BAE SYSTEMS

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THE SCIENCE OF AUTONOMOUS VEHICLES

FORMULA 1 ROLEX AUSTRALIAN GRAND PRIX 2020 12-15 MARCH

25TH RACE MELBOURNE

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STUDENTS WILL LEARN

1. How Autonomous Vehicles work

a. What is an autonomous vehicle? How are they classed?

b. How autonomous vehicles work and 3 main technologies involved: Sensors, Connectivity, Software/Control Algorithms.

c. How AI works: machine learning, algorithms and pseudocode.

d. Powering an autonomous vehicle: battery-electric vs hybrid-electric powertrains.

2. Examples of Autonomous Vehicles

a. Formula E's Robocar.

  i. The difference between Robocar and DevBot 2.0.

  ii. Roborace: Racing Robocar and DevBot 2.0.

    1. The science behind racing (aerodynamics, Newton's 3 laws of motion and law of universal gravitation, energy, material science).

b. Australian Army M113 AS4 Armoured Personnel Carriers.

c. BAE Systems' Taranis: Unmanned Air Vehicle.

  i. How sound works.

3. STEM career pathways:

a. Various STEM roles within the autonomous vehicle department and other BAE System opportunities.

b. Hear from BAE Systems engineer - Q&A.

INTRODUCTION

Autonomous vehicles, also referred to as self-driving vehicles are cars or trucks that don't require human drivers to operate the vehicle and that combine sensors, and software to control, navigate, and drive the vehicle.

Autonomous vehicles can be classified into 6 categories.

Layers of autonomy

Level 0: All major systems are controlled by humans.

Level 1: Certain systems, such as cruise control or automatic braking, may be controlled by the vehicle, one at a time.

Level 2: The vehicle offers at least two simultaneous automated functions, like acceleration and steering, but requires humans for safe operation.

Level 3: The vehicle can manage all safety-critical functions under certain conditions, but the driver is expected to take over when alerted.

Level 4: The vehicle is fully-autonomous in some driving scenarios, though not all.

Level 5: The vehicle is completely capable of self-driving in every situation.

How they work?

Autonomous vehicles use 3 technologies: **Sensors**, **Connectivity**, and **Software/ Control Algorithms**.

1. Sensors

- RADAR sensors dotted around the vehicle monitor the position of other vehicles nearby.
- LiDAR sensors help to detect the edges of roads, and identify lane markings by bounding pulses of light off the vehicle's surroundings.
- Ultrasonic sensors in the wheels detect the position of kerbs and other vehicles when parking.
- High Powered Cameras detect traffic lights, read road signs and keep track of other vehicles, while also looking out for pedestrians and other obstacles.
- GNSS and GPS provide vehicle positioning information that helps the vehicle to stay on course.

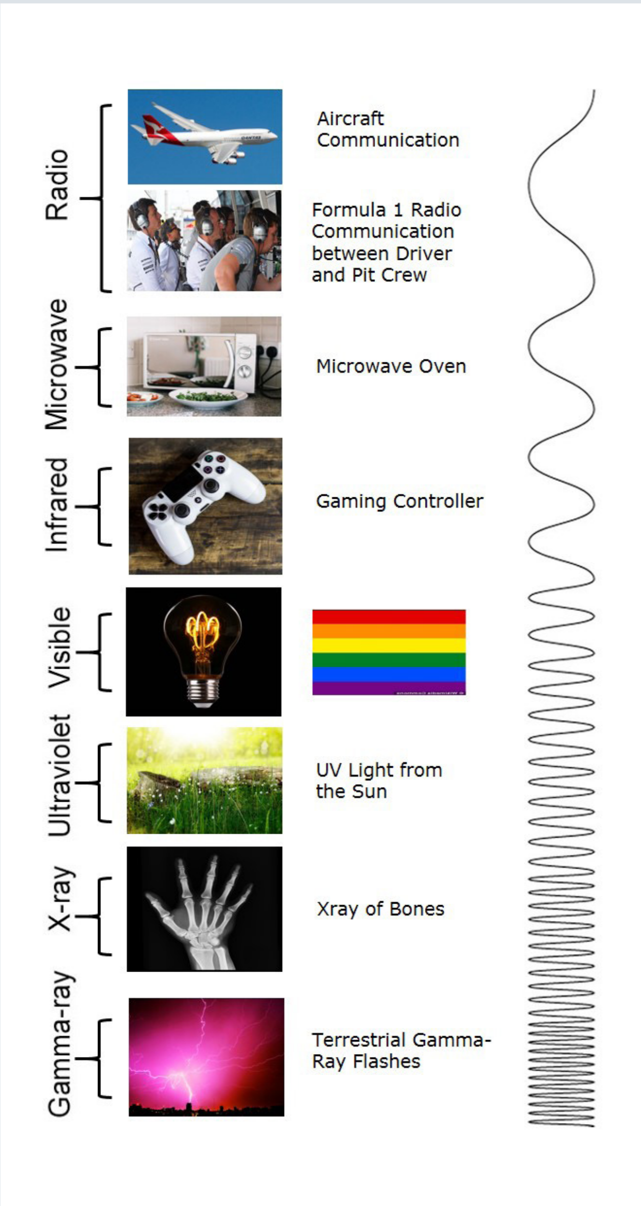
2. Connectivity systems allow access to the latest traffic, weather, surface conditions, construction, maps, adjacent vehicles, and road infrastructure.

3. Software/Control Algorithm analyses all of the data from the various sensors and connectivity to anticipate braking or avoid hazardous conditions, and to make decisions about steering, speed, and route guidance.

SENSORS How They Work

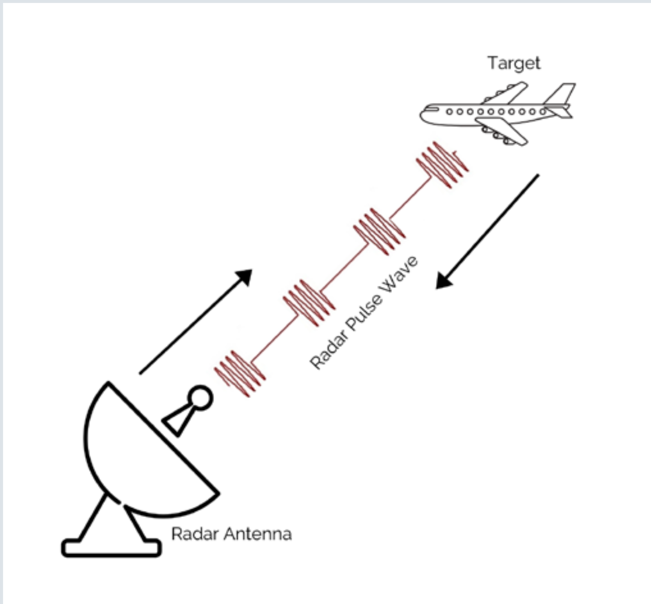
RADAR (RAdio Detection And Ranging):

RADAR works by transmitting electromagnetic waves in the radio or near microwave bandwidths with the use of an antenna pointed in a particular direction to determine range, angle or velocity of an object while the receiving antenna (usually the same antenna is used for transmitting and receiving) detects the echoes (radio waves reflecting off the object) in the path of the signal. A processor determines the information about the object such as location and speed.

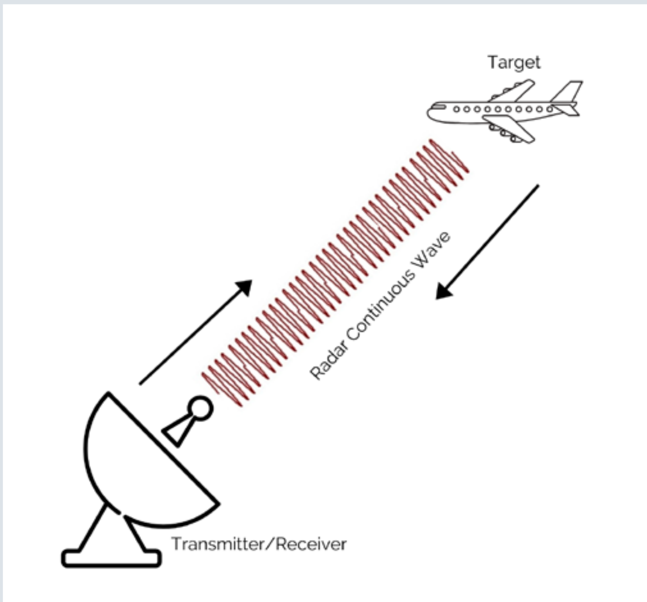


Did you know that there are 2 types of RADAR?

1. **Pulsed Wave** which emits radio wave pulses, has only 1 antenna and is subject to jamming and can provide range and altitude.



2. **Continuous Wave** emits a continuous wave which needs 2 antenna, is more resistant to jamming and has a higher signal-noise ratio (SNR) which is a way of determining how much the signal coming in is stronger than the noise.

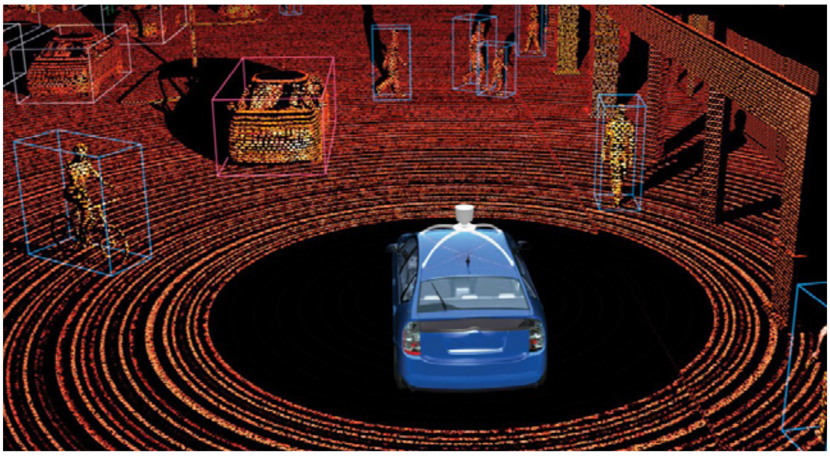


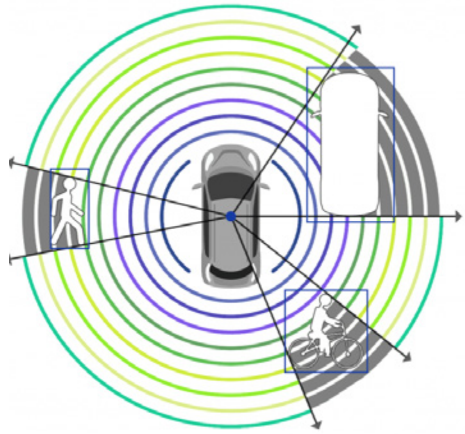
SENSORS How They Work

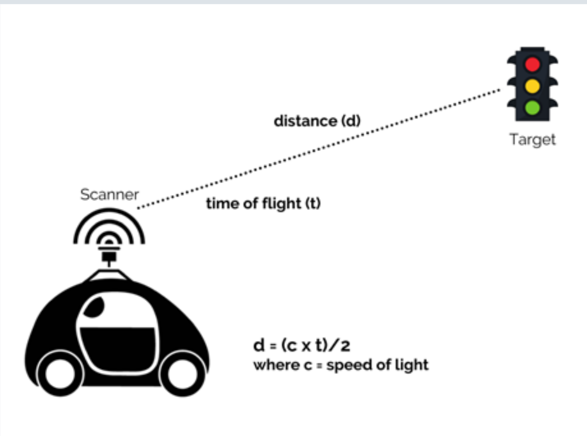
LiDAR (Light Detection And Ranging):

measures distance to an object by illuminating the object with LASER (Light Amplification by Stimulated Emission of Radiation) and measuring the reflected light with a sensor. The variation in return times and wavelengths are then used to make a 3D image of the object.

The LiDAR instrument fires rapid pulses of LASER light at a surface, some at up to 150,000 pulses per second. A sensor on the instrument measures the amount of time it takes for each pulse to bounce back. Light moves at a constant and known speed so the LiDAR instrument can calculate the distance between itself and the target with high accuracy. By repeating this in quick succession the instrument builds up a complex 'map' of the surface it is measuring.







Did you know that when you shine a torch on a surface what you are actually seeing is light being reflected and returning to your retina? That's how LiDAR works. The equipment needed to measure the reflected light (or returning photons) has to be super-fast since light travels very fast - about 300,000 kilometres per second also written as 300,000 km/s or 3x105 km/s.

To measure the distance a photon has travelled to and from an object, the following formula can be used:

$$\textit{Distance} = \frac{\textit{(Speed of Light} \times \textit{Time of Flight)}}{2}$$

Test Yourself!

Using the formula, calculate the distance a photon has travelled if we know the Time of Flight was 3.4 seconds.

SENSORS How They Work

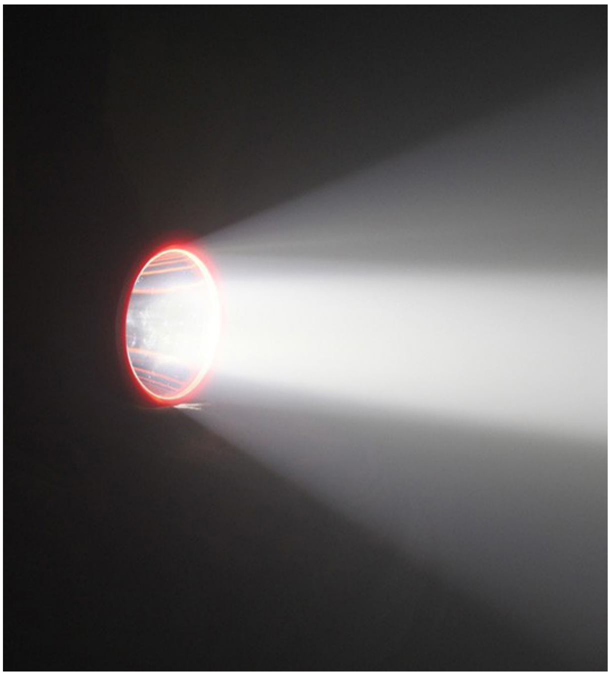
LASER (Light Amplification by Stimulated Emission of Radiation):

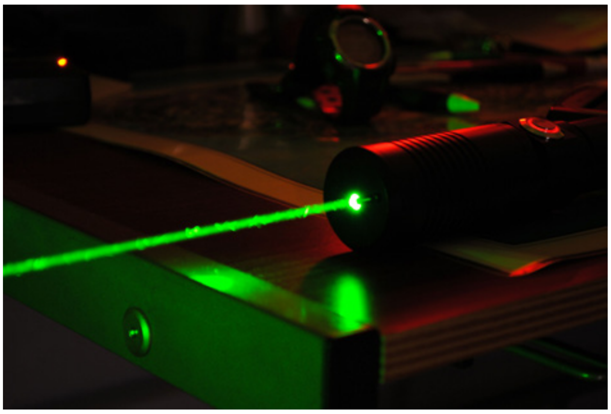
We mentioned that LiDAR fires rapid pulses of LASER light at a surface but what exactly is a LASER? Well a LASER is a device that amplifies light and focuses light into a tight narrow spot or beam; this is known as emitting light coherently.

For example, a flashlight produces 'white' light (a mixture of all different colours, made by light waves of all different frequencies), while a LASER makes what's called monochromatic light (of a single, very precise frequency and colour—often bright red or green or an invisible 'colour' such as infrared or ultraviolet).

Also, a flashlight beam spreads out through a lens into a short and fuzzy cone, a LASER shoots a much tighter, narrower beam over a much longer distance. This is referred to as being highly collimated.

Lastly, light waves in a flashlight beam are all jumbled up (with the crests of some beams mixed with the troughs of others), the waves in laser light are exactly in step: the crest of every wave is lined up with the crest of every other wave. This is referred to as being coherent. Think of a flashlight beam as a playground full of your friends, running around in all directions playing all kinds of games like footy, and tiggy at the same time but a laser beam is like a parade of soldiers all marching precisely in step.





SENSORS How They Work

Ultrasonic Sensors

An ultrasonic sensor is an instrument that measures the distance to an object using ultrasonic sound waves. High frequency sound waves, too high for human ears to hear, are sent via transducers and these sound waves reflect from objects to produce distinct echo patterns and the sensor then works out how far an object is. By calculating the travel time and the speed of sound, the distance can be calculated.

Test Yourself!

If we know that speed = distance/time calculate the distance of the kerb from the Autonomous Vehicle's sensor, if the time the sound wave took to get back to the sensor was 4.8 seconds.

SENSORS How They Work

High Powered Cameras

High powered cameras are used to enable an autonomous vehicle to accurately and precisely recognise its own position and that of objects around it at any given time so the vehicle can execute its desired manoeuvre. To do this a number of different cameras are used.

1. Stereo cameras simulate a pair of eyes

Stereo cameras are 2 digital cameras working together. These images allow depth perception of a surrounding area which gets information about the position, distance and speed of objects. The cameras capture the same scene from two different viewpoints.

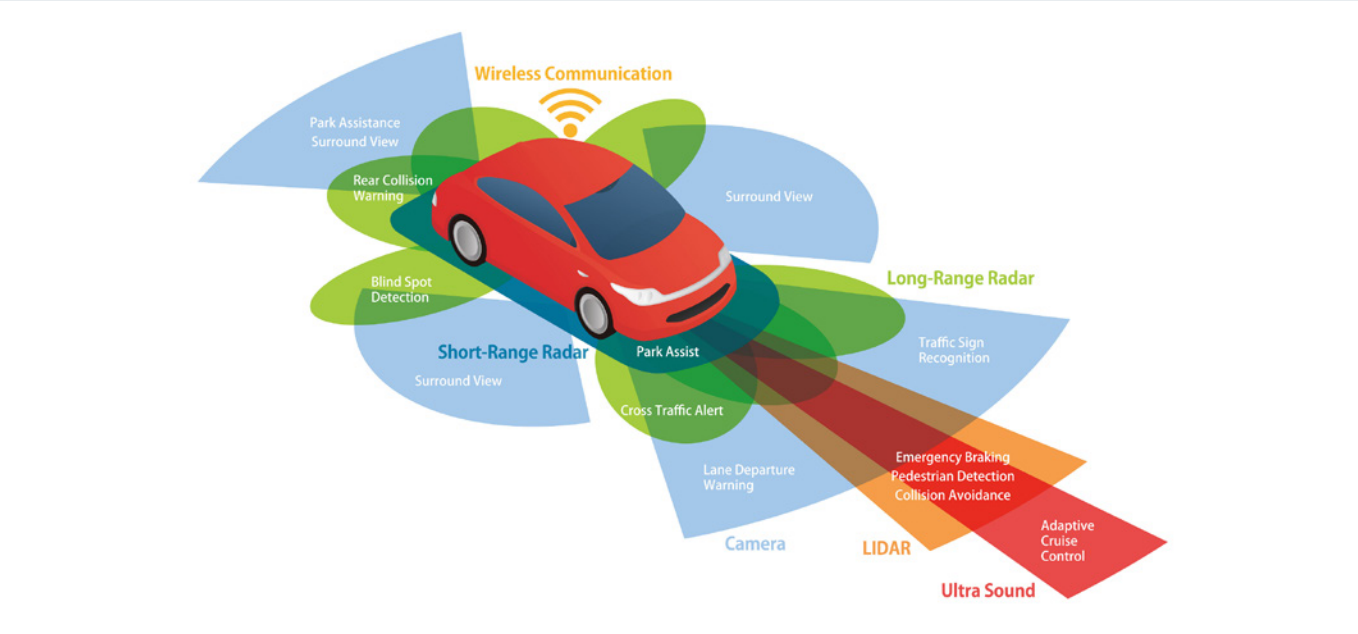
2. ToF cameras measure the speed of light

Another method is Time-of-Flight (ToF), which determines distance based on the transit time of individual light points. A ToF camera provides 2 types of information on each pixel: the intensity value – given as grey value – and the distance of the object from the camera, known as the depth of field.

3. Eagle-eyed vision

Modelled on an actual eagle's eye this camera is capable of producing a high-resolution image in the centre, and that of the wide-angle lens on the very outer edge. For example, all new Tesla cars come with 8 surround cameras that have 360 degrees of visibility around the car and up to 250 metres of range. Three cameras (Wide, Main and Narrow) forward cameras mounted behind the windshield provide broad visibility in front of the car, and focused, long-range detection of distant objects. The wide camera provides 120 degree fisheye lens which captures traffic lights, obstacles cutting into the path of travel and objects at close range. The main camera covers a broad spectrum of use cases and the narrow camera provides a focused, long-range view of distant features which is useful in high-speed operation.

Forward looking side cameras provide 90 degree visibility and are able to detect cars unexpectedly entering a lane, and provide additional safety when entering intersections with limited visibility. Rearward looking side cameras monitor rear blind spots on both sides of the car which is important for safely changing lanes and merging into traffic. Lastly, the rear view camera used for performing complex parking manoeuvres and backing up.



SENSORS How They Work

GNSS (Global Navigation Satellite System)

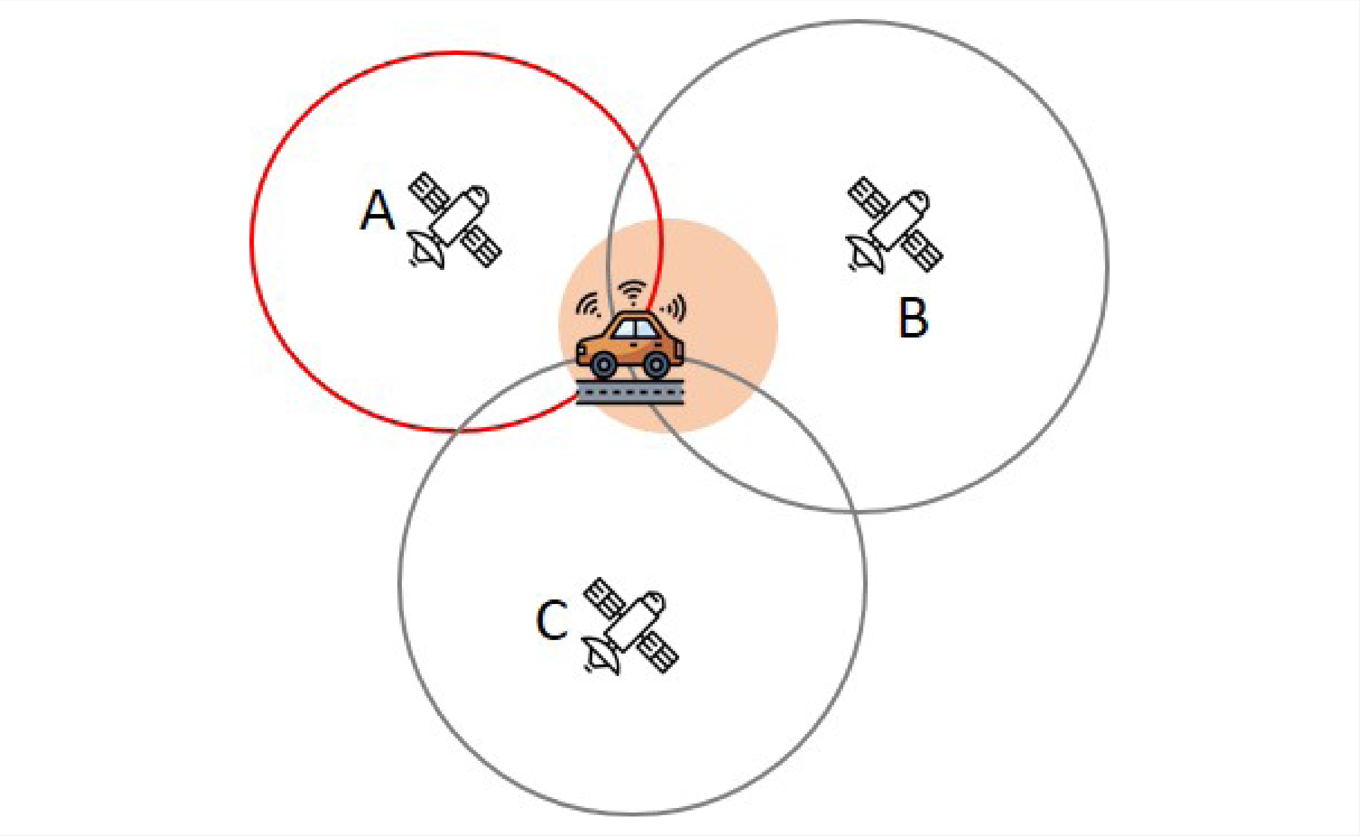
is the standard term used worldwide to describe the satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. This term includes GPS, GLONASS, Galileo, Beidou and other regional systems. Access to multiple satellites improves accuracy, redundancy, and availability at all times since GNSS receivers can pick up signals from other systems.

GPS (Global Positioning System)

is a satellite-based radionavigation system that consists of a network of about 30 satellites orbiting the Earth at an altitude of 20,000 km. The GPS was developed by the United States government for military use and is now available to anyone that has a GPS device, mobile phone or handheld GPS unit. GPS uses Trilateration to work out where you are and this is how autonomous vehicles are able to use GPS to figure out where they're located.

Each satellite transmits a radio signal (also called a carrier wave) with information (known as modulation) about its current time and position and this is done at regular intervals. These signals, travelling at the speed of light, are intercepted by your GPS receiver, which calculates how far away each satellite is based on how long it took for the messages to arrive.

Imagine you are standing somewhere on Earth with 3 satellites in the sky above you. If you know how far away you are from satellite A, then you know you must be located somewhere in the red circle. If you do the same for satellites B and C, you can work out your location by seeing where the three circles intersect. This is just what your GPS receiver does, although it uses overlapping spheres rather than circles.



SENSORS How They Work

The Brains behind the Sensors: Artificial Intelligence (AI)

Autonomous vehicles use Convolutional Neural Networks (CNNs) which are machine learning models. Software Engineers use CNNs to teach and train the algorithms to steer a vehicle the same way a human would by matching the steering wheel rotations to road curvatures using the vehicle's sensors (high powered cameras, GPS etc) eventually learning steering commands for different driving situations.

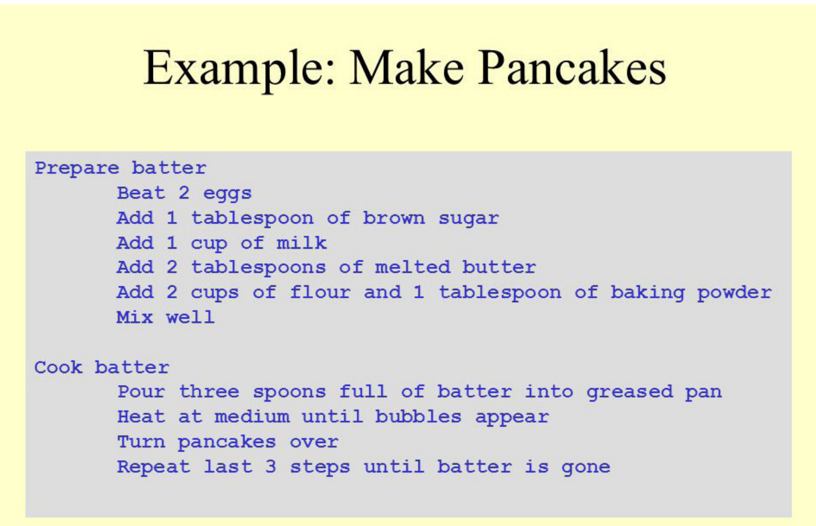
But it doesn't stop there. The algorithms process all the inputs from the sensors, connectivity systems, the hard-coded rules, and obstacle avoidance information to plot a path and send instructions to the vehicle which controls acceleration, braking, and steering.

So what's an algorithm?

An algorithm is a **series of ordered steps that we give to computers to solve a problem or achieve some end**. A good example of an algorithm is a recipe. Say you want to make pancakes. To do this you'd need a recipe which would tell you the exact steps to take and what ingredients (referred to as inputs) to add to create your delicious pancakes (the output).

Test Yourself!

What's another example of an algorithm? Write out the algorithm and compare it with your classmates.



SENSORS How They Work

Computing algorithms are written in pseudocode, and programming languages. Pseudocode is an informal high-level description of the algorithm using structural conventions of programming but is intended for human reading rather than machine reading. Here's how to do it:

How to write a Pseudocode!

1. Arrange a sequence of tasks and then write the pseudocode. Well we know that a sequence of tasks is an algorithm.
2. Start with the statement which is the main goal or aim. For example: This program will allow the user to check whether a number is even or odd.
3. Indent statements such as **if-else**, **for**, and **while loops**. This allows you to make sense of the decision control and execution mechanisms and it improves readability.
4. Use appropriate sentence casings, such as CamelCase for methods, upper case for constants and lower case for variables.
    a. CamelCase is where you write a phrase capitalised first letters without any intervening spaces. There are 2 types of CamelCase:
        i. UpperCamelCase: the first word is uppercase
        ii. lowerCamelCase: the first word is lowercase
5. Elaborate everything which is going to happen in the actual code. Don't make the pseudocode abstract.
6. Keep it simple therefore don't add too many technical terms
7. Now you're ready to write some pseudocode.

Pseudocode Example:

```
if "1"
    print response
        "I am case 1"

if "2"
    print response
        "I am case 2"
```

Test Yourself!

Following from the algorithm you wrote earlier, write the corresponding pseudocode, remembering to keep it simple.

POWERING AN AUTONOMOUS VEHICLE

Battery-Electric vs Hybrid-Electric Powertrains: What's the Difference?

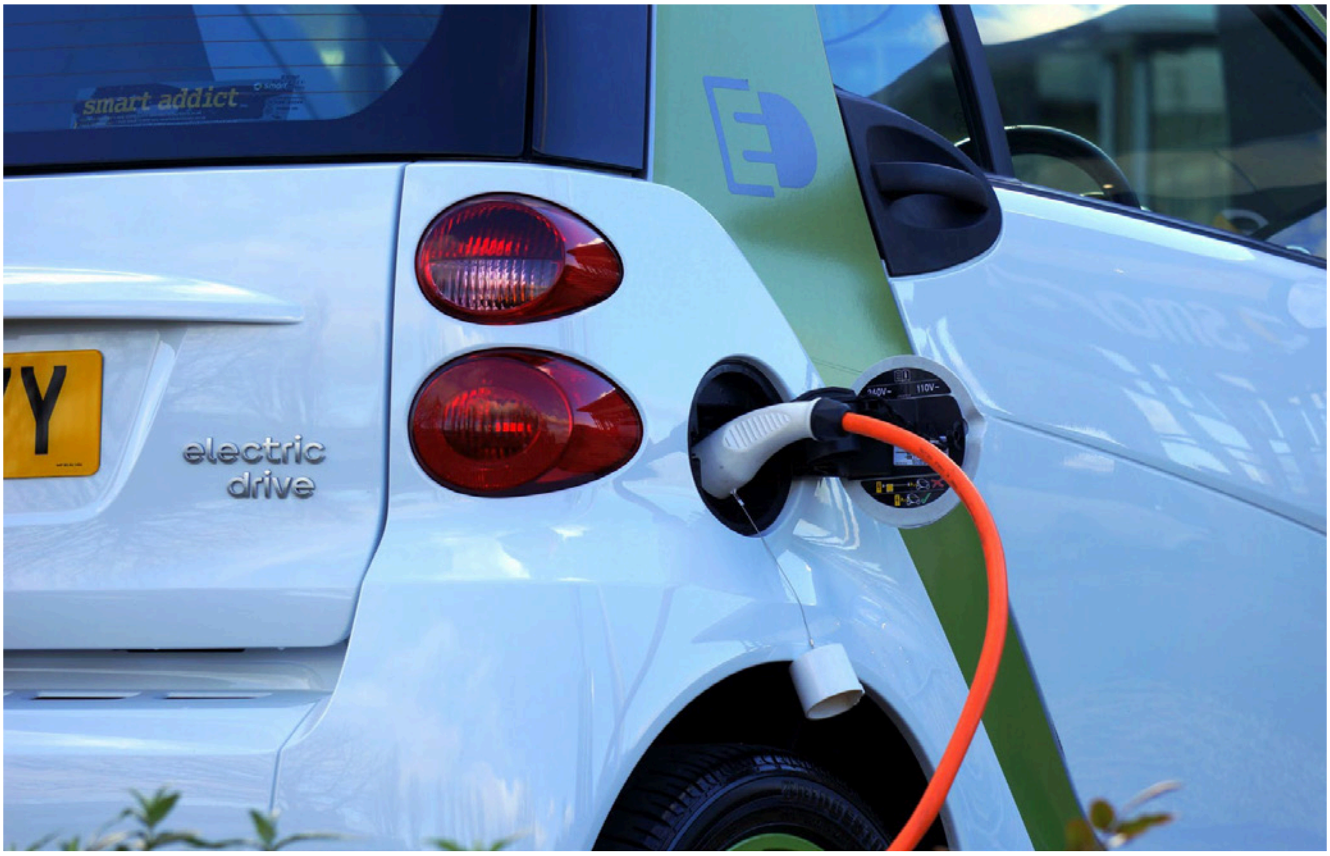
A drivetrain is the group of components that deliver power from the vehicle's engine or motor to the vehicles wheels. These components are generally the engine, generator, battery, electric motor (depended on the type of hybrid configuration used).

Battery Electric Vehicles (BEVs) consist of a battery, connected to an electric motor (either AC or DC) and have no internal combustion engine. As automotive batteries generally operate on DC current, while the grid operates AC, a converter is needed to transfer power to the battery.

Hybrid-electric vehicles (HEVs) use 2 or more distinct types of power, generally the internal combustion engine and an electric generator, the latter powering an electric motor. The basic principle of hybrid vehicles is that different motors work better at different speeds:

1. The electric motor is more efficient at producing torque
2. The combustion engine is better for maintaining high speed

In HEVs the drivetrain design determines how the electric motor works in conjunction with the conventional internal combustion engine and hybrid vehicles can be broken down into 3 categories, *series*, *parallel* and *series-parallel*.



POWERING AN AUTONOMOUS VEHICLE

Battery-Electric vs Hybrid-Electric Powertrains: What's the Difference?

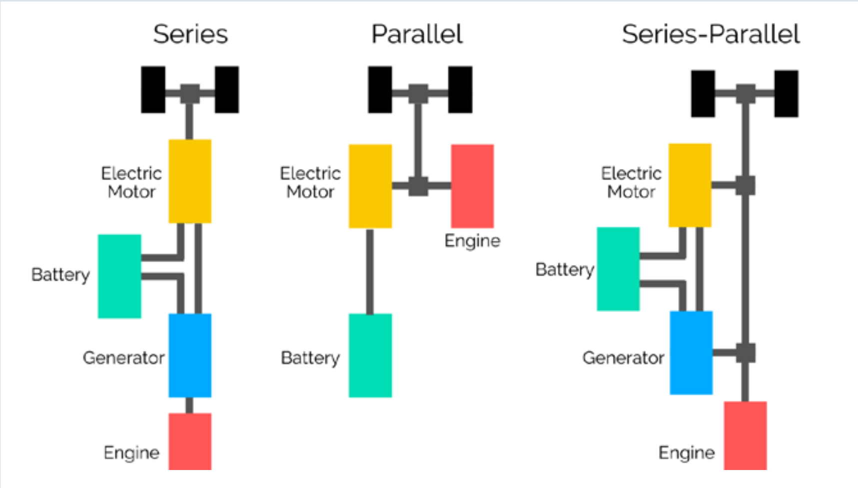
Series Hybrid have electric motors drawing current from a battery which drives the wheels; basically it's a BEV. The difference is that a series hybrid has an engine which is connected to a generator instead of the wheels and keeps the battery topped up. Series hybrids run solely on battery power in all conditions, with a relatively small internal combustion engine available to recharge the batteries when zero-emissions are not required and to act as a "range extender".

Because the internal combustion engine is only driving a generator, it can run at a constant speed and reasonably constant load, which is very efficient.

Parallel hybrids can run simply on battery power and purely on their parallel internal combustion engine for higher speeds and/or longer distances. In this mode they can also recharge the battery for the next phase of battery operation. In addition they can usually use both power sources together to give additional acceleration, and this means that the internal combustion engine can be relatively small and low powered, and largely avoid inefficient "transient" operation, because of the boost provided by the battery power.

Series-parallel hybrids combine the 2 designs ensuring the engine can both drive the wheels directly (like the parallel powertrain), be disconnected, with only the electric motor providing power (like the series powertrain) and be disconnected, with only the electric motor providing power (like the series powertrain). At lower speeds it operates more as a series vehicle, while at high speeds, where the series drivetrain is less efficient, the engine takes over and energy loss is minimized.

This system incurs higher costs than a pure parallel hybrid since it requires a generator, a larger battery pack, and more computing power to control the dual system. Yet its efficiencies mean that the series/parallel drivetrain can perform better–and use less fuel–than either the series or parallel systems alone.



Test Yourself!

Now that you know how the varying powertrains work what do you think autonomous vehicles will be using? Explain why?

Meet the future of motorsport racing -
THE BOT GANG

Robocar

What does futuristic racing look like? Autonomous, connected and electric of course!

Meet Robocar the fastest autonomous car on the planet, having set a Guinness Book World Record in early 2019. Robocar reached an awesome average speed of 282.42 km/h (attempt 1 setting a speed of 280.365 km/h and attempt 2 of 284.492 km/h). The bot was designed by Daniel Simon who also designed the cars in the sci-fi movies, Tron Legacy and Oblivion.

Robocar is impressive to say the least. Robocar is 4.8 m long, 2 m wide and weighs 975 kg. There are 4 independent electric motors each with 300 kW of power, and 540 kW battery. There are 5 LiDAR sensors, 6 AI cameras, 2 RADARs, 18 ultrasonic sensors dotted around the car, 2 optical speed sensors, and GNSS positioning, and the car's on board computer processes 24 trillion calculations per second.

What do missiles, gaming & Robocar have in common?

The team had to get special export licence restrictions because the GNSS unit, which is a fibre optic gyro that Robocar uses, is so accurate that it could be used to guide a missile. The processing power needed to compute all those calculations comes from the custom made automotive NVIDIA Drive PX2 on board which is equivalent to 160 laptops!

Meet the future of motorsport racing - THE BOT GANG

Robocar Racing: Roborace!

Did someone say autonomous vehicle racing? The new car raced against other autonomous Robocars in a series that was created as a platform for software engineers and suppliers to develop software, technology and materials that will filter down into driverless road cars.

Roborace's debut competition, **Season Alpha**, was held in 2019 with events taking place in Europe and the USA.

Multiple teams raced against each other and were given the same hardware but were required to develop the AI software which essentially is the 'driver'. The actual vehicles used for Season Alpha were the DevBot 2.0, different from the Robocar that set the Guinness World Book of Records. The DevBot 2.0 has room for a driver which lets the teams set human lap times which they can then try and beat with the AI. From the image below, the top bot is the DevBot 2.0, and the bottom one is the Robocar.

These are the Robocars that'll be used for Season Alpha all equipped with room for a human driver to take control of the vehicle.

DevBot versus Human

There's a 10 to 20 per cent difference in lap times between human and AI but this difference dependents on the quality of the human driver and because of the 1m safety margin that is left to the barrier. Concrete barriers, like the ones at Formula E tracks, are really good for LiDAR but if the mapping is out by even a centimetre, wheels get knocked off.

Meet the future of motorsport racing - THE BOT GANG

The science involved in racing?

Aerodynamics

Aerodynamics is the science that studies objects moving through air especially how air flows around objects like cars and airplanes. When engineers study aerodynamics to improve the speed and safety of race cars they have 2 main concerns:

1. Creating downforce, which helps push the car's tyres onto the track, and improve cornering performance, and
2. Minimising drag, which can slow the car down (and is a result of air resistance).

The Robocar must be able to reduce air resistance and increase downforce. Robocar is low and sleek to decrease drag and air resistance.

DID YOU KNOW?

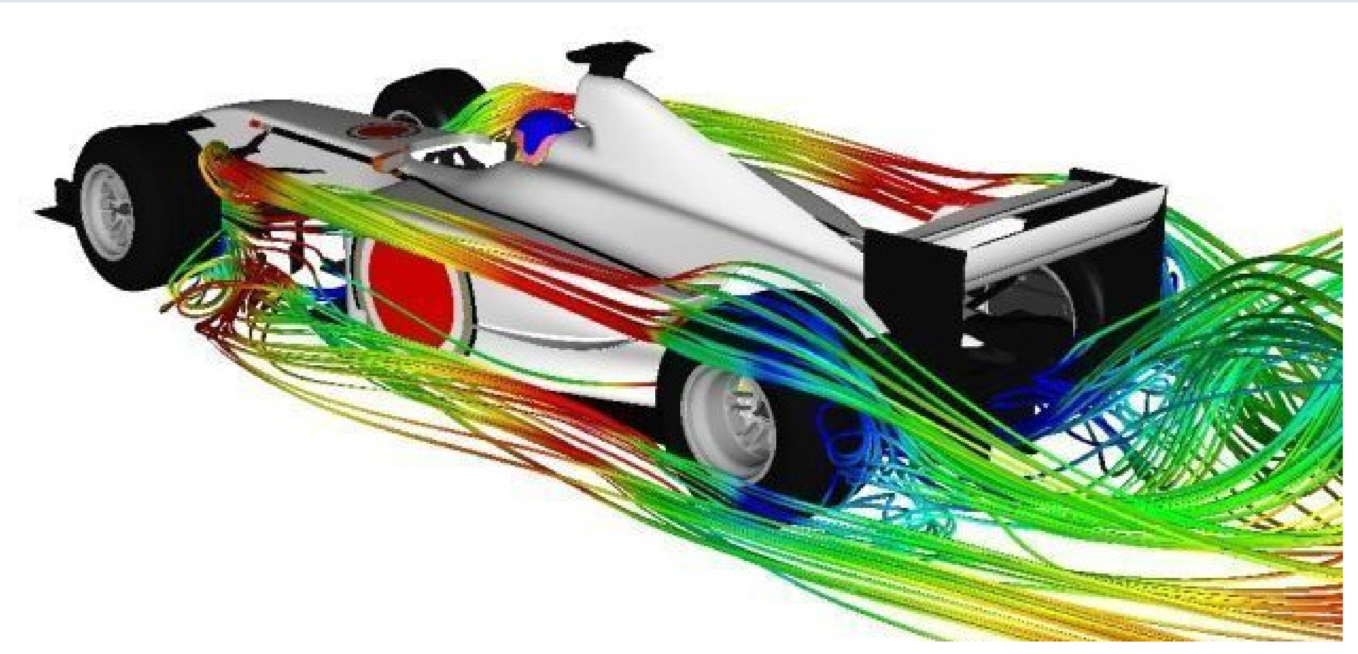
Without aerodynamic downforce, racing cars would flip over and crash once they go faster than 160 km/h. Current F1 cars race at over 300 km/h.

Meet the future of motorsport racing - THE BOT GANG

DID YOU KNOW?

Race car wings can produce amazing aerodynamic down force. When a car is traveling over 160 km/h, it can generate enough downforce to hold itself to the ceiling and drive upside down. Now that's awesome!

Air flowing over and under the car.



FORMULA 1 ROLEX AUSTRALIAN GRAND PRIX 2020 12 - 15 MARCH

25TH RACE MELBOURNE

Meet the future of motorsport racing - THE BOT GANG

Wings on a racing car work the opposite way to the wings on an aeroplane. Aeroplane wings create lift which causes flight but in a racing car they produce downforce which makes the car stick to the road. Did you know that engineers have designed the wings to be adjustable? That means they can move the wings to different angles: the front and rear wings have multiple settings they can be adjusted to.

Flat Wing:
less drag, more speed

Steep Wing:
more drag, more downforce

DID YOU KNOW?

Racing circuits that are in cities like Monaco have lots of tight corners, so race cars have their wings set steep but on tracks that have long straights and fast corners like at Monza in Italy the wings are set to a lower or flatter setting.

Can you explain why?

Test Yourself!

Can you think of other sports where aerodynamics is really important?

Name 5 sports where athletes make themselves smaller or larger to improve performance?

1. __________
2. __________
3. __________
4. __________
5. __________

THE SCIENCE OF AUTONOMOUS VEHICLES

Australian Army M113 AS4 Armoured Personnel Carriers go Autonomous!

BAE Systems Australia is working with the Australian Army to develop an autonomous version of the service's M113 AS4 armoured personnel carriers (APCs) as part of a demonstration project. Two APCs are being converted at BAE Systems Australia's Edinburgh Parks facility located in South Australia using autonomous technologies developed by the company.

These APCs will be used to conduct experiments to learn how better to use autonomous APCs on the battlefield for activities such as intelligence gathering, and logistics support.

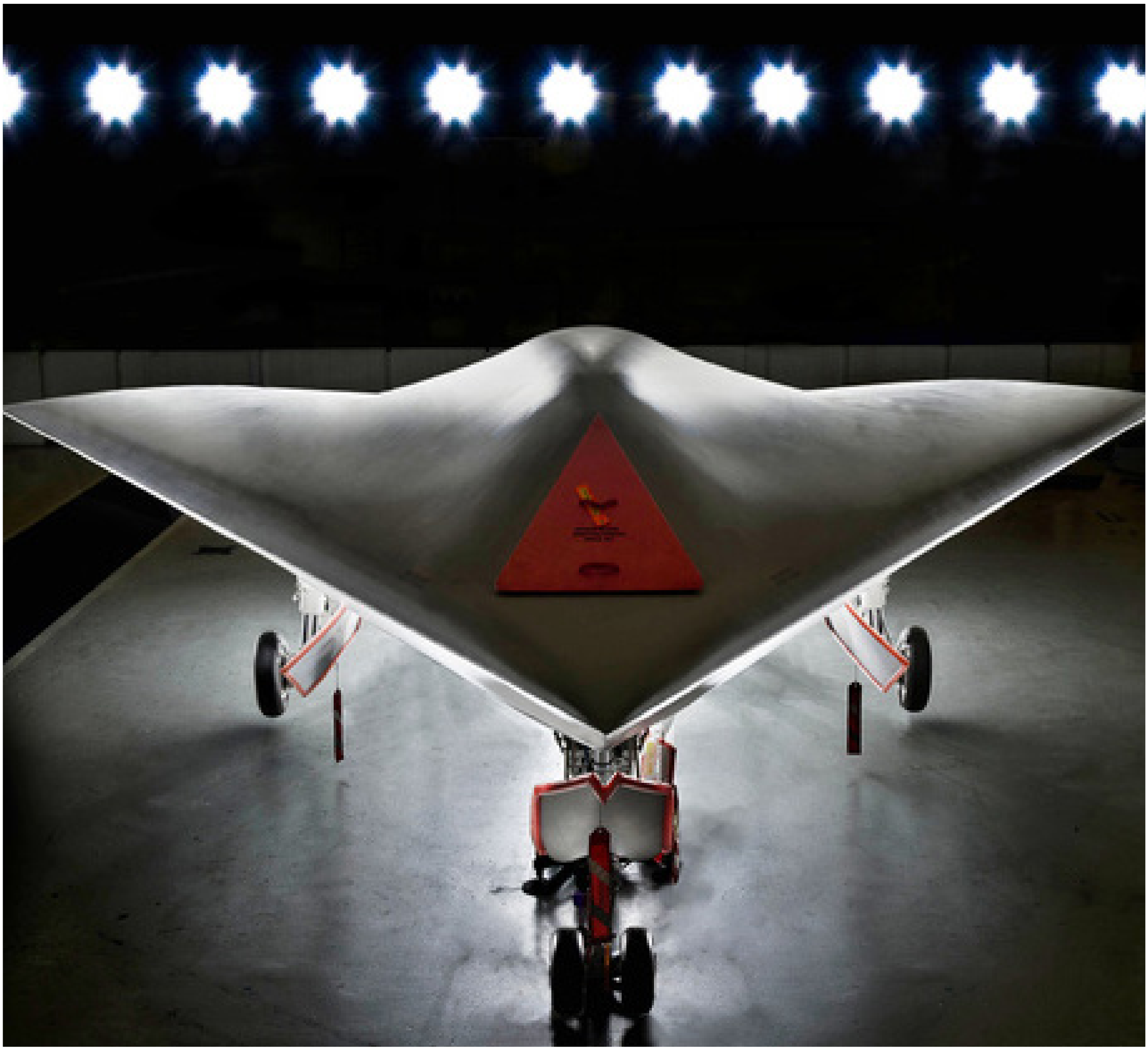
THE SCIENCE OF AUTONOMOUS VEHICLES

BAE System's Taranis: Unmanned Air Vehicle (UAV)

BAE Systems have also been working on an UAV demonstrator programme – better known as the Taranis, an aircraft that can fly and think for itself.

The Taranis is one of the world's largest UAVs and is approximately the same size as the BAE Systems Hawk advanced jet trainer which is 11.35 m long, 3.98 m high, has a wingspan of 9.94 m, and weighs 8,000 kg.

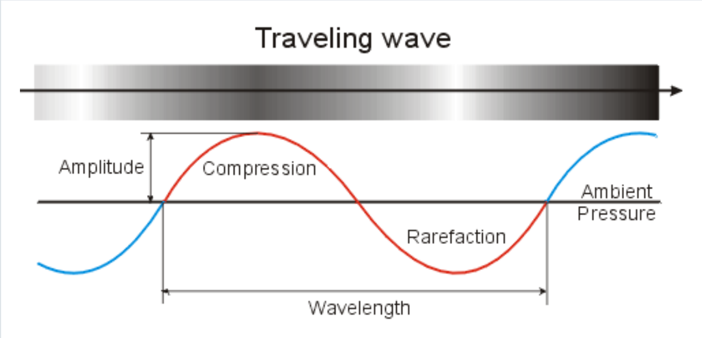
Taranis was tested in August 2013 and successfully passed testing that included take-off, rotation, climb-out, landing, and changes in altitudes and speeds. This stealth UAV can hit speeds of 1,127 km/h, that's supersonic flight, thanks to its Rolls-Royce propulsion system which outputs a whopping 28,825 N of thrust, and can almost break the sound barrier. So what's so special about the sound barrier anyhow? Let's find out.



THE SCIENCE OF AUTONOMOUS VEHICLES

What is Sound?

To understand what the sound barrier is we first have to learn about sound. Sound is the energy things produce when they vibrate or the speed of transmission of a small disturbance through a medium (solid, liquid or gas). The vibrating body causes the medium the sound is travelling in to vibrate. These vibrations are called travelling longitudinal waves which is what we hear. These waves have areas of high and low pressure called compressions and rarefactions, respectively.



The shaded area above the wave represents changes in pressure where the lighter areas are low pressure (rarefactions) and darker areas are high pressure (compressions). One wavelength of the wave is highlighted in red. The wavelength and the speed of the wave determine the frequency of the sound, also referred to as the pitch. Wavelength, frequency, and speed are related by the equation

Speed = Frequency × Wavelength

Sound waves travel at 340 m/s (1,224 km/h) at sea level and standard atmospheric conditions of 15 °C. But if an airplane was at cruising altitude 11,000 m – 20,000 m where the ambient temperature is -57 °C the speed of sound would be slower at 295 m/s. This is because the speed of sound in air depends on the type of gas and the temperature the sound is travelling in. These disturbances are transmitted through the gas, a result of collisions between the randomly moving molecules in the gas.

Did you know that the speed of sound in air is slower than it is in solids and liquids? Here's why.

We've learnt that sound is nothing more than a local disturbance whose propagation is aided by collisions between particles creating a longitudinal wave. We also know that solids, liquids and air are made up of molecules; solids have tightly packed molecules while air does not. So now imagine one molecule hitting the next molecule and then that molecule hitting the next, and so forth. Since solids are a lot denser than liquids and gases, that is, their molecules are much more tightly packed the distances between molecules is very small. Because molecules in solids are so close together they collide really quickly which means it takes less time for a molecule to bump into its neighbour; therefore, sound travels a lot quicker in solids.

THE SCIENCE OF AUTONOMOUS VEHICLES

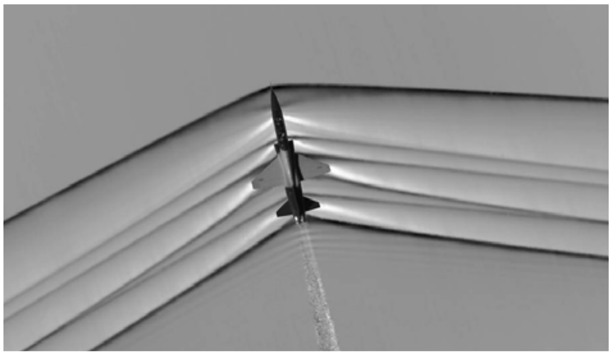
Test Yourself!

Knowing what you know about how sound travels, can sound travel through a vacuum? Explain why or why not?

To understand the sound barrier, let's take the military F/A-18C Hornet jet fighter (as seen in the image). Because the propagation (also known as transmission) speed of sound waves are limited, sources of sound that are moving can begin to catch up with the sound waves they emit, that is, the F/A-18C Hornet catches up with the sound waves. As the speed of the F/A-18C Hornet increases to the sonic velocity (the local velocity of sound waves), these sound waves begin to pile up in front of the F/A-18C Hornet. If the F/A-18C Hornet has sufficient acceleration, it can burst through this barrier of sound waves and move ahead of the radiated sound.

The change in pressure as the F/A-18C Hornet outruns all the pressure and sound waves in front of it is heard on the ground as an explosion, or sonic boom. The picture below shows the sonic boom produced.

Amazing isn't it? But what do these shockwaves actually look like? Thanks to NASA we now know.



THE SCIENCE OF AUTONOMOUS VEHICLES

We've learned that as an aircraft moves through the air, the air molecules near the aircraft are disturbed and begin to move around the aircraft. If the aircraft passes through the air at a low speed, typically less than 112 m/s the density of the air remains the same. But when aircraft travel at higher speeds, some of the energy from the aircraft goes into compressing the air and locally changes the density of the air. This compressibility effect alters the amount of resulting force on the aircraft. The effect becomes more important as speed increases. Near and beyond the speed of sound, about 330 m/s, small disturbances in the flow are transmitted to other locations on the aircraft. But a sharp disturbance generates a shock wave that affects both the lift and drag of an aircraft.

The ratio of the speed of the aircraft to the speed of sound in the gas determines the magnitude of the many compressibility effects. This speed ratio is referred to as the Mach number in honour of Ernst Mach the late 19th century physicist who studied gas dynamics.

To calculate varying M numbers we use an equation:

$$\textit{Mach Number(M)} = \frac{\textit{Object Speed}}{\textit{Speed of Sound}}$$

The M number allows us to define flight conditions in which compressibility effects vary.

1. Subsonic conditions occur for Mach numbers less than one ($M < 1$). For the lowest subsonic conditions, compressibility can be ignored.

2. Transonic conditions are met as the speed of the object approaches the speed of sound, the flight Mach number is nearly equal to one ($M \approx 1$).

3. Supersonic conditions occur for Mach numbers greater than one, ($1 < M < 5$). Compressibility effects are important for supersonic aircraft, and shock waves are generated by the surface of the object.

   For high supersonic speeds ($3 < M < 5$), aerodynamic heating also becomes very important in aircraft design. The nose of any supersonic aircraft is generally the hottest part of the aircraft other than the engines. During supersonic flight, the nose temperature of an aircraft can approach 127 °C.

4. Hypersonic flow is when speeds greater than five times the speed of sound ($M > 5$) are generated. At these speeds chemical bonds which hold nitrogen and oxygen molecules in air are excited. The Space Shuttle re-enters the atmosphere at high hypersonic speeds, ($M \sim 25$) and the heated air becomes ionized gas, or plasma, and the spacecraft must be insulated from the high temperatures of the plasma.

So now that we know how sound works and that sound travels faster in solid objects than in air, here is an comparison table of the speed of sound in 3 different mediums.

	Solid Steel	Sea Water	Air
Speed of sound in m/s at 21°C	5,180m/s	1,524m/s	331m/s
Speed of sound in km/h at 21°C	18,648km/h	5,487km/h	1,192km/h

THE SCIENCE OF AUTONOMOUS VEHICLES

So you want to be involved in Autonomous vehicle racing?

STEM Career Pathways:

To prepare you for engineering studies at university you should be studying mathematics and science at school.

To join the Defence industry as an engineer, you'll need a degree in an engineering discipline such as software, mechanical, electronics/electrical, aerospace, mechatronics, materials, ICT or similar.

Check out your local universities by going to university open days, the Good University Guide or speak with your School Careers Advisor. Universities all have great degree programs and RMIT for example have the Bachelor of Engineering (Mechanical Engineering), Bachelor of Engineering (Automotive Engineering) and Bachelor of Engineering (Software Engineering) degrees. There is a real shortage of Software Engineers and ICT professionals which is why Roborace is more than just a discipline, it's an environment to develop talent. So if you want to race Robocar now's the perfect time to prepare yourself.

THE SCIENCE OF AUTONOMOUS VEHICLES

Hear from a BAE Systems Australia Engineer

1. What's your role?

Hello! I work as a systems engineer. I work on autonomous vehicles. I make sure the vehicle works when our team puts together all the parts and software together.

I like my job because I get to team up with the smartest and fun people and build a self-driving vehicle. It is an amazing feeling to see our ideas work!

2. What kind of things do you do day to day?

Each day is different. I could be designing concepts in the office, other days I'm buying equipment, and other times I'm testing designs in the lab. When the design is ready, we then install them on the vehicles in the workshop, and then fun part is taking it outside to test and seeing if it works (or didn't).

3. What did you study, and what was your career pathway?

I studied engineering at university. To get into university I worked reasonably hard on my high school subjects. But even now, I do a bit of study and tinker in my own time to keep up with the latest technologies.

4. What did you want to be when you were younger?

When I was around seven, I remember wanting to be an astronaut. I thought it was so cool because they were brave adventurers with high tech equipment. Then when I was around ten, but before I knew what engineering was, I remember wanting to be a designer: I drew a lot, made heaps of lego models, and had lots of crazy ideas for vehicles like rockets, spaceships, cars.

5. Any advice for students wanting to work on autonomous vehicles?

Projects! Start by working on robotics projects. It can be hard to know where to begin so I recommend joining a robotics competition. There's MANY out there but the ones that come to my mind are First Lego League Junior, RoboCup Junior, and for high school students, Zero Robotics and First Robotics. You'll learn a lot and have a fantastic time. In high school doing maths, physics and coding helps. But don't just focus on these subjects! Be well rounded. Engineering isn't just about numbers, and ones and zeroes. You need to be able to work well in teams and communicate your ideas.

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