



# The AOPA Aerobatic Certificate Courses



## Technical Companion Pitts S-2A Special

2011 v1



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## **AOPA Aerobatic Certificate Courses Technical Companion - Pitts S-2A Special**

### **Introduction**

You should already hold a copy of one of the AOPA Aerobatic Course syllabuses. These are available for the Basic, Standard and Intermediate proficiency levels. The relevant sub-sections of the pertinent syllabus will be signed off by your instructor as you complete each exercise. The syllabus should be retained against the unlikely eventuality that AOPA wish to inspect them.

This Technical Companion provides a précis of the general and technical information relevant to course study.

### **Airmanship**

**Minima.** AOPA recommends that all aerobatic manoeuvres be completed above 1,500 feet AGL and not come within 500 feet of controlled airspace. During the Basic course, we will complete all manoeuvres at or above 2,000 feet AGL until sufficient experience has been gained by the student. Towards the end of the course, the minimum height may be reduced to 1,500 feet AGL for flying the Basic 5-figure test sequence (usually the BAeA Beginners' Known sequence for the current year). During the Standard and Intermediate courses, the minimum height may be reduced to 1,000 feet for practicing the Standard or Intermediate contest sequences.

**Locations.** Repetitive aerobatics can be irritating to people living beneath the chosen location. Practice above point or line features should be kept to a duration of less than 10 minutes in any one place on any sortie. Subsequent sorties on the same day should be undertaken at different locations, separated by at least 4km. The ANO stipulates that aerobatic manoeuvres are not to be conducted over towns or inside controlled airspace. Active airfields, danger areas, cloud and other aircraft should also be avoided. The sections of the ANO relevant to aerobatic flying are at Annex A.

## **GROUND SCHOOL - THEORETICAL KNOWLEDGE**

### References:

- A. The Air Navigation Order, CAP393.
- B. Pitts S-2A Airplane (sic) Flight Manual
- C. *Basic Aerobatics*, Campbell and Tempest, 1984.
- D. *Better Aerobatics*, Cassidy, 2003, ISBN 0-9544814-0-2

Most of the required reading for the theoretical aspects of the Basic course is outlined below and at the Annexes. Candidates should be familiar with these concepts prior to the competency check flight. As the courses progress, further required reading can be found in Reference D.

## Legislation Effecting Aerobatic Flying

Article 73 of the ANO states: "A person shall not recklessly or negligently act in a manner likely to endanger an aircraft, or any person therein."

Article 74 of the ANO states: "A person shall not recklessly or negligently cause or permit an aircraft to endanger any person or property."

Rule 5 of the Rules of the Air contains the regulations for low flying. It includes a blanket exemption for aerobatic flying during formally organised contests.

Rule 15 of the Rules of the Air states: "An aircraft shall not carry out any aerobatic manoeuvre:

- a) over the congested area of any city, town or settlement; or
- b) within controlled airspace except with the consent of the appropriate air traffic control unit.

The full content of Rules 5 and the relevant part of Rule 6 are included in Annex A. Rule 5 is not strictly about aerobatics, but is always worth a re-read. Rule 6(f) includes an exemption from Rule 5 for aircraft flying in a contest, interpreted as including aerobatic contests. This is necessary not only for Unlimited contests, where the base height is 100 metres ASL, but also for Advanced contests where pilots might get below 500 feet by a relatively small error.

## Airframe and Engine Information - Pitts S-2A Special

**Load Factors.** The aircraft Load Factor is the load on the airframe which can be varied by the pilot during manoeuvres, derived from lift generation by the wings. The load factor is defined as the ratio of the instantaneous load over the normal load associated with the Earth's gravity. The ratio is expressed in units of G; hence 1G is the force of gravity at the surface of the Earth.

In order to fly level in a turn with  $60^\circ$  of bank, it is necessary for the wings to generate twice the normal lift required for straight and level flight. The pilot will need to 'pull' (or 'push') to generate a load factor of 2G. The relationship between bank angle and load factor is an inverse cosine function, tabulated below.

Bank °	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
Factor	1.00	1.00	1.02	1.04	1.06	1.10	1.15	1.22	1.31	1.41	1.56	1.74	2.00	2.37	2.92	3.86	5.76	11.47

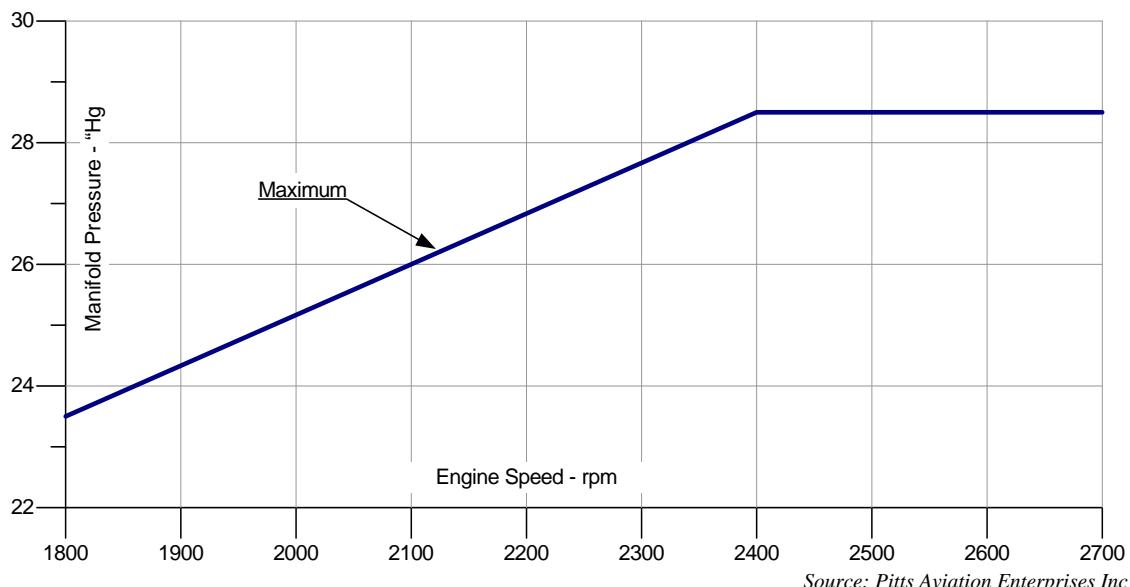
Thus to turn level at  $80^\circ$  of bank requires a constant 5.76G. In order to generate higher levels of G and not stall the wing, it is necessary to fly faster. It is necessary to fly faster than *the 1G stall speed multiplied by the square root of the Load Factor*. Further calculations and diagrams are at Annex B.

**Airframe.** The limiting load factors are +6G and -3G.  $V_{NE}$  is 203 mph. Manoeuvring Speed, the maximum speed at which full control deflections can be applied, is 154 mph. This is indicated on the ASI by the change from a green band to a yellow band. The 1G stall speed varies with weight and density altitude, but is approximately 60 mph IAS.

**Engine.** The aircraft is equipped with a Lycoming AEIO-360-A1A or equivalent engine which generates 200 hp at 2,700 rpm. It is fuel injected and has the Christen inverted oil system. There is no arbitrary limit on the duration of inverted flight, but prolonged flight upside-down will eventually lead to un-recoverable oil loss. The entire contents of the single fuel tank are available to the inverted system via a flop-tube.

Maximum power is developed at 2,700 rpm and 28.5 inches of mercury ("Hg). On high-pressure days at low elevations, the manifold pressure may exceed 28.5" Hg at full throttle. This condition should be used only for short periods when maximum thrust is required. The graph below shows the relationship between rpm and maximum permitted manifold pressure. Above 2,400 rpm the maximum of 28.5" Hg may be applied.

### Manifold Pressure vs RPM - Pitts Model S-2A



### Engine Limitations

The following engine limitations should also be observed:

Maximum oil temperature  $240^{\circ}\text{F}$

Minimum oil temperature for take-off  $100^{\circ}\text{F}$

Minimum oil pressure, low rpm  $30\text{ psi}$

Minimum oil pressure, high rpm  $60\text{ psi}$

Oil sump capacity is 8 quarts, the minimum for aerobatics is 6 quarts

## Fuel System data

Useful fuel system data is as follows:

Maximum capacity (transit)	96 litres
Maximum fuel (aerobatics)	64 litres
Minimum fuel (aerobatics)	20 litres

Note: Once the fuel level reaches 20 litres, the flop tube may not be able to keep up with fuel movement in the tank during rolling exercises, causing a lean cut which will be resolved once rolling ceases, upright or inverted. If you detect this condition, return to land asap.

On local aerobatic flights, the approximate fuel consumption will be 50 litres per hour if the flight duration is between 25 and 45 minutes.

Cruise at 2,400 rpm, 26" Hg will produce about 140 mph (120 kts) and consume 45 litres/hr. Fuel consumption can be reduced by flying higher and leaning the mixture.

## Propeller

The aircraft is fitted with a 3-bladed, wooden MT propeller of 188cm diameter in place of the original Hartzell, 2-bladed, aluminium unit. The red arc shown on the tachometer between 2,100 and 2,350 rpm is only applicable to the Hartzell propeller, and no such restriction applies to the MT propeller fitted.

The MTV-9 propeller fitted to G-ODDS has a very low coarse stop. If the pitch lever is pulled fully out, or if the oil pressure is lost or if the governor fails in certain modes, then the blades of the propeller will reach a very coarse angle indeed. This results in a much improved glide angle when compared to the Hartzell propeller, but it also means that level flight cannot be maintained in the event of lost oil pressure or if the governor fails. In either of these events, a forced landing will be inevitable.

If power is lost but oil pressure remains, such as would happen in a fuel starvation situation, the pitch lever should be used to extend the glide as required (coarse) and can then to shorten the hold-off/float before touchdown (fine).

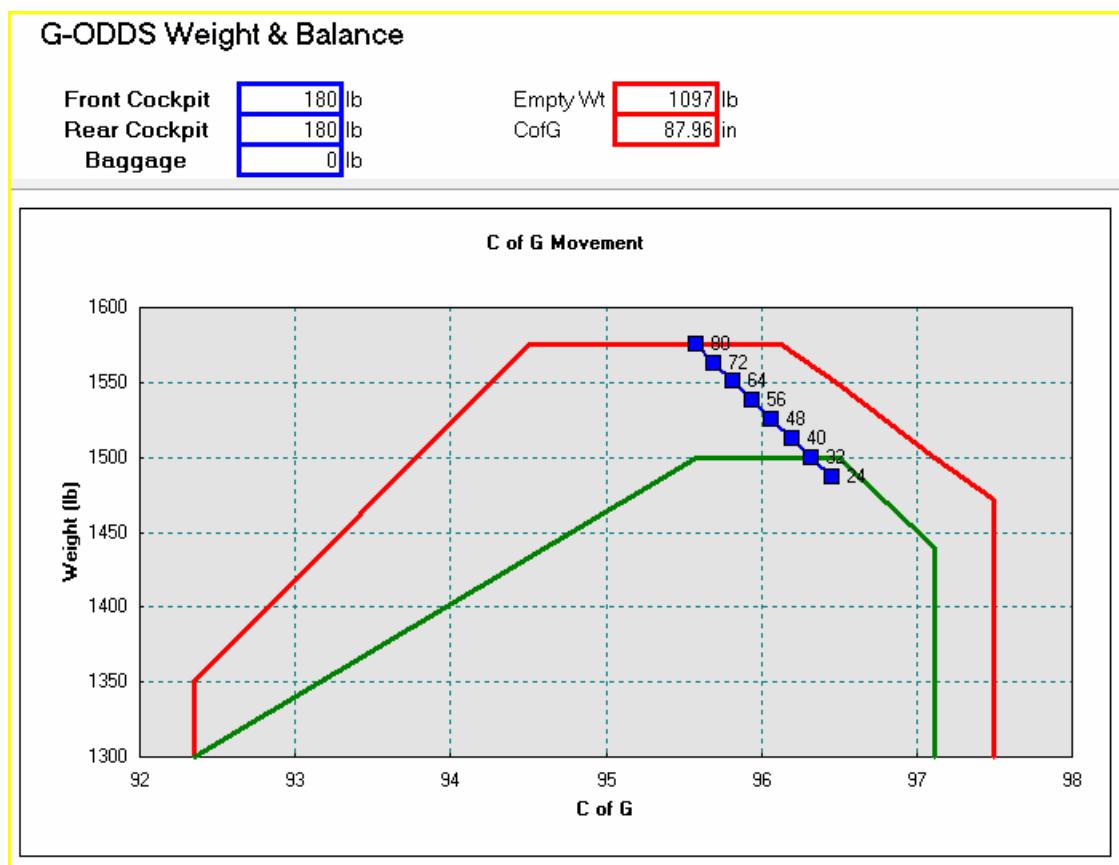
If it becomes necessary to fly through rain, slow down and reduce the engine rpm to 2,100 with a manifold pressure of 23" Hg. This will maintain level flight and reduce the risk of erosion to the propeller leading edge and tips.

## Weight and Balance

The Pitts S-2A is fairly flexible with respect to loading, but care must be taken not to exceed permissible loadings during aerobatics with two people on board. The forward limit is 92.35" Aft of Datum (16.3% of Mean Aerodynamic Chord) while the aft aerobatic limit is 97.12" (28.7%) and the aft transit limit is 97.5" (29.6%). Maximum take-off and landing weight is 1575 lb. maximum weight for aerobatics at +6G/-3G is 1,500 lb.

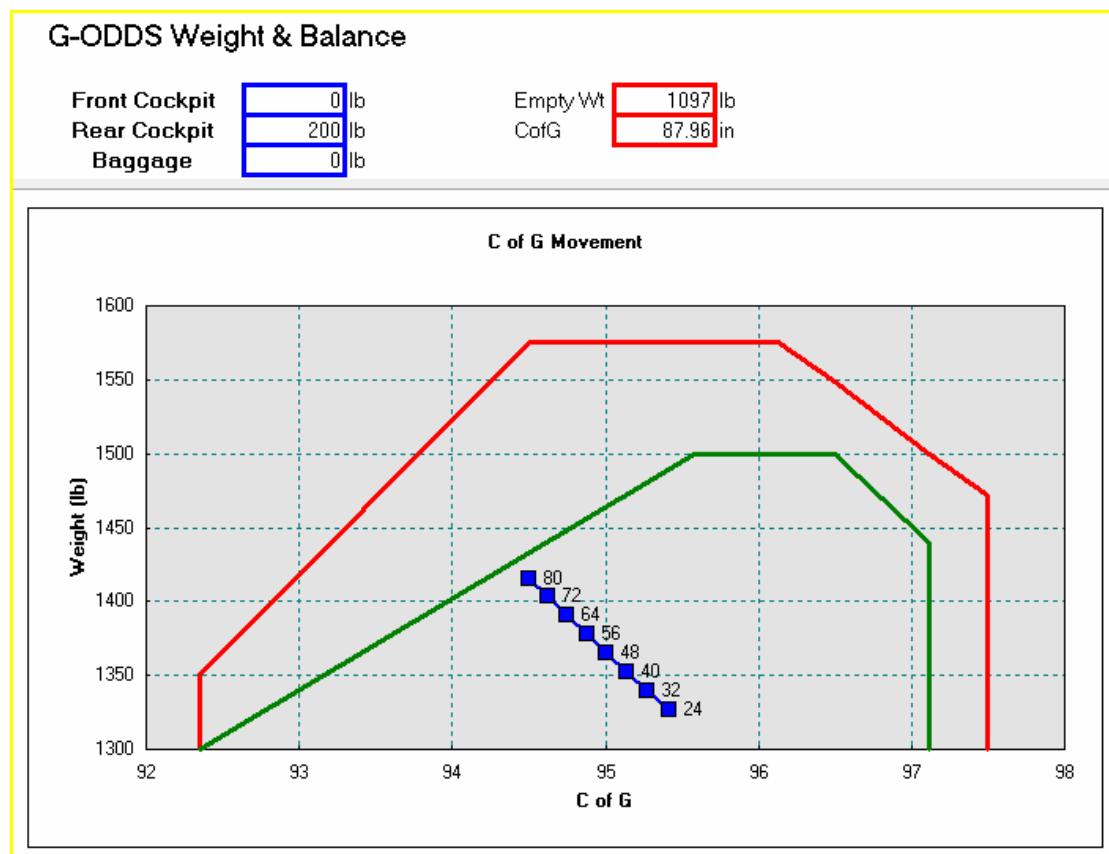
With no baggage and two occupants, each weighing 180lb, the maximum aerobatic envelope may only be used once fuel has dropped below 32 litres. With more fuel than this, the aircraft may safely operate at lower load factors, as the Centre-of-Gravity will be away from the aft end. For example, if two such occupants are flying with 60 litres of fuel, then the applied load should not exceed +5G/-2.5G.

The full aerobatic envelope is shown in the following diagram by the green line, and the gross envelope by the red line. The blue line shows how the CofG moves as fuel burns down from 80 litres to 24 litres.



During training flights, your instructor will make sure that the weight and balance of the aircraft are acceptable for safe operation. If a solo hirer is allowed to fly with a passenger, then the hirer must make a suitable weight and balance calculation before booking out for the flight.

When flown solo, the Pitts S-2A is flown from the rear seat. Nevertheless, the resulting CofG will be further forward than when the aircraft is flown dual. Solo aerobatic pilots should take the minimum fuel needed in order to avoid having the CofG further forward than necessary. This diagram shows the situation for a 200lb solo pilot as fuel is reduced:



In this case an initial fuel load of 48 litres and a planned flight duration of 25 minutes would be quite sensible. Flying with the CofG far forward will make stall turns, spins and flicks more difficult because of the increased pitch and yaw stability of the aircraft.

Weight and Balance calculation forms are available in the aircraft technical log for pre-flight calculations.

### Physiological Limitations

Information on disorientation and the effects of G-forces on the human is at Annex C.

### The Arresti System of Aerobatic Notation

The pertinent Chapter from Reference D is reproduced in full at Annex D. This is perhaps more detail than is required for the Basic course, but will become of more and more interest as later courses are started.

## COMPETENCY CHECK RIDE

The flight profile for the competency check ride is detailed below. It may need some amendment from day to day as weather conditions dictate.

The aim of the check ride is to demonstrate your ability to conduct an aerobatic sortie in the local area in safety. You are responsible for the planning and execution of the sortie and you will need to pre-select a suitable area or areas in which to conduct the manoeuvres. You are responsible for look-out, the conduct of safety checks (HASELL, HELL, FREDA) and for the avoidance of weather, controlled airspace, active airfields and congested areas.

Individual figures and any aerobatic sequence flown should be completed above 2,000 feet on the Waltham QFE. In certain weather conditions, your instructor may authorise a minimum height of 1,500 feet QFE for the Basic sequence or 1,000 feet QFE for Standard or Intermediate sequences.

### Profile

**Climb** to 4,000 feet QFE, remaining below the London TMA; complete HASELL checks. Look-out using 90° turns or wingovers.

Demonstrate a **spin** from S&L, stalled entry. start recovery after 2 turns and recover to a sustainable climb. The instructor may ask you to repeat the spin in the opposite direction. Complete HELL checks after spinning and maintain lookout as before. Work for next few minutes with a good line feature. For the Intermediate certificate, this will be an **inverted spin**.

At roughly 3,000 feet QFE, demonstrate **slow flight** at 70 mph. Turn right and left, through roughly 60° each time, at this speed, adding power to maintain height and speed as necessary. Flying relative to your line feature, conduct a **clean stall** recovering by reducing the Angle of Attack when buffet is felt, the nose drops or when the instructor directs. Limit wing drop with rudder. Regain 3,000 feet QFE after recovery. Intermediate candidates should be prepared to demonstrate **inverted stalling**. After another HELL check and lookout, go to full throttle and enter a shallow dive prior to the...

**Max Rate level turn.** When the speed is between 150 and 160 mph level the aircraft and roll on 70° of bank. Smoothly increase the load factor to +3.5G and try to stay level. The aircraft will decelerate during the turn and the stall speed will have increased to something like 110 mph. You will feel light buffet as the aircraft slows towards this speed. Once the buffet is recognised continue the turn level but with reduced bank angle until the line feature is regained. Complete another HELL check and lookout. For Intermediate, **inverted steep turns** at 60° bank will be substituted here.

Respecting the height minima briefed earlier, work with your line feature for the **individual figures** appropriate to the skill level of the course. Typical figures for each level in the pertinent syllabus - more advanced figures are at Annex D.

Reposition to a pre-briefed location to complete the **demonstration sequence** of figures (for the Basic Certificate, the Beginners Sequence for the relevant year), again being sure to respect the briefed height minima. In the event of a handling error in the sequence, it is important to stop the programme and take remedial action rather than continuing out of position or low. The test is of situational awareness rather than technique.

After completion of the sequence phase of the flight recover to base as planned, being sure to remain clear of controlled airspace. Carry out FREDA checks and make radio calls as appropriate.

Your instructor will advise you of the type of approach that you should make, which might include simulating an engine failure in the circuit and landing from the ensuing glide.

## CAP393 Extracts, Rules 5 and 6 (selected parts)

### SECTION 3 *LOW FLYING RULE*

#### Low flying prohibitions

5.—(1) Subject to paragraph (2), an aircraft shall comply with the low flying prohibitions in paragraph (3) unless exempted by rule 6.

(2) If an aircraft is flying in circumstances such that more than one of the low flying prohibitions apply, it shall fly at the greatest height required by any of the applicable prohibitions.

(3) The low flying prohibitions are as follows—

(a) Failure of power unit

An aircraft shall not be flown below such height as would enable it to make an emergency landing without causing danger to persons or property on the surface in the event of a power unit failure.

(b) The 500 feet rule

Except with the written permission of the CAA, an aircraft shall not be flown closer than 500 feet to any person, vessel, vehicle or structure.

(c) The 1,000 feet rule

Except with the written permission of the CAA, an aircraft flying over a congested area of a city town or settlement shall not fly below a height of 1,000 feet above the highest fixed obstacle within a horizontal radius of 600 metres of the aircraft.

(d) The land clear rule

An aircraft flying over a congested area of a city, town or settlement shall not fly below such height as would permit the aircraft to land clear of the congested area in the event of a power unit failure.

(e) Flying over open air assemblies

Except with the written permission of the CAA, an aircraft shall not fly over an organised open-air assembly of more than 1,000 persons below the higher of the following heights—

(i) 1,000 feet; or

(ii) such height as would permit the aircraft to land clear of the assembly in the event of a power unit failure.

(f) Landing and taking off near open air assemblies

An aircraft shall not land or take-off within 1,000 metres of an organised, open-air assembly of more than 1,000 persons except—

(i) at an aerodrome, in accordance with procedures notified by the CAA; or

(ii) at a landing site which is not an aerodrome, in accordance with procedures notified by the CAA and with the written permission of the organiser of the assembly.

#### Exemptions from the low flying prohibitions

6. The exemptions from the low flying prohibitions are as follows—

(f) Flying displays etc

An aircraft taking part in a flying display, air race or contest shall be exempt from the 500 feet rule if it is within a horizontal distance of 1,000 metres of the gathering of persons assembled to witness the event.

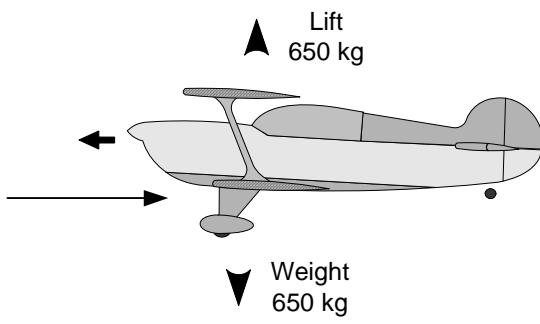
## LOAD FACTOR AND ADVANCED TURNING

### LOAD FACTOR

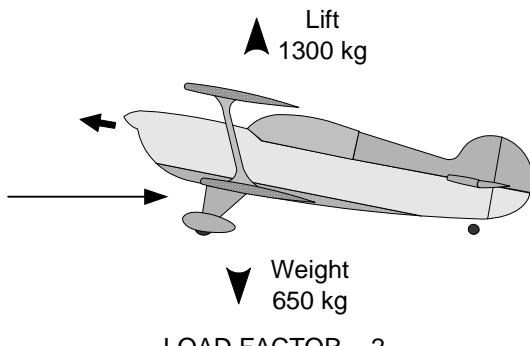
(adapted extracts from Reference C)

The Load Factor is the load on the airframe which can be varied by the pilot. It is not the wing-loading which is a term used to define the relationship between aircraft mass and wing area.

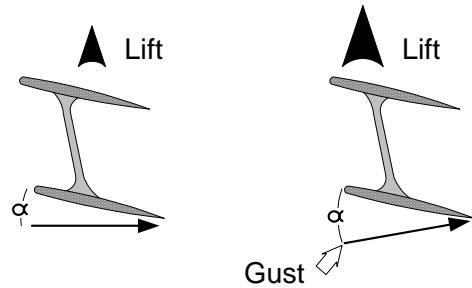
Assuming an aircraft weighing 650 kg is flying level, in order to maintain level flight at any airspeed the angle of attack chosen must produce 650 kg of lift:



If the pilot now applies a positive back pressure to the control column, the elevator will change position increasing the down-force on the horizontal stabilizer. The relative airflow will now reach the wings at a larger angle of attack and cause an increase in lift. If the lift is increased to 1300 kg then a load factor of 2 would have been experienced by the airframe:

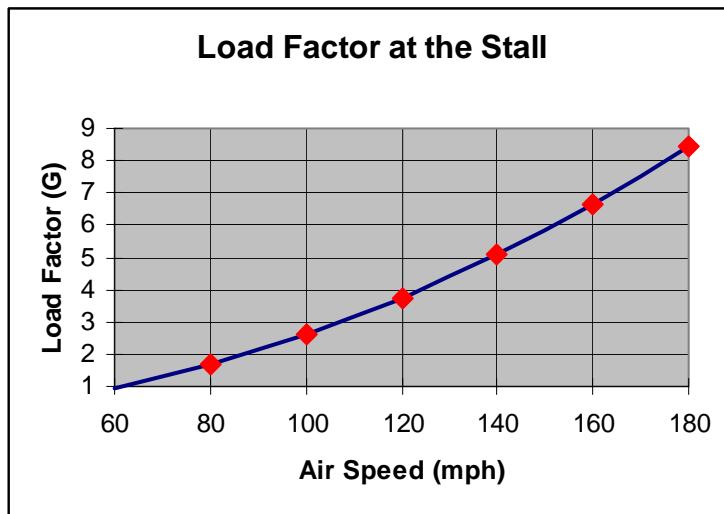


A similar situation could occur if the aircraft flew through a strong up-current. If at this time an increased load factor was being applied, the enlarged angle of attack caused by the gust could cause the limiting load factor to be exceeded. Hence in gusty conditions the aircraft should be flown at relatively low speed and high angles of attack avoided.



## Stalling Load at Increasing Airspeed

The faster you fly, for any given angle of attack, the higher will be the wing loading applied to the aircraft. The wing, however, will always stall at the critical angle of attack, which is roughly  $15^\circ$ . The "stalling speed" invariably quoted in aeroplane manuals is the speed at which the critical angle generates 1G of lift. Of course, with a powerful elevator it is possible to achieve this same critical angle of attack at higher speeds, such that at twice the 1G stalling speed the wing will generate 4G just before the stall. Thus at 4G the "stalling speed" is double that at 1G. The ratio of the "stalling speeds" is equal to the square root of the load factors, as shown in the adjacent diagram. Note that the limiting load factor of 6G is reached at the manoeuvre speed, roughly 154 mph.



From this diagram, you can also deduce that at 100 mph the wing will stall at approximately 2.6G and at 140 mph at 5.1G. Thus at these lower speeds it is not possible to over-stress the wing simply by pulling abruptly backwards on the control column. At 160 or 180 mph, however, the risk does exist.

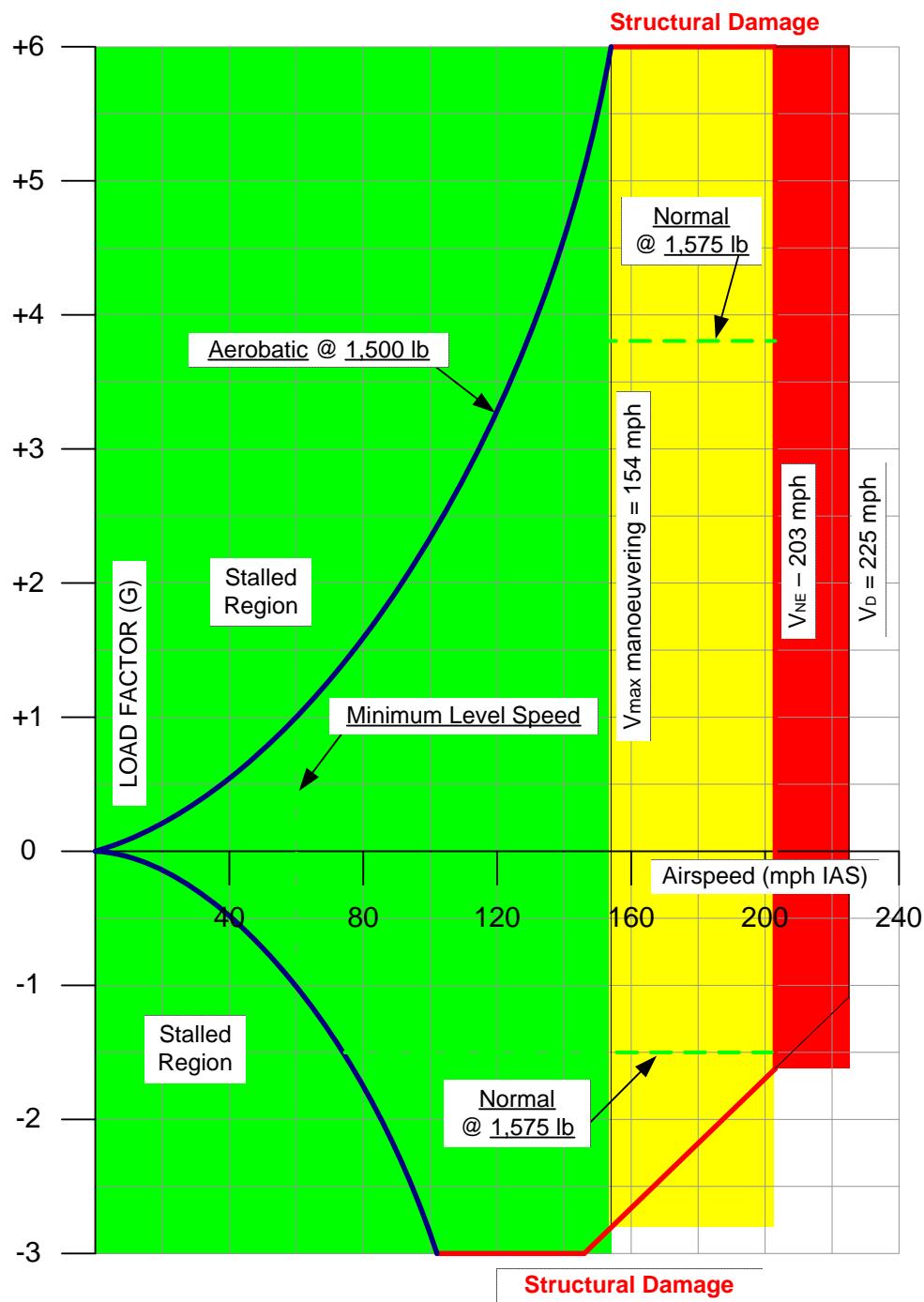
## The Flight Envelope

The Flight Manual contains a complex graph illustrating the permitted flight envelope for the aeroplane. The key points of this graph are reproduced on the next page.

The horizontal axis of the graph represents the aircraft's air speed and the vertical axis the wing loading, from -3G to +6G. The strength of the aircraft is contingent upon four items:

- 1) The all up weight of the aircraft.
- 2) The configuration (if the aircraft has flaps or retractable undercarriage - so not in the Pitts)
- 3) The symmetry of the loading. (This is important because when complex loading is applied, a combination of rolling and pitching for example, the structural limitations can be reduced by about a third).
- 4) The density altitude - which we need not consider further here as we always fly in the lower levels of the atmosphere.

In consequence of item 3) above, if you are rolling with a moderate to large aileron input, you should not exceed +4G or -2G at the same time. When flick rolling, the limiting speeds of 140 mph positive and 110 mph negative must be strictly observed.



Source: Pitts Aviation Enterprises Inc

### Pitts S-2A V-G Diagram

It is not normal, although it is possible in some circumstances, to fly to the left of the blue lines, as the wing is stalled. Safe aerobatic flight is possible in the area between the blue and red lines as long as the all-up weight does not exceed 1,500 lb. Flight to the left of the green minimum level speed line must be at less than  $\pm 1G$ . If the weight is between 1,500 lb and 1,575 lb (the maximum allowed), flight is additionally restricted by the horizontal green dashed lines.

Structural damage can be expected if the upper and lower load limits are exceeded. There is a further safety factor of at least 1.5 built in to the design of certificated

aircraft, so structural collapse would not be expected below +9G and -4.5G, but this is no reason to exceed the stated limits. Always exercise care with elevator inputs when flying faster than 154 mph.

$V_D$  is the demonstrated maximum diving speed flown during development testing and is usually about 10% higher than  $V_{NE}$ .

### The Accelerometer



The Pitts S-2A is equipped with accelerometers (G meters) in both cockpits. These instruments measure acceleration parallel to the Normal axis of the aeroplane. That is to say the axis about which the aeroplane yaws. Sometimes this acceleration is called  $G_N$ , where the subscript 'N' stands for Normal.

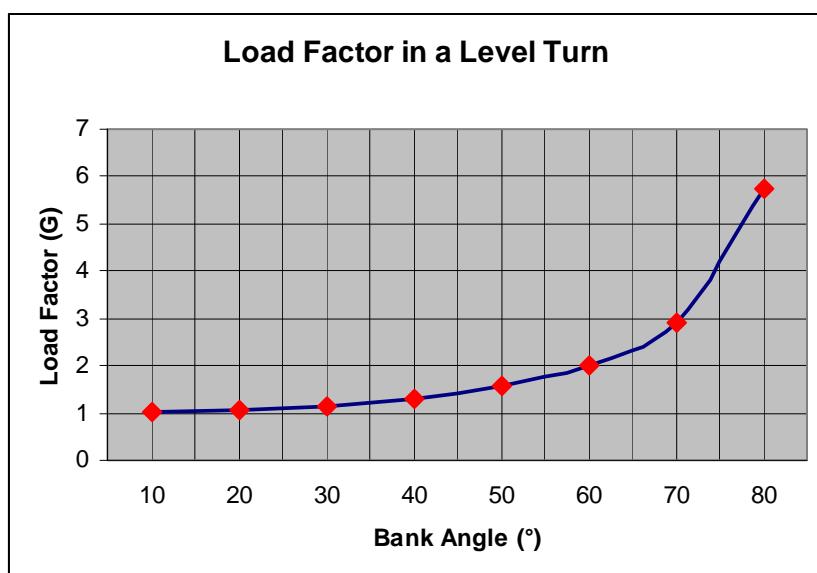
The accelerometer has three pointers, one "live" showing current G and two "memory" pointers showing max and min G since the last reset. At the end of each flight, you can see the maximum and minimum G loads experienced, but do **NOT** reset

the instrument after flight. Leave the meter showing what you have done so that the next crew can have the confidence from knowing that the aeroplane has not been overstressed. If you find the aircraft with an indication that the limits of +6G or -3G have been exceeded, report the situation to your instructor and still do **NOT** reset the meter.

Note that some pilots refer to the resetting of the G meter as "zeroing" it. This is clearly wrong, as when reset each of the pointers will indicate +1G!!

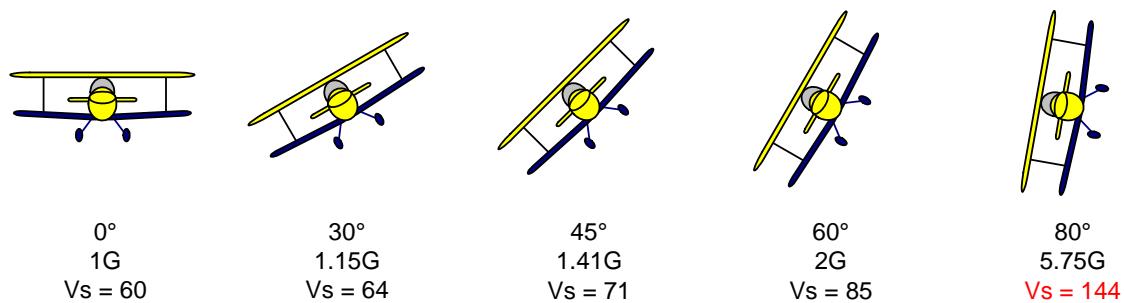
### ADVANCED TURNING

Stalling at high speed will put a high load on the airframe and that this leads to the determination of manoeuvring speed, which is 154 mph in the S-2A. You also saw a table showing how G-load at the stall increases with bank angle' shown here:



We can now use this information to discover what are the minimum speeds at which we can turn level at differing bank angles. The previous graph, we know that at 60° bank the load produced in the turn will be 2G. If we take the square root of this load factor, 1.414, and multiply it by the 1G stall speed, 60 mph, we get a stall speed for the turn of roughly 85 mph. You might be surprised how low this is, and in practice we would add at least a 20% margin on this. So a sensible minimum speed for a 60° banked steep turn would be perhaps 105 mph; certainly not less than 100 mph to keep something in reserve.

Look at the picture below, however, to see what happens if you let the bank angle get a bit too high.



If the bank angle got to 80° and you pulled to try to keep level, you would fail at any speed below 144 mph. Suddenly the safety margin at 100 mph seems a bit thin. The real lesson here is that precise control of the bank angle is essential for accurate steep turns.

### Minimum Looping Speed

The published minimum looping speed for the S-2A is 140 mph. At this speed the wing will stall at 5.44G. So if you start the loop from this speed with 4.5G you will be fairly close to the stall boundary. As the speed reduced you would have to make really sure that you added no more back stick or you would almost certainly enter heavy buffet.

On the other hand, if you were to be too cautious and pull too gently, the aircraft would slow down too much before the apex; you would run out of aileron control to manage the torque, even if you did not stall. Thus looping from minimum speed is like walking a tightrope, balancing between stalling and getting too slow for adequate roll control. Better at first to have a little more speed in hand, say 150 mph, so that you can pull 4G initially and still have adequate stall margin. Starting this way and keeping the pitch rate reasonably quick for about 160° of pitch will get you to the top with good control speed.

## PHYSIOLOGICAL LIMITATIONS

Apart from knowing the limitations placed upon the airframe and engine, pilots who wish to become proficient in aerobatics must have a grasp of how these manoeuvres will affect the human body with respect to physiological stresses, disorientation and airsickness. To start aerobatic training without this knowledge can result in an unnecessary de-motivation or a reduced rate of progress in developing the skills required for accurate execution.

In normal daily life, and level flight, the aircraft and pilot are subjected to normal gravity; 1G. During flight, however, we can impose changes to the "local" gravity by manoeuvering. Usually, this will be manoeuvering in pitch, although the aircraft can also generate small amounts of "sideways" G by generating fuselage lift.

As a potential aerobatic pilot, there are a few bits of information about G-tolerance with which you should be familiar.

### Positive G

To maintain high-level motor skills you keep a healthy blood pressure supply to your brain. Under 1G, your heart has been doing this since birth. You also have in your head a kind of 'hydraulic accumulator' which means that if greater values of positive G are applied to your body for a few seconds, you will keep this critical blood pressure intact. The critical time here is of the order of 3.8 seconds. During this short time you can experience really quite high G levels, up to the +6G limit on the S-2A, without serious difficulty.

However, if you apply even +3G for more than this short time you will start to develop the symptoms associated with losing cranial blood pressure. Initially, you will lose colour vision, so that everything appears in shades of grey (*grey out*). Then your field of vision will reduce to a small central area (*tunnel vision*). Thereafter, if you maintain the G, you will lose all vision but retain hearing (*black out*), before eventually losing consciousness (*GLOC*). It is possible to come back quite quickly from the *black out* stage and be reasonably aware, albeit a bit giddy. Recovery from *GLOC* takes much longer - possibly longer than it takes for the aircraft to impact something unyielding.

With practice, you can improve your tolerance of positive G, such that you are able to sustain longer periods at 3G or higher. Some aerobatic figures, especially prolonged looping segments at high speed can last for perhaps 6 seconds, even in the Pitts. The best way to approach these situations involves two techniques. Firstly, for 2 or 3 seconds before the onset of the G, hyperventilate your lungs by rapid breathing in and out. This will increase the oxygen in your blood. Finish on an in-breath. Then tighten your neck muscles really hard, so that they bear down upon the veins through which blood drains from your head. Grunting between clenched teeth will give you a good idea of this function. You will keep the blood in your head until the G goes away and all will be well.

It is also important for good G tolerance to be well hydrated and to have a reasonable blood sugar level. Drink plenty of water for the hour or two before flying and have some slow-release sugars (carbohydrates - porridge is good for breakfast) in your tum.

There is quite a lot of positive G tolerance data from military flying and space exploration. Very little of this is relevant to aerobatics in light aircraft because the military and NASA are much more concerned with exposure to prolonged periods of G, while in aerobatics we have only to resist for a relatively short time. Knowledge of the effects of high negative G values has come almost exclusively from competition aerobatics.

### **Negative G**

Under negative G conditions, the risk to health comes from increased blood pressure which can lead to the rupture of blood vessels in the head. Minor indications can be small reddish spots on the surface of the skin, especially around the eye brows, which indicate small haemorrhages in skin cells. Other visible damage can include bleeding in the white of the eye. Invisible damage can occur by rupture of blood vessels in the brain.

Funnily enough, although we have only been flying for 100 years or so, we do all have an evolved reflex action which kicks in to protect us if we hang upside down. This has good and bad points. Under negative G conditions, small 'valves' start to constrict in the arteries supplying blood to the head and these work to keep the pressure low. You can help this process in much the same way as you did to resist outward blood flow under positive G.

Before pushing **DO NOT** hyperventilate, just breathe normally but then **DO** squeeze up those neck muscles. They will now help to constrict the arteries and help keep down cranial blood pressure. Negative G will also induce mild headaches - severe ones if you do too much too soon, so take it easy and build up slowly. The Pitts is limited to -3G. At this level of force, the only likely symptoms from those listed above are the small red spots.

### **Negative to Positive Transitions**

The situation most likely to cause *GLOC*, and therefore that which is most dangerous, is the transition from negative G to positive G. As noted above, even a relatively short exposure to negative G will set off the arterial constriction process. You cannot stop this happening. After even 2 or 3 seconds inverted, your cranial blood pressure will be reduced. If you subsequently roll upright and establish +1G, it will take several seconds for the normal blood pressure to restore itself in your brain.

Consequently, if you go from a few seconds at -1G to something as apparently innocuous as +2G, quickly and without taking any precautionary techniques, you will probably black out. This is just one of the reasons why recovery from botched inverted figures **MUST** be done by rolling erect, **NOT** by pulling down and looping to upright.

The precautionary techniques (tensing) are considerably more effective if they are started before the G onset.

### **Disorientation**

Spatial disorientation is a condition which occurs when a pilot is confused about the attitude or motion of his aircraft due to inadequate sensory input or false physical sensations. Mild and temporary disorientation is a fairly common experience during a

pilot's initial training, but usually is quickly overcome as a pilot adapts to the normal sensations of flight.

Markedly unusual attitudes, however, such as those involved during aerobatics give the pilot some very marked false bodily sensations during early training in these manoeuvres. For example, at the apex of a loop or barrel roll, the balance sensing equipment in the inner ear will give the same inputs to the brain, from the local gravity generated in the aircraft, as they would when upright. The pilot's eyes, on the other hand, will be telling the brain that the body is inverted. The brain then has to rationalise these two conflicting messages, and build a perceptive model of the world that is different from previous experience. Fortunately, the brain is able to adapt its internal modelling, and the potential conflicts soon disappear.

Many flight situations may lead to the onset of spatial disorientation, but the most common are:

- a) A lack of flying practice.
- b) A lack of visual cues.
- c) Sudden head movement made at a time when the aircraft is rapidly manoeuvring.
- d) Impairment of brain function due to lack of oxygen, the effects of alcohol, fatigue, emotional disturbance or medication.
- e) Aerobic manoeuvres (including spinning). Disorientation can occur either during these manoeuvres or immediately afterwards, particularly during figures containing both looping and rolling motions.

The answer to lack of flying practice is to avoid aerobatics until a period of normal flight has been resumed. Because the eyes are the most powerful, and the only reliable, sense used to determine attitude, refrain from aerobatics in conditions of poor horizontal visibility and away from clouds.

When initiating looping, either positive or negative, it is better to turn your head to look at the wing sight while still flying level. Turn your head, sight on the horizon in your 9 o'clock and then start the loop. This is much better than starting to pull while looking ahead and then turning to watch the horizon. Refrain from excessive alcohol consumption the night before an aerobatic lesson. Drink lots of water in the 2 or 3 hours before flight, and urinate regularly!, to maintain your body in a state of good hydration.

If you experience any symptoms of disorientation during your training, be sure to advise your instructor immediately. If you persist with a flight when feeling off colour, you will just be wasting your money, as you won't gain any instructional benefit.

Some pilots regularly flying at higher negative G levels, in excess of -5G, have developed adverse symptoms in their balance sensing systems. This has been colloquially called "The Wobblies" and is very similar to a medical condition called "Benign Positional Vertigo", although I'm not so sure about the "benign" part. If during or after flying you experience any symptoms that feel a bit like losing your balance, or

the horizon rocking from side to side you should talk to your instructor as a matter of urgency.

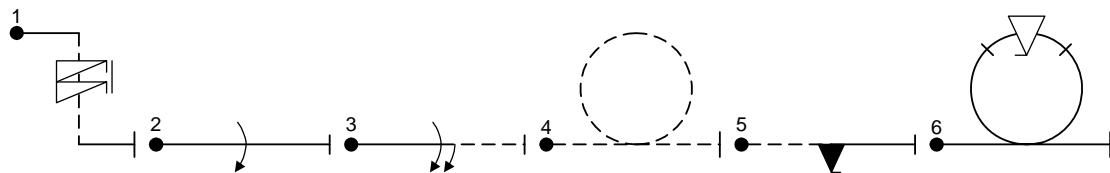
### **Airsickness**

The primary route to airsickness is through spatial disorientation. Stop aerobatics and return to base at once if you sense symptoms of disorientation. Remember, the best way to avoid disorientation is always to be looking at the horizon, whenever attitude changes are taking place.

Many people initially experience mild symptoms of airsickness when they start aerobatics, but they find that these become less frequent and disappear with further experience. This is because they are better able to preserve their spatial awareness.

Airsickness caused purely by the actual motion, as is more likely the case in seasickness, is relatively rare. Seasickness usually takes several hours to become a factor and most flights last in the order of 35 minutes, so motion sickness is less likely to become apparent. Some pilots can suffer from true motion sickness, as opposed to nausea induced by disorientation, in these short periods. There are proprietary medications available which help with this problem if it persists. There are, however, some very competent aerobatic pilots who solve the problem by flying shorter flights, of just 20 minutes duration, on a more regular basis.

## AEROBATIC DRAWING NOTATION: THE ARESTI SYSTEM



Pilots have always had the problem of putting down on paper an easily digestible description of their flight. Up to the 1950s there were many such individual styles, and some were beginning to be codified nationally, but there was no international agreement over any form of notation.

A Frenchman, François D'Huc Dressler, published a system in *Aviasport* and *Aeronautics* in 1955/56. This was in general use up to 1962, despite Dressler's death in 1957. But in 1961, a new book was published, the *Sistema Aresti*, of Colonel Jose Luis de Aresti Aguirre.

As the 1964 World Championship was to be held in Aresti's native Spain, the Aresti System was selected by CIVA in 1963 to be the standard for that contest. This system not only used a range of basic symbols in combination to represent many thousands of possible figures, but also attributed difficulty coefficients to each figure so that a nominally objective form of judging could be undertaken. In its later forms, the Aresti Dictionary included upward of 15,000 figures.

In the mid-80s, the system was rationalized and simplified to form the Condensed Aresti System (from now on just "the System"). This more closely reflected the requirements of international competition as it had evolved to that date. This system remains the copyright and intellectual property of Col. Aresti's heirs and their company Aresti System SL, of Madrid, Spain.

The System is reviewed annually by a committee having representatives of both CIVA and Aresti System SL, and is still used as the basis for all competitions worldwide. Throughout this book, illustrations of the various figures and sequences using the System are used by permission of and under licence from Aresti System SL. A software version of the System, licensed by Aresti System SL, is also available from Freestyle Aviation, Maidenhead, UK.

### Notation

#### Figures and Manoeuvres

These two terms are generally interchangeable in normal conversation, but they have different meanings when applied strictly in aerobatic parlance.

A figure is a complete entity that is made up of one or more manoeuvres. For example, a loop is made up of a single 360° looping manoeuvre. A stall turn, on the other hand consists of five manoeuvres: a 90° looping segment, a straight vertical line up, a 180° yaw turn manoeuvre, a straight vertical line down and finally another 90° looping segment back to horizontal flight. Further manoeuvres, such as fractions of aileron or flick rolls may be added to the stall turn to further complicate its design.

In competition flights where a pre-published sequence of figures will be flown, the figures are separated, and distinguished one from the next, by periods of level flight. This short level line is considered, from a judging point of view, to be part of the figure that follows it.

In Freestyle competition flights, the pilot's plans are not published in advance to the judges. These programmes are regulated solely by timed duration, and the various elements flown are judged, not as individual figures, but by a more general set of criteria which encompasses ideas about the synthesis of the sequence as a whole. None of the contents of this chapter is really applicable to such Freestyle flying, as the discipline of System-based design is not strictly applied in that case.

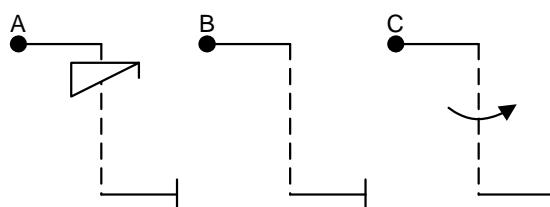
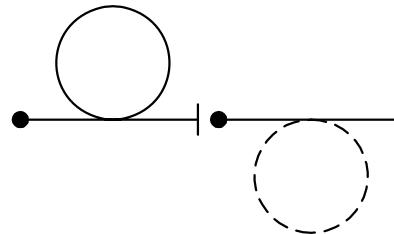
## Lines

Straight and curved lines are used in the notation to illustrate the flight path of the aircraft's centre of gravity. For periods when the wing is loaded with a positive angle of attack the lines are drawn continuous.

For periods when the wing is loaded with a negative angle of attack the lines are drawn dashed. In colour drawings, positive lines are conventionally shown in black while negative lines can be additionally highlighted by being in red.

The line convention is clearly illustrated in this diagram which shows a positive, up-ward loop followed by a negative, down-ward one (not an actual combination I would like to fly often, but a good illustration).

It is important to realise that the solid or dashed nature of the line shows its aerodynamic loading, not the aircraft attitude. Thus, at the top of the positive loop, the aircraft is upside down, but still positively loaded, so the line stays continuous throughout. The status of some lines is less obvious, so I'd better show some of those as well.



The diagram on the left shows three figures, all of which incorporate a vertical down line. There are a number of things to consider.

Firstly, it is not possible to go from horizontal flight to vertical flight without a curved bit in between. But because the curved section turns through less than  $180^\circ$  it is conventionally shown as a hard angle. This is the first instance of a kind of short-hand that simplifies the notation from a full artistic representation.

The figure labelled A also has the symbol for a one-turn upright spin (more on such symbols later). During the spin the aircraft would have a positive angle of attack, yet the vertical down line is shown as negatively loaded.

The figure labelled B has the spin removed. To get from upright level to vertical down, you have to push and perform a quarter outside loop. This is not shown because of the 'less than  $180^\circ$ ' convention, but it results in the aircraft continuing to carry a slight

negative load until the pull-out is started. Hence the dashed line. Thus the status of the line is determined by the loading it would carry if it were flown with no rotation superimposed.

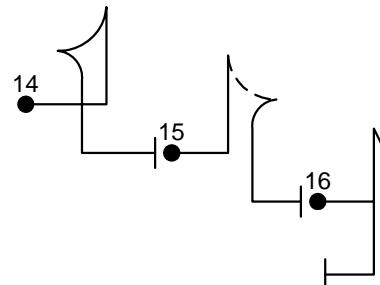
The figure labelled C has a full 360° aileron roll on the down line. In this case, the line would cease to carry its ‘negative’ connotation once the roll is started, but the drawn line remains dashed for simplicity.

Currently, the System contains no figures inside which there is a prolonged period of flight in knife edge, i.e. with sustained bank of 90°, so there are just these two sorts of line.

### Pitch and Yaw Translations

Tail slides include pitch translations that are rapid and do not form part of a looping segment. Stall turns include a rapid yaw turn that also requires its own type of annotation.

This diagram shows two tail slides and a stall turn. In the first two, the elliptical segments show the slide. Number 14 is a canopy-up slide while Number 15 is a canopy-down slide, distinguished by the dashed line.



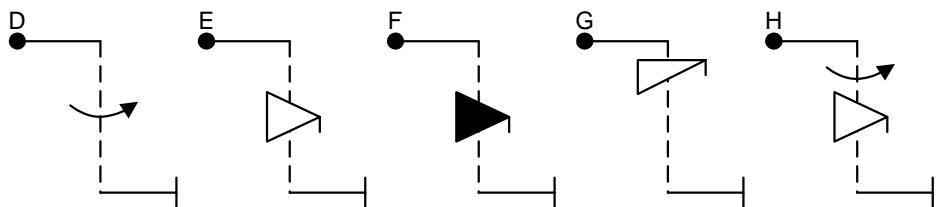
The yaw rotation in the stall turn, number 16, is shown by the small oblique stroke at the end of the vertical line. No direction is implied by the orientation of the oblique, which could quite correctly lie on the left or right side.

### Rotations

The two sections above have covered all there is about pitch and yaw changes, so that just leaves movement about the roll axis: rotation.

In the System there are two types of rotation, rolls and spins. There are also two types of roll, aileron and rudder (flick). So this means we need three types of symbol. In Freestyle flying, there is another type of rotation which is a gyroscopically-driven combination of rapid pitch generally called tumbling. No such figures occur in the System and so there is no standard symbol for such a manoeuvre.

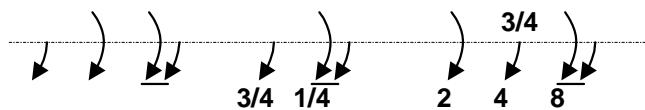
The diagram below shows our familiar vertical down line, but this time with the full range of rotational possibilities.



## Aileron Rolls

The symbol for an aileron roll is a curved arrow (D). The curve confirms the direction of flight because it is always drawn so that it is approached from the concave side as you work your way around the figure. As well as simply conveying the requirement for an aileron roll, it is necessary to convey the extent of the rotation and whether there are to be any hesitations during the roll.

When the arrow is drawn on one side of the line only it represents a fraction. Allowable fractions are any multiple of  $90^\circ$ ; thus  $\frac{1}{4}$ ,  $\frac{1}{2}$ ,  $\frac{3}{4}$  etc. When the extent of the continuous rotation is greater than  $360^\circ$ , up to the maximum permitted of  $720^\circ$ , two arrow symbols are drawn and linked with a short line at their tips. So in this diagram the first three symbols from the left represent a half roll, a full roll and  $1\frac{1}{2}$  rolls, none with any internal hesitations or stops.

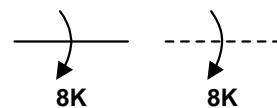


The next two symbols are also continuous rolls with no hesitations, but some numbers are added because the fraction to be specified is other than a half. For the  $1\frac{1}{4}$  roll only the fraction needs definition so the text reads just ' $\frac{1}{4}$ ' not ' $1\frac{1}{4}$ '.

The last three symbols show the further addition of text notation to indicate hesitations. The number '2' indicates two stops per revolution: a 2-point roll. The next symbol is a  $\frac{3}{4}$  roll but it must have stops at the interval appropriate for 4 stops per revolution. This is in effect three consecutive  $\frac{1}{4}$  rolls with evenly spaced hesitations.

The final element is  $540^\circ$  of rotation with stops at the rate of eight per  $360^\circ$ . This would amount to 12 individual roll segments of  $45^\circ$  each:  $1\frac{1}{2}$  8-point rolls.

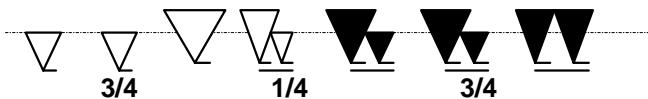
The difficulty coefficient of any particular aileron roll manoeuvre is the same, regardless of the line it is on being positive or negative. Thus a full level roll from upright to upright is 8K, as is the same roll when flown from inverted to inverted.



## Rudder (Flick) Rolls

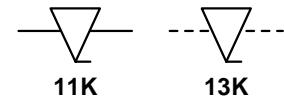
The symbol for a flick roll is an isosceles triangle (Diagram 4-4, E, F and H). At the apex of the triangle is a small tell-tale that confirms the direction of flight (in each case in Diagram 4-4, downward).

The minimum extent of rotation for flick rolls is  $180^\circ$ . The next diagram shows a progression of all possible degrees of rotation from half to double, with their text annotations. These are all orientated left-to-right as you look at the page. The last four are all greater than  $360^\circ$  and have two triangles, their tips linked by another small line.



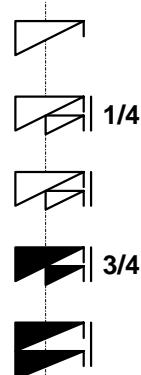
The last three are filled with solid colour, which may be red or black, to indicate that they are negative flicks (stalled with the stick forward). You may note also that the angle of the apex of the triangles is allowed to vary. This is not significant.

The difficulty coefficient for a flick roll has one of two possible values, depending on the wing loading immediately before the flick is initiated. Thus a level positive flick has a value of 11K when flown from upright to upright, but 13K when flown from inverted to inverted.



## Spins

Spins only occur on vertical down lines at the entry to a figure. The minimum extent of rotation is  $360^\circ$  and the maximum, as for rolls, is  $720^\circ$ .



In System-based competition, positive spins are always initiated from level upright flight; inverted spins from level inverted. It is possible to enter an inverted spin from low-speed upright flight, and vice versa, but these 'cross-over' spins are no longer included in the System.

The symbol for a spin is a right-angled triangle. Note that the tell-tale at the apex is always downwards and that all rotations greater than one have two triangles with the additional linking line at the tips. The black-filled symbols represent inverted spins.

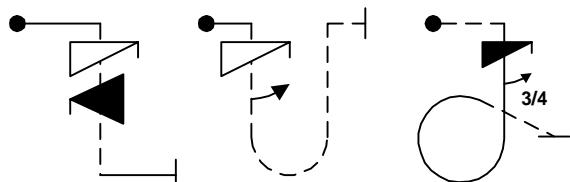
## Combinations of Rotations

As well as being used singly as described above, all three types of rotation can be put together in pairs in what are known as 'Unlinked' or 'Opposite' rolls. I'll deal with combinations that include spins first, as that is the simplest section to get out of the way.

## Spin Combinations

If you combine a spin with any other form of rotation, the spin must come first. This is forced on you because of the entry conditions – level entry, with vertical down finish. After you have stopped the spin, however, you can execute either an aileron or flick roll, while still on the down line, before you recover to level once again. While it might be possible to fly a second spin after the first one has stopped, there is a convention that says this should not be done in a sequence based on figures from the System.

This diagram shows a number of examples, all with a one-turn spin. In the left-hand picture, the spin is followed immediately by a one-turn negative flick. Because the two



triangles have their tips on opposite sides of the down line, these two rotations must be flown with their roll components in opposite directions. So a positive spin to the right must be followed by a negative flick with right rudder. The flick will then have a left roll component.

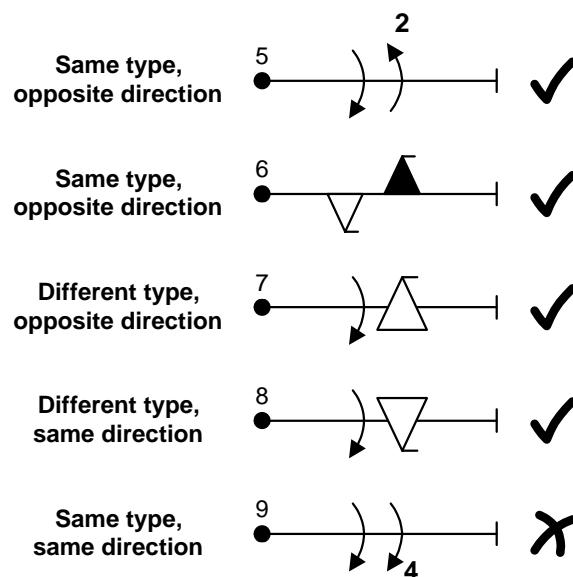
In the centre picture, the spin is followed by a half aileron roll and this must be in the same direction as the spin because the spin apex and the roll arrow tip are on the same side of the line.

In the right-hand picture, we have a one-turn inverted spin followed by a  $\frac{3}{4}$  roll in the same direction. If the spin is executed with right rudder, its roll component will be to the left. So in that case the  $\frac{3}{4}$  roll would have to be to the left also. This rotational combination is also the only one shown to include an odd quarter. As a consequence, at the exit to the figure you will be on a new heading at  $90^\circ$  to the original. This 'cross-box' finish to the figure is indicated by the little cross-bar at the end being horizontal instead of vertical as on the other two.

### Non-Spin Combinations

Combinations that do not include a spin can be flown on vertical,  $45^\circ$  or level lines. In this case, both elements of the combination can be aileron rolls, or both can be flick rolls. If the two elements are, as just described, of the same type, then they must be in opposite directions.

If your combination includes a flick roll and an aileron roll, then the two elements can be in the same or opposite directions. Diagram 4-11 shows four legal combinations and one illegal one, to illustrate these principles.



### Web Links

[www.arestisystem.com](http://www.arestisystem.com)  
[www.freestyleaviation.co.uk](http://www.freestyleaviation.co.uk)