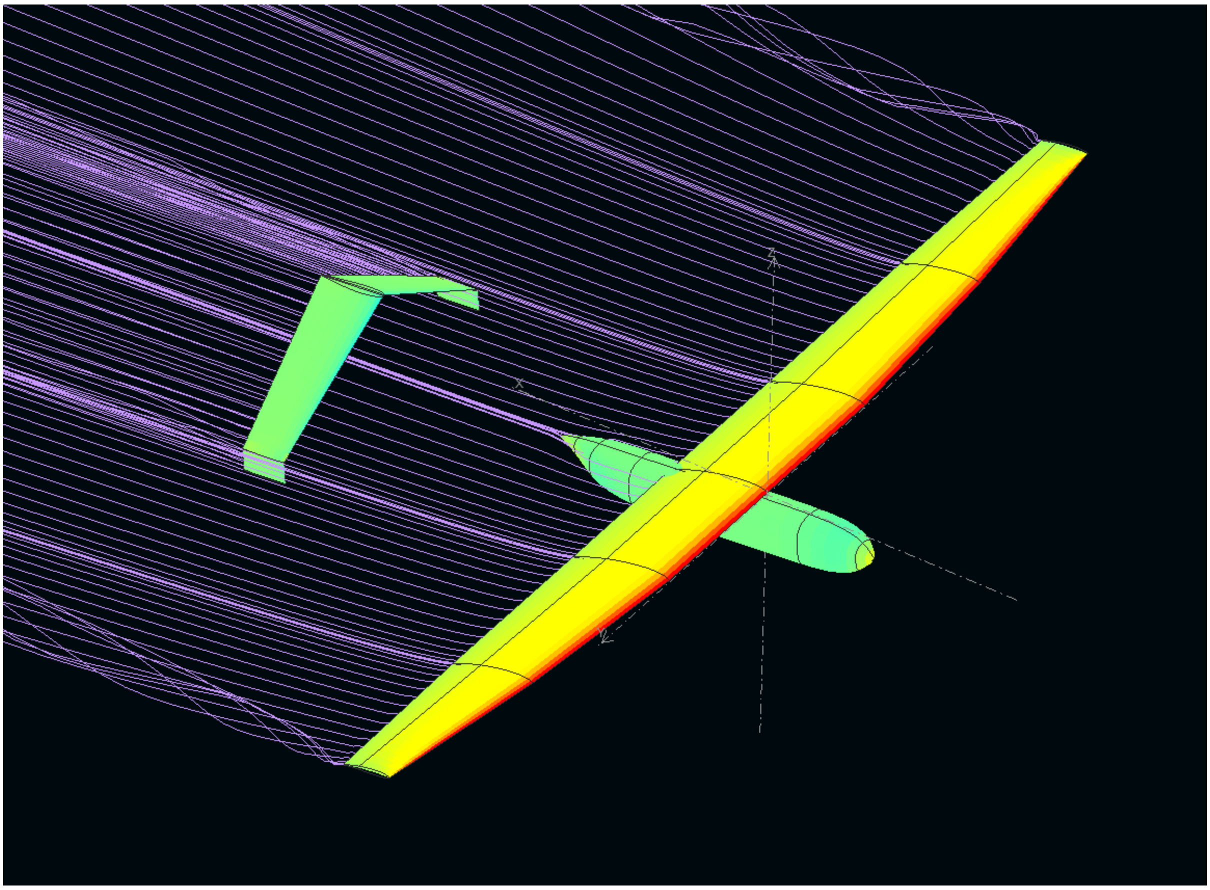
XLFR5 For Dummies

The UAV Society guide to all things XLFR



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Section 1: What is XFLR5?

XFLR5 uses a combination of the thin aerofoil, lifting-line and vortex lattice approximations to model the aerodynamic effects of aircraft wings and fuselages. Despite being vastly simplified aerodynamics compared to a full Naiver-stokes solver, full aircraft simulations are usually accurate to better than 10% (and honestly, effects from inaccuracies in building will probably be worse than that) providing when you use it, you're well aware of the limitations of the model.

Using this approximation, it outputs all of the important aerodynamic data you are likely to need, in particular the lift, drag, balance and stability characteristics of your aeroplane. XFLR5 is actually two parts: an XFOIL back end (an ancient program dating back to the internet dark ages) that works out the 2D aerofoil polars, and the XFLR5 GUI which sends instructions to XFOIL and adds in the 3D effects.

XLFR5 is completely free and open source, and can be downloaded through their website: https://www.xflr5.tech/xflr5.htm

If you're so inclined, and like text interfaces and hand-written config files, you can also download XFOIL on its own with some added functionality (e.g. automated calculations of the 2nd moment of area of a section), and a similar program called AVL (Athena Vortex Lattice, dating from the same era as XFOIL) to do simple validation work.

Limitations

Mach

XFOIL and XLFR5 implement the Prandtl-Glauert correction to correct subsonic C_p values for compressibility. This is valid up to the drag divergence value of around ~0.8M.

High Reynolds

XFOIL does an excellent job of predicting the airfoil pressure distribution, but is tuned for low Reynolds numbers. This means that accuracy falls off slightly above ~1 million. Drag is increasingly underpredicted due to wake effects.

Low Reynolds Numbers and Viscous Effects

At low Re numbers drag is dominated by viscosity and a laminar wake. Due to XFOIL predicting the flow transition much later than in reality, and little prediction of trailing edge separation, the drag on some 2D sections (usually highly cambered foils at higher angles of attack) can be underpredicted by as much as 50% (though 10% is more usual). A good rule of thumb to judge if this is an effect is by varying the forced transition point. Significant variation in polars usually indicates this may be an issue. However, since most 3D wings are dominated by vortex drag the inaccuracy of the drag polars due to XFOIL's shortcomings is rarely greater than 10%. XFOIL also tends to overpredict the stall angle by ~1-2 degrees.

Workflow

The basic workflow for building a model on XFLR5 usually follows the same basic steps:

1. Obtain aerofoil geometry(s). Usually by importing a Selig format .dat file, although XFLR5 has a variety of internal methods to also generate aerofoils
2. Simulate the 2D aerofoil across the required range of Reynolds numbers. The pre-set Re List that runs between 30k and 3000k is usually a good first guess for UAVs
3. Define an aircraft geometry, and input masses

4. Run a static VLM1 or VLM2 simulation to get a basic idea of the design characteristics, and adjust as necessary
5. Run stability analyses across the expected flight envelope, and adjust the design as necessary
6. Export results and/or geometries as CSV or XML files for use elsewhere

This guide will step you through the various steps in increasing detail, so as to serve as both a tutorial and a reference document.

Section 2: Aerofoil Analysis

Downloading and Importing Aerofoils

In XFLR5 aerofoils are imported in the Selig format (‘.dat’). This is a plain text file consisting of the x-y coordinates of the aerofoil running either clockwise or anticlockwise from trailing edge to trailing edge. Note that the points do not need to link up as the trailing edge, indeed this is often undesirable – Solidworks will throw a fit if you try to import a self-intersecting curve, and in the real-world trailing edges will have about a millimetre of thickness, depending on your exact building technique.

The best place to download an aerofoil is http://airfoiltools.com/. This has around ~1,600 aerofoils to choose from, including those from microlights, airliners, WW2 fighters, wind turbines, model

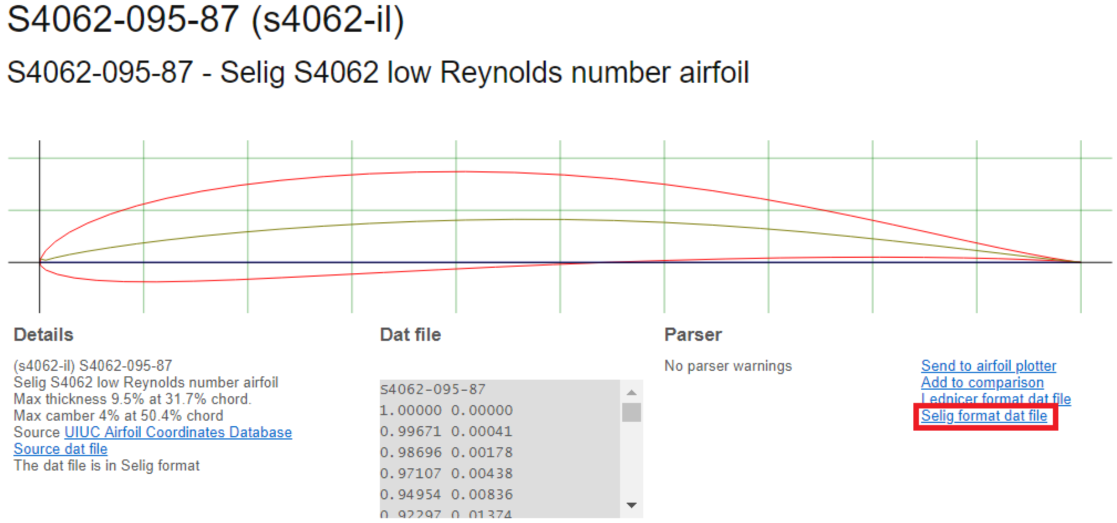


Figure 1 - aerofoil data and download page on Airfoil tools

airplanes, propellers, and specialised low-Reynold number aerofoils, plus a reasonably good search function to boot. As a society, we do have our own much larger database of around 2,800 aerofoils and counting, plus pre-run polars and a python script to search by various characteristics. Once you’ve picked your aerofoil, right click on the “Selig format .dat file” link, and hit “save as” then save it in your project folder (in my case ‘S4062-95-87.dat’), making sure to set the file extension to ‘.dat’ instead of ‘.txt’.

Then, open XFLR5, and you will be presented with a black screen.

Go to File->Save As and save in your project folder. Then, go File->Open, then navigate to wherever you saved your aerofoil and hit “open”.

Your screen will now look something like this:

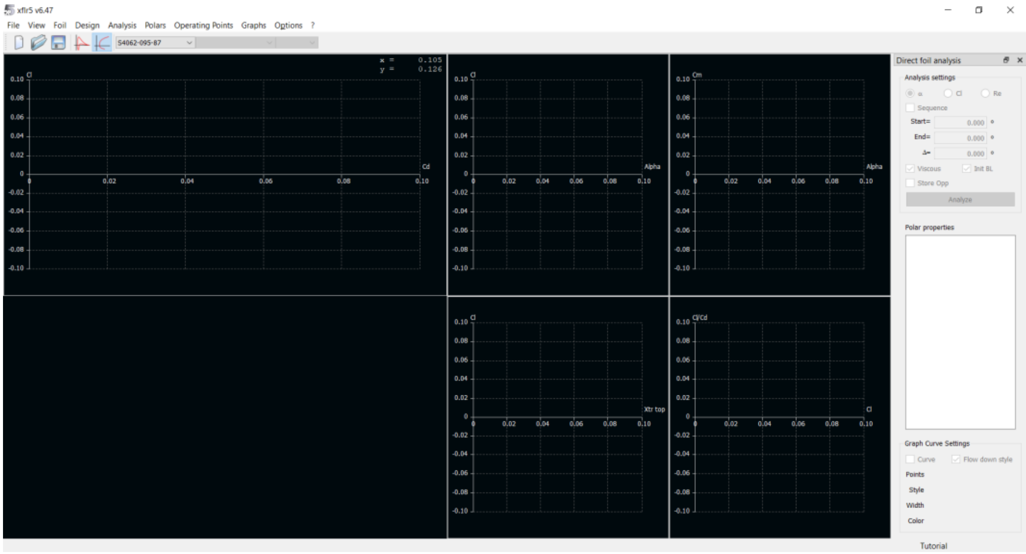


Figure 2 - starting screen after loading in an aerofoil for the first time

To check your aerofoil has loaded in properly, click the button that looks like an X-C_p graph for an aerofoil (on the right of the Save button at the top of the screen). Your screen should now show the aerofoil as such:

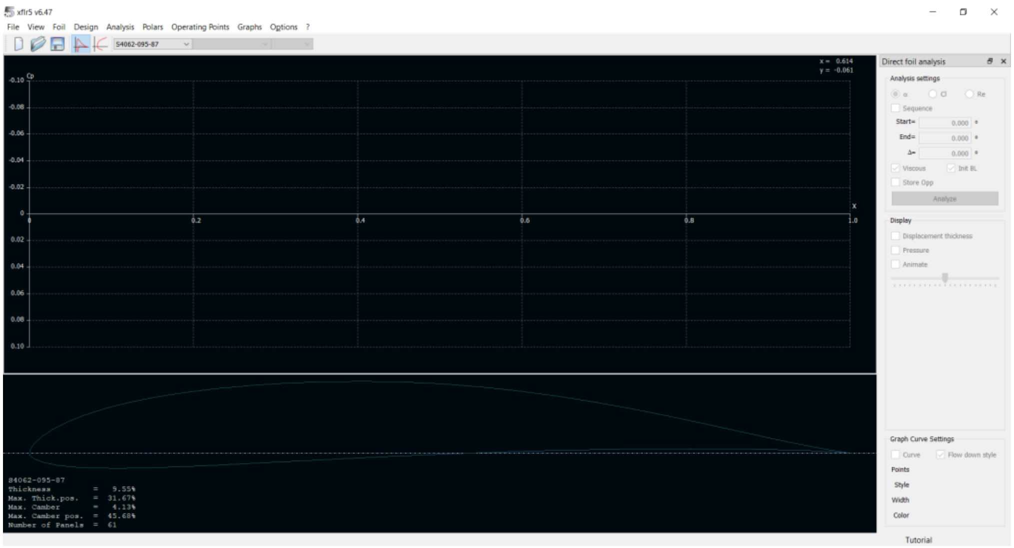


Figure 3 - Aerofoil visualisation page. This shows the geometry of the aerofoil being simulated, and distributions along the aerofoil chord

Great! Now we've successfully imported an aerofoil, we can either edit a variety of parameters about it (thickness, camber, trailing edge thickness, flaps, and so-on), or we can proceed directly to analysis.

Creating Aerofoils within XFLR5

This is a whole can of worms, largely beyond the scope of this introduction, so we'll just touch on the basic functions.

NACA foils

Clicking Design->NACA foils will bring up a window allowing you to enter the name of a 4- or 5-digit NACA foil, which XFLR will then generate with the specified number of points. This is particularly useful for generating generic symmetrical tail sections, such as the 0009.

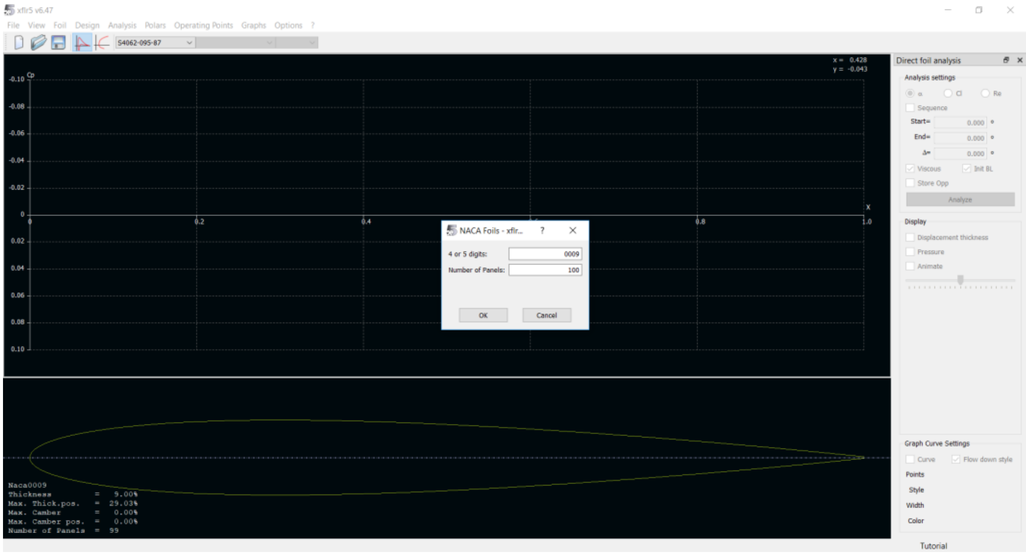


Figure 4 - Generating a standard NACA foil

Direct Foil Design

File->Direct Foil Design

Allows you to do things like design a foil with spline curves, overlaid on an image – especially useful for reverse-engineering models from plans.

Inverse Foil Design

File->Inverse Foil Design

Just don't. You need a PhD to use this.

Editing your Aerofoil

For the purposes of this Tutorial, I'll just be setting the trailing edge thickness. To do this, go to Design->Set Trailing Edge Gap. In the resulting window, you can set the gap as a % of the chord, and the distance from the leading edge (by default 80%) that it should alter the foil from. In this case, a 200mm chord is a pretty standard wing chord, and 1mm a typical trailing edge thickness, so I've set it to 0.5%. Unless you start setting values that are a significant percentage of the wing's thickness, it will make precious little difference to your analysis, so 0.5% generally just a good rule of thumb.

XFLR will then give you the option to create a new foil or overwrite as you see fit.

Analysing Aerofoils

To open the analysis window, go to Analysis->Batch Analysis.

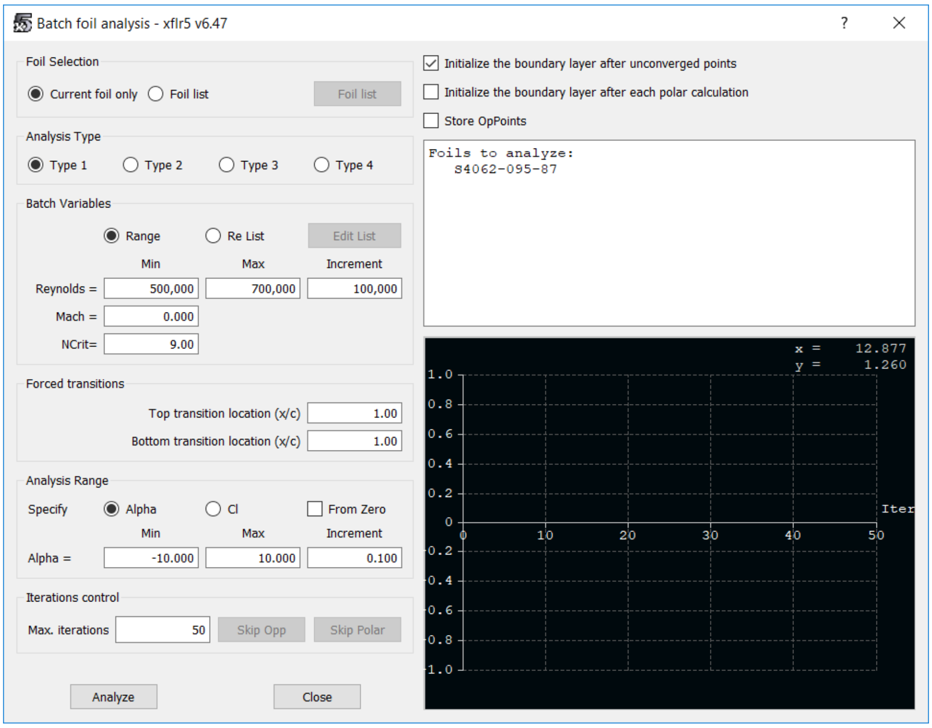


Figure 5 - Foil batch analysis window

This window allows you to set the parameters that will be passed to the XFOIL backend. Starting from the top:

- Foil Selection – do you want to apply these settings to just this foil, or multiple foils?
- Analysis Type – this determines which parameters you wish to vary and keep constant. For the moment, leave it as Type 1 (Fixed Reynolds, varied angle of attack, CL is free)
- Batch Variables – setting the values you want each analysis in the batch to start with.
  - Reynolds – this is the likely range of Reynolds numbers you expect your flight to take place in. Most R/C planes tend to operate in the region of 100-600k – note that turbulent transition occurs at 400k, which is one of the reasons model aircraft aerodynamics are typically a mess
  - Mach – this determines the Prandtl-Glauert correction that will be applied to the flow. Model aircraft Mach numbers rarely exceed 0.1, so this is best left at zero. This will also save you a ton of compute power. If for some reason your design Mach number is likely to exceed 0.3, note that the correction is really only valid up to Mach numbers of 0.7-0.8. For what it's worth, the current dynamic soaring speed record is ~520mph, or ~M0.68.
  - NCrit. Related to the freestream turbulent kinetic energy. Leave it alone.
- Forced Transitions – this is the point at which the airflow over the wing transitions from laminar to turbulent. XFOIL will attempt (based on the NCrit value) to determine where this happens, but upper surface transition is *extremely* hard to predict – although a good rule of thumb is it happens a little behind the wing peak.
  At low Reynolds numbers, however, it is usually advantageous to force the airflow to transition to turbulent flow around the peak of the wing – this prevents hysteresis in stall recovery, laminar separation bubbles, reduces drag, and often increases the maximum C_L. This is usually achieved with a boundary layer trip at the 20-30% chord mark, which consists of a ~0.1mm step down in the wing profile (think tape thicknesses). It is usually best to set a

transition value on the upper surface on or slightly in front of the wing peak, at the 20-30% mark, then leave the lower surface at 1.00. If it's a symmetrical section, think carefully about whether you want to trip one, neither, or both sides.
Additionally, XFOIL usually grossly overpredicts the upper surface separation point – especially on NACA and high lift profiles – so a rule of thumb for best accuracy set it to around 0.2.

- Analysis Range – usually best to vary the wing Alpha. Most sections at low Re numbers stall at 8-12 degrees, so -10->+15 degrees for cambered sections, and -10->+10 for symmetrical sections should be ample. I usually set the spacing to 0.1-0.5 degrees.
- Iterations Control – XFOIL will iterate until either the solution converges, or it reaches this number. Depending on how much you care about picking up all the possible points, values of 30-200 are in order. 50 will net you the vast majority of the points that will converge.

Once you've set all these values to your satisfaction, hit Analyse!

Interpreting XFOIL Polars

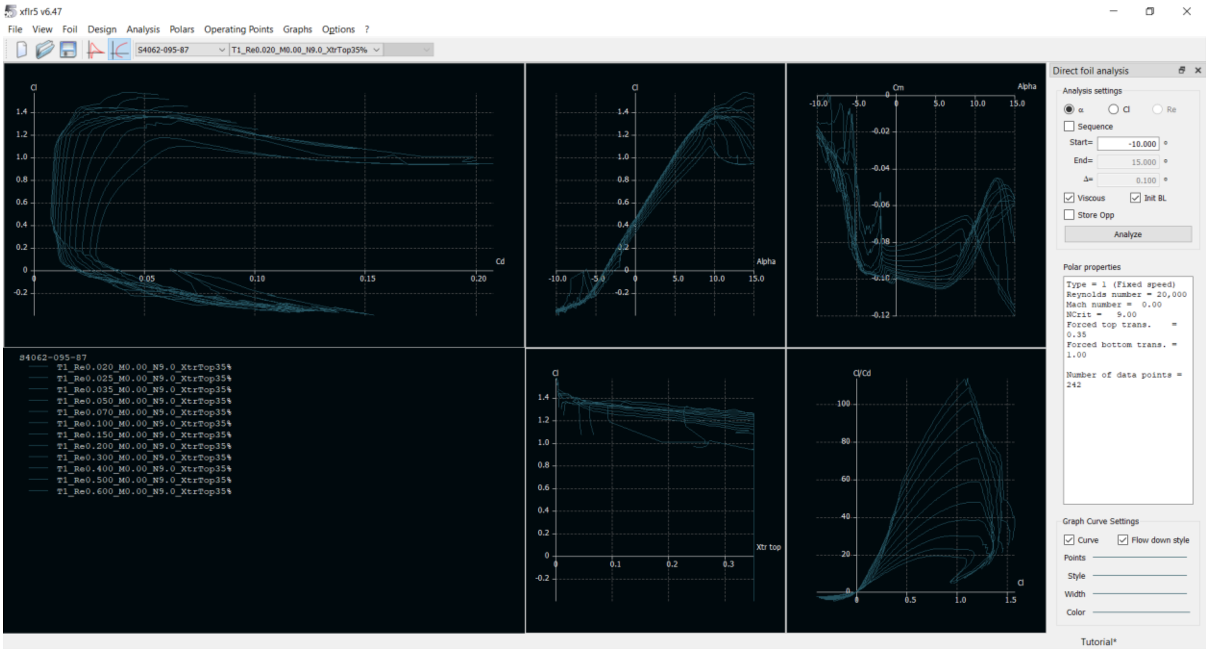


Figure 6 - Graphs generated across a spread of Reynolds numbers for a particular aerofoil

Once you've run your analysis, you should end up with a screen that looks roughly like this.

Each of the lines represents the aerofoil characteristics at the chosen Reynolds number. If you don't have these many graphs and want more, got to Graphs->All Graphs for *maximum graphing*.

On the bottom left, you can see the name of each polar. In this case, T1 means "Type 1 Analysis", Re0.xyz is the Re number of the polar in millions, M is the analysis Mach number, N is the NCrit value, and Xtr is the percentage of chord the flow has been forced to turbulent at. This style of naming scheme will crop up regularly across XLFR, so I hope you like it.

To edit what you see in a polar, double click on it, and you will get the following fairly self-explanatory window:

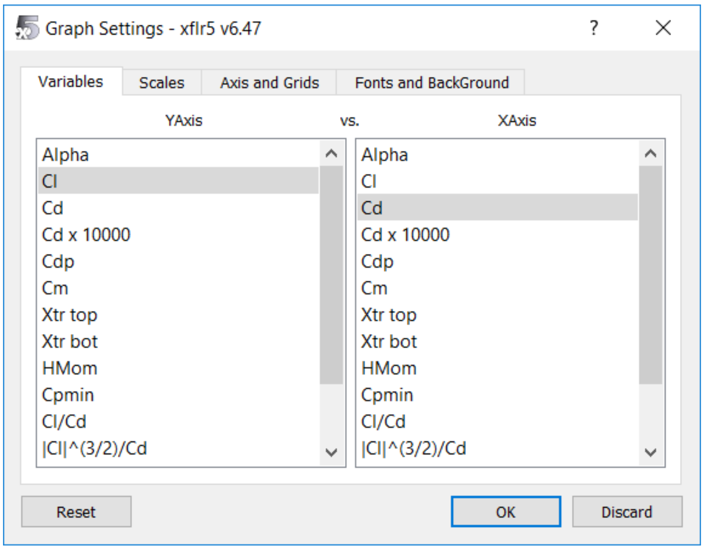


Figure 7 - Graph Settings window, allowing selection of what shows up on each axis. This window is accessed by double-clicking on the graph at hand

In my case, I have the following graphs: C_l vs C_d; C_l vs Alpha; C_m vs Alpha; C_L vs the turbulent transition point; and C_l/C_d vs C_l. You may or may not want to duplicate these, depending on exactly what you're trying to find out.

Older versions of XFLR will make each Re number a different colour (rather than each aerofoil), so if you wish to edit the polar appearance look in the window either docked or floating around (if you closed it go to Options->Restore Toolbars and it will reappear), then click on the 'Points' 'Style' etc menus on the bottom.

Once you have all your aerofoils analysed to your satisfaction, it's time to build a plane!

Section 3: Aircraft Geometry

Go to File->Wing and Plane Design. Your window will now look like this:

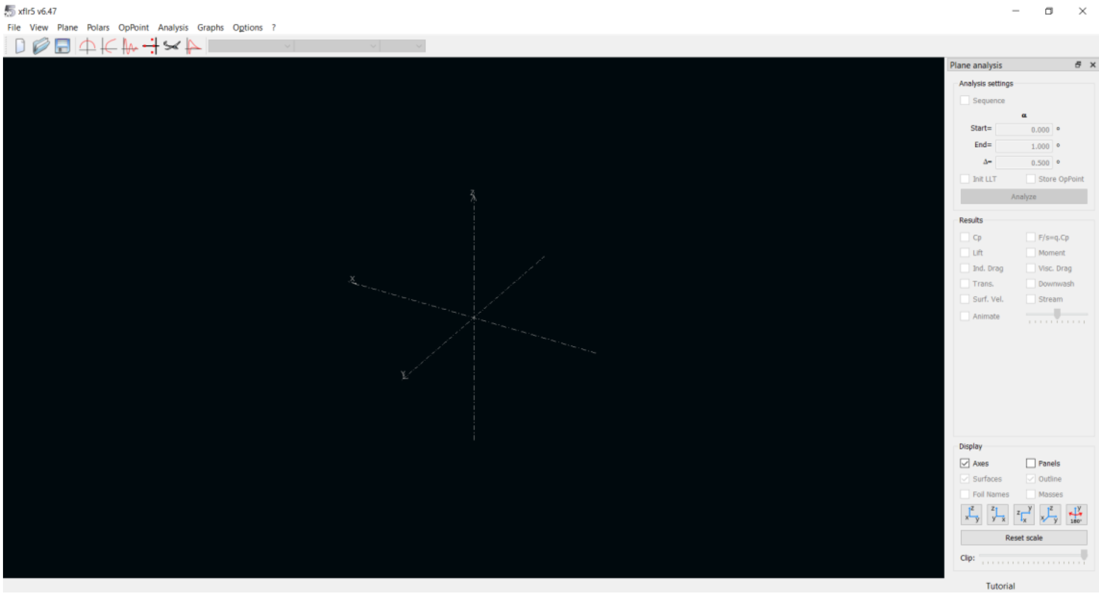


Figure 8 - Blank aircraft geometry window

This is the aircraft design window. To create your first aeroplane model, go to plane->Define a New Plane, and the following window will appear:

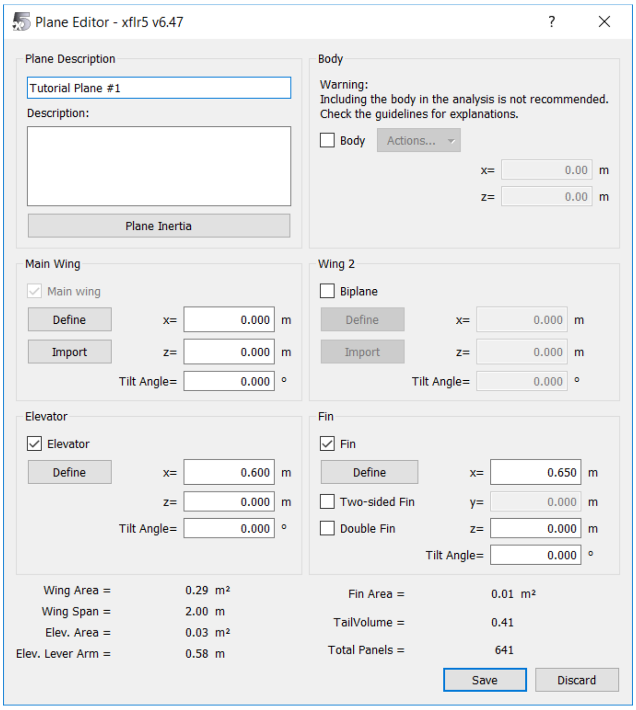


Figure 9 - Plane Editor window. This is where the aircraft design work is done

This allows you to edit all the characteristics of your aeroplane. Once created, the aircraft can be subjected to various analysis, duplicated and re-edited.

Main Wing

Click on the "Define" button to open up the wing editor:

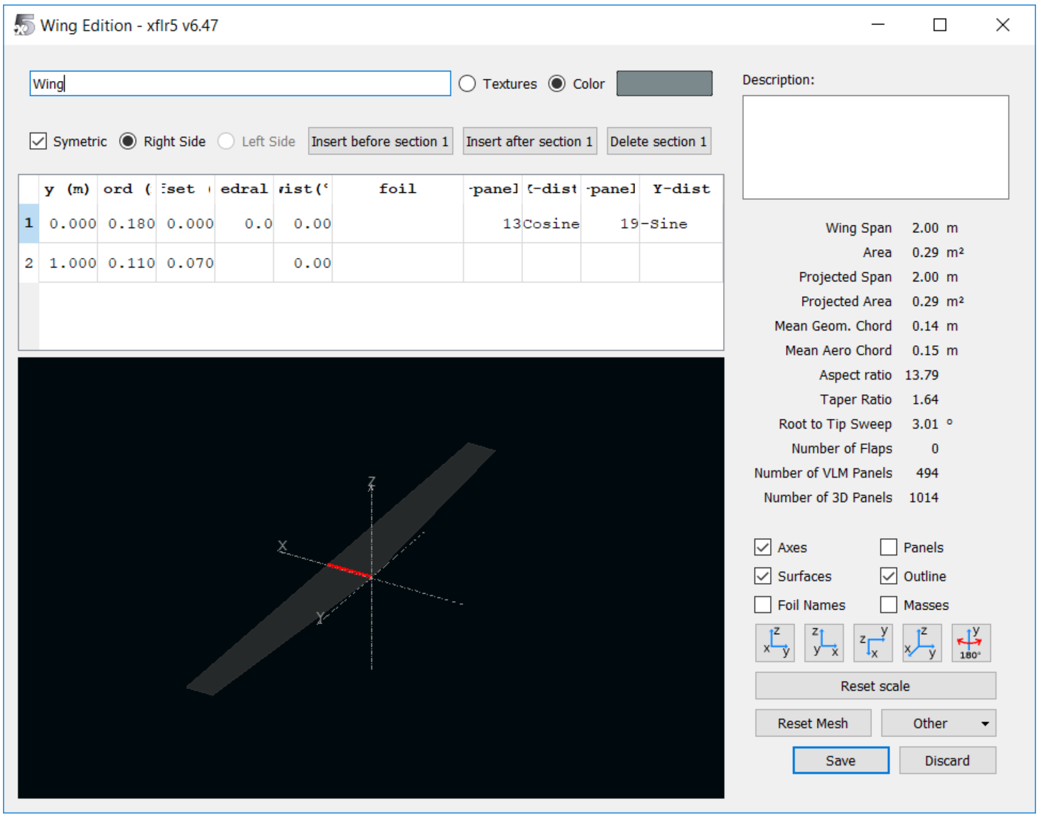


Figure 10 - Wing Editor window with default geometry loaded.

XFLR5 models all work by specifying a cross-section profile, and then linearly interpolating between them. For the wings, this means specifying sections at a given Y (spanwise), chord, leading-edge offset along the X-axis, dihedral angle, twist angle (around the local quarter-chord point), aerofoil, then X and Y panel distributions (usually hitting “reset mesh” does a good job of this).

A completed wing may look something like this:

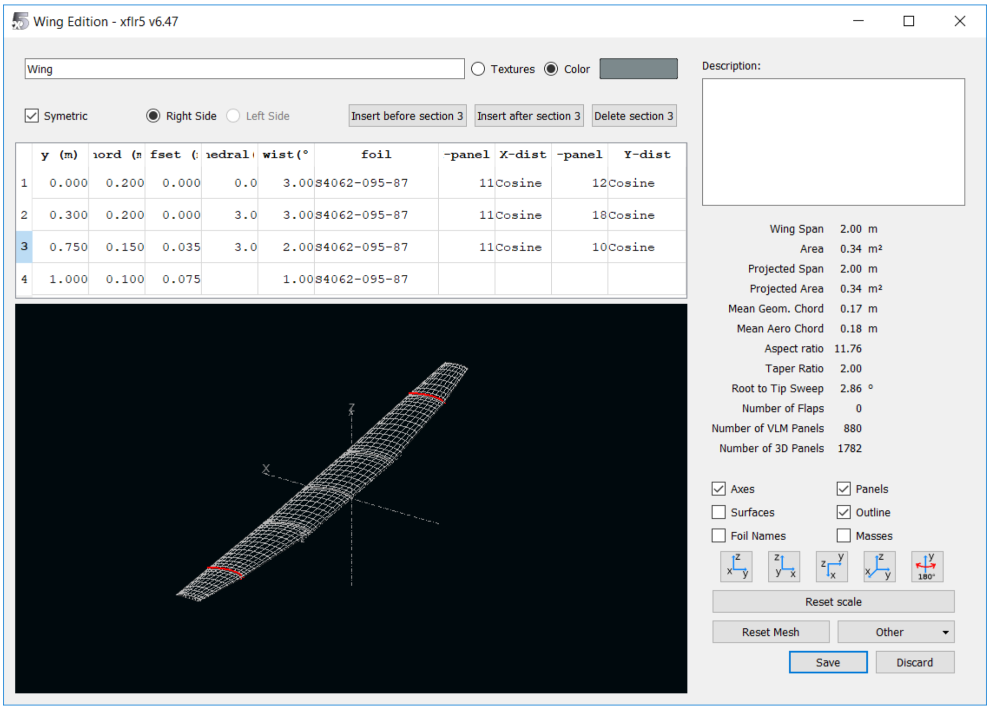


Figure 11 - Example wing geometry with surfaces turned off and discretisation panels enabled

Note firstly that all the X distribution panel counts are the same (discontinuities in the mesh will create artefacts), and the panel distribution has been set to "Cosine" in all cases, causing the mesh to bunch up towards section changes, which is where errors and interesting aerodynamics are most likely. Once you're happy, click "save" and the window will close itself.

Elevator

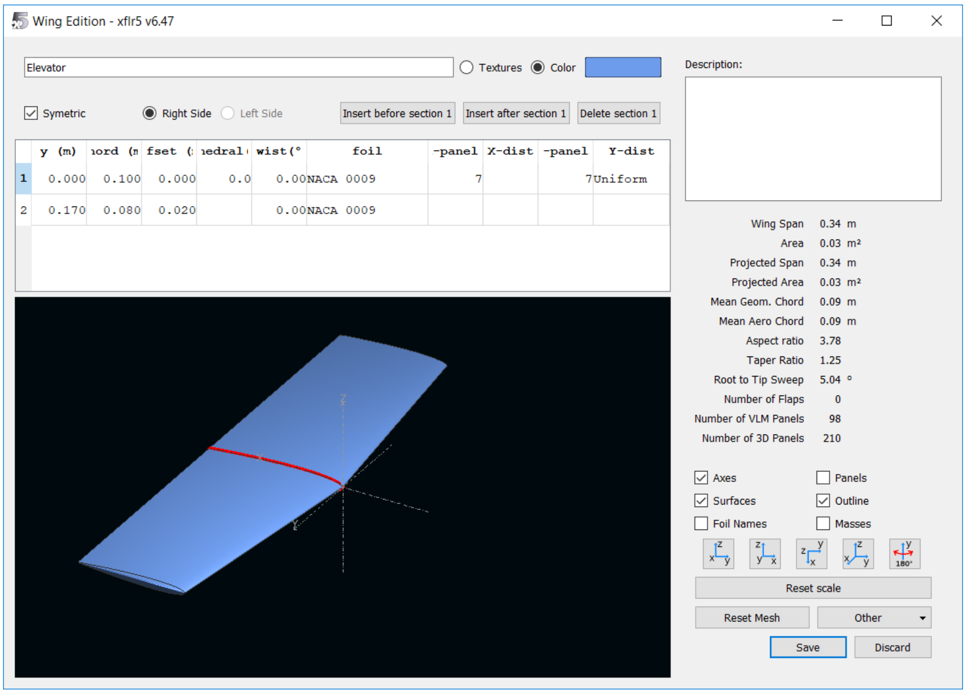


Figure 12 - Tail plane Editor with example geometry entered

The process for designing the elevator is exactly the same as the wing. In this case, I have used a symmetrical NACA 0009 section. You can also set the elevator position and angle in the main window, relative to the origin.

Fin

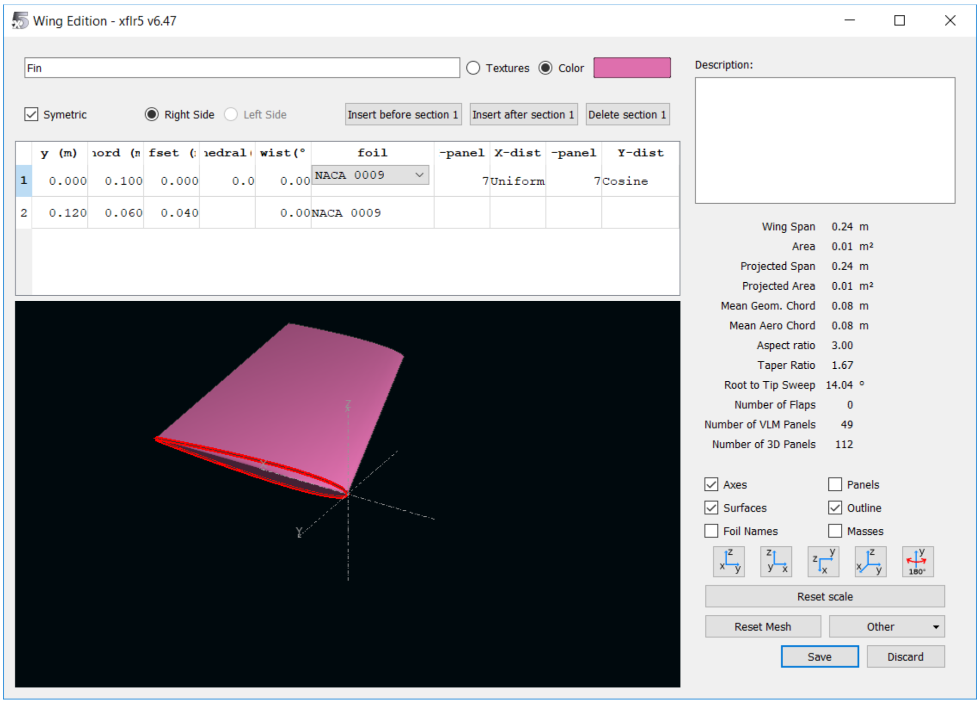


Figure 13 - Tail Fin editor with example geometry entered

Like the wing and the elevator, the position and angle can be specified in the main aircraft window. Additionally, the fin can be specified to be two-sided (i.e. a symmetrical bottom is added) or double (i.e. two fins equally spaced on either side of the X-Z plane).

Inertia

To perform constant-lift and stability analyses, the aircraft weights need to be known. This can be done in one of two ways – either by setting the mass and inertia to be used directly in each analysis, or by specifying point and distributed masses in the aircraft model. Clicking on "Aircraft Inertia" will open the following window:

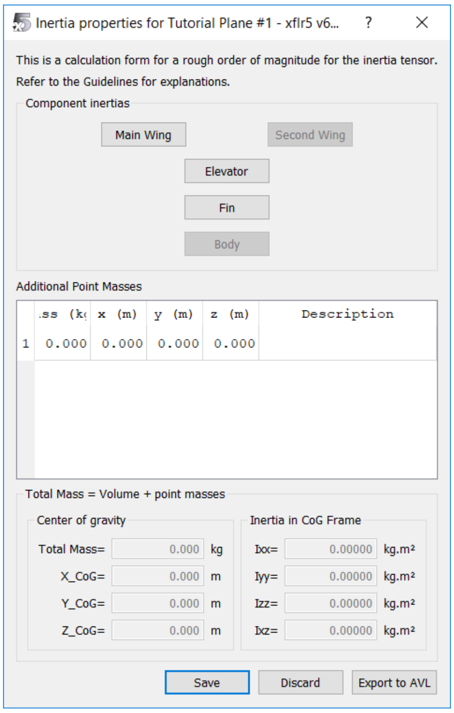


Figure 14 - Inertia window. Calculated values are output in the box at the bottom, with negative x values being in front of the wing leading edge

Point masses set in this window will be relative to the global coordinate system, so typically include things like batteries, motors, ESCs, receivers, and so-on. Within the “Main Wing” window, masses can be set relative to the wing’s position, so tend to include things like servos and water tanks. The wing itself is assumed to be of uniform density, so weight distribution varies with local volume – this is quite handy, as it produces a very good first guess (usually slightly overestimated) at the aircraft inertia. When you re-iterate through your design, you can input the inertia outputs from your favourite CAD package directly into the analysis (just be careful of the coordinate system).

It’s worth saving at this point, XFLR5 does occasionally crash during the analysis stage.

Section 4: Static Aircraft Analysis

Your fully assembled aircraft probably looks something like this:

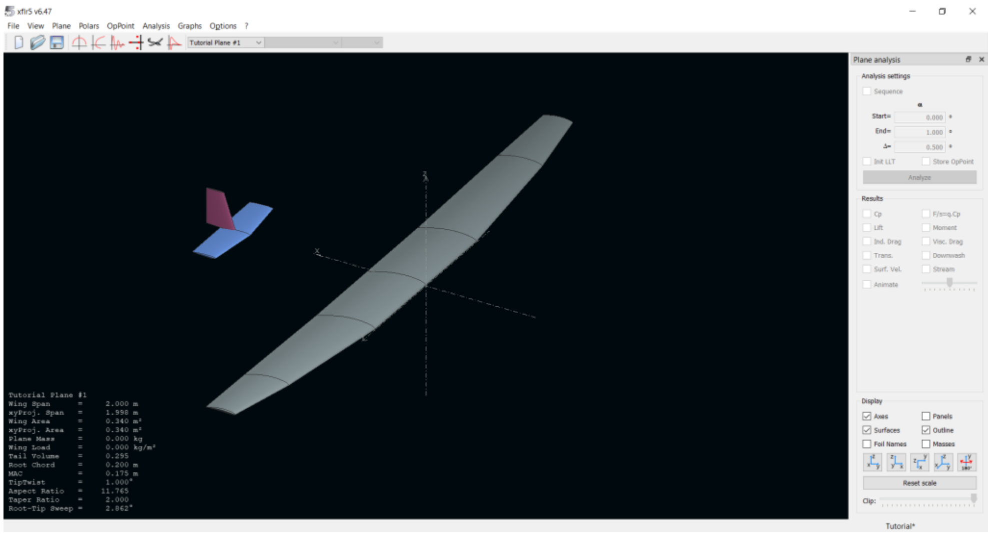


Figure 15 - Completed example aircraft geometry

Now, go to Analysis->Define Analysis. This will open up the static analysis window:

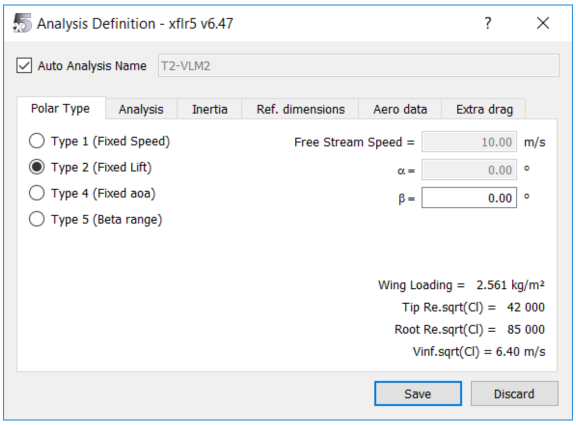


Figure 16 - Analysis setup window

Assuming you reckon you've got an accurate guess as to your weight, "Fixed Lift" is probably the most useful. This will ensure that for a given angle of attack, lift will equal weight by varying airspeed.

Clicking through onto the analysis tab, the VLM2 analysis is the most accurate available, so select that. Also make sure that the viscous option is ticked, else your drag figures will be extremely low. The Tilt Geometry option is unnecessary except when you are going all-out for accuracy. The other tab options are best left alone unless you're doing something unusual.

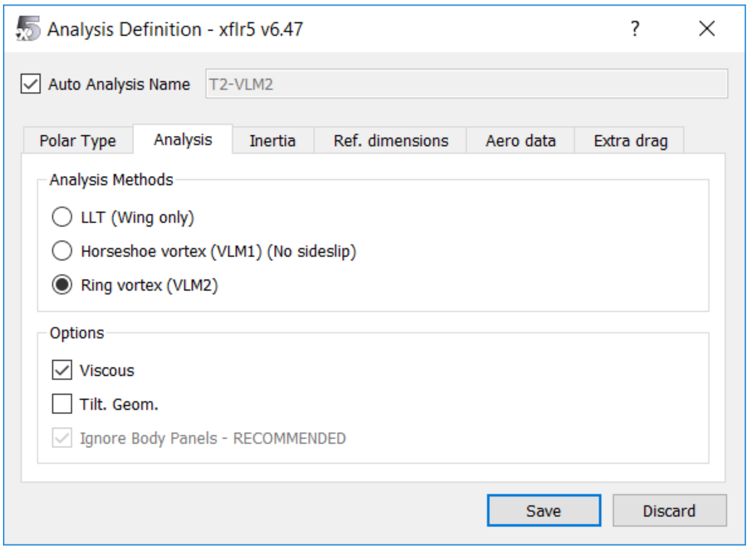


Figure 17 - Setting the static analysis model type to VLM2

Hit "Save" (now is also a good time to save your project if you haven't), and you're set up to do the analysis! On the pop-out "Plane Analysis" window, tick the "Sequence" box, and set the analysis to run between a likely range of angles of attack – -5->+10 is usually more than enough. Then hit Analyse, and the simulation will run through the Alpha sweep.

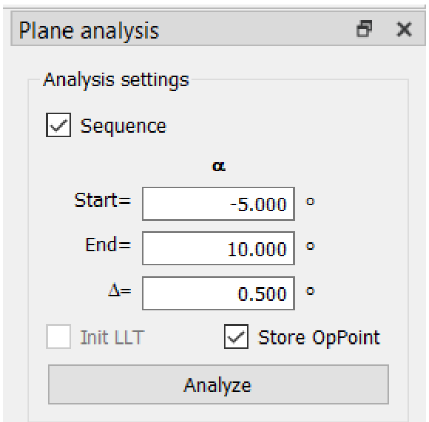


Figure 18 - Plane analysis setup/run window

Troubleshooting

You'll almost certainly get a couple of errors the first time you run your analysis, which may or may not matter. These are generally one of two messages:

- "Could not be interpolated" – if a surface is doing this at all alphas, it probably means you forgot to analyse the aerofoil, or didn't analyse it to a high or low enough angle of attack. Otherwise, it means the aerofoil at that wing segment has probably stalled or the variation between wing sections is too extreme, preventing XFLR from properly interpolating it. This can sometimes be fixed by running the airfoil polars at tighter alpha increments or Reynolds numbers around the point that is throwing errors. Changing your mesh can also help.
- "Is outside the flight envelope" – this means you did not run the profile analysis to high or low enough Re numbers. Fix it.

Interpreting your results

The first and most useful screen is accessed through the button on the top that looks like a drag bucket, two to the right of the save button. Depending on what options your graphs have been set to, your screen will look something like below. The graphs can be changed in exactly the same way as in the Foil Analysis window.

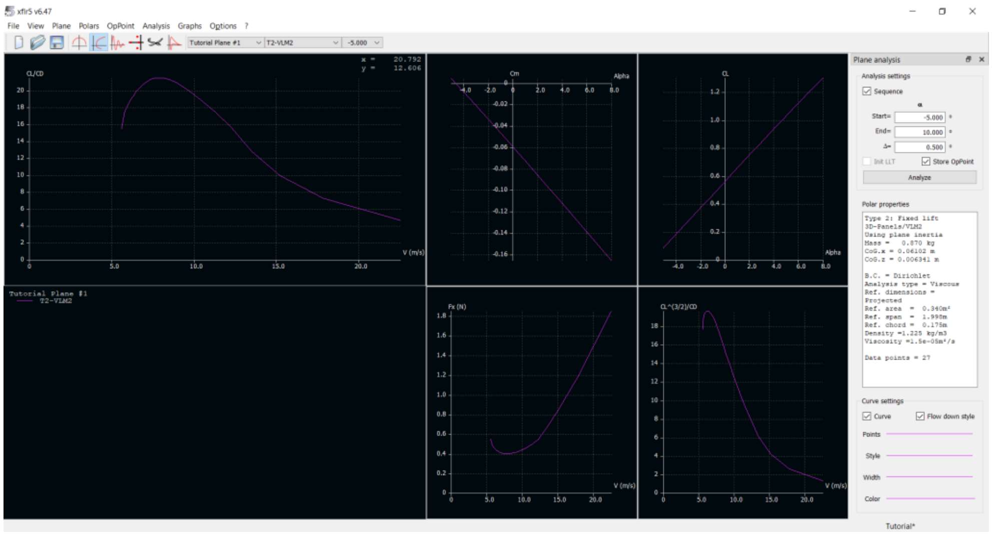


Figure 19 - Example complete geometry polars

Starting with the graph of C_L/C_D, it can be immediately seen this is quite a slow model, but very efficient, with a maximum Lift/Drag of nearly 21:1. Coupled with the high value of $C_L^{3/2}/C_D$ (and therefore low sink rate), that puts it firmly in the "floater" category. It should be noted that these figures will be optimistic, in reality L/D ratios of 10-15% less are likely. If you wanted the aircraft to be faster than this, increasing wing loading or selecting a lower-camber aerofoil are your best options.

The C_M-α graph indicates the aircraft is stable by its negative slope – if the slope is positive, the aircraft is tail-heavy, and will be dynamically unstable in flight. Note that it also does not pass through the origin, meaning the aircraft is currently trimmed for an equilibrium angle of attack of -4.5 degrees – depending on what your target is, this can be brought closer to 0 by employing a tail plane with a negatively cambered aerofoil (i.e. upside down, *achieved in XFLR's case by setting a dihedral angle of 180 degrees*), or more commonly by setting the tail plane angle ("decalage") to be negative in the aircraft window. A good response rate is usually somewhere between 0.5- and 2-degrees alpha change per degree of decalage change, depending on tail volume and static margin.

Section 5: Stability Analysis

Background and Theory

This form of analysis will predict the various longitudinal and lateral stability modes of your aircraft. The aircraft is modelled in a similar manner to a damped oscillating mass, with a given inertia calculated frequencies and damping constants. This means that all the standard phenomena apply – in particular in oscillating modes the aircraft can be driven to oscillate at a particular frequency (randomly in turbulence, or in Dutch roll by waggling the rudder at a particular frequency, for instance), and if the damping constant is insufficient, large oscillations can be forced to occur - at best a nuisance and at worst catastrophic.

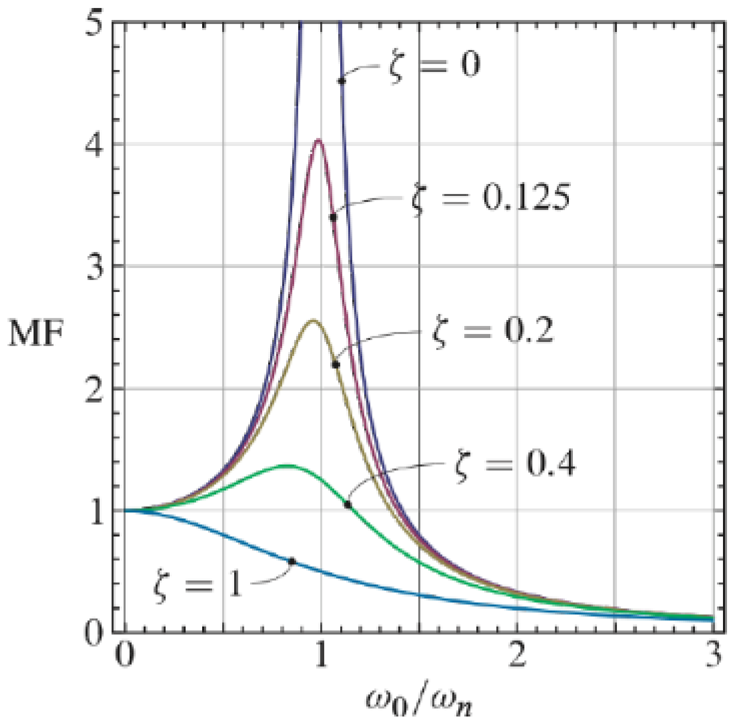


Figure 20 - The harsh realities of resonance. Magnification factor is defined as the maximum obtained deflection vs the input deflection - for poor damping constants, having a peak amplitude many times the input can be catastrophic

Additionally, *negative* damping constants will cause an aeroplane to diverge from a given position when perturbed – for most stability modes, this will cause you to crash uncontrollably. While such aircraft can be flyable in simulators (and be highly manoeuvrable), in the real world the existence of random perturbations such as turbulence usually renders an aircraft unflyable.

Finally, the assumption that the aircraft is a linear oscillating system is only a good one when the aircraft's deflections are small – and therefore there is a linear relationship between deflection angle and restoring force, as derived from the aircraft's stability derivatives. This linearization greatly simplifies the mathematics, but renders the approximation invalid for large oscillations.

Setting up a Stability Analysis

A Quick Sanity Check

The first thing to check is that your aircraft is statically stable. If it does not meet this criterion, the lateral modes will rapidly diverge, and the longitudinal modes will be rendered invalid. To check this, click through to the graph window, then set one of the graphs to plot C_m on the y-axis and Alpha on the X-axis. Your graph should look something like this:

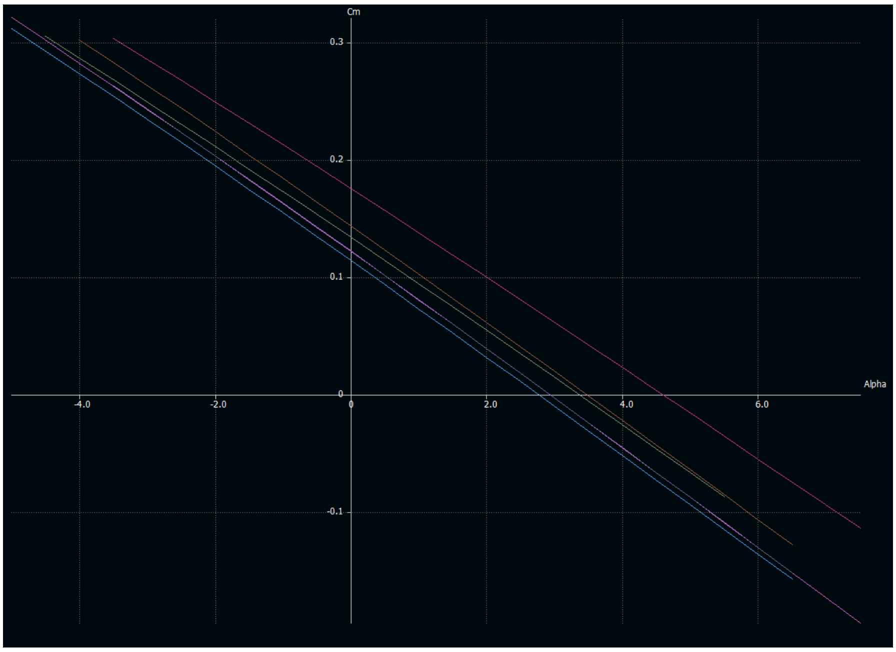


Figure 21 - Example Cm vs Alpha graph for several different cg positions. Note the negative gradient, and the x-intercept (i.e. trim angle) sitting at a reasonable angle of attack

If the gradient is very shallow or positive, that usually means your centre of mass is behind the centre of lift (very roughly the 30% mean average chord mark). Move the point masses on your aircraft (such as the battery and motors) around to fix this. The x-intercept of the graph should sit at an alpha between about -3 and +5 – this is the angle of attack your aircraft will naturally assume.

Setting Up the Stability Analysis

Go to the toolbar and select Analysis->Define a Stability Analysis. The following window will open up:

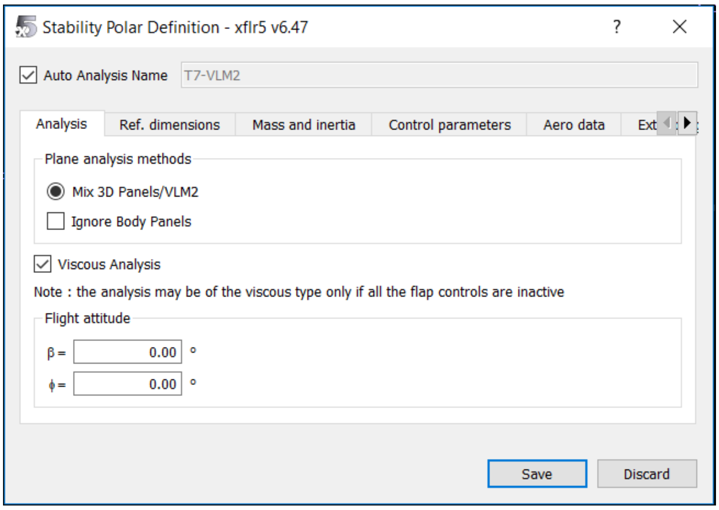


Figure 22 - Stability Analysis window

Unlike with the static analysis, you should leave the fuselage in the simulation for best accuracy, so leave the “ignore body panels” box unticked. Next, click through to the “Mass and Inertia” tab.

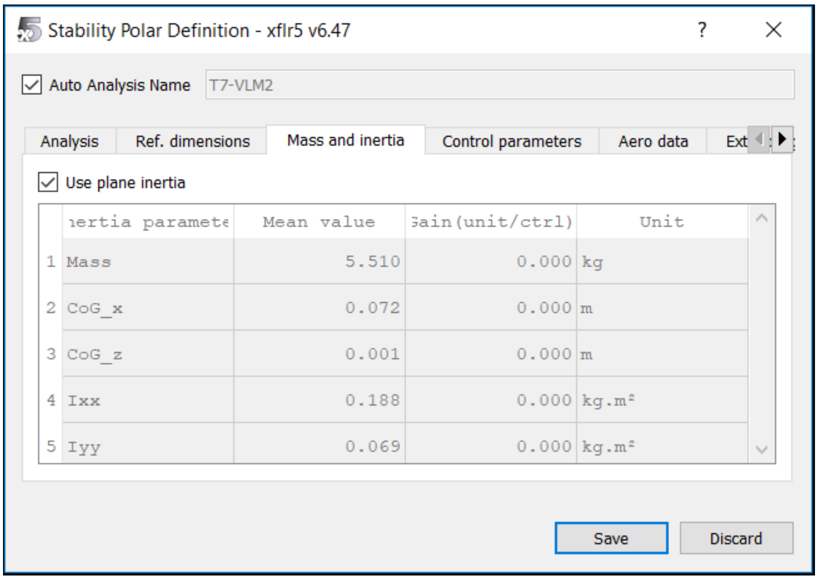


Figure 23 - Mass and inertia window

The default mass and inertia values are those calculated from the point and volumetric masses you defined for the aeroplane. If you have better or different values (such as obtained from Solidworks), you can enter them by unticking “Use plane inertia”. If not, leave the window as it is

Then, click through to “Control Parameters”, which will look something like this:

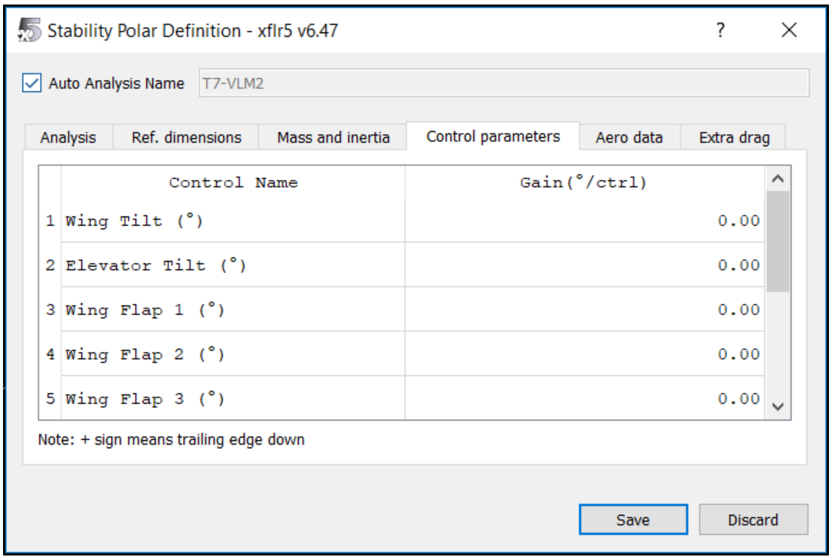


Figure 24 - Control parameters window. The number of entries varies depending on what control panels you have set, and what lifting surfaces you have

Set the elevator tilt gain to 1.00. This means that for each increment in the value of the control variable when the simulation is run, the tail plane will rotate by 1 degree. The all-moving tail plane is a good approximation of an elevatored surface, however including moving flaps requires XFLR5 to remove the viscosity equations.

Hit “Save”.

Running a Stability Analysis

Go to the pop-out window, tick the “Sequence” box, and set a range of control variables. Since a negative angle of attack will induce a pitch up moment, -10 through +5 at intervals of 0.5 or 1 is usually a good starting range to get a handle on the likely range of trim angles.

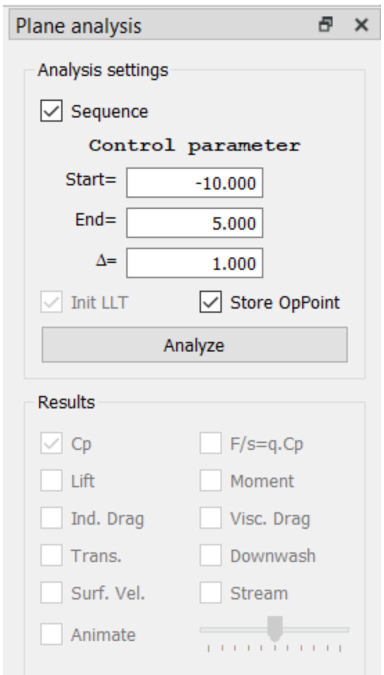


Figure 25 - Simulation control values window

Click “Analyse” to run the simulation. Depending on your computer, the complexity of your model and the number of points you intend to simulate, this may be a good moment to make a coffee.

Common Errors

- “Negative lift, aborting calculation” – the trimmed angle of attack is too low to produce lift. Try more negative elevator angles, or adjusting the basic tail setting angle, or the centre of mass/static margin of the aeroplane if you have too much or too little control
- “Failed to trim, aborting calculation” – the simulation couldn’t find an x-intercept that trimmed the aeroplane. This is common in tailless designs. Either search a wider range of control inputs, change your static margin, or redesign your aeroplane. However, the initial C_m vs alpha sanity check should avoid this error.
- “Could not interpolate at X CL” – the wing concerned (or some section of it) is most likely stalled. This error should not occur at lower angles of attack. If it does, the twist on your wing may be too extreme.
- “Reynolds number XXX out of range” – the aircraft is flying too fast or too slow for the aerofoil data you provided. Go back to the direct analysis page, and broaden your polar range.

Interpreting Your Stability Results, and Getting Oddly-Satisfying Satisfying GIFs

Animations

Immediately on completing the calculations, a second pop out window labelled “Stability” will appear:

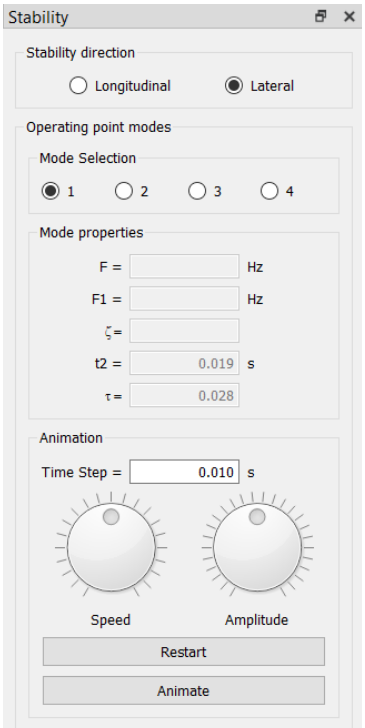


Figure 26 - Stability Window

To run in approximately real time, twist the speed button all the way clockwise, and twist the starting amplitude all the way clockwise for maximum visual effect. Click the "Restart" and "Animate" buttons to run the animation, and you should see your aeroplane go through some apparently random gyrations. Click through the Mode Selection radio buttons for the longitudinal and lateral modes to see all the different oscillation modes.

To change the elevator setting, go to the drop-down menu at the top next to the analysis name, and select the control variable angle you want. The flight stats (airspeed, CL/CD, etc.) will update on the bottom right.

Graphs

While looking at the modes in the stability window and the graphical representation is useful, it doesn't give a very cohesive picture of the aircraft's characteristics. For this, we need the graphs. Click through to the graphs window, then double click on each graph to open up the graph settings window. The stability variables are near the bottom of the list:

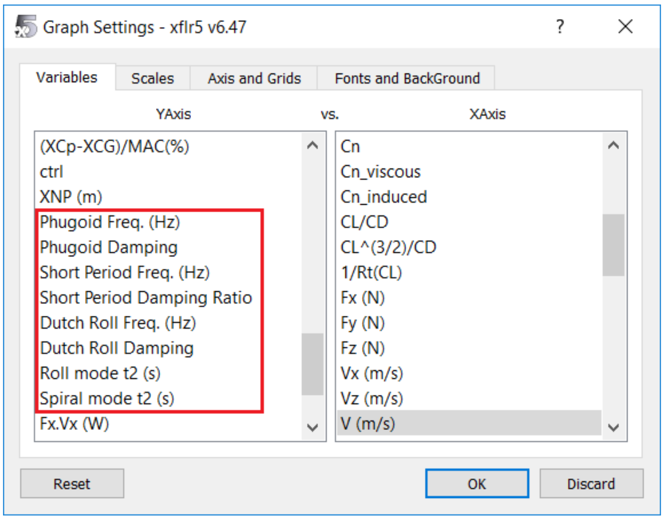


Figure 27 - Stability related variables in the graph settings window

I usually find it most helpful to plot the modes against airspeed rather than angle of attack or some other variable, since as a pilot airspeed is your primary sense of where in the performance curve the aircraft is sitting. In extreme cases (such as Prandtl flying wings) a never-exceed speed is defined by the reducing stability of the aeroplane. Another useful variable to plot is alpha vs ctrl, as that gives you an idea of the sensitivity of the aeroplane and the elevator effectiveness – if 1 degree of elevator deflection will move the aeroplane's angle of attack 5 degrees, this is probably too much!

But what do they all mean?

Short Period – Longitudinal Mode 1 & 2

This is the instantaneous pitch disturbance response. When the aircraft is perturbed in pitch – for instance by turbulence, by a sudden elevator impulse, or by payload release – this indicates how fast the aircraft will return to its trim angle of attack. For this, you want a damping constant of between roughly 0.8 and 1.2. The closer to 1, the better. Frequency should also be several Hz. This mode is best seen as a function of static margin and horizontal tail volume.

Phugoid Modes – Longitudinal Mode 3 & 4

When left to fly straight and level, most aircraft tend to develop a longer period pitching motion. This consists of the nose dropping, the aircraft building up speed causing the nose to rise, which causes the airspeed to fall and the nose to drop again. This mode is generally long period (of the order 0.2-0.1Hz), and usually poorly damped (<0.1) for conventional aircraft. Due to the slow nature of the mode however the pilot can usually easily keep this tendency under control, often without realising. Slightly negative damping is also acceptable providing it stays greater than roughly -0.05 and the period remains long.

Roll Mode – Lateral Mode 1

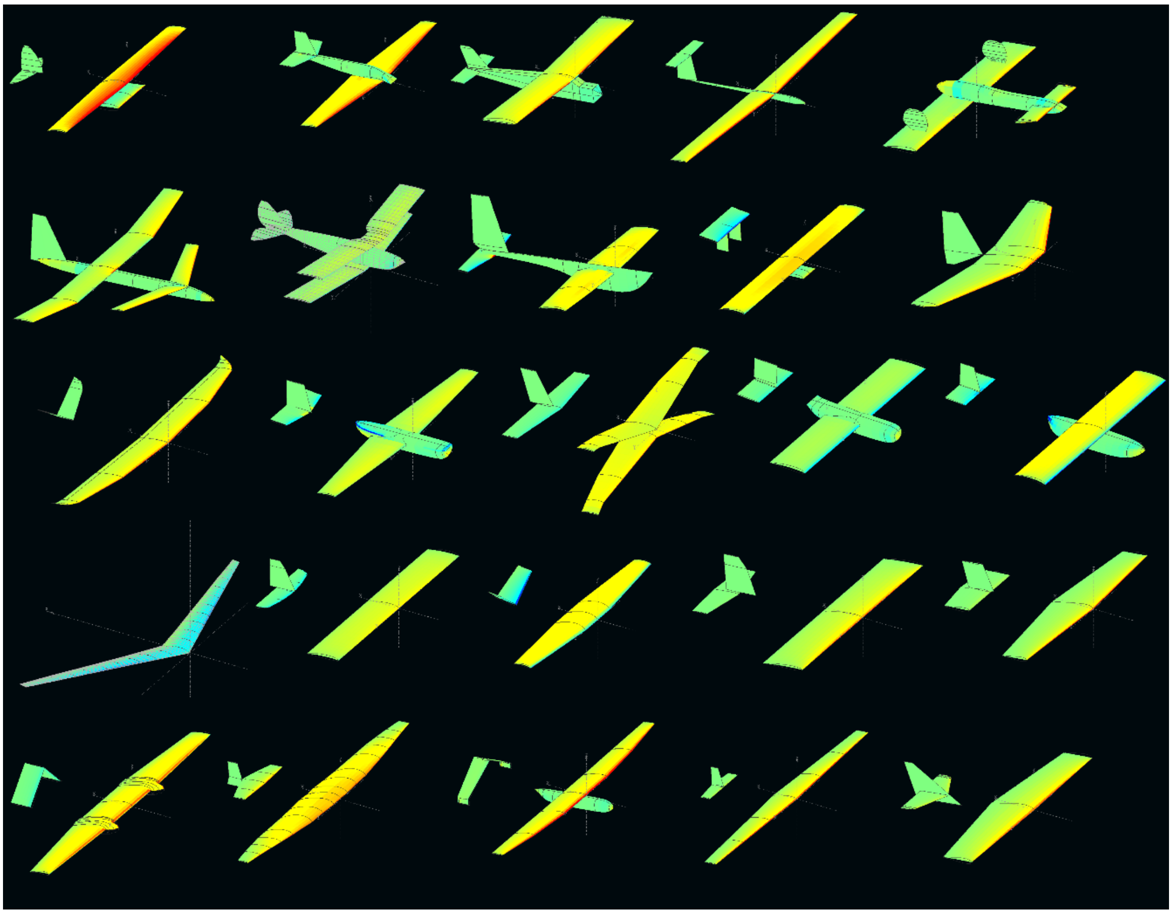
This mode is analogous to the short period mode, describing how fast rolling motion is damped out. Conventional aeroplanes have this mode heavily damped due to their long span wings, however low aspect ratio aircraft such as deltas tend to have poor roll damping, and hence large fins.

Dutch Roll – Lateral mode 2 & 3

Second to the short period, this is the most important mode of the aeroplane as it defines the directional stability. When the aeroplane is perturbed in yaw, it is desirable that it corrects itself rapidly and with high damping. Due to various other affects – particularly dihedral, wing sweep and vertical cg positioning – it is common for the yaw response to be coupled to a rolling motion, resulting in a "Dutch roll". It is possible to excite this mode with concerted rudder and sometimes aileron inputs – when well damped this isn't a problem, however with a low damping constant or in the hands of an inexperienced pilot, this can (and has been) catastrophic, often resulting in fin failure, complete loss of directional stability, and subsequent aircraft breakup. Frequencies are best kept >0.8Hz and damping constants greater than 0.25, usually in the range 0.3-0.8.

Spiral Mode – Lateral Mode 4

Similar to the phugoid mode, when left to fly hands off an aircraft will slowly wind itself into a spiral dive – usually halving radius every 3-10 seconds or so. This arises through a combination of dihedral, different airspeeds over opposite wing tips, and directional stability. Like the phugoid mode, this is subconsciously controlled by the pilot, so providing the doubling time is longer than a few seconds, this isn't a problem. It is worth noting that a long spiral doubling time and well damped Dutch Roll are mutually exclusive characteristics, so focus on achieving a good Dutch Roll first, and compromise on spiral mode second. Additionally, doubling times tend to increase with increasing airspeed, meaning the aircraft actually tends towards a constant turn radius as the mode fully develops, assuming overspeed limits aren't reached (in which case your turn radius will be zero. Like your altitude.)



Section 6: Exporting Data from XFLR5

Aerofoil Performance Curves

Aerofoil curves and associated data can be exported as .csv (comma-separated variable) files. These can be opened in notepad or excel. To export, from the XFOIL direct analysis screen go polar -> current polar -> export to export the selected polar. If you wish to export every polar in the file, go Polars -> export all -> text format.

A common error is a cryptic "could not export polar". This is because the foil file name has an illegal character in it (usually a "/"). Rename the foil and try again.

Aerofoil Operation Points

Everything that varies by chord along the aerofoil, such as pressure coefficients. Go Operating Points -> Current -> Export.

Aerofoil Geometry

This is the most commonly used function, and the first step in creating a Solidworks model. Go to Foil -> Current Foil -> Export. This will generate you a Selig format '.dat' file, that can be opened in notepad. The left column is the normalised x-coordinates of the foil, and the right column is the normalised y-position. Points start at the trailing edge, then run either clockwise or anticlockwise around the foil.

Aircraft Performance curves

From the aircraft design window, go to Polars -> Current Polar -> Export Results. This will create a .csv file of all the parameters calculated. This can be opened in Excel or in notepad.

Aircraft Operation Points

This is most commonly used when you want detailed data about the aircraft at a particular point in flight. We most commonly use it for pressure distribution information so that we can determine optimal modifications to planform or twist via a python script.

To generate the csv file, go to OpPoint -> Current OpPoint -> Export.

Aircraft Geometry

Aircraft geometry can be exported either in XML format to be re-imported into a different XFLR5 project, in a format AVL (Athena Vortex Lattice, a similar but much older program with a command line interface) can read, or as an STL file (if you want to print it, I guess?). Unfortunately, what you can't do is export directly into Solidworks.

Solidworks

Once you've got your aircraft designed in XFLR, you probably want to build it. If it's a simple aeroplane (such as Gertie) an XFLR model is probably all you need. However, for more complex aircraft, you'll need some way of making an accurate Solidworks model. Unfortunately, it's quite a manual process.

Exporting the Aerofoil

This is the only data you will export directly from XFLR. The most important thing to check is that your foil has a gap at the trailing edge. If you import into Solidworks with a gap of zero, it will throw a fit and refuse to import the curve (usually "Curve is self-intersecting"). Additionally, making a perfectly pointed trailing edge is practically impossible – particularly with foam cutting – so it is also desirable from a manufacturing perspective.

To set a gap, go to Design -> Set TE gap. In the window that opens up, set the blending distance to 70 or 80%. Set the foil gap so that on your intended wing chord it'll be approximately 1-2mm. If in doubt, 0.5% is a good value.

Now, go to Foil -> Current Foil -> Export. This will generate you a Selig format '.dat' file, that can be opened in notepad. The left column is the normalised x-coordinates of the foil, and the right column is the normalised y-position. Points start at the trailing edge, then run either clockwise or anticlockwise around the foil.

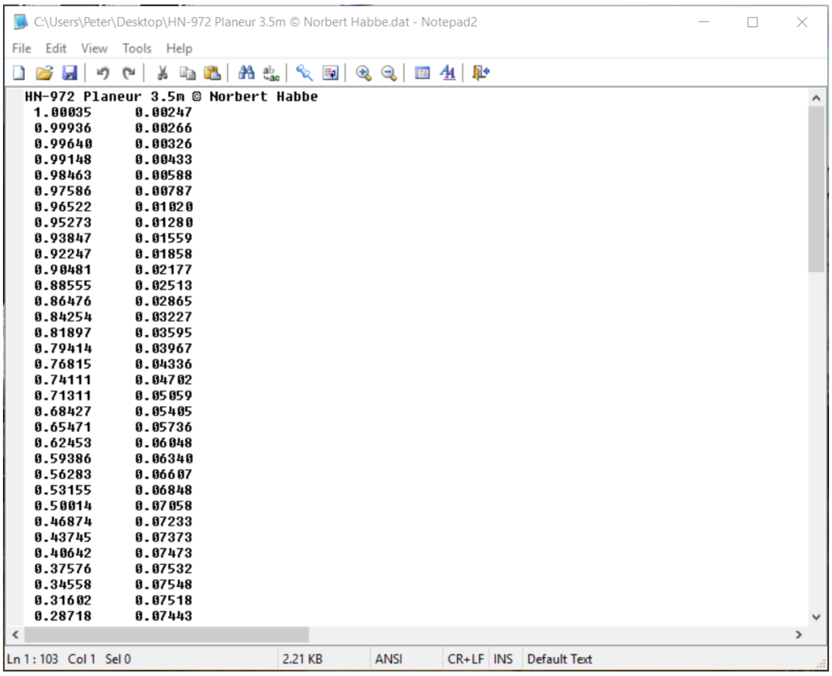


Figure 28 - typical exported foil geometry in notepad

Making the file Solidworks-readable

Open excel, and copy-paste into the first cell. This will give you a single column of text (though it may spill over visually). Selecting this column, go to Data -> Text to Columns. A dialog box will open up. Click the "delimited" radio button, and click next.

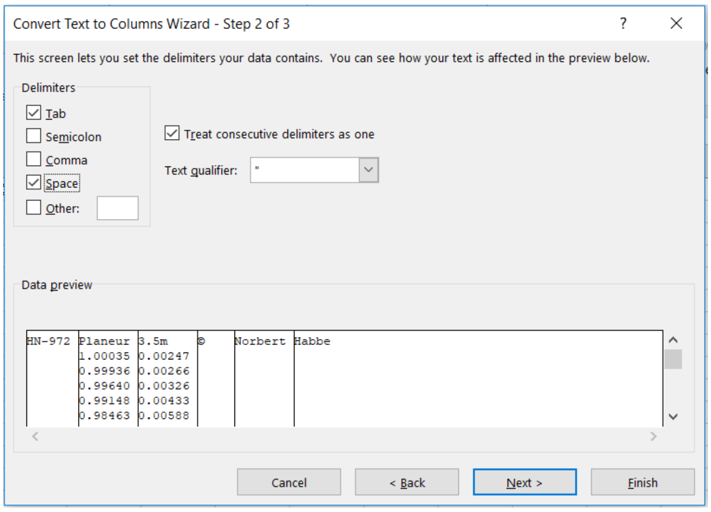
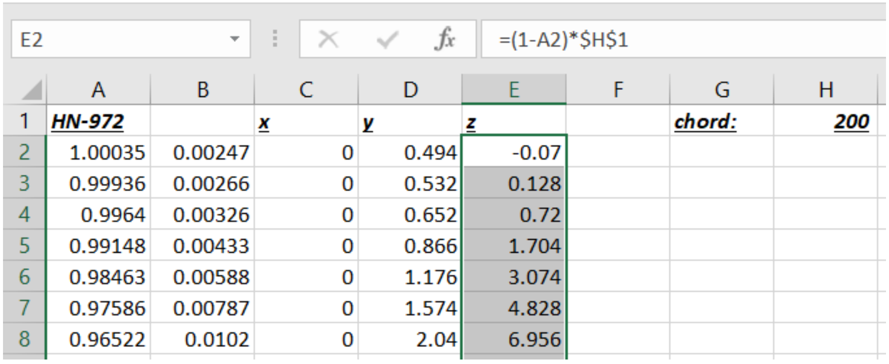


Figure 29 - Second "Text to Columns" window

In the next window, set the delimiter to “Space” and make sure the “Treat consecutive delimiters as one” box is still ticked. Click finish, and your data will magic itself into two columns. The title messes things up a bit, so move things around until you’re happy.

The next stage is to re-scale the aerofoil to whatever chord you’d set (in millimetres!), and make the coordinate system the same as Solidworks. This means the x-column is set to zero, the y-column is the second imported column, and the z column is the first imported column. Additionally, I usually flip the chord coordinate (“z” in Solidworks cords) so the aerofoil nose faces the front plane when imported.



E2 =(1-A2)*H1

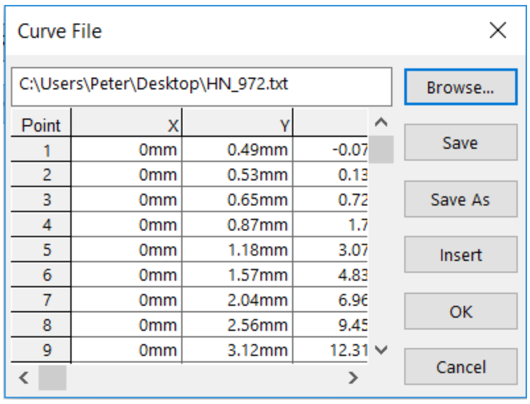
	A	B	C	D	E	F	G	H
1	HN-972		x	y	z		chord:	200
2	1.00035	0.00247	0	0.494	-0.07			
3	0.99936	0.00266	0	0.532	0.128			
4	0.9964	0.00326	0	0.652	0.72			
5	0.99148	0.00433	0	0.866	1.704			
6	0.98463	0.00588	0	1.176	3.074			
7	0.97586	0.00787	0	1.574	4.828			
8	0.96522	0.0102	0	2.04	6.956			

Figure 30 - Typical re-scaling of aerofoil for Solidworks import. Note the equation in the z column.

Finally, copy the x/y/z cell values out (NOT including the column titles!), and paste them into a notepad file. Save it as a .txt file this time, preferably somewhere near your SolidWorks model directory.

Importing the Re-scaled File into SolidWorks

Start a new part in SolidWorks. Ensure the file units are set to millimetres. To import the file, go to Insert -> Curve -> Curve through XYZ points. This will bring up a dialog box with an empty table. Click “Browse” and change the file type from curves to text files, and you should be able to see your file. Open it, and the columns in the dialog box should fill in. You may see a yellow outline of your foil appear in the model.



Point	X	Y	
1	0mm	0.49mm	-0.07
2	0mm	0.53mm	0.13
3	0mm	0.65mm	0.72
4	0mm	0.87mm	1.7
5	0mm	1.18mm	3.07
6	0mm	1.57mm	4.83
7	0mm	2.04mm	6.96
8	0mm	2.56mm	9.45
9	0mm	3.12mm	12.31

Figure 31 - Successfully imported coordinates. Note the automatically assigned units of millimetres.

Click okay, and your foil should appear! You may need to re-centre the view to find it. If everything has been done right, it should be parallel to the right plane, facing forwards, with the trailing edge on the origin. Name the curve something sensible so you don’t lose track of it.

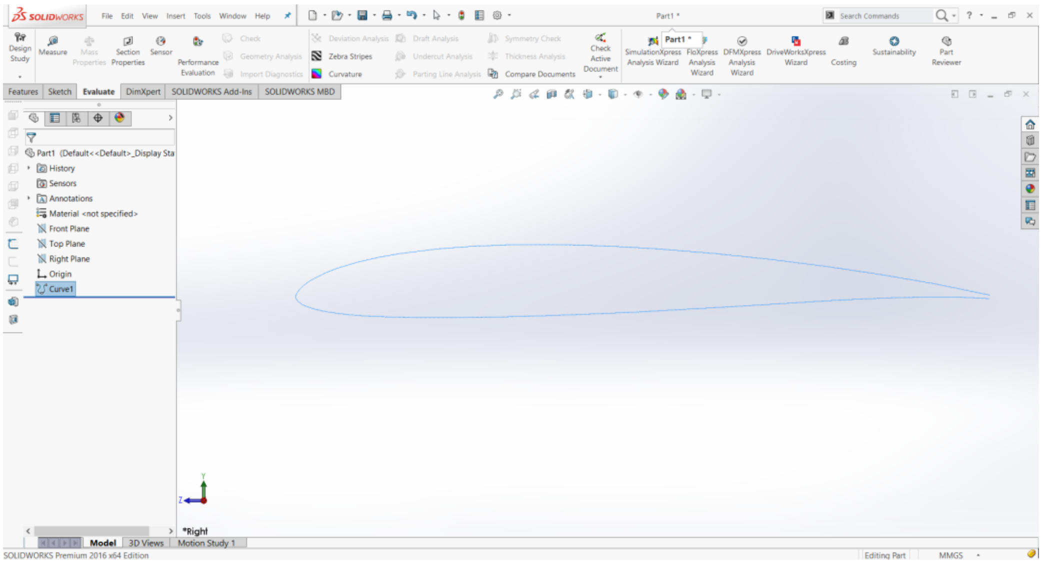


Figure 32 - Foil successfully imported as a curve to Solidworks

Doing Something Useful with It

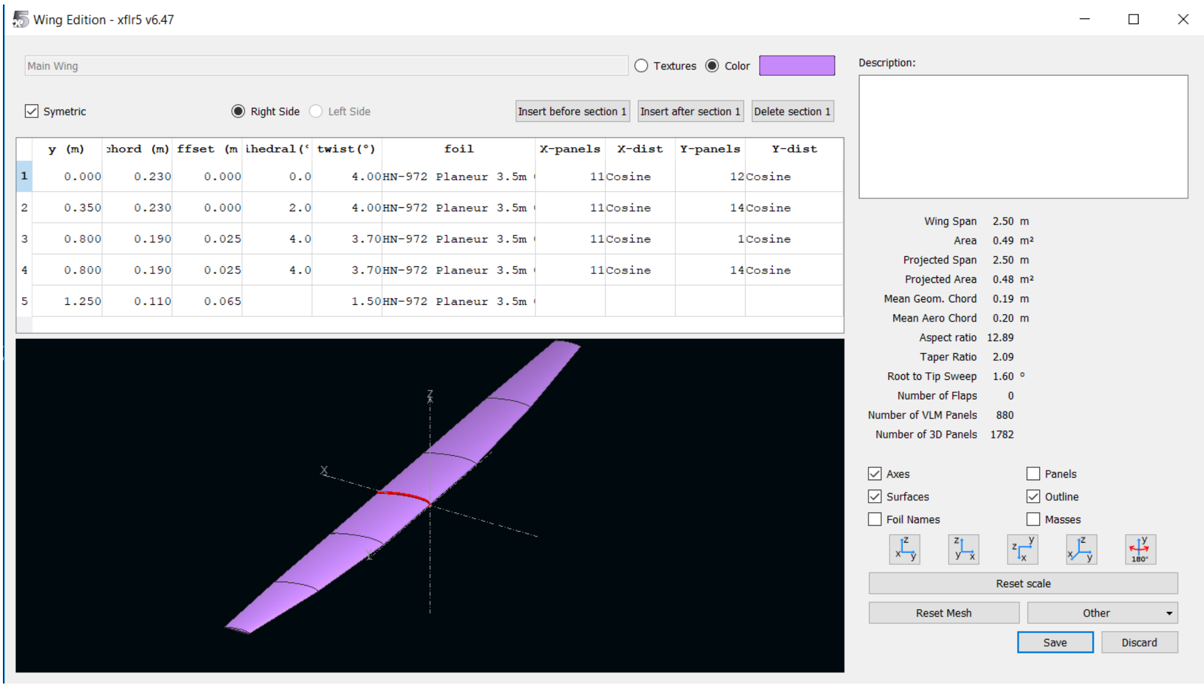


Figure 33 - an example wing geometry as specified in XFLR. Keep this handy, it gives you all the dimensions you need.

The next step is usually to convert the curve into a sketch, with the aim of eventually lofting a wing out of it. To do this, create a plane parallel to the Right Plane at the desired location for the foil (this is the span position you set in the XLFR aircraft geometry window), and name it something useful (I usually for '500mm plane' or similar). Next, create a sketch on that plane, then click "Convert Entities". Select the foil curve, and complete the dialog. A solid black sketch line should appear.

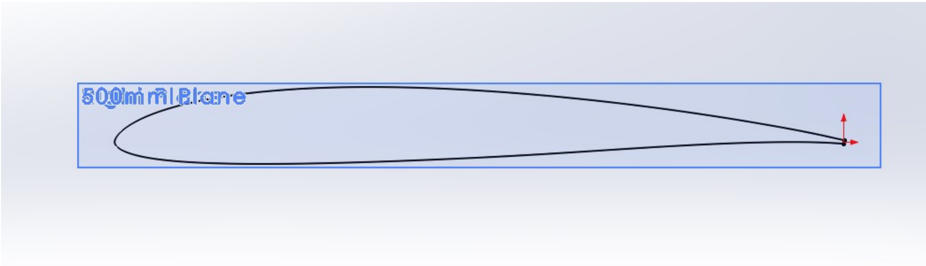


Figure 34 - Curve geometry converted to a sketch

Insert a line across the trailing edge to close up the sketch.

If you have a basic rectangular wing with no twist, dihedral or sweep, you can now repeat this for the wing root and tip, then create a loft between them.

If your wing is not a simple rectangle, read on.

Creating Complex Wing Geometries

The first step is to set a twist to your wing. To do this, you will first need to unlink the sketch from the defining curve. Select the sketch curve, and delete the little box-shaped relation. DO NOT TOUCH THE CURVE IT WILL RE-SCALE.

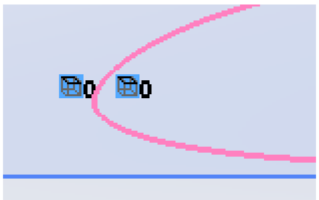


Figure 35 - The little box of doom

Immediately next, add a dimension on that trailing edge line. If the line is angled, make sure the dimension is also angled. This will prevent you (and Solidworks) from accidentally re-scaling the aerofoil. You should now be able to happily drag the foil around the screen without anything bad happening. Create a vertical construction line, and set it to be tangential to the leading edge of the aerofoil. Use this to define the leading edge offset you specified in XFLR. Next, create a horizontal line from the midpoint of your leading edge to your offset line – this will be the aerofoil chord line. Additionally, set an angle between the chord line and the trailing edge line – this ensures the aerofoil always remains at the same angle relative to the chord line. Finally, set either the midpoint or the quarter-chord point of the chord line to be horizontal to the origin (or with whatever vertical offset you desire. Your aerofoil should now look something like Figure 36.

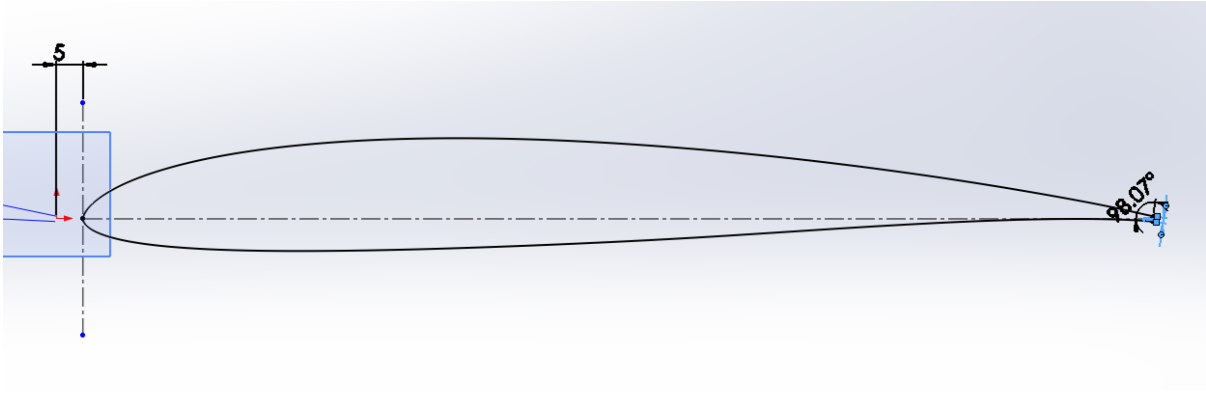


Figure 36 - Aerofoil with nose and chord line set. Note that it is fully defined again.

Delete the horizontal relation of the chord line, and drop an angled line from the pivot point you specified. Set the incidence angle from XFLR, then set the angled line to be horizontal. Your wing section will now magically rotate to the correct angle!

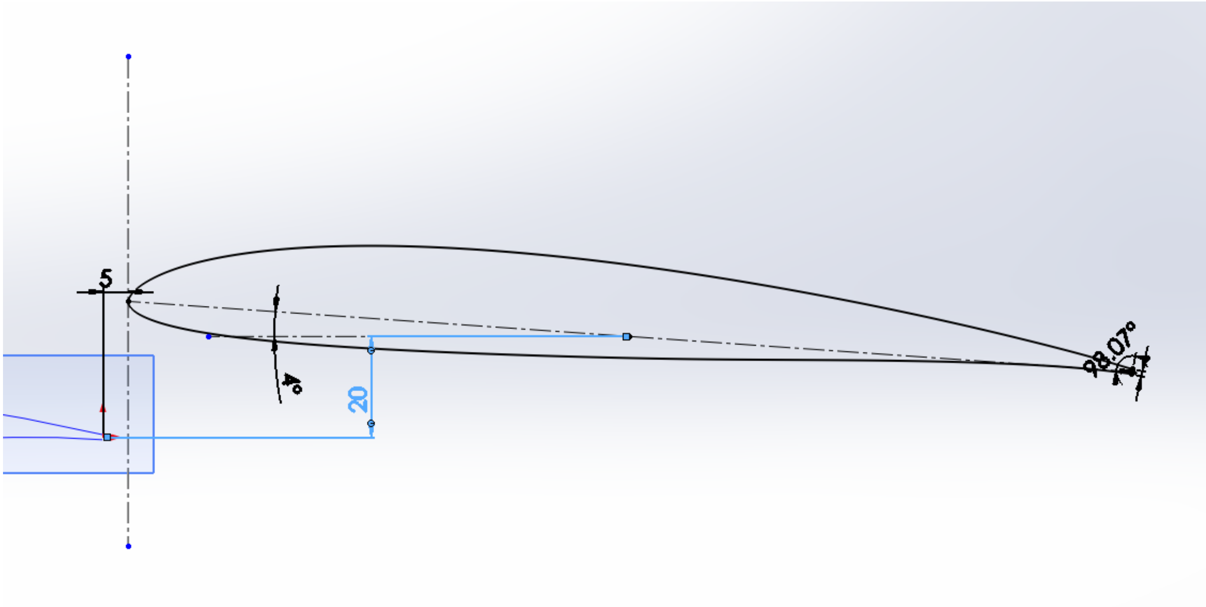


Figure 37 - Fully translated and rotated aerofoil, ready to be used in lofting

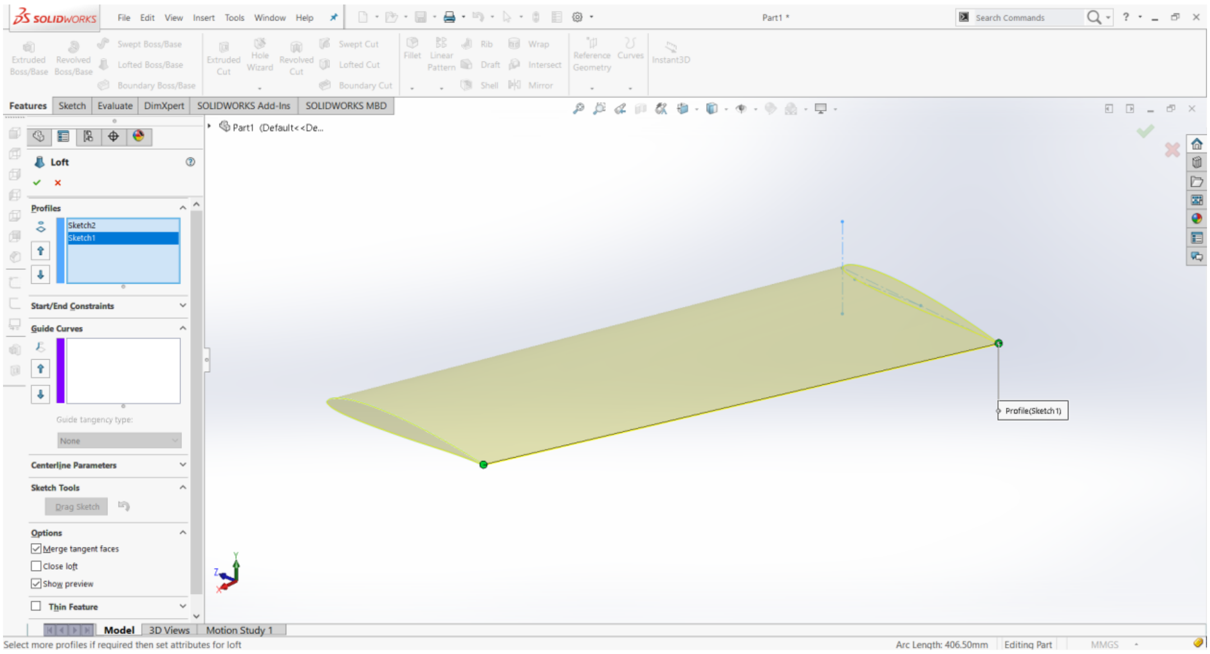


Figure 38 - Wing section being lofted from two aerofoils. Complex wing geometries can be made up of either linear sections, or complex curves using the foils as intermediate profiles. If you're foam cutting, keep it linear.

Provided each section is linear, most wing planforms can be hot wire cut. Complex interpolated curves can be built within reason from built-up balsa structures (such as Paul V2 or Spitfire wings). The next stage is to slice up the wing model to carve out ailerons, servo pockets, wing spars, ribs etc.

A Brief Word about Master Models

Most of the Solidworks aeroplanes we build are based off so-called "master model" geometries. These work by creating an overall geometry – usually the wing or tail – and then splitting parts off it (such as ailerons or most usefully, dozens of wing ribs) via "Insert Feature -> Split" to create linked sub-parts that can then be more easily edited, have other parts added, and then re-assembled in the assembly. Since these parts are linked, any changes in the master model (such as a change in twist) will roll forwards into the child parts, automatically updating them. Being Solidworks it's never quite that smooth, but it will save you a ton of CAD time, particularly if you have an aeroplane made up of nearly 50 wing ribs.

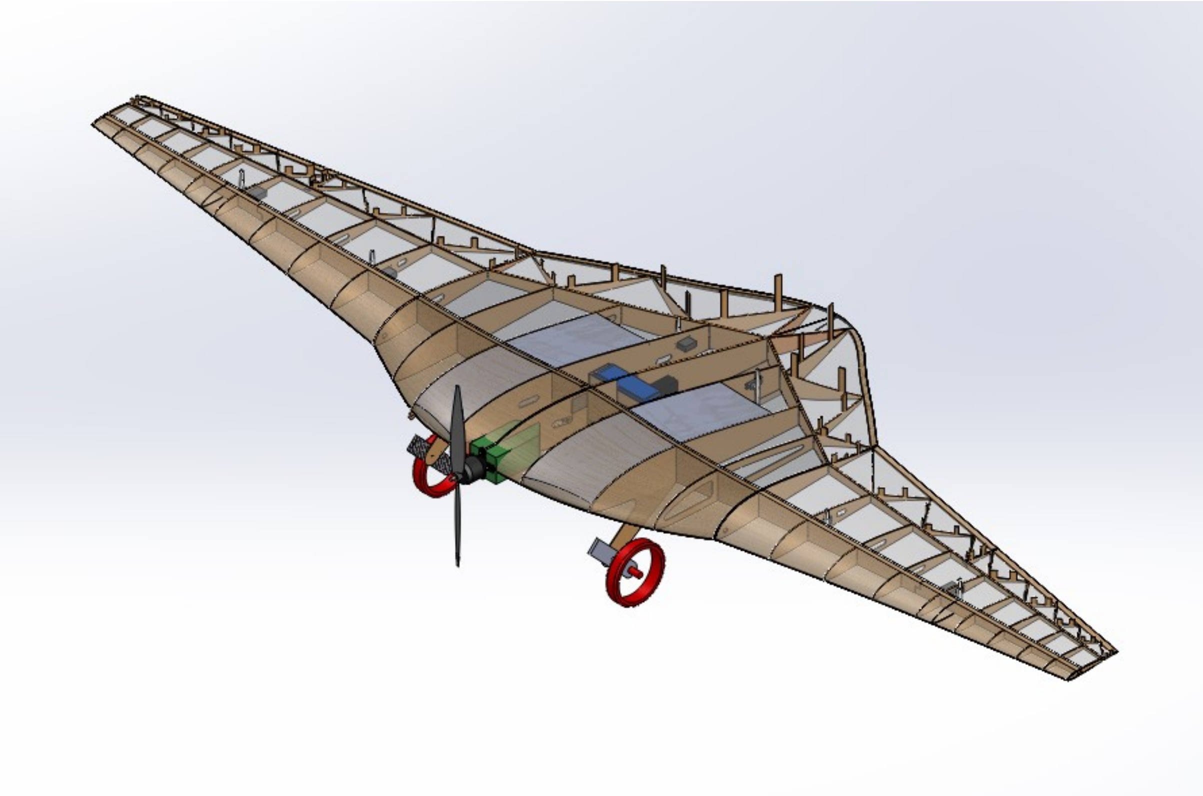


Figure 39 - Montgomery flying wing. This aeroplane design would have been even more hellish without the use of master models!

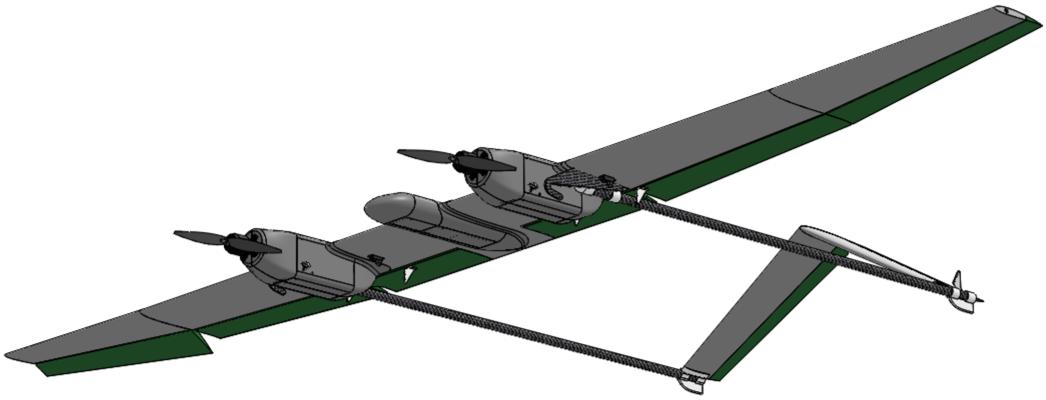


Figure 40 - IMechE 2020 Design. This is a much more standard foam-fibreglass construction, using master modelling for items like control surface and spar cut-outs. The fibreglass moulded pods also use master modelling to accurately follow the wing contour and generate 3D printed moulds.