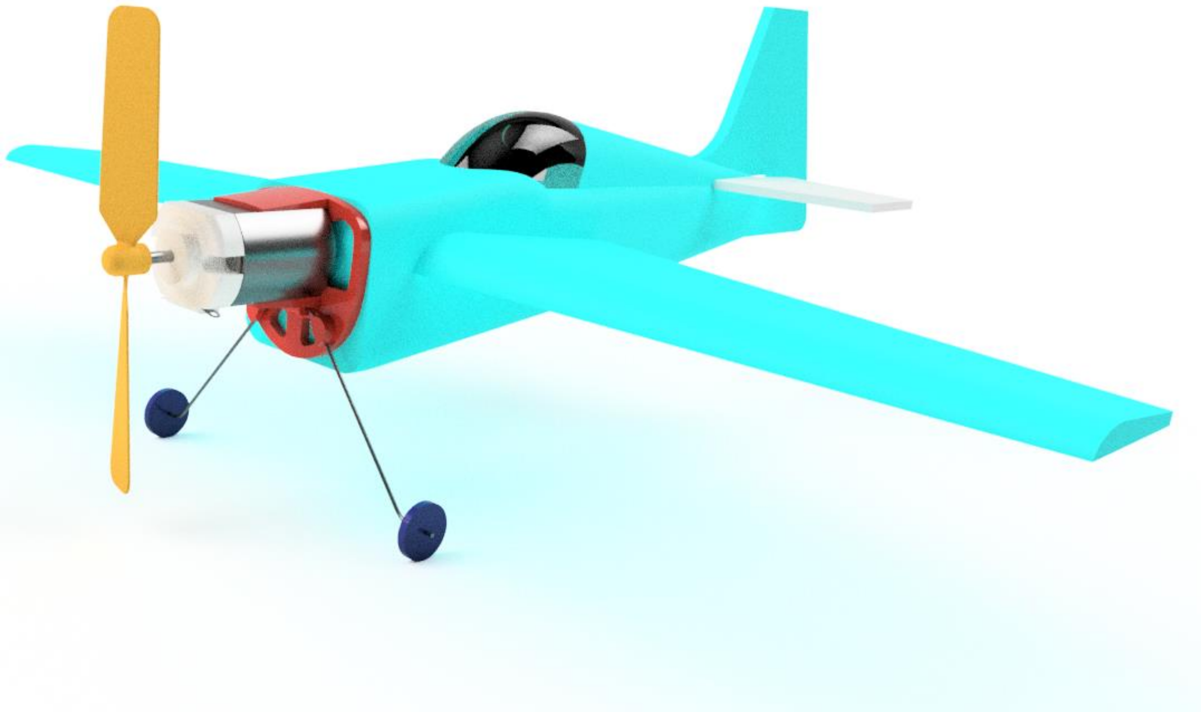
STEM into Action – Pylon flight



Pupils will learn how aircraft fly and use digital design and manufacture tools to design, make and fly their own powered aircraft.

A **STEM into Action** resource from The **Design and Technology Association**.

Contents

Overview

Flight can be a challenging, technically rich and fun D&T activity. The principles of flight are well documented but will need to be interpreted for students at an appropriate level when designing, making and testing designs for aircraft.

Paper, card and foam lend themselves to rapid design development and their low cost enables iterative testing and incremental improvement.

Success criteria can include time in the air, distance travelled, directional accuracy and load carrying capacity with no single ‘correct’ solution which allows for success on many different levels.

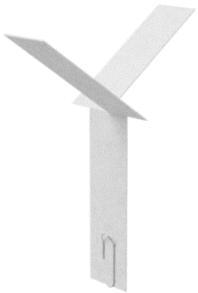
For many years flight has been used as a context for activities in schools with children of all ages.

SCIENCE

Sycamore seeds

A popular science activity in schools has children making paper spinners to explore how sycamore seeds fly.

Nature is an excellent reference for design activity and uses the term ‘biomimicry’.



Parachutes

These control the descent of objects and younger pupils might create a parachute for teddy whilst older students could be tasked with modelling the delivery of aid supplies from low-flying aircraft.

The British Model Flying Association (BMFA)

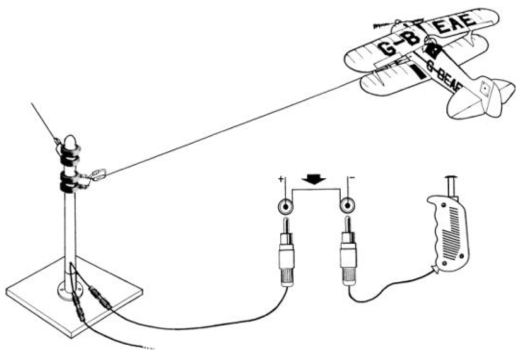
Model aircraft enthusiasts formed this organisation and they have free-flight, elastic band powered models that are ideal for school projects. Low cost kits like this one are available on the BMFA web site. http://education.bmfa.org/products

SCIENCE

Pylon flight

Pylon flight has been a popular for many years and is often referred to as 'round the pole' (RTP) flying. Low cost electric powered models are tethered to a central pylon which provides the model with electrical power.

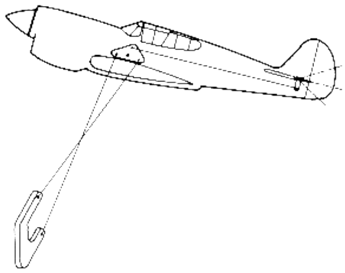
Pylon flight is the focus of the design, make, fly challenge later in this **STEM into Action** activity.



The RTP Hut supplies materials, components and kits for pylon flight.

Control line flying

This was popular in in the 1960s and 1970s but getting glow-plug engines running could be tricky and, all too often models were badly damaged or destroyed on their first flight!



This link introduces control line flying. http://www.go-cl.se/clinf.html

DESIGN

Remote control

The paper aircraft shown here is called Powerup 3. A Bluetooth connection allows the model to be controlled from an app on a mobile phone. These models operate at high speeds and are challenging to fly accurately.
https://www.poweruptoys.com/products/powerup-v3

Radio control

The need for complex electronics makes radio control flight expensive and so outside the budget of most class projects.

Where budgets allow, and for individual projects, radio control offers the widest range of design and engineering challenges for pupils.

To show what is possible, even fully 3D printed models, visit 3D LabPrint.

Cannibalising low cost RC toys is a useful source of RC receivers, servos, motors, etc.

Drones

These have become very popular and range from micro drones that fit into the palm of your hand up to professional models used for filming and sports events.

Airgineers is a competition for schools challenging pupils to design, make and fly their own drones. Autodesk provides their Fusion 360 Cad software free to schools and the 3D models pupils create can be 3D printed. Starter kits are available from Rapid Online.

Pylon flight

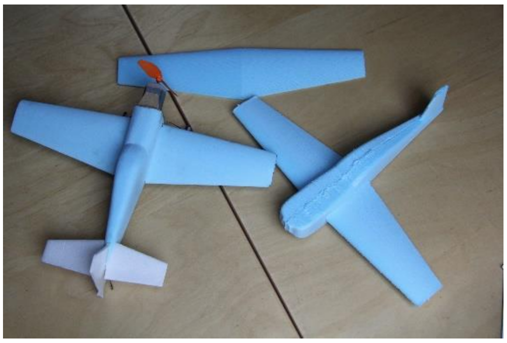
This project was initially developed and taught by two talented Design and Technology teachers: Chris Jarman and David Eyre, whilst teaching at Edgecliff High School in Staffordshire, UK.

The video, **RTP_Extra_in_classroom.AVI** shows Chris on the left and David on the right testing a high-performance model.

This project builds on their work adding the use of 3D computer modelling to create accurate designs.

The parts modelled on the computer can be manufactured using a variety of processes.

CNC machining will cut lightweight, precision foam parts for wings and fuselage.



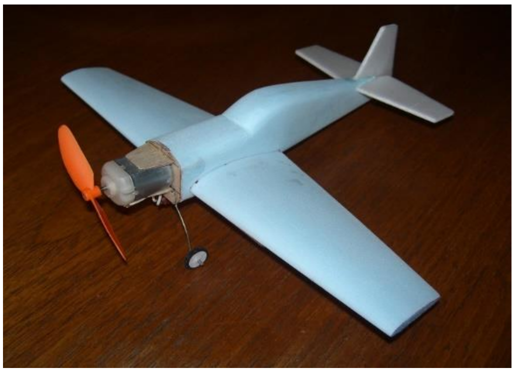
DESIGN

3D printers are ideal for building strong, components from a range of thermoplastic polymers.

The component shown here is a 3D printed motor mount.

Pylon flight aircraft vary from very low-cost, simple designs to highly detailed models.

Most of the designs are fixed wing although autogyro designs have been tried.



Pylons

Central to this form of flight is the pylon.

Two insulated wires are attached to the pylon through rotating contacts. The other end of the wires tethers the aircraft to the pylon, controlling the aircraft trajectory and supplying power to the aircraft motor.

The flight path of the aircraft can be controlled by altering the power supplied to the pylon. This can be done from outside the flying circle.

Two commercially available pylons are shown here.

Power Anchor **Dual flying pole**

Technology Supplies **The RTP Hut**

With simple tools and readily available components, you can construct your own low-cost pylon.

Later in this guide we provide instructions how to do this.

Appendix six outlines the Excel spreadsheet that accompanies this project. The spreadsheet lists the parts, suppliers and costs of the components for the aircraft and pylons. Prices were correct at the time of writing this guide in December 2018.

Principles of flight

How planes fly – Four forces of flight

The forces on an aircraft in flight are usually shown with lift opposing the weight of the aircraft and thrust opposing drag.

Lift/weight

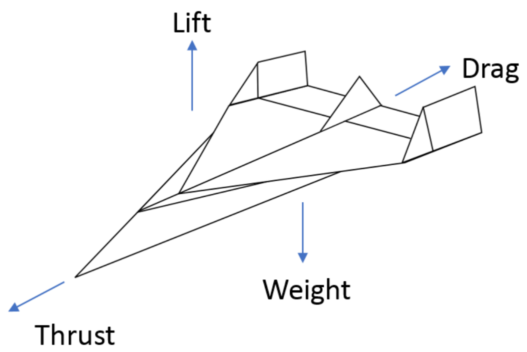
Lift in a paper glider comes from air trapped air under the wings as the aircraft tries to descend.

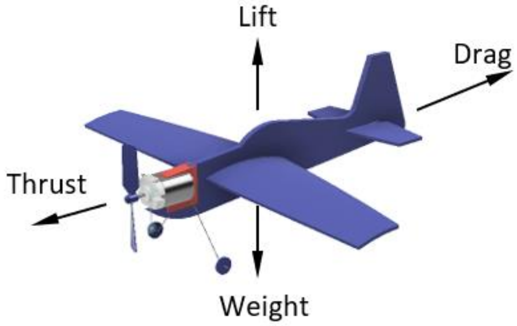
The aerofoil section of more complex wings provides lift which opposes the weight (gravity acting on the mass) of the aircraft.

Thrust/drag

For a paper glider, thrust is provided by a downward trajectory causing air to spill from the rear of the wings.

The motor/propeller combination in a powered aircraft provide the thrust to overcome drag.



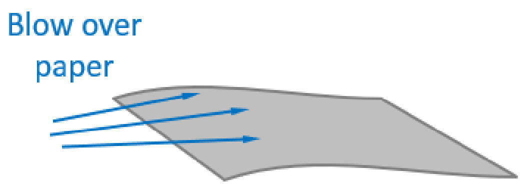


SCIENCE

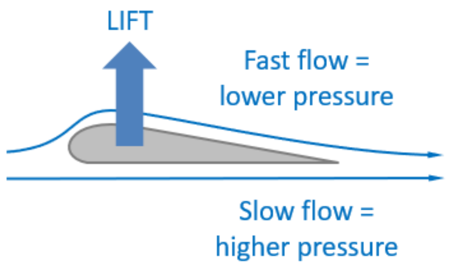
Lift – Bernoulli effect

Daniel Bernoulli was the first scientist to explain how an increase in airflow will result in a decrease in air pressure.

This can easily be shown by holding a sheet of paper by the corners with the edge horizontal in front of your mouth. Blow over the top of the paper and the paper will rise in front of you.



Applied to an aerofoil shape wing, air flowing over the top surface of the wing has further to go so speeds up, reducing the pressure over the top of the wing and causing an upward force.

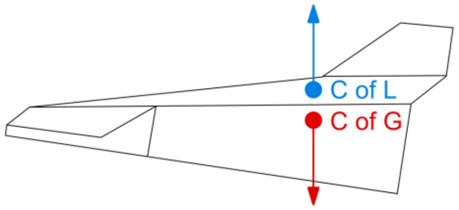


SCIENCE

Longitudinal stability

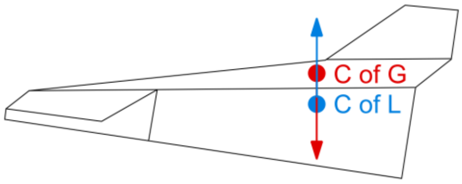
Stable

Looking from the side, an aircraft will be naturally stable in pitch if the centre of lift is located above the centre of gravity.



Unstable

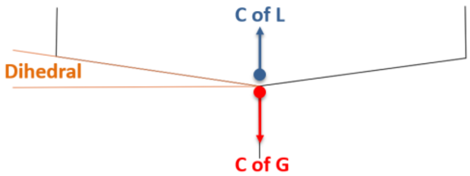
If the centre of lift is located below the centre of gravity, the aircraft will be naturally unstable in pitch.



SCIENCE

Lateral stability

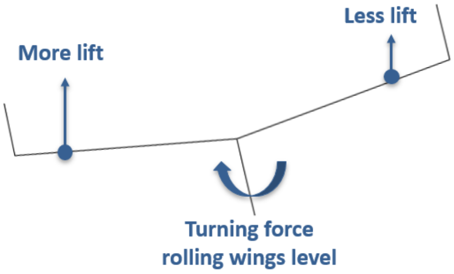
Looking from the front of the aircraft, the wings are higher at the tips – This is called dihedral.



If the C of G is below the C of L, the aircraft is naturally stable in roll.

As the aircraft rolls, the lower wing provides more lift than the higher wing.

The difference in lift causes a turning force which rolls the wings level.

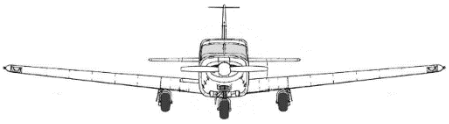


High wing

This Cessna C150 aircraft has a high wing with the centre of gravity well below the centre of lift so doesn't need any dihedral.

Low wing

The centre of lift for this, low wing, Piper Pa-24 Comanche is below the centre of gravity so requires dihedral to create lateral stability.



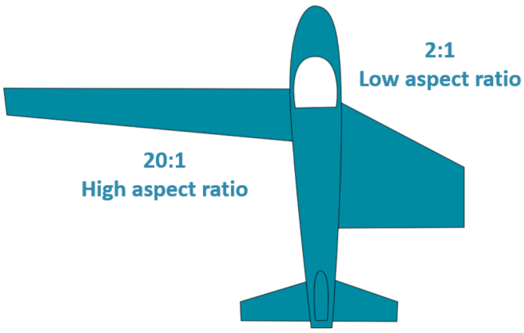
SCIENCE

Aspect ratio

Aspect ratio is the term used to describe the relationship between the wing length and wing width.

Short, stubby wings like those seen on fighter aircraft have a low aspect ratio with low lift and low drag and are suitable for high speed flight.

Long thin wings like those seen on gliders have a high aspect ratio with high lift and drag and are ideal for low speed flight.

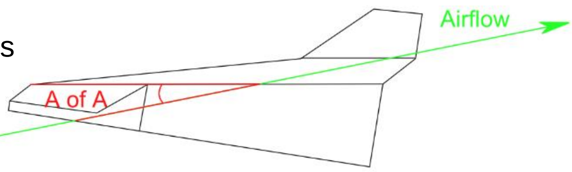


MATHEMATICS

Angle of attack

Angle of attack refers to the angle the wind hits the wings as the aircraft moves through the air.

For a thrown paper airplane, the initial angle of attack is determined by the angle of the wings relative to the direction the dart is thrown.



SCIENCE

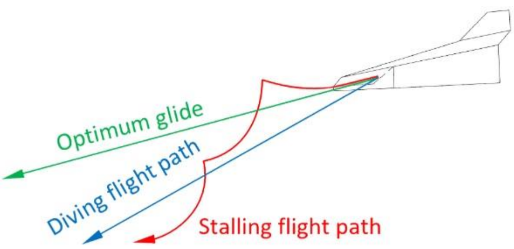
Control

If the angle of attack is too large, the aircraft will climb steeply and slow down causing the aircraft to stall. If this happens close to the ground, the aircraft may be damaged on hitting the ground.

Too small an angle of attack and the aircraft will dive steeply, not travel very far and may be damaged as it hits the ground.

At a shallow angle of attack, the aircraft will glide a long way.

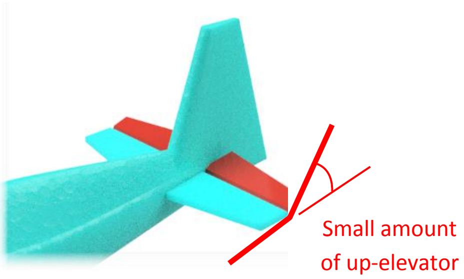
The optimum angle of attack, for an aircraft flying slowly, is just below the angle at which it will stall.



SCIENCE

For pylon flight, aircraft should be trimmed for level flight at around half power with a small amount of up elevator.

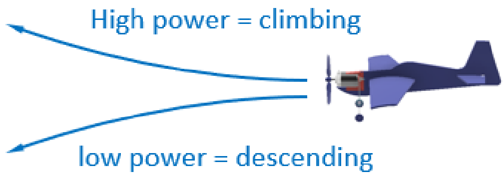
The up elevator allows the trajectory to be altered using different power settings.



ENGINEERING

A higher power setting will increase airflow over the tail and elevators causing the aircraft to climb.

A lower power setting will decrease airflow over the tail and elevators causing the aircraft to descend.



SCIENCE

Flying wires

Reducing the affect flying wires have on the aircraft model is important and so they need to be as thin and light as possible.

For these reasons, single strand 0.36 mm (28 SWG) copper wire with a PVA coating was chosen for the flying wires.

RTP Hut – Reel of flying wire

ENGINEERING

Motors

The criteria for selecting the motor for this project include:

1. Low-cost keeps the total cost of a finished aircraft to a minimum.
2. Small size allows the motor to be hidden in the fuselage of the aircraft.
3. To match toy speed controllers like those used in slot car sets which work at 12v

DC motors are available in different sizes and voltages. The higher the voltage the less the motor will be affected by voltage drop across the long flying wires which is explained later.

Japanese company Mabuchi has been designing and manufacturing DC motors of all sizes for decades and their 130 size motors can be found in many household products.

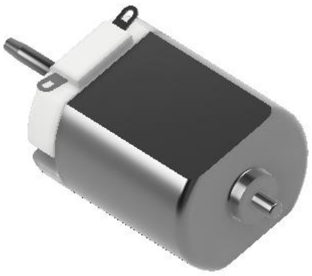
At the time of writing, supplier Banggood offered the lowest price on these motors.

See the spreadsheet for details. **Pylon flight - Parts list.xlsx**

ENGINEERING

Motor rating

Mabuchi 130 motors may be supplied with connections at either end.



Low-cost DC motors like the ones used here are built with large tolerances and individual motors will perform differently.

On motor specifications you may see the term maximum continuous rating (MCR). This specifies the maximum rate the motor will operate at without damage. A 12v MCR rated motor should operate continuously at this voltage.

A motor with a continuous rating will operate for short periods at higher voltages without damage. Pylon flight aircraft are rarely in the air for more than a few minutes at a time so the motors will usually cope with voltages slightly above their rating. Motors treated in this way may get quite hot, a sign they are running near their limit, so make sure you leave them to cool before their next flight.

ENGINEERING

Propellers

The propellers sourced for this activity were supplied by Hobby King, one of the largest suppliers of parts and kits for aeromodelling.

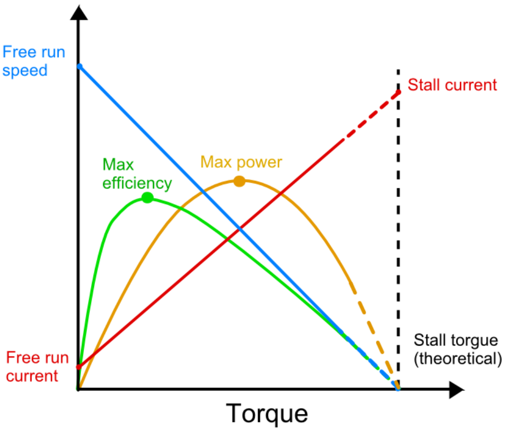
They are deliberately too long for the standard design in order to cater for a variety of designs.

For the aircraft design in this guide the propeller tips should be shortened by the same amount (10mm) at both ends.

Cuts must be equal to ensure the propeller is balanced and does not vibrate.

Propellers are specified according to the diameter and distance travelled through the air for one rotation and must be matched to the torque and RPM of the motor.

Matching propellers to motors can be done using geometry and mathematics but this is beyond most school pupils, so an alternative approach is to measure the thrust and current being drawn by the motor for different propellers looking for a match that allows the motor to operate somewhere between maximum efficiency and maximum power.



The diagram above is adapted from the data sheet provided by Polulu, the supplier listed in the spreadsheet. **Pylon flight - Parts list.xlsx**

A more detailed study of motor/propeller matching can be found here: http://rcadvisor.com/simplified-motor-propeller-selection-method

ENGINEERING

SCIENCE

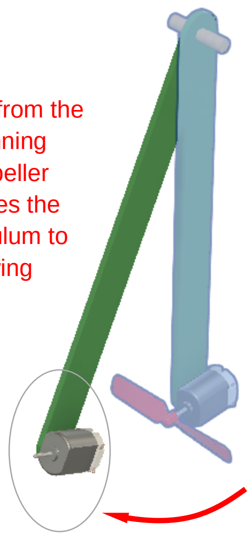
Measuring propeller thrust

A pendulum provides a simple way of finding out how much thrust a motor/propeller produces.

The pendulum swings freely on a spindle at the top. The motor is mounted at the bottom so that thrust from the propeller makes the pendulum swing.

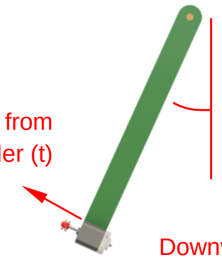
Once the pendulum has settled, its angle from the vertical indicates the amount of thrust.

Using the same motor and pendulum setup, the thrust provided by different propellers can be compared simply using the angle of the pendulum.



Calculated thrust

Using vector diagrams, thrust force (t) can be calculated.



s = 30 degrees (measured from experiment)

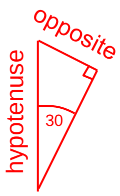
m = 0.04 kg (weighed)

g = 9.81

d (Newtons) = 0.04 x 9.81

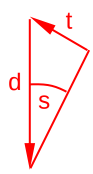
d = 0.39 Newtons

The triangle of forces contains a right angle allowing us to use trigonometry to find the value for t.



$$\sin = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$30 = \frac{t}{0.39}$$



t = 30 x 0.39

t = 11.7

SCIENCE

MATHEMATICS

The thrust from the propeller/motor combination has been calculated as **11.7 Newtons.**

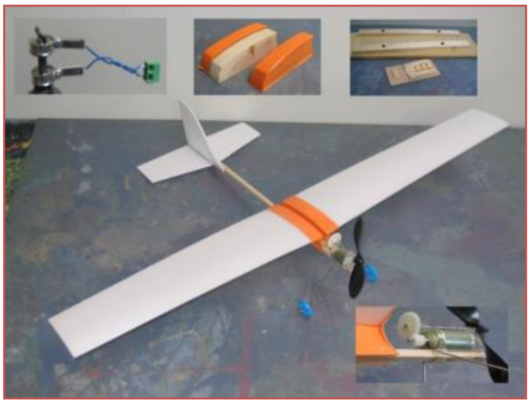
If you are testing many different propeller designs it would be worth setting up a spreadsheet with these calculations. Swap the propeller, re-run the test and measure the angle. Enter the angle in the spreadsheet and the thrust will be calculated and displayed.

Profile models

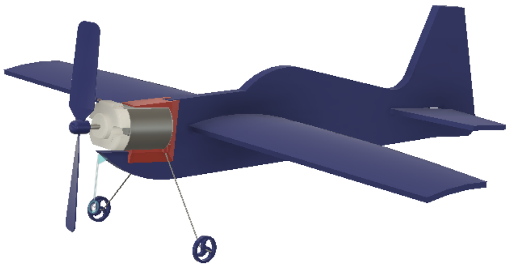
The simplest pylon flight aircraft are made from sheet Depron foam due to its high strength to weight ratio and smooth surface.

Curved slots in the fuselage curve wings giving them an aerofoil shape.

The design shown here is a free-flight model made from Depron sheet and balsa. The orange wing roots are vacuum formings that define the curved profile and the angle of attack of the wings.



This model was created as a sheet Depron design in Fusion 360 and is based on the Extra 540 used in the Red Bull Air races.



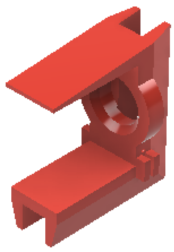
DESIGN

Motor mount

Motor mounts can be created in many ways.

This motor mount was designed for 3D printing and has slots at the bottom and rear for fixing onto the Depron fuselage.

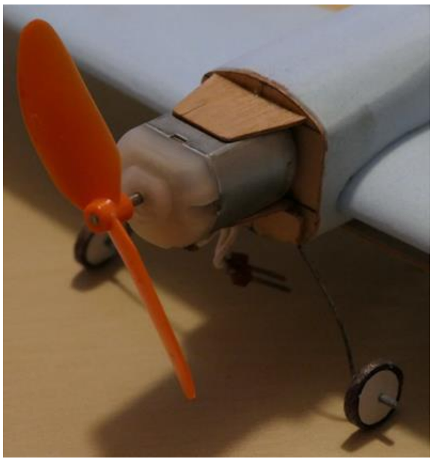
The motor slides between the top and bottom flanges and is held in place using glue or double-sided adhesive tape.



DESIGN

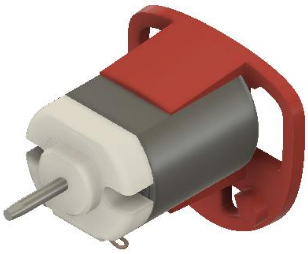
Shown here is a motor mount fabricated from 1mm thick plywood, glued together at the edges.

Plywood is inexpensive, strong and light and used extensively in aeromodelling for high stress areas.



Motor_mount_3D

This motor mount was designed for 3D printing and accommodates motors with electrical connections at the propeller end.



Extra_540_motor_mount_rear_tags v2 v3

This version of motor mount was created for motors with the connections at the opposite end to the propeller and is also designed to be 3D printed.

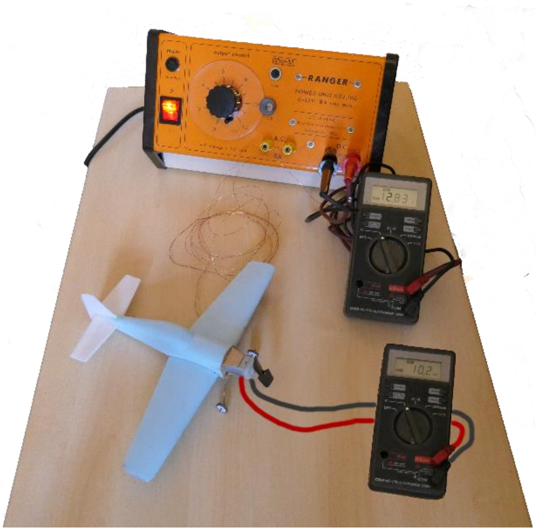
3D printed mount designs are supplied as STL files for immediate 3D printing and as editable Fusion 360 CAD models so that pupils can modify the shapes for their own designs.

Voltage drop

The down-side to using long, thin wires is the voltage at the aircraft can be significantly less than the power supply.

This is called ‘voltage drop’.

To measure voltage drop set up the model connected by the flying wires to a power supply. Connect one voltmeter to the supply terminals and the other voltmeter to the motor terminals.



Hold onto the aircraft then turn up the voltage on the power supply.

Make a note of the voltages at the supply and motor. In this example the supply voltage was 12.83v and at the motor 11.2v.

Now we know the voltage drop we can calculate the maximum voltage at the power supply to make sure you do not exceed the maximum voltage for the motor. In this example:

12.83 – 11.2 = 1.63v.

To achieve 12v maximum at the motor, the supply should never exceed:

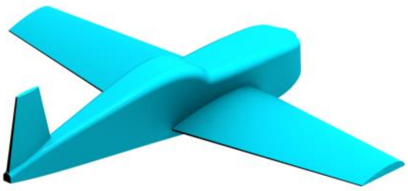
12 + 1.63 = **13.63v**

SCIENCE

MATHEMATICS

Digital design

The precision needed to create models that will fly reliably is beyond many younger students and without digital design and manufacture this activity would be impossible.



There are many other advantages of using digital design and manufacture including:

- Precise geometry
- Mirrored parts
- Editable designs
- Wind tunnel analysis (CFD)
- Repeatable parts using CNC
- Assembly simulation
- Automated manufacture

DESIGN

ENGENEERING

Register for F360 Academic

Students and teachers can register here for the Academic version of Fusion 360.

Fusion 360 online tutorials

Autodesk provide extensive tutorials for all aspects of Fusion 360:
https://www.autodesk.co.uk/products/fusion-360/get-started

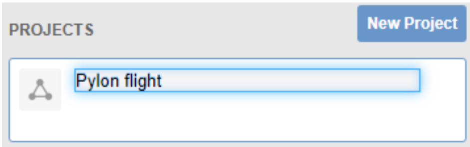
Also, Autodesk have a Fusion 360 YouTube channel dedicate to the software. A search on YouTube using the term '**Fusion 360**' will find a huge number of unofficial videos. Add a topic such as '**Fusion 360 extrude'** and you will find more focused results.

Fusion 360 pylon flight models

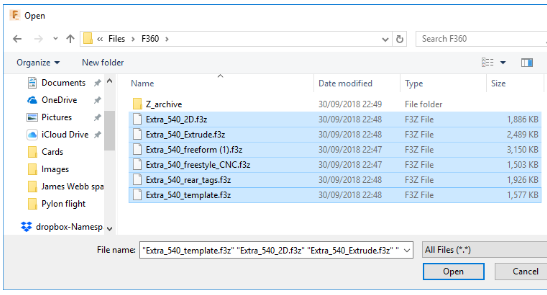
The Autodesk Fusion 360 (F360) models for this activity are in the download file for this project with a *.f3z file extension. These are archive files and will need to be imported into your data panel.

Importing an archive

1. In your F360 **data panel**, projects list, create a new project called **Pylon Flight**.
2. Open the new folder.



3. Click the **Upload** button.
4. In the dialog, click **Select Files**.
5. Navigate to where you saved the downloaded project files and select all *.f3z files.
6. Click **Open** and the files will be listed in the Upload dialog.
7. Click **Upload** to import the files into your project folder.



Depending on the speed of your internet connection, this may take a few moments.

8. When the upload is complete, **Close** the dialog.

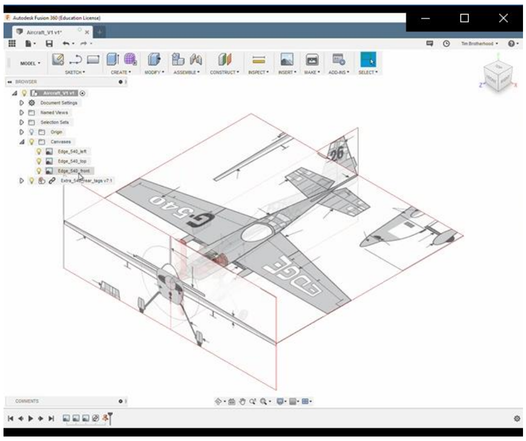
The models will be listed in your project folder.

9. In the data panel, double click on one of the assemblies and it will open in the F360 modelling window.

ENGINEERING

Parametric modelling

Viewing the template assembly

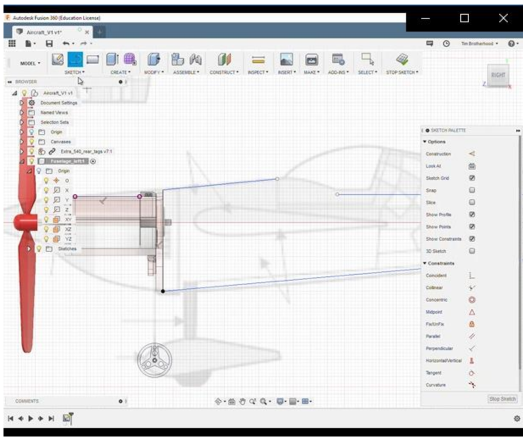


This video explains how to open the template file and save it with a new name. The template is closed, and the new version opened. This preserves the template for future use.

The video then shows how to change how the model is viewed in the graphics screen.

Video - 01_Opening_template_and_viewing.mp4

New part and fuselage profile



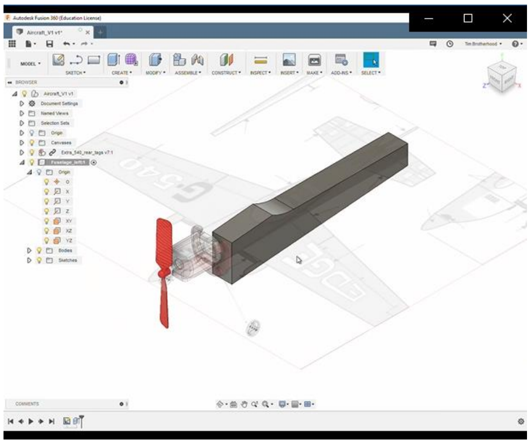
This video shows how to create a new component in the assembly called **Fuselage_left**.

It goes on to demonstrate how to sketch a fuselage side profile by tracing over the canvas image.

Video – 02_Fuselage_profile.mp4

ENGINEERING

Fuselage extrude



In this video you are shown how to extrude the side profile to the correct width for the left half of the fuselage.

Only the left half of the fuselage will be modelled. Once it is finished, a mirrored version is created for the right half of the fuselage.

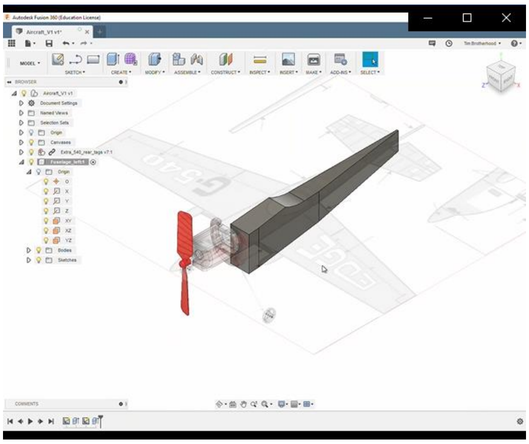
Video - 03_Fuselage_extrude.mp4

Side cut

You are shown in this video how to create an extruded vertical cut through the fuselage.

The result is a fuselage that tapers towards the tail.

Video - 04_fuselage_cut.mp4

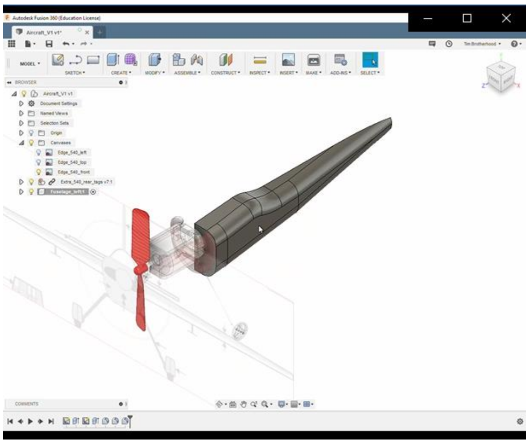


Fillet top and bottom edges

Creating a radius or 'fillet' on the long edges makes the fuselage look much more like the canvas images.

Fillets modify existing geometry.

Video - 05_Fuselage_rounds.mp4

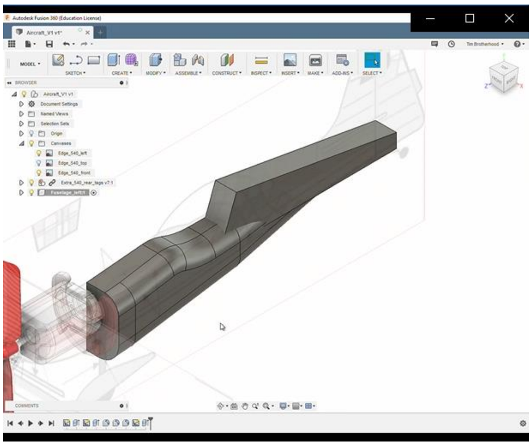


Sketch and extrude the pilot fairing

Behind the pilot there is a fairing or turtle deck that is designed to reduce turbulence.

This video shows how to sketch the side profile and extrude as a solid intersecting the fuselage.

06_Turtle_deck.mp4

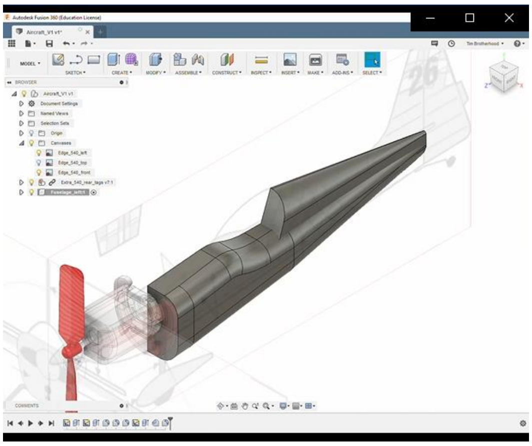


Chamfer and fillet the fairing

A chamfer is applied to the side of the fairing tapering it towards the tail.

Next, a variable section fillet is applied along the top, outside edge of the fairing.

07_Turtle_deck_rounds.mp4

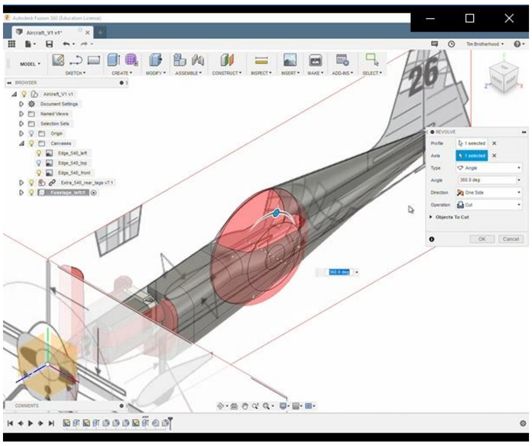


Revolve cockpit canopy

This video shows how to create a revolved solid from the front of the pilot fairing.

The revolve is anti-clockwise through 110 degrees using the bottom edge of fairing as the axis.

08_Cockpit_revolve.mp4

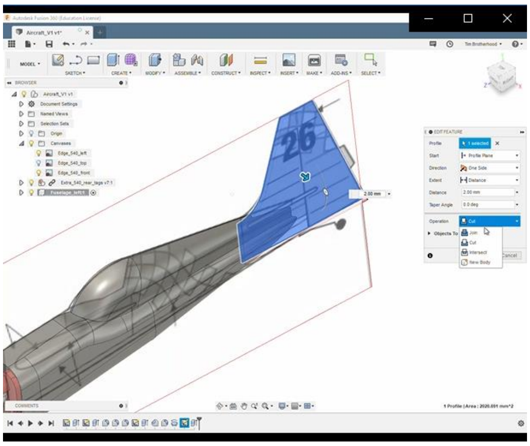


Sketch fin profile

The vertical stabiliser or fin is created from a sketch extruded by 2mm.

The front and rear edges are radiused using a 2mm fillet.

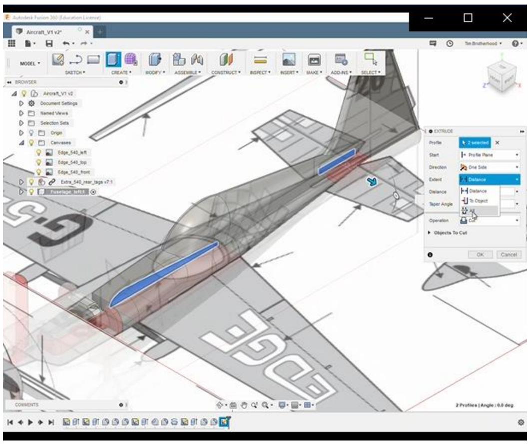
09_Fin_extrude.mp4



Wing recesses

Profiles are sketched and cut through the fuselage, creating holes for the wing and horizontal stabiliser.

10_Wing_resesses.mp4

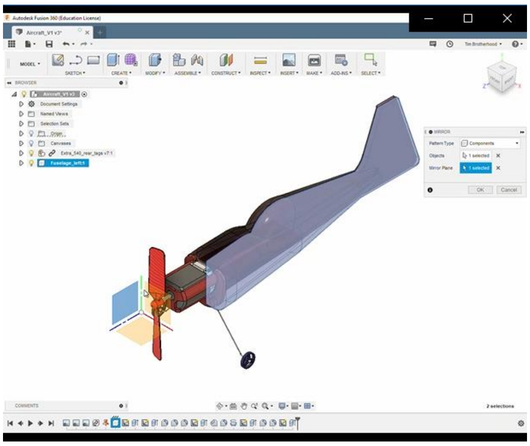


Appearance and mirror fuselage

This video show how to change the visual appearance of the part and then creates a mirrored version of the fuselage.

We create two fuselage halves to make it easier to machine them as two separate foam parts.

11_Appearance_and_mirror_fuselage.mp4



Modelling the wing

Centre section

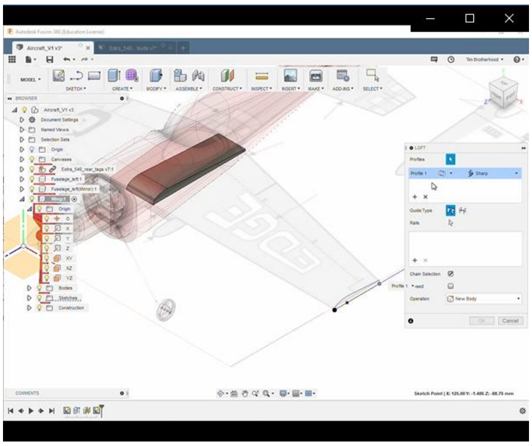
Geometry for the centre wing profile is traced from the hole in the fuselage.

The profile sketch is extruded on one side, to the width of the fuselage.

Outer section

The outer section of the wing is modelled using a lofted shape between two profile sketches.

12_Wing_extrude_loft.mp4



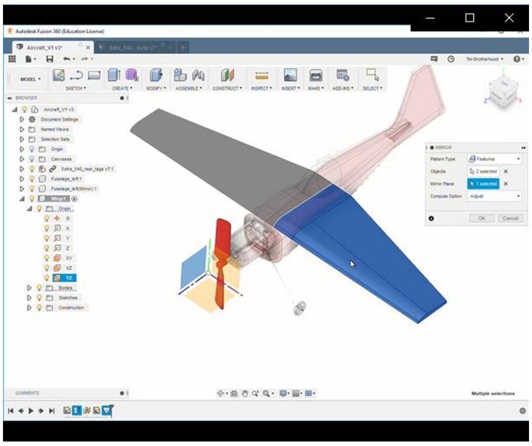
ENGINEERING

Mirror wing

The centre and outer sections are mirrored to create the other half of wing.

This is done in a single part as this will be stronger than two halves joined in the middle.

13_Wing_mirror.mp4



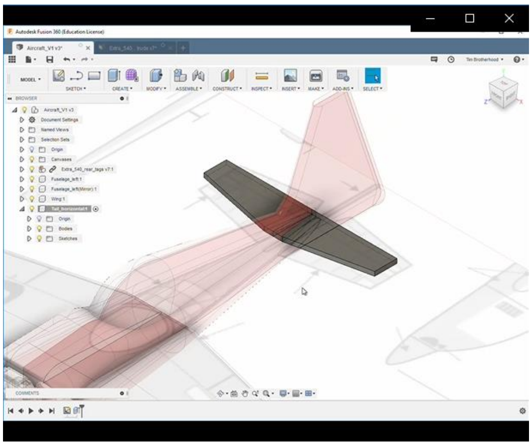
Horizontal stabiliser – Tail

The horizontal stabiliser is created from a sketch looking from above.

Edges of the slot where the tail passes through the fuselage are referenced to ensure it is an exact fit.

The moving elevators are added later.

14_Tail_horizontal.mp4

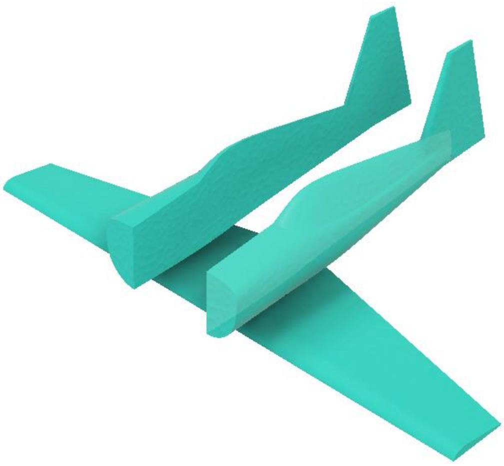


Digital manufacture

Overview

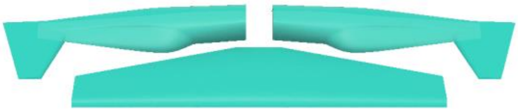
These are the key steps in creating a physical part from a computer model.

- Create a ‘flat’ assembly.
- Save as a an STL file.
- Import STL file into postprocessing software.
- Use wizards to specify tooling, billet material and size.
- Specify machining cycles
- Calculate toolpaths
- Simulate cutting, checking for; surface finish, time taken, tool changes and collisions.
- Machine the parts.
- Clean up and assemble.
- Check the finished assembly against the original specification.



ENGINEERING

Export to CNC – Flat assembly



The fuselage halves and wing were created inside an assembly and need to be saved as parts, so they appear in the data panel.

The parts are imported into a new file and positioned onto a flat plane ready for saving.

15_Export_to_CNC.mp4

Exporting an STL file

STL is an abbreviation for stereolithography, the first mainstream 3D printing process.

Converting a file to STL format involves mathematics to convert all of the surface geometry into linked triangular facets.

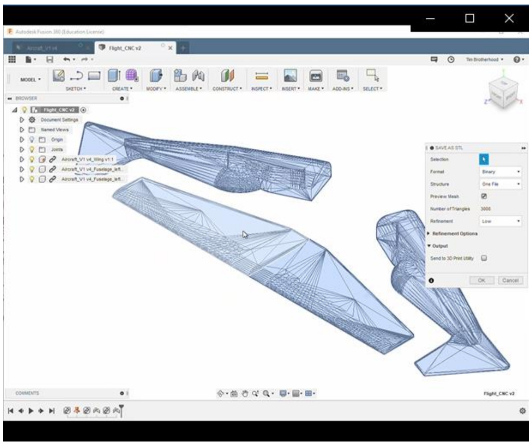
A rectangle, no matter how large, becomes just two triangles. Complex curves will become hundreds or even thousands of tiny triangles.

By changing settings, the user controls the size of triangles. Fusion 360 has High, Medium and Low Refinement settings plus a Custom option which lets the user change the individual mathematical parameters used during the conversion process.

Steps in procedure

From the model tree, there is a right-click to **Save As STL**. Once a refinement setting is selected the mesh of triangles is previewed on the model. Once this is accepted, you are prompted where to save the STL file.

Video > 15_Export_to_CNC.mp4



ENGINEERING

Tooling information

This will be stored in the software that controls your router or milling machine. Ideally this tooling information will be shared with the post-processing software that converts the STL file into a set of machine instructions.

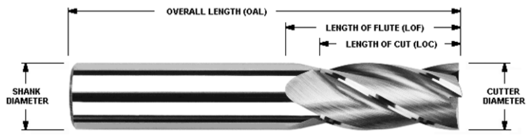
Common types of tool include: end mill, slot drill and ball nose cutters.

Schools may be using cutters made from High Speed Steel or with carbide cutting edges.

Larger cutters may be fitted with inserts which are available in a wide range of materials.

http://www.directindustry.com/prod/dormer-pramet/product-14461-176787.html

The tool definition will contain information including: cutter diameter, cutter length and flute length which, combined with the material being cut, will determine the RPM, feed rate and maximum depth of cut.



http://www.harveytool.com/cms/Terminology_18.aspx

Post processing

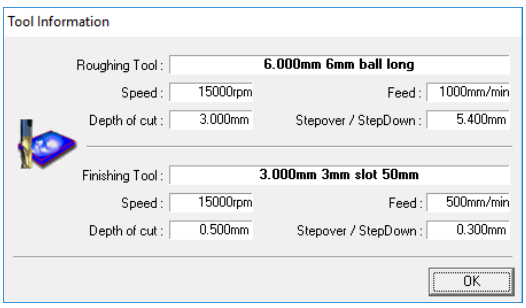
Converting a computer-generated shape into a set of machining instructions is called **post-processing** and involves a great deal of complex 3D spatial calculations.

Tooling will affect the toolpaths and must be known from the start of the post processing.

Tooling will be specific to the CNC machine being used and is defined in the software that comes with the machine tool.

Screen shots in this section are taken from Boxfords 3D GeoCAM software supplied with their A3HSRi three axis routers and milling machines.

Information like feed rates, depth of cut, stepover, etc. will be stored alongside each tool in the tool library and used in combination with the properties of materials to determine how fast the cutting process is carried out.



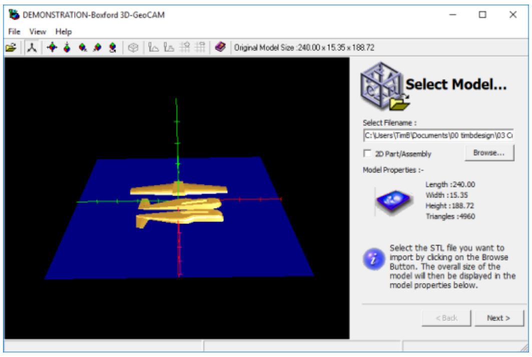
ENGINEERING

Importing a model

The STL file is opened in the post processing (PP) software.

The modelled shapes will be visible in the PP software with a plane showing the cutting depth and direction.

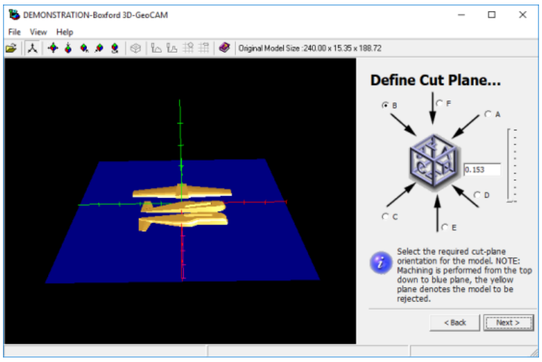
The side panel lists overall dimensions for the part to be machined. This will be used later to define the size of block or 'billet' of material.



Cut direction

The cut direction specifies the orientation of the cutting plane and a slider moves the plane through the model. Anything on the yellow side of the plane will not be machined.

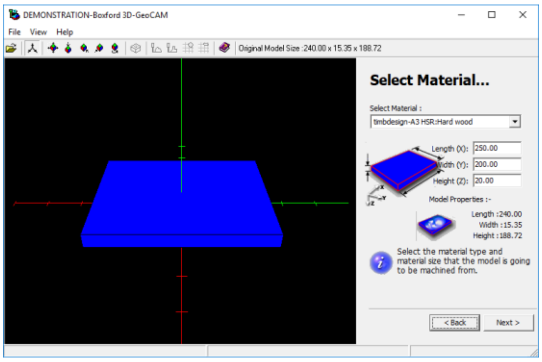
By default, the plane cuts through the centre of the parts to be machined. The slider must be dragged fully down to ensure all surfaces are machined.



Material/billet

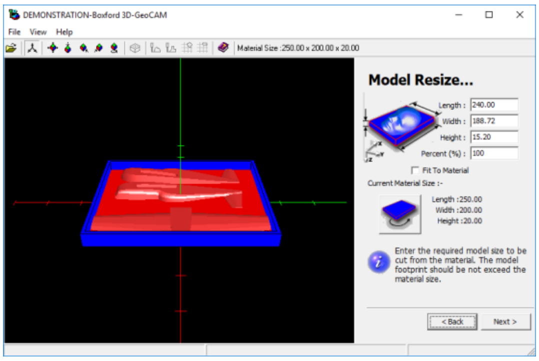
In this screen the material is selected. Later the software will use this to determine cutting speeds and feed rates.

The billet size in this example was typed in and must be larger than the model by at least the diameter of the largest cutter.



Model Resize

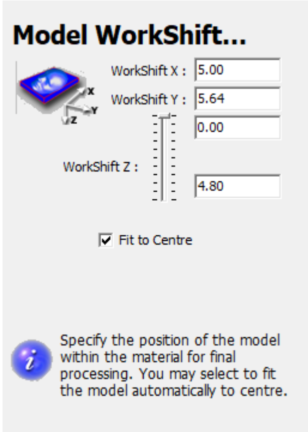
The computer model was created full size so the **Percent (%)** value must be set to 100.



The next screen shows **WorkShift** which moves the model up and down in the block of material.

For our model, drag the slider to the top.

For parts with flat surfaces on top, dragging the slider down by a small amount ensures these top surfaces of the model are machined.



Select Tooling

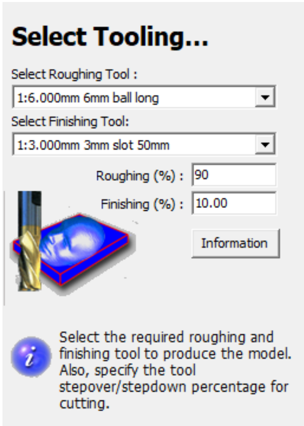
The top two fields list the tools contained in the tool library.

A 6mm diameter ball nosed long shank cutter is selected for the roughing cycle. This removes large amounts of material quickly.

A 3mm dimeter slot drill with shank length of 50mm is selected for the finishing cycle which smooths the rough surface left by roughing.

Roughing (%) defines how far the tool moves between cuts. In this example 90% of the tool diameter.

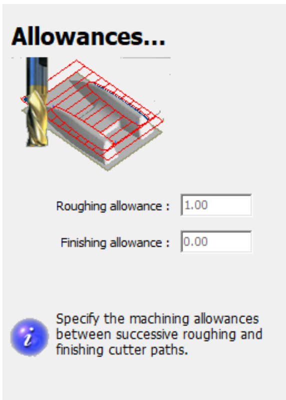
Finishing (%) defines how far the tool moves between cuts when finishing. In this example 10% of the tool diameter.



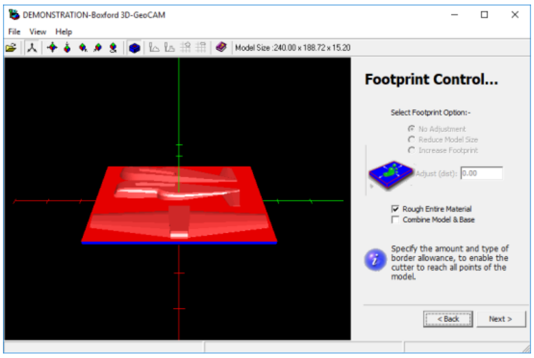
Allowances

In allowances we specify how much material is left between the roughing and finishing cycles.

Here, 1 mm is left after roughing for the finishing cutter to remove. Only one finishing cut is planned so no finishing allowance is needed hence the zero value.



Footprint Control



Footprint control specifies the amount of material around the outside of the model.

Allowance was made for this when setting the billet size earlier so the **Adjust (dist)** value here can be left at zero.

Select **Rough entire material** to ensure all outside edges are machined.

Roughing and finishing

The PP software contains several pre-programmed cutting sequences and in the next two screens you select which ones will be followed for roughing and finishing.

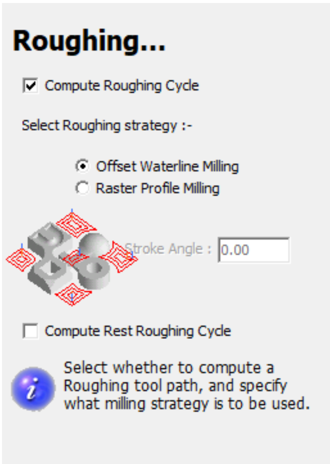
Roughing

It is important to select **Compute Roughing Cycle**. Not selecting this allows the cutter to plunge through a large amount of material, most likely breaking the tool!

Choose **Offset Waterline Milling**.

Boxford Help explains clearly which settings are most appropriate for different shapes.

Compute Rest Roughing Cycle creates a smoother finish but takes longer to compute and machine.



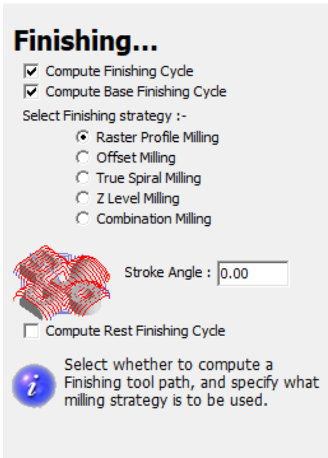
Finishing

Select **Compute Finishing Cycle**.

Select **Compute Base Finishing Cycle**. This machines the lowest Z axis of the model.

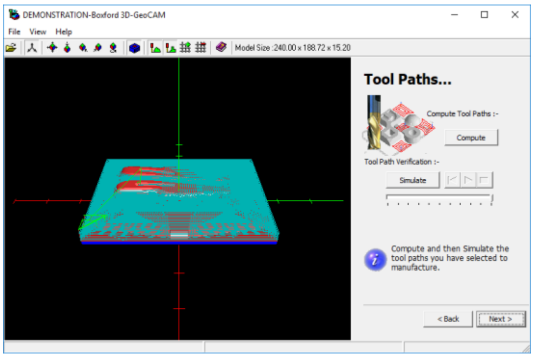
Select one of the finishing strategies. For beginners the **Combination Milling** option will produce good results. Some of the other strategies will complete in a shorter time but at the expense of surface finish. This may not be a problem if the surface is going to be sanded and painted.

Compute Rest Finishing Cycle profiles the outside shape creating a smoother surface.



Generate tool paths

This is where a lot of complex mathematics is done by the computer, converting the settings you have chosen into a series of tool movements that follow the outer shape of the CAD model.



Click on **Compute**. Depending on the speed of your computer, this could take some time…

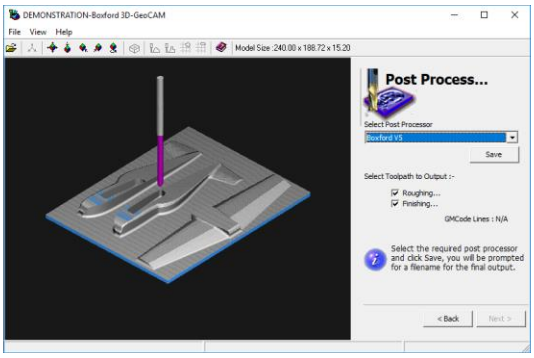
Once calculations are complete, you can **Simulate** machining using the playback buttons.

When the simulation is paused or finishes, the current cycle time is displayed and the model window will display an accurate representation of the resulting shapes and surface finish. Also displayed will be the total number of **Tool Collisions**.

VERY IMPORTANT WARNING *- A Tool Collision occurs when the shank of a cutter (the section of cutter above the cutting flute) or tool holder collides with the material. This can be seen in the verification animation as an area marked in purple.*
If tool collisions have occurred during verification of a program, ***YOU MUST*** *either; a) select tooling with a flute length sufficient to avoid collisions or b) modify your original CAD model so it can be manufactured with the available tooling.* ***Failure to follow this advice could result in tool breakage and/or machine tool damage.***

Export machine file

From this screen the machine instructions are saved. Make sure you select the correct file format for your mill/router control software.



CNC machining

CNC machine tools usually come with their own control software which performs these actions.

- Import the PP instructions (G&M code).
- Run a simulation to check for errors and tool collisions.
- Confirm tooling plus any tool changes then install the first tool to be used.
- Fix the material to the bid with any sacrificial material if needed.
- Set/check the x,y,z datums.
- Run the machine cycles.

On manual tool change machines, the cutting process will pause and you will be prompted to change the tool before cutting resumes.

- The video **CNC foam body & wings.AVI** shows a set of aircraft parts being machined.

If you have completed your model or design and manufacturing the parts you can skip to the section on **Assembly and finishing**.

If you would like to learn more about creating geometry from coordinates complete the next section.

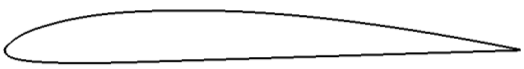
If you are feeling confident with Fusion 360 and would like to create more aerodynamic, curved shapes skip to the section titled **Modelling – Sculpted fuselage**.

Creating sketch geometry from coordinate data

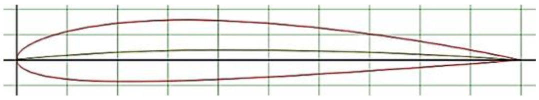
Outline

A great deal of research has been carried out on aerofoil sections and much of the resulting data is freely available on the internet.

Invented in 1922 by Virginius E Clark, the Clark Y aerofoil is one of the most commonly used wing sections for low to medium speed flight.



Early in the 20th Century the US government sponsored aerodynamic research including aerofoils and the results were published by the National Advisory Committee on Aeronautics (NACA). NACA profiles have been used extensively in civilian, military and model aircraft. NACA developed a mathematical method of plotting wing shapes based on key parameters. The illustration here is the NACA 2412 shape in their four-digit series and explains what the digits stand for.



2412 - **NACA profile code**

12 % ratio between thickness and chord.

4 Maximum camber – 0.4 of the chord length from the leading edge.

2 Maximum value for camber = 2%

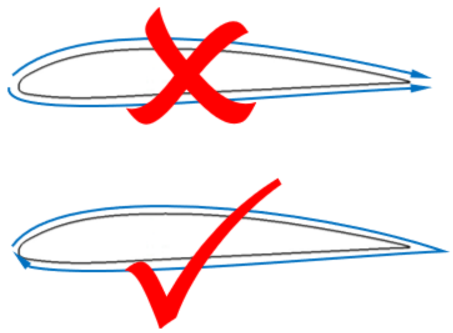
Source - http://airfoiltools.com/

MATHEMATICS

Preparing coordinate data

Fusion 360 is able to take a set of coordinates and create a sketch profile automatically.

Coordinates must be saved in a comma separated variable (CSV) file format and list the coordinates moving around the shape starting and ending at the same point.



Some aerofoil creation software and web sites create coordinates with two sets of points. Both start at the same point, say the leading edge, and both finish at the same point, say the trailing edge.

To use this data you will need to cut/past/reverse some of the coordinates into a single sequence progressing around the profile. The CSV file format is a Save As option in MS Excel.

The airfoiltools web site displays the coordinate set in a small window. A Word document **NACA6409.docx** shows how the raw data is edited to make it suitable for F360.

1. Copy the coordinates from the web page.
2. Paste the coordinates into Word.
3. Remove any lines above first line of coordinates.
4. Remove all spaces at the start of the lines.
5. Search and replace white spaces with tabs.
6. Check the coordinates are in the correct sequence.
7. Use **Copy All** in Word and paste into a blank Excel sheet.
8. Add zeros in a third column.
9. **Save As** a CSV file.

NACA6409 9%

1.00000 0.00000
0.99732 0.00084
0.98930 0.00333
0.97603 0.00737
0.95760 0.01284
0.93423 0.01954
0.90615 0.02724
0.87357 0.03571

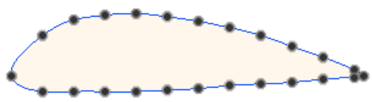
1.00000	0.00000
0.99732	0.00084
0.98930	0.00333
0.97603	0.00737
0.95760	0.01284
0.93423	0.01954
0.90615	0.02724
0.87357	0.03571

1	0	0
0.99732	0.00084	0
0.9893	0.00333	0
0.97603	0.00737	0
0.9576	0.01284	0
0.93423	0.01954	0
0.90615	0.02724	0
0.87357	0.03571	0

MATHEMATICS

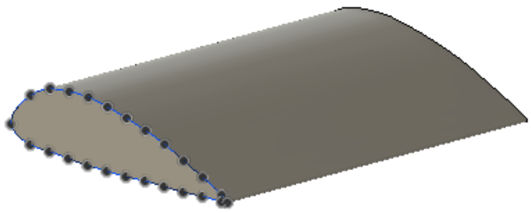
Importing data into F360

The coordinate points are imported into Fusion 360. The software selects the creates the points and joins them with a spline.



Extruding the profile

If the outline generated from the coordinates is continuous, the profile will extrude to make a 3D shape.



Video – 16_Aerofoil_from_coordinates.mp4

Modelling – Sculpted fuselage

The Sculpt tools in Fusion 360 allow the creation of curved, aerodynamic shapes and make it possible to trace canvas images much more closely.

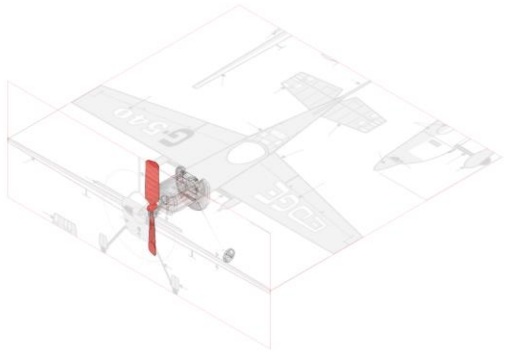
The template and initial procedure for the sculpt videos is the same as that used for the introductory videos and is outlined next.

Outline

Open template file – **Extra_540_template**.

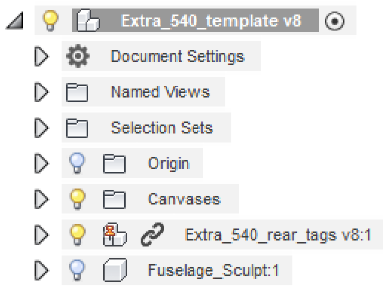
The file contains:

- Images (canvasses) for front, side and top views
- Motor
- Motor mount
- Propeller
- Undercarriage.



Before starting to model:

- Save the model with a new name to preserve the template for future use.
- Create a new component in the assembly and rename it **Fuselage_sculpt**

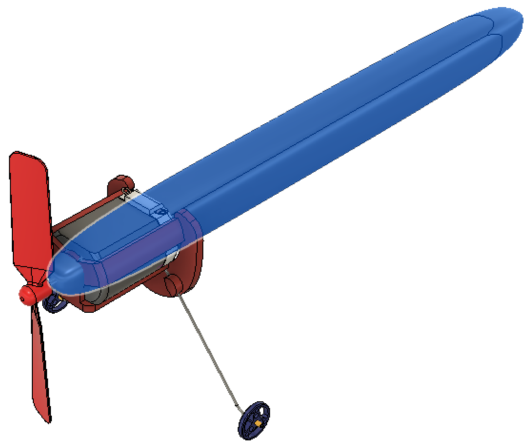


Sculpt environment

This initial shape was the basis for adjustments to more closely match the outline of the main fuselage.

Additional control points are added to achieve greater detail where it is needed.

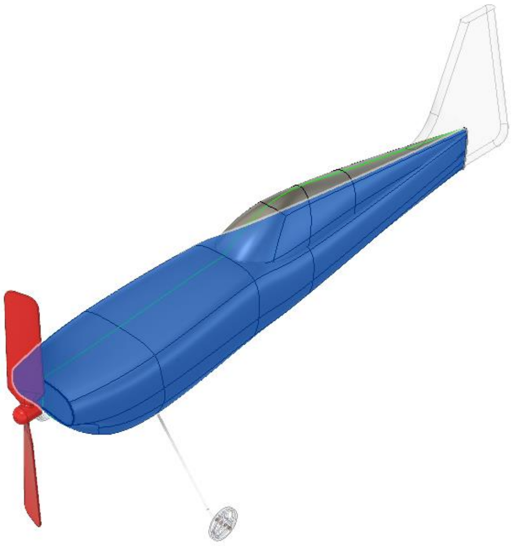
Video - 25_Sculpt_creating_a_shape.mp4



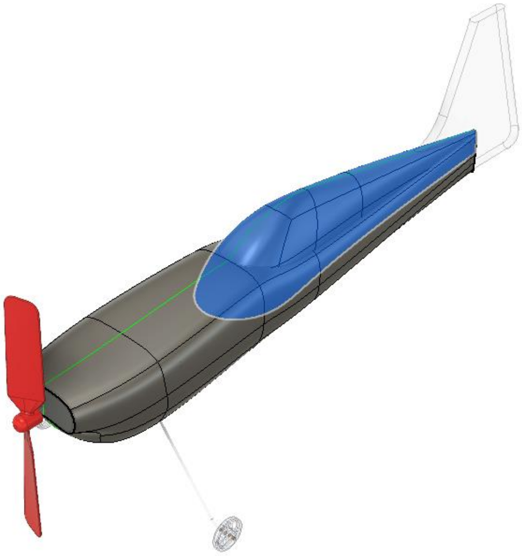
DESIGN

The geometry highlighted in blue is the final shape of the first sculpt, representing the main part of the fuselage.

Video - 26_Sculpt_editing_a_shape.mp4



Another sculpt feature, shown here in blue, was added to create the windscreen and fairing behind the pilot.

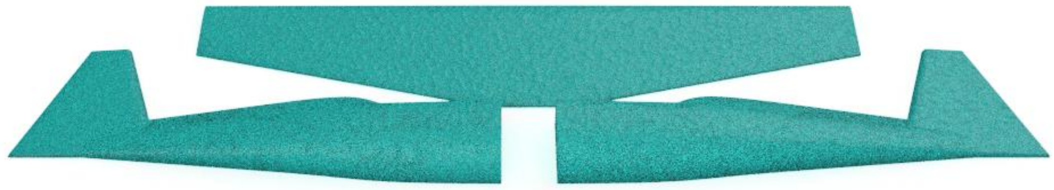


Assembly and finishing

Assembly and finishing use the same procedures, techniques and safety considerations as those used for foam modelling in product design. These include:

- Foam friendly adhesives for assembly.
- Light sanding using PPE
- Surface sealer
- Paint and decals

ENGINEERING

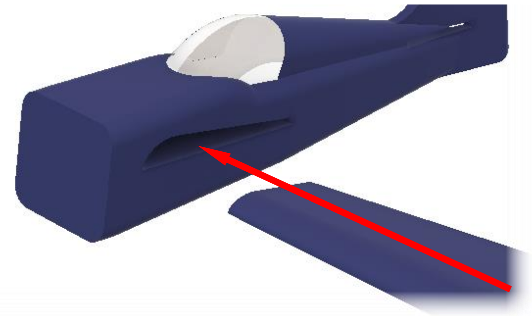


Foam parts

These can be joined using several techniques.

Wings slotted into recesses may not require glue.

Adjustments and repairs will be much easier with no glue and relying on friction in the joint.



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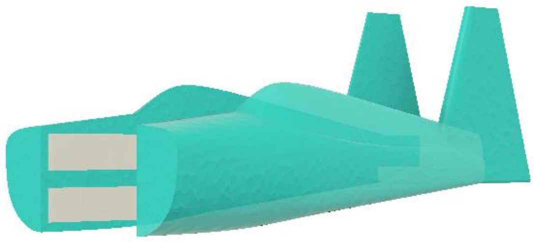
Double sided adhesive tape can be used to fix fuselage halves together.

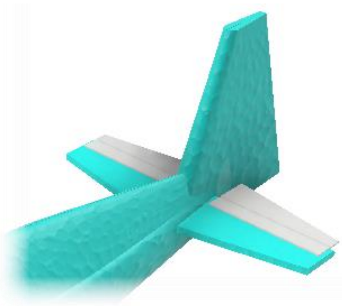
Foam friendly adhesives are available but check the list of ingredients against your hazardous materials guidance (CLEAPSS in the UK) to make sure they are safe to use in school.



Control surfaces

The simplest way to create a control surface is to glue on a piece of thin card folded at the hinge point. If the surface moves too easily, trap a piece of thin wire beneath the glue/tape.

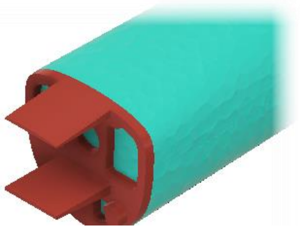
Higher pressure on the top surface make this the best place for the card hinge.



Motor mount

The motor mount we supply is designed to be glued to the flat front of the fuselage. This could be done using foam-friendly adhesive or double-sided tape.

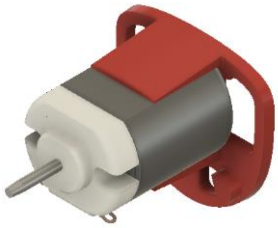
How about creating a motor mount that fits entirely within a hollowed-out foam fuselage?



Motor

Two different designs of motor mount are provided.

The version here uses double sided tape between the mount and motor.



This mount captures the motor inside the mount and against the front of the foam fuselage.

This could make changing the motor difficult.

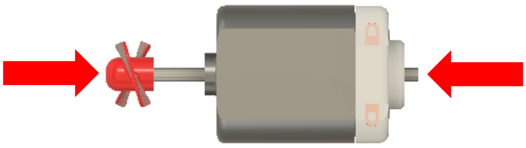
Propeller

The motor spindle is 2mm in diameter and the propeller should be a push fit onto this.

If your propellers have a smaller hole it will need to be drilled out. A 1.9 mm drill should provide a tight fit.

When pushing the propeller onto the spindle, it is important you don't move the spindle inside the motor case.

Use a vice or clamp across the propeller boss and the opposite end of the motor spindle.



Undercarriage

The undercarriage must absorb the impact of heavy landings on hard floors.

A strong and rigid undercarriage would withstand the forces but may be so heavy the aircraft would struggle to leave the floor.

An alternative approach is to make the undercarriage flexible so that it absorbs energy and springs back into shape.

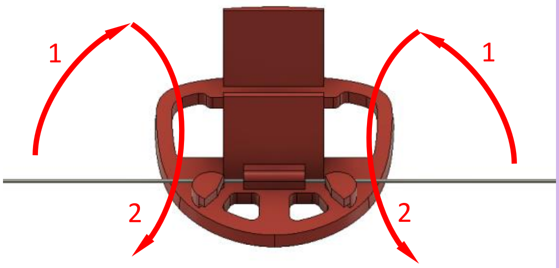
Springs are made from high carbon steel which is annealed before bending into shape and then hardened and tempered to make it flexible and springy again.

Piano wire is made from high carbon steel which is supplied hardened and tempered.

0.5mm diameter piano wire works well for our design and, if it isn't bent at sharp angles, it doesn't need to be annealed.

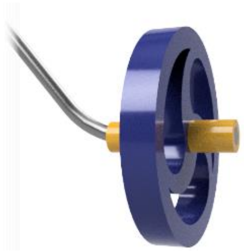
Insert a piece of piano wire 100mm long through the hole in the motor mount with equal lengths sticking out on each side.

At both sides, bend the wires forwards (**1**) then rotate the wires (**2**) threading them behind the plastic bosses.



Use pliers to bend the last 10 mm until the ends are co-linear. This is where the wheels will be located.

Thin plastic tube or wire insulation pushed over the undercarriage wire will hold the wheels in place but allow them to rotate.



Wheels

Wheels are available in many different sizes from aero model suppliers but can be made very easily from laser cut acrylic.

DXF files of wheel designs like those shown here are available for laser cutting.

Wheel_V1.dxf

Wheel_V2.dxf

ENGINEERING

Tether/motor connections

Molex connectors make the electrical connections and a 1mm thick plywood arm provides the physical anchor.

Together, these let you attach and remove the aircraft from the flying wires easily and quickly.

Flying rules

Powered flight is the culmination of this exciting design–make–fly challenge but needs to be carefully managed to keep students safe and avoid injury or damage to the tower, wire tethers and aircraft.

- Power supply should be unplugged when changing aircraft.
- Only one person should be allowed inside the flying circle when changing aircraft.
- Safety goggles should be worn by everyone at all times
- Keep spectators behind a taped off area away from flying circle.
- Pilots should be positioned next to PSU, set back from the flying circle with a clear, unobstructed view of the entire flying circle.

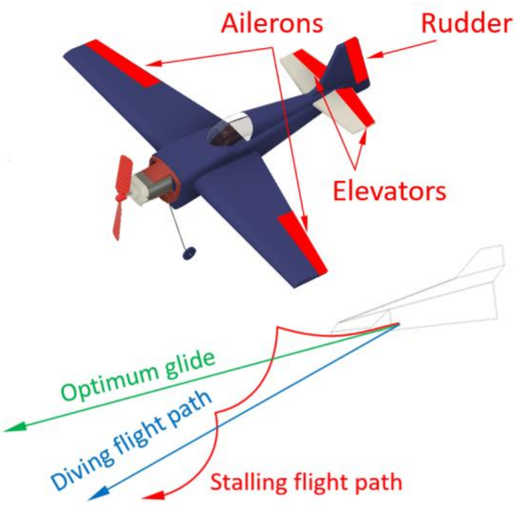
Gliding flight

Once the model is finished the initial setup aims for a long, gentle glide with control surfaces in the neutral positions. This is the most aerodynamic state with least drag.

This diagram describes the flight paths and changes to the control surfaces needed to achieve a long, straight, shallow flight.

Adjustments should be small and retested between each change.

- Model dives – bend elevators upwards.
- Model stalls – bend elevators downwards.
- Model turns to the left – bend right aileron up and left aileron down.
- Model turns to the right – bend the right aileron down and left aileron up.



ENGINEERING

Once a long, straight, shallow flight is achieved, powered flights can begin.

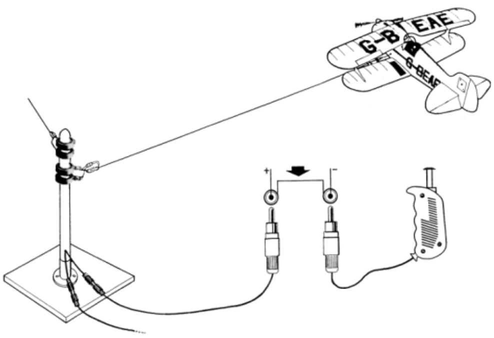
When redesigning the aircraft, the centre of gravity or centre of lift can be moved to remove the need for offset control surfaces.

Powered flight

Flying lines should be shortish (2-3m) with beginners to make wire management easier. Hard floors are essential to ensure the models roll easily on take-off and landing.

Trimming aircraft for flight

- High power may be required to get the model rolling for take-off.
- Reduce power to prevent a steep climb.
- If the models turns into the circle, move the flying wire attachment rearwards.
- If the model is turned away from circle move the flying wire attachment forwards.
- Trim with some up elevator for level flight.



http://www.thertphut.co.uk

Aerobatic flight should only be attempted when experienced with stable flight, changing height on demand and the different flight characteristics of a range of aircraft designs.

For aerobatic flying, lines will need to be five metres or longer.

ENGINEERING

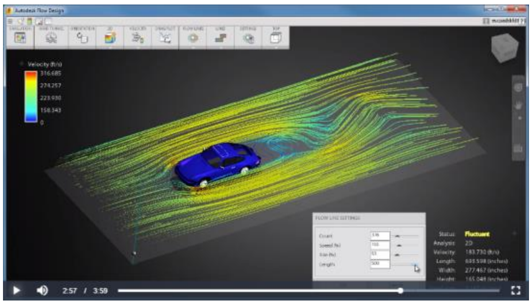
Digital design – Simulation

Computer simulation is a very wide field covering: structural, thermal, flow, electrical, etc. In the context of flight, airflow simulation will help evaluate designs and inform improvements prior to expensive manufacture and time-consuming physical testing.

Flow design

Computational fluid dynamics or CFD is the accepted engineering term for fluid flow simulation.

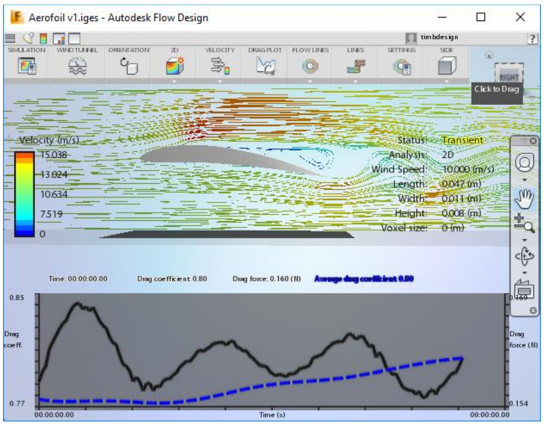
Autodesk CFD software **Flow Design** is shown on the right. A video introduction to Flow Design can be seen here.



Airflow over the wing

You may want to analyse the airflow over your wing. Things to keep in mind include:

- Angle of attack
- Pressure difference above/below
- Centre of pressure
- Lift force
    - Must exceed the mass/weight of the aircraft
    - Pose the question – Flight on another planet?

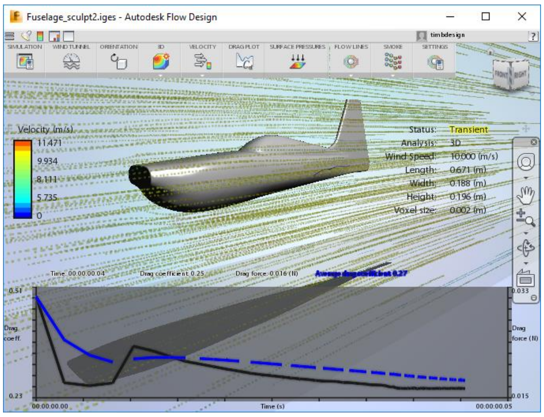


Flow design may not be able to help you find solutions to all these bullets.

Airflow over the fuselage

The fuselage is another opportunity for optimising a design and can benefit from CFD analysis. The following feedback would be helpful in optimising the shape of the fuselage.

- Areas of turbulence
- Drag coefficient
- Thrust from the motor must exceed the drag force resisting movement.



Complete aircraft

Be wary of attempting a CFD simulation of an entire aircraft.

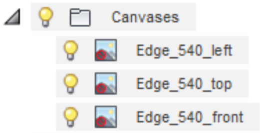
Static structural analyses require complex mathematics. Multiply this by the continuous calculations required by dynamic CFD simulations and complex assemblies can take inordinate amounts of time and may never fully compute.

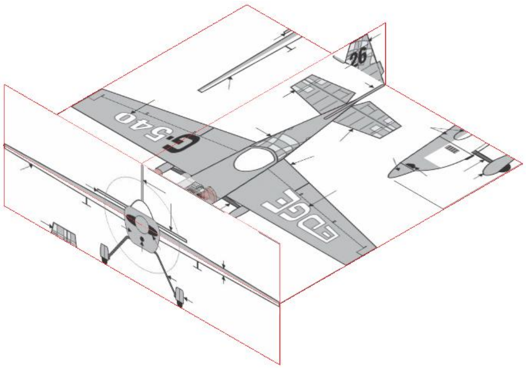
Appendix one – Assembly template

This assembly was created for pupils to use as a starting point for the modelling guides.

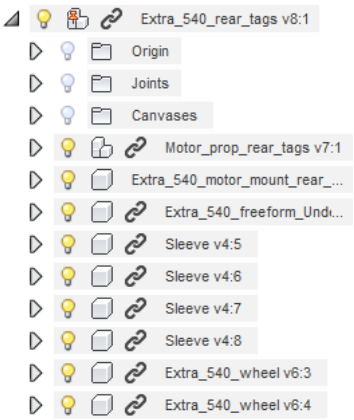
Three canvas images have been positioned and scaled to act as a reference when creating geometry for the fuselage and wings.

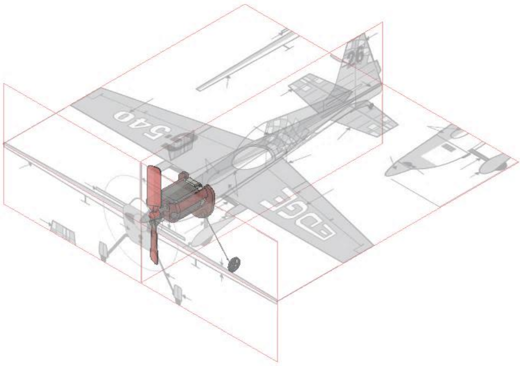
This YouTube video explains the process of adding, scaling and positioning canvas images.





The motor, motor mount and undercarriage have been added as a sub-assembly in the correct position relative to the canvas images.



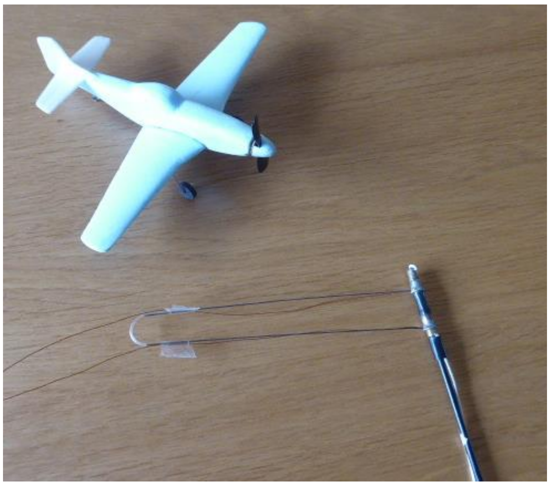


DESIGN

Appendix two – Pylons

Pylon for small, light models

A small, light pylon is needed for smaller models and this design can be put together using low-cost materials.



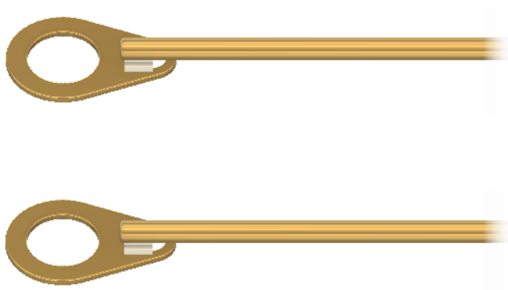
DESIGN

Rotating contacts

Two thin brass rods and two 4 mm brass terminal tags are needed to make these.

The large holes in the terminal tags must be filed out until they fit snuggly over the brass sleeves and rotate smoothly.

Solder a brass rod to each washer without obstructing the holes.



Pylon tube

A 300mm long rigid plastic tube with 4mm outside diameter and 3mm internal diameter forms the main pylon support.

DESIGN

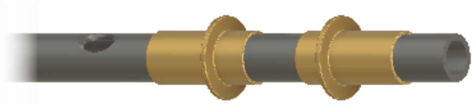
Brass sleeves

These provide the fixed electrical contacts on the pylon tube and can be turned from brass rod or made from thin tube with brass washers soldered on one third of the way along.

DESIGN

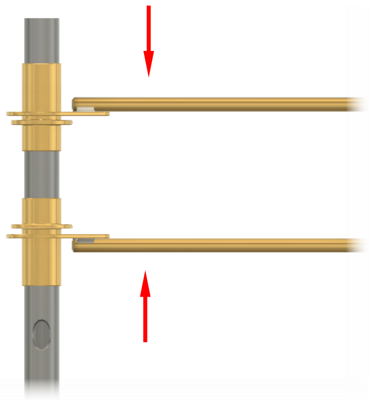
Assembling the pylon

Slide the brass sleeves onto the rigid plastic tube.



Slide one rotating contact up from the bottom of the pylon.

Slide the other rotating contact on from the top of the pylon.



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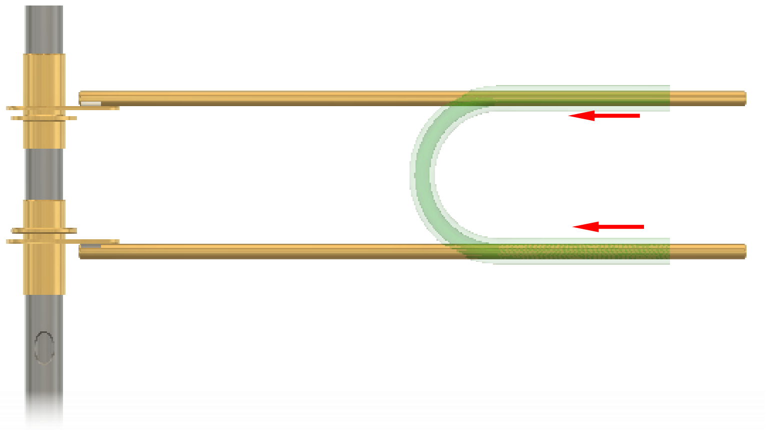
Tubing link

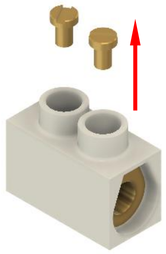
Flexible plastic tube about 80 mm long is used to connect the two rotating contacts. The tube should slide smoothly over the wire. Insulation stripped from electrical wire may work for this.

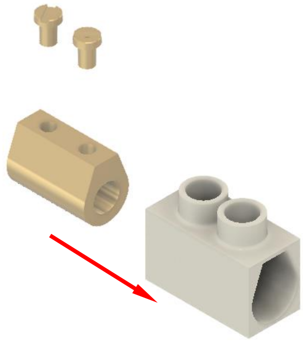
Cut holes in the side of the plastic tube at one third and two thirds distances.

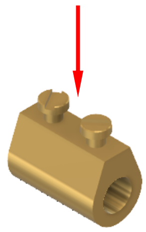
Slide the plastic tube over the ends of the brass rods through the cut holes until the rods emerge from the ends of the tube.



Screw connectors





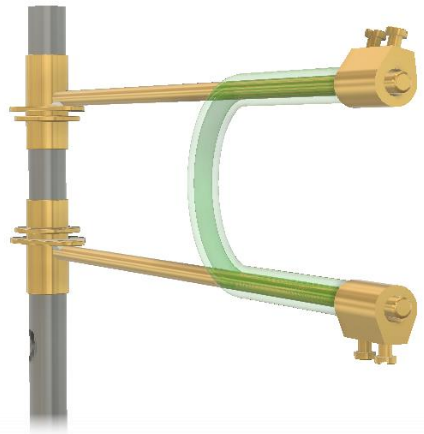


Remove the two screws from a 2A terminal block.

Slide the plastic case off the brass block and discard.

Replace the screws in in the brass block.

Use the screws to clamp connectors to the end of both rotating contacts.



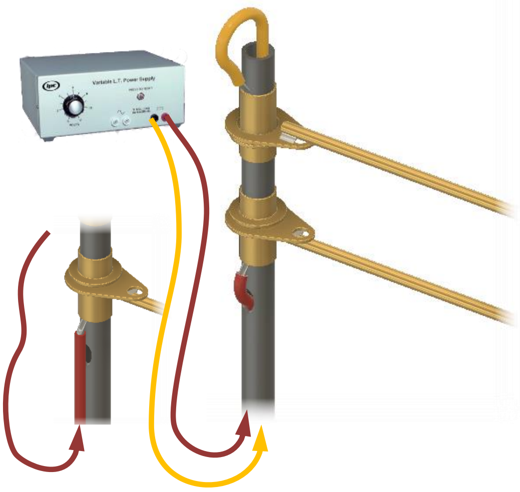
Power supply wires

One wire from the power supply passes up through the tube and out of the top. The bared wires are then trapped underneath the upper brass sleeve.

You may need to file a flat in the plastic to create space for the wires to fit under the sleeves.

Thread the second power supply wire up through the tube emerging through a hole drilled in the side. Trap the stripped end of the wire under the brass sleeve.

If there isn't room for the wire inside the tube, it can be taped to the outside.



Flexibility in the plastic tube will keep the rotating contacts located on the brass sleeves and ensure they always rotate together.

A spray of light oil between washers and brass sleeves will help maintain electrical connection as they rotate.

Make sure you remove PVA insulation from the ends of the flying wires before clamping them inside the brass connectors.

This can be done by scraping with a blade or with fine abrasive paper.

ENGINEERING

Appendix three – Speed control

There are lots of opportunities for design and engineering in how electrical power going to the DC motor in the aircraft is controlled.

Power supply

The desktop variable power supplies in school science departments are ideal for pylon flight.

DC output is continuously variable from 0–12 volts at several amps.

Located outside the flying circle the pilot uses the knob on the front of the power supply to control the aircraft.

Variable resistor

Toys like classic Scalextric use a low-cost fixed voltage power supply with a variable resistor speed controller.

This is probably the easiest and cheapest way to control the speed of small DC motors.

The major disadvantage to this method is the heat produced in the resistor: an indication that a lot of energy is being wasted.

Another downside is the lack of control at low voltages. Small DC motors are most efficient when spinning fast and at low voltages they do not operate in a smooth and predictable way.

Electronic control

An alternative to altering the voltage is to provide very rapid pulses at full voltage and change the ratio of on to off time.

Called pulse-width modulation (PWM), electricity is supplied as pulses with a fixed length, typically 20ms. Speed control is achieved by altering the ratio of on to off time.

At all speed settings, the motor is receiving full supply voltage. This, and energy efficiency, are the two key advantages of PWM speed control.

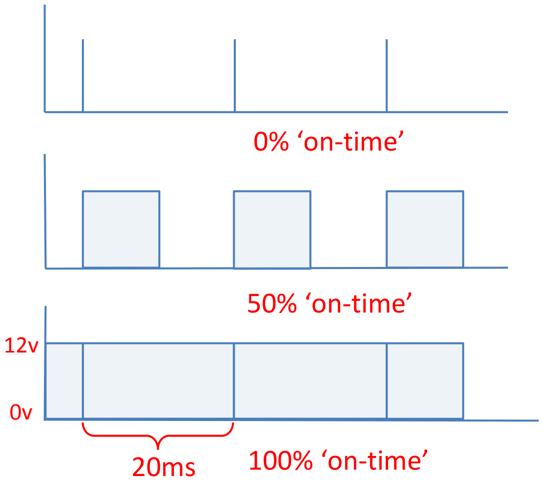
ENGINEERING

SCIENCE

When there is no ‘on-time’ the motor doesn’t rotate.

If the on and off-times are equal the motor runs at 50% speed.

When there is no ‘off-time’ the motor runs at full speed.



PWM is used widely in commercial applications of DC motors and in modern toys including Hornby trains and Scalextric racing cars.

https://www.scalextric.com/

PWM circuits designed specifically for schools are available from Electron through the link below.

https://www.electronelec.co.uk/cgi-bin/sh000002.pl?WD=pwm&PN=PWM_CONTROLLER_KIT_SURFACE_MOUNT-1%2ehtml#a525_2d180

A guide to this PWM circuit is available here:

http://www.paulgardiner.co.uk/EiSS/EiSS.html?Resources.html

SCIENCE

ENGINEERING

Appendix four – Computer files

Documents

The following documents are provided in the download for this project.

Slides for class presentations. The notes section contains comprehensive descriptions for each slide.	**STEM into Action - Pylon_flight.pptx**
Course document contains more detail and is aimed at teachers and students working independently.	**STEM into Action - Pylon flight.docx**
List of parts and suppliers A comprehensive list of resources needed to run this project. Links to suppliers and costings were current and correct in December 2018.	**STEM into Action - Pylon flight - Parts list.xlsx**

Aerofoils Zip folder

Coordinates for a Clark Y aerofoil. Used in the Fusion 360 activity showing how to create geometry from coordinates.	**Clark Y.csv**
Coordinates for a NACA 6409 aerofoil. Used in the Fusion 360 activity showing how to create geometry from coordinates.	**NACA6409.csv**
Document showing how raw aerofoil coordinates from the web site need to be edited before they will import successfully into 3D modelling software.	**NACA6409.docx**

ENGINEERING

CAD models

CAD models are provided for the hands-on activities in this guide in native Fusion 360 format and as IGES files which can be imported into most other 3D parametric modelling software.

Fusion 360

Part file containing an **extruded aerofoil profile** which was created from coordinates.	**Aerofoil.f3d**
Assembly with fuselage and wings created using **extrude, revolve, fillet**, etc.	**Aircraft_V1.f3z**

ENGINEERING

Assembly with **2D fuselage and wings** intended to be cut from sheet Depron.	**Extra_540_2D (1).f3z**
Assembly with fuselage and wings created using **extrude, revolve, fillet**, etc.	**Extra_540_Extrude (1).f3z**
Assembly with fuselage created using the **Sculpt tools** in Fusion 360.	**Extra_540_freestyle_CNC (1).f3z**
Assembly with several fuselages all created using the **Sculpt tools** in Fusion 360.	**Extra_540_Sculpt.f3z**
Starter assembly containing canvas images and motor/mount/propeller.	**Extra_540_template (1).f3z**
Motor mount for **2D fuselage and wings and front motor connections**	**Motor_mount_2D.f3d**
Motor mount for **3D fuselage and wings and motors with front connections**	**Motor_mount_Inter.f3d**
Motor mount for **3D fuselage and wings and motors with rear connections**	**Motor_mount_rear_tags v2.f3d**

Neutral – IGES (Flow Design and CNC_3D_Print folders)

IGES is an industry recognised neutral format for CAD files. Each file contains accurate external geometry but without any model history. The features that were used to create the shapes are no longer available for editing. The geometry can be modified using direct modelling tools.

Part file containing an **extruded aerofoil profile** which was created from coordinates.	**Aerofoil.iges**
Assembly with fuselage and wings created using **extrude, revolve, fillet**, etc.	**Aircraft_V1.iges**
Assembly with **2D fuselage and wings** intended to be cut from sheet Depron.	**Extra_540_2D.iges**
Assembly with fuselage and wings created using **extrude, revolve, fillet**, etc.	**Extra_540_Extrude.iges**
Assembly with fuselage created using the **Sculpt tools** in Fusion 360.	**Extra_540_freestyle_CNC.iges**
Assembly with several fuselages all created using the **Sculpt tools** in Fusion 360.	**Extra_540_Sculpt v1.iges**

Starter assembly containing canvas images and motor/mount/propeller.	**Extra_540_template.iges**
Motor mount for **2D fuselage and wings and front motor connections**	**Motor_mount_2D.iges**
Motor mount for **3D fuselage and wings and motors with front connections**	**Motor_mount_Inter.iges**
Motor mount for **3D fuselage and wings and motors with rear connections**	**Motor_mount_rear_tags.f3d**

Appendix five - Risk assessments

With any practical activity it is important to perform risk assessments to ensure pupils are kept safe.

In addition to hands-on modelling processes, flying even small paper dart aircraft presents additional dangers. During testing, model aircraft travel at high speed and risk assessments for this activity should require eye protection at all times and demand good behaviour.

In many countries, suppliers of materials, chemicals and adhesives are required by law to supply data sheets covering any hazards associated with the material, associated risks and any control measures that should be followed. Schools should ask suppliers for these documents when ordering materials and equipment.

In the UK CLEAPSS provide health & safety advice and guidance that include exemplar risk assessments (MRAT) for most of the materials and processes used in schools. To access these resources, schools will need to be members of CLEAPSS. Membership may be available through Local Authorities, Multi Academy Trusts or organisations governing schools.

The suggestions that follow are meant as a starter and not intended to be a comprehensive list.

Adhesives for Depron foam

Solvent adhesives attack foam and should be avoided. Advice on aeromodelling forums suggest the following glues for Depron foam:

UHU Por – a contact adhesive that stays slightly flexible.
Gorilla glue – a polyurethane adhesive that foams slightly in contact with water.
Hot glue gun – these can melt Depron so must be used carefully.
CA (**Foam safe)** – some super glues are foam safe but may be prohibited in schools due to the problems of gluing skin.

Epoxy – two-part epoxy adhesives are very strong but can be messy and some take a long time (24h) to set.

Cutting foam by hand

This is covered by the following CLEAPSS risk assessments.

- MRAT - 1.052 - Plastics: Abrading and Trimming Equipment
- MRAT - 1.053 - Plastics: Abrading Dust and Fumes
- MRAT - 1.055 - Plastics: Hazards of Materials

Cutting foam using CNC

This is covered by the following CLEAPSS risk assessment.

- MRAT - 1.010 - CNC Machines

3D printing

This is covered by the following CLEAPSS risk assessment.

- MRAT - 1.088 - Additive Manufacturing: 3D Printing

Appendix six – parts list

The Excel spreadsheet has details of the parts required for this activity including suppliers, part numbers and prices which were correct in December 2018.

STEM into Action - Pylon flight - Parts list.xlsx

Aircraft

Item	Supplier	Order code	Unit cost	Min	# req'd	cost
DC motor FA 130 6-12v (USD)	Polulu		1.31	100	0	0.00
DC motor FA 130 6-12v (USD)	Banggood	964015	0.40	10	1	0.40
Motor mounts – 3D printed	STL files supplied	NA			1	0.00
Depron sheet - 2mm x 1250mm x 800mm	Depron.co.uk	2mm thick	2.50	60		0.10
Depron sheet - 3mm x 1000mm x 700mm	Gliders UK	G5233.3	3.99		0	
Piano wire 910mm x 0.5mm	Technology Supplies	560-183	0.44		0.25	0.11
Propellor - 2.5" x 1" (pack of 5)	Hobby King	HKP2510	1.20		1	0.24
Propellor - 2.5" x 1" (pack of 5)	Hobby King	HKPR2510	1.25		0	0.00
Two small wheels 10mm dia x 1.5mm	DXF File supplied	NA				0.10
Wire for motor connections 2x50mm	Technology Supplies	250-891	5.93	1	0.001	0.01
Blue modelling foam	Technology Supplies	496-006	57.02	1	0.004	0.23
Molex connector - male	Rapidonline	22-0838	0.16	100	1	0.16
					Total	**1.34**

Total cost of parts and materials for one aircraft

Pylons

Option one

Item	Supplier	Order code	Unit cost	min order	# req'd	cost
Power Anchor	Technology Supplies	400-340	£780.38	1	1	£780.38
					Total	**£780.38**

Option two - Lightweight pylon						
Estimated total cost	NA	NA				£2.75
Base - plastic container with lid	Recycled container	NA	0.00	NA	1	0.00
					Total	**£2.75**

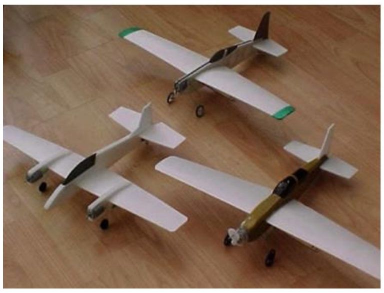
Option three						
Bearings - SKF 6000/C3	RS Components (UK)	286-7568	2.37	NA	4	9.48
Acrylic tube 10mm O/D x 500mm	Technology Supplies	490-293	1.50	4	1	1.50
Base - plastic container with lid	Recycled container	NA	0.00	NA	1	0.00
					Total	**£10.98**

PSU, flying wires and connections						
Flying wire - 70m reel	RTP Hut	4603	4.00	NA	0.2	0.80
Wire for tower connections 4 x 5 metres	Technology Supplies	250-891	5.93	1	0.2	1.19
Molex connector - female	Rapidonline	22-0820	0.10	100	2	0.19
Molex connector crimp terminals	Rapidonline	22-0836	0.04	100	2	0.08
0- 12v 4A power supply	Irwin	Web page	139.95	1	2	0.00
					Total	**24.22**

Appendix seven – Aircraft examples

The pylon flight models in these images were created by teachers Chris Jarman, David Eyre and their students.



Appendix eight - Motor efficiency

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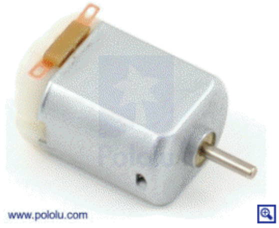
Brushed DC Motor: 130-Size, 6V, 11.5kRPM, 800mA Stall



Pololu item #: 1117 **5452** in stock
Brand: Generic

Price break	Unit price (US$)
1	1.79
5	1.59
25	1.45
100	1.31

Quantity: 1 Add to cart

backorders *allowed* Add to wish list

This 130-size brushed DC motor has a recommended operation voltage of 3 – 12 V and is used in the larger Pololu plastic gearmotors. Approximate specifications at 6 V: free-run speed of 11,500 RPM, free-run current of 70 mA, and stall current of 800 mA.

Compare all products in Motors and Gearboxes or Pololu Plastic Gearmotors.

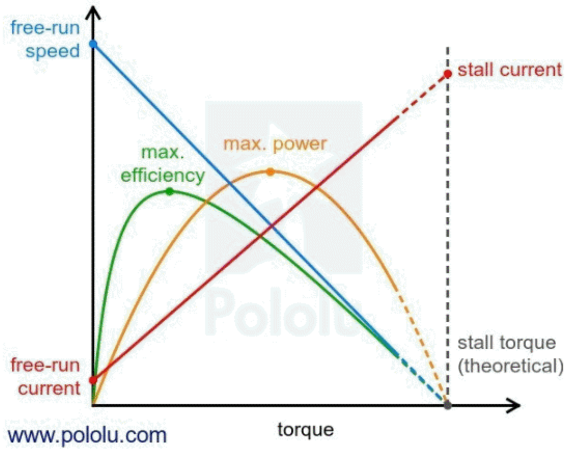
Description | Specs (6) | Pictures (0) | Resources (1) | FAQs (1) | On the blog (0)

I need additional information about this motor; do you have a datasheet?

No; the information we have available for this motor can be found on its product page. However, you can approximate various additional motor parameters from the information found in the "Specs" tab.

The electrical resistance of the motor can be approximated by dividing the rated voltage by the stall current (at the rated voltage). The electromotive force constant (Ke) can be approximated by dividing the rated voltage by the free-run speed (at the rated voltage). To approximate the motor torque constant (Kt), you can divide the stall torque by the stall current.

For pretty much any DC motor, the current, speed, power, and efficiency curves as a function of torque will look like those in the graph below (assuming motor voltage and temperature are constant):



The current and speed curves are approximately linear, and the product pages for our motors provide the approximate end points for these lines: (0 torque, no-load current) and (stall torque, stall current) for the red line, and (0 torque, no-load speed) and (stall torque, 0 speed) for the blue line.

The orange output power curve is the product of the speed and the torque, which results in an inverted parabola with its peak at 50% of the stall torque.

The green efficiency curve is the output power divided by the input power, where the input power is current times voltage. The voltage is constant, so you can divide the output power curve by the current line to get the general shape of the efficiency curve, which in turn lets you identify the torque, speed, and current that correspond to max efficiency.

There are many programs out there that you can use to generate these curves. For example, if you have access to MATLAB, you can use this customer-created MATLAB script to generate these motor plots for you from the specifications we provide for each gearmotor.

Note: A good general rule of thumb is to keep the continuous load on a DC motor from exceeding approximately 20% to 30% of the stall torque. Stalling gearmotors can greatly decrease their lifetimes, occasionally resulting in immediate damage to the gearbox or thermal damage to the motor windings or brushes. Do not expect to be able to safely operate a brushed DC gearmotor all the way to stall. The safe operating range will depend on the specifics of the gearmotor itself.

Related Products

- Brushed DC Motor: 130-Size, 3V, 17kRPM, 3.6A Stall
- Solarbotics RM2 (high-power motor for GM2/3/8/9)
- Tamiya 980112M Mabuchi FA-130 Motor
- Pololu Qik 2s9v1 Dual Serial Motor Controller
- DRV8833 Dual Motor Driver Carrier
- Baby Orangutan B-328 Robot Controller
- DRV8835 Dual Motor Driver Carrier
- Tamiya 70168 Double Gearbox Kit
- Tamiya 70097 Twin-Motor Gearbox Kit
- TB6612FNG Dual Motor Driver Carrier
- Tamiya 70167 Single Gearbox (4-Speed) Kit
- Tamiya 70093 3-Speed Crank-Axle Gearbox Kit
- Tamiya 70110 4-Speed Crank-Axle Gearbox Kit
- Tamiya 70103 Universal Gearbox Kit
- 228:1 Plastic Gearmotor, Offset Output
- 120:1 Plastic Gearmotor, Offset Output
- 200:1 Plastic Gearmotor, 90° Output
- 120:1 Plastic Gearmotor, 90° Output
- Solarbotics GM2 224:1 Gear Motor Offset Output
- Solarbotics GM3 224:1 Gear Motor 90 deg. Output
- Solarbotics GM8 143:1 Gear Motor Offset Output
- Solarbotics GM9 143:1 Gear Motor 90 deg. Output
- Ceramic Capacitor 6-Pack 0.1uF 50V

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- Robot Controllers

https://www.pololu.com/product/1117/specs

Appendix nine – Flying Competitions

Airgineers – Drone challenge
https://www.airgineers.co.uk/

BMFA – Payload Challenge
http://payloadchallenge.bmfa.org/

Flying Start Challenge
http://www.flyingstartchallenge.co.uk