Our Personal Gyro Safety Envelope

Part 5

The Stability Tools and Assessing Gyro Stability

Last month we discussed the numerous static and dynamic moments and other factors that effect or complicate the stability of a gyro or the stability of the gyro/pilot system. These issues are explored in this series of articles specifically to raise awareness of these concepts and the potential that they may effect our own personal Gyro Flight Safety envelope. These discussions are intended primarily to raise our awareness and attention to these issues so that we might be better prepared the next time we consider venturing to the extremes or beyond our personal or gyro's capabilities.

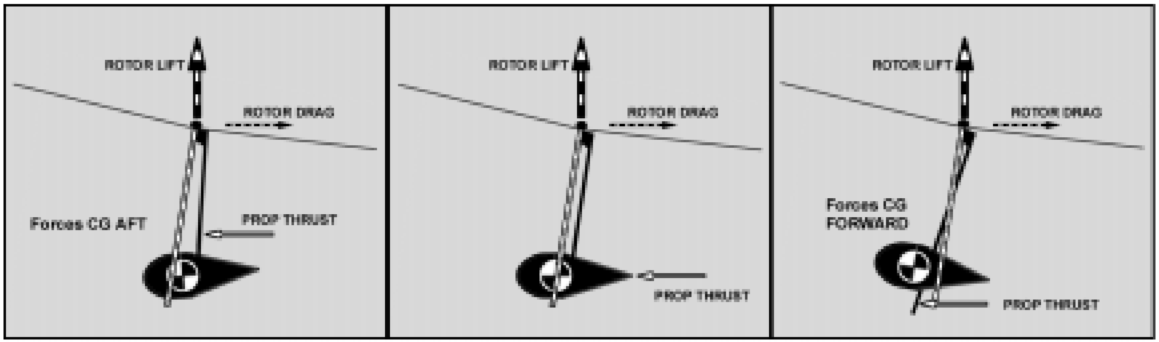
In this installment we will explore other factors that affect the stability of a gyro and some of the tools and techniques the gyro designer may employ to address these stability issues. We will also suggest some criteria that might be used to assess the stability of your particular gyro.

The Stability Tools:

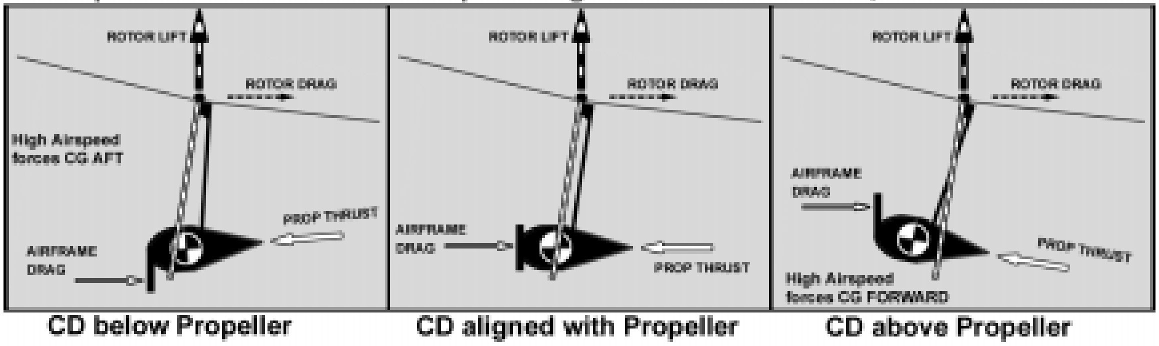
Lest you get the impression from the previous installment, those gyros are untamed beasts requiring super-human skills to avoid a bad day, that is not necessarily the case. There are numerous pitch stability factors that might contribute to a bad day, but gyros are also extremely capable and forgiving flying machines and can be readily tamed, even in less-experienced hands, by careful design.

Previously we discussed the government requirements for fixed-wing certification that, even without many of the stability and control aggravating mechanisms that exist in gyros, fixed-wing aircraft be stable in BOTH the "stick free" AND the "stick fixed" modes! That is to say, the government does not depend on pilot skills to correct unstable situations in certified aircraft! They probably do this for a reason - they may have learned that Murphy often rules the airways also - "if it can happen it will!" Gyros CAN be configured to meet these same stability criteria in all flight regimes in the hands of most pilots and under both stick free and stick fixed modes. To achieve this, designers have many tools available, including:

1. Vertical position and angle of the Propeller Thrustline
2. Vertical position of the Center of Drag (CD)
3. Vertical position of the Center of Gravity (CG)
4. Use of a Horizontal Stabilizer (HS)



Propeller above CG Propeller aligned with CG Propeller below CG



CD below Propeller CD aligned with Propeller CD above Propeller

FIGURE 1: Effects of Propeller Alignment with CG and CD

5. Aerodynamics and streamlining of the airframe
6. Moment of Inertia of the rotor
7. Moment of inertia of the airframe

1, 2 and 3: As shown in Figure 1, the vertical position of the Propeller Thrustline relative to the airframe CG and/or the CD can position the CG fore or aft relative to the RTV. The lower the Prop Thrustline, the further forward the CG will be located in flight. The higher the CD, the further forward the CG will be located in flight.

Airspeed may change the pitching moment from the CD, depending on the CD location relative to the CG or Propeller Thrustline, due to changes in the location of the airframe CD and/or the total drag on the airframe.

Some designers may not find it desirable from an aesthetics or configuration standpoint to lower the Propeller Thrustline as far as required to achieve a dynamically stable CG location from propeller thrustline alone. In this case, the designer may utilize a Horizontal Stabilizer to compensate or balance the adverse static moments from the offset propeller thrustline.

4: A Horizontal Stabilizer (HS) can provide a double benefit for the price of one! The HS can readily apply a STATIC airframe nose-up moment to position the CG well forward of the RTV – as discussed in a previous installment of this series of articles.

This, in itself can improve the DYNAMIC stability of the machine if the designer so configures the HS to raise the nose or to hold it up as a function of airspeed and/or engine power/thrust.

A HS has another major beneficial impact - aside from helping to position and hold the CG statically forward, the HS will also aerodynamically hinder any DYNAMIC pitching of the airframe - much as do the feathers on an arrow. A vertical gust will raise or lower the airframe nose into the vertical gust - exactly as it does on a fixed-wing aircraft. This effect is the more intuitively appreciated effect and considerably adds to the DYNAMIC stability margin.

The combination of the STATIC pitching effect and of the DYNAMIC stabilizing effect can give the HS a double whammy benefit for the price of one set of feathers! In my opinion, the bigger the HS the better - not just the Cierva guideline of 12-15%. The Cierva guideline was determined empirically on the almost purely centerline thrust and drag tractor Autogyros of the 1930's.

This 12-15% factor was determined to be adequate for stabilizing the naturally unstable rotor system alone - there was little need to stabilize the airframe in the Cierva configuration. Today's pusher gyros need to stabilize the rotor system as well as the airframe.

5: Aerodynamic shape and efficiency of the fuselage and other airframe components can be effectively used to raise the vertical location of the CD and to alter any nose-down tendencies induced aerodynamically over the airframe.

Often, however, the use of a significant fuselage, because it is forward of the CG, can be destabilizing itself, requiring extra Horizontal and Vertical stabilizer volume to negate the effects.

6: The spinning rotor itself can help slow down or counter some destabilizing characteristics of the gyro configuration. The rotor has a very high Moment of Inertia (MOI) - gyroscopic action that resists the pitching of the disk.

The MOI may be increased with use of a heavier or faster spinning rotor. In the absence of cyclic control inputs, the rotor tends to ignore all these pitching mechanisms and movements of the airframe - this is GOOD.

That is why the gyro/pilot system tends to ignore destabilizing pitching movements, IF the pilot is not restricting stick movement or commanding other destabilizing rotor reactions (Pilot Induced Oscillations -PIO)!

Heavier or faster rotors, however, strongly determine other handling characteristics the designer may also be concerned, such as stick forces - it is all a trade-off!

7: Airframe Moment of Inertia (MOI): Now here is an interesting parameter available to the designer. The MOI of any object is determined by its weight AND by how tightly all its weight is concentrated around its CG.

In other words a 2-seat tandem gyro will have a higher airframe MOI than a 2-seat side-by-side model because one pilot is further forward and the engine is further aft of the CG to balance that forward seat. The tighter mass concentration, such as in a side-by-side configuration is often referred too as "close coupled".

This means that the lower airframe MOI or "close coupled" machine will accelerate more quickly in pitch rotation with the same moments applied, than the higher MOI gyro will.

For instance, if both a tandem and a side-by-side gyro weigh the same, the tandem will be more stable in turbulence - simply because any moments resulting from turbulence (lift and drag changes) will have a slower effect on pitching the airframe. This applies for single seat gyros as well, and can help explain why perhaps a lot of PIO and PPO accidents occur in the very light machines.

All of these above tools (and others) can be applied alone or in combinations to improve stability. No single factor or tool is likely to determine the stability of the overall gyro/pilot system. There are many trade-offs; and all design goals may not be fully achievable.

These tools and factors may change dramatically in their effect at higher power, higher speeds, lighter or heavier loads, etc. Indeed, some of these factors may contribute to instabilities under unfamiliar or extreme conditions.

Since full scale wind tunnels are not generally available to the average gyro designer, and since gyros are almost as complicated to model in computers as helicopters are, only trial and error and iterative testing by the designer can approach the desired results. And then, each designer may have different desired results.

Gyros are designed for many purposes and many design goals. Some may be designed to be lightweight or inexpensive. Others may be designed for extreme maneuverability, or for high speed util ity. Even a machine that meets all of it's designer's goals may be unsuitable for flight outside the envelope the designer intended or outside the capabilities of the pilot. Even a machine that demonstrates good static stability (flies steady and easily in smooth air) may surprisingly demonstrate dynamic instabilities in other conditions or in the hands of an unfamiliar pilot.

<u>What's best?</u>

We never seem to get an easy answer to this question! The answer depends on how the designer intends for each individual machine to be used and how it is intended to perform under various conditions. And, the answer depends on how well the designer met his/her goals. In my individual opinion, weighing the current safety issues and situations, the generally preferred sport gyro would be one that does not require pilot proficiency to assure stability.

To me that would be a gyro that applies the various aerodynamic and configuration tools to keep the airframe CG far in front of the RTV - at all speeds, but especially at higher airspeeds and power settings. The further the CG is held forward at higher airspeeds, the less sensitive and demanding are the control inputs of the pilot, and the machine is more self-correcting to wind gusts - and does not rely on pilot proficiency to maintain inherent stability.

As discussed in previous installments, such inherent stability, properly achieved, does not necessarily limit the maneuverability or controllability of the gyro.

<u>How can I tell if my gyro is Safe?:</u>

Without a lot of testing, you can't be 100% sure! But with appreciation of the complexities and perhaps jeopardies discussed above, you may hopefully be at least aware when you might be flirting with reduced safety margins.

Actually, you can make some rough assessment of how well your machine achieves or maintains the CG location necessary for positive dynamic stability.

1) Typically, a normally loaded and hung gyro will fly keel level at its best L/D airspeed (about 45 mph). If your gyro is normally loaded and hangs ideally (2-3 degrees nose-down as measured on the pitch block of the rotorhead - more on the Hang Test in the next installment), you may be able to apply the following test and criteria:

In calm air and flying level and steady at 45 mph, have a ground observer carefully eyeball the keel of your gyro to a horizontal reference on the horizon behind the gyro. The keel should be level or angled slightly nose-up. If the keel flies noticeably nose-down (visually from a ground observer), even at 45 mph, all bets are off, the CG may be already forced aft of the RTV due to the Prop Thrustline relationship to the CG and CD. This is so because normally the keel is angled 9 degrees (nose-down) from the rotor head angle.

The ideal hang angle for a gyro (keel) is typically 11-12 degrees nose down. A typical rotor will fly at a 9 degrees AOA at 45 mph, so if the keel is level in flight the CG is 2-3 degrees forward of the RTV. Remember, for improved dynamic stability, the CG should be forward of the RTV - not just on the RTV. That is why that extra 2-3 degree nose-down is the ideal hang angle. This is not an absolute guarantee that all is OK, but it is a starting point. If the hang angle is different than ideal, other keel angle criteria would need to be determined.

This criteria might not be valid also if the rotor is a less efficient rotor. Most rotors will fly at no more than 9 degree AOA at 45 mph. A draggy rotor, flying at a higher AOA, would have its RTV angled more forward toward the CG, and the keel might need to fly more nose-up than level to maintain normal margin. For most quality rotors, flying at less than 9 degrees AOA, a level keel on a properly hung gyro should assure the CG is adequately forward of the RTV - at 45 mph!.

2) In calm air and flying level, trimmed and steady at 45 mph, reduce power to idle - slowly the first time! A sudden reduction of thrust should not result in a sudden rise or drop of the nose or require stick action to prevent the nose from pitching up or down. The nose of the airframe should only gradually lower to maintain airspeed. Gradually increase the rapidity of the power reduction to gage the actual nose pitch movement as a result of loss of thrust.

What does this indicate?

a) If the airframe nose pitches up or down (or tries to pitch up or down) as a result of a power reduction, this indicates that normal thrust is affecting the static longitudinal CG location relative to the RTV. At 45 mph, this is mostly an indication of a vertical offset of the CG to the propeller thrustline - since airframe drag and CD is less significant at 45 mph.

This means that propeller thrust may be adding dynamic stability or detracting dynamic stability by causing the static longitudinal CG location to be more fore or aft than for the normal gyro.

b) If the nose rises sharply as a result of a sudden power reduction, this indicates that normal propeller thrust is forcing the static longitudinal CG aft (less than desirable). The reduction of propeller thrust allows the CG to "swing" forward to its more normal or typical gyro position.

This indicates a less than normal stability margin prior to power reduction - even at this lower airspeed. This would suggest caution at even lower airspeeds in turbulent wind conditions because the dynamic stability is less than normal gyro stability at even this lower airspeed.

c) If the nose drops sharply as a result of a power reduction, this indicates that the normal propeller thrust is forcing the static longitudinal CG further forward than normal (a desirable condition). The reduction of propeller thrust allows the CG to "swing" aft to its more normal or typical gyro position.

This indicates an improved stability margin under power - at this lower airspeed. This would be the typical re sponse of an "offset keel" or "low thrustline" gyro. This does however suggest caution or at least awareness that the extra degree of stability margin is not present when power is reduced or not applied.

3) Repeat step 2 above at increasing airspeeds. A change in the amount of nose drop or rise upon reduction of power at the higher airspeeds indicates the additional effect of an offset of the propeller thrustline to the CD of the airframe. At higher airspeeds, the drag or CD offset becomes much more significant and can result in better or worse dynamic stability margins because of the forced fore-aft static longitudinal position of the CG relative to the RTV.

A sudden rise in the nose as the result of a sudden reduction of thrust indicates that that initial condition of high thrust and higher airspeed is forcing the CG into a less dynamically stable position prior to the reduction of power. The reverse is true for a gyro that displays a sudden nose drop upon sudden reduction of power - the machine is more stable under conditions of power and speed than it is under the condition of reduced or no power at those airspeeds.

4) Generally, a sudden rise or fall of the nose upon sudden power reduction indicates that under that condition of airspeed, there may be a power situation that will result in a less dynamically stable machine. This is a bit less important at the moderate airspeed of 45 mph than it is at higher airspeeds.

At lower airspeeds, the rotor AOA is naturally higher, with less pitch sensitivity and more safety margin before reversed airflow through the rotor can occur. But, any nose shift upon sudden power change indicates a less than perfect balance of the propeller thrustline offset with the aerodynamic HS moments and may indicate some combination of power and airspeed that results in reduced dynamic stability.

Generally, low propeller thrustline designs utilize the propeller thrust to force or hold the static CG further forward for improve dynamic stability under normal powered conditions and even at higher airspeeds (stability is improved by propeller thrust in that type gyro).

Be aware however, that, with the absence of that stability augmenting thrust, the dynamic stability and safety margins may be reduced and pilot proficiency under those conditions might not be adequate to avoid problems under those conditions - generally a fast descent under low power!

5) Traditionally, controlling a gyro is often described as a series of "jabs" and counter "jabs" to initiate and stop a pitch or roll movement. These are often unconscious control inputs by a pilot experienced in flying that machine. However, it is a sure sign of a degree of instability if a series of "jabs" is required for even moderate maneuvers or steady flight.

The truly stable and forgiving aircraft, requires only small forces in the direction of intended movement to initiate and control that motion - such as in the typical fixed-wing aircraft. Note that the truly stable machine does not necessarily mean that machine is not highly maneuverable.

If you are experienced in your machine and have mastered the "jabs" required to fly that machine, be aware of two things: One, this machine might be risky if flown by someone who has not developed the proficiency to fly that machine. Two, this machine may be much more difficult for even you to fly in gusty winds or at high airspeeds.

6) It is extremely important for all gyro pilots, experienced OR new to the sport, to realize that every individual gyro may certainly be different from other configuration gyros or other similar gyros with higher power engines.

It is also important to realize that even the same gyro may behave quite differently under different power and airspeed conditions - requiring different proficiency levels than we may be tuned to and familiar with. For instance, a high time pilot might be very proficient and experienced at high speed under power - but may have very little experience in the same machine at high airspeed and low power. With awareness of that potential difference, the prudent pilot might approach that less familiar environment with appropriate caution in gustier wind conditions.

We should all be aware that considering ourselves to be a "gyro pilot" does not necessarily mean we can proficiently pilot ANY gyro in all environments without adequate practice and familiarity in that different machine - the pilot "tuning" required can be as different as that required between a Cessna and a Pitts - even with seemingly minimal configuration or environmental changes! We should also be aware that a seemingly small change in speed or power, in some gyro configurations, can present the difference in control and stability margins between a "Cessna" and a "Pitts"! I know of few Cessna pilots who would confidently jump into the seat of a Pitts without more training - the stability margins are reduced!

Meeting these six tests is certainly no guarantee of dynamic stability or reason to lower your guard at the limits of your personal safety envelope. But, failing these tests certainly indicates reason for increased diligence in any conditions other than those in which you are extremely proficient and experienced.

These criteria, or any of the technical discussions or theories above, may certainly be open for debate. As stated previously, these subjects are presented primarily to heighten our awareness that there are issues and factors involved in gyro flight that may present situations for which we are not adequately prepared.

It is my sincere hope that these presentations might peak at least one pilot's attention enough to avoid treading into an unknown and dangerous situation.

The next installment to this series will discuss the often-misunderstood Hang Test. The Hang Test actually plays almost no obvious part in how stable your gyro will be! It is not directly analogous to the standard Wt & Balance of a fixed-wing aircraft. We'll explain what is important and why!