Doug Brooker during an airshow performance in his MXS

Aerobatic Sequence Design Part 1

Given the importance of energy management during an aerobatic routine, not to mention safety, a wise pilot will follow a well-considered sequence of figures which include entry gates and escape options. Grant Benns explains:

According to the Oxford English dictionary, a 'sequence' (when used as a noun) means:

1. A particular order in which related things follow each other.

2. A set of related events, movements, or items that follow each other in a particular order.

In the world of competition aerobatics, the NZ Aerobatic Club and others define a sequence as 'a grouping of aerobatic figures which constitutes one flight programme.'

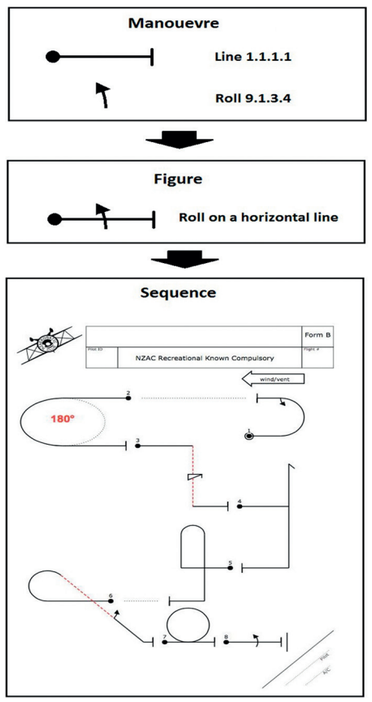
There is actually a hierarchy of definitions which fully describe the sequences flown in the competition arena, and this is worth briefly explaining before we get back to looking at sequences.

Manoeuvres, figures and sequences

The most basic component in aerobatic nomenclature is the manoeuvre, defined as 'any one of the basic aerobatic movements'. Basic aerobatic movements range from a straight-and-level line, to a loop, roll and cuban, and then on to more complex but still singular 'movements' such as a stall turn, snap roll and spin. The definitive guide for 'basic aerobatic movements' is the Aresti catalog of aerobatic manoeuvres, which I discussed in an earlier article. Each singular movement is issued with one catalog number, for example a straight wings-level line has the catalog number 1.1.1.1 and a half-loop is 7.2.1.1. An aileron roll is another basic movement, allocated the number 9.2.1.1.

A figure is 'an individual component of an aerobatic sequence, which may contain one or more manoeuvres in combination'. So, a figure can be just one basic manoeuvre /movement, or a combination of manoeuvres.

Using the above examples, if we



combine a line manoeuvre with a roll manoeuvre, we get a figure that represents an upright, level-flight aileron roll.

If we combine the half loop manoeuvre with a half roll manoeuvre we get a 'roll-off-the-top' figure.

So, to put all of the above waffle into simple terms, a sequence contains a group of figures, individually made up of a variety of manoeuvres, which follow each other in a particular order. Phew!

Planning your sequence

The degree of preparation of your aerobatic sequence will depend on what sort of aerobatic flight you are planning to do, presuming – hopefully – your aerobatic flight is planned. (I highly recommend you plan each aerobatic flight!)

If you are out for a lazy Sunday aerobatic sortie, you will possibly be flying a single figure/manoeuvre at a time, then reflecting on your amazing skills whilst you climb for the next manoeuvre. If you are flying in front of a crowd, you should have a sequence mapped out, to best show the audience how good you/your plane (strike out as applicable) is. For competition aerobatics, you will have an official sequence to fly, prescribed by the rules of the event and flown with precision in order to win – or that's the plan.

Regardless of which category you are in, it would be best to have in mind some consideration of the basics of sequence design, either on-the-go or in a more long-term, prepared manner.

Here are my thoughts on the basics of sequence design, which I will expand on following this summary:

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

Know each figure

Logically, you should know something about the figure you are proposing to fly. At the least, you should have sufficient knowledge and experience to understand the requirements of the figure (entry speeds, height loss/gain). This may sound like an odd statement, however in the higher categories of competition aerobatics you often get confronted with a figure you have never flown before, but whose individual elements you may have some experience with. Ideally, you will have learnt and practised the intended figure many times and can comfortably fly the figure, both within your capabilities and the aircraft's too.

Know the speeds

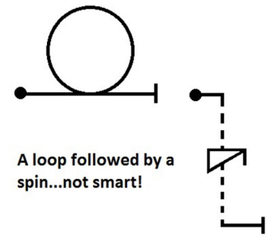
Most figures will have an ideal commencement speed for your aircraft type and possibly a range of entry speeds from which the figure will be 'flyable'. That's not to say commencing at other than the ideal entry speed will be pretty, or that it will put you in great shape for the next figure - it might well be a case of having to postpone the next figure and climb for more height – but knowing the range will help with your sequence design.

Know the height loss/gain

With practice and knowledge of the figure, you will have an idea of the height loss or gain that comes from executing the figure well - add or subtract a margin for nerves/wind/turbulence/miss-handling. Many figures will have a range of loss/gain based on the 'G' you pull, but there are trade-offs with altering this – you may get another 100-200 feet of extra height out of the 'roll-off-the-top' (above) by not pulling as hard, but you will then be quite slow, and maybe sink/stall coming out of it, or be too slow to contemplate the next figure. As mentioned in previous articles, aerobatics is a yo-yo game of energy transfer – kinetic (speed) to potential (height) and back again.

Define your height limits

Having a current aerobatic rating will define your lower height limit, this being 1500' AGL solo or 3000' AGL with a passenger. Note these numbers are AGL (above ground level) therefore you need to know the ground level below you. At many events the pilots will set QFE / zero feet on the altimeter prior to take-off for an aerobatic flight overhead the field. You may also have a display authorisation that



allows you to come lower. Either way, by knowing your potential height loss you can plan the positioning of figures in a sequence to ensure you stay above your minimum heights – with a margin.

Also consider anything that may define your upper limits of a sequence – this may be cloud-related but most often it may be airspace. If there is controlled airspace above you, into which you don't have a clearance, consider your height gain on figures like loops and stall-turns to ensure you don't get a 'please call the tower' message, or worse – a near miss with a big shiny jet.

Figure placement considering speed

A figure requiring a high speed for entry (e.g. a loop) should follow a figure that exits at a high speed (e.g. a stall turn). Equally, a low entry-speed figure (e.g. a spin) should follow a low exit-speed figure (anything that finishes after a climb, e.g. a roll-off-the-top).

Start high, finish low

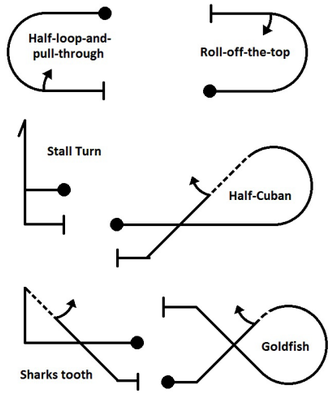
Unless your plane has after-burners, and/or a thrust-weight ratio greater than 1:1, gravity always wins. Therefore, it is generally best to start your sequence high, with the expectation of losing a bit of height through most figures – pulling 'G' creates drag and few light aircraft have the power to overcome the relentless pull of drag and gravity. Therefore, start as high as you can and plan you figures around this.

Place energy sappers early

Energy sappers are figures which don't allow you to yo-yo your height/energy loss into a near-equal gain. For example, you will generally finish a loop or a stall turn at the same height and speed as you started. The 'roll-off-the-top' half loop/half roll will have you losing speed but gaining height – energy conversion. However, any spin is a total energy sapper – you will potentially loose 500'-1000'

and come out with insufficient speed to regain the height loss back. Snap rolls are another example of an energy sapper – the exit speed, due to drag, is much lower than the entry speed. With this in mind, and following on from the previous paragraph, it is best to place your energy sappers (like a spin) towards the beginning of your sequence.

Remember to turn around



Generally, you will want to keep your sequence within a relatively confined space, for a number of reasons – the crowd or judges, terrain, airspace or other traffic in the vicinity. With this in mind, you will need to have a few turn-around figures in your repertoire to incorporate into your sequence. Sorry, you're flying aerobatics now so a plain 180 degree turn won't cut it (although it is a judge-able aerobatic figure) – how about a stall turn, half-cuban, half-loop/half-roll (up or down), half-square loop, 'goldfish', 'sharks-tooth' etc.? Each of these figures have many variations, and most are not energy-sappers. You can also use some of these figures to counter any cross-wind drift, whilst most will also give you a good look at your display area/box as you dive back down.

Horizontal distances

Some figures go a long way across the sky, such as a very slow/point-roll, while some go a long way up and/or down. Some do both, such as this

crazy thing called an 'N'. The horizontal distance required can always be changed by positioning the figure into wind or downwind, but what if, on the day, you have no wind or all-crosswind? Perhaps it might be best to leave that 200kt downwind 8 point-roll out of your sequence!

Create height/speed gates

Going right back to our first three points, by knowing your figure's speed and height requirements you will be able to assess throughout the sequence design likely 'gates' that you both need and will achieve. Through practice – at a higher altitude! – you will determine if the assumptions you made during the design of your sequence are valid, and if you need to make any adjustments to selected figures. Writing critical entry 'gates' at various points in your sequence, down on your sequence card provides you with numbers to hang your hat on when your brain is spinning and your eyes are bouncing – if the numbers you are seeing on your ASI or altimeter aren't enough, stop and climb. For example, you have determined that you need to start your sequence at 160kts and 3000' in order to get through it without stopping, all going well. You may also have put in a check-point/gate half way through, as a 'how goes it?'. There is no place for guessing or hoping when you get low.

Consider 'outs' or escapes

Some figures are inherently safe – generally those that climb and/or finish higher than they started. There are a few that have claimed lives and/or keep dry-cleaners very busy – anything that pulls towards the ground, has the potential to skid/slip lower, or the potential to enter a spin. Half-roll-and-pull-though, barrel rolls, reverse half-cubans, stall turns are all potential trouble-makers. Rolls-Royce famously lost a beautiful Spitfire years ago to a humble loop, albeit one that started near ground level and finished six feet below it. In the design of the sequence you must be particularly aware of the inherently dangerous figures and place them in the sequence at a point where there is height to manage any issue that might arise from poor execution of the figure. In a previous column, I made mention of good manoeuvres that can go bad – the mitigation is practise and a margin of spare height. The escape is using your situational awareness to recognise a figure going bad early and then having a plan of how to abandon it. Generally, this will involve a fast roll and/or pull to the closest horizon, given you know where this is and you have the height to execute the recovery.

Don't ad-lib

When I wrote this, I thought "what does ad-lib actually mean" - back to the Oxford dictionary!

Ad-lib, short for ad-libitum means 'performed without previous preparation', which does not sound like a good recipe for aviation safety, particularly in the realm of aerobatic flight where you are flying closer to edge of the aircraft's operating envelope.

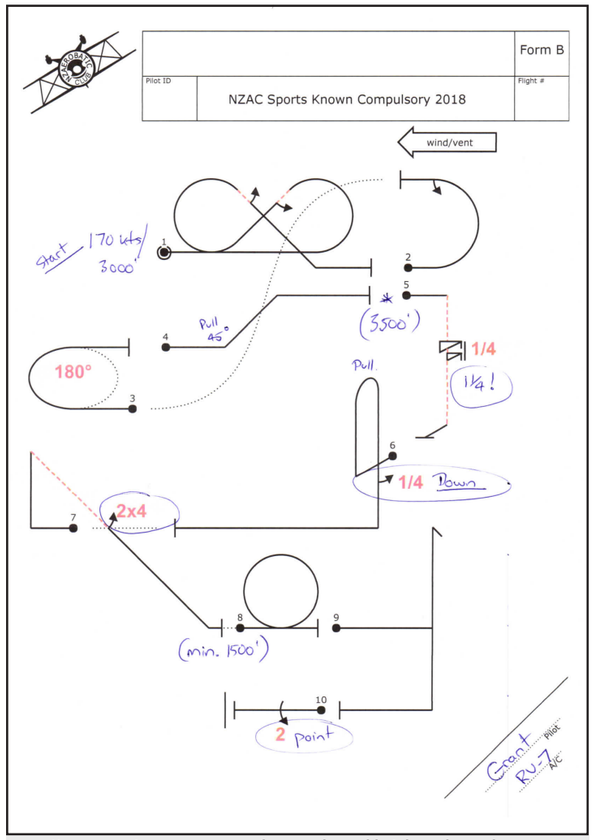
Rattling though a relatively un-planned, 'ad-libbed', but low-risk sequence at height should present few issues, so long as you maintain your margins of height and speed, and know when to break off and climb up for more of both.

Aerobatic competition sequences are prescribed and in theory pilots will fly what is on the sequence card in front of them - but not always! Occasionally, the sequence gets out of order and a figure is flown in the wrong place, which may lead to a big issue with speed or height. Whilst not intentional, this is a form of 'ad-libbing' however normally at a competition there is the safety backup of eagle-eyed judges on the ground, ready to call a 'break' (over the radio) requiring the pilot to immediately stop the sequence and resume normal upright flight.

The display regime has, sadly, demonstrated the worst outcomes of ad-libbing, where both the pressure to perform in front of a crowd mixes with diminished height margins and little room for error. Here, practise and discipline must come to the fore, to remove the temptation of adding something different or unplanned to the sequence.

Part 2 to follow

There is some really great software online which can help with sequence design, but first you need to understand the basics, as I have covered off above. In a future article we will look at creating a flyable, safe and enjoyable sequence that might just help you win a $10 plastic cup!



Not annotations on sequence for pre-planned height and speed gates.

Footnote: These articles are intended to whet appetites for advanced flying and to offer tips to aerobatics beginners. Dual instruction and observance of CAA rules is a must-have - especially for safety and also for learning correct techniques and finesse of manoeuvres for the particular aircraft you are flying. For more information, enquire about aerobatics instruction at your local aero club or see www.aerobatics.co.nz