"PITCH DAMPENER" for Gyroplanes

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This article is an attempt to clear up confusion over the arguments and controversy about horizontal stabilizers, thrustlines, and gyroplane pitch stability. There appear to be many concepts about what it takes to make a gyroplane safe and stable so as to avoid pitch related accidents, including Pilot Induced Oscillations (PIO) and Bunt-Overs. (Power Push-Overs are a common term for "Bunt-Over" but are technically only a type of Bunt-Over that is caused by an unbalance high propeller thrustline that contributes to the bunt-over by propelling the nose-down pitch action of the bunt-over.)

Pitches related accidents in any aircraft, but especially in gyroplanes, are related to the propensity of the aircraft to sustain dynamic pitching oscillations and/or accelerate a forward pitching movement into a full Bunt-Over.

Aeronautical engineers and test pilots use a term called "pitch dampener" or "pitch dampening" to refer to an effect from a component or configuration that tends to self-correct for a disturbance. A disturbance in an aircraft may be the wind or a pilot input. Pitch Dampening is a necessary attribute for any aircraft if it is to be flown safely by a human being. Human beings have limits beyond which they cannot correct for divergent or destabilized tendencies of an aircraft. The FAA has recognized this for years and has required certain minimum dynamic pitch responses of the aircraft in order to be certified in the Normal or Utility categories of certified Standard aircraft. The Normal and Utility categories establish that the dynamic pitch responses of an aircraft are such that an average pilot can reasonably be expected to safely fly these aircraft. A human being can be trained to safely fly a less stable aircraft than this (Aerobatic category for example), but this requires special training and experience for such aircraft.

An explanation of some terms:

Dynamic Response: This is how a system (pendulum, rocket or gyroplane) responds when disturbed from its equilibrium or "trimmed" condition. Think of movement - how fast and how much. When you push on a swing hanging from a tree limb, the swing goes through a "dynamic response" - in this case, swinging back and forth until it finally settles down to it's "trimmed" condition again! That is the "dynamic response" of that swing system. Notice that this dynamic response varies when conditions change, such as the length of the swing, or the actions of a child in the swing seat.

All gyroplanes have "dynamic responses" to a disturbance, depending on the configuration and situation of that particular gyroplane. Gyroplanes may have different pitch responses "excited" by different disturbances. One response might be that that gyroplane oscillates in pitch continuously - with a specific cycle speed or period of oscillation (neutral dynamic pitch stability). Another response might be that it starts to oscillate and gets larger and larger pitch oscillations over time - not good! (negative dynamic pitch stability). Another response might be that it starts to oscillate in pitch, but each oscillation gets smaller and smaller until the oscillations quit and the aircraft is steady in pitch at its original trimmed condition - good! (Positive dynamic pitch stability). An even better response might be that the aircraft pitch returns immediately to it's steady-state, trimmed condition without any oscillations - VERY good (critically damped positive pitch stability). Guess which response is harder for the pilot to compensate! Which responses does the pilot have to intervene to restore steady flight? Which responses require little or no pilot intervention or skill?

Another element of a dynamic response of a gyroplane would be the natural period or rapidity of the oscillation. As the result of a disturbance, a gyroplane may respond with pitch oscillations that are rapid and difficult to stop, or slow and easy for a pilot to correct and stop. Which would you guess to be the more desirable condition?

Disturbance: Anything that disturbs a system from its "steady-state" or "trimmed" condition. This can be a gust of wind, a vertical, up or down draft. A disturbance can also be a pilot input, especially an over-reactive pilot input. A disturbance is what "excites" a dynamic response from a system (gyroplane).

Dampening: The reason a swing finally stops swinging is that it is "dampened" by the friction in the air and the friction or resistance of the rope. Almost all systems have natural dampening mechanisms of some sort - if only the friction of the air. A "dampener" can simply be normal friction. Or, a dampener can be a specific element or condition or device that causes a response in a direction and timing to counter or correct the natural dynamic response of a system. A dampener used by a designer might be more powerful than just the natural friction of the air - so that it tends to diminish or "damp" any oscillations more quickly. Some systems might require more aggressive "dampeners" because the natural dynamic response of the un-dampened system is so negatively stable (unstable).

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So what is a Pitch Dampener on a gyro? A pitch dampener on a gyro is the configuration or any component that reduces the severity of the natural dynamic response of that gyroplane - causes the natural response to be slower and to tend to "dampen" out more quickly. By doing so, the demand on the pilot is reduced. For simplicity sake, we'll define two types of pitch dampeners:

1) A pitch dampener that causes a pitch reaction of the gyro in the direction that reduces or lessens the initial reaction to the disturbance. An example would be an in increase of rotor disk angle of attack - to restore normal g load - when the g load is suddenly changed by a vertical wind gust. In other words, the rotor disk tilts back when the system (gyro) encounters a downward wind gust. This tilting back would cause an increase in g load - more lift - tending to correct the lesser g load of the disturbance. For an updraft - increased g load, the same pitch dampener function on the gyro would cause a reduced rotor disk angle of attack, tending to correct the higher g load to restore the g load toward the normal, "trimmed" condition. This type of pitch dampener acts to diminish or eliminate the pitch oscillations after a disturbance.

2) A device or condition that slows the natural pitch oscillation frequencies of the gyroplanes after a disturbance. This would mean a slower oscillation that the pilot could more easily correct or stop. A slow oscillation, say one with a 20 second period or cycle length would be relatively easy for a pilot to sense and correct. A much faster oscillation, say less than 5 second cycle periods, may be much more difficult for the pilot to keep up with.

Can you imagine which situations or combinations of situations might make it harder for the pilot to keep up with or correct a disturbance?

Examples of Pitch Dampeners on a gyroplane:

Offset gimbal and trim spring: This was employed a long time ago by Igor Bensen to help make it easier for pilots to learn to fly a gyro - make it more self-stabilizing. When the gyro encounters an increased g load, the spring stretches allowing the rotor disk to tilt downward (nose-down) thereby reducing the lift and reducing the g load. The amount the spring is able to stretch under the g load disturbance (maybe an updraft) determines the amount of correction imparted to the rotor disk. The weaker the spring, the more corrective reaction of the rotor. The same thing happens in reverse for a downdraft - reduced g force disturbance. One can reason through similar corrective responses of the gimbal / rotor disk as a result of a rapid pilot input on the cyclic causing a sudden change in g load.

Aerodynamic dampening: This is the response of the whole airframe to a vertical wind gust disturbance. The airframe (minus rotor) is of itself an aerodynamic body. This airframe reacts to the wind or airflow over it because of all the surfaces, and the drag and lift and pitching moments of those surfaces. Those surfaces affecting the aerodynamic reaction of the airframe include the drag of the airframe and all of its components, the lift or anti-lift of a windscreen or cabin contours, and the lift and drag of any horizontal surfaces. Surface areas in front of the gyros CG tend to destabilize the gyro - cause the airframe to react in a direction that tends to increase the effect of a wind disturbance. Surface areas behind the CG tend to stabilize the gyro by causing it to pitch in the direction to reduce the effect of a wind disturbance. This is generally true, but it is possible that slanted surfaces anywhere on the airframe may have either stabilizing or destabilizing effects. Generally, a horizontal stabilizer (HS) is intended to provide aerodynamic dampening, because, placed well behind the CG, it tends to force the nose of the airframe to pitch in the self-stabilizing direction - the direction that tends to lessen the effect of a wind disturbance.

Aerodynamic dampening is most effective if the movement of the airframe - in the correct or dampening direction - is allowed to feed into the rotor disk through cyclic action. In other words, the pitch movement of the airframe also causes the rotor to move in the corrective direction, adding more effect to the self-dampening from the airframe.

Alternatively, if the airframe is not aerodynamically pitch dampened and reacts to a wind disturbance in the destabilizing or wrong direction, it is desirable, if not imperative, that the stick be allowed to float freely so that wrong airframe reaction is not transferred into a wrong-direction reaction of the rotor disk as well. This situation could cause a bad situation to get worse as the disturbance nets a worse continued disturbance and a bunt-over or PPO (Power Push-Over) event occurs.

However, this cyclic transfer of a wrong-direction airframe pitch response cannot be fully prevented from affecting the rotor, even if the cyclic stick is allowed to float free. The normal offset gimbal / trim spring arrangement automatically forces the rotor disk to follow the airframe in a large degree. This is not good in the case of an aerodynamically unstable airframe, because it does automatically cause the rotor disk to pitch in the aggravating direction - but the spring itself, reacting to the g load change, does help a bit in this matter.

Airframe inertial dampening:

The rotational inertia or "mass dampening" of the airframe can affect the rate or frequency of the natural oscillations. Or put more correctly, the Moment of Inertia of the airframe mostly establishes the natural frequency of any excited oscillations. The further the mass of the gyro is spread out lengthwise (longitudinally), the higher the Moment of Inertia and the slower the natural frequency of any oscillations. This is somewhat similar to the rate of oscillation of a swing being dependent on the length of the swing. And obviously, from a pilot control perspective, slower is better, or maybe the pilot can't keep up! At higher natural frequencies of pitch oscillations, it is more likely that the reactions of the pilot may be slow or "out-of-phase" with what is really necessary to slow or stop the oscillations. It would be best that the system automatically "damp" the oscillations quickly to zero without pilot intervention, but if the pilot is inclined to intervene, it would be best that the oscillations were slow enough for the pilot to intervene correctly - and not aggravate the situation into PIO.

Another example of this would be a child on a swing. If it is a rather long swing , the child can easily swing his/her legs to either cause greater swings, or to cause the swings to decrease and stop. This is because the oscillations happen slow enough that the "pilot" can control them to decrease and stop. But, try this on a very short swing - the oscillations are so quick, that the "pilot" has extreme difficulty in either making it wing more or causing it to swing less. This would be analogous to a gyro pilot's inability to "stay ahead" of the pitch oscillations and therefore either aggravating the situation or making control inputs that cause the oscillations to diverge, or get worse - PIO. In the case of the swing, the mass dampening is less due to the shorter rope, making it more difficult for the child to control the swinging.

Rotor inertial dampening:

The rotor, is what is doing all the lifting and maneuvering of the gyroplane. So the rotor disk is the thing that we want, in the end, to provide the self-correcting reaction, or at least not contribute to a divergent or worsening reaction. That is why the offset gimbal / trim spring is so effective - it causes a rotor disk reaction. This is also why we either want or don't want the airframe to influence the rotor in a wind gust - depending on the stabilizing or destabilizing pitch reaction of the airframe. The rotor disk is what we want to prevent from moving in the de-stabilizing or divergent direction, because it's strong effect will contribute greatly to the rate and frequency of pitching oscillation.

So, a heavier rotor, spinning faster, has a rotational or gyroscopic inertia that is less able to react quickly, thereby lessening or slowing any natural frequency oscillation of the rotor / airframe system. Don't worry, even the heaviest rotors will still respond rapidly to pilot commanded inputs through the cyclic control. It is just that we would rather the rotor not respond so rapidly that the other stabilizing features of that gyroplane can't respond and correct. The pilot has no reason to command rotor pitch or roll rates beyond what the pilot or aircraft can survive. The roll rates of a Bunt-Over are way beyond the capacity of human response. We are talking about keeping gyroplane reactions below that rate so that Bunt-Over can be avoided and PIO can be prevented by the pilot's ability to perceive and correct.

LCG dampening:

Longitudinal CG dampening is similar to airframe inertial dampening above, except that it is achieved in a different manner. This dampening comes from the fact that the CG of the airframe is far in front of the Rotor Lift Vector (RLV). This forward positioning of the CG in front of the RLV may be achieved by a number of design details. The airframe aerodynamics, especially the downward lift provided by the HS, can hold the nose high and the CG forward. Another common way of holding the CG forward of the RLV is a low propeller thrustline - below the vertical CG. Both of these hold the CG forward of the RLV. The further forward the CG is relative to the RLV, the more dampened the pitch reaction of the airframe is. This is the issue so often addressed from the propeller thrustline perspective. Offset propeller thrustlines (from the vertical CG) must be balanced so that the attitude of the airframe assures the CG stays appropriately forward of the RLV.

The pitch dampening of a CG forward of the RLV comes from the inertial reaction of the airframe to a g load change. When the CG of the airframe is forward of the lift line of the rotor, the nose of the airframe tends to react to g load more and more quickly - and in the correct direction to impart a stabilizing pitching of the rotor disk through cyclic action. Again, this correct and aggressive pitching movement of the airframe, this time due to the CG location of the airframe, is most effective when being transferred to the rotor disk through cyclic friction or pilot restriction. And again, the further forward the CG is held relative to the RLV, the more effective this dampening is.

Control Configuration:

Cyclic control inputs can be applied automatically by a control configuration that reacts to disturbances. The offset gimbal / trim spring arrangement is actually a version of this. However, other control mechanisms can be offered and have been suggested. One such suggested mechanism is a flexible mast - that responds to g loading or rotor drag loading disturbance - that through control rod arrangement actually causes a cyclic input. Theoretically, it would also be possible to arrange mass or airstream reactive components in the control system that would also cause a corrective or "pitch dampening" cyclic input. Such mechanisms can rightly be called pitch dampeners, if they tend to counter a pitch disturbance in the direction that reduces the excited pitch oscillation from a disturbance.

Control Computers:

It is certainly possible to employ a computer in the control system that is programmed to "dampen" any pitch oscillations. This is high tech stuff, the same as they do in F-18 fighter jets. Pitch dampening can also be incorporated in an autopilot system. This may not be a practical option for gyroplanes at this time, but who could have predicted GPS 15 years ago. Any control computer requires feedback parameters to tell the computer what's happening to the aircraft - rate sensors, airspeed sensors, g load sensors, attitude sensors, etc.

Pilot:

Yes the pilot can be considered a "pitch dampener" device. After all, what is that lump of gray matter if not a very effective computer. That computer can be programmed to "dampen" or stabilize some pretty unstable gyros. All it needs is proper "programming" - commonly referred to as training. It does take a bit of training and experience to program that computer. It takes more training if we are going to ask it to stabilize or dampen a highly unstable system. But, we've all seen examples of experienced pilots making tricky gyros look to be as stable as a rock!

All computers require feedback sensors to tell the computer what is happening with the aircraft. Your brain is no different than the electronic control computer - it needs sensors. Fortunately, your sensors are attached in the form of your eyes, your ears, your touch and even your seat-of-the pants. But, some sensors take some really fine tuning (ie; training) to be most effective. The seat-of-the-pants sensor is probably the most effective as an indicator for the pilot, but this sensor takes the most time to program or train. Until the other sensors are programmed to their full potential, our brain naturally relies on our eyes for primary feedback.

Now, consider this: If the novice pilot relies mostly on his/her eyes as feedback to control the gyro, what happens if your eye perception deceives you. Here is a scenario, when your eyes perceive that the nose of the aircraft is going down - pitching down, the natural reaction is that you should pull the nose up with a commanded cyclic input. However, if the airframe is not aerodynamically "pitch dampened" - in the right direction - the pilot will react and respond wrongly - because his eyes told him to. A pilot depends heavily on visual feedback. But, for some gyroplanes that nose-pitch feedback can be the wrong direction. If the pilot reacts to this reversed sensor signal, the wrong control response may be initiated - nose goes down, tail goes up, pilot pulls rotor disk down into rising tail - just one example! PIO is another example!

Actual pitch dampening in a gyroplane is the sum of the responses of all pitch dampeners on that gyroplane. How these pitch dampeners, intended and not intended, harmonize or de-harmonize together determine the final dampening or response to a disturbance. Static effects are easier to visualize and analyze - static effects are what are commonly discussed and argued.

But, the dynamic effects are harder to define and predict. The destabilizing tendencies and natural frequencies combine with the dampener tendencies, in a complicated interrelationship and cross-effect of their timing relationships, amplitudes and natural frequencies to produce the final response to disturbances - whether those are difficult and dangerous and misleading divergent responses, or they are benign, self -correcting and stabilizing and entirely intuitive to the pilot.

Final results cannot be determined on paper or by subjective "test flying". The formulas for a paper analysis would be far beyond the skills of any designer and there are no computer programs available that can accurately predict the results. Some general and subjective judgements can be made from our experiences and some good aerodynamic application. But, the final results must be determined or checked through performance or results testing. This testing is not as simple as "seeing how it flies". The characteristics of the machine are easily corrupted by the "test pilot" from subtle and even unconscious control inputs. The test method must be stringent and isolated from interference from the human test pilot. The test method and results must be repeatable so as to compare the resulting data with other machines fairly. The test must be designed so as to not subject the "test pilot" to undo risk (if the machine being tested were treacherously unstable).

The Light Sport Aircraft ASTM Gyroplane Subcommittee is attempting to develop this test and establish test results that would best assure a dynamically stable and safe design. This is being done for the Consensus Standard required by the new Light Sport Aircraft (LSA) rules. This testing will assure that new LSA aircraft purchased from a manufacturer will meet the safety requirements of the new rules.

For the rest of us, it is hoped the Consensus Standard work will develop trusted and universally accepted guidelines for safe machines, and that a consistent understanding and appreciation of the intricacies of gyroplane pitch dampening / stability issues will guide the gyroplane sport to safer skies in the near future.