Landing Gear Considerations

Introduction

Chapter 4 Section 2 of the Agricultural Aircraft Safety Review considered the high rate of landing gear failures amongst New Zealand produced agricultural aircraft. A contributor to this failure rate is the practice of operating at the Part 137 overload weight which is approx 30% higher than the weight used for design and certification of the landing gear. Design of a reasonably reliable landing gear for NZ conditions requires some consideration of the loads likely to be encountered in service. Only if the service loads are correctly anticipated can the design and certification requirements be correctly specified. The obvious modification to the certification requirement would be to certify the landing gear for operation at the selected agricultural overload weight (i.e. MCTOW+30%). However there are two other factors unique to agricultural operations that this approach overlooks, uphill landings and the disposable load effect.

Uphill Landings

On landing uphill another calculation has to be performed. Normal undercarriage design loads are detailed in Federal Aviation Regulation 23.473. The full set of requirements is complex but the calculation starts with the requirement that the landing gear be capable of withstanding the loads generated by contacting the ground with a rate of descent equal to:

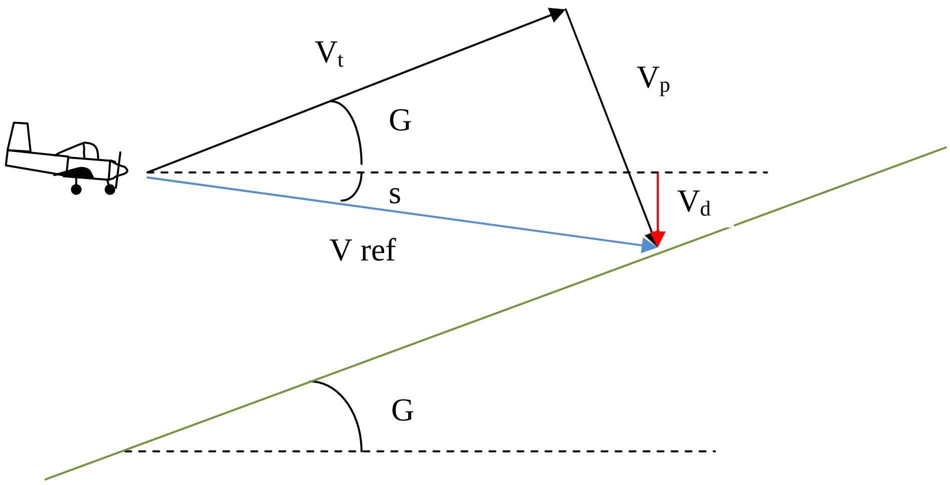
$$V_d = 4.4(W/S)1/4 \qquad \{FAR\ 23.473\}$$

where W = Landing weight , S = wing area, (W/S is the wing loading in lbs/in^2)

For the FU24 at the Part 137 weight of 6367 lbs and a wing loading of 24lbs/sq in, this calculation produces a descent velocity of 1584 fpm. (15.5 knots) FAR 23.473 then states that the rate of descent need not exceed 10 fps which is equal to 600fpm.

This then is the standard design condition for FAR 23 light aircraft. The landing gear should be strong enough to withstand the loads seen by the undercarriage if the pilot sets the aircraft up in a 600fppm glide, and flew all the way down without the usual round out and flare. Subsequent section of FAR 23 deal with calculating the resulting deceleration ‘g’. Long travel ‘soft’ undercarriage can accept that rate of descent without imposing large loads on the airframe, while short travel undercarriage with firm springs will have to arrest the 600fpm descent in fewer inches of travel and produce a greater deceleration and thus loads into the undercarriage and supporting structure.

All of this presumes a descent onto a level runway, with a rate of descent perpendicular to the runway. In NZ agricultural operations, landing s are routinely made up slope. The effect of an up slope is to increase the apparent rate of descent, from that shown on the aircraft vertical speed indicator (VSI).



G = slope of the ground relative to horizontal.
V_d = rate of descent indicated on aircraft VSI.
V_t = aircraft approach speed tangential to the ground
V_p = aircraft approach speed perpendicular to the ground.
s = aircrafts glide slope, below horizontal
V_{ref} = Aircraft approach speed

Figure 1: Uphill landing

When landing on a level runway, Angle G = zero and $V_p = V_d$ which for design purposes can be taken as the 10fps/600 fpm from FAR 23.473.

When the ground slopes up, the glideslope is effectively steepened to angle (s+G) and the speed perpendicular to the ground becomes V_p, which is larger than V_d the rate of descent shown on the aircraft's VSI.

The new velocity perpendicular to the ground is :

$$V_p = \sin(G + s) \times V_{ref}$$

The increment in apparent descent velocity perpendicular to the ground is:

$$dV_p = \sin(G) \times V_{ref}$$

For the FU 24 with a V_{ref} of 55 kts, a range of runway slopes gives the following increases in apparent descent velocity,

Slope	Grade %	Angle G	Descent velocity increment (fps) V ref =55 knots
1:20	5.00	2.86	4.64
1:15	6.67	3.81	6.19
1:10	10.0	5.71	9.25
1:5	20.0	11.31	18.24

Figure 2: Descent Velocity Increments

Recalling that the maximum rate of descent required by FAR 23.473 was 10 fps, even a relatively gentle 5% up slope increases the rate of descent by more than 40%. from that encountered on a level runway.

In day to day operation on sloping strips experienced pilots would compensate and adjust the flare until they are landing almost parallel to the up slope with a slight rate of climb at touchdown. But most pilots operating FAR 23 aircraft also flare and achieve landings with a minimal rate of descent. The point of a certification standard is that is intentionally a worst case. Designing FAR 23 aircraft to withstand the loads of a 600 fpm descent, which they may only experience once in their lifetime, gives them sufficient static strength to withstand a long service life at the much lower everyday landing loads.

Therefore, although most agricultural pilots will flare sufficiently to compensate for the slope, to provide NZ agricultural aircraft with the same confidence in their landing gear as regular FAR 23 aircraft they probably need to be certified to a load 40%-50% higher than the FAR 23.473 case.

Disposable Load Effect

As discussed in Chapter x, the choice of landing weight at which these calculation is s performed also becomes important for NZ agricultural operations, as FAR 23 usually assumes the landing weight is not less than 95% of the take-off weight. If that is true the 600fpm landing loads exceed anything likely to be encountered during taxiing or take-off. But if the take-off weight is 40% greater than the landing weight the protection provided by that assumption is no longer present. In that case FAR 23.473 paragraph g) states:

g) No inertia load factor used for design purposes may be less than 2.67, nor may the limit ground reaction load factor be less than 2.0 at design maximum weight, unless these lower values will not be exceeded in taxiing at speeds up to takeoff speed over terrain as rough as that expected in service.

This means that unless it can be shown otherwise,[1] the aircraft can be expected to experience acceleration of up to 2 G when encountering to bumps in the runway at speeds up to take-off speed. This requires that the landing gear be designed to withstand a force sufficient to accelerate the aircraft at take-off weight upwards at 2G. This needs to be assessed for NZ agricultural operations as, the 2G acceleration at Take-off weight may be more severe than the 600fpm landing at landing weight.

Conclusion

The effect of uphill landings on ground closure speeds and the effect of the marked difference in weights at takeoff and landing are two of the factors that need to be assessed during the engineering assessment of the aircraft’s ability to operate at weights above it’s maximum certified takeoff weight. Failure to account for these factors will reduce the factor of safety of the landing gear from that which it was certified with.

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[1] Due perhaps to very compliant landing gear, or a limitation to paved surfaces.

Figure 3: FU24 performing an uphill landing, note dirt flying up at point of impact.