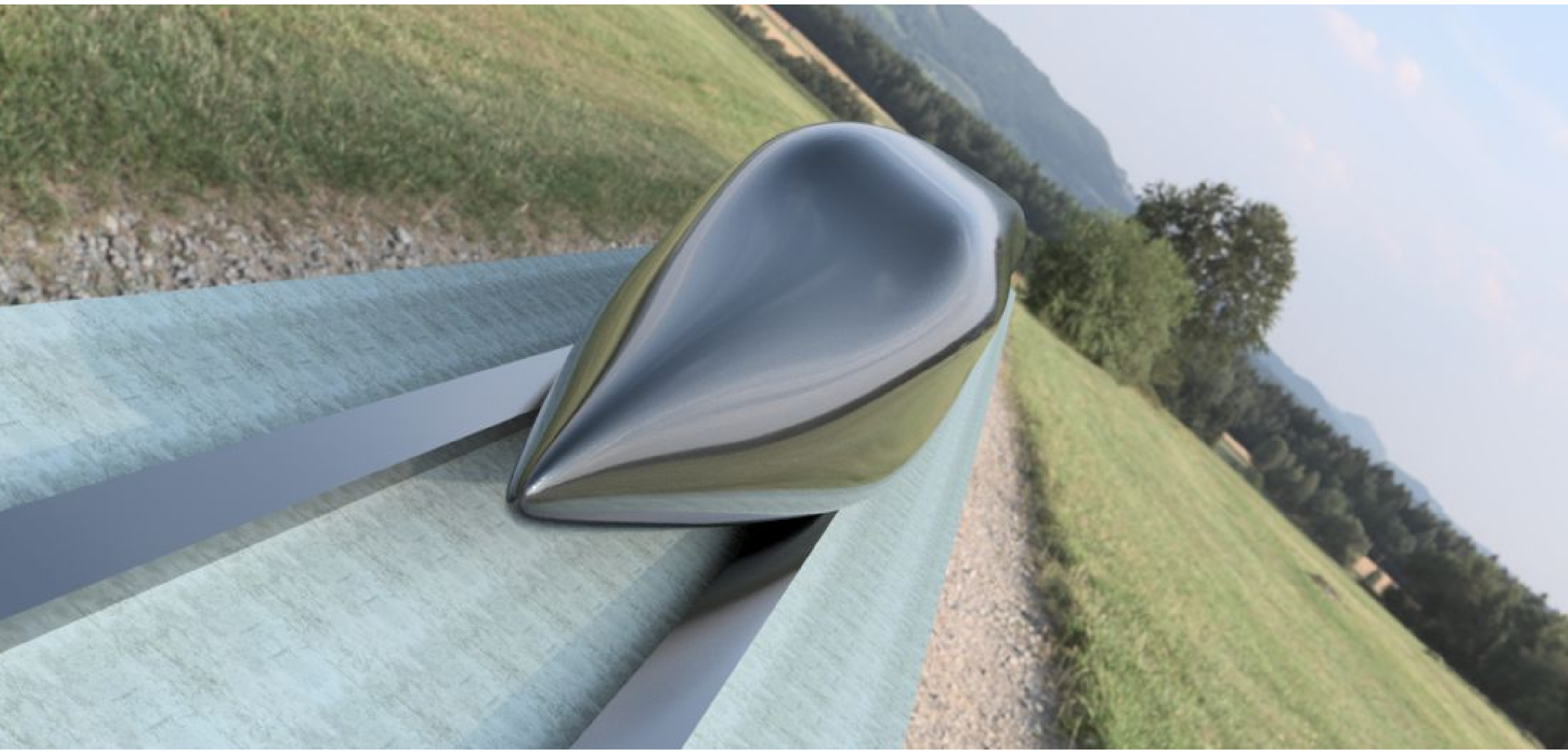

A Proposal by Team Daedalus:

Presenting **Aerolink**,

An innovative solution for turning London's five main airports into a distributed system

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Team Daedalus

ABINGDON SCHOOL

Alex Moss, Tom Shaw, Noah Williams, Bryce Jersing, Josh Washington

Alex Moss:
I am studying Chemistry, Physics, Maths, Further Maths and Latin and when I get the time I enjoy playing various sports such as Rugby, Hockey and Athletics. I am hoping to study Chemical Engineering at Oxbridge. I am the Project Manager of the team and assist in making sure everyone is focused and working towards a common goal. I have also been more heavily involved in the routes and human aspects of our proposal.

Tom Shaw:
I am currently studying Chemistry, Maths, Biology, Physics and Further Maths for my A Levels. I am planning to do either biomedical or general engineering at university and this project has been a challenging but enjoyable way to gain some knowledge of different fields. My main role was civil and electrical engineering for the team but I was also involved in odd jobs for other sections. Outside of school, I play for my local rugby team.

Noah Williams:
I am an A Level student studying Maths, Physics, Chemistry and DT. Outside of school, I am a keen cyclist and enjoy various DIY projects. In the future, I am looking at doing engineering at university and possibly becoming a mechanic in Formula One racing. My role in the project has been designing the station platform layout for maximum efficiency, in addition to track layouts and civil engineering.

Bryce Jersing:
I am currently studying Maths, Physics, Chemistry and DT for A Level. I have chosen these subjects as I wish to go into the field of aerospace engineering in the future, hopefully studying for an MEng at the University of Cambridge. Outside of academics, I enjoy rowing for Abingdon, as well as running and cycling when I have the time. My role in the team has been in the mechanical engineering, materials, fluid dynamic aspects of the train design process, as well as use of specialised CAD software for these tasks and assisting with the civil engineering side of things. I also participated in the financial, marketing and advertising side of the project.

Josh Washington:
I am studying Maths, Physics, Biology and Geography to allow myself to go into (aeronautical) engineering at university. Aside from academics, I represent the school in Hockey, Rugby and Cricket teams and also fly-fish outside of school. At home I enjoy designing and creating practical solutions for different issues. Within the Daedalus team, I have mainly been involved in numerous jobs throughout each section, but I was in charge of the interior aspect of the train.

Acknowledgements

Team Daedalus would like to thank the following people for their involvement and feedback on the project:

- Victoria Griffiths
- Jeremy Thomas
- Ben Simmons
- Abingdon School
- Autodesk

And thanks in particular to the Blott-Matthews Challenge, Richard Blott and Charles Matthews for providing us with this challenge and insight into the real-world applications of engineering. We will carry this experience forwards into our further education and careers and are most grateful for the opportunity.

Summary of Proposal

We propose a system based on electric motor powered trains to provide transportation between the five main airports of London, turning them into one, decentralised ‘mega-airport’ which will be more efficient than five individuals.

Overground track will be used for the majority of the distance covered, the only exceptions being in urbanised areas such as the vicinity of London City airport, where a subterranean section will be needed to avoid disruption to existing infrastructure.

Trains will be driven by electric motors, which will be powered via electricity from overhead power cables allowing them to reach cruising speeds of 360kph (224mph). Stations outside airports will be overground too, with London City being the exception again, and passengers will be able to join the system, which we have titled “AeroLink”, after they have passed security. Checked luggage will be loaded autonomously from check-in and carry-on bags will be taken with passengers as they board the train.

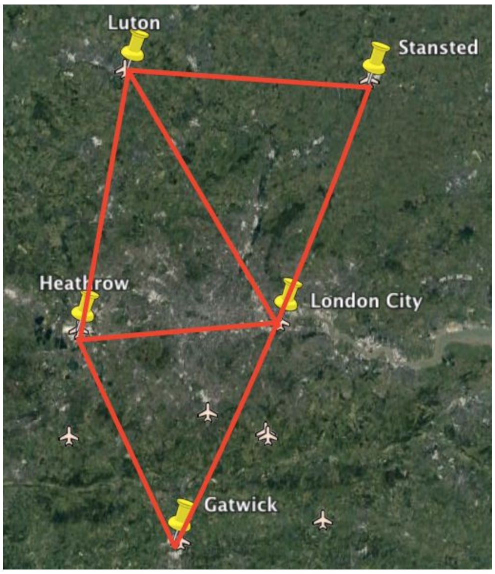
ROUTES:

The satellite image shows the locations of the five airports that AeroLink will connect.

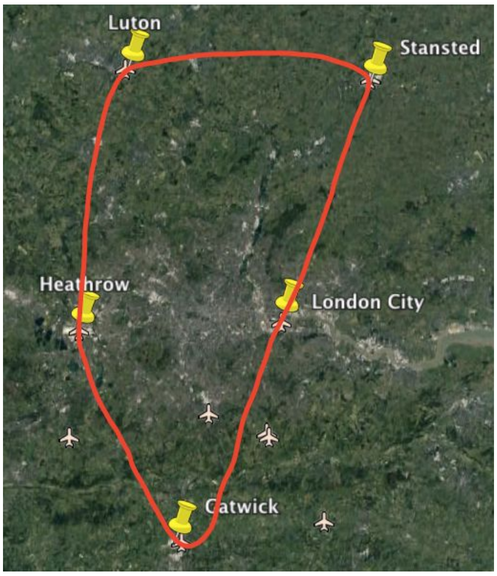
Originally, we had planned to use straight line tunnels between each station, with one line from Stansted to Gatwick with London City as a stop. However we soon discarded this idea, mainly due to the vastly increased cost of tunnelling for 100% of our travel length. The added price of all the tunnelling equipment and safety measures, as well as the disposal of the large volumes of earth extracted, made this method unviable in our eyes.

From here, we moved to the obvious next step, travelling overground as this will be far cheaper than tunnelling. Additionally, we overhauled our existing plan of tunnel connections, discarding the straight line connections and replacing them with a continuous loop connecting all five airports. Thankfully, their placement makes a semi-loop shape easier.

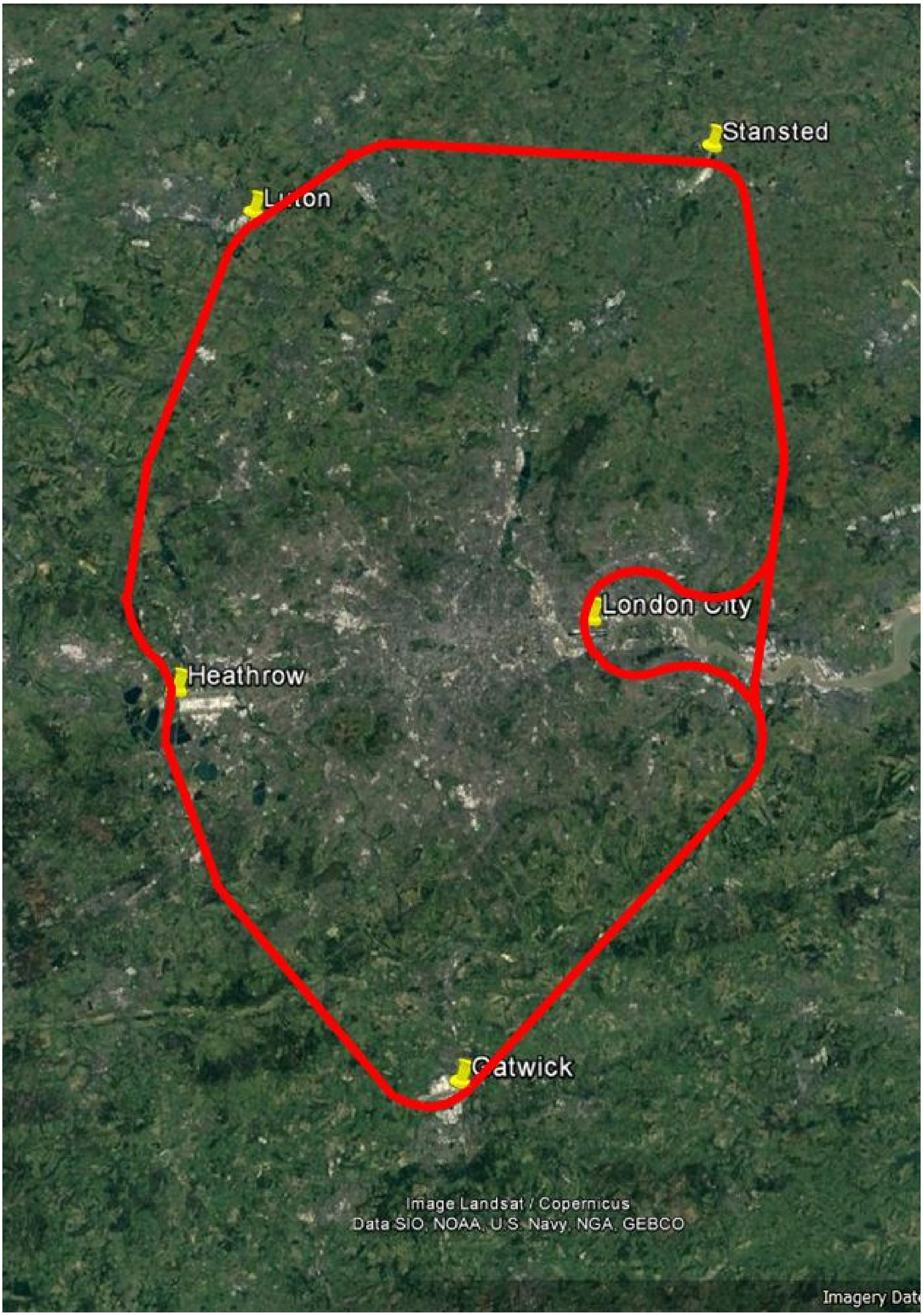
Previous layout:



Current layout:



Detailed Layout:



Tunnels vs Overground:

Because London is densely populated we felt that we would need to go underground for at least some parts of our journey, especially because the time requirements meant that the necessary speeds would be impossible along roads similar to trams. As a result our initial ideas included plans for a complete network of tunnels connecting all the airports, and various routes were proposed such as a central hub that all trains passed through that would reduce the track distance required. These were rejected after a British Tunneling Society conference that we attended on Crossrail. This revealed the full extent of the problems and costs associated with tunneling and so we decided to reduce the distance underground as much as possible.

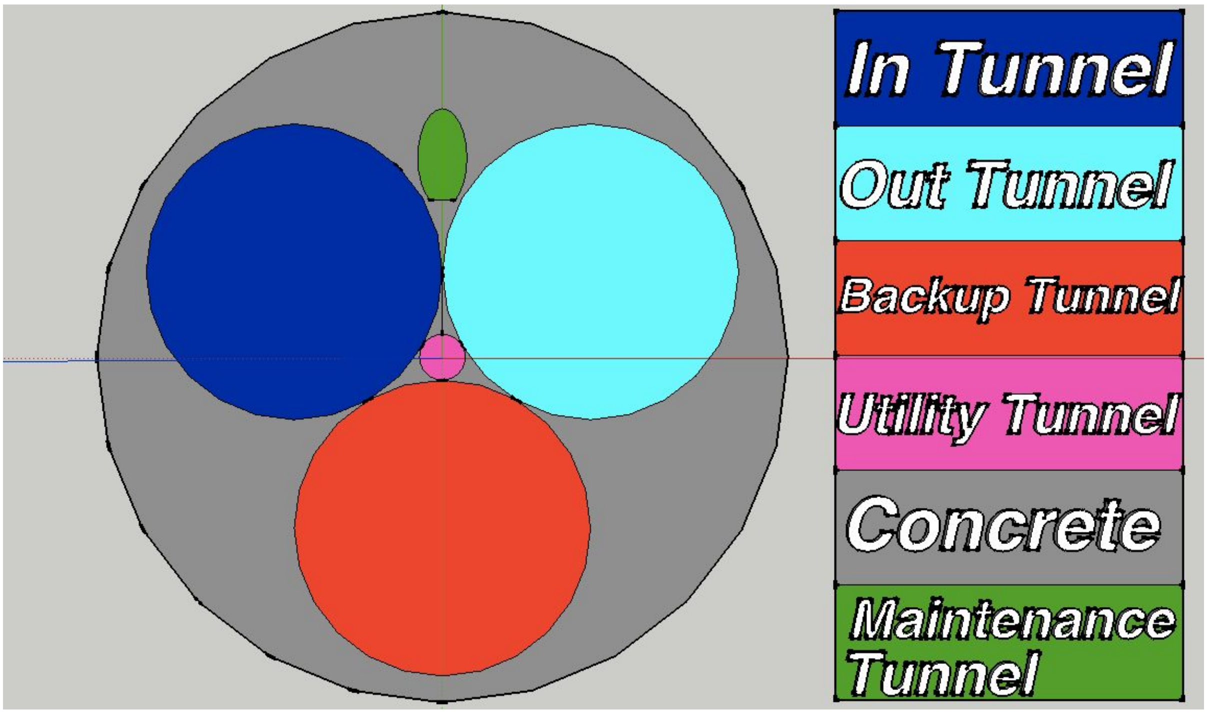
Without London City Airport we could have managed purely above ground, because they are all in relatively open areas with few buildings. This would reduce the costs but as it is we must go underground for 6.2km in order to reach London City Airport without running through large stretches of built up areas that would need to be torn down to make way for the track.

Costs, Problems and Solutions:

Even for the short distance we are covering, many problems crop up. Water causes most of the issues underground and the fact that the airport is almost surrounded by water means that we must be careful when excavating the station and tracks. Before we can even start, a year of monitoring the ground changes around the river would be necessary to see how it varies without interference. We estimate this would cost £30,000, based on the experience of ground testing by Crossrail, who stated they spent double that for the same distance and believed this to be excessive. London City Station will be located in a warehouse currently used by a removal company.This building will need to be purchased from them for approximately £2 million (market value plus incentive to sell). The ground around the station and low lying stretches of the tunnels would require dewatering before any construction could take place and dry compensation grouting would need to be used under the river and at the station to reduce the structural impact of dewatering and excavation. Dewatering would pump out 650 litres per second (based on Crossrail equipment data), but should be monitored for trapped air as this could cause heave, which would lead to structural damage. Another potential danger is confined space hypoxia which is caused when reducing compounds in the soil react with air trapped during dewatering, lowering the oxygen level to a degree that could interfere with respiration. This can controlled by extracting the air that becomes trapped or slowing the rate of dewatering.

One possible way to measure the effect of the excavation is using InSAR which are satellites that can detect changes in the ground level from light reflecting off asphalt. Houses also need to be checked around the station because there is a potential for settlement (downward movement of soil) too which causes cracks that would need to be paid for. London City station would be relatively small and would connect directly to the airport through a walkway. The tunnels would only be 2 tracks wide to reduce cost and space needed. In terms of requirements they would be about 7m high and 12m wide. The tunnels could also potentially provide a source of revenue as fibre optics can be laid alongside the tracks which could be paid for by broadband companies such as BT.

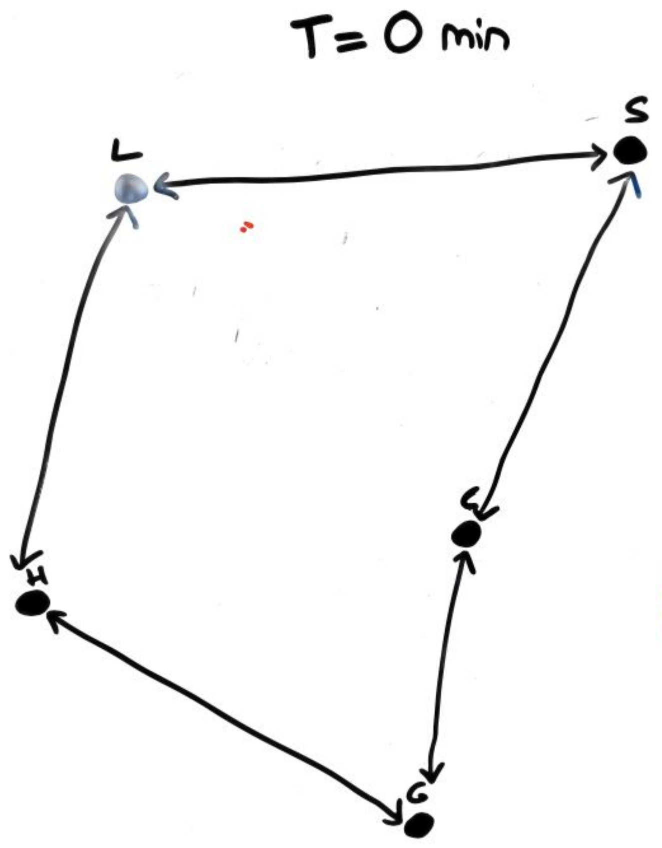
Back in the very early stages of planning, when we had proposed to tunnel for the entirety of the project, we came up with the design below. It would have only required one Tunnel Boring Machine (TBM) with a bore diameter of about ten metres, only half the largest TBM constructed. Because it was created before our current proposal, it only features two main tunnels for the trains, as well as a backup track for any maintenance faults, as well as a man sized inspection tunnel. The main drawback of this method was the sheer volume of concrete required as well as the entirety of the route being underground, which was far too expensive.

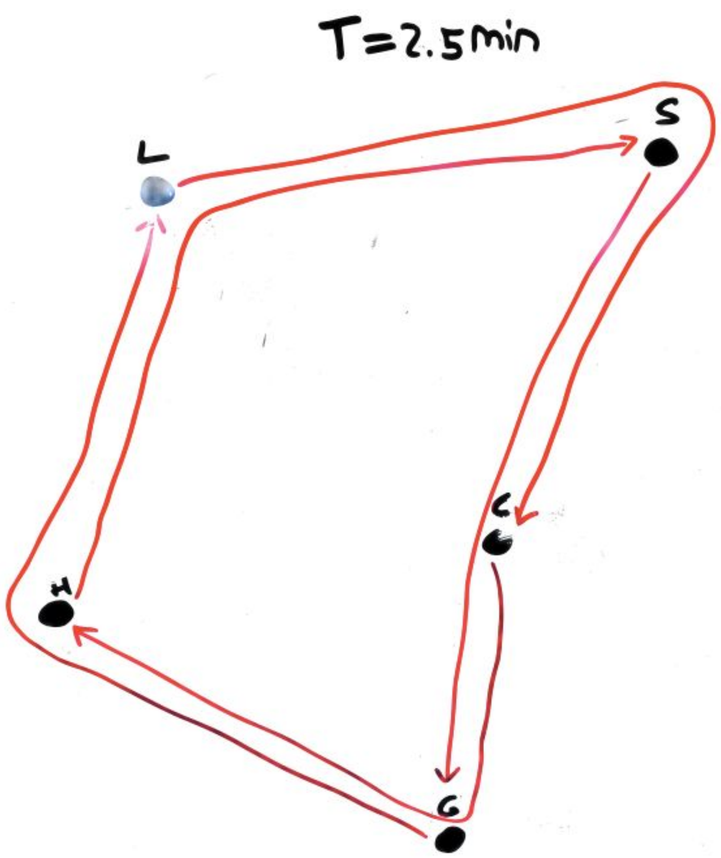


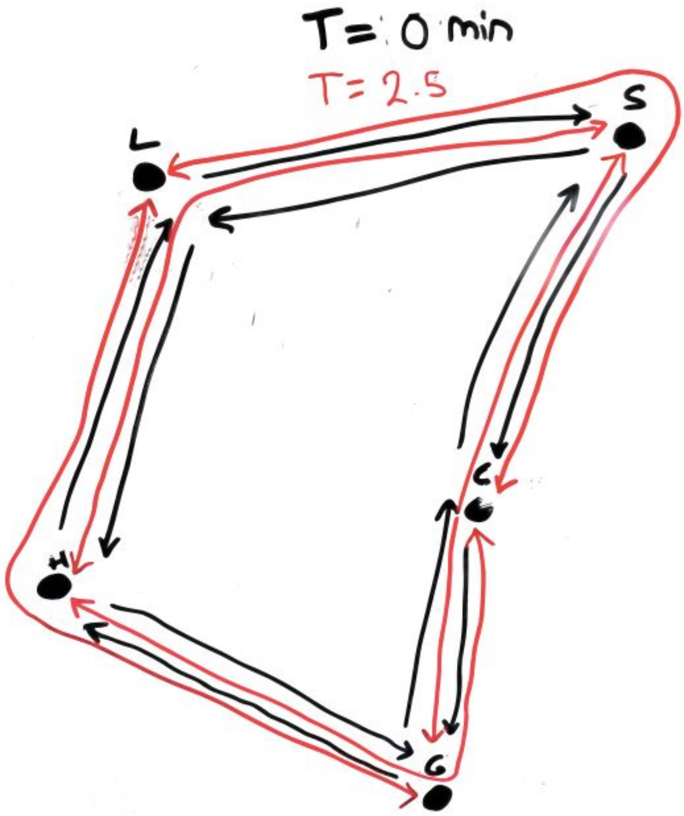
Scheduling and Circulation:

Since it was specified that passengers could wait at a station for no longer than 5 minutes we have created a two part system to transport passengers around various airports. Generally the system runs off a single outer track which runs into each station. The first part of our system is where each train travels to the next station in the loop, for example a train leaving from Heathrow would stop at Stansted and a train leaving Luton would stop at London City. Every 5 minutes this would repeat so no passengers are waiting for more than 5 minutes. Let the first 'set' of trains leave at t=0 and the second 'set' leave at t=5. The second part of our system involves trains leaving t=2.5, these 'sets' of trains would travel at the same speeds as the first to eliminate the possibility of collisions but would drive straight through the express line of our station and continue on to the second station from where it started, for example a train leaving from Heathrow would stop at Luton. As there is a difference in the length of tracks for each connection then if a train arrives at a station before others in it's 'set' then it would just wait so they all leave together at precisely the right time. Additionally the proposed system (running clockwise) above would also run in reverse (anti-clockwise) thereby ensuring that all possible routes are achievable within 20 minutes and the wait time at each station is less than 5 minutes.

To calculate the number of trains required for the entire system to operate, we treat the two 'sets' separately. The station-station set have a maximum distance of 50km. Since our trains are running at 360kph then it would take 8.5 minutes to reach the station. In this time 1 other set would have to leave so that we meet the 5 minute waiting time constraint. Since there are 5 stations, each with one train leaving the first part of our system will require 10 trains to operate. For the second bi-station part the longest distance is 100km. This will take our trains 17 minutes to cover and hence will have 4 sets leaving to meet the constraints. Therefore 20 trains are required for the second part of the system. This gives a minimum total of 30 trains required. However since there is always the possibility of breakdowns and maintenance we would construct an extra 10 trains and leave 2 at each station, hence meaning we require 40 trains in total.







Beside and above is the timing and circulation diagram, colour coded to show the routes each train will take at each time interval.

Below is a mocked up timetable of when trains would arrive at each station, based on our measured speeds and distances. Leaving from either Gatwick or Heathrow, the timetable shows times for both the clockwise and anti-clockwise routes of the tracks.

	Clockwise Trains		Anti-Clockwise Trains	
From Heathrow	To Luton	To Stanstead	To Gatwick	To London City
09:00	09:10		09:10	
09:02		09:18		09:18
09:05	09:15		09:15	
09:07		09:23		09:23
09:10	09:20		09:20	
09:12		09:28		09:28
09:15	09:25		09:25	
09:17		09:33		09:33
From Gatwick	To Heathrow	To London City	To Luton	To Stanstead
09:00	09:10		09:10	
09:02		09:18		09:18
09:05	09:15		09:15	
09:07		09:23		09:23
09:10	09:20		09:20	
09:12		09:28		09:28
09:15	09:25		09:25	
09:17		09:33		09:33

Station Design:

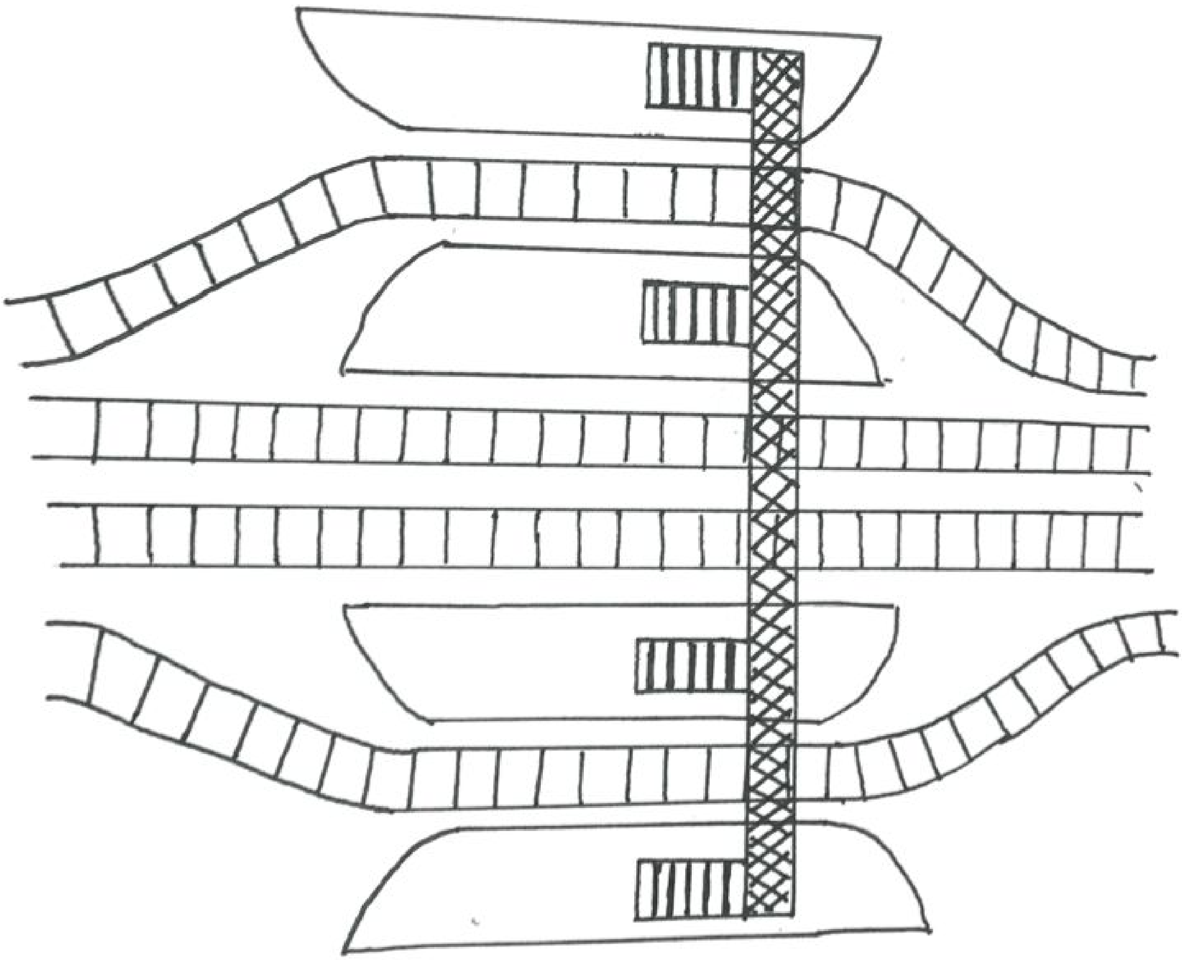
The station designs will be based on standard rail stations in existence today in Britain, incorporating four platforms, two for each direction of travel. The station will have two express lines down the middle for trains not stopping and two side tracks for trains pulling into the station for passengers to board. An elevated bridge would connect all four platforms to allow for easy movement between them, with both stairs and a wheelchair access elevator to the bridge. Below is a sketch of the proposed station layout:

Platform 1

Slow line for
Platform 1
------------->
Express Line

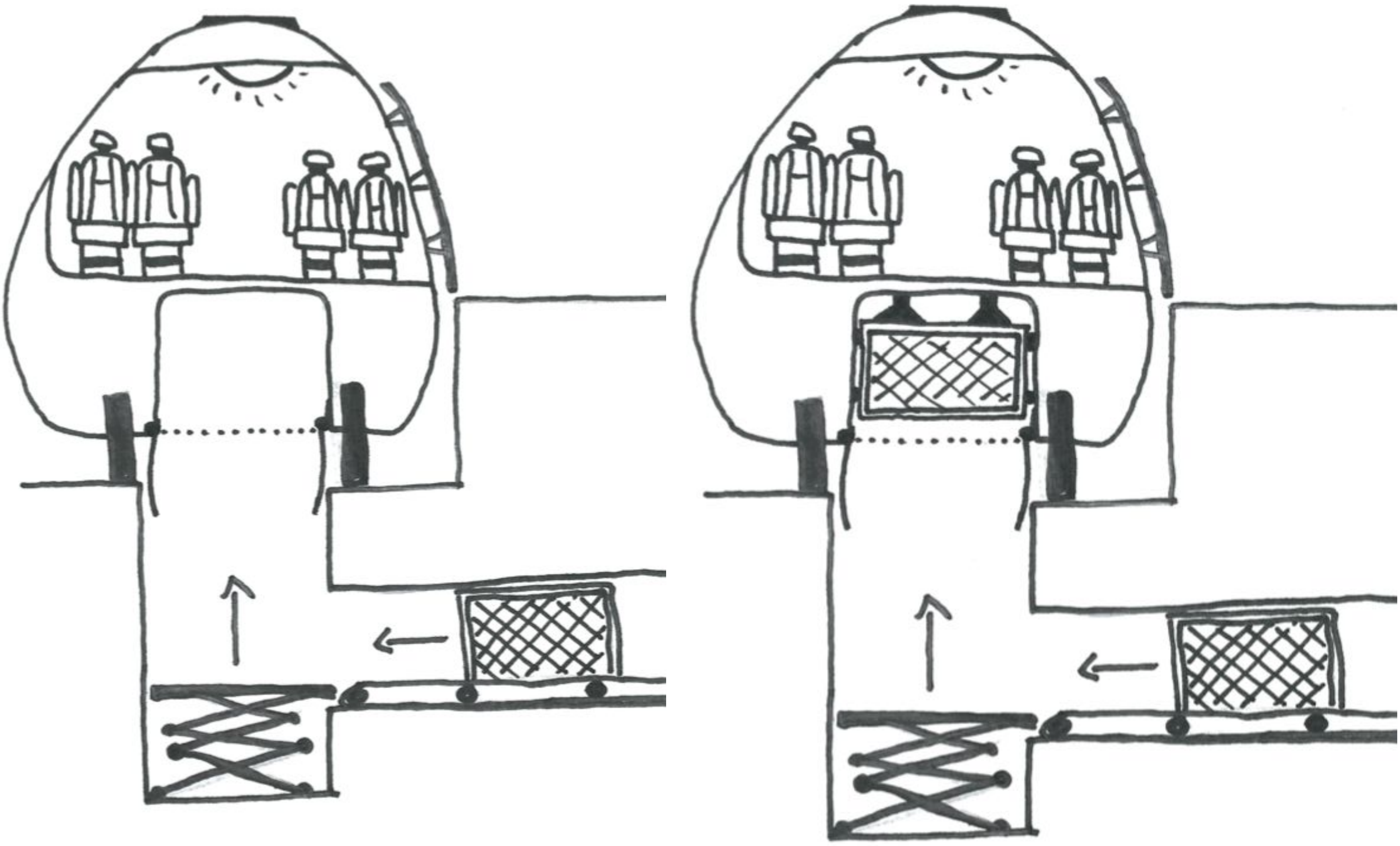
Express Line
<-------------
Slow line for
Platform 2

Platform 2

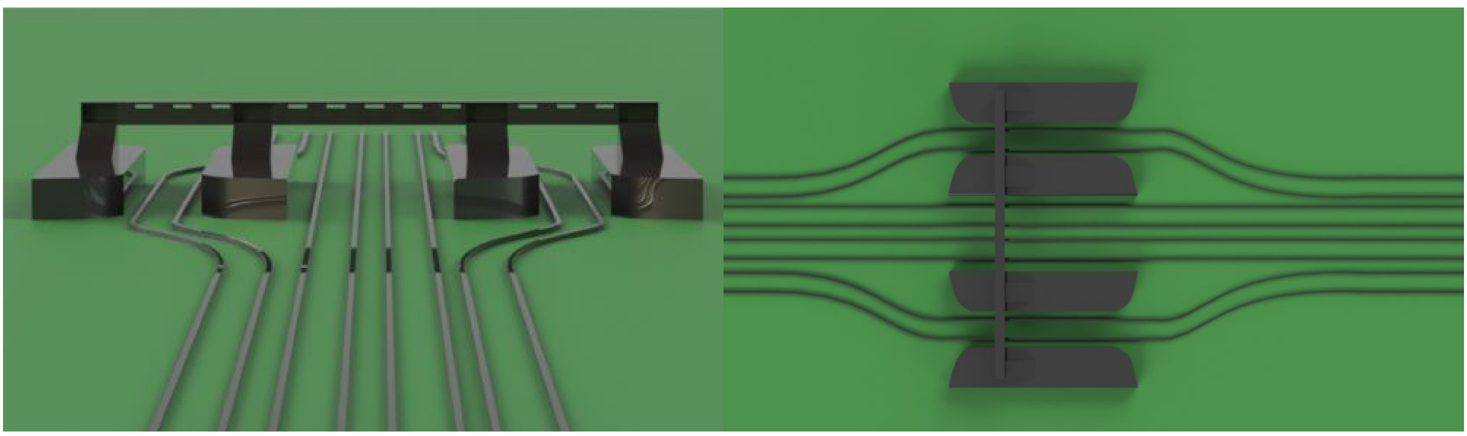


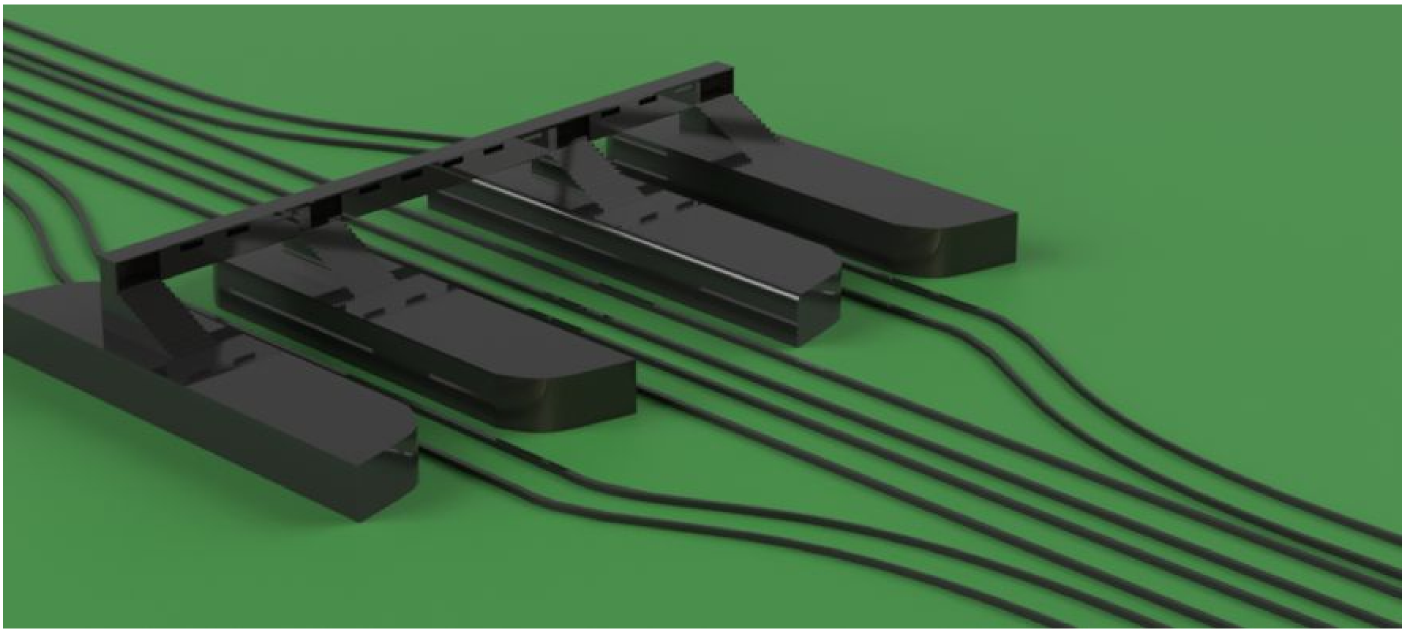
In order to speed boarding of the train and stay within the allotted time for stopping at each station, passengers will board from one platform and exit via another. This will streamline the boarding of the train, allowing for quicker turnaround times after each stop.

In terms of luggage, passengers would bring their carry-on bags with them onto the train, having already gone through security. Checked in luggage will be packed at the airport via standard systems already in place, into crates, which would in turn be sent to the AeroLink station by an underground conveyor belt. These luggage crates would then be loaded into the bottom of the train, through the tracks and latched into place securely. The use of this system will also improve efficiency and turnaround times at each station. A scissor-lift mechanism will lift the crates from conveyor belt to the storage compartment underneath the train. The sketches below depict what the mechanism would look like and give a rough idea of how it would function visually.



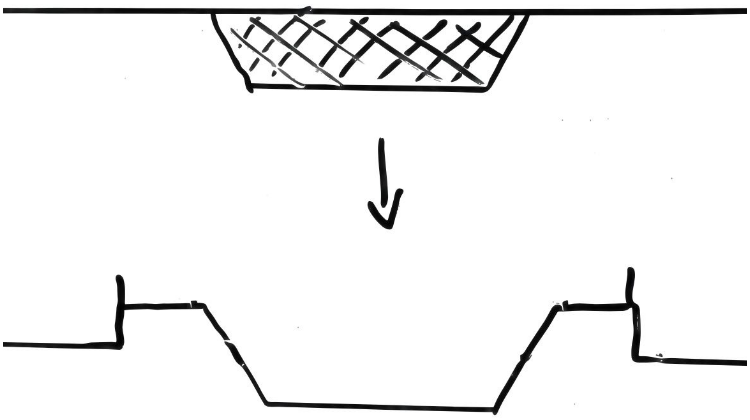
Below are some CAD renderings for what the station would look like when finished:





Track Design:

The effects of the recent Storm Doris on transportation across Britain, highlighted the problem of having to deal with high velocity crosswinds on the train whilst travelling at 360+ kph. As a result of a group brainstorming session, we decided to incorporate a semi-buried



track layout into our overall scheme, using earth excavated from the track foundations to build berms either side of the rails. This would provide crosswind protection at high speeds, as well as increasing the height of our perimeter fence with no added cost, saving on materials costs for the chainlink fencing. In the long run, this will save a small portion of our budget.

Due to the circulation nature of our train system, a quadruple track is necessary, four tracks side by side with two going each way. One track in each direction will go to the next station, whereas the other track will skip this next station and continue onto the one after, as an express train. The quadruple track format is also good for handling large volumes of traffic, which AeroLink will be experiencing under four trains every five minutes. It also allows for easier and

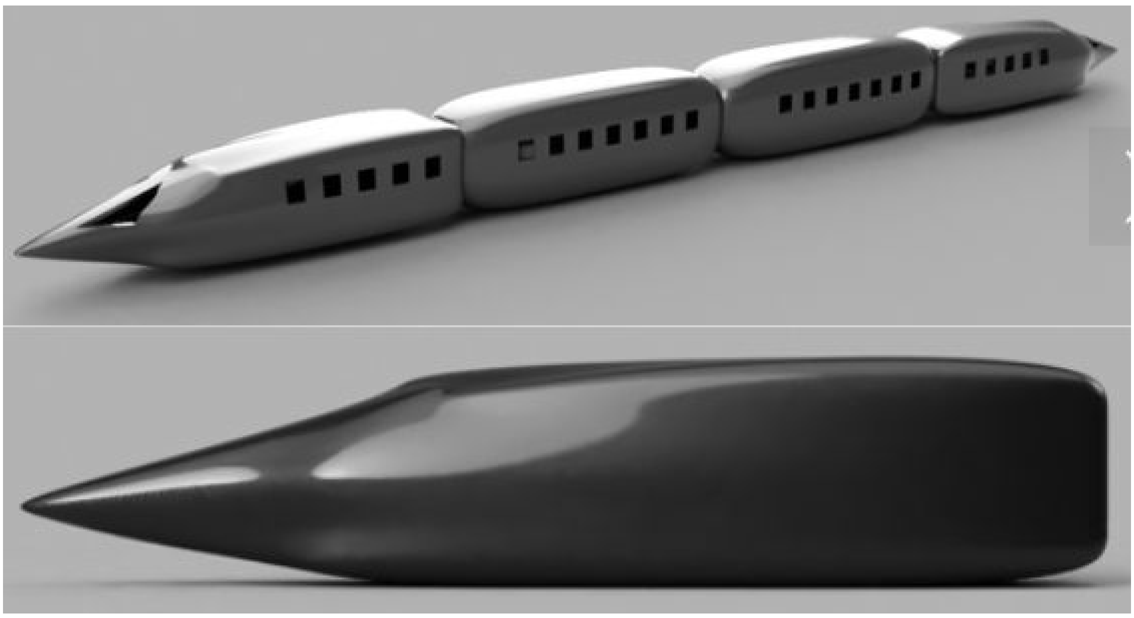
less disruptive track maintenance work, but of course means added land for purchase and development.

Power will be supplied via overhead cables, the voltage and current of which will be elaborated upon in the Electrical Engineering section. The trains will receive electricity via overhead cables, contact will be kept via a brush system, and the rails will act as the other terminal of the completed circuit.

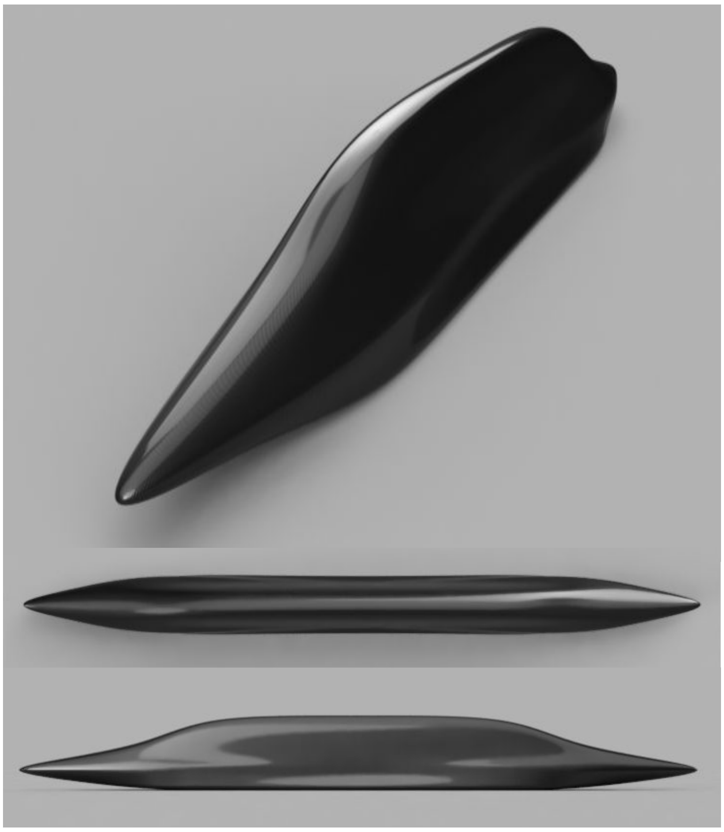
Exterior Design:

To make the train as efficient, and thus as cheap as possible to run, it had to be as aerodynamic as we could make it. The current fastest trains in the world are the Shinkansen 'bullet' trains of Japan; with streamlined noses, long profile and MagLev track, they can reach speeds of up to 603 kph. Obviously, even though we don't need such high speeds, we can learn from their aerodynamics to improve the design of our trains. All designs below run as standard permanent magnet motor electric trains, supplied from overhead power lines.

To start with, AeroLink was based on the traditional train model, consisting of multiple, flexibly joined carriages. It had the advantage of adapting to changing passenger numbers by joining or removing carriages and storing them at the stations on a different offshoot of track. CAD renderings had them looking like this:



But we moved from this idea onto a more decentralised, "pod" based system, with mass produced trains that were smaller but far greater in number which could also cope with uneven passenger distributions. In our estimates, they would have only carried twenty people at a maximum to be most efficient.



These pods were 15.2m long, 3.6m high and 3.1m wide.

We then ran the STL files of the pod design from Fusion360 into Autodesk Flow Design to run fluid dynamics testing. Our pod design returned a relatively small drag force of 8.4kN at 100m/s due to it's small size, making it favourable in terms of aerodynamic efficiency.

After the pod, we arrived on our final design for the train, which was much longer, incorporating design elements from both the pod and carriage designs previously. Our current model keeps the streamlined shape of the pod whilst extending the carriage until it can accommodate 120 passengers for the duration of the longest journey. To transverse our constantly turning track layout, the wheelbases of the trains will be mounted via a pivot to the body, so the body can turn separately from the wheelbases. The motors will be built into the wheelbases and flexible cables will supply power to them.

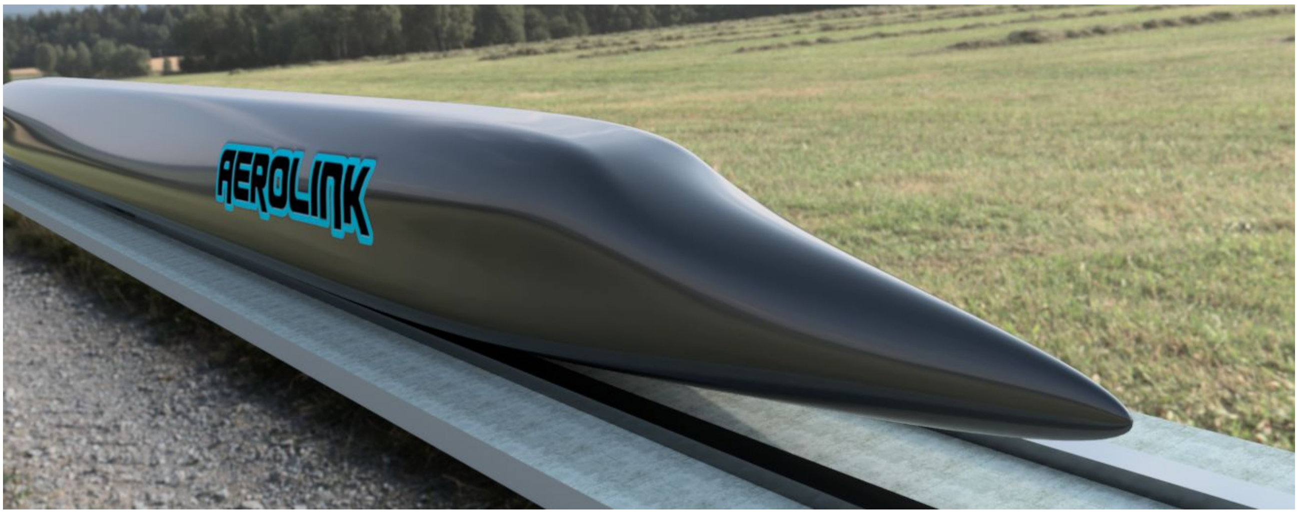
The necessity of two wheelbases is down to basic geometry, a straight line can be drawn between any two points of a circle, but not any three or more. Due to the large distance these sets of wheels will be apart, the floor of the trains will have to be reinforced with a light, stiff material such as a carbon fibre composite truss or similar structure that will not add much more weight or take up space.

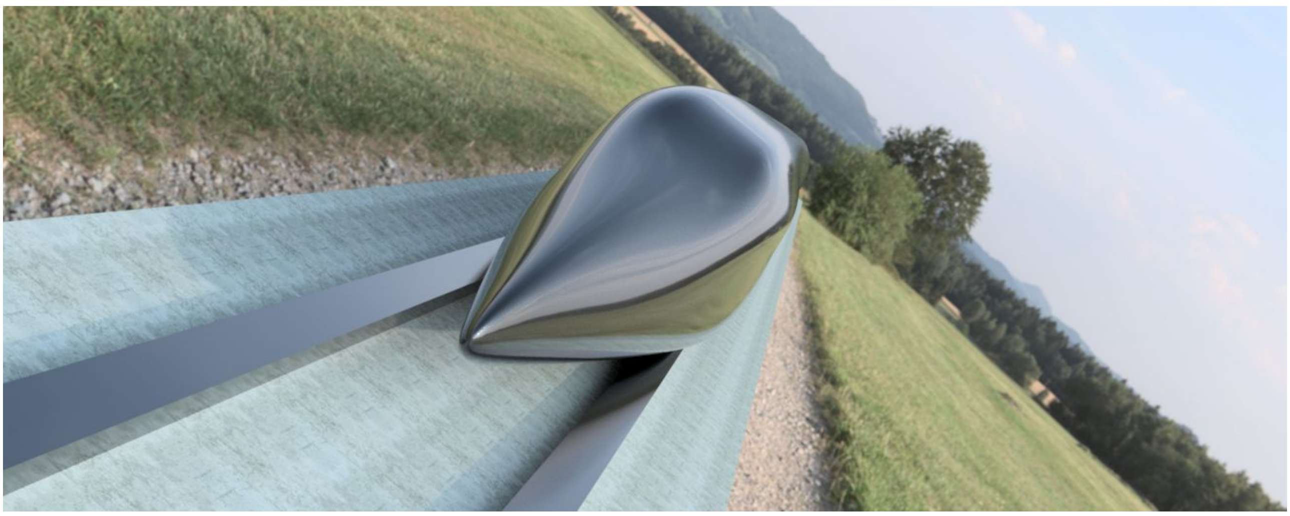
Underneath the train will be a luggage compartment where checked baggage will be loaded after it has cleared security, pushed up through a tunnel beneath the tracks as the trains stops at each station, and will also be offloaded in the same manner.

The train is 48.8m long, 3.6m high and 3.1m wide, with an average drag force of 18.3kN.

Using Fusion360, we mocked up a CAD model of the final train, allowing us to both measure it's performance aerodynamically at high speeds, render what the finished train would look like in real life, as well as getting material volumes, masses and cost estimates. The renderings below show both the base model, in addition to it rendered in a mock environment.

The in-depth fluid dynamics report on each train will follow in the Fluid Dynamics section of this document.





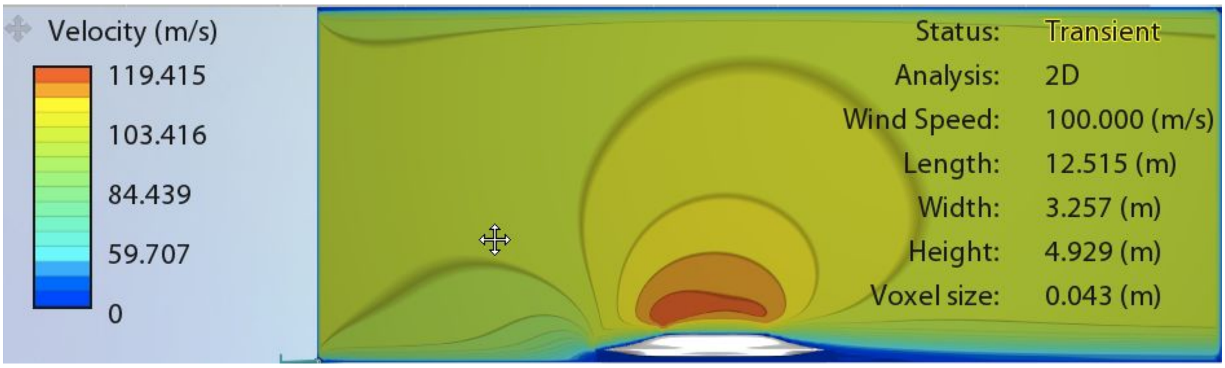
Fluid Dynamics:

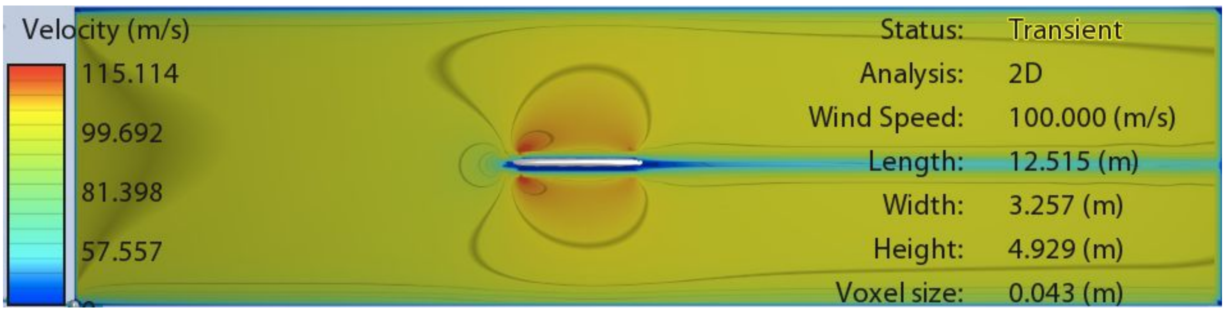
Thanks to the advent of CAD software for analysing airflow patterns around moving objects, we were able to simulate the stresses affecting each of our train models using Autodesk Flow Design. The Autodesk Student partnership gives us access to some of the most powerful CAD programs in use in the industry, for free, giving us realistic feedback to what actual engineers would face.

For each train, we modelled them moving at 100m/s, measuring the average drag force for each model, as well as looking at the pressure zones around each train.

The Pod Design:

This design faired well in fluid dynamics testing, giving us the lowest drag coefficient and force of our models. In the end, it had a drag force of 8.4 kN, relatively low for a train moving at such high speeds and meaning the motors of the train would only have had to exert a force of 8.4 kilonewtons to move at constant velocity. The colour coded fluid dynamics results are shown below.

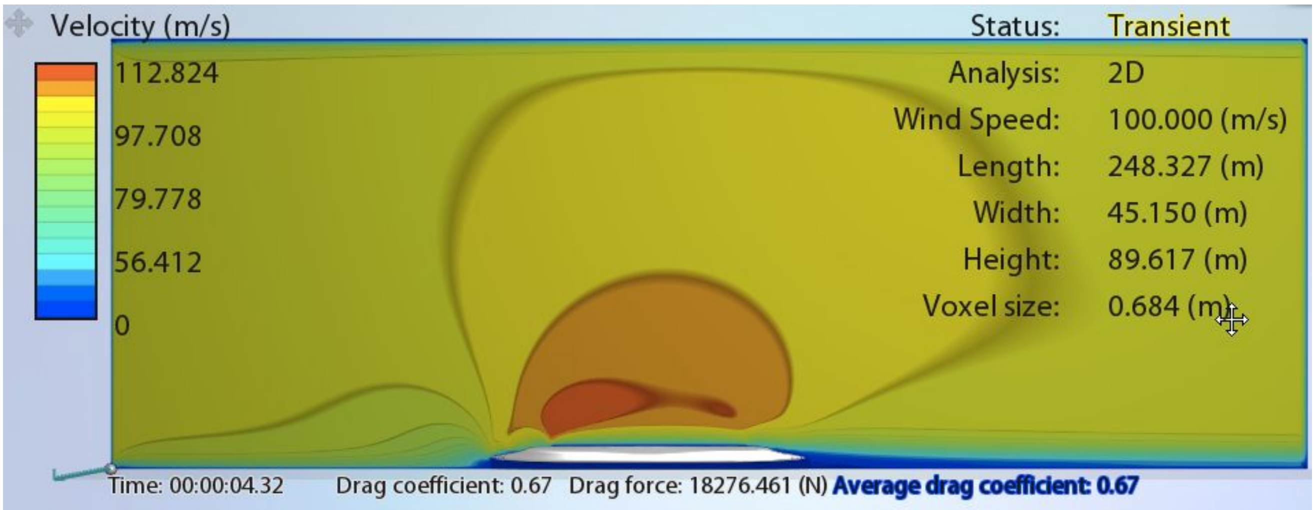




Due to the Bernoulli principle, the faster a fluid is moving, the lower pressure it is. Therefore analysis of results show that redder areas are lower pressure, with blue being higher.

The Final Design:

The final train design also went through Flow Design well, although it's larger size gave it a higher drag force and coefficient than the pod. This design gave a drag force of 18.3 kilonewtons, an amount that the electric motors driving the train could easily match at high speeds. It also returned a drag coefficient of 0.67, relatively high for such a streamlined train, but this is a result of a far higher fluid velocity. The colour coded fluid dynamics results are shown below.



Upon analysing the result of fluid dynamic testing, the final design emerges as a better alternative to the pod, as its ratio of drag force to passenger numbers is preferable, transporting more people per unit energy spent overcoming drag. On an efficiency basis, this makes our final design the best out of all of our iterations, and so will be used for the trains that will be manufactured for AeroLink.

Materials:

The train will be constructed as a sandwich of materials with different properties to both get the least weight from the train, thus using less energy, as well as make it as stiff, strong and safe as possible.

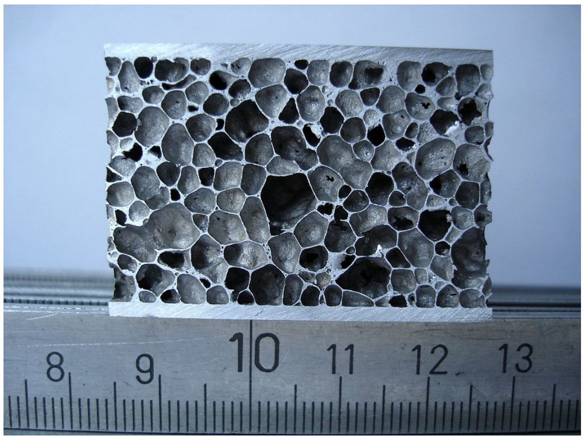
From the outside in, the train will be made from:

- Aluminium foam sandwich, 50mm
- 10mm gap for wiring and electrics
- Corrugated steel, 4mm
- Recycled High-Density Polyethylene (HDPE), 2mm

Windows will be made from polycarbonate laminate, skinned with an aluminium oxynitride layer, 12mm, and the truss structure keeping the train rigid will be a Curran/carbon fibre composite.

Materials choice:

1. Aluminium foam sandwich is a class of metal foams, made from aluminium, faced with two solid, smooth aluminium layers on its outer surface. This material utilises aluminium's primary two engineering properties, its high strength-to-weight ratio and resistance to



corrosion. The aluminium foam sandwich (AFS) offers a high stiffness-to-mass ratio, keeping the structure of our train very stiff, without the weight that other materials would bring. It also has a high energy absorption capacity, letting it absorb both vibrations in normal use, ensuring a smoother ride, but also in the unlikely event of a crash, where it would absorb the majority of the impact force without breaking. AFS is formed by adding a foaming agent into the molten aluminium alloy and facing the resulting metal foam on both sides with aluminium sheet. Because the base metal only results in being less than 20% by volume of the foam, the material has a very low density, keeping material costs down.

2. Corrugated mild steel is a low carbon steel that is strong and tough, without being as brittle as higher percentage carbon steels. This not only makes it easier to work with, but also lowers the cost of the materials, making it suitable for when large quantities of structural reinforcement are needed. Whilst its tensile strength is relatively low, its surface hardness can be increased through the use of carburisation. In a corrugated format it will increase the stiffness of our train, despite adding more weight, but will also be far stronger than aluminium in the event of a crash. It will also prevent any foreign objects from outside piercing through to the interior if a crash were to occur.

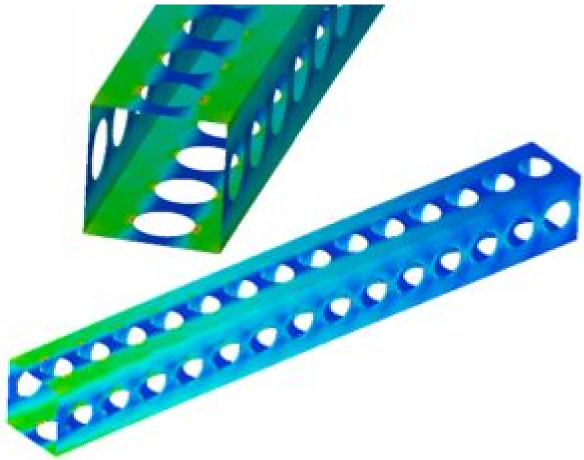
3. Recycled HDPE is a thermoplastic, recycled mainly from milk bottles and sewer pipes. It is a high density plastic, as the name suggests, with a high strength to density ratio and can resist temperatures up to 120ºC for several minutes. In our train, this recycled HDPE will serve no structural purpose, being more for aesthetics, hygiene and safety. The clean, smooth surface that coating the mild steel with will not only protect the steel from corrosion, but will also give the train a spacious, modern feel on the inside. HDPE will also be easier to clean, so the interior will be more hygienic as both graffiti and bacteria can be wiped off easily. Lastly, it provides a certain level of fire protection and electrical insulation in the unlikely event of the train suffering a crash, protecting passengers from further danger.

Windows:
The train windows will be made of a polycarbonate laminate, a thermoplastic that is optically transparent in the visual range. It is a strong, tough engineering grade plastic that can be

formed easily. Polycarbonate is highly impact resistant, being used in most forms of bullet-resistant glass, and can undergo large amounts of plastic deformation without cracking or breaking. However, it is a very soft plastic, and is scratched easily, meaning vandals would find it easy to put graffiti on the inside of the windows as I have seen many times on trains in Australia. The solution to this dilemma would be to coat the polycarbonate in aluminium oxynitride, a transparent ceramic that is 85% the hardness of sapphire. This would provide scratch protection to the polycarbonate below it, as well as adding to the impact resistance of the glass. Aluminium oxynitride is similar to the transparent aluminium of Star Trek lore and its invention was inspired by the fictional material. Together, the windows of the train would be able to withstand multiple 9mm handgun bullets, but any instance in which they would be required to do so would be worrying.

Truss Structure:

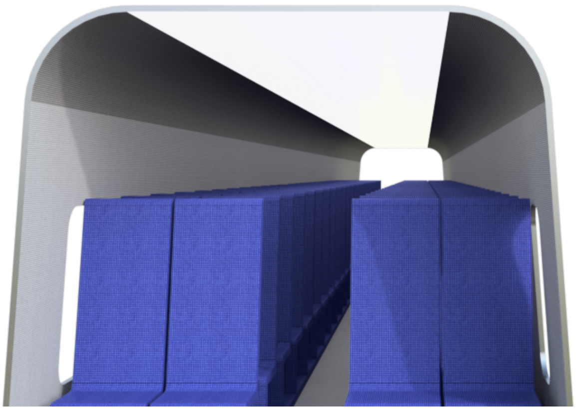
Due to the width of the wheelbases from each other, the force causing the train to sag in the middle will be quite large. To counter this, a lightweight, stiff truss structure made from fibre reinforced polymers will run along the underside of the train.

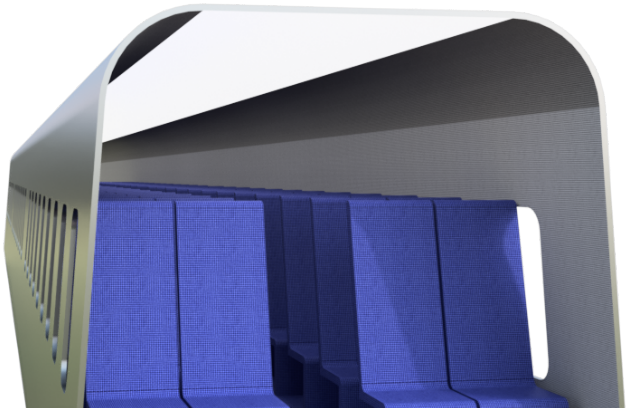


Carbon fibre reinforced polymer utilises a composite of carbon fibres embedded in an epoxy resin, resulting in an incredibly stiff and lightweight non-metallic composite, reducing the weight required to reinforce the underside of the train. Curran is a plant-based, sustainable fibre extracted from root vegetables, and has a similar, if not higher, tensile strength as carbon fibres. Used in a 50/50 ratio with the carbon fibre, it would reduce the overall material cost of the train without compromising in structural integrity. As it is biodegradable and harvested from vegetable waste, it will reduce our environmental impact.

Interior Design:

The interior of our trains must be both comfortable for passengers over a twenty minute journey, as well as being easy to board and disembark within two minutes. To prevent the train from feeling cramped, we have designed it to provide a spacious and light atmosphere which we will accomplish by using expansive polycarbonate windows, as well as an electroluminescent (EL) panel embedded in the roof. These together will flood the train with soft light, meaning the train interior will feel open and spacious, making a far more relaxing environment for potentially fatigued passengers. We used Fusion360 to simulate the interior, including both windows and the EL panel as well as seating arrangements.





Together, the renders show the general idea of how the train will be laid out on the inside, but the colour schemes aren't accurate within the rendering. We have opted for a softer colour scheme to open up the interior and make the train more welcoming. This scheme would feature seats of a light grey colour, as opposed to the blue featured in the rendering above. Seats will have storage underneath the seat in front to stow carry-on luggage, allowing the passenger more space as well as letting us achieve higher passenger density per train. We have calculated, based on measurements and anthropometric data, that each passenger will need about 75 centimetres of length and 45 centimetres of width on their seats as a compromise between passenger density and comfort. This lets us achieve transportation of our peak passenger numbers in the space available on the train.

Electrical Engineering:
Propulsion Systems:

Originally, when we had a straight line tunnel network between the five airports, we had planned to use a combination MagLev and rail gun system using only electromagnetic force to propel the train. However, after extensive calculations (shown below) we found that the amount of energy required to fire a train of our intended mass at our intended velocity was inordinately high. Too high to justify, in fact.

The rail-gun effect works by passing an electric current through two conductive parallel rails, upon which a sliding armature sits. The armature is then accelerated by electromagnetic effects of current, which flows down one rail, through the armature and then into the second rail.
The current makes the armature behave as an electromagnet, creating an electromagnetic field inside the loop. According to the left hand rule, the armature experiences a force, and is accelerated by the Lorentz force along the rails.

"The force is proportional to the square of the magnitude of the current and inversely proportional to the distance between the conductors" - https://en.wikipedia.org/wiki/Railgun#Theory

As a result, we had hoped to be able to use this force to propel the train by having armatures built into the train that connected the two rails. This would have provided the accelerating force required for the train.

However, rail-gun rails and armatures typically have very short life spans as a result of the enormous currents and therefore temperatures involved. This would have reduced the lifespan of our train, and made it very expensive to maintain. The strong magnetic fields produced would also have been dangerous to those using pacemakers, and the shielding required to limit such effects to health would have been heavy.

The speed of a railgun slug is determined by several factors; the applied force, the amount of time that force is applied, and friction. Friction will be ignored in this discussion, as it's effects can only be determined through testing though we can, assume a friction force equal to 25% of driving force. The projectile, experiencing a net force as described in the above section, will accelerate in the direction of that force as in equation 1.

$$a=F/m \quad (1)$$

- a=Acceleration (Metres/second^2)
- F=Force on projectile (Newtons)
- m=Mass of projectile (Kilograms)

Unfortunately, as the projectile moves, the magnetic flux through the circuit is increasing and thus induces a back EMF (ElectroMagnetic Field) manifested as a decrease in voltage across the rails. The theoretical terminal velocity of the projectile is thus the point where the induced EMF has the same magnitude as the power source voltage, completely canceling it out. Equation 2 shows the equation for the magnetic flux.

$$H=BA \quad (2)$$

- H=Magnetic Flux (Teslas x Metre^2)
- B=Magnetic field strength (Teslas) (Assuming uniform field)
- A=Area (Metre^2)

Equation 3 shows how the induced voltage V(i) is related to H and the velocity of the projectile.

$$V(i)=dH/dt=BdA/dt=BLdx/dt \quad (3)$$

- V(i)=Induced voltage
- dH/dt=Time rate of change in magnetic flux
- B=Magnetic field strength (Teslas)
- dA/dt=Time rate of change in area
- L=Width of rails (Metres)
- dx/dt=Time rate of change in position (velocity of projectile)

Since the projectile will continue to accelerate until the induced voltage is equal to the applied, Equation 4 shows the terminal velocity v(max) of the projectile.

$$v(max)=V/(BL) \quad (4)$$

- $v(max)$=Terminal velocity of projectile (Metres/second)
- V=Power source voltage (Volts)
- B=Magnetic field strength (Teslas)
- L=Width of rails (Metres)

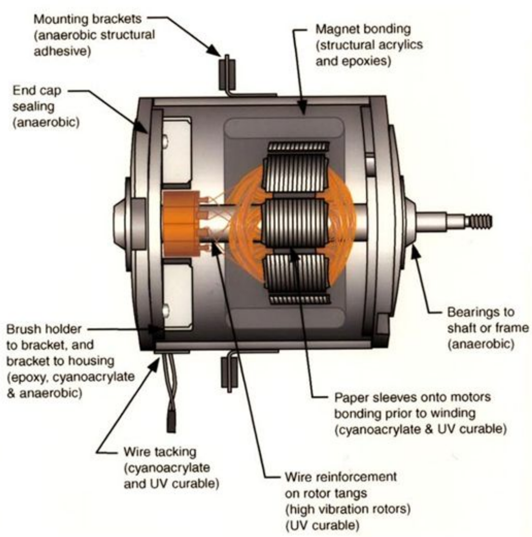
These calculations give an idea of the theoretical maximum velocity of a railgun projectile, but the actual muzzle velocity is dictated by the length of the rails. The length of the rails governs how long the projectile experiences the applied force and thus how long it gets to accelerate. Assuming a constant force and thus a constant acceleration, the muzzle velocity (assuming the projectile is initially at rest) can be found using Equation 5.

$$v(muz)=(2DF/m)^{.5}=(2DILB/m)^{.5}=I(2DLu/m)^{.5} \quad (5)$$

- $v(muz)$=Muzzle velocity (Metres/Second)
- D=Length of rails (Metres)
- F=Force applied (Newtons)
- m=Mass of projectile (Kilograms)
- I=Current through projectile (Amperes)
- L=Width between rails (Metres)
- B=Magnetic field strength (Teslas)
- $u=1.26\times10^{-6}$ (The magnetic permeability of free space, Henries/Metre)

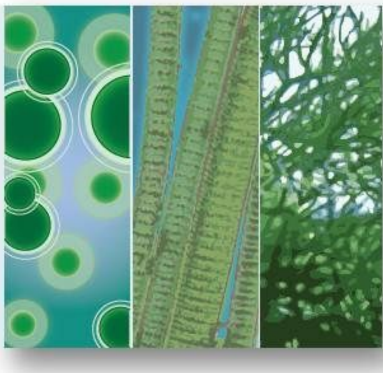
These calculations ignore friction and air drag, which can be formidable at the speeds and forces applied to the railgun slug. Top rail gun designs currently can launch a 2kg projectile with a muzzle velocity of close to 4km/s on roughly 6 meter rails. To reach this kind of velocity, the power source must provide roughly 6.5 million Amps for our trains. Due to the electrical friction and heating this would cause, it would melt any rail material after relatively few uses, leading to an increased cost of constantly replacing materials or investing in low-resistance high-temperature conductors.

Instead, we will power the train system using 25kV 50Hz overhead lines. This will ensure that the motors receive enough power to drive the train at 360 km/h. The motors will be part of a distributed power system that is much more efficient that a single power hub driving the train. Overhead lines are necessary because battery powered trains would need recharging too often and trains with a 3rd electrified rail are limited to 175 km/h and they waste more power due to a higher current. The motors will be permanent magnet motors in line with the AGV model in France (bogie mounted) because they are smaller and light enough to sit under the carriage, which means more space for passengers (necessary on this high volume transport system). A minor issue with them is that they are only able to to spin at a set speed but this is not a problem as we are only looking for our trains to travel at 360 km/h.



The motors work by pulling a permanent magnet in a circle using electromagnets that change polarity based on the frequency. First the north pole of the magnet is attracted to one coil and the it is repelled from it and attracted to the next coil. This drives a series of gears that drive the axle for the wheels underneath the motor. 2 motors will power each train and the motors will be connected separately to the overhead line because it is illegal in the UK to have a wire under the train carrying electricity from one end to the other and it would get in the way of the luggage carrying system.

We could draw this power from the grid but one estimate suggested it would be around £41,000 per day at current UK industrial costs for the 72 MW required to run 30 trains all day.
9.5p per kWh
This works out at £300 million for 20 years, however there is a much better way to produce this energy: algae biofuels. Algae can be genetically engineered to produce a fuel that would be carbon neutral and so with funding for scientists and money to build a power plant it would come to around £300 million and this would provide energy for the lifetime of the plant. Maintenance would be an issue but government subsidies and the potential to sell electricity during the night back to the grid means that it would easily be worth the investment. It is not currently available but the advances in genetic engineering mean that, with dedicated research, it will be a realistic option within the next 10 years. There has been a backlash against biofuels in recent years with complaints about a lack of food in developing countries because biofuels can make so much more money than grain. This has negatively affected the research into algal fuels but there are still some companies, such as Solazyme, working on it and so cooperation with them could result in a source of energy that requires just a hundredth of the land space as crop fuels. Also it is purely carbon neutral as it could be piped to the power station and processing would not be a problem.



Lastly, interior systems such as the EL panel, announcements and opening doors will be powered partly through regenerative braking, wherein the kinetic energy of the train decelerating is converted via a flywheel into electricity. It would then be stored in a battery for use whilst the train isn't decelerating.

Maintenance:

To keep our trains functioning well, they will need continual maintenance to ensure no systems have malfunctioned during the large distances they traverse every day. A side rail will be incorporated at each station, used for storing trains that are not in use and are being maintained.

In our system, trains 1-30 would be in use, with trains 31-40 being serviced on the side rails at each station. At the end of each day, the serviced trains would be swapped onto the active tracks, and another ten taken off to be serviced. During this time, the cleaning personnel would also clean the interiors of the trains to ensure they are hygienic. This would continue in a four day cycle, with each train being fully checked over and problems fixed in this time.

From HS2 cost estimates, extrapolating for our trains, we will need £1 per kilometre travelled for maintenance. This is roughly £20,000 a day for maintaining all the trains not travelling.

Any trains that break down whilst in service will be accounted for via the dead man's switch system elaborated upon in the SAFETY section, and moved to the stations for an active trainset to be swapped in. In this way, breakdowns can be managed with minimal risk to the passengers and other trains on the same track, whilst ensuring service continues smoothly.

Marketing and Advertising:

In order to attract passengers to use the AeroLink system to travel between the London airports, we would need to invest in advertising in airports and other commonly used transportation systems. Under such a system, this advertising would be essentially free, as airports would benefit financially from AeroLink due to increased passenger numbers and usage, and it would also benefit us by reaching a wider audience of potential customers.

Getting the word out that such a system is operational is vital to continued operations of the AeroLink system once it is up and running. This would be accomplished through the use of posters containing basic information about AeroLink and explaining its advantages over other methods of transportation between the five airports. Such an example is given below:

Advertising the system would also take the form of announcements on both planes (for connecting flights) and in airports as a general message. That way, passengers without enough time to read all the information on posters, would still be aware of our system.

Additionally, we would create social media accounts and pages for AeroLink that would both serve as platforms for any disruptions to service, as well as providing us with a free method of advertising. Signs on the train and around the stations would encourage passengers to ‘like’ and ‘follow’ AeroLink on various services such as Facebook and Twitter, getting the news spread via social media to a much wider customer-base. It would be important that the system provides an excellent service, so that news of such is spread by word of mouth and so that people will associate AeroLink with speed and quality.

Within the airport itself, the AeroLink system would be designated a sign in order for passengers to locate it with ease. The design itself would have to be simplistic to allow passengers easy recognition of our service, and would adhere to standard airport colour schemes. In this instance, the sign which we have created is yellow and black (conforming to the regulation of yellow/black signs for airport utilities) and is a compound of the letters A and L (AeroLink), as well as including the symbols for airport departures and the railway service. The sign is pictured on the left:

There is also the ability to generate an income from advertising on the train itself, as well as on the platforms and stations. By selling certain areas to be used by other companies to advertise their products, a substantial amount of money can be generated for very little maintenance cost. In the London Underground train system, it can cost up to £64 000 to buy out a 15 x 48 sized advertising board for a fortnight, figures taken from the Underground’s website. With such high number of commuters utilising our transport system on such a regular basis, selling out areas for advertising promises to be a reliable and worthwhile revenue stream.

FINANCIALS:

Below we have summarised the costs of each aspect of our project, as well as where we have derived and estimated them from. The individual aspects are as follows:

- Track, excavation and additional infrastructure
- Tunnels
- Stations

- Train materials
- Fence
- Manufacturing and maintenance
- Electricity
- Ground testing
- Land costs for acquisition
- Obstacle navigation
- Salaries
- Additional money for unforeseen costs

Track:
Based on the Madrid High Speed Rail network, we found the average cost per kilometer of track by dividing the total cost of constructing the rails by the overall length of track placed. As high speed rail is of a higher quality than normal track, this is a similar cost to what we will require. The average cost per kilometer was €10 million, approximately £8.5 million. Our total overground track length was 194.7km and we have four rails, so multiplying this out gives us a total track cost of £6.2 billion.

Tunnels:
Tunnels are far more expensive than normal rails, and installing a double track tunnel to London City will cost a lot, even though we only have 6.6km of tunnel to dig. Based on an average amount from various tunneling projects with similar lengths and sizes to us, our cost per kilometer of tunneling is £120 million. This because the number of rails is already included, this will give us a cost of £792 million.

Stations:
We will have two different kinds of stations, one underground, in London City, and four overground at the other locations. The cost estimate for an underground station was based on a small London Underground station, which would have the two rails and platforms as we need, this cost ranged between £10 and 20 million, which we have called £15 million as an average. The four overground stations were based on the construction of an overground station in Reading, and gave us a cost of £10 million per station, giving us a total of £55 million for station construction.

Train Materials:
The costs of the following materials were determined using their volume as calculated from the Fusion360 CAD model. The aluminium occupied a volume of 10 cubic metres, which, at a density of 2700 kg per cubic metre and a cost of £1,500 per ton gives us an end cost over the 40 trains of 10 x 2.7 x 1500 x 40 = £1,620,000

The steel occupied a volume of 0.8 cubic metres, which at a density of 7850 kg per cubic metre and a cost of £240 per ton gives us an end cost over the 40 trains of 0.8 x 7.85 x 240 x 40 = £60,288
The recycled HDPE occupied a volume of 0.4 cubic metres, which at a density of 970 kg per cubic metre and a cost of £640 per ton of recycled pellets, gives us an end cost over the 40 trains of 0.4 x 0.97 x 240 x 40 = £9,932.8
The Curran fibre reinforced polymer truss was harder to calculate, but given Curran is practically free besides processing costs, we assumed this number to be quite low. The CelluComp factory in Scotland produces 400 tons per year, so if we source the vegetable fibre waste then we can reduce the potentially large cost. Adding in the 50/50 carbon fibre to Curran ratio, this also increases the cost. Between 40 trains with 2 truss' per train, and 36 metres of each truss, we estimate that each truss will cost several thousand pounds. Calling this as £25,000 per truss, this gives us 40 x 25,000 = £2,000,000
Total material cost is £3,690,220

Fence:
In order to prevent people from intruding on the tracks and potentially inflicting self harm, as well as possibly endangering passengers and the train itself, which would halt our operations, we must consider constructing a barrier between the track and the surrounding land. An effective and relatively cheap method would be the fabrication of a chain link fence atop the berms on either side of the track. This has been estimated as costing £15 per metre, at 2 metres high with barbed wire, multiplying out by 194,700 metres and by two for both sides, to give a total fence cost of approximately £5,841,000

Manufacturing and Maintenance:
Due to the size of the trains, they will have to be manufactured locally, as shipping costs from factories in China would be too large to justify, as well as transporting them all by road to the rails. To find manufacturing costs for these trains locally, we found a rail network in Turkey called TCDD required 80 high speed trains as well, that were operating at virtually the same speed as us. These cost £4 million per train on average, with all 40 trains costing £160 million. HS2 is projected to cost £2.97 per kilometre of maintenance; our trains are smaller but more technical so we have estimated them to cost £1 per kilometre to maintain. Assuming each train will cover the 194.7km of track in an hour, then over 20 years, maintenance would cost our fleet of 30 active trains £1.02 billion to maintain. This totals as £1.18 billion in manufacturing and maintenance costs.

Electricity:
To power the trains, we had two options; either draw from mains electricity or build a dedicated power plant. The algal powerplant chosen in the **ELECTRICAL ENGINEERING** section provides 80 MW continuously at a cost of £300 million, providing electricity for the entirety of its lifetime.

Ground testing:
For the tunnelling in London, the ground will need to be tested for its tunnelling viability and to make sure it is stable. This will cost £30,000 roughly, with figures found from the Crossrail project.

Land costs for acquisition:
We will have to buy all of the land that our track sits on, which will be one of the largest costs of our project. Our track is 194.7km long overground, and, given approximately 4 metres per train in width, will have a surface area of 3,115,200 square metres. The average land cost for land on the outskirts of London is £818 per square metre, however this cost is for developed land so the actual figure is much more uncertain, but we will use this as it was the closest value we could find. Multiplying this cost out gives us 818 x 3,115,200 = £2.55 billion.

Salaries:
Our system would necessitate the creation of about 120 jobs, of which the salaries must be taken into account for the end cost of the project and thus factored into the ticket pricings. Each train will need one employee of AeroLink, who will act as both security officer (as a deterrent) to keep an eye out for trouble, but will also function as a safety officer, helping any person with bags and making sure nobody gets trapped in doors. They will be paid £10 per hour and work 8 hour shifts, with 90 of these jobs needed. Additionally, four employees will be stationed at each station, and their job will be to assist with boarding and disembarking, as well as making sure the doors close properly and safely. They will also be paid £10 per hour and work 8 hour shifts, with 60 of these jobs needed. The shifts will be timed to end halfway through the safety/security officer’s shift to ensure even coverage. Lastly, the trains systems will be monitored remotely by a control centre by the algae biofuel power station, which will both monitor CCTV cameras inside the trains and make sure the trains are performing as well as they can. We estimate that one person can keep an eye on two trains at the same time, so we will need to have 45 jobs, each paying £10 per hour and working 2 four hour shifts so they can maintain optimal focus for watching the trains. This is because 8 hours shifts would end in loss of concentration due to fatigue. Lastly, we would need a cleaner at each station who would be in charge of cleaning the train at off peak times, who would receive £10 an hour for three hours of work a day. This results in a total of 140 jobs, which will each receive £80 per day with 5 cleaners getting £30 a day. Factoring in a 5 day week, and 4 weeks holiday unpaid, with 48 weeks working, this gives a total wage bill of £54,480,000.

Total costs:
Adding up our values for each aspect gives us the total cost of building AeroLink:

Section:	Cost:
Track, excavation and additional infrastructure	£6,200,000,000
Tunnels	£792,000,000
Stations	£55,000,000
Train materials	£3,690,220
Fence	£5,841,000
Manufacturing and maintenance	£1,183,000,000
Electricity	£300,000,000
Ground testing	£13,000
Land costs for acquisition	£2,552,000,000
Obstacle navigation	£3,000,000,000
Salaries	£54,480,000
Unforeseen costs in the future	£1,000,000,000
Total:	**£15,146,024,220**

Ticket Pricing:

Tickets will cover the main cost of repaying our loans as well as contributing to profit, over the twenty years given. We need to pay back the loan in 20 years as part of the specifications for the challenge. We estimated that £5 billion could be made in 20 years from advertisements and so that takes some of the stress off ticket sales.

- 203280 passengers per day
- 74197200 per year
- £20 flat fee
- £10 concessions (students and over 65s) and children under eleven are free.
- Profit will go up over time because as loan is paid off interest is reduced

We split it down into per year so £0.75 billion to be paid off in addition to the 5% extra from interest means that costs will be around £1.5 billion pounds including salaries, maintenance and loan repayments for the first year. Around 25% of travellers are concessions (actually a little less because the data only gave 16-25 year olds) and so potential profit is reduced significantly. However there are no numbers on under 16s so it will balance out, 18 million concessions will travel giving £180 million and 55 million standard fares should be bought per year and so that will bring in £1.1 billion per year. When coupled with the money made from ads (£0.25 billion per year) this gives a healthy £1.54 billion per year. This means around £40 million profit will be made in the first year and this will only increase because the interest will go down as the loan left to be repaid decreases and there is also room for an increase in the numbers of passengers

Cost recuperation schemes:

Advertising:

The London Underground system makes £3.8 billion in ten years from advertising revenue, helping to keep costs down. If we factor in the relative size of our system and passenger numbers we estimate that we can achieve roughly £5 billion over the twenty year period however the breadth of passengers using the systems means placement would get a message to many people from many countries and thus we could potentially charge more.

Selling power back to the grid:

Because our algal fuel based power plant will generate more power than all trains will use, it will both provide a continual trickle of power to the grid, as well as peaking to higher amounts when service is lower at night. In the US, the only location we could find data for selling power back to the grid, electricity was valued at \$0.12/kWh, which is £0.10/kWh. Since the power plant produces 80 MW and our system only requires 72, we have a continual supply of 8MW that we can sell back to the grid. Over the twenty years, we can make 8000 x 0.1 x 24 x 365 x 20 = £140 million, which rises to £175 million if we factor in peaks of power supply in lower passenger number sections. Although this will not make a significant dent in our overall cost, it will be enough to pay for the maintenance of the powerplant and and some of the trains.

Safety:

Fences:

Most railways have to deal with the unfortunate consequences of suicides by train, as well as incursions onto the tracks by intruders and animals. Due to the high speed of our trains, this will cause severe trauma and/or death to the intruder, in addition to a possible derailment or fouling of train mechanisms. This would result in both risk of life and increased maintenance cost for any strikes.

In order to keep the chances of any intrusion onto the tracks at a minimum, it will be necessary to construct a chain link fence on both sides of the rails. The fence will run for the entirety of the overground portion of our system, a total distance of 194.7 x 2 = 389.4 km. To deter intruders and keep animals out it will be approximately 2 metres tall, as well as being topped with either barbed or razor wire.

Due to the frequent nature of our train's circulation pattern, we will not need to put up signs warning people as to the dangers of our trains. As trains will be passing four times in five minutes, people will be adequately warned as to the danger of high-speed trains, if the 2 metre chain link fence isn't deterrent enough. Additionally, these signs constitute an unnecessary extra cost.

Seatbelts:

We are not going to use seat belts on our trains, for the same reasons as those given for most trains including the bullet train; the mass of our train is large enough that it will have a high momentum when traveling at 360kph and if it should roll upon crashing, the centripetal forces would exert such high G-forces on the passengers it is unlikely any would survive. Due to the incredibly small percentage of trains derailing in this fashion, the majority of operators omit seatbelts due to statistical evidence.

In the case of a crash, a five point harness could possibly save the passengers from the centripetal forces, but people travelling on a train might not like to experience such constriction. The majority of all train death are in carriages without seats, and as we have none, passengers will be at a much lower risk of injury and/or death.

Stations:

We will be applying the existing system currently used on many train networks such as the London Underground. There will pressure sensors on the inner edge of the doors so that if an object such as a bag or person gets trapped the doors will automatically re-open allowing such obstruction to be moved. When the doors close they will exert very little pressure on each other as they will be made to be an exact fit and hence any pressure that is recorded by the sensors can be assumed to be a bag or person in the way. In this way we ensure that there is very little risk of people getting trapped when getting onto and off our train.

Additionally the gap between the train and the station platform will be kept to a minimum so that we reduce the risk of falling onto the tracks when getting onto the train as much as possible. It is impossible to prevent people from deliberately falling onto the tracks, even if we invest in a glass door system that is closed when the train is not in station, similar to the one being used on the Jubilee line at the moment. Hence we are not going to invest in these glass doors as the cost would be huge and it would not save that many lives, so the money could be invested elsewhere.

Breakdowns:

Due to the large number of trains running on our tracks, this requires the use of a failsafe mechanism such as a dead man's switch. This would consist of a high frequency signal transmitted by all trains, which would stop broadcasting in case of a malfunction. This would then connect using fibre optics along the track to Heathrow where as part of the station, there would be a control room.

If a train stops sending a signal for 3 seconds then the trains on that track between the same stations (ie Gatwick and Heathrow) automatically brake gently and the gears change over for a more powerful but slower drive. This would allow the train to potentially push the broken down one along to the next station where it can be taken off the tracks and repaired. The train would monitor all vital internal motion electronically and would shut down the signal to the nearest tower if a problem arose. In the tunnel to London City the trains would instead communicate with receivers inside the tunnel because radio frequencies cannot penetrate the ground and these would communicate with the nearest station.

Fire and Crashes:

To ensure passengers are safe in the event of an emergency, they must be able to leave the train quickly and safely in all manner of circumstances. The windows will be removable by catches that can only be unlocked once the train has stopped moving and a glass panel has been smashed, in a similar manner to a fire alarm. This will allow the passengers to leave the train via the large windows if it has rolled and come to rest on it's roof or side.

The doors will be manually operable in the event of a crash, and can only be opened when the train is not moving to prevent any accidents.

Construction Timetable:

During the construction process there are four main stages to consider. These are site clearance, initial construction, civil engineering and railway installation.

During the site clearance process, the required land is acquired and cleared for initial work to be undertaken. This will most likely be the longest stage of the process as this will require debates and meetings with the many local councils that we will be running through. We will probably have to deal with protesters who oppose our system, as there are always protesters against construction, especially of public services. On top of this, diversions are put in place to help deal with infrastructure disruption when we start building. More than likely, this stage will take several years to get the project through all the proper authorities, such as Parliament and local borough/district councils.

Once the site is cleared, initial construction can take place in which the first embankments are built, foundations are laid and bridges are built to avoid obstacles. Before tunnelling can begin, a year of ground testing has to be undertaken to ensure the land will be stable and safe for construction. This can begin during the initial stage, along with mapping the precise route of the tunnels to avoid existing subterranean infrastructure.

With the general route established, the major civil engineering projects can start, such as tunnels, bridges and stations. These are all the support structures needed for the railway. Stations will begin construction outside of the four airports, with digging beginning for London City. The control centre and algae power plant will also be constructed at this stage, allowing for testing of the latter, which could sell power back to the grid during its observation period. Bridges and tunnels over and under roads, railways or rivers will also be made, after which diversions can be removed and transport can go back to normal.

Finally once, all of these stages are completed the railway itself can be installed. This includes the track, power supply and the final finishes to all railway infrastructure. During this time, the system will undergo a wide variety of tests and checks to make sure all of our system operates in a safe manner. A soft opening will be conducted to ensure passengers are happy with the system and will spread word of its opening, in addition to giving us time to troubleshoot any errors that arise.

Stage:	**Approximate Time to Completion:**
Site clearance	2 years
Initial construction	3 years
Civil engineering	3 years
Railway installation	2 years
Total:	10 years

Bibliography:

Below is a list of the resources we used to find information for this proposal and the majority of websites. A talk by the British Tunnelling Society about Crossrail was attended.

https://tfl.gov.uk/info-for/business-and-commercial/commercial-media

https://en.wikipedia.org/wiki/Aluminium_foam_sandwich

http://en.metalfoam.de/processing/

https://www.plasticsmakeitpossible.com/about-plastics/types-of-plastics/professor-plastic-high-density-polyethylene-hdpe-so-popular/

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