Acceptable Climb Performance

Introduction

The Agricultural Aircraft Safety Review detailed how the requirement to meet a minimum angle of climb had been omitted from the overload provisions of Part 137. The previous regulation of agricultural operations had required the aircraft to be capable of achieving climb gradient of at least 6% at the weight and conditions under which it was to be operated. The FAA document CAM 8 used to require a minimum of 350 fpm or 8 xV_s whichever was higher, (gives rate of climb in fpm, Vs in MPH)

To improve the safety of agricultural operations in New Zealand, the rules governing operation at weights greater than the aircraft's maximum certified take-off weight (MCTOW) need to ensure a certain performance margin is available. Some performance margin is necessary, not just for the obvious need to out climb terrain and obstacles, but also to permit the aircraft to manoeuvre. The following section explains the requirements for performance margin in relation to manoeuvrability and consider the special case of downhill take-offs. Both of these factors need to be considered in the selection of a minimum climb performance for agricultural operations. This section does not calculate what the minimum climb performance should be. That decision should be reached in consultation with experienced industry member and backed by flight testing. The following is intended to aid that process.

Manoeuvrability

To turn an aircraft or any other vehicle requires the application of a force at 90 degrees to its direction of motion acting, inwards towards the centre of the turn. The obvious example is a tennis ball on a string, where the string provides the inwards force to keep it travelling in a circle. Road vehicles rely on the front wheels to provide an inwards component of force when they are angled in the direction of the turn.

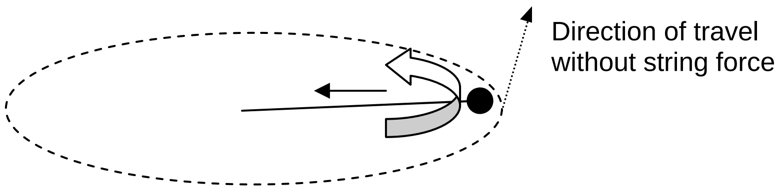

Figure :. Tennis ball and string in circular motion

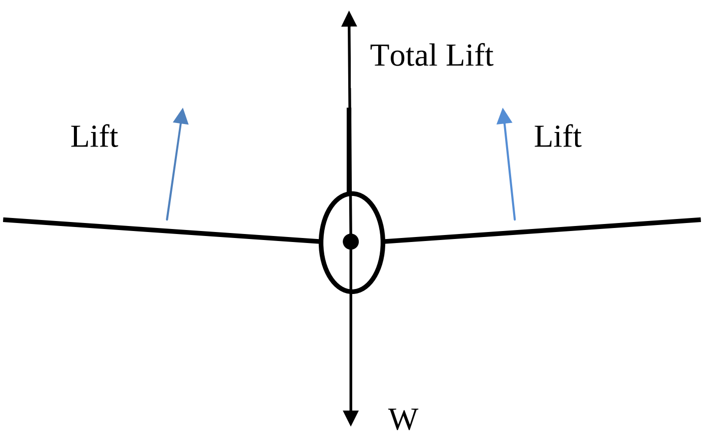

Figure 2: Aircraft in straight and level flight

An aircraft in straight and level flight is represented in Figure 2. The aircraft is flying away from the viewer. The lift generated by each wing (blue) combines to provide a total lift force that is equal in size and opposite in direction to the weight force. The aircraft continues straight ahead neither climbing nor descending.

To make a balanced turn, aircraft (and birds), roll to angle their lift vector toward the direction of the turn. As shown in the figure 3 this provides an inwards component, and accelerates the aircraft in the intended turn direction. Without the inwards force it would continue straight ahead.

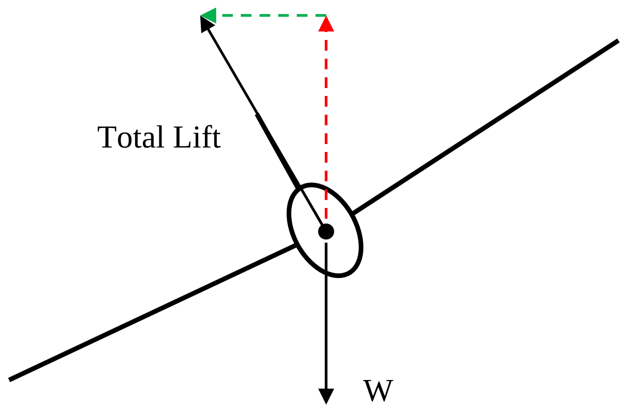

Figure 3: Aircraft turning left

As the total lift vector is tilted, the component acting upwards (red) is decreased. If this was not compensated for, the aircraft would start descending as the upwards component would no longer balance the weight due to gravity (W), which remains unchanged. To avoid sinking in the turn the pilot increases the aircraft's angle of attack slightly to increase the total lift vector, until the upwards component once again equals the aircraft weight. The increase in angle of attack produces an increase in drag so the engine power needs to be increased to prevent the speed reducing and decreasing the lift again. In gentle turns at light weight where the angle of bank is small and the turn duration is short, the loss of height and speed may be small enough to neglect. However, if flying only slightly above the stall speed, and/or close to the ground, they become important.

The steeper than angle of bank, the more pitch, and power needs to be applied to maintain height. At a given speed, the aircraft's radius of turn is proportional to its angle of bank. Tight turns require steep bank angles, which require more power to perform without height loss. Therefore the rate at which an aircraft can perform a level turn is proportional to how much extra power is available from that required in straight and level flight, at the given speed. This is known as the 'excess power' for that speed. At an extreme, an aircraft that was using full power just to maintain height at a speed just above stalling would not be able to turn at all, as without additional power to compensate for the tilted lift vector, it must sink or slow down in the turn. If already close to stalling it cannot keep flying if it slows down.

The 'excess power' available at a given speed is difficult to calculate. While the engine rated horsepower is known, and the thrust the propeller produces can be calculated (thrust decreases with airspeed), the drag produced by the aircraft at a given weight and speed (hence angle of attack) is difficult to predict.

However the amount of excess power also determines the aircrafts rate of climb. At a given airspeed, the rate of climb is proportional to the difference between the thrust available and the airframe drag produced at that speed. Rate of climb is relatively simple to measure and provides an indication of the aircraft's excess power. Therefore the attainable rate of climb also provides a measure of the aircrafts ability to manoeuvre around obstacles in the horizontal plane as well as its ability to climb over them.

Safe agricultural operations require adequate climb performance and manoeuvrability, and hence a certain amount of excess power. The easiest way to measure the excess power is to measure the aircraft climb performance. Therefore the selection of a minimum climb performance acceptable for agricultural aircraft operations, needs to assess the rate of climb and the maximum bank angle (and turn radius) that is attainable at the selected weight.

Downhill Take-offs

Another factor that needs to be accounted for in NZ agricultural operations is the effect of downhill take-offs. Agricultural operations in New Zealand often take place on sloping airstrips. Take-offs are invariably made in the down-slope direction to take advantage of gravity to accelerate to flying speed. While the slope helps the aircraft to accelerate, it also means that immediately after take-off the aircraft is actually descending. The following is a means of calculating the initial rate of descent.

Knots	Feet Per Second	km/hour
60	101.2	111
65	109.7	120
70	118.1	129
75	126.6	140
80	135	148

Figure 4

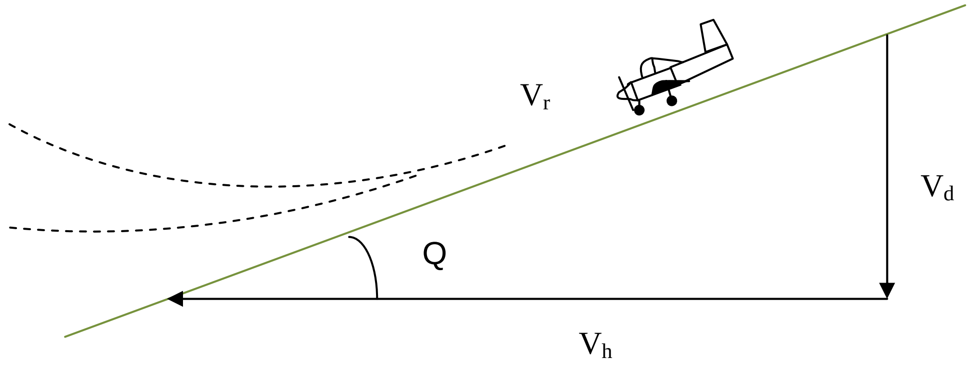

Figure 5

The descent velocity in feet per second can be calculated using

$$\text{Descent Velocity} = \sin Q \times V_r$$

where Q = slope in degree from horizontal

V_r = Velocity at takeoff in feet per second

Multiplying the result by 60 gives the more customary units of feet per minute (fpm).

Gradient	Grade %	Slope (degrees)	ROC (fpm) V_r 60 kts	ROC (fpm) V_r 70 kts
1:20	5%	2.86	- 303	- 386
1:15	6.67%	3.81	- 404	- 514
1:10	10%	5.71	- 604	- 770
1:5	20%	11.31	- 1191	- 1518

Figure 6

The table in figure 6 shows that take-off even from a moderate 1 in 20 sloped airfield results in an initial descent velocity of over 300 fpm. At the upper end, steeper slopes and higher rotate speeds produce initial rates of descent of over 1000 fpm.

Unfortunately the selection of a minimum acceptable rate of climb is not as simple as saying it should exceed the rate of descent attained immediately after takeoff.

Consider an aircraft that has climb rate of 100 fpm at its best climb speed of 80 knots. If the aircraft has accelerated to best climb speed while descending at 500fpm, it can commence climbing at 100fpm, as long as it maintains 80 knots. To pull out of the descent and establish the climb the aircraft needs to pitch upwards while maintaining 80kts. If the aircraft pitches up too rapidly, the speed will decrease below 80 knots and the rate of climb will decrease. While pitching up from the descent to the climb the aircraft travels along an arc. The radius of the arc is proportional to the rate at which the aircraft can pitch up without losing speed. The rate it can do this is proportional to the excess power at 80 knots. If the excess power is small, the radius will be large, and descent will continue for longer before the climb is established.

Therefore ability to arrest the rate of descent is once again proportional to excess power. As described earlier, excess power is most easily quantified by measuring the rate of climb at a given aircraft weight.

Conclusion

The minimum acceptable climb rate for agricultural operations beyond MCTOW should be selected to ensure the aircraft at the specified weight have sufficient excess power to ensure a safe margin for manoeuvrability. In addition, consideration should be given to the aircrafts ability to pull up from the descent after takeoff on anticipated slopes. Its ability to do this will be proportional to its excess power/available rate of climb. The available rate of climb required to compensate for downhill takeoff trajectory should be established by flight tests.

Figure 7: Cresco taking off downhill. Dave Wareham photo.

Figure 8: FU24 Downhill takeoff in South Island, Jim Nimmo photo.