Richard Hood in Pitts Model 12 ZK-PTS. Gavin Conroy captured the image at Warbirds Over Wanaka 2014.

Aerobatic Sequence Design

Flying a display ranges from a top level competition aerobatic routine all the way back to a quick beat-up in front of your friends, or a zappy low-level impromptu hoon around (though this might only be something that gyro pilots your Editor associates with get up to). Wherever you are on this spectrum, there are some very simple considerations (legality notwithstanding) to keep top of mind in order to stay safe.

Resident KiwiFlyer Test Pilot and Aerobatic Champion Grant Benns has had a break over recent issues. Prior to that he wrote an introductory article on designing aerobatic sequences (available for free download online in Issue 54).

To recap Grant's advice via the sub-headings from that article:

1. Know each figure you intend to fly and be confident you can fly it
2. Know the entry speed range for each figure
3. Know how much height you will lose (or gain) with each figure
4. Define your height limits
5. Place figures in order of exit speed achieved to entry speed required
6. Start high, finish low
7. Place energy sappers early
8. Remember to turn around
9. Consider the horizontal distance required and available

And when you contemplate flying the sequence:

10. Create height/speed 'gates'
11. Consider 'outs' or escapes
12. Don't ad-lib

Grant continues here with a presentation of sequence design for competition aerobatics where a variety of rules must be accounted for to keep the playing field level and judging fair. The modern way to design a compliant sequence is (of course…) with an App (and in the next issue we'll explain how to program the drone to fly it for you… don't worry, kidding ☺). Grant writes:

Last year I wrote an article on sequence design, where considerations about the use and placement of manoeuvres in a sequence was discussed.

A poorly designed aerobatic sequence will, at-best, be a struggle to cleanly fly and, at-worst, be outright dangerous. The aim of competition aerobatics is to win, so why start on the back foot with a bad sequence?

Free Sequence Origins

Unfortunately, sometimes you have to work with what you have got, such as the prescribed 'Known' sequence, in which all competitors must fly the same sequence of manoeuvres in a category. Generally, these sequences have been designed by seasoned and experienced senior competitors, quite often in a small group with an appropriate name like 'Sequence Design Committee'. A proposed sequence will be tested and peer reviewed before being released to the masses. In New Zealand, we generally adopt the Known sequences proposed by either the International Aerobatic Club (funnily enough, an American organisation) or the truly global organisation CIVA, after a process of peer review that starts along the lines of 'whaddaya think?'!

Design Rules

More challenging for competitors is to freely design their own sequence, which can seem somewhat daunting at first, given the rules and regulations to which the sequences must abide by. As with other forms of motorsport, the rules are there to ensure the playing field is level and competitors know the boundaries in which they must operate - in the case of competition aerobatics this is to ensure the different categories from Primary to Unlimited have limits of difficulty that reflect the supposed skills of the pilots flying them, the capabilities of the typical aircraft that may be expected to compete, and suitable safety margins. As you would expect, the lower categories have more simple manoeuvres flown at higher altitudes, while the higher categories have progressively more complex manoeuvres flown to lower altitudes. For a newbie, there is an expectation that you start in the lower categories!

Category Differences

When confronted with designing a sequence for competition, you could be presented with a selection of manoeuvres you may not have actually flown, such as in a programme flown at competitions called the Free Known. In this programme, flown in the Intermediate, Advanced and Unlimited categories, competitors construct a sequence using a selection of five prescribed manoeuvres as well as some additional self-selected manoeuvres to link them nicely together. For the Recreational and Sports categories, you can freely select your manoeuvres however they must comply with the category rules in terms of difficulty (simplicity) and variation.

OpenAero

The rules that govern the selection of the manoeuvres are somewhat complex, however I would recommend reading them first before moving to the design stage using the online software that I will describe soon. Fortunately, in recent times, several clever IT people, also passionate about aerobatics, have developed an on-line software programme called OpenAero. This portal has the various rules for each category built-in - it knows the limits of difficulty and variety, and enables you to easily manipulate the

layout and substitute different manoeuvre, all while keeping a total of the overall difficulty score (called K).

The best news is it is free, a term that has ring to it for pilots! There are no pop-up adverts or suggestions for upgrades, and you can play around on it, whist saving and printing your results, to your heart's content.

Step by step

As a demo/tutorial, what follows is an intro into using OpenAero which, I hope, will demystify another aspect of this big scary thing called competition aerobatics (you can also use this programme for drawing up your Sunday/airshow routine too). I would recommend having this article sitting beside your computer keyboard.

Open OpenAero

First of all, you will need to be on-line (on the internet) to get the best out of OpenAero, and the programmers recommend using Google Chrome too - other web browsers can cause the odd glitch. Search for OpenAero and you should find https://openaero.net. When you open this website it will load OpenAero into your browser as an extension. Now, each time you open OpenAero on this computer, it will 'remember' you and any sequences you have been working on.

There is a really good 'help' section accessed off the Help tab at the top of the page, if you need to delve deeper.

You will want to 'save' your sequences, so it would pay to set up where you want to download your sequence file to - in Chrome this is done from *Preferences* in the Chrome menu (top left corner), then select *Advanced* and look for *Downloads*. You can now *Change* the place in your computer that you wish to save your completed sequences.

Sequence Info

When you first open OpenAero you will be on a screen full of blanks spaces titled *Sequence Info* and *Figure Editor* tabs in orange. The start/default tab is *Sequence Info.* This is where you can set up personal data, such as name, aircraft type and registration, which will personalise the completed sequence sheets for use by the judges.

You need to select the *Class* (Power or Glider) and the *Rules* - for flying in New Zealand competitions select NZAC (NZ Aerobatic Club). You now select the *Category* you wish to fly, which will determine the complexity and variation rules - for this article we will use *Sports*. You now need to select a *Programme* - in this category your only choice is *Free*. You are now all set to create your sequence.

Figure Editor

By clicking on the *Figure Editor* tab you are now in the side of the programme that enables you to build your chosen programme's sequence of figures (manoeuvres).

You will notice an *Alerts* box in red/orange below the *Add Figure* area. This, effectively, represents the Rules, telling you what you are missing to complete the sequence in accordance with the underlying rules. The *Family* describes the different base manoeuvres - for example, Family 1 are lines with roll/snap or spin elements, Family 7 are loops, Family 8 are cuban and humpty-bumps and so on.

To the right of the *Add Figure* box is a running total of *Total K*, or difficulty factor, with the maximum K in brackets below, as a reminder/target. As you add figures to your sequence, the Total K increases by the amount of each new figure. When you have finished building the sequence, the *Total K* must be no more than the maximum allowable K - the *Alerts* box will tell you if you have exceeded it.

Time to add figures

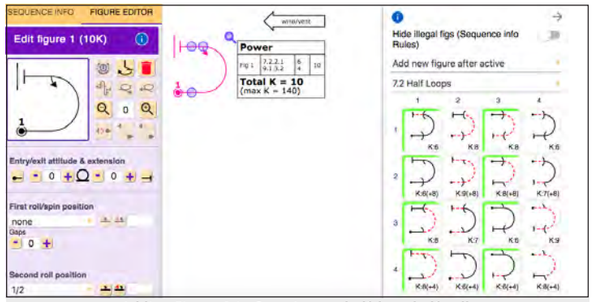
Clicking anywhere in the Add figure box will bring up a menu of allowable figures on the right side of the screen, starting with *1.1 Single Lines* - this is a Family 1 figure that you must include, somewhere in your sequence. However, just because it is numbered Family 1 doesn't mean you have to use it first - you may elect to start with something different, like a Family 8 loop.

At all times remember that it is in your interests to select manoeuvres you like, your plane likes and you are good at - this is your chance to design a friendly sequence which can impress the judges. So let's add a good starting manoeuvre - normally a start-high/fast manoeuvre, as this may be the only time you have speed and height to burn! How about a half-loop with a roll off the top?

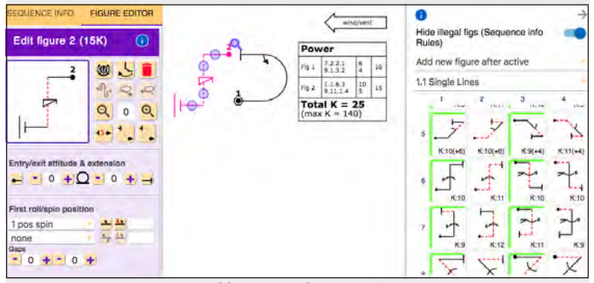
Figure 1

In the right-screen box, select *7.2 Half Loops*, which will bring up a selection of different half-loop combinations that are able to be used. Black solid lines are the positive-G parts of a figure, while dashed-red lines are inverted-G portions. The half- and full-arcs across the main lines represent either a half-roll that must be completed for the figure to be flown correctly, or an optional roll that may be inserted in the figure.

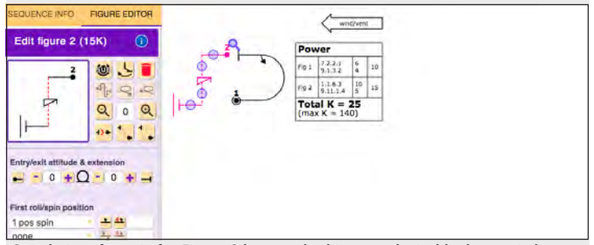
By clicking on the figure in column 1 of row 2 we select our desired half-loop/half-roll and it gets displayed in the main screen, complete with a summary of the elements of the figure in the adjacent *Total K* box. Because it is red, we can modify it further if we like, for example by making the roll 1 1/2 rolls instead of a half-roll. This is done in the *Edit Figure* box, where you will find an option called *Second Roll Position*. Click on the drop-down to change 1/2 to 1 1/2 and the figure updates, with increased K, to your new selection. Do you want to do a 1 1/2 roll in your Robin? Probably not, so let's change it back to a 1/2 roll!



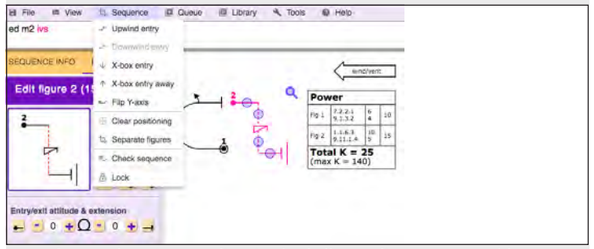
Adding Figure 1 in OpenAero, a half loop half roll.



Adding a spin for Figure 2.



Our choice of a spin for Figure 2 has resulted in an undesirable down-wind entry.



Convert the spin entry direction (and all preceding manoeuvres) here.

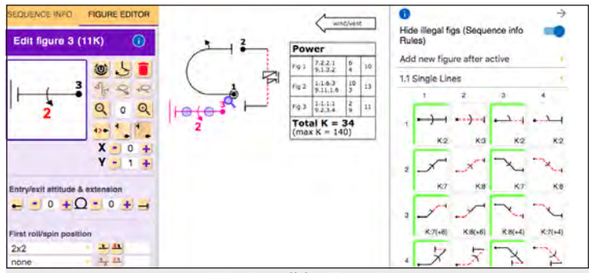
Figure 2

Time to add a second figure - we are high and slow, and we must have a spin (check the Alerts) so let's do that. A spin is created using a single line with a spin element, so we select *1.1 Single Lines* and search for an upright entry (black horizontal line), and inverted down line (the nose drops into a spin, with slightly negative G) and a solid black line to exit (upright = positive G). This will be found in column three, row six - don't ask me why it is so buried, considering it is the most used and most basic spin, but from this you can start to see the vast array of figure variations available to be flown. After selecting the base element - the line - we now must add the spin element, from the drop-down in *First roll/spin position* menu of the edit figure box. Click on 1, for 1 turn, and see how this is added to the figure, with the *Total K* increasing accordingly. Magic!

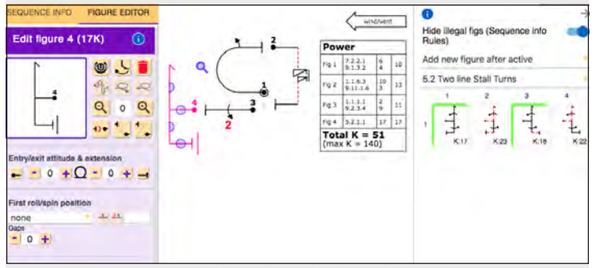
Wind... start direction

Above the Total K box is the wind arrow, an assumed wind direction. When your final sequence is saved and printed, there will be a form produced with the sequence shown flown in both assumed wind directions. The wind direction for a competition flight is set by the Contest Director, on the day of the comp, so you must have a form that the judges can use for either direction. When creating your sequence in OpenAero, the wind is always displayed right-to-left on the screen.

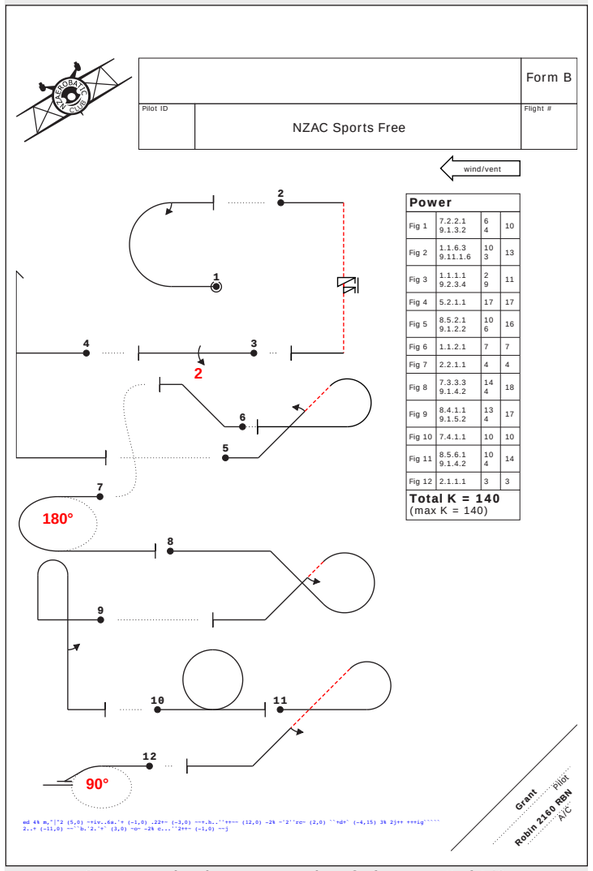
Spins aren't great to do 'down-wind' - they chew up a lot of box-space, which is only 1000m from side-to-side - so we could either place it somewhere else in the sequence (even start with it) or change the direction of our first manoeuvre so that the spin is flown into wind. The menu at the top of OpenAero has some other tabs, like File, View, Sequence, Queue and so on. By selecting *Sequence* we find an option for *Downwind Entry* - selecting this will change the entry direction of the first manoeuvre and therefore swap all the subsequent manoeuvres too. This can be switched back with the Upwind entry selection.



A 2 point roll for Figure 3.



And a stall turn for Figure 4.



Grant's completed sequence, ready to fly for a max K of 140.

At right: Doug Brooker performing in his MXS.

Changing the spin

I don't like the one-turn spin, as it has me exiting in the wrong direction for what I want to do next, so while the spin figure is still red I can change the spin into a 1 1/2 turn spin, which has a K due to being easier to more accurately recover. Really!

Figure 3

We come out of the spin low and fast, and will need to turn around to stay in the box. But we have a bit of room here to throw in an aileron roll - in fact, so much speed we can show how good we are by doing a 2-point roll. Select 1.1 Single Lines and row 1 column 1 has an upright straight a line, to which we add a roll by selecting the First roll drop down under the Edit Figure 3 purple box on the left. There are a multitude of roll options, but a 2-point roll is called 2/2, i.e. one complete roll split into two. Four-point rolls follow a similar convention - a half roll flown with a hesitation at each 90 degree point would be shown as 2/4, while full 4-point roll would be 4/4. Easy?

Now we can turn around.

Figure 4

We could do a variety of manoeuvres here, so long as we don't repeat anything we have already done - a rule called No Repetition (the *Alert* box will tell you if you do repeat something). A half-cuban? How about a stall turn? Yes, I like those and I am quite good at them! Stall turns are in the base family 5.2, which you can find on the right side of the screen and drop down. There is only one row, and columns 2 to 4 have either inverted starts or finishes or both - we don't want to do that, so select column one, a vanilla stall turn. You will see small arcs through the up and down lines, representing places you may insert optional roles, but let's not… this is only Sports and a slightly underpowered Robin. Clicking on column 1 selects the figure to the main screen, updating the Total K (to 51…only 89 K to go).

Layout

At this stage, you may want to spread our three selected figures out a bit, to make it easier to read. The finished sequence needs to fit on the page nicely, in a flow or manner that is easy to ready in the heat of the actual flight. OpenAero has a range of buttons that allows you to manipulate the layout - scaling, shrinking and stretching, linking etc. Clicking-and-dragging the figure you want to move is the easiest way to move figures around - a small dotted line gets drawn between the selected figure and the previous figure. Hovering your pointer over the various buttons in the *Edit Figure* box will allow you to explore the other options. The blue circles in a highlighted figure are also points you can click-and-drag to change the length of the various lines of a figure. Also, in the *Figure Editor* box below the *First Roll/Second Roll* boxes you will find Gaps boxes, which have a similar effect.

With a bit of time and artistic license, the basic sequence drawn by the system can be changed into something much more easy to follow, by the pilot and the judges. An easier-to-read form may even improve your score…

The final result

Once you have finished inserting all the figures required by the rules, without exceeding the K limits, you will see no messages in the Alerts box. Hopefully, with great skill, you will also be at the maximum allowable K - this will ensure you have the best chance to maximise your score, as the total score for the sequence you fly is the individual score for each figure (a score of between 0 and 10) multiplied by the K (difficulty factor). For Sports, the theoretical maximum is therefore 1400 points, being 140 (total maximum K) x 10 (perfection!). If you think about this some more, you may realise that it is best to spread the K reasonably evenly across your chosen figures, so that getting a bad score on a high-K figure doesn't drag down your total score. In Sports, the maximum number of figures you may have in a sequence is 12 so it would not be sensible to fly just two incredibly complex figures of 70K each, with a high chance of scoring poorly in either, when you could fly 12 figures with an average closer to 12k each. Alas, it is practically impossible to achieve this, but it is still worthwhile making an attempt to both get to 11 or 12 figures AND spread the K evenly.

Save/Print

Click on the OpenAero *File* drop-down and select *Save Sequence*. This will open a *Save File* box, reminding you how to change where Chrome will save your file.

If you wish to print your forms, you have variety of options and formats, also found on the File drop-down menu, at the bottom. Click on *Print/save Forms* to open the dialog box.

My attempt

So, continuing on from the first four figures described above, I have completed a Free sequence that complies with the rules for the 2019 NZAC Sports rules. What do you think? Is it flyable? I think so, although if I flew it in a Robin or Cessna 152A I would plan on taking a break after figure 5 and probably after figure 9 too. Remember, 'breaks' or interruptions, used to climb higher and regain energy before recommencing the sequence, are 'cheap' - the penalty is only 10 points for each break in Sports, so two breaks will only penalise you by 20 points out of a total of 1400 potential points. Given you are more likely to fly the subsequent figures following a break with more energy that comes from the regaining your star height, and thus score better, it is a highly recommended strategy to take planned breaks. Of-course, an aircraft such as an RV6/7/8, Pitts or G202 should eat this sequence without stopping, although maybe not in a winning way - many a well-flown lesser aircraft has beaten high-performance aircraft over the years.

You can do it too.

Grant Benns