Forces in a Coordinated Turn

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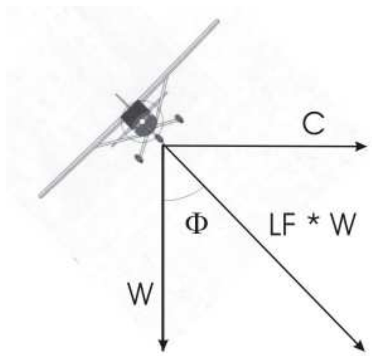
INTRODUCTION – Everyone has seen the force diagram for the forces in a level turn. Just for as a refresher it's shown below.



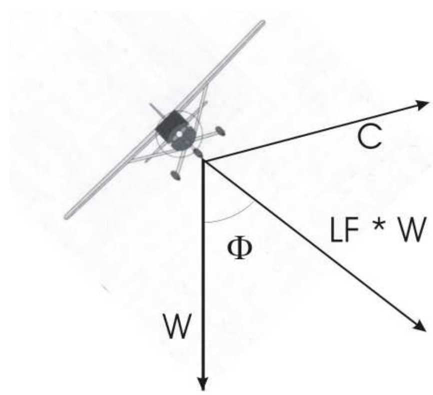
In the level coordinated turn the *Centrifugal Force*, C combines with the *Aircraft Weight*, W to produce the force you feel labeled here as the *Load Factor* times the *Weight*.

The Load Factor, also referred to a "g" factor is a multiple of the force produced by gravity. In a coordinated turn the resultant force must be perpendicular to the aircraft – this holds the ball of the *Turn Coordinator* in the middle. So we can calculate the Load Factor from basic trigonometry.

W = cos(Φ) * W
LF = 1/ cos(Φ)

The Load Factor at a 45^{o} bank will be 1.414 and for a 60^{o} bank will be 2. Almost all pilots can recite these facts. But what happens when you are descending, or climbing, is the Load Factor the same as for level flight at the same bank. Typical aviation texts never mention this, so what is the answer.

DESCENDING TURNS – The next figure shows the same aircraft in a coordinated descending turn. In order to understand the forces in this figure we can start with the easy one, the Weight. It is produced by gravity so will always be straight down with respect to the Earth.



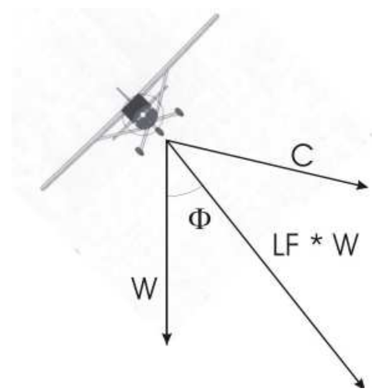
But the *Centrifugal Force*, **C**, is inclined upward. This is because it is in the plane of the aircraft's motion and opposite to the *Centripetal Force*. The *Centripetal Force* is produced by the wing lift being banked of the left (from our view point), and is the force that pulls the aircraft in a circular track. The *Centrifugal Force* is inertial force that we feel as we are pulled in the curved path. It's easy to calculate the inclination of this force. For example if we have an airspeed of 100 kts and are descending 500 ft/minute the force vector C, must slope upward 5 units for every 100 units of our speed, or 2.8^{o}. For 100 kts airspeed and 1000 ft/m descent the slope is 5.6^{o}. NOTE: The slope is easy to come by if you convert your vertical speed in ft/min to kts. One nautical mile is 6072 ft, so in one hour you would descend, or climb, 60/6072 or about 1/100 of your vertical speed in ft/min converted to knots.

Next the Load Factor must be perpendicular to the lateral axis of the airplane if the turn is coordinated (ball in the middle).

Once the vector C and LF is drawn we can construct a parallelogram and calculate the new *Load Factor*. Without going through the match you can see that the load factor is less than that generated in a level turn with the same bank and decreases with increasing descent rate. A good approximation is that for a 45° bank and 500 ft/m descent at 100 kts the *Load Factor* will be reduced by about 5% and 10% for the 60° bank.

Correspondingly, the Load Factor being reduced will decrease the stall speed by about 2% for the 45° bank and 5% for the 60° bank at the same rates. You can pretty much double these numbers for a descent rate of 1000 ft/m at the same airspeed.

CLIMBING TURNS - What happens during a climbing turn? The next figure shows these forces during a coordinated climbing turn.



In this case it's obvious from the sketch that the load Factor will increase above that for a level turn at the same bank. You can use the same rule of thumb for this turn. At 500 ft/min climb and 100 kts the Load Factor will increase about 5% and 10% for the 60° bank.

The stall speed will be increased as well 2% for the 45° bank and 5% for the 60° bank at the same climb and airspeeds. You can pretty much double these numbers for a climb rate of 1000 ft/m at the same airspeed.

SUMMARY – The *Load Factor* is not the same for all turns of the same bank. It will decrease with decreasing rates of descent at a constant airspeed. It will increase at an increasing rate for increasing climbing rates at the same airspeed. Correspondingly the stall speed is decreased for increasing descent rates in a turn maintaining a safe margin above the stall.

But, during climbing turns the stall speed will be increase decreasing the margin that you are operating above a stall. In important lesson here is the main reason why the dangerous practice of *buzzing* is so dangerous. As the aircraft climbs and turns away the stall speed increases and what often results is an accelerated stall. Unfortunately, in this case it happens close to the ground.