

PentaGliders



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MEET THE TEAM

PentaGliders consists of four college aged students from Tasmania, Australia. This is the second generation of PentaGliders. In 2010 Nathan Clark and Jack Ball joined up with two of the original members, Amy Winter and Tristan McCarthy to form the PentaGliders' second generation.

PentaGliders competed in the National Finals in Sydney and became the 2011 Senior Professional Champions. Along with PentaGliders, Trident Racing and wildcard team, Trans Tasman Racing, complete Team Australia.

Awards at the Sydney National Finals, 2011:

- Environment Award
- Australian Grand Prix Fastest Car Award.



About the Team

Amy Winter – Project Manager



F1inSchools has been a large part of my life for the last four and a half years. Managing three teams and having mentored teams worldwide is a rare opportunity! I hope to be employed by Re-Engineering Australia, or to work alongside them to create a new incentive for school aged students!

Nathan Clark – Resource and Graphics Manager



I was first introduced into the F1inSchools Challenge a few years ago. While competing in the team, I secured an electrical engineering apprenticeship with Rio Tinto Alcan at Bell Bay. I believe that the F1inSchools Challenge had a large influence on obtaining my apprenticeship.

Tristan McCarthy – Design and Aerodynamics Engineer



F1inSchools has not only expanded my knowledge of engineering, but has taught me more about teamwork, marketing and working with different people in industry. Before I was not planning on attending university, but now I am looking at degrees in aerospace or mechanical engineering.

Jack Ball – Manufacturing and CATIA Engineer



Over the past four years I have learnt a lot of different skills and techniques. I have built upon a range of interpersonal skills and workplace skills, some in the areas of 3D modelling in CATIA, public speaking and working within a team.

MANAGEMENT

Project Management

Unique. Timescale. Budget. Resources. Risk. Change.

Project Management is one of many contributing factors to planning and delivering a successful project. Specialist knowledge, experience and skills were required to reduce levels of risk and enhance probability of success. Many challenges in the project cost valuable time. Tools such as checklists, document templates and review forms were used during and at the end of tasks to lessen problems and conflict.

Various management techniques were used to assist in the process of creating and marketing the team branded wheel kits, design of the car and car components and other tasks in between. Examples include:

- Time management
- Quality management
- Cost management
- Change management
- Issue and risk management

When things were most challenging, having a good management plan guided us through the issues.

Appointing a Project Team

The team selection process was not an easy task to undertake, many factors were put into consideration to ensure the right team choices were made. Applications of interest were sent to three different schools, both high school and college level, giving a larger chance at recruiting a team with a vast range of skills.

After a two month trial, a final decision was made and the addition of two team members was made. All team members are from different parts of Tasmania and hold different occupations such as college student, working from home or as an apprentice.

Team management

A team needs a range of members, who can work effectively on their own as well as a group. Each person should be flexible enough to cover/step in on another team member's job. These were split into four different areas:



Project Manager

There are many responsibilities to this role. For example, being able to strongly manage the team and to control all expenditures and, more importantly, to look after marketing and promotion in all areas. Also, the Project Manager is responsible for raising funds to support the financial needs of the team.



Resource and Graphics Manager

This role creates the colour schemes and graphic design work for all project elements. Secondly, the role involves liaising with the Project Manager, and going into industry to gather different resources needed for competitions and testing.



Design and Aerodynamics Engineer

The responsibility of this role is to design and test the teams' car and car components in programs such CATIA and Virtual Wind Tunnel. The final testing phase data shows whether anything needs to be changed for better racing performance. In addition, they are responsible for the research component of aerodynamics.



Manufacturing and CATIA Engineer

This role controls the manufacture of the car and its components such as front and rear aerofoils and axles. This role is also responsible for reviewing the car's design, creating NC machining codes, controlling the quality of manufacture, and producing orthographic drawings of the car and its components.



Denial is a common tactic that substitutes deliberate ignorance for thoughtful planning.

CHARLES TREMPER



Team Facebook page.

Communication

Meeting as a team proved challenging, the internet formed a large part of our communication; email being the most effective way. Marketing and advertising was a big tool for the team and its products and services as it is a way to communicate our team identity to a broad range of people.

The main forms of communication the team used were:

- Emails – Most common form of communication between the team and sponsors. Around 3 000 emails have been sent and received from the team email over the last two years.
- Cold calling – Directly seeking sponsorship, and for communication within the team.
- Facebook – Marketing the team and keeping followers and sponsors up to date.
- Team website – Providing more in-depth information, and helping new supporters and sponsors to find us.

Other forms of communication:

- Letters in post
- Newsletters
- Radio
- TV news broadcasts
- Local newspapers

The last three have a large range of listeners, viewers and readers, giving greater exposure for the team and public events they have held.

Risk management

Many things could change or go wrong, even at last minute. The team developed a list of things which could stop progress or inhibit tasks from being finished. A few things were put into consideration:

- Event – What could happen?
- Probability – How likely is it to happen?
- Impact – How bad will it be if it happens?
- Contingency – Can you lessen the impact?

In addition a list was made of the risks which could affect the team at any time:

- Illness
- Grievances
- Employment, and school and extra curriculum activities

- Damage to team property
- Loss of resources; e.g. CATIA licences and data loss

After those multiple risks were brought to attention, a list of solutions was compiled with the intentions of lessening stress. In addition a timeline was created.

The teams focussed on the following concerns:

- College and exams
- Overseas trips
- Sickness and hospitalisation
- Full time employment

These areas affected one or more of the team and cost weeks of setback.

Even though these areas caused setbacks, the risk management plan helped to:

1. Identify the risks – Noting the things which would inhibit the team's ability to meet its objectives. For example, losing a team member, IT network outage, and delayed sponsor/team liaison.
2. Identify the causes – Tracing a risk to the beginning to find the root cause.
3. Identify the controls – Find suitable strategies to lessen the likelihood of issues arising in the first place.
4. Evaluate the threats – What is the cause of the problem?
5. Monitor and review – After completion, regularly review the risks profile to reduce the risks.

Finance Management

A plan was developed to determine how much funding was needed to support the purchase of resources. The majority of money was raised by team events such as fundraising dinners, barbecues, as well as public events, rotary dinners, and community grants. Alone, funds raised in this way amounted to AUD \$12 000, and when combined with sponsorship, a little over \$24 000.

These sponsorships included generous donations in excess of a total of \$10 000 by the Defence Materiel Organisation (DMO). Also when things were quiet and money was needed, The University of Tasmania twice provided generous donations.

A budget was devised in the areas of car, uniform, pit display, travel and extra expenses. This funding also helped us to pay for smaller products and undertake ideas that were not otherwise possible.

SPONSORSHIP, COLLABORATION AND MENTORING

One of the most important undertakings was obtaining sponsorship. It was not an easy task, working to demonstrate that the team is a “business” worthy of investment and support. Many methods were used to obtain potential sponsors, such as cold calling, emails and industry visits. The team was lucky because as Tasmania is relatively small, there is a lot of community and business support at no cost. It was a motivating experience, being supported by many businesses that see potential in the team to succeed as a group and as individuals.

The team created a potential sponsor/collaboration document offering different packages for Bronze, Silver, Gold and Platinum class sponsorship. The following factors came into consideration of how to determine which business falls into which category:

- Years supporting
- Money contributed
- Mentoring given

The amount of return a business receives depends on the category in which they are placed. For example: Platinum Class return is advertising on the team website, facebook page, newsletters, car, team videos, pit display, promotional gear, team uniforms, folio and radio etc. Compared to Bronze Class which has a return of advertising in the folio, team videos, and pit display etc.

Platinum: Businesses who have been involved for longer than three years and have contributed \$15 000 to the F1inSchools Challenge in Tasmania, our school or our team directly.

Gold: Businesses who have been involved for two or more years and have contributed \$10 000 to \$15 000.

Silver: Businesses who have been involved for two or more years who have contributed \$6 000 or more.

Bronze: Businesses who have been involved for less than two years who have contributed between \$6 000 or less.

The team has received a lot of mentoring from a variety of business and different people. This has been more than helpful in the areas of public speaking, team identity, form and finish of the car, etc. Examples include:

- Rostrum Breakfast Meetings - This was purely for public speaking, the team worked with Dr Frank Madill – an author, public speaker and lecturer – who introduced the team to these meetings where they were given time to practice team speeches and were given a range of topics to talk on the spot. Before the competition, a shortened presentation was given using a computer as practice for the competition.
- Team coaching – Bruce McLeay from McLeay Consulting travelled from interstate to coach the team in public speaking for the day. The team unlocked new ways to enhance their speaking abilities and how to react to “on the spot” speeches and presentations.
- Car Components – ACL Bearings and Rio Tinto Alcan have mentored the team in regard to the wheel setup; materials and type of axles and bearings.



Verbal presentation coaching.



Meeting regarding poster design.



Meeting at Think Big Printing.



Meeting at ACL Bearing Co.

PROMOTION



ABC Radio interview at Longford Revival Festival, April 2011.



The Examiner – Local newspaper

The Examiner has been a follower of the team since 2009, writing follow-up stories on the team and advertising team fundraising dinners and other events. This had a positive impact on the team in raising needed funds for resources and travel to Malaysia.

Fundraising and Community Events – Local

The team had held many fundraising events to support themselves financially and to promote a positive image of the team. Events such as team fundraising dinners, barbecues, information nights, auctions and setting up stalls at public events, such as:

- Longford Revival Festival
- National Science Week (TAS)
- Van Diemens 2011 Motor Sport Show
- Parliament House Presentation

These were only a few but all were successful in raising funds and really getting the community involved. It was great to involve kids and adults too, you are never too old to race!

The team went out of their way to make themselves known. It was a celebration in itself to be the first Tasmanian team to get through to the World Finals! Mass media was used for promotion. The team held many public events and attended events to push the team name and their products, such as:

Southern Cross News and Win News – Local news broadcasts

They have both covered stories on the team, Southern Cross News in particular have been following the team's progress since 2010. Footage of the track and the cars was used as well as public team events and interviews with the team to boost the image of the F1inSchools Challenge, the team, and our sponsors.

ABC Radio – Local and state wide

ABC Radio has covered two interviews on the team, one in the studio and one at the Longford Revival Festival. ABC have helped to advertise team events and promoted us with an article and interview published on their website.

The Examiner – Local newspaper

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Jack helping with CATIA at Prospect High School.

Visiting Rocherlea Primary School, encouraging future student involvement.

School Visits

The team do a lot of mentoring for students both in and out of Tasmania. Running classes and fun days for the students was another way to positively promote the team to different schools but also the opportunities you get while participating in such programs as the F1inSchools Challenge. This included CATIA training days in Launceston High Schools run by our teams' engineers, as well as organising an activity for the local primary school to generate interest in grade 5 and 6 students to form junior teams. We also provided some mentoring in CATIA and in the project generally via email for local and interstate teams.

School Holiday Program – Queen Victoria Museum and Art Gallery (QVMAG)

The team assist in running holiday programs for junior primary students. There are two different classes:

Beginner Design Class: Where the team provides basic machined cars which the children sand, paint and put wheels and axles in, before concluding with a reaction and race competition.

Advanced Design Class: The team helps in the design of key chains in a CAD program, QuickCAM, and then machines them out using the Denford CNC Milling Machine. They are introduced to engineering and aerodynamics as well as the basics of how to use CATIA. This is a great program to get not only kids, but adults and schools involved, while having fun and learning at the same time!



School Holiday Program at the Queen Victoria Museum and Art Gallery.

GRAPHICS AND PIT DISPLAY

It is important to have an identity, a way where people can remember who you are. A lot of thought went into the graphic design work, the teams colours are yellow and black and are used as a way to stand out from the crowd.

The team have been working with Think Big Printing who have been the main graphic design partner. The team worked closely with Scott Lovell, who has given them insight on not only public image of the team but how to effectively promote, market and sell the team along with their products and services at events.

Booth

Three basic layouts were sketched, from which we chose a design with a curve in the centre. This design initially attracts attention to the centre of the booth; screens on either side of the booth then divert people's attention. The layout of the booth is designed to be 'read' from left to right. A mock-up of the booth was designed in CATIA to predict any problems and get an idea of appearance.

Aim: To keep the booth appearance clean and uncluttered, putting emphasis on the items on display. These include physical cars, the wheel die and produced kits, augmented reality software and, a racing simulation complete with steering wheel.

A display was setup with the table and computer we would be using in Malaysia at the Van Diemen's Motor Show. This gave us experience in setting up and a chance to find any issues.



Augmented reality software

Augmented Reality – BuildAR

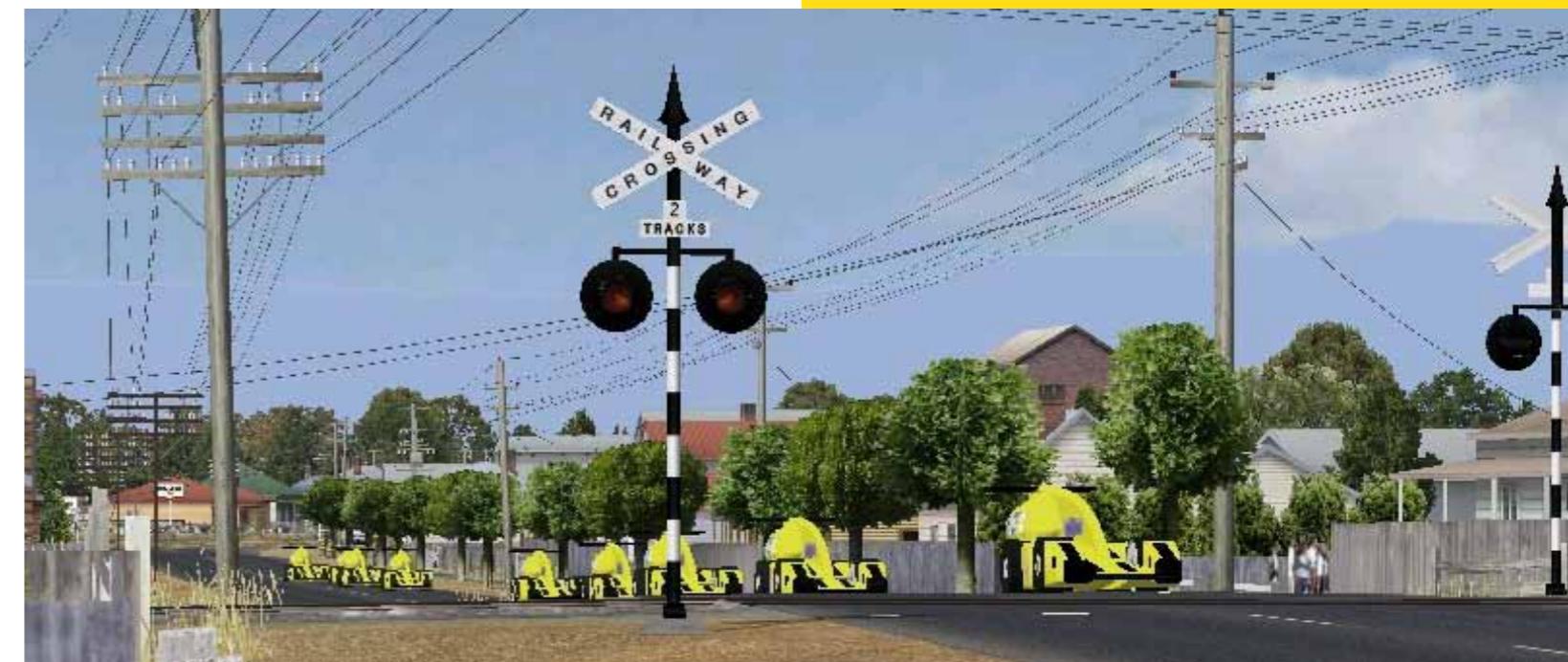
This is a new area of computer interaction. Virtual reality is like any modern computer game, augmented reality is a mix between the physical world and a virtual world through use of a video camera. In the case of *BuildAR*, a physical marker is held in front of a webcam where the software recognises it and displays a virtual object on it. This was used to interactively display car components in our booth.

rFactor Racing Simulation

Automotive Components Limited (ACL), one of the major sponsors, was formerly known as Repco Bearings Company. Repco part developed the Repco-Brabham engine in the 1960s which was the lead performance engine in Formula One for years. The Brabham Formula One car raced at the Longford racetrack in the 1960s – a town less than a half hours drive from our city.

A computer simulated Longford Track was remade by a University of Tasmania student at the HITLab a few years ago. A current HITLab student helped to import a model of the team car into the racing simulator rFactor.

Now people can race the team car with ACL's old engine, on an old Tasmanian F1 track which was remade by a University of Tasmania's student at the HITLab.



PentaGliders cars racing at the old Longford racing track in the simulator rFactor.



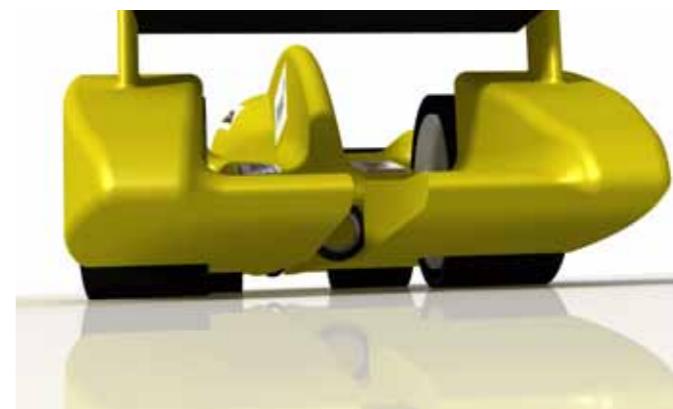
Mock-up of pit display in CATIA.



RENDERING CAR GRAPHICS

CATIA's Photo Studio was used to add colours and stickers to the car and to create the photo realistic renders on this page. This allows us to decide on colour scheme and logo placements before painting or printing stickers.

Reflectivity, refraction, transmission, diffraction and ambience of surfaces was experimented with, using mirrors, paints and metals of varying shapes to produce some interesting effects. The car material was also changed to gold in some cases to create a render of a car that would be far too expensive to produce!



TEAM BRANDED WHEEL KITS

"We think of our team as a business, we wanted to come up with an innovation for not only our team, but also for future teams. With the support of collaborators and sponsors, we came up with an innovation never attempted by other teams!"

Idea

The idea of team produced wheel kits started back in 2007, and was passed down to teams, but was never successful because of financial problems.

The wheel kits are Acrylonitrile butadiene styrene (ABS); a thermoplastic and are injection moulded. The idea of injection moulding wheels seemed practical, it was expensive to start up but cheap as wheel kits would be in mass production. Having wheels made individually on a lathe made sense in the short term, but in the long term is very time consuming and costly!

Most teams aim for minimum dimension wheels and with a bit of research into teams in the local area it was found most teams could not source wheels or had quality control issues in manufacturing them. This led to the idea of marketing the team branded wheel kits to other schools. Considering this and the hundreds of wheels needed over a few years at our hub school alone – the idea of mass producing wheels became feasible!

Development

The Tasmanian Department of Economic Development were contacted to see if they could assist with a grant to contribute towards manufacturing team branded wheel kits, the team were successful in the end, and members of the department were excited to see the project go ahead!

Wheels and stub axles were designed in CATIA and then meetings with Paul Gofton from Dixon Plastics and Tooling were held to discuss requirements to make the kits suitable for mass production.

Paul then built a plastic injection moulding die – a steel mould that would produce the wheels as had been designed. Read about the injection moulding process on page 19.

Marketing

"We not only have sales and interest in Australia, but as far as Malaysia, England, and the United Arab Emirates."

Having a good marketing campaign is crucial for the sales of a product and overall interest in a business. Being able to use technology to help boost the marketing as well as customer word of mouth is very important; always provide a good service and a positive attitude!

The team used a few different media's to try to attract a wide "audience". The wheels have been marketed locally and nationally at each competition whether it be State or National Finals. The wheel kits are also promoted on the teams' facebook page and website.

Welcome F1inSchools The team Services Wheel kits News Media Videos

Specifications

Research and Design

Marketing

Specifications

The wheel kits were designed for other teams participating in the F1InSchools Challenge. The wheels and stub axles are plastic injection moulded by our sponsor, Dixon Plastic and Tooling.

The wheels are designed to the minimum legal specifications to have low friction and less air resistance.

Each kit contains the following:

- 4x wheels
- 4x stub axles
- 4x holding screws
- 4x ball bearings

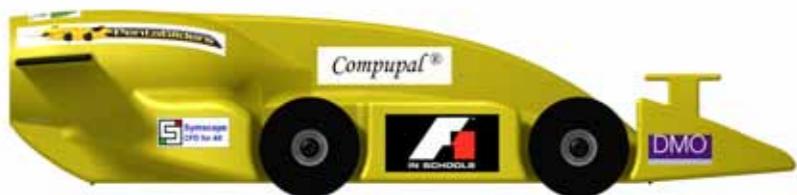
Wheel kit promotion on team website.



Our wheels kits started off as an idea which grew into reality.

They are one of our biggest marketing weapons.

Our aim:
To design a
miniature F1
car that fits all
regulations,
is strong
enough to
survive without
breakages
throughout the
competition,
and do so with
as fast a time
possible.



World Car

DESIGN IDEAS, THEORY AND PHILOSOPHY

While designing, there is an initial idea, an inspiration, which becomes a sketch and then a mock-up in CATIA – the Computer Aided Design (CAD) program that was used. Testing and refinement then occurs, finally, a physical model is machined to see if the idea is achievable.

Our stated aim came about with the philosophy that the engineers must satisfy certain criteria when designing a car including aerofoils, a central cargo, four wheels and a tether line slot; i.e. minimalism was kept in mind when designing. We went about designing the car with priorities in this order:

- Satisfying the technical regulations, as an illegal car would lose more points than would be gained by any advantage in racing.
- Strength of the design must be ensured, as 15 points are lost if the car is damaged in racing due to engineering deficiencies.
- Achieving a high quality finish, as this is judged in engineering. Minor trade-offs in design may slow the car by a fraction, but they may be enough to improve finish by simplifying the painting and that is more likely to improve overall scoring.
- The car is designed to be as fast as possible.

Theories behind the factors that contribute to the speed of the car are:

Mass

The heavier a car, the less increase in velocity it will experience from the thrust of the CO₂ canister. The impulse (force x time) produced by each canister is fairly consistent and due to Newton's second law of motion: $\Sigma F = \Delta mv$, a heavier car will have a slower race time.

However, once all the CO₂ gas has been expelled from the canister, the only forces acting on the car will be resistance forces (decelerating the car). In this phase of racing, a greater mass will cause a lesser deceleration. The net force (sum of resistance forces) is approximately independent of vehicle mass and therefore ΣF is approximately equal for two cars differing in mass only. Due to ($\Sigma F = ma$), a greater mass is beneficial for the deceleration phase, as deceleration will be reduced. This achieves a higher average velocity.

The first effect of a lighter car experiencing a greater increase in velocity overpowers the benefit of lessened deceleration later on. This was proven by testing heavier cars; the aim was therefore to be around the minimum legal mass of 55.0 g with a 0.5 g tolerance.

CO₂ Canisters

Variations in mass and hole puncture size affect performance but these are variables that cannot be controlled.

Friction

Friction results from two surfaces moving in contact with each other, which generates a force that opposes motion. In F1inSchools car designs, friction acts between the wheels and track surface, within the bearings, and also between the tether line and guides.

Wheels

Minimum size wheels are desired as the frontal cross section is minimised, reducing aerodynamic drag. Light wheels have less rotational inertia, meaning they can accelerate faster. But heavy wheels provide more straight line stability when spinning, acting as gyros – the reason bicycles are stable at high speeds. This reduces yawing (side to side movement) of the car, which improves race time. Our wheels are a compromise of these two conflicting ideals.

Centre of Gravity

The *Centre of Gravity* (CG) is the point on the car which if hung by a string would balance perfectly level. Because of the significant weight of the canister at the rear, the aim was for the car design to be as light as possible, making the weight up with the front axles to keep the CG as far forward as possible.

Evaluation of Ideas

There is a balance reached between possible ideas and resources available. The two most restrictive of which are time and money.

Wheels with outside caps that did not spin had been designed in CATIA to reduce turbulence formed by rotating wheels. While it is likely these would have slightly improved race time, it was a very time consuming idea that would also come with financial costs.

The default competition wheels in Australia have a much larger radius and mass than the wheels that our team developed in 2009/10. These were raced on the teams car to gauge how much of an effect wheels had on overall race time. While our wheels were noticeably faster, it was not by a massive margin. This suggested that the slightly improved wheels that had been designed would have almost negligible impact and that time could be better spent on achieving other goals.

We considered bearings that cost over AUD \$100 each but any increase in performance was indeterminable between them and \$10 bearings.

It is these sorts of evaluations that enabled us to make effective use of money.

Aerodynamics

Aerodynamics is the single most important design consideration, because it directly affects the speed and performance of the car and for a large part can be optimised, although the temperature, pressure, density, and humidity cannot be controlled. The aim is to minimise aerodynamic drag and keep lift minimal. Specific aims when designing were:

- To minimise the wake of slow moving and/or low pressure at the rear of the car, as this is as if the car is pulling a trailer, or has a vacuum cleaner attempting to suck the car backwards.
- Ensure the front and rear aerofoils caused minimal disturbance.
- Have air flow freely around nose cone – no high pressure build-up or disturbed air from wheels, as this act like a barrier in front of the car.
- To minimise the rate of change of velocity of volumes of air, for example, a steady rise of air over the car body, not a rapid rise at the front. Air that rises rapidly forms areas of largely varying velocity and pressure, which causes turbulence.

To help demonstrate these, an un-aerodynamic car was designed and run through the Virtual Wind Tunnel program to see what the effects that would slow a car look like. See the pictures opposite.

Drag

Aerodynamic drag can be split into two types: Induced drag and parasitic drag. Induced drag is a byproduct of the generation of lift. It has high relevance in aviation, although analysing the lift force formula: $F_L = C_L \times \frac{1}{2} \rho v^2 \times S$, where S = Surface Area, shows the lift forces involved in F1inSchools racing are considerably smaller than in aviation, or actual F1. As a design is scaled up, for example ten times in size, the aerofoil is ten times wider and ten times in span; thus one hundred times the surface area. It can be seen that the lift force increases by the square of the increase in length, meaning induced drag is almost negligible for small aerofoils.

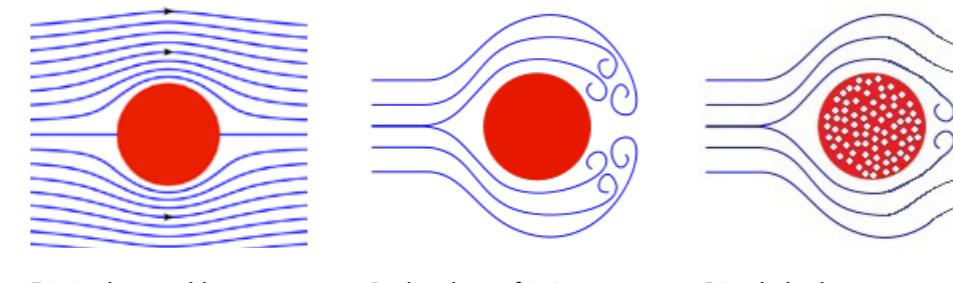
Parasitic drag is caused by an object moving through a fluid. The main types of parasitic drag are:

- Form Drag: This refers to the shape of the object. A more streamlined shape produces less drag; a tear drop is the most aerodynamic shape (i.e. it has low form drag).
- Skin Friction: It was mathematically proven in 1752 that a sphere moving at constant velocity should have no drag force at all! Yet this is certainly not the reality. This became known as "Aerobert's Paradox" and was a mystery for decades. A few theories eventually accounted for the contradiction by the

early 20th century, although to this day there is no formal mathematical proof. The basic problem, however, is that skin friction was ignored in the original mathematics! Skin friction results from friction between the surface of a body and the particles of the fluid through which it moves. A smooth and slippery surface finish reduces skin friction.

Understanding these sources of drag is fundamental to the design the teams cars. Form drag can be reduced by having the most aerodynamic shape, which is the aiming point for all car designs.

In the past golf ball dimples were added to the designs which left small pockets of air that were stationary relative to the car when moving. The friction between the stationary air and the relative airflow is less than the friction between the body and air, reducing resistance. Also, dimples where the car body curves helps the air to change in velocity faster, producing a smaller wake. This is the reason golf balls travel much straighter and farther than a conventional shape ball with otherwise identical properties.



Frictionless world.

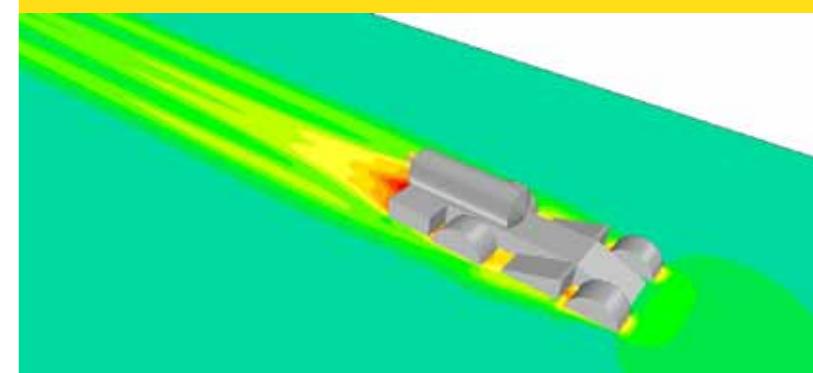
Reality due to friction.

Dimpled sphere.

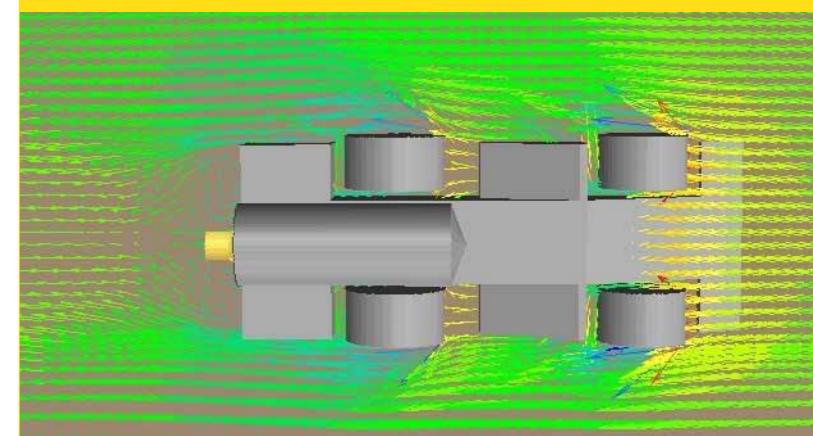
Lift, Down Force and the Ground effect

Lift or down force can be produced by angling an aerofoil, and in the shape of the body itself. The aim was to not produce excessive lift, but enough that the car is not affected by the ground effect. The ground effect is the sucking force that a vehicle low to the ground experiences. It is useful in actual F1 racing as it provides more traction for corners allowing cars to go faster. However, for our racing the ground effect is not desired as there are no corners and any extra grip increases friction and drag. The most effective way to control lift is to vary ride height – the body to track distance. Having a low enough ride height will activate the ground effect, whereas a large ride height increases lift production.

Un-aerodynamic car

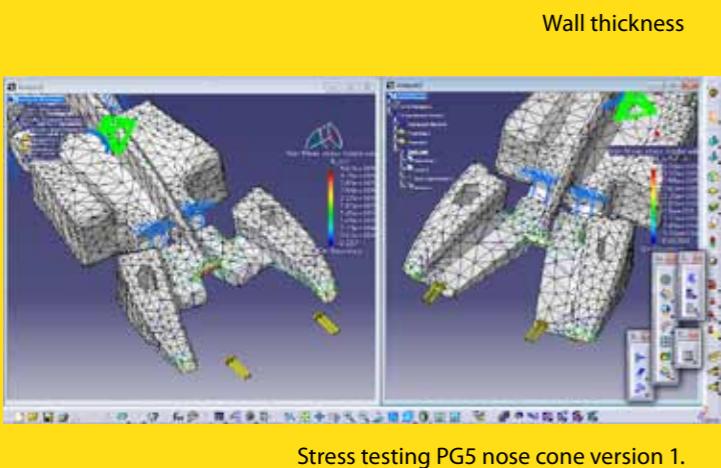
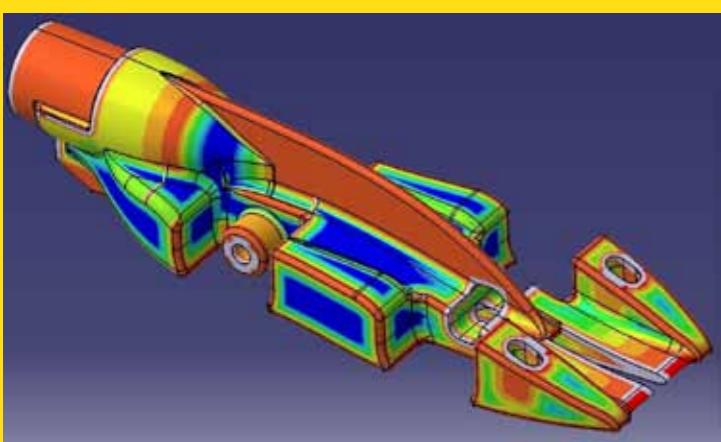


The flat back produces a large wake.



Blunt shapes and sharp angles produce areas of high pressure and large rates of change of velocity, resulting in turbulence.

DEVELOPMENT AND TESTING OF IDEAS



Stress testing PG5 nose cone version 1.



Mass Control - Car being weighed.

Use of CATIA as an ICT

CATIA is a vast computer program; the everyday engineer would likely never use every function available. The student version we use offers 91 functions, but does not allow the use of the aerospace components of the program. Components of CATIA used in our project include:

- Part Design: In designing individual car components.
- Assembly Design: Assembling components to form complete car assembly.
- Material Library: Used to select and edit materials to add to car components. We created the material balsa wood as it was not in the default library and added our calculated density to the properties. This enabled us to estimate masses of components.
- Generative Structural Analysis: Used to stress test components.
- Generative Shape Design: Used to reduce the number of faces to simplify CFD testing in Caedium.
- Drafting: To produce orthographic drawings.
- Photo Studio: To add stickers to the car assembly and create photo realistic renders.

Regulations

An issue was discovered when developing our World Car (PG5) when considering the following regulations:

- T1.3: Body consists of only balsa wood and does not include any balsa forward of centre line of front axle(s) (nose cone).
- T3.7: Body to track distance cannot be lower than 3 mm.
- T4.4.1: No part of the body is allowed to be less than 3 mm thick.
- T6.2: The tether line slot must be a square of 6 mm in cross section.

Our wheels are 26 mm in diameter therefore the centre line of axle is 13 mm above the track. The body to track distance must be a minimum of 3 mm; therefore the distance between the centre line of the axle and bottom of car body can be a maximum of 10 mm. The tether line slot is 6 mm high therefore the distance between top of slot and centre line of axle is 4 mm. If the axle is 6 mm in diameter, that means the balsa thickness will fall to 1 mm: illegal. Even with a 3 mm diameter axle, it is too thin.

Ideas were brainstormed, including having off centre axles that would rise as they enter the car body, stub axles, or machining the entire area out so thickness was 0 mm; therefore legal and then adding a separate support piece for the axle.

A separate plastic support for the front axles was designed, which meant the balsa thickness was either greater than 3 mm, or balsa was not present at all. For the rear, two stub axles were placed in balsa extrusions from the car body which improved stability and kept the axles parallel to the track surface.

Stress Testing

CATIA's Generative Structural Analysis was used to test strength of the car, to reduce the likelihood of breakages. Clamps are placed in the appropriate areas and then a force was applied to an area. Different nose cones were analysed after the actual car broke in testing. Once the weak area was found during stress testing, the problem was fixed by lengthening the pad that holds the nose cone to the car body.

Wall thickness

Can be shown in CATIA (see opposite), it helped us to ensure that no part of the car body would be less than the minimum legal thickness of 3 mm. It also indirectly indicates strength.

Mass Control

To achieve the target mass, balsa blocks were weighed before machining and huge variances were found, some as light as 50 g and some as heavy as 200 g. Qualitatively (no specific calculations) it was theorised that a lighter block with heavier components (axles, aerofoils etc) at the front of the car was best as this improved centre of gravity (CG). Quantitatively (calculations considered), densities of balsa blocks were calculated. Volume of the block can be measured by multiplying side lengths and subtracting the volume of the canister chamber hole and the tether line slot. The blocks were calculated to be 702 cm³ in volume. $\rho=m/V$, where ρ is the density, m is the mass and V is the volume. Therefore for a 50 g block, $\rho=50/702= 0.071 \text{ g/cm}^3$.

This density can be added into CATIA to the material properties and the volume of the car can be measured in CATIA, it can also calculate the mass of the car before machining. The same can be done for axles, as the density of Aluminium is known. This gives an idea of the mass of the car assembly without paint, before manufacturing. Modifications of the design of individual components can be made to add or subtract mass, meaning the target mass was better able to be achieved.

Final coats of paint were used to achieve the target mass and the fact of the paint drying out after a few days, but also the car absorbing moisture in the more humid climate of Malaysia were considered.

COMPUTATIONAL FLUID DYNAMICS (CFD)

Phoenics

Phoenics is the Virtual Wind Tunnel (VWT) program used by most F1inSchools teams. This was used to gain a basic understanding of air flow around each of our designs.



Symscape – Caedium

Through partnership with Symscape – a company in the US – we have had full access to a product of theirs: *Caedium Pro*, a VWT program. It was used in conjunction with Phoenics. Caedium, however, has more capabilities. When the car is racing on the track, the track surface is moving relative to the car and the wheels are rotating as well as CO₂ gas being released from the canister. These can be factored into a simulation done in Caedium, none can be taken into consideration in Phoenics.

Compupal

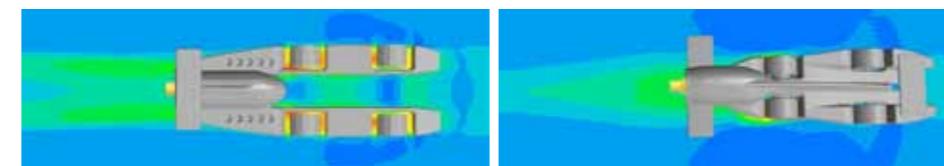
Compupal®

Compupal is a business based in Melbourne, Australia. The CEO was a member of the world champion F1inSchools team – the *Stingers*. Our team have been collaborating with Compupal for two years to improve the aerodynamics of our designs by having our cars tested with flow simulations generated on a super computer. Tests on our latest car recommended an angle between the horizontal and wing - the Angle of Attack (AoA) – of exactly +4.27199584° for the rear aerofoil, as opposed to remaining neutral. An angled and a level rear aerofoil were tested on the physical track, however over 10 runs there was no statistical difference in times. Acknowledging the fact that the CG is much more rearward than the centre of the car once a canister is added, the slight lift generated at the rear of the car helps balance the car during racing. While this effect must be minimal, it is backed by flow simulations, whereas competing with a level wing has no backing in theory or results.

Another specific simulation on our 2011 National Car (PG4) – which is similar in design to our World Car (PG5) – was to test ride height. Excessive lift was not desired and certainly not down force from the ground effect. At 3.9 mm in ride height (which is on the lower end of legal) neither effect was discovered. This therefore remained the ride height of our car.

Virtual Wind Tunnel Results

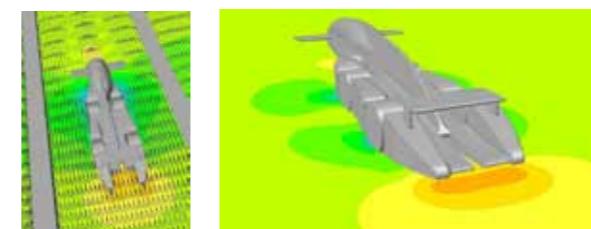
Comparing the wakes of PG3 (left) and PG5 (right). They are both much better than in the *un-aerodynamic car*, but PG5's wake converges whereas PG3's diverges, meaning the kinetic energy of the car is doing work on a greater air mass.



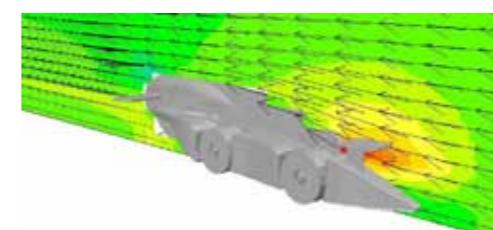
Wake of *un-aerodynamic car* – large and does not converge. PG5's is smaller and converges for the most part within a body length of the car (200 mm).



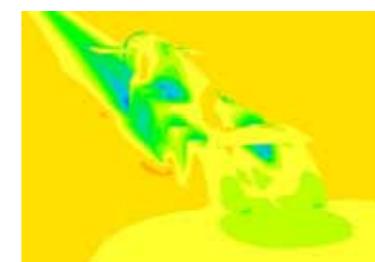
Testing pressure with the track factored into the simulation.



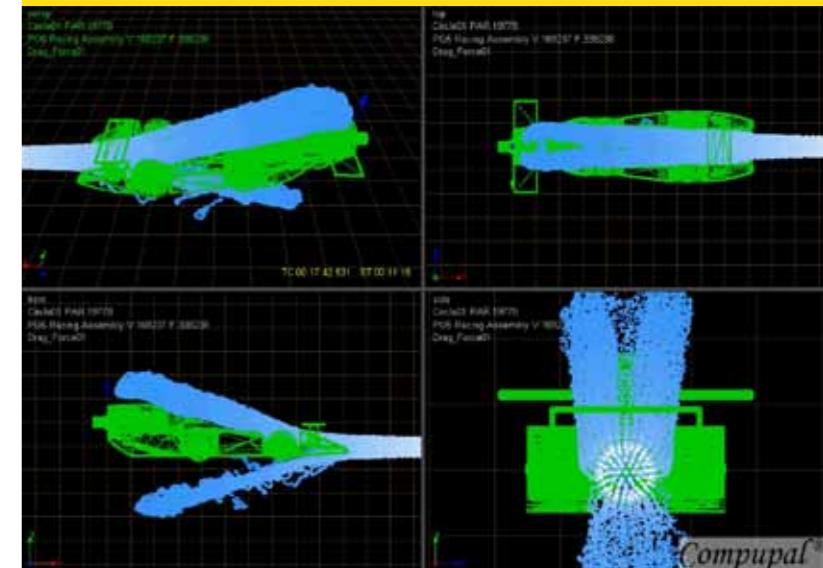
Testing the change in vertical velocity of the air, it was aimed to have the air rise gradually through the centre and this is demonstrated. At the rear, changes are minimal.



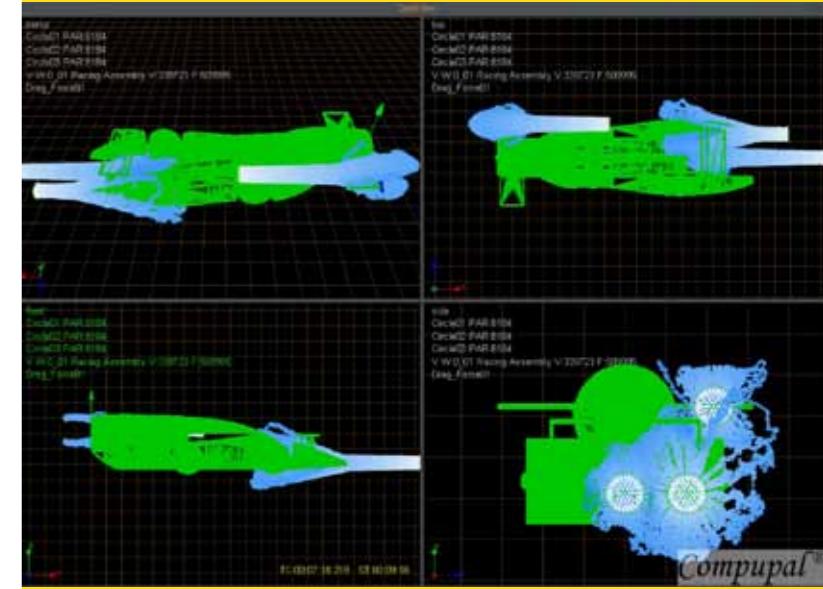
The overall velocity (in any direction) of air as it flows around car. In this case, blue is the slowest moving air, seen in the wake.



Compupal Flow Simulations



PG5 flow through centre of car.



Flow around PG5's nose cone and rear aerofoil.



Smoke Tunnel Testing PG5.



A variety of wheel designs.



Wheel roundness testing at ACL Bearing Co.



PHYSICAL TESTING AND DEVELOPMENT

Smoke Tunnel

With access to a small smoke tunnel specifically for the testing of F1inSchools cars, areas of turbulence and where the air was most disturbed on car designs was able to be seen. On the final car, PG5, the only turbulent area was behind the canister chamber. This cannot reasonably be reduced any further on the design. The only area largely disturbed was airflow around wheels where they contact the track, which was also already at or near a minimum.

Wheels

Previous teams at our school (Brooks High School) manufactured and tested aluminium and ultra-high-molecular-weight polyethylene (UHMWPE) wheels. The aluminium wheels were larger, heavier and noisier when raced, meaning kinetic energy was being converted to sound energy; slowing the car. The UHMWPE wheels would bend when stresses were applied, which would absorb energy from bumps in the track, taking energy out of the system, also slowing the car. Our current wheels are minimum size and are rigid ABS plastic.

Plastic Aerofoils

Plastic aerofoils are stronger than balsa and therefore are less prone to breaking, and can also be made thinner to reduce drag. However plastic is also heavier and the rear aerofoil is larger in volume than the front, which is a negative for the ideal CG, but it is a necessary trade-off. The support for the front aerofoils is made deeper than is necessary which replaces more of the nose cone with plastic, which helps counteract this slightly.

Testing at ACL Bearing Company*

Through collaboration with ACL, the surface finish of the car body after painting and the roundness of our wheels were able to be tested. The surface finish relates to aerodynamics; the smoother the finish the less resistant to the motion the car. The machine that tests finish works similar to a needle moving over each crest and trough on the surface, measuring each height. It then calculates an average known in industry as Ra (Roughness average). The wheel roundness results were a tribute to the quality tool maker, our partner Paul Gofton of Dixon Plastics and Tooling Tas. On average they were within 20 µm of a perfect circle – keep in mind that a human hair is on average 50 µm thick!

*Ask the team about the surface finish result.



Nose diving of car just after launch.

Photography

Photography was used to see what happened to the car initially after launch and in the stopping phase of the race. Unable to source a high speed camera after exploring a few avenues, a digital camera was used. Occasionally a lucky frame came out of a video such as the one above. It is clear that the car is 'nose diving'. This is backed up by evidence of a wear line (below right) where the tether line was in contact with the front aerofoil on our National car, PG4. The reason for this angle is due to the centre of thrust being above the CG. To help reduce this difference a complete redesign of the car focussed around this idea was explored, but proved to be impractical (see p. 17). In the stopping phase it was seen that the car would crash onto its side (below left) – often breaking the rear aerofoil. This then helped when considering designs for a stopping device.



PG4 in the stopping phase. It is tipped on its side; potentially breaking the rear aerofoil.



Wear mark from the tether line.

PHYSICAL TESTING AND DEVELOPMENT

Stopping phase

In stopping, the car experiences large deceleration. When testing for our World car, PG5, it would break at the nose cone connection to the body each time. We increased the thickness of the connection and developed different stopping devices to overcome this problem.

Stopping Device 1: Through working with a mentor from ACL – a 94 cm long device housing bristles to slow the car was built. Different heights and densities of the bristles were tested, along with different materials after finding that the first sets of bristles were too stiff. However, the way the car stopped was unpredictable, sometimes riding over the bristles not slowing the car enough and sometimes bouncing off the front bristles, causing large stresses on the nose cone – subsequently breaking it. A different method was needed.

Stopping Device 2: A much simpler idea: use of soft cloth to slow the car. Silk cloth was tested with a 100% success rate – no breakages. This then became the stopping device of choice.



Break at nose cone connection.



Stopping Device 1.



Close-up of Stopping Device 1.

Reaction Times

Reaction and knockout racing involve manual launch where a 'driver' sets the car off racing. Reaction time is a very important factor in this racing where total time is everything in terms of points. Reaction times of team members were tested with the starting gates of the track and recorded the results to determine who had the quickest average and the least false starts. Index finger and thumb were also tested and it was found that using the thumb was faster for all team members. Amy had the fastest reaction time with an average of 0.15 seconds (to two significant figures), as tested over 15 runs – but also generally backed up by years of fast reaction times. This is an incredibly fast reaction time compared to 0.2 – 0.25 seconds which is considered the average for a young adult. At every competition (State and National), our team have won the knockout event due to a fast car, and more importantly, a fast reaction time. At all competitions Amy has had the fastest consistent reaction time and is unofficially known in F1inSchools within Australia as having the fastest reaction time in the country!

New Tech Ceramics – BAM*

New Tech Ceramics (NTC) is a company in the United States, the exclusive licensee of a material known as BAM – aluminium magnesium boride with titanium diboride. This material is very hard, with a hardness value of around 45 GPa, 65% diamond's 70 GPa and ten times as hard as titanium! As well as being hard, BAM also has the lowest known coefficient of friction of any known solid; 0.02 compared to Teflon's 0.04 and steel's 0.80, meaning it is incredibly slippery.

Discussions were had with the Chief Operating Officer (COO) of NTC – a former engineer, about the possibility of coating our wheels with a thin; 2 – 3 μm thick coating of BAM which would reduce friction between the wheels and track and therefore improve race times. Our wheels are ABS plastic; NTC had never coated plastics and were unable to sponsor research and development into the process and our funds were short at the time. It would be a risk to attempt to coat the wheels as the process is expensive and it may not have worked. Following our risk management plan, it was decided not to go ahead.

However, just four weeks out from competition, NTC contacted the team: They had completed testing on plastics for another customer with quite positive results. After re-evaluating the risk, a decision was made with haste; a package of wheels was express posted to the US!

*Collaboration with New Tech Ceramics was a special case, talk to the team to find out the outcome of this collaboration.



Testing reaction times.

After research, development, testing, and evaluation of ideas, it is time to put the results into practice!

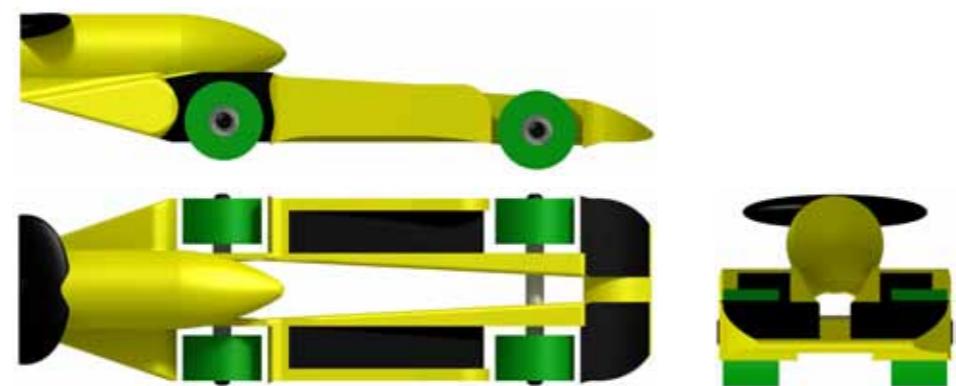


Centre of Gravity State Car 2010

CAR DESIGNS IN PRACTICE

PG1 (PentaGlider 1): State Car 2009

This car was based on the split body, hollow centre idea, to allow air flow through the centre, reducing the frontal cross sectional area and also the wake at the rear of the car. This car was the fastest in the state for 2009 with a time of 1.140 seconds.



V1: 2009 Season

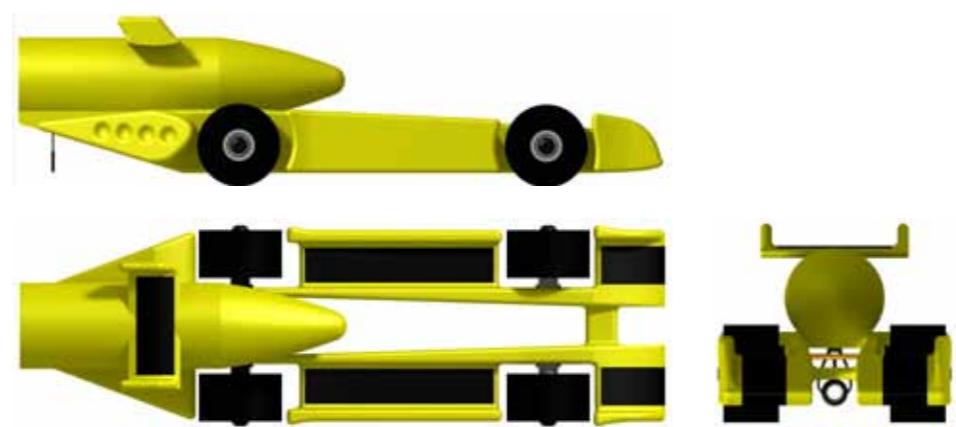
This was the first PentaGliders car to factor golf ball type dimples into the design, an idea that continued for over a year up until PG4. Different shapes for canister chambers were also experimented with.

V2: 2009 Season

This car had a hollow centre, but was solid over the top. Whilst almost resembling a brick, the race times were comparable to PG1, but slower than PG2, so development was stopped.

PG2: National Car 2010

While there were another three complete designs considered, the final PG2 drew from the very same principals as PG1, with some refinement. The aerofoils were



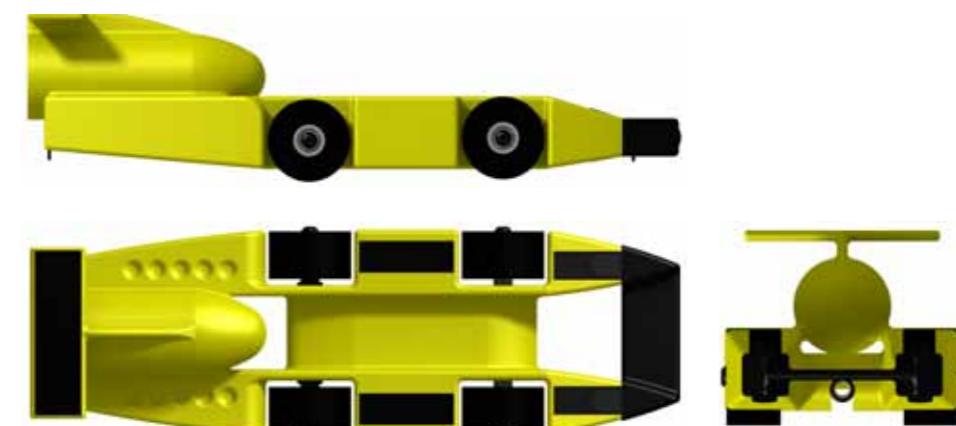
reshaped to minimise the size of the rear aerofoil and to improve flow over the front aerofoil. The golf ball effect was trialled with 12 dimples on the car body. This car was fifth fastest in the country for 2010 with a time of 1.096 seconds.

V3: 2010 Season

The ideology behind this car was a rethink of V2 from the 2009 season, but could no longer have a hollow centre due to a new rule. The car looked 'blocky' and had slower times than other designs at the time, so was not used.

PG3: State Car 2010

With the introduction of a few new rules, designs similar to PG2 were now illegal: A 30 x 50 x 10 mm 'cargo' had to be contained in the side pod area of a design. PG3 maintained a hollow centre, but at the cost of having to move the rear wheels forward and shorten the canister chamber to make the design machine-able. These moved the CG considerably relative to the wheels – the car would be borderline to tipping when a canister was placed inside, despite a heavier front aerofoil and steel front axle (see opposite). Flow simulations showed air travelled slowly underneath the canister chamber, producing a moderate wake. This car, however, was the fastest car in the state for 2010 with a time of 1.161 seconds. The number of dimples on this car increased to 46.

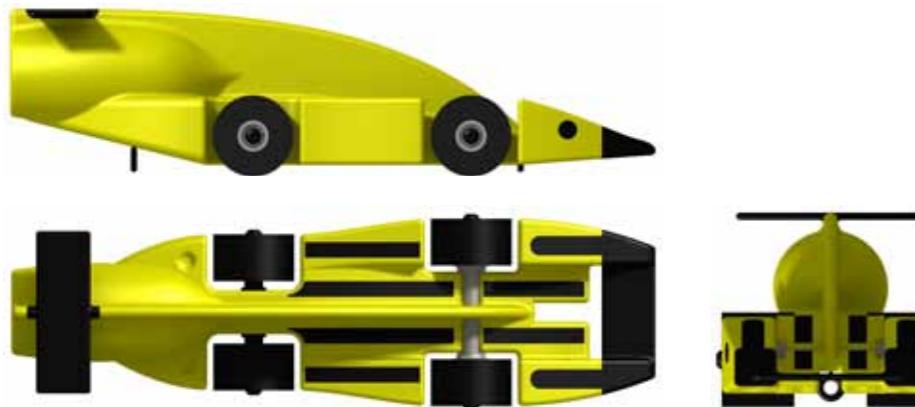


V4: 2010 Season

The hollow centre idea was maintained, but as an experiment, the necessary 'cargo' was positioned to be 10 mm wide and 30 mm tall – reverse of what is normally done. This was legal under the Australian rules at the time. The car as a whole was weaker than other designs at the time (PG4), but it was thought that it could have been strengthened if it was to be entered in competition. Development stopped when it was found through testing using flow simulations from Compupal that the vertical cargo was producing significant drag, even after a fairing was added to reduce this. Also, the velocity of the air through the centre was slower – in the order of 10 m/s – which was causing a larger than desired wake at the rear of the car.

PG4: National Car 2011

This car was a complete rethink, leaving behind the hollow centre idea. The idea is that often cars are designed where the centre of the car body rises evenly with the nose cone that is directing air over the wheels, however, this is not necessary. In PG4, the centre of the car rises slowly to direct air over the rear wheels, at which the width of the car is narrowed. This shapes the car like a tear drop, which allows the air more distance to reconnect at the rear, reducing the wake. It was largely a step of faith which paid off, producing a time of 1.068 seconds, considerably ahead of the next two competitors whose entries achieved 1.096 and 1.117 seconds. When tested in a Scout wind tunnel – a small wind tunnel often used in F1inSchools – at the event, the car had 0.12 N of drag force at a given speed, 30% less than the second placed car which had 0.17 N of drag at the same speed! This car had 51 dimples; 49 on the underside of the car.



V5: 2010 Season

The idea behind this car was to reduce the distance between the CG and the centre of thrust, to prevent the car nose diving at launch, as was seen in a photo taken just after the starting mechanism firing (see p. 14). Dense plastic aerofoils are at the maximum legal height, but because of the density of plastic and the thin connection point to the balsa body, it was weak and far too prone to damage for us to continue with the design.

PG5: World Car 2011

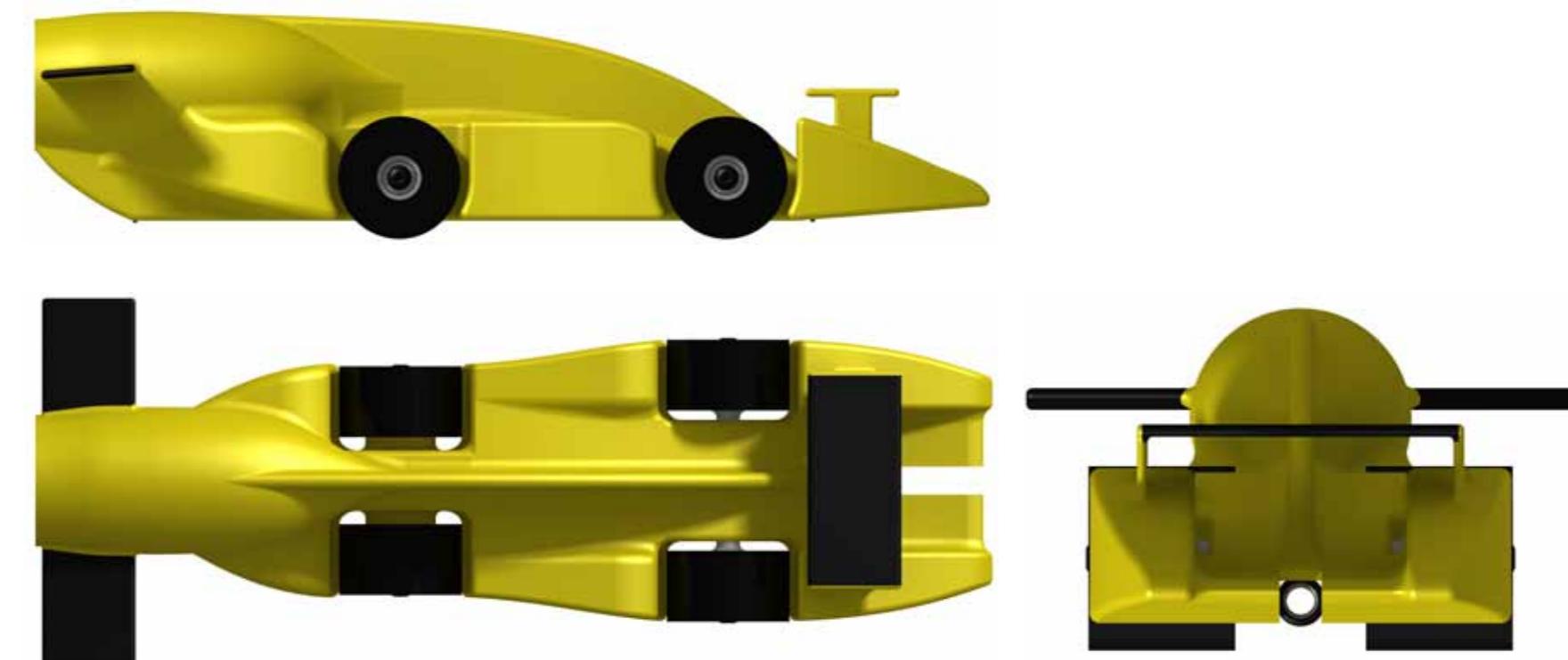
This car is the most refined that our team has designed, and quite obviously stems from PG4. As PG4 was such a successful design, it was decided to continue its development and modify it to be legal under the world regulations. Small details could then be concentrated on, knowing that the car in general was fast. To satisfy world regulations, the tether line slot had to be extended and the front aerofoil raised. The rear aerofoil was modified to increase strength and the angle was refined. There are no dimples on this car, as we had been losing points in form and finish because of difficulty in sanding and painting inside dimples, receiving 15 out of 20 points in this area. Using denser balsa blocks produced better finishes as the material is less 'furry'. A trade-off had to be made as it could not have the best of all three factors. A heavy car is significantly slower, a poor finish is very costly in engineering judging, and dimples give only a slight advantage in racing and so were dropped from the design.



V4: 2010 Season



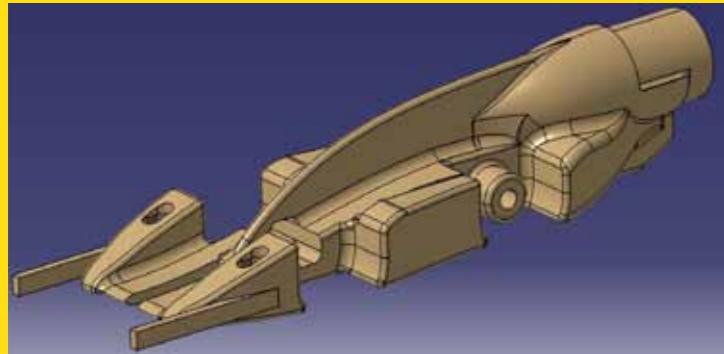
V5: 2010 Season



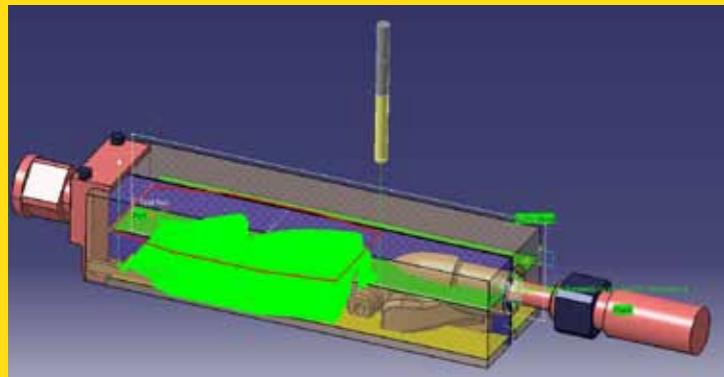
MANUFACTURE AND MATERIALS



Car being machined.



Machining supports



Top machining operation in CATIA (note the yellow 'top' and green 'bottom' machining plates).

Quality of Manufacture of Balsa Body

A 6 mm diameter ball nose drill bit was used to machine our cars. This leaves rounded scallops (bumps) with each line of tool path. In CATIA, step-over distance can be controlled. This is the distance that the drill bit moves over at the end of each line of the tool path. For example if step-over distance was set to 6 mm, the machining operation would leave scallops 3 mm in height.

There are three machining projects on PG5: Machining from the side, top and bottom, with a total of ten machining operations. First, in the side machining project, a roughing operation removes most of the material layer by layer, which reduces stress on the drill bit, and prevents the balsa tearing. Next the side was machined by a 45°, 0.2 mm step-over sweeping operation and again at 315° to eliminate machining scallops that arise from using a ball nose drill bit. The top and bottom projects had limiting contours, such that only the areas which could not be reached from the side were machined. This saves time, money and wear on the machine. These operations were also machined at 45° and 315° with a 0.2 mm step-over. The total machining time (calculated in CATIA) was, coincidentally, 314.2 minutes (100π!). Which is five and a quarter hours.

Machining Supports

When machining any car, it is necessary to include an extra support of balsa at the front between the car body and the front fixture. Pictured left is the car with the two small supports used, the benefit of two is it minimises hand finishing afterwards, as one central support would be more difficult to remove in the case of our design. Having two also maintains stability when machining. It was observed that a car with one support would twist as it machined.

Issues

With the Denford CNC Milling Machine used to machine our cars, it became apparent that as the machine gets older the micro switches wear out just like any other part. A car was machined one day with no issue. The next day another car was machined; this one was not quite symmetrical in the Y-axis. The day after this the next car machined was out quite a bit more. It was suggested by REA in Sydney that the micro switches might need replacing and that each time this particular model of Denford CNC Milling Machine was turned off the Y-axis homing point would move. After replacing the micro switches, PG5 car bodies continued to be machined, and rather than running one machining project and then shutting machine down, it was run it for the entirety

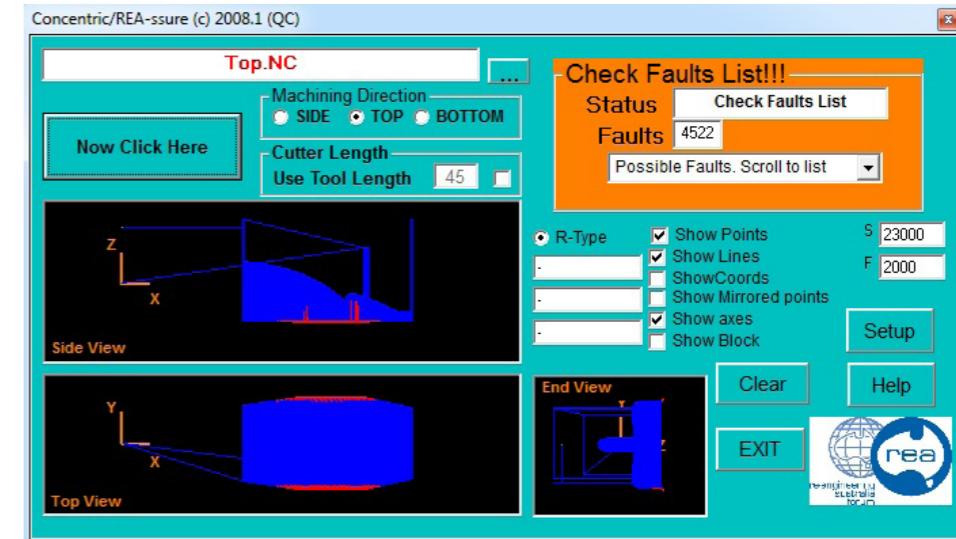
of the machining for each car, preventing the y-axis home point moving relative to each machining project. It was also likely that a build-up of dust was pushing the axis out continuously, so the machine was more carefully checked before use.

In the past there had been a problem with the car not being machined out in the centre of our designs in both the top and bottom machining operations. To fix this, two small plates were added into the machining assembly in CATIA, one near top of block and one near the bottom. These were then selected as a part to be machined for each operation; effectively telling the drill to machine down to and up to these plates. From this moment on there have been no similar.

There was also a minor problem with some balsa material remaining on the canister housing when machining some designs. This was due the drill staying within the set safety plane. The offset on check was reduced from 3.5 mm to 2.0 mm which solved this issue.

REAssure

REAssure is a program used to check for errors in the generation of NC machining codes. It shows any errors or areas where the drill passes a safety plane, which may harm the machine. In most cases REAssure would find many errors and clashes in our codes, but upon interpretation of an image of the errors it was determined that the machine would not be damaged; it was due to our machining operations pushing new limits. Our final car had 6 209 'faults' in the NC codes, yet caused no harm to the machine, although these 'faults' were carefully checked beforehand and the machine was nervously watched the first few times!



Checking NC machining codes in REAssure.

3D Printing

3D printing is similar in process to a mig welder, the way a wire is fed through the welder and onto the metal, but in this case, a coil of plastic is fed through the printer head and melted into place. It is then rapidly cooled to create the figure designed. The printer first puts down a construction layer out of a different material so that it can build the model on top, because it cannot just build in air. After the process is completed the construction material can be broken off, or it can also be dissolved in warm water and washing detergent.

Aerofoils

For testing purposes, and to gain a better understanding of the 3D printing process, we worked with a teacher from another school – Scotch Oakburn College, as they have a small 3D printer. After learning how to use the printer, we were allowed full access to print test aerofoils and axle supports.

Final aerofoils were 3D printed at a local business – Louten Designs, as their quality was higher. CATPart computer files were converted to STL (Stereolithography) format for rapid prototyping.

Manufacturing of Axles

The front and rear axles were machined by lathe at ACL Bearings. ACL also mentored the team on orthographic drawings for the axles, the knowledge of which could then be applied throughout all of our orthographic drawings.

Painting – Surface Finish

Because of advanced machining in CATIA, minimal sanding was needed to prepare the car for painting. First, the machining supports were removed and the car was sanded. Then the aerofoils and axle support were glued into place. Body filler was added to the small gaps between these components and the car body and then

the body was doped and an undercoat applied. This was followed by three coats of *Holden Sports Vehicle (Monaro colour)* yellow. Team produced waterslide transfer stickers were put onto the car in locations already decided when rendering in CATIA. Finally, we worked with Finn's Bodyworks to apply a clear gloss finish as this gives a quality surface finish and appearance.

Manufacturing the Wheel Kits

The first wheels our team used were oilon (a type of nylon) wheels run off on a lathe for the 2009 State Finals. For the 2010 National Final, and from then on, ABS plastic injection moulded wheels have been used.

The injection moulding die has two parts (male and female) which fit together. The injection moulding machine controls the movement of these. They fit together, molten plastic is injected to fill the voids and within 20 seconds two wheels and two stub axles (half a kit) have cooled and are ejected.

For the Australian competitions, the minimum legal diameter for the wheels is 26 mm; with a 0.5 mm tolerance. Because of the accuracy of manufacture the wheels were able to be manufactured to 25.7 mm in diameter in the past. However, for the World Finals the tolerance is 0.1 mm and our wheels would be deemed illegal. The die was slightly widened such that the wheels are now legal for not only our team, but any other countries with narrow tolerances that wish to purchase our wheel kits.

The steel die has also been upgraded with water cooling so that changes in ambient air temperature do not affect the produced size of our wheels. Steel has a moderate coefficient of thermal expansion meaning it expands more than other materials per unit increase in temperature.



Die: Male part



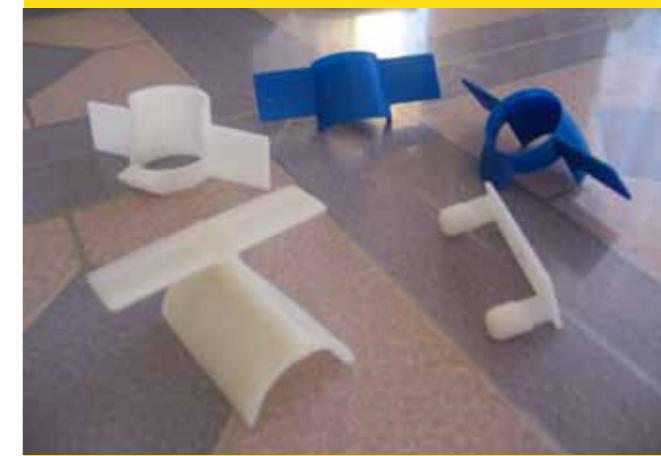
Die: Female part



Meeting at Dinon Plastics and Tooling.



3D Printer

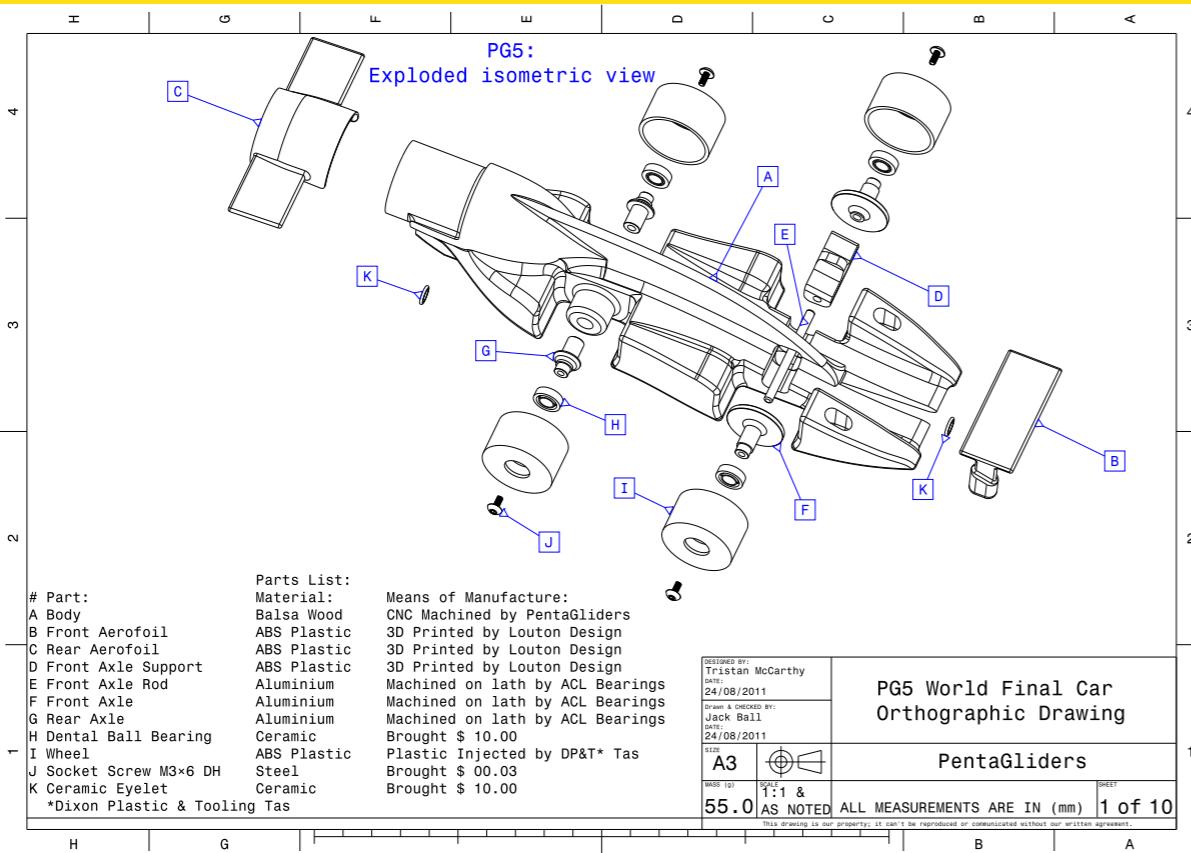


3D Printed Aerofoils



Mass produced ABS plastic wheels.

ORTHOGRAPHIC DRAWINGS



TECHNICAL DRAWINGS

