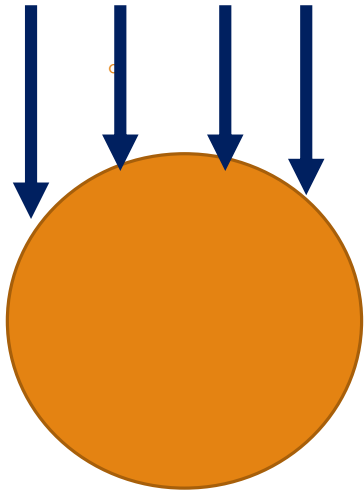
- Pressure is a scalar quantity (No direction)
- It is a property of a fluid at a particular point.
- However the force exerted on a boundary, by a pressure, does have direction
- Pressure is measured in terms of this force.

$$\text{Pressure} = \text{Force}/\text{Area} \text{ (N/m}^2\text{)}$$



Example Question

A force of 25N is distributed onto a circular area of a diameter 40mm, what is the pressure?



$$\text{Pressure} = \text{Force} / \text{Area}$$

Bernoulli's

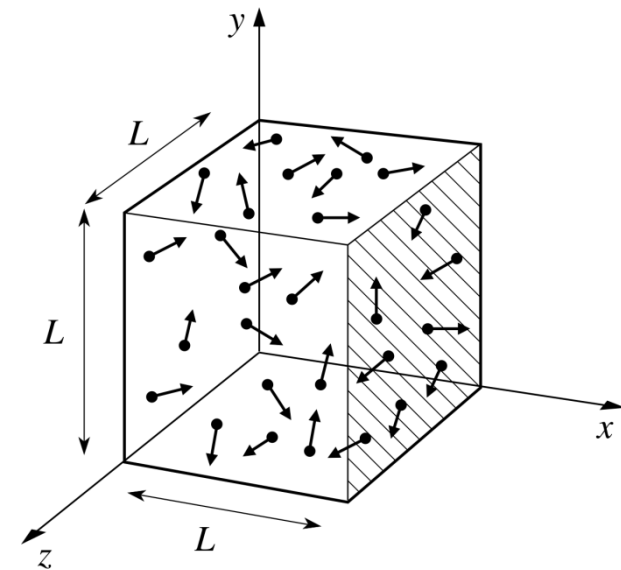
There is another way of thinking of pressure;

Pressure = Energy/Volume

Pressure = Energy per unit volume

Units show that the above statements hold

$$\begin{aligned}\text{Energy/Volume} &= \text{J} / \text{m}^3 \\ &= \text{N m} / \text{m}^3 \\ &= \text{N} / \text{m}^2 \\ &= \text{Force/Area} \\ &= \text{Pressure}\end{aligned}$$



Bernoulli's

Bernoulli's principle is just an expression of the 1st law of thermodynamics;

3 forms of energy in a fluid–

- Kinetic energy – $\frac{1}{2} m v^2 \rightarrow \frac{1}{2} \rho v^2$
 - Potential Energy – $mgh \rightarrow \rho gh$
 - Pressure energy (P_{static})
-
- Energy cannot be created or destroyed

$$P_{\text{Static}} + \frac{1}{2} \rho V^2 + \rho gh = \text{CONSTANT}$$

So what does this mean?

If you increase the speed the pressure will drop

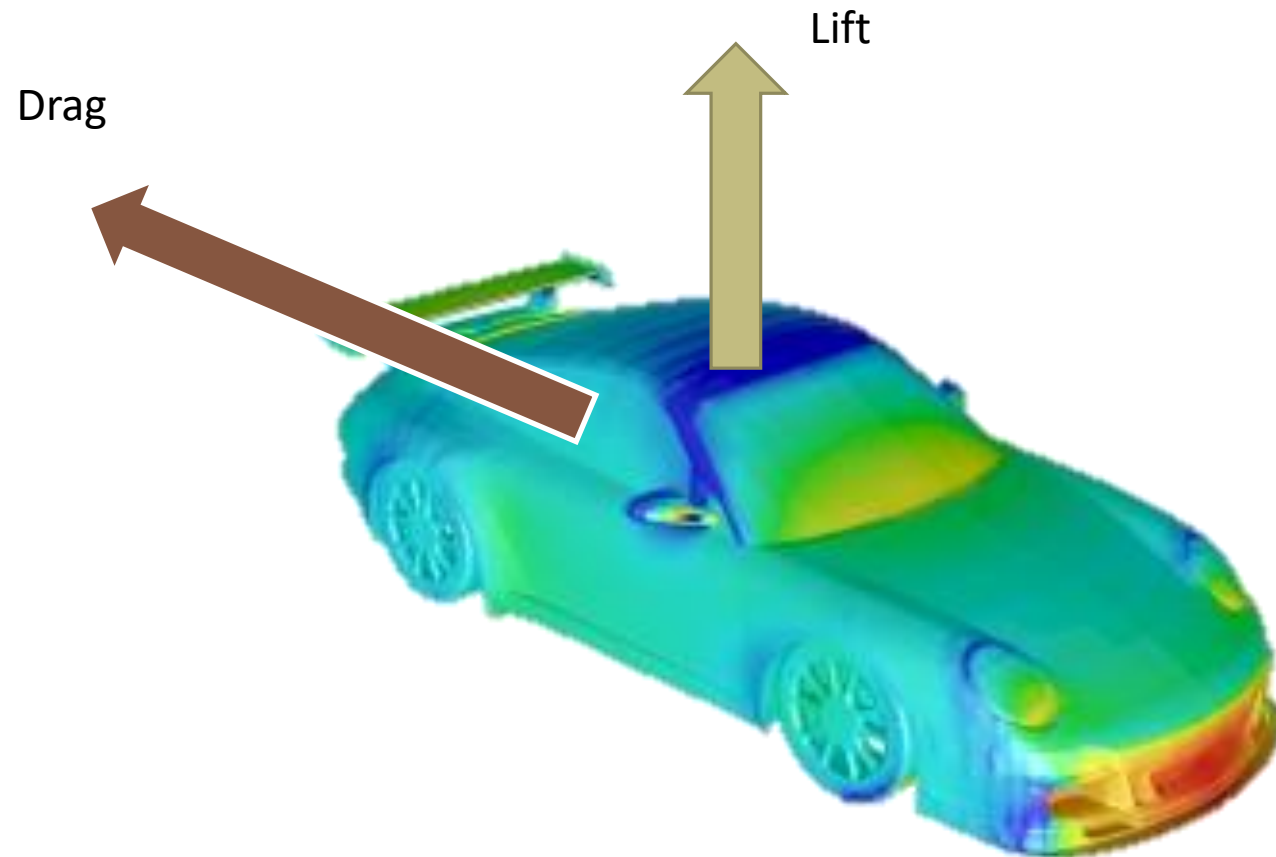
If you decrease the speed the pressure will rise

If you increase the pressure the speed will drop

If you decrease the pressure the speed will increase

Bernoulli's

The forces that result from the pressure distribution



Drag

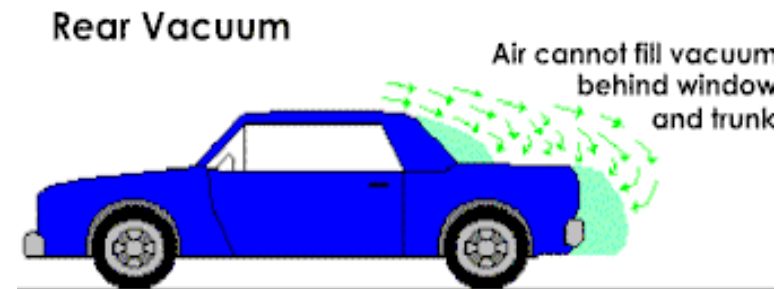
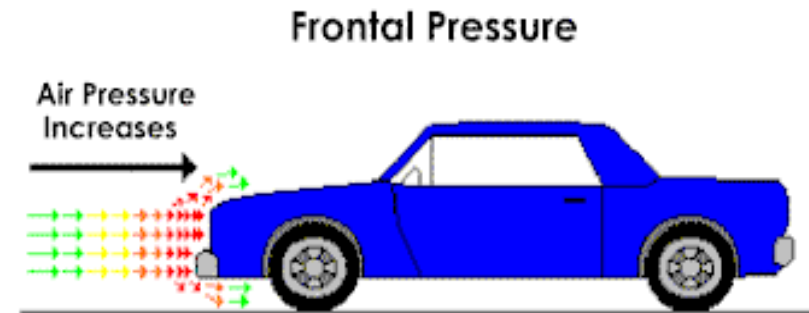
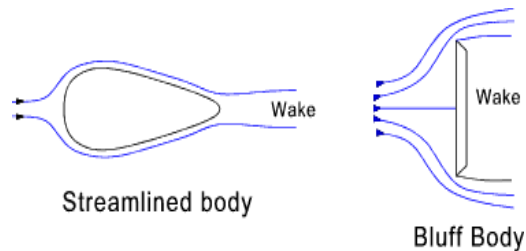
What is drag?

Resistive Aerodynamic force

Opposes motion

Made up of three elements

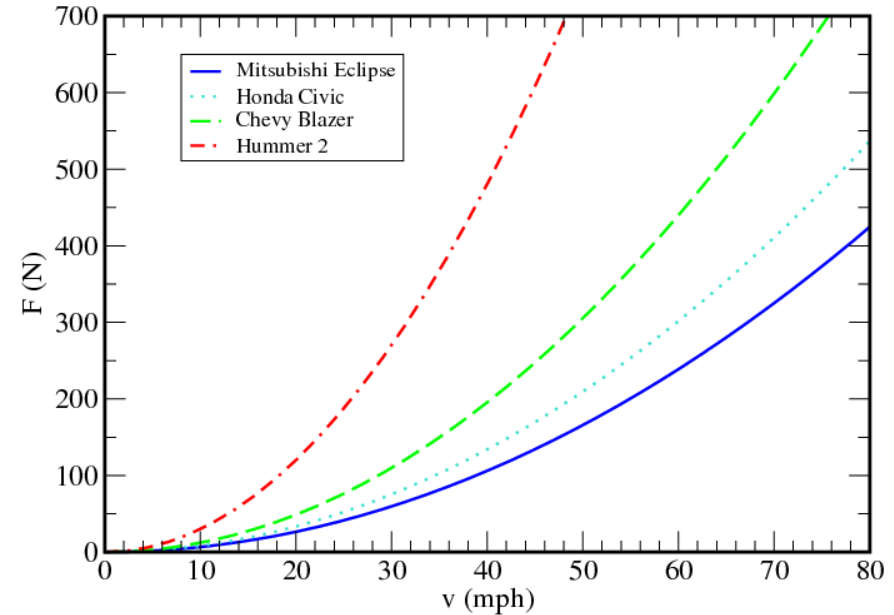
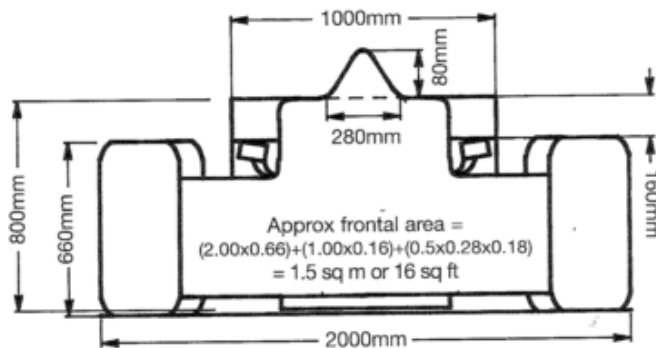
- Frontal Pressure
- Rear Vacuum
- Skin Friction



Drag

Equation for drag

$$\text{Drag Force} = C_D \times 1/2 \rho V^2 \times A$$



Drag

Drag Coefficients

Modern Car like Toyota Prius	0.26	frontal area
Sports Car, sloping rear	0.2 - 0.3	frontal area
Common Car like Opel Vectra (class C)	0.29	frontal area
Saloon Car, stepped rear	0.4 - 0.5	frontal area
Convertible, open top	0.6 - 0.7	frontal area
Bus	0.6 - 0.8	frontal area
Old Car like a T-ford	0.7 - 0.9	frontal area
Tractor Trailed Truck	0.96	frontal area
Truck	0.8 - 1.0	frontal area

Lift

What is lift?

Vertical force acting on body

Reduces (or increases) load on tyres

Occurs when pressure above vehicle is different to pressure below vehicle

For negative lift pressure above > below

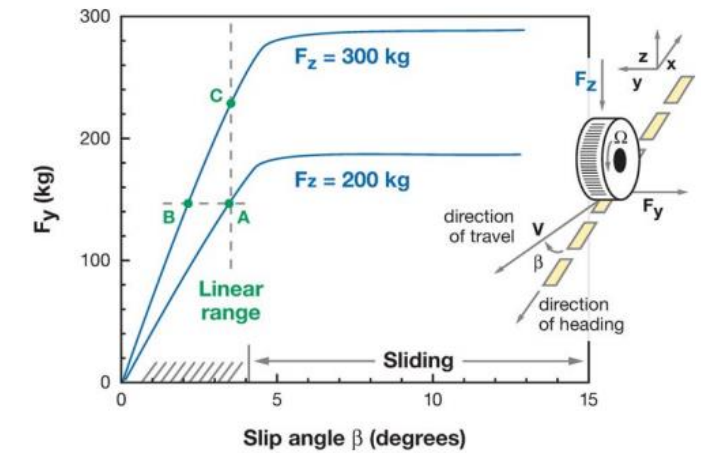
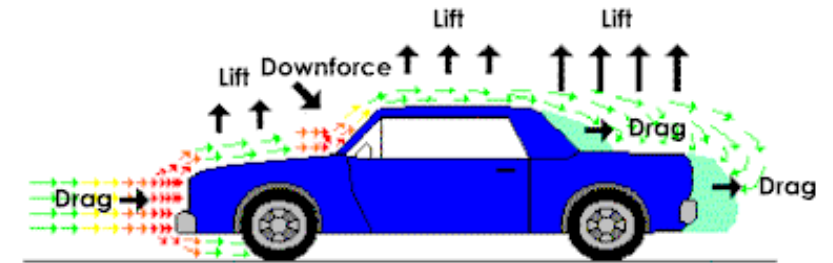
For negative lift pressure below > above

Why increase load on tyres?

More grip!

Aero vertical force does not have to be accelerated like increased mass.

Lift and Downforce From Over Body Flow



Lift

Equation for Lift

$$\text{Lift Force} = C_L \times 1/2 \rho V^2 \times A$$



Table 2.3 Lift and Drag Coefficients for Several Road Vehicles

	Year/Make	C_d	C_l	Remarks
Sedans	1973 Opel Record	0.47	0.36	Ref. 2.3
	1980 Peugeot 305 GL	0.44	0.44	Ref. 2.4, p. 128
	1986 Subaru XT	0.29–0.31	0.10	Ref. 2.5
Sports cars	Porsche 911 Carrera	0.38–0.39	NA	Ref. 2.6, p. 198
	1982 Camaro Z28	0.37–0.38	NA	Ref. 2.6, p. 198
	1982 Corvette	0.36–0.38	NA	Ref. 2.6, p. 198
Race cars	1990 Mazda GTO (rear deck spoiler)	0.51	–0.44	Ref. 2.7
	1991 Mazda GTO (rear wing)	0.48	–0.53	Ref. 2.7
	1973 Porche 917/30	0.57	–1.04	Ref. 2.8 p. 170
	1985 generic prototype	0.74	–1.79	Ref. 2.9
	generic Porsche 962 C	0.80	–4.80	Ref. 2.10
	1992 Mazda RX-792P	0.70	–3.80	Ref. 2.11
	1992 Nissan P35, C	0.50	–3.00	Say so
	1983 generic F-1, no sidepods	1.07	–0.99	Ref. 2.12
	1987 March Indy	1.06	–1.71	Ref. 2.13
	1991 Penske PC20, high downforce	1.11	–3.33	Ref. 2.14
	1991 Penske PC20, speedway	0.740	–2.073	Ref. 2.15
	1992 Galmer G92, high downforce	1.397	–3.688	Ref. 2.15
	1992 Galmer G92, speedway	0.669	–1.953	Ref. 2.15
	2000 Ferrari F-1 (high downforce)	0.99	–2.85	Ref. 2.22
	2002 Dodge NASCAR	0.39	–0.42	Ref. 3.13
	2004 Lola Indy car (high downforce)	0.96	–2.75	NA
	2004 Audi R8	0.54	–2.60	NA

NA = not available

Example 2

A hill climb vehicle is tested in CFD and is found to have the following aerodynamic coefficients

$$C_d = 0.741$$

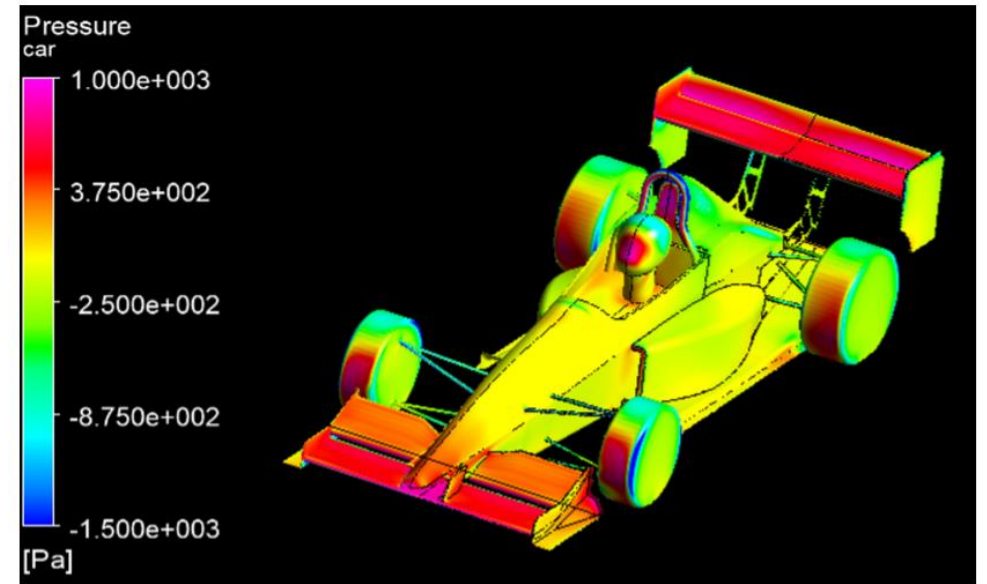
$$C_l = -1.760055$$

A) If the car has a frontal area of 1.09m^2 , calculate the resulting lift and drag forces at 35m/s if the density of air is 1.225kg/m^3

B) Explain the significance of the negative lift coefficient and the effect on the vehicle performance

C) Calculate aerodynamic efficiency of the vehicle

$$E = \text{Lift/ Drag}$$



Example 2 answers

A) Lift = -1437N

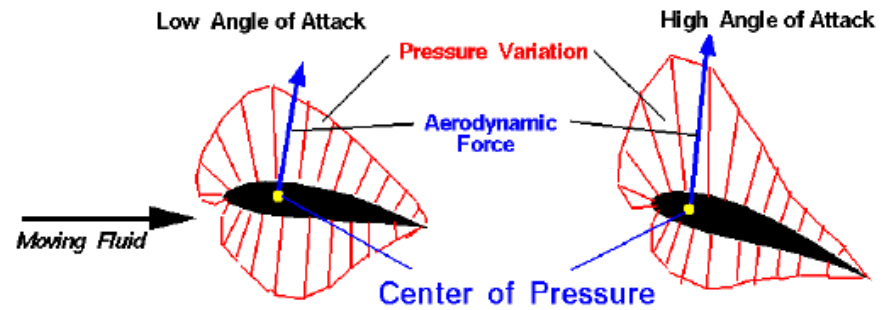
Drag = 605N

B) Negative lift is known as downforce. It increases the reaction force between the tyres and ground and hence increases grip. As the mass of the vehicle is not increased by downforce, an increase in cornering performance is yielded.

C) Efficiency = - 2.38

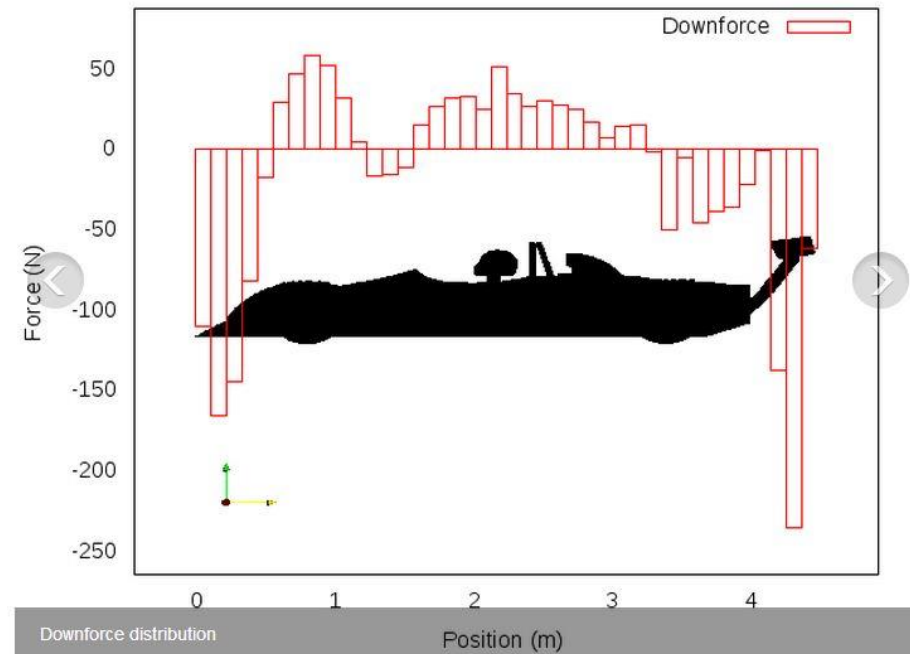
Lift

Centre of Pressure



Center of Pressure is the average location of the pressure.
Aerodynamic force acts through the center of pressure.
Center of pressure moves with angle of attack.

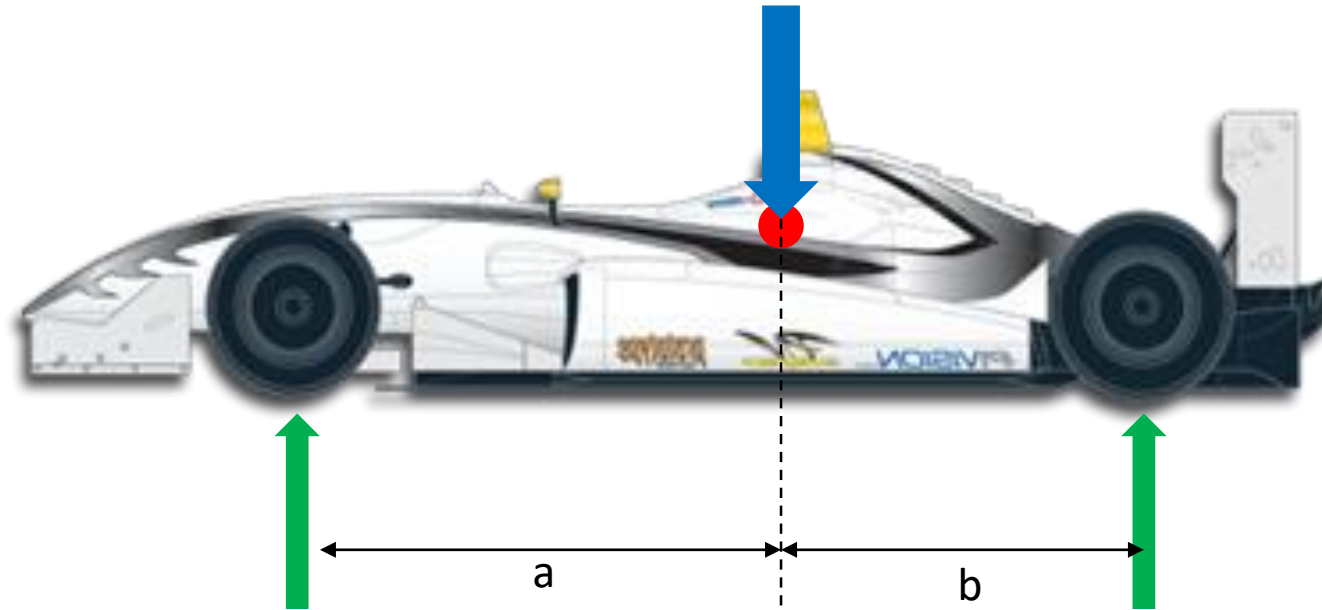
Drag & Downforce Distribution



BALANCE

Centre of Pressure

Total Aero Load



Front Axle Aero Load

Rear Axle Aero Load

$$CoP = \frac{\text{Front Axle Aero Load}}{\text{Total Aero Load}} \times 100$$

$$CoP = \frac{\text{Front Axle Aero Load}}{\text{Front Axle Aero Load} + \text{Rear Axle Aero Load}} \times 100$$

Example 3



The MIRA produces -939.8N of lift and 541.6N of downforce at 35m/s when tested in the MIRA wind tunnel. The Centre of Pressure is 58% towards the rear.

Given the MIRA has a frontal area of 1.52m^2 , calculate;

- Coefficient of Lift
- Coefficient of Drag
- Aerodynamic Efficiency
- The distance, x , from the front axle to the centre of pressure given the MIRA has a wheelbase of 2.65m

Example 3 Answers

Coefficient of Lift = -0.83

Coefficient of Drag = 0.476

Aerodynamic Efficiency = -1.74

Distance x = 1.537m

Coursework explained

Step 1

Calculate static vertical loads

- using notes from Tim's 1st lecture
- remember Static Weight Distribution

Vertical Static Loads (N)		
(N)	Left	Right
Front		
Rear		

E.g. Front Left = Static Front Load * Left Static Weight Distribution Percentage

Step 2

Calculate the Aero Load of the vehicle?

$$V = 30\text{m/s}$$

$$\textit{Aero Load} = Cl * 0.5\rho V^2 * A$$

Step 3

Calculate vertical loads for each contact patch for each scenario;

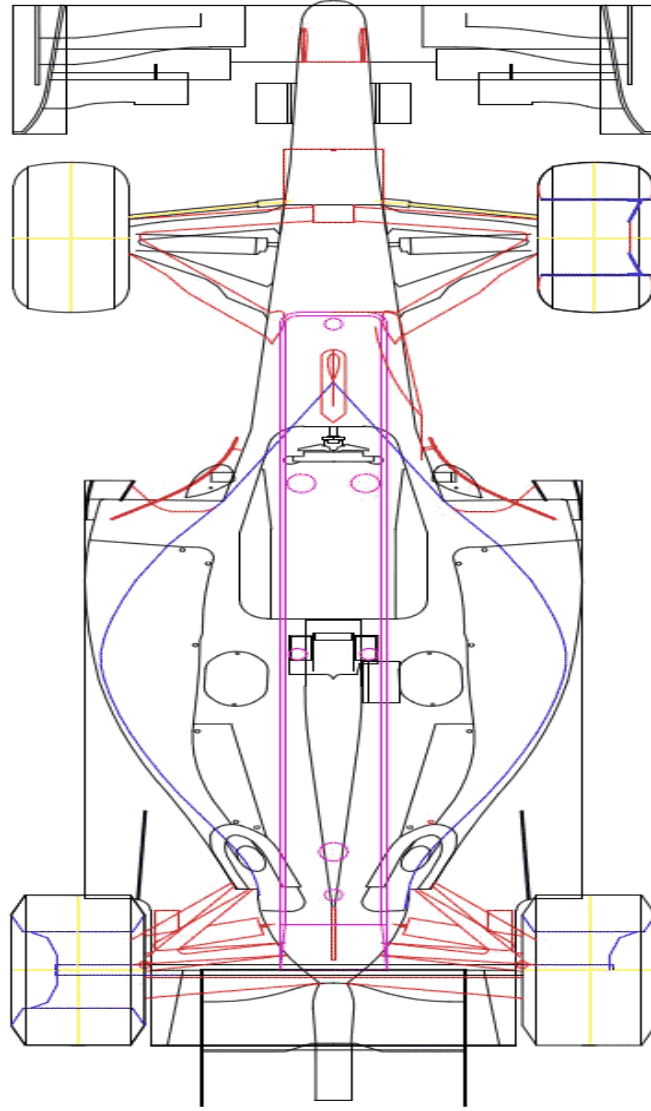
Assuming

Front Track = Rear Track

Left Wheelbase = Right Wheelbase

This is the data provided in the coursework

Mass	628	kg
Wheelbase	2.8	m
Centre of Gravity Height	0.36	m
Static Weight Distribution (Front)	47	% Front
Static Weight Distribution (Left)	51	% Left
Cl	-0.62	
A	1.2	m ²
Air Density	1.223	kg/m ³
Centre of Pressure	42	% Front
Average Track	1.62	m
Maximum G	1.5	G



Step 3

Calculate vertical loads for each contact patch for each scenario;

Assuming

Front Track = Rear Track

Left Wheelbase = Right Wheelbase

E.g.

FR = FR Static Load + (Lateral Weight Transfer * % of weight at front) + (Longitudinal Weight transfer * % of weight at right) – ((Aero Load/2) * % of aero force at front)